TRANSACTIONS

OF THE

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PHILOSOPHICAL SOCIETY.

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VOLUME THE FIRST.

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PREFACE.

A BRIEF statement of the circumstances which led to the formation of THE CAMBRIDGE PHILOSOPHICAL SOCIETY may not perhaps be thought an improper introduction to this first part of its Transactions.

The various departments of Mathematical and Philosophical Learning have long occupied a distinguished place in the system of Education adopted in the University of Cambridge; and a successful cultivation of them has on all occasions been rewarded with the highest Academical Honours. Hence, as might naturally be expected, men, eminent for their proficiency in those branches of learning, have never been wanting in this University. Of those who have been thus trained to habits of accurate investigation, not a few have endeavoured to direct the principles of science to practical purposes;—have applied those principles in the manner in which they might be the most beneficially applied — in strengthening the foundations, and in extending the boundaries, of Physical Knowledge.

Many productions of persons thus connected with the University have, at different times, been received with approbation. There is, however, reason to believe that many other works — deemed perhaps by the authors of them not sufficiently considerable for separate publication, but yet replete with important information — have been suffered to remain unknown; and that many observations, the result of careful inquiry, have been imperfectly recorded. Under these circumstances, it was thought that great advantages might be derived from the establishment, in the University, of a Society, the main object of which should be the advancement of Natural Philosophy. By the formation of such a Society, new facilities would be presented for the communication of knowledge: and thus, many ingenious Speculations on Philosophical subjects would, in all probability, be drawn from obscurity; and, by means of the Volumes of Transactions which the Society might occasionally publish, be effectually preserved, and recommended to the attention of the world.

When, moreover, it was considered, that there are resident in the University many students, who, after completing with honour to themselves that course of reading which has been laid down for them, have both leisure and disposition for more extensive researches — it appeared highly desirable to excite, among persons so well prepared for mental exertion, a common interest in the advancement of Philosophical Knowledge. The association of men of cultivated understandings, and of similar pursuits, has a tendency to keep alive the spirit of inquiry, and to direct it to proper objects. Hopes were therefore entertained that, by the co-operation of minds thus accustomed to investigation, some services, not otherwise to be expected, might eventually be rendered to the cause of Science.

Such, it was conceived, were the consequences which might reasonably be anticipated from the establishment of a Philosophical Society in the University of Cambridge; but at the same time it must be observed that the plan of the Society was not confined to those parts of Natural Philosophy, which form the more immediate objects of Academical pursuit. It was intended that the proposed Institution should embrace the studies of Chemistry, Mineralogy, Geology, Botany, Zoology, and other branches of Natural Science which have in modern times engaged so large a share of the public attention, and can be cultivated with success only by means of a continued series of experiments, and an unceasing vigilance of observation. Some of these subjects have already been partially illustrated by the application of Mathematical principles, and may perhaps be destined to acquire a still greater portion of the precision and certainty which attend the conclusions of demonstrative science:—others lay claim to regard by the practical value of the results which they present:—and of most of them, it may be justly asserted, that they afford ample scope for the exercise of the intellectual powers, in the methods of reasoning by Analysis and Induction.

In other points of view, considerable advantages were anticipated from the proposed Society. Many Members of the University, although no longer resident within its precincts, have yet opportunities for observation and inquiry. From them it was confidently believed that very interesting communications would be obtained;—communications which would manifest the utility of a Philosophical Institution in the advancement of Physical Science. Great hopes were also entertained of forming such a connexion with other Societies of a similar kind as might, by means of mutual reports of experiments and observations, continually present new subjects of investigation and afford new motives for exertion.

Such on the whole were the considerations which induced a few individuals in the University, well known for their zeal and activity in scientific research, to communicate to some of their Academical friends the plan of a Philosophical Institution. Their sentiments were received with so much approbation, that hopes were speedily entertained of carrying the plan into effect. For the purpose of ascertaining the general feeling which might prevail on the subject, a meeting was soon after held, which was numerously attended by Graduates of the University. At this Meeting, it was unanimously agreed, that a PHILOSOPHICAL SOCIETY should be formed; and at the same time, a Committee was appointed to make such arrangements as might appear necessary for the completion of the design.

At a subsequent Meeting, held on the 15th of November 1819, the Report of the Committee, together with a Code of Regulations, was read and approved of, and the Officers and Council of the Society were appointed. From that day, therefore, THE CAMBRIDGE PHILOSOPHICAL SOCIETY dates its Establishment.

The first general Meeting of the Society, for the despatch of business, was held on Monday the 13th of December, 1819; at which, after an appropriate address by the President from the Chair, a paper stating the design and objects of the Society, was read by the Professor of Mineralogy, Dr. Clarke. The general meetings of the Society have since been held at stated intervals during each term.

To this brief narrative of the origin and progress of The Cambridge Philosophical Society, nothing more needs be added, than that a commodious house has been hired, in which its meetings are held; and in which arrangements have been made for the reception of Books, and of Specimens in the different branches of Natural History. For the specimens which have been already collected the Society is indebted to the liberality of some of its Members*.

* A list of donations to the Society will be printed at the end of the first Volume of Transactions.

The Society takes this opportunity of expressing its grateful acknowledgments to the Syndics of the University Press, for their liberality in taking upon themselves the expense of printing this first part of its Transactions.

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OF THE

CAMBRIDGE PHILOSOPHICAL SOCIETY.

Established—Nov. 15, 1819.

The Cambridge Philosophical Society is instituted for the purpose of promoting scientific enquiries, and of facilitating the communication of facts connected with the advancement of Philosophy and Natural History.

Sect. I. *Of the Constitution of the Society.*

1. The Society shall consist of Fellows and Honorary Members.

2. The Officers shall be chosen from the Fellows, and shall consist of a Patron, Vice-Patrons, President, Vice-President, Treasurer, and two Secretaries, who with seven other Fellows shall constitute a Council.

Sect. II. *Of the Election of the Officers and Council.*

1. The Patron of the Society shall be elected for life.

2. The Vice-Chancellor and High Steward of the University (if Fellows of the Society) shall be considered as Vice-Patrons.

3. The President, Vice-President, Treasurer, Secretaries, and three ordinary Members of the Council, shall be annually elected by ballot from among the Fellows of the Society.

4. The same Fellow shall not be eligible to fill the office of President, or Vice-President, for more than two years successively.

5. The three senior ordinary Members of the Council shall retire annually.

6. No Fellow under the degree of M.A. M.B. or LL.B. shall be a Member of the Council.

SECT. III. *Of the Election and Admission of Fellows.*

1. The Fellows shall be elected from such persons only as are Graduates of the University of Cambridge.

2. Every person desirous of admission into the Society, shall be proposed and recommended by three or more Fellows, who shall deliver to one of the Secretaries a paper, signed by themselves, specifying the Christian and Surname of such person, with the name also of his College, together with his usual place of residence; all of which must be certified from the personal knowledge of at least one of the subscribing Fellows.

The following is the Form of the CERTIFICATE *required.*

———— of ———— Coll. ————, being desirous of becoming a Fellow of the Cambridge Philosophical Society, we, whose Names are underwritten, do recommend him as a proper person to be a Fellow of the said Society.

(Signed) ————
————
————

This certificate shall be read by one of the Secretaries at the Meeting at which the Candidate is proposed, and remain suspended in the meeting room of the Society till he be ballotted for.

3. The ballot shall take place on the second Meeting after that at which the Candidate is proposed: but all Heads of Houses, Doctors, and Professors, and all persons who have been admitted to Honorary Degrees, shall be ballotted for at the Meeting at which they are proposed.

4. No person shall be declared elected, unless he have in his favour at least two-thirds of the Members voting, and if it appear upon the ballot, that the person proposed is not elected, no notice thereof shall be taken in the minutes.

5. The Vice-Chancellor for the time being, when regularly proposed, shall be admitted a Fellow without a ballot.

6. No person shall be admitted a Fellow, till he has paid his subscription for the current year, or the sum specified in lieu of annual contributions.

SECT. IV. *Of Honorary Members.*

1. No Graduate or Member of the University of Cambridge, shall be admitted an Honorary Member.

2. Honorary Members shall be proposed by at least six Fellows of the Society, and their mode of election shall be subject to the same regulations as that of the Fellows.

SECT. V. *Of the Funds of the Society.*

The annual subscription of each Fellow shall be one guinea, to be paid in advance; or in lieu of annual payments, the sum of ten guineas.

SECT. VI. *Of the Council.*

1. The Council shall have the management and direction of all the affairs of the Society, their proceedings being subjected to the approbation of the *general meetings* of the Society.

2. The Council shall meet at the house of the Society at least once in every fortnight during full term, and not less than five shall constitute a quorum. Due notice of each Meeting shall be sent to every Member of the Council.

3. All questions shall be determined in the Council by vote, unless a ballot be demanded. The determination of the Council, whether by vote or by ballot, shall at the desire of any two or more members present, be deferred to the next succeeding Meeting. If the number of votes be equal, the Chairman shall have the casting vote.

4. The Council shall draw up a Report on the state of the affairs of the Society, to be presented at the general annual Meeting. In this Report shall be inserted an abstract of their proceedings during the year.

5. Nothing shall be published by the Society, which has not been previously approved by the Council; and, the Council shall be at liberty to call in the aid of any Fellow of the Society, well skilled in the particular branch of science, which may happen to be the subject of any paper, under consideration.

SECT. VII. *Of the Ordinary Meetings.*

1. The Meetings of the Society shall be held on a Monday, once in every fortnight, during full term.

2. The President shall take the chair at 7 P. M. and shall quit it before nine.

3. The business of each Meeting shall be conducted in the following order:

I. The minutes of the preceding Meeting read and approved.

II. Notices of new Motions presented.

III. Members proposed.

IV. Members ballotted for.

V. Motions on the Minutes brought forward and determined.

VI. Miscellaneous business.

VII. Communications read, and presents acknowledged.

4. Any motion to be submitted to the Society shall be expressed in writing, and signed by at least three Fellows of the Society; it shall be read by one of the Secretaries and if not withdrawn, shall be ballotted for at the next succeeding Meeting.

5. Each *Member* shall be at liberty to introduce a visitor on delivering his name to the President or Chairman at the time.

SECT. VIII. *Of the Annual General Meeting.*

The Annual General Meeting of the Society shall take place on the day succeeding the last meeting of the Society in the Easter term of each year, for the purpose of receiving the Report of the Council on the state of the Society, of auditing the accounts of the Treasurer, and of electing the Officers for the succeeding year.

SECT. IX. *Of Special General Meetings.*

1. The President and Council may at any time call a special general Meeting of the Society.

2. At least three days' notice of such a Meeting shall be given by one of the Secretaries to the resident members of the Society.

SECT. X. *Of the Duties of the President and Vice-President.*

1. The duty of the President shall be, to take the chair at the Meetings of the Society and Council; to regulate and keep order in all their proceedings; to state questions and propositions to the Meeting; to report the result of ballots; and to carry into effect the regulations of the Society.

2. In the absence of the President, the chair shall be taken by one of the Members of the Council in the following order; viz. The Vice-President, Treasurer, or senior ordinary Member of the Council.

SECT. XI. *Of the Duties of the Treasurer.*

The Treasurer shall receive all sums of Money due to the Society, transact all its pecuniary affairs, and keep a regular account of receipts and payments, in the mode which may seem most proper to the Council.

SECT. XII. *Of the Duties of the Secretaries.*

1. The Secretaries shall have the management of the correspondence of the Society and Council.

2. They shall attend all Meetings of the Society and Council, take minutes of their proceedings, and enter them in books provided for that purpose; they shall transact the business of the ordinary Meetings according to the mode specified in SECT. VII. Rule 3.

3. They shall have the charge, under the direction of the Council, of printing the Memoirs of the Society and of correcting the press.

SECT. XIII. *Of the Society's Property.*

An inventory of the furniture and other articles in the Meeting Room of the Society, shall be made every year. Catalogues of the Library, Collections in Natural History, &c. shall also be made for the use of the Members of the Society.

SECT. XIV. *Of Donations.*

Every person who shall contribute to the Collection or Library of the Society, shall be recorded as a benefactor, his name shall be read at the annual general Meeting, and shall be inserted in the next succeeding volume of the Society's Memoirs.

SECT. XV. *Miscellaneous Regulations.*

1. All communications, presents, &c. shall be sent to one of the Secretaries, if not personally presented by a Member at a meeting of the Society.

2. The author of any communication, if a Member, shall have the liberty of reading his own paper.

CONTENTS.

ADVERTISEMENT.

The Society as a body is not to be considered responsible for any facts and opinions advanced in the several Papers, which must rest entirely on the credit of their respective Authors.

I. *On Isometrical Perspective.*

BY WILLIAM FARISH, B.D.

JACKSONIAN PROFESSOR,

AND PRESIDENT OF THE PHILOSOPHICAL SOCIETY

IN THE UNIVERSITY OF CAMBRIDGE.

[Read *February* 21, *and March* 6, 1820.]

IN the Course of Lectures which I deliver in the University of Cambridge, I exhibit models of almost all the more important machines which are in use in the manufactures of Britain.

The number of these is so large, that had each of them been permanent and separate, on a scale requisite to make them work, and to explain them to my audience, I should, independently of other objections, have found it difficult to have procured a warehouse large enough to contain them. I procured therefore an apparatus, consisting of what may be called a system of the first principles of machinery; that is, the separate parts, of which machines consist. These are made chiefly of metal, so strong, that they may be sufficient to perform even heavy work: and so adapted to each other, that they may be put together at pleasure, in every form, which the particular occasion requires.

Those parts are various; such as, loose brass wheels, the teeth of which, all fit into one another: axes, of various lengths, on any part of which the wheel required may be fixed: bars, clamps, and frames; and whatever else might be necessary to build up the particular machines which are wanted for one Lecture. These models may be taken down, and the parts built up again, in a different form, for the Lecture of the following day. As these machines, thus constructed for a temporary purpose, have no permanent existence in themselves, it became necessary to make an accurate representation of them on paper, by which my assistants might know how to put them together, without the necessity of my continual superintendence. This might have been done, by giving three orthographic plans of each; one on the horizontal plane, and two, on vertical planes at right angles to each other. But such a method, though in some degree in use among artists, would be liable to great objections. It would be unintelligible to an inexperienced eye; and even to an artist, it shews but very imperfectly that which is most essential, the connection of the different parts of the engine with one another; though it has the advantage of exhibiting the lines parallel to the planes, on which the orthographic projections are taken, on a perfect scale. This will be easily understood, by supposing a cube to be the object represented. The ground plan would be a square representing both the upper and lower surfaces. And the two elevations would also be squares on two vertical planes, parallel to the other sides of the cube. The artist would have exhibited to him, three squares; and he would have to discover how to put them together in the form of a cube, from the circumstance of there being two elevations, and a ground plan. This method, therefore, giving so little assistance on so essential a point, I thought unsatisfactory.

The taking a picture, on the principles of common perspective, was the next expedient that suggested itself. And this might be adapted to the exhibition of a model, by taking a kind of bird's-eye view of the object, and having the plane of the picture, not as is most common in a drawing, perpendicular to the horizon, but to a line, drawn from the eye, to some principal part of the object. For example: in taking the picture of a cube, the eye might be placed in a distant point on the line which is formed by producing the diagonal of the cube. But to this common perspective, there are great objections. The lines which in the cube itself, are all equal, in the representation are unequal. So that it exhibits nothing like a scale. And to compute the proportions of the original from the representation, would be exceedingly difficult, and, for any useful purpose, impracticable: there is equal difficulty too, in computing the angles which represent the right angles of the cube. Neither does the representation appear correct, unless the eye of the person, who looks at it, be placed exactly in the point of sight. It is true that, as we are continually in the habit of looking at such perspective drawings, we get the habit of correcting, or rather overlooking the apparent errors which arise from the eye being out of the point of sight, and are therefore not struck with the appearance of incorrectness, which, if we were unaccustomed to it, we should feel at once.

The kind of perspective, which is the subject of this paper, though liable in a slight degree, to the last-mentioned inconvenience, till the eye becomes used to it, I found much better adapted to the exhibition of machinery; I therefore determined to adopt it, and set myself to investigate its principles, and to consider how it might most easily be brought into practice.

It is preferable to the common perspective on many accounts, for such purposes. It is much easier, and simpler in its principles. It is also, by the help of a common drawing-table, and two rulers*,

* It is unnecessary to describe the drawing-table any further than by observing that it ought to be so contrived, as to keep the paper steady on which the drawing is to be made.

There should be a ruler in the form of the letter T to slide on one side of the drawing-table. The ruler should be kept, by small prominences on the under side, from being in immediate contact with the paper, to prevent its blotting the fresh drawn lines, as it slides over them. And a second ruler, by means of a groove near one end on its under side, should be made to slide on the first. The groove should be wider than the breadth of the first ruler, and so fitted, that the second may at pleasure be put into either of the two positions incomparably more easy, and, consequently, more accurate in its application; insomuch, that there is no difficulty in giving an almost perfectly correct representation of any object adapted to this perspective, to which the artist has access, if he has a very simple knowledge of its principles, and a little practice.

It further represents the straight lines, which lie in the three principal directions, all on the same scale. The right angles contained by such lines are always represented either by angles of 60 degrees, or the supplement of 60 degrees. And this, though it might look like an objection, will appear to be none on the first sight of a drawing on these principles, by any person who has ever looked at a picture. For, he cannot for a moment have a doubt, that the angle represented is a right angle, on inspection.

And we may observe further, that an angle of 60 degrees is the easiest to draw of any angle in nature. It may instantly be found

represented in the plate, fig. 1, so as to contain with the former ruler, in either position, an angle of 60 degrees. The groove should be of such a size, that when its shoulders *a* and *d* are in contact with, and rest against the edges of the first ruler, the edge of the second ruler should coincide with *de*, the side of an equilateral triangle described on *dg*, a portion of the edge of the first ruler; and when the shoulders *b* and *c* rest against the edges of the first ruler, the edge of the second should lie along *ge*, the other side of the equilateral triangle. The second ruler should have a little foot at *k* for the same purpose as the prominences on the first ruler, and both of them should have their edges divided into inches, and tenths, or eighths of inches.

It would be convenient if the second ruler had also another groove *r s*, so formed that when the shoulders *r* and *s* are in contact with the edges of the first ruler, the second should be at right angles to it.

For representing circles in their proper positions the writer made use of the inner edge of rims cut out from cards, into isometrical ellipses as represented in the figure; of these he had a series, of different sizes, corresponding to his wheels. Such a series might be cut by help of the concentric ellipses in fig. 5, but he thinks that it would be an easier way to make use of that set of concentric ellipses as they stand, by putting them in the proper place under the picture, if the paper on which the drawing is made, be thin enough for the lines to be traced through, as by help of them the several concentric circles will go to the representation of one which might be drawn at once. It is difficult to execute them separately with sufficient accuracy, to make them correspond. For this purpose a separate plate of fig. 5, should be had, and one edge of the paper on the drawing table, should be loose to admit of the concentric ellipses being slid under it, to the proper place, as described, page 9.

by any person who has a pair of compasses, and understands the First Proposition of Euclid. The representation, also, of circles and wheels, and of the manner in which they act on one another, is very simple, and intelligible. The principles of this perspective which, from the peculiar circumstance of its exhibiting the lines in the three principal dimensions, on the same scale, I denominate "Isometrical," will be understood from the following detail:

Suppose a cube to be the object to be represented. The eye placed in the diagonal of the cube produced. The paper, on which the drawing is to be made to be perpendicular to that diagonal, between the eye, and the object, at a due proportional distance from each, according to the scale required. Let the distance of the eye, and consequently that of the paper, be indefinitely increased, so that the size of the object may be inconsiderable in respect of it.

It is manifest, that all the lines drawn from any points of the object to the eye, may be considered as perpendicular to the picture, which becomes, therefore, a species of orthographic projection. It is manifest, the projection will have for its outline an equiangular, and equilateral hexagon, with two vertical sides, and an angle at the top and bottom. The other three lines will be radii drawn from the center to the lowest angle, and to the two alternate angles; and all these lines and sides will be equal to each other, both in the object and representation: and if any other lines parallel to any of the three radii should exist in the object, and be represented in the picture, their representations will bear to one another, and to the rest of the sides of the cube, the same proportion which the lines represented, bear to one another in the object.

If any one of them, therefore, be so taken, as to bear any required proportion to *its* object, *e. g.* 1 to 8, as in my representations of my models, the others also will bear the same proportion to *their* objects; that is, the lines parallel to the three radii will be reduced to a scale.

I omit the demonstration of this, and some other points, partly for the sake of brevity, and partly because a geometrician will find no difficulty in demonstrating them himself, from the nature of orthographic projection; and a person, who is not a geometrician, would have no interest in reading a demonstration.

For the same reason, it is unnecessary to shew that the three angles at the center, are equal to one another, and each equal to 120 degrees, twice the angle of an equilateral triangle; and the angle contained between any radius and side is 60 degrees, the supplement of the above, and equal to the angle of an equilateral triangle. All this follows immediately from Euclid, B. IV. Prop. 15, on the inscription of a hexagon in a circle.

In models, and machines, most of the lines are actually in the three directions parallel to the sides of a cube, properly placed on the object. And the eye of the artist should be supposed to be placed at an indefinite distance, as before explained, in a diagonal of the cube produced.

DEFINITIONS.

The last-mentioned line may be called the *line of sight*.

Let a certain point be assumed in the object, as for example *C*, fig. 2, and be represented in the picture, to be called, ***The regulating point***. Through that point on the picture, may be drawn a vertical line, ***CE***, fig. 2, and two others, ***CB***, ***CG***, containing with it, and with one another, angles of 120°, to be called ***the isometrical lines***, to be distinguished from one another by the names of the ***vertical***, the ***dexter***, and the ***sinister*** lines. And the two latter, may be called by a common name,—the ***horizontal isometrical*** lines. Any other lines, parallel to them, may be called respectively by the same names. The plane passing through the dexter, and vertical lines, may be called the ***dexter isometrical plane***; that passing through the vertical, and sinister lines, the ***sinister plane;*** and that through the dexter and sinister lines, the ***horizontal plane***.

By the use of the simple apparatus described above in the Note, the representation of these lines in the objects may be drawn on the picture, and measured to a scale, with the utmost facility: the point at the extremity being first found, or assumed. The position of any point in the picture, may be easily found, by measuring its three distances, namely, first its perpendicular distance from the ***regulating horizontal plane***, (that is, the horizontal plane passing through the regulating point) secondly, the perpendicular distance of that point, where the perpendicular meets the horizontal plane, from the regulating dexter line; and thirdly, of the point, where that perpendicular meets the dexter line, from the regulating point; and then taking those distances reduced to the scale, first, along the dexter line, secondly, along the sinister line, and thirdly, along the vertical line, in the picture. These three may be called the ***dexter distance*** of the point, its ***sinister distance***, and its ***altitude***. And it is manifest they need not be taken in this order, but in any other that may be more convenient to the artist: there being six ways in which this operation may be varied.

If any point in the same isometrical plane, with the point required to be found, is already represented in the picture, that point may be assumed as a new regulating point, and the point required found by taking two distances; and if the new assumed regulating point is in the same isometrical line with the point, it is found by taking only one distance. And this last simple operation, will be found in practice all that is necessary for the determination of most of the points required. Thus any parallelopiped, or any framework, or other object with rafters, or lines lying in the isometrical directions, may be most easily and accurately exhibited on any scale required. But, if it be necessary to represent lines in other directions, they will not be on the same scale, but may be exhibited, if straight lines, by finding the extremities as above, and drawing the line from one to the other; or sometimes more readily in practice, by help of an ellipse, as hereafter described, page 11.

If a curved line be required, several points may be found sufficient to guide the artist to that degree of exactness, which is required.

The method of exhibiting the representations of any machines, or objects, the lines of which lie, as they generally do, in the isometrical directions; that is, parallel to the three directions of the lines of the cube, as has been already shewn ; and likewise the mode of representing any other straight lines, by finding their extremities; or curved lines, by finding a number of points.

But in representing machines, and models, there are not only isometrical lines, but also many wheels working into each other, to be represented. These, for the most part, lie in the isometrical planes. And it is fortunate that the picture of a circle in any one of these planes, is always an ellipse of the same form, whether the plane be horizontal, dexter, or sinister ; yet they are easily distinguished from each other, by the position in which they are placed on their axle, which is an isometrical line, always coinciding with the minor axis of the ellipse.

This will be obvious from considering the picture of a cube with a circle inscribed in each of its planes, fig. 3, and considering these circles as wheels on an axle. The two other lines (or spokes of the wheel) in the ellipse, which are drawn respectively through the opposite points of contact of the circle with the circumscribing figure, are isometrical lines also; for the points of contact bisect the sides of the circumscribing parallelogram, and therefore the lines are parallel to the other sides. They give likewise the true diameter of the wheels, reduced to the scale required. It further appears from the nature of orthographic projection, that the major axis of the ellipse, is to the minor axis, as the longer, to the shorter diagonal of the circumscribing parallelogram, that is, (since the shorter diagonal divides it into two equilateral triangles) as the square root of three, to one; as appears from Euclid, Lib. I. Prop. 47. And since the sum of the squares of the conjugate diameters in an ellipse, is always the same, if we put $\sqrt{1}$ for the minor axis, the $\sqrt{3}$ for the major, and i for the isometrical diameter, we shall have $2i^2 = 1 + 3, = 4$, and $i = \sqrt{2}$.

Therefore the minor axis, the isometrical diameter, and the major axis may be represented respectively by $\sqrt{1}$, $\sqrt{2}$, $\sqrt{3}$, or nearly by 1, 1.4142, 1.7321; or more simply, though not so nearly, by 28, 40, 49.

These lines may be geometrically exhibited by the following construction:

Let *AB*, fig. 4, be equal to *BD*, and the angle at *B*, a right angle. In *BA* produced, take $B\alpha$ = to *AD*. Draw αD, and produce both it, and αB. Then will *BD*, $B\alpha$, and αD, be repectively to one another, as $\sqrt{1}$, $\sqrt{2}$, $\sqrt{3}$ by Euclid I. 47. Therefore if $\alpha\beta$ be taken equal to the isometrical diameter of the ellipse required, $\beta\delta$ drawn perpendicular to it will be the minor axis, and $\alpha\delta$ the major axis. The ellipse itself, therefore, may be drawn by an elliptic compass, as that instrument may be properly set, if the major, and minor axes are known. If it is to represent a wheel on an axle, care must be taken to make the minor axis lie along that axle. In the absence of the instrument it may be drawn from the concentric ellipses, fig. 5, which may be placed under the paper, in the position above described, and seen through it; if the paper be not too thick, and in this method the smaller concentric circles of the wheel may be described at the same time, as they may be seen through the paper; or if they should not be exactly of the right size, it would be easy to describe them by hand, between the two nearest concentric ellipses; and thus also the height of the cogs of a wheel in the different parts of it may be exhibited, longer and narrower towards the extremities of the major, and shorter and wider at the extremities of the minor axis. Their width may be determined from the divisions of the ellipse. In most cases, this may be done with sufficient accuracy from the circumference of the ellipse being divided into eight equal divisions of the circle, by the two axes, and two isometrical diameters, each of which parts may be subdivided by the skill of the artist; and not only the face of the wheel in front, may be thus exhibited, but the parts of the back circles also, which are in sight, may be exhibited, by pushing back the system of concentric ellipses on the minor axis, or axle through a distance representing the breadth of the wheel, and then tracing, both the exterior, and interior circles of the wheel, and of the bush on which it is fixed, as far as they are visible. Care should be taken to represent the top of the teeth, or cogs, by isometrical lines, parallel to the axle, in a face-wheel, or tending to a proper point in the axle in a bevil-wheel. And nearly in the same way may the floats of a water-wheel be correctly represented. If a series of concentric ellipses, such as are given, fig. 5, be not at hand, it will still be easy for an artist to draw the ellipses with sufficient accuracy for most purposes, by drawing through the proper point in the axle, the major, and minor axes, and the two isometrical diameters, thus marking eight points in the circumference, to guide him.

If in any case it should become necessary to represent a circle, which does not lie in an isometrical plane, we may observe that the major axis will be the same, in whatever plane it lies: and it will be the picture of that diameter, which is the intersection of the circle with the plane parallel to the picture, passing through its center. And the major axis, will bear to the minor axis, the proportion of radius, to the sine of the inclination of the line of sight, to the plane of the circle. We may observe further that the diameters of the ellipse, which are to the major axis, as $\sqrt{2}$ to $\sqrt{3}$, when such exist, are isometrical lines*.

And the representation of every other line parallel, and equal to any diameter of the circle, may be exhibited by drawing it equal and parallel to the corresponding diameter in the ellipse.

If it should be desired to divide the circumference of an ellipse into degrees, or any number of parts representing given divisions of the circle, it may be done by the following method:

Let an ellipse be drawn, fig. 6, and on its major axis, *AG*, a circle described, with its circumference divided into degrees, or parts in any desired proportion, at *B, C, D, E, F*, &c.: from which points, draw perpendiculars to the major axis. They will cut the periphery of the ellipse in corresponding points. It would be difficult, however, in this way, to mark, with sufficient accuracy, the degrees, which lie near the extremities of the major axis. But the defect may be supplied by transferring those degrees in a similar way, from a graduated circle, described on the minor axis. In this manner, an isometrical ellipse, may be formed into an isometrical circular instrument, or an isometrical compass, which may shew bearings or measure angles on the picture, in the same manner, as a real compass, or circular instrument would do in nature.

It may be often useful to have a scale, to measure distances, not only in the isometrical directions, but in others also. And this may

* We may remark, that if a cone be described, having its vertex at *C* which lies in the line of sight, fig. 2, and passing through the three radii *CB, CE, CG*, all the straight lines in the superficies of that cone passing through *C*, and all other lines parallel to any of them, are isometrical, as well as those parallel to the three principal isometrical lines, *CB, CE, CG*; and no other lines but these can be on the same scale. But though this multiplies the number of isometrical lines infinitely, it is of little practical use: because it is only those, which are parallel to the three principal lines, that can be easily distinguished at sight, to be isometrical.

We may further remark, that if a line be drawn through the point *C* parallel to any given line whatever, and that line be made to revolve round the line of sight, at the same angular distance from it, so as to describe the surface of a cone, all other lines parallel to it, in any of its positions, will be isometrical, as they respect one another.

be done, by a series of similar concentric ellipses, as in fig. 7, dividing the isometrical diameters into equal portions. The other diameters will be so divided, as to serve for a scale, for all lines parallel to them respectively.

Thus, in the isometrical squares, exhibited in fig. 2, distances measured on the longer diagonal, or its parallels, would be measured by the divisions on the major axis, those depending on the shorter diagonal, by the divisions on the minor axis.

To describe a cylinder, lying in an isometrical direction, the circles at its extremities, should be represented by the proper isometrical ellipses, and two lines touching both, should be drawn: and in a similar way, a cone, or frustum of a cone, may be described. A globe is represented by a circle, whose radius is the semi-major axis of the ellipse representing a great circle.

It would not be difficult to devise rules for the representation of many other forms which might occur in objects to be represented. But the above cases are sufficient to include almost every thing which occurs in the representation of models, of machines, of philosophical instruments, and indeed, of almost any regular production of art.

Buildings may be exhibited by this perspective, as correctly, in point of measurement, as by plans and elevations, under the advantage of having the full effect of a picture.

A bridge, or any circular, or gothic arch, consisting of portions of circles lying in isometrical planes, may be represented by portions of isometrical ellipses, which will easily be adapted and drawn, upon the principles already explained, by which wheels are exhibited on their axles. The centers of those circles must be found, with which the centers of the ellipses must be made to coincide, their minor axes lying along the lines drawn from those centers perpendicular to the planes of the circles. The shaft of a pillar consists of a frustum of a cone, and a cylinder united; or perhaps of a cylinder alone, or a congeries of cylinders: and we have already shewn the method of exhibiting these, as well as their bases. And on the same principles, the position, and size of the volutes and ornaments of the capital, may be found, and such guiding points, as will make it easy to trace their forms. Thus the different courts, and edifices of a Cathedral, a College, or a Palace may be correctly depicted; and even the rooms, and internal structure, though less in the form of a picture, may be exhibited in such a way as to enable an architect, or his employer, to contemplate their situation, their ornaments, furniture, or any other circumstance belonging to their appearance; and to mark down exactly what he would have done, in such a way, as could hardly be misunderstood by an attentive agent, though at a distance.

But in thus exhibiting buildings as transparent, and their interior laid open, there is a danger of being confused by a multiplicity of lines; which is a difficulty in a building containing many rooms, that would need some address to get over. It is better adapted to exhibit the inside of a single room, of a Cathedral, for instance, the aisles, and transepts of which would not cause any great perplexity.

In the same manner a plan of a city might be given, which would not only represent its streets, and squares, as well (by the help of the scale above described fig. 7.) as a common plan, but also a picture of its churches, and public buildings, and even its private houses, if such were the design contemplated by the artist, as they would almost all become visible, when looked down upon, from the commanding height which this perspective supposes. And such a single exhibition, if well executed, might give a better idea of a distant capital, than a volume of description.

In the instances which have been given, most of the lines are isometrical. But the art is applicable to many cases, where there are few, or none such. It may be necessary, in many of them, to draw isometrical lines, or isometrical ellipses, by way of a guide, to determine the position of certain lines, and points, to enable the artist to describe with accuracy what he has in view. And there is scarce any form so anomalous, as to preclude the artist from taking advantage of these methods of ascertaining such lines, or points in it, as will give him much assistance, in representing it with precision. If the intention be merely to make a picture, the guiding lines may be obliterated as soon as they have served the purpose designed, or they may be retained, in some cases, and their lengths or diameters noted down in figures, if it be wished, to give ready information. And often, if the artist wishes to provide materials to enable him, at his leisure, to give accurate descriptions, or exact drawings, the rudest exhibition of such lines may completely serve his purpose, provided he notes down on the spot, such measurements with accuracy, however unexact the lines may be on which they are recorded. In many cases it may be expedient to take liberties with this perspective, or with the picture, which will make it suit the purpose designed. And this will produce no confusion, provided those liberties are explained: for instance, it may often be expedient to make the scale, in the vertical direction, larger, sometimes very considerably so, than in the horizontal. It may in some cases be necessary to represent on paper, what is hid in nature. What has been said on the internal structure of buildings, in p. 13, is an instance of this as well as what we shall observe on the exhibition of subterraneous objects. We shall proceed to give some examples of these observations.

To give such a representation of an Etruscan vase, as would enable an artist to model it exactly, would be exceedingly easy. Let a vertical line be drawn to represent the axis of the vase, fig. 8, and let points be taken in that axis, corresponding to the centers of the principal circles of the vase; through which the horizontal isometrical lines may be drawn representing the radii of those circles, by the help of which the isometrical ellipses representing them are easily drawn. These will become a complete guide to the artist. He may assist himself by looking at the object along the line of sight, and then, if he has any skill in drawing, he will find no difficulty in tracing the outline from one of these to the other, with sufficient correctness. If he is unskilled in the art, of course he must be at the trouble of finding a larger number of ellipses to guide him. And in a similar manner, any solid, formed by the revolution of a plane figure round one of its sides, may be represented.

The laying down the timbers of a ship, or making a picture of one, shall be another example.

Let a vertical isometrical plane be conceived to pass through its keel, and to be intersected by the perpendicular planes passing through the ribs, and by planes parallel to the decks. The isometrical lines, which are the intersections of these, may be measured in the ship, and represented, with their proper measures noted down, in the picture; which will afford the means of representing the ribs, and laying them down in their proper places.

If this should be designed for the purpose of constructing a ship from a given model, it might be sufficient to represent the ribs only on one side; those on the other side being the exact counterparts. If the purpose should be to make use of these lines for a drawing, they need be marked but very faintly, and the artist will have little difficulty, when guided by them, to fill up the representation by hand.

In a similar manner, this perspective may be applied to the exhibitions of animals, for the illustration of Natural History. All the leading points may be thus accurately designated, and a good artist will find no difficulty in making, by their help, a picture from the animal, which will shew its proportions distinctly.

By this means, those agriculturists, who of late years, have so much improved the breeds of our cattle, might explain their ideas with precision, on the points, to which they wish to call the attention of their readers.

A regular fortification, which we will suppose to have eight bastions, will afford another example.

A person not conversant in such a subject, is in general puzzled with plans, and sections, and has very little idea of what is meant to be conveyed.

But he would easily understand it, if he should see every thing exhibited in a correct picture, especially where he has the view of his object varied, as in a fortification, such as has been proposed. Let an isometrical ellipse be drawn expressing the internal circumference of the place; and another concentric one, which marks the salient angles of the fortification, on the principles already explained. Draw other guiding lines to every necessary point; the lines of the fortification may be easily transferred from a common plan, to the isometrical, by the help of the scale of concentric ellipses described above, fig. 7, which will serve also to lay down the length of the bastions, and curtains, &c. in whatever direction they lie. Find the elevations of every part on the isometrical scale; and thus the body of the place, the ditches, counterscarpe, covered way, glacis, ravellins, and all the outworks will be represented to the eye as they appear in reality, and in every varied position; with the advantage of having all the admeasurements laid down with geometrical precision. If the artist should think the vertical lines, in such an exhibition, too small to give a correct idea of all the minute elevations, there would be no harm in his increasing the scale in that dimension in any desired proportion.

The face of a hilly, or mountainous country, like Switzerland, or the district of the Lakes in the north part of England, will afford another example.

Isometrical horizontal lines may be drawn representing lines in the level from which the height of the mountains is to be reckoned, so that vertical lines drawn from the summits of the mountains may meet them, on which the heights may be marked; (as well as recorded in figures, if required). And the mountains themselves may be drawn in their topographical situation. Their bearings may be marked by the help of the isometrical compass described in p. 11. It would be easy to transfer them from a common map to the isometrical plan; and thus the face of the country might be represented, just as it would appear from the commanding height which the isometrical perspective supposes.

Yet, as the slopes of hills and mountains are seldom so steep as the line of sight, it might sometimes suit the purpose to represent the height of elevations as twice, or three times the reality, in order that mountains might project an outline on the plane behind; otherwise, the summit might be projected on the mountain itself; which would in a degree destroy the effect of a picture.

This art might be advantageously employed also, for tracing what is below the surface of the earth, as well as what is above it.

It may be applied to geological purposes, and give, not only the order of the strata, but their variations, and their geographical situations. And for this purpose it might be useful to increase the vertical scale, in a great proportion, above the horizontal. It would be easy to mark the dip, or rise of the strata, as well as of the earth above them: to represent their various disruptions, to shew the situation, and extent of fissures, and metallic veins, to mark the boundaries where the upper strata have been swallowed up, or cease to appear; or where the under strata push up towards the day. It would be easy to mark the variations in the thickness of the strata in different places, and to record the result of experiments made at any point, by boring, or sinking shafts: which might be done by drawing a vertical line downward, so as to represent the thickness of the laminæ, which might be marked by different colours. By such a method, the geologist might obtain a map of the country, which might exhibit at one view, the general results of all the experiments, and enquiries, that had been made relative to that science. And the owner of an estate might record in a small compass, all that is known respecting its minerals, and be able, from a comprehensive view of them all, to judge of the probability of success in sinking a shaft, or driving a level. He might also make good use of this perspective, in tracing his shafts, and drifts, in all their windings, elevations, and depressions; and comparing them with the surface above: marking also the veins, and strata, in which they run. For if the artist knows what is beneath the surface, he has no difficulty in representing it as transparent. He must be careful however not to perplex himself by lines too much multiplied, and take advantage of his being able to paint the lines with different colours, for the purposes of distinction, and he must use a considerable address in throwing out such lines as would be of little use, and in retaining such as will produce the effect of a picture; which should be well preserved, in order to make the exhibition easily intelligible.

If he should wish to make a drawing of minerals, or crystals, this perspective would be well suited to the purpose.

The point, however, on which the writer of this paper can speak with the greatest confidence, is on the representation of machines and philosophical instruments: having been himself so much in the habit of practically applying to them the principles that have been detailed. And this he has exemplified in the plates.

The correct exhibition of objects would be much facilitated, by the use of this perspective, even in the hands of a person who is but little acquainted with the art of drawing; and the information given by such drawings, is much more definite, and precise, than that obtained by the usual methods, and better fitted to direct a workman in execution.

The writer of this paper cannot help flattering himself, that what he has delivered in it, may be found of some use, in rendering more clear, and intelligible, communications to societies, such as that, of which he has the honour to be the President.

II. *On certain remarkable Instances of deviation from Newton's Scale in the Tints developed by Crystals, with one Axis of Double Refraction, on exposure to Polarized Light.*

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[Read *May* 1, 1820.]

The discovery of crystals which possess two axes of double refraction, which we owe to Dr. Brewster, is perhaps the greatest step which has been made in physical optics since the discovery of double refraction itself by Bartholin, and its reference to an axis by Huygens. It has opened new views on the structure of crystals, and will in all probability be the means of leading us to a more intimate knowledge of the nature and laws of those forces by which the ultimate particles of matter act on light and on each other. When we reflect on the situation of these axes in different crystallized media, we cannot fail to be struck by the variety of the angles they include, and of the positions they hold with respect to the prominent lines or axes of symmetry of the primitive molecules, and the question immediately suggests itself, what are the circumstances which determine their position in the interior of a crystal?

It seems to have been all along taken for granted that, whatever these circumstances may be, the nature of the ray must at least be a matter of indifference; in other words, that a red and a violet ray similarly polarized and incident in the same direction on the same point of a doubly refracting surface, will either both undergo or both not undergo a separation into two pencils, without any distinction arising from the place of the ray in the prismatic spectrum. Were this the case, the two axes would be fixed lines within the primitive form, absolutely determined by the nature of the body, as much so as the lines which bound the primitive form itself, and any attempt to substitute for them hypothetical axes coinciding with remarkable lines in the latter figure, however ingeniously devised, must be regarded as mere speculation. The fact however is otherwise. In a paper recently presented to the Royal Society, I have shewn that the axes of double refraction in one and the same crystal differ in their position according to the colour of the intromitted ray, a violet ray being separated into two pencils, when incident in the same direction in which a red one would be refracted singly. This remarkable fact, which is almost universal in crystals with two axes places the question in a very different light. It appears that the nature of the ray as well as that of the medium, has its share in determining the position of the axes, and that the intensity of the action of the medium on the ray is one of the elements involved in this problem. Now it is hardly possible to conceive the neutral axis of a crystal otherwise than as a position of equilibrium, or direction in which the axis of translation of a luminous molecule (if such exist) must be placed, that certain forces may act in opposition, and balance one another; but since forces which balance will likewise counteract each other when increased or diminished all in the same ratio, it follows that the partial or elementary forces so held in equilibrium do not observe the law of proportionality when the colour of the incident ray varies. If we suppose then with Dr. Brewster that these partial forces emanate from certain fixed axes coincident with remarkable lines in the primitive form, it will follow that each separate axis has a peculiar specific law which regulates the intensity of its action on the differently coloured rays, and that each axis, supposing the others not to interfere with it, would exhibit separately a set of circular rings of which the tints would manifest a more or less marked deviation from the Newtonian Scale of Colours, as displayed by their uncrystallized laminæ.

This view of the subject will be remarkably supported by the facts about to be described, by which it will appear that among crystals with one axis only, there exists the greatest, I might almost say, the most capricious diversity in this respect, and that probably no two crystals, either with one or two axes, have the same scale of action, or polarize the differently coloured rays with an energy varying according to the same law precisely.

To this it may be objected, that from the result of a most elaborate examination of the colours exhibited by sulphate of lime, rock crystal, and mica, M. Biot has concluded that they follow in their action on coloured light, precisely the order and proportions stated in the Table of Newton, for the colours of thin plates of air. This coincidence is certainly extremely remarkable, supposing it rigorously exact, and antecedent to further experience, would appear to authorize the conclusion, that the proportional lengths of the periods performed by differently coloured rays within crystallized bodies depend essentially on the nature of the rays themselves, and not at all on the interior constitution of the crystal. Indeed in a case very analogous, M. Biot himself has attributed great and decisive weight to a presumption resting on the very same grounds. I allude to his Memoir on the Rotatory Phenomena exhibited by rock crystal and certain liquids, where having observed that in the former substance, the rotatory velocities impressed on the planes of polarization of differently coloured rays, are inversely as the squares of the lengths of their fits; he argues that this relation being independent of any datum involving the peculiar constitution of rock crystal, ought to be the general law for all other subtances which possess the rotatory property. "Où "pourrait considérer d'abord que la rotation dans le cristal de roche "s'étant trouvée réciproque aux carrés des longueurs des accés des "divers rayons simples, cette loi se présente comme une propriété "des rayons mêmes, et non comme un résultat dépendant de la "nature des corps qui agissent sur eux. Ou doit donc s'attendre, "d'après cette remarque, que la même loi subsistera dans toutes "les substances, comme on y voit se maintenir les rapports des "accès mêmes dont la seul longueur absolue varie."

However convincing this line of argument may appear, and however exactly supported by experiment in the case of the rotatory phenomena, its conclusions are not verified in that of the polarized rings, to which it nevertheless applies with as much or greater force as in the other instance, and this may serve to shew how very cautious we ought to be in our attempts to generalize antecedently to experience in this branch of optical science. In the paper above alluded to, I have demonstrated that this law of proportionality admits of exceptions, and to the instances there adduced, I have now to add other still more remarkable ones, which if I mistake not, afford abundant proof that it has no foundation whatever in the nature of light. Indeed it may be observed, that the last sentence in the passage just quoted, is sufficient to destroy in a great measure the force of the argument in the former part of it: for, since Newton has demonstrated that for rays of a given colour, the lengths of the fits in different media are proportional to the sines of refraction corresponding to a given angle of incidence out of a vacuum, and since the more recent discovery of the different dispersive powers of substances has proved that media differ very considerably in the proportion of these sines for the different rays of the spectrum, it follows that the proportional lengths of the fits must differ in every different medium. Hence will arise a difference in the scale of colours which their laminæ of different media should exhibit, and though we may certainly fix on one (that exhibited by a vacuum for instance) as a standard, and call it the Newtonian Scale, yet this, though convenient, is nevertheless in some degree arbitrary, as we know not the nature of the media, with which what we call a vacuum may be filled, nor their action on light. Nor is this cause of deviation so small as to be safely neglected in all cases. In oil of Cassia the difference in the refractions of red and violet rays amounts to no less than $\frac{14}{100}$ of the whole refraction, and the colours exhibited by thin or thick plates of this liquid should therefore deviate very sensibly from those in air or in vacuo. Various solids too as chromate of lead, realgar, &c. could they be obtained by any means in sufficiently thin leaves, ought to exhibit a scale of colour differing altogether from that of Newton.

The very remarkable succession of colours exhibited by that variety of the Fish-eye Stone (Apophyllite) which possesses a single axis of double refraction, has been noticed by Dr. Brewster, and since shewn in my paper already alluded to, to indicate an action on polarized light very nearly the same for all the colours, being equal upon the red and indigo-blue rays, a little greater for the yellow and green, and a little less for the violet, being the only instance yet adduced in the whole circle of optical phenomena of a maximum taking place between the extreme limits of the spectrum. I was led by this to conceive the possible existence of bodies, in which the law of proportional action should be so far subverted, as to render the periods performed by a red ray, within their substances, actually shorter than those passed through by a violet one; but certainly did not expect to find any conjecture almost immediately verified in the striking manner I am now to detail, and on the very substance which first gave rise to it.

By the kindness of my friend Mr. Lowry, (to whose liberality in rendering his invaluable collection accessible to scientific examination, I have every reason to bear honorable testimony) I was provided with a very large, and indeed splendid crystal of Fish-eye Stone, which though not very transparent, owing to air included between its laminæ, was yet sufficiently so to exhibit the rings of one axis with perfect distinctness, especially after a few days' immersion in oil of turpentine. The character of these rings was however altogether different from that of the rings exhibited in the ordinary variety, their tints, instead of being alternately white and black, with a little intermediate shading of lilac and greenish yellow, as described by Dr. Brewster, being those of the following Table, in which the colour of the extraordinary pencil only is given.

Table I.

1st *Order*.	Black, ruddy or yellowish white, white, faint blue, violet.
2d *Order*.	Indifferent pink, orange yellow, dilute imperfect green, blue, purple.
3d *Order*.	Good pink, orange yellow, tolerable green, blue, purple.
4th *Order*.	Fine pink, yellow, green, light blue, indifferent purple.
5th *Order*.	Rich pink, yellow, bluish green, indifferent purple.
6th *Order*.	Pink, pale yellow, pale green.
7th *Order*.	Pink, whitish, pale green.
8th *Order*.	Pale pink, whitish, pale green.
9th *Order*.	Ditto, ditto.
10th *Order*.	Very pale pink, very pale green.
11th *Order*.	Extremely pale pink, extremely pale green.
12th *Order*.	Scarce perceptible pink and green.

In this series, the less refrangible rays evidently perform their periods with greater rapidity than those of the opposite end of the spectrum, but the number of alternations is still pretty considerable, and indicates a nearer approach to equality between the extreme red and violet than in the Newtonian Scale. Struck by this circumstance, a passage in a letter of M. Biot* now occurred to my recollection, in which, speaking of the conclusion I had arrived at by observations on homogeneous light in the ordinary variety of this mineral, he says, "Si vous êtes bien assuré de cette anomalie, "je désirerai beaucoup que vous voulussiez bien essayer si elle se "soutient a toutes les épaisseurs, ou si elle éprouve quelque "variation avec la longueur du trajet que fait le rayon a travers la "substance cristallisée. Je serais extrêmement curieux de savoir "le quel de ces deux cas a lieu."

To this surmise of a variation in the proportional lengths of the periods depending on the thickness of the plate, or the length of the path traversed within the crystal, all my previous observations had certainly enabled me to answer decidedly in the negative. But so singular a deviation from what I had before observed, led me to suppose that there might be something in this observation deserving a minuter examination, and I resolved to sacrifice this specimen to the enquiry. The result, as will be seen, by a most accidental coincidence, actually verified the suggestion of that acute Philosopher, though in a way which he certainly never could have contemplated.

The crystal is represented in fig. 13. It was about $\frac{3}{4}$ inch in its greatest breadth and 0.27 inches in thickness, being a portion of a right prism, the plane angle (*bac*) of whose base was about 96°. The sides were striated longitudinally, and appeared to have been encased with a thin and highly polished exterior coat, of which a small portion was still adhering†. The structure was perfectly lamellar, the laminæ being parallel to the base of the prism. On examining it more narrowly, a remarkable flaw was perceived commencing at *f* and running along *fg*, parallel to the laminæ.

* Dated, *Oct.* 21, 1819.

† The specimen, as I learn from Mr. Lowry was brought from Utöe in Sweden, and was attached to a mass of oxidulous Iron.

On this I set the edge of a knife, and succeeded without difficulty, by a smart blow, in cleanly separating the two portions. The little irregularities in their surface being ground away, and a good polish communicated to them, their thicknesses were taken by the sphærometer and found respectively 165900 and 94499 millionths of an inch. On examining them separately in polarized light, I was now much astonished to find the rings exhibited by the two portions, though both circular, yet differing altogether in their characters. Those in the thicker portion were in every respect precisely analogous in the scale of their tints, to those of that variety with one axis, which seems to form the central portion and upper lamina of Dr. Brewster's *Tesselite,* and of which I need not here particularize the succession of colours, as it is given at full length in my paper above alluded to. On the other hand, the rings in the thinner portion exhibited a complete inversion of the Newtonian Scale, the red rays being more energetically acted upon than the violet, and that to so extraordinary a degree, that the whole prismatic spectrum was displayed in the very first ring.

To obtain a sufficient range of incidence, this plate was enclosed in olive oil, in a proper apparatus for measuring the inclination, and being exposed to polarized light, (the plane of incidence being 45^{0} inclined to that of primitive polarization) the succession of tints and their corresponding angles of incidence were as in the following Table, in which the angles are deduced from two observations of the same tint on opposite sides of the axis. The measures of length in this and the subsequent pages are in millionths of an inch, for the sake of placing in evidence their proportion to the lengths of the fits of easy transmission and reflexion.

TABLE II. *Second variety of Apophyllite in olive oil. Index of refraction* 1.0497. *Thickness of the plate* = 94499.

Incidence.	Ordinary Pencil.	Extraordinary Pencil.
0° 0′	White.	Black.
	White.	Sombre orange red.
	White.	Pretty good orange.
	Very light blue.	Good orange yellow.
	Sky blue.	Fine orange yellow.
	Fine deep indigo.	Fine light yellow.
23 35	Rich dark purple.	Pale yellow.
	Fine crimson.	Light greenish yellow.
27° 11′	Fine pink	Fine light green.
28 48	Pink, somewhat inclining to brick red.	Good bluish green (maximum of contrast).
	Light pink, inclining to orange.	Blue, rather greenish.
	Pale pink yellow.	Dirty and sombre blue.
33 2	Yellowish white.	Dull, indifferent purple.
	Light yellow green.	Good pink.
36° 48′	Good bluish green.	Good pink, inclining to brick red.
	Dull blue green.	Orange pink.
	Very dull blue green.	Yellow pink.
39 41	Pale purple, almost white.	Pale yellow, almost white.
41° 35′	Pink, inclining to brick red	Bluish green, rather pale.
	Yellow pink.	Dull pale blue.
43 55	White.	Very dilute purple.
46° 37′	Pale blue green.	Pale pink.
	White.	White.
50° 2′	Very pale pink.	Very pale blue.
	White.	White.

Beyond this inclination, the colours are no longer distinguishable. The whole series indicates a separation of the colours much more considerable than in the Scale of Newton, but to examine the variation of the polarizing energy for the several simple colours more minutely, we must have recourse to homogeneous light. The requisite measures were taken with every precaution in very fine sunshine, and though owing to the imperfections of the specimen, they do not pretend to great precision, the resulting numbers can scarcely be erroneous to the extent of $\frac{1}{15}$ or $\frac{1}{20}$ of their own value. I think it necessary to premise this, as the law of action indicated by the following Table of the results is so very surprising and unexpected, that it was not without scrupulous examination I could persuade myself that no enormous oversight had been committed. The first column expresses the colour of the incident ray, the second the length of the shortest period of alternate polarization it is capable of performing within the crystal, computed by M. Biot's formula,

$$l = t \, . \frac{\sin. \theta \, . \tan. \theta}{n},$$

in which t represents the thickness of the plate, θ the angle an intromitted ray makes with the axis (supposed perpendicular to the surface), n the number of periods and parts of a period it executes during its passage through the plate, or the order of the ring to which it is referred at its egress, and l the length of a period performed by the same ray supposed to traverse the crystal at right angles to its axis, or the minimum length above-mentioned. The third column contains the value of $\frac{1}{l}$, which measures the polarizing energy of the crystal on that particular ray; the last the number of observations employed in computing the values in the preceding.

TABLE III. *representing the Law of Action of the Second Variety of Apophyllite, on the differently coloured Rays of the Spectrum.*

Name of Colour.	Value of l.	Value of $\frac{1000000}{l}$.	Number of Observations.
Extreme red.	20213	49.475	20
Mean orange.	25465	39.270	20
—— yellow.	30374	32.923	20
—— green.	38057	26.277	20
—— blue.	93904	10.649	10
—— indigo.	250000 +	4.000 –	—
Indigo violet.	250000 +	4.000 –	—
Mean violet.	45992	21.743	3
Extreme violet.	35043	28.536	13

By this Table we see that the action of the crystal decreases rapidly, but regularly enough from the extreme red to the blue rays, when it sinks all on a sudden, and throughout the whole extent of the indigo and first portions of the violet is so small, that I was unable to obtain a measure even of the first ring at its maximum, within the range of incidence my apparatus would admit. It then increases again, more suddenly than it fell, and for the extreme violet has a value intermediate between those for the yellow and green. If we construct a curve ***roygbiv***, whose abscissas AR, AO, &c. are reciprocally proportional to the lengths of the Newtonian fits, and drawing the line ArB at an angle of 45° with AV, take the ordinates Rr, Oo, &c. every where proportional to the value of $\frac{1000000}{l}$ in this Table, this curve will represent the action of this variety of apophyllite on the whole spectrum, while rB represents that of a crystal whose tints follow the Scale of Newton, (fig. 14.)

This is in perfect agreement with the succession of tints given above, if we cast our eye over it, a deficiency of the indigo rays is perceived in all the scale of the extraordinary pencil, no pure or rich blue occurring throughout its whole extent. In the ordinary pencil on the other hand, the excess of indigo appears immediately in the rich tints of indigo, purple and crimson which occur in the first order. The yellow rays too afford us a numerical verification of the number assigned to them. The maxima and minima of these coincide, as Newton has observed, with the most luminous, and obscurest parts of the rings, which is a necessary consequence of their great illuminating power. Now these occur at the incidences 23° 35′, 33° 2′, and 39° 41′ respectively, and if we compute the angles of refraction (θ) corresponding to these, and take n successively $\frac{1}{2}$, 1, $\frac{3}{2}$, the formula already employed gives

by the first maximum - - - $l = 29269$
by the first minimum - - - $l = 29822$
by the second maximum - - $l = 29370$

$l = 29487$ Mean.

which differs from the result in the third Table by less than $\frac{1}{33}$ of its value.

The absolute polarizing powers of the two portions into which the crystal was divided, differed no less remarkably than the characters of their tints. In the thicker plate, by a mean of 20 careful observations made by the interposition of a certain standard red glass, on the ring of the third order at its minimum (in which the evanescence of the extraordinary pencil was complete, I found 37° 3′ for its apparent semi-diameter in air, and hence we find $\theta = 23°\ 7'$, $n = 3$, $t = 165900$, which substituted give

$$l = 9269\,; \quad \frac{1000000}{l} = 107.886,$$

and (as is sufficiently evident from the scale of tints in this portion) their value of l is nearly the same for all the other colours. Now it is well worthy of observation, that this value coincides almost precisely with the number similarly determined for the variety examined in my paper above alluded to, which I have there found to be 9281. The difference is little more than $\frac{1}{1000}$ of the whole, and so exact an agreement could hardly have been expected even in plates detached from the same specimen. This circumstance, together with the identity in the scale of tints exhibited by the two substances, establishes not only their exact similarity as individuals, but, what is of much more importance in this case, the definite nature of the variety itself; and at the same time proves that in detaching the two portions from one another, no part of the second variety remained adhering to the first, as it must have become sensible by enfeebling the polarizing power, if not by altering the tints.

But the structure of the crystal under examination is yet more compounded than what I have been describing. Dr. Brewster has already, in a highly interesting paper in the Edinburgh Transactions, described the union of our first variety of apophyllite with another, possessing two axes of double refraction, forming regular columnar crystals, consisting of an interior portion of one kind surrounded by a case, or border of the other, &c. The specimen I am now describing, however, presents the hitherto unique combination of no less than three distinct substances, having each but one axis of double refraction, uniting to form a single crystal, and following regular geometrical laws of juxta-position. In examining the two plates as above detailed, the portions most transparent and uniform in their structure were selected, and insulated from the rest by fastening them over holes of about an eighth of an inch in diameter in sheets of lead. But when the whole plates were exposed to a polarized beam, each was observed to consist of two distinct portions or compartments, as represented in fig. 15, where the interior parts *abcde* are those already examined; the border *ABCDcba* being separated from the interior portion by a plane of junction which, in the thicker plate appeared on inclining it, to be marked with a series of pretty broad coloured fringes, whose origin is sufficiently obvious. Considerable irregularity appeared in the structure of this border, but, at a perpendicular incidence, or when inclined at any angle in the plane of primitive polarization, or in one perpendicular to it, it had no action upon the incident ray, however turned round in its own plane. Of course it has but one axis of double refraction, and that at right angles to its laminæ.

The best and most transparent portion being selected and insulated as before, the plate was enclosed in the oil apparatus, when the tints developed on inclining it in a plane making an angle 45° with that of primitive polarization, were as follows:

TABLE IV. *Apophyllite, third Variety.* *Thickness* = 94499.

Incidence.		Ordinary Pencil.	Extraordinary Pencil.
0°	0′	White.	Black.
		Yellowish white.	Sombre indigo.
17	0	Pale yellow.	Indigo inclining to purple.
		Pale greenish yellow.	Pale lilac purple.
28	15	White, slightly greenish.	Very pale reddish purple.
39	14	Very pale green.	Pale rose red.
47	36	White.	White.
		White, scarce perceptibly tinged with pink?	White, scarce perceptibly greenish?

This Table of tints indicates a much more energetic action on the red and violet ends of the spectrum than on the intermediate colours, especially the yellow, and this was fully corroborated by observations in homogeneous light, which gave the values of l for the several simple colours as in the subjoined Table.

TABLE V. *Scale of the Minimum Lengths of the Periods of the different simple Rays in the third Variety of Apophyllite, and their Reciprocals.*

Name of Colour.	Minimum length of period value of l.	Polarizing power or value of $\frac{1000000}{l}$.	Number of Observations.
Extreme red.	43634	22.918	10
Mean orange.	101238	9.878	10
—— yellow.	366620 +	2.728 −	10
—— green.	89646	11.155	10
—— blue.	32211	31.040	10
—— indigo.	21947	45.565	10
Extreme violet.	13704	72.970	10

The curve representing the values of $\frac{1}{l}$ or the polarizing energy of the variety now under consideration, constructed as in the former case is represented in fig. 16. Its ordinate, as we see, decreases rapidly from the red to the yellow, where it is beyond the reach of the present observations, then increases again yet more rapidly, and is greatest of all for the violet rays. For the sake of comparison, fig. 18, represents the curve similarly constructed for the ordinary variety which has a maximum where the variety last described has a minimum. The straight line rB inclined at 45° to the abscissa in all the figures represents the values of $\frac{1}{l}$ for such crystals as follow Newton's Scale in their tints.

The apophyllite has furnished us then with no less than three instances of remarkable deviations from Newton's Scale in crystals with one axis. It would certainly be in the highest degree interesting to subject them all three to chemical analysis, but as the total weight of the specimen presenting these anomalies did not exceed 60 grains of which nearly one half consisted of the ordinary variety, I have not sufficient confidence in my own chemical dexterity to enter on so very delicate an enquiry, which would obviously call for a degree of precision attainable only by consummate masters in the art of mineral analysis. It remains therefore to be ascertained whether their different actions on light be owing to a difference in composition or merely in their state of aggregation. Meanwhile, as we have seen that the union of two crystals differing in their scale of tints produces a scale differing from either, it may not be irrelevant to enquire whether the alternation of laminæ of two of the varieties above described may not be capable of producing the remaining one.

To this end, let t, t', t'', &c. be the thicknesses of the 1st, 2d, 3d, &c. lamina so superimposed as to have their axes coincident, and of the same refractive density: l, l', l'', &c. the minimum lengths of the periods susceptible of being performed by a ray of any colour within these several crystallized plates, and θ the angle with the axis, at which a similar ray traverses the system. Then, as M. Biot has proved, the number (n) of periods, and parts of a period actually performed by this ray during its passage through the first plate is given by the formula,

$$n = \frac{t}{l} . \sin. \theta \times \tan. \theta,$$

the laminæ being supposed all of one class (i. e. all positive, or all negative) or t being regarded as negative for those of a contrary class. The periods performed by the same ray in traversing the second lamina will be

$$n' = \frac{t'}{l'} \times \sin. \theta \times \tan. \theta,$$

and so on, and, according to what the same eminent philosopher has proved, the ray will assume at its emergence from the system, the same plane of polarization as if it has executed $n+n'+n''+$&c. periods in one lamina. If then we take

$$n+n'+n''+ \&c. = N; \qquad t+t'+t''+\&c. = T,$$

we have

$$N = \left(\frac{t}{l} + \frac{t'}{l'} + \frac{t''}{l''} + \text{\&c.}\right) \times \sin.\theta \times \tan.\theta$$

$$= \frac{T}{L} \times \sin.\theta \times \tan.\theta,$$

provided we take L so that

$$\frac{T}{L} = \frac{t}{l} + \frac{t'}{l'} + \frac{t''}{l''} + \text{\&c.}$$

Let p, p', p'', &c. represent the polarizing power of each lamina on the given ray, and P, that of a lamina equivalent to the compound system, and we have, $p = \frac{1}{l}$, $p' = \frac{1}{l'}$, &c. $P = \frac{1}{L}$, so that

$$T.P = t.p + t'.p' + t''.p'' + \text{\&c.}$$

and
$$P = \frac{t.p + t'.p' + t''.p'' + \text{\&c.}}{t + t' + t'' + \text{\&c.}}.$$

If then P be so assumed, an imaginary plate whose polarizing power is P and thickness that of the compound plate $(t + t' + \text{\&c.})$ will exercise precisely the same action on the ray as the system so constructed, and it appears from the nature of this formula that it is indifferent in what order the elementary laminæ are distributed; so that all those of the same species may be conceived grouped together and united into one.

Now suppose the colour of the ray to vary, and let c be any quantity whose magnitude determines its place in the spectrum (as for instance, the reciprocal length of one of its fits of easy transmission and reflexion in vacuo). Then if we represent as we have done before, the quantity c by the abscissa of a certain curve, p, (a function of c) may be represented by its ordinate; p' (another function of c) by the ordinate of another curve, and so on, and P, the ordinate of a similar curve for the compound plate may be computed by the above formula.

But it is evident from a moment's consideration of the forms of the three curves representing the polarizing powers of three varieties of apophyllite, that no one of them can be produced by any combination of the other two according to this law, and we are therefore necessitated to admit each as a distinct variety or at least composed of laminæ of not fewer than three kinds. This alternation or superposition of laminæ of different polarizing powers is no hypothetical case. I have observed its occurrence not only in the instance before us, but in other crystals of perfect regularity in their external forms. Dr. Brewster has also observed phenomena referable to this principle in his paper on the apophyllite.

Hyposulphate of lime (formed by the union of that base with the hyposulphuric acid lately discovered by Welter and Gay Lussac, (see *Ann. de Chimie*, X. *March* 1819,) affords another instance of deviation from Newton's Scale in crystals with one axis of double refraction. This salt crystallizes in bevilled hexagonal tables which have no distinct cleavage, the axis being perpendicular to their broad surfaces. The following is the scale of tints developed by a plate of this salt on exposure to polarized light:

Table VI. *Hyposulphate of Lime. Thickness* =35701. *The axis was inclined* 5° 12′ *to the surface in the plane of incidence.*

Incidence.	Ordinary Pencil.	Extraordinary Pencil.
0° 0′	White.	Black.
	White.	Very faint sky blue.
10° 32′	Very pale yellow.	Pretty strong sky blue.
	Sombre yellow.	Very light bluish white.
	Sombre pink yellow.	White.
	Sombre purple crimson.	White.
15° 1′	Beautiful rich dark purple.	White a little yellowish.
	Beautiful deep blue.	Bright straw colour.
	Bright blue.	Yellow.
	Fine light blue.	Yellow verging strongly to orange pink.
	Light greenish blue.	Fine pink.
	Light yellow green.	Sombre pink.
21° 27′	Light greenish yellow.	Purple.
	Ruddy but pale yellow.	Blue.
	Pink, light and approaching to brick red.	Bright greenish blue.
25° 3′	Fine pink.	Splendid green.
	Pink.	Light green.
26° 7′	Pale purple.	Greenish white.
	Dull blue.	Ruddy white.
	Bright greenish blue.	Tolerable pink red.
29° 33′	Blue green.	Fine rose red.
31° 45′	White.	Dull pale purple.
	Ruddy white.	Blue, rather pale.
	Good Pink red.	Green blue.
35° 27′	Dull pale purple.	White.
	Light blue green.	Pink red.
39° 32′	White.	Very pale purple.
	Light Pink.	Very light blue.
	White.	White.
	Extremely pale blue.	Almost imperceptible pink.
	White.	White.

The colours here cease to be perceptible after the fourth order, and the degradation of the tints is evidently much more rapid than in Newton's Scale. Thus the blue of the first order, which in that scale is scarce perceptible, is here sufficiently strong to influence its complementary tint, depressing it to a pale yellow. The green and its complementary pink of the second order in this Table are fully equal in brilliancy to those of the third in Newton's Scale, while those of the third are scarcely equal to Newton's fifth. Accordingly, by a series of measures taken with considerable care in homogeneous light, I found the values of l for the several simple colours as follows:

TABLE VII. *Scale of the Minimum Lengths of the Periods in Hyposulphate of Lime, and their reciprocals.*

Name of Colour.	Minimum length of its period, or value of l.	Polarizing power or value of $\frac{1000000}{l}$.	Number of Observations.
Extreme red.	3241	308.54	38 very exact.
Mean orange.	2454	407.45	26
—— yellow.	2129	469.65	28
—— green	1861	537.32	20
—— blue.	1658	603.21	20
—— indigo.	1480	675.83	20
Extreme violet.	1129	885.77	29

The curve constructed from this Table, as in the case of the apophyllites, is given in fig. 18.

The rings in this crystal when crossed by a plate of sulphate of lime are affected in the same way as those in carbonate of lime, tourmaline, &c. and the axis is therefore of a repulsive character.

The facts above adduced suffice to shew that vast differences exist in the scale of action which a single axis may exercise on the differently coloured rays; and that, whether we regard the single apparent axis of any of the above crystals as the resultant of two others equal to it in energy but of an opposite character situated at right angles to it and to each other, with Dr. Brewster, or as being itself the real axis of polarization. For the resultant axis being the same for all the colours, the partial actions of each of the supposed axes on the former hypothesis, having the same point of compensation for all the colours, must be equal to each other and to the resultant force for them all. The mere fact therefore of a deviation from Newton's scale, however enormous in the tints of any regular crystal with one axis, cannot be regarded as affording of itself any argument for the substitution of two others for it in that particular substance, because each of such axes acting separately would exhibit a scale of tints perfectly identical with that of the axis whose place they supply, and therefore by parity of reasoning should be regarded as the resultant of two others, and so on, *ad infinitum*. This reasoning appears to me conclusive against any analogy between crystals with one and two axes, founded on a deviation of tints in the rings of the former. But I cannot help regarding the phenomena I have described as affording considerable support to the very ingenious theory of the philosopher just mentioned, as applied to crystals with two axes, inasmuch as they establish the existence of that diversity in the scales of action of the simple or elementary axes, without which their points of compensation (or the poles of the lemniscates they exhibit in polarized light) must of necessity be coincident for all the simple colours, a coincidence which, as has been already remarked at the beginning of this paper, seldom or never takes place. This I conceive to be the view which Dr. Brewster himself has taken of the phenomena of the deviation in crystals with two axes, and to afford ocular demonstration of the existence of what he has called the different dispersive powers of his elementary axes.

J. F. W. HERSCHEL.

SLOUGH, *Feb* 19, 1820.

III. *On the Rotation impressed by Plates of Rock Crystal on the Planes of Polarization of the Rays of Light, as connected with certain peculiarities in its Crystallization.*

By J. F. W. HERSCHEL, M.A.

FELLOW OF THE ROYAL SOCIETIES OF LONDON AND EDINBURGH, AND OF THE CAMBRIDGE PHILOSOPHICAL SOCIETY.

[Read *April* 17, 1820.]

THE phenomena of the developement of colour in plates of Rock Crystal when polarized light is transmitted through them in the direction of the axis of double refraction, and analysed at its egress by a doubly refracting prism, were originally noticed by M. Arago in 1811, and have since been examined in a very masterly manner by M. Biot in two Memoirs communicated to the French Institute in 1812 and 1818. It results from the experiments described in the latest of these, first, that a plate of this substance exposed to polarized light in the manner above described, possesses the singular property of displacing the plane of polarization of an incident ray, and turning it aside in one invariable direction, through an angle always proportional to the thickness of the plate, so that at its egress, the plane of polarization will assume the same position *as if* it had revolved in one direction during the passage of the ray through the whole thickness with an uniform angular velocity depending on the nature of the ray. Secondly, that this rotation of the plane of polarization, (for so we may be permitted to call it, though we know not whether any rotation actually does take place within the crystal, but only that the result is *as if* it were so) though invariable in its velocity for rays of the same colour, differs for those of different colours, being greater for the more refrangible rays, and that in the inverse ratio of the squares of the lengths of their fits in *vacuo*.

Thirdly, that although the direction of this rotation with respect to the observer (who is supposed to receive the ray in his eye) be invariably the same in the same specimen of rock crystal, whatever be the length of the ray's path within it, or whichever side of the plate be turned towards him, yet it differs in different specimens; in some being always from right to left, and in others from the left to the right of the observer so placed.

Fourthly, that this singular property is common to rock crystal with a variety of other bodies, and among the rest with various *liquids*, such as oil of turpentine, solutions of camphor, sugar, &c. in all which precisely the same law of rotation of the differently coloured rays is observed, the absolute velocity only differing. Many of them carry this property with them into their chemical combinations, solutions, and mixtures with other substances— they preserve it in their solid, fluid, and even gaseous form, with an energy proportional to their actual density, nor can any thing short of the decomposition of their molecules deprive them of it.

From these circumstances, as well as from a number of delicate and accurate experiments on the compensation of opposite rotations by the mixture of different liquids, and others which it is not necessary to enumerate here, M. Biot has concluded that there exists a property inherent in the ultimate molecules themselves of certain bodies, independent of their regular disposition in crystalline forms, their state of aggregation or proximity to each other, in virtue of which each individual molecule turns round the plane of polarization of a ray traversing it, through a certain minute but determinate angle depending only on the nature of the substance and of the ray. "Cette propriété consiste dans la faculté qu'ont "les molécules dont il s'agit de faire tourner d'un certain angle, et "dans un certain sens les axes de polarization des rayons lumineux."

Mysterious as such a property may seem and entirely opposing all our preconceived notions of the nature of the ultimate particles of bodies, unless we deny the precision of M. Biot's experiments, it is hardly possible to refuse our assent to the general tenor of the conclusions he deduces from them. Admitting then, for the present the truth of the inference, we are left to conjecture the circumstances in the intimate constitution of the molecules which can determine an invariable tendency of a ray of light to turn its plane of polarization in one direction rather than another, in whatever way they may be presented to it; and though it seems very difficult to form a definite hypothesis to explain the fact, yet the general impression left on our minds is that of a want of symmetry in the disposition within the molecules themselves, of some of the elementary forces by which they act on light; a thing not incompatible with perfect symmetry in their external forms, or in the distribution of the more powerful forces which determine the laws of their aggregation in regular crystals. Now so far as the action of crystallized media on light has been examined, there appears to exist an intimate connexion between the crystallographical and optical properties of bodies, and as we have every reason to imagine that the forces by which the particles of matter act on light and on each other, do not differ essentially in their nature, it is easy to conceive that any deviation from perfect symmetry in the distribution of even subordinate forces of any kind, will in some degree influence the molecules in their mode of aggregation with one another, and however feeble, yet, being a cause constantly in action, may possibly, under favourable circumstances, produce a sensible modification and deviation from symmetry in their crystalline form, such as might arise for example, from a preference given to more rapid laws of decrement on some of the angles and edges than on those adjacent to them, though similarly situated with respect to the axis of symmetry of the primitive form. From such laws of decrement would result faces unsymmetrically situated with respect to that axis, and having a bias, or tendency to lean as it were in one direction rather than another.

In the variety of quartz to which Haüy has assigned the name of "Plagiédre," such unsymmetrical faces do in fact occur. One of these crystals is represented in fig. 19, in which we may observe that the faces x, x, x, and x', x', x', peculiar to this variety, lean or tend as it were, in one uniform direction round the summit A adjacent to them, the angle made by them with the adjacent sides of the prism being greater on one side (the right, for instance) than the other. If we invert the crystal so as to bring the summit a uppermost, the plagiedral faces adjacent to this summit observe the same law, and lean in the same direction, nor so far as I know, does any instance occur of this law being broken, or of faces of this kind leaning opposite ways co-existing on the same crystal*. No inference however could be drawn from this circumstance, were it not for the very remarkable peculiarity of this substance, in virtue of which different specimens of it produce opposite rotations. This, it is evident, furnishes us at once, with a means of verifying or dis-

* The faces in question originate in those laws of decrement which Haüy has called intermediate. The primitive form of quartz is a rhomboid slightly obtuse whose axis is parallel to that of the hexagonal prism. The subtractive molecule by which the decrement on the angles E (fig. 20.) takes place to produce the faces x, is composed of eight of these rhomboids, its edges consisting respectively of 1, 2 and 4 edges of the primitive rhomboid, and the decrement resulting is represented in Haüy's Notation by $(E^{4}_{x} D^{2} D^{1})$. The alternate faces x' arise from a different law (as they obviously must, the angles upon which they are produced being differently related to the superior vertex). Their law of decrement cannot be reduced to an integer expression, but is represented by $(\frac{4}{5} E_{x} D^{2} B^{1})$ in the same notation. See Haüy, *Traitè de Mineralogie*. 4to. Plate 45. (Tom. II, p. 297.)

proving the existence of such a cause as I have suggested in any case where we suspect it to have operated in producing such unsymmetrical faces.

Now, on examining with this view different crystals of the plagiedral variety, I observed that in some specimens the peculiar faces do actually lean always to the right, while in others, similarly placed with respect to the observer, they as regularly tend the opposite way, or towards his left. In other respects, as in hardness, lustre, transparency, specific gravity, &c. no marked difference appears to exist between those of the one kind and the other.

Here then we have a phenomenon precisely analogous to the opposite rotations produced by the same body in the planes of polarization of light, and it could not but appear probable that both originated from a common cause. To convert this probability into certainty, it only remained to ascertain whether or not the direction of rotation of a polarized ray be invariably dependent on that of the plagiedral faces in such crystals as possess them. It is true M. Biot in his Memoir above cited, has assured us that no peculiarity in the crystalline form (among other characters) can lead us to conjecture what may prove the direction of rotation in a given specimen of rock crystal previous to trial, but as crystals of this variety are comparatively rare it seemed not unlikely that they might have escaped his examination *.

When this idea first occurred to me, the only plates of rock crystal in my possession fit for the purpose were nine very fine ones cut from a single crystal, of which I had fortunately preserved the summit, on which were two small but very distinct and brilliant faces of the plagiedral kind, leaning to the left when the vertex of

* His words are "Enfin, puisqu'il existait des aiguilles a rotations contraires (j'en tirai comme consequence qu') il fallait quelles fussent composées ou au moins uniformement mêlées, de deux substances de nature différente, sans qu'aucun indice dans leur transparence ou leur forme cristalline pût faire soupçonner cette diversité."

the pyramid was uppermost. (This for brevity I will call a left-handed crystal). The rotation in all these plates was to the left, to an observer looking in the direction of the ray's progressive motion or to the right of one receiving the ray in his eye. I shall adhere to the former position. As to the direction of rotation, it is easily recognized. We have only to enclose the plate between two cross tourmalines and notice the center of its rings, or place it in a polarized beam traversing its axis, and analysed by a prism of Iceland spar, attending only to the extraordinary image. Suppose the rotation to be the left of the ray's motion, then, if we turn the tourmaline next the eye, or the prism of Iceland spar continually to the left (of the observer), the minima of the blue, yellow and red rays will occur in the order here set down and of course the image will appear successively red, purple, and blue or green, or will appear to descend in the order of the rings, whereas in a crystal of a contrary character the colours succeed one another in a contrary order, or which comes to the same, the motion must be made from the observer's left to his right, to produce them in the same order.

In this instance then we have,

Direction of the plagiedral faces, right to left

——————— Rotation ——— ditto ditto

On examining all the quartz crystals in my possession, I could discover but one more in which a plagiedral face occurred. This was however very perfect and was directed to the right .
From this crystal I procured a plate to be cut, and was not a little gratified, on placing it in a proper apparatus to find its rotation such as I supposed it would. In this instance therefore we have

Plagiedral faces

Rotation

Encouraged by this trial, I procured, after some search, several crystals of the variety in question, and selecting seven of the best put them into the hands of a lapidary. Of these crystals, three were left-handed $\longleftarrow$, and four right $\longrightarrow$, and to avoid confounding them, besides giving particular directions to the workman to fold each crystal with the plate cut from it separate from the rest, I took the precaution to identify them by corresponding diamond marks, and for greater security took care on their return to assure myself by the fitting together of the pieces, their lustre, flaws and striation, &c. &c. that no misarrangement had taken place. They were then subjected to the same examination, and the result in each instance was conformable to that of the two preceding trials, the direction of rotation to an observer looking in the direction of the ray's motion, being in each of them the same with that of the plagiedral faces.

Perhaps I might have rested satisfied with having pre-determined eight times without a failure the direction of rotation, but as this seemed rather too small a number to found a general rule upon, I selected five more, in two of which the peculiar faces turned to the right $\longrightarrow$, and in the other three to the left, and having procured a plate to be cut from each, placed them in succession on a proper apparatus, and requesting a friend to notice the succession of colours on turning the index one way or the other, named the order of succession in the colours proper to each plate from the inspection of the crystals to which they belonged, and the prediction so made previous to any observation on my own part was declared to be verified in each instance, of which, for fear of a mistake, I took care to satisfy myself at leisure.

The induction from so many instances without an exception seems conclusive, and we are authorized to state it as a fact, general as far as our present observations go, that the direction of rotation in quartz corresponds with that of the unsymmetrical faces in the plagiedral variety of its crystals, and that consequently *these* *faces are produced by the same cause which determines the displacement of the plane of polarization of a ray traversing the crystal parallel to its axis.*

What this cause may be, I have ventured to hazard something like a vague conjecture. Should the fact itself be regarded as in any way corroborating the idea of a force inherent in the molecules of bodies there still remains a great obscurity and indistinctness in our conception of such a force. If I mistake not, however, much of this arises from the difficulty we find in conceiving that part of M. Biot's hypothesis which supposes a particle of matter to act on a ray with precisely the same force and in the same direction in whatever way it is presented to it. Now this condition is not necessary. There may possibly exist in every molecule, a direction or axis in which the force of rotation is a maximum, and others in which it is nothing or even negative, that is, tending to produce a contrary rotation, while in other positions it may be intermediate, and follow some unknown law in its intensity. In liquids, in which the axes of the particles have every possible direction, the rotatory force resulting from their joint action will be an average or mean among all the values it is susceptible of, regard being had to the comparative frequency of their occurrence while in crystallized bodies, whose molecules are all similarly arranged, and in which, owing to their polarizing action the effects of the rotatory forces can only be discerned in one or at most two directions (those of their neutral axes) its apparent intensity may have any value from the maximum to the minimum, according to the position of these axes within the molcule. It seems not impossible, therefore, that substances actually possessing the rotatory property, and capable of exhibiting it in a liquid state may appear divested of it in their solid form by the coincidence of their axes with positions in which it is really evanescent, and *vice versâ,* that solids possessing the property of rotation in a very energetic degree on account of the coincidence of their axis by double refraction with that of their maximum rotation may, when held in solution, act much more feebly, or not at all. This may possibly be the reason why a solution of silica in potash (liquor silicum) possesses no rotatory power*. It may perhaps explain too, the very inferior energy of the rotatory force, as developed in all the fluids in which it has been recognized hitherto, to that exerted along the axis of rock crystal: a remarkable circumstance of which no other account has yet been given.

The fact above recorded is interesting in another point of view. It may lead us to pay a minuter attention to those seemingly capricious truncations on the edges and angles of crystals which appear to be commonly regarded as the effect of accidental circumstances prevailing during their formation. It may be so, but the much greater comparative frequency of some of them than others is an indication at least of greater facilities afforded to the decrements by which they are produced, by the constitution of their molecules, and it is not improbable that an accurate examination of them may afford us evidence of the operation of forces of which we have at present no suspicion.

* By my own experiment. The silica employed was a portion of a plagiedral crystal which turned the plane of polarization to the left. Had siliceous sand been used, the result might have been foreseen as the opposite rotations of the minute crystalline fragments (some perhaps of one kind, some of another) of which it consists, would, among so many thousands, compensate one another.

J. F. W. HERSCHEL.

SLOUGH, *March* 15, 1820.

NOTE.

THE general fact announced in the above pages resting on mere induction, it seemed desirable to extend this as far as lay in my power, and I have accordingly (since the communication of this paper) examined nine specimens in addition to those already enumerated, making in all twenty-three, without meeting with an exception to the law. One crystal has, however, fallen under my notice, of a very singular character which renders me cautious in asserting the absolute generality of the conclusion. It is in the possession of Mr. Brooke, and has on one and the same angle of the prism, plagiedral faces perfectly distinct and in contact, but tending opposite ways round the summit. I was not permitted to examine the action of this rare specimen on light, and can therefore say nothing of its internal structure.

In the amethyst it is very rare to find plagiedral faces, even small and imperfect ones; but in searching over bags containing several hundreds of purple amethysts from Brazil, I met with three, in one of which the face in question had some extent, in another it was distinctly visible but of microscopic dimensions, while in the third, considerable doubt subsisted of its identity. In the first only could I succeed in tracing satisfactorily a uniform rotatory structure up to the immediate neighbourhood of the plagiedral face, and in this the rotation corresponded in direction with that of the face itself. It may be permitted me to mention, that in the course of this enquiry I was led by independent observation to a knowledge of the essential distinction between Amethyst and Quartz, while yet ignorant that the subject had engaged the attention of Dr. Brewster. Very shortly after, however, I received, by the kindness of that ardent and indefatigable observer, a copy of a Memoir communicated by him in Nov. 1819. to the Royal Society of Edinburgh, and printed in the beginning of the present year, in which I find all my observations on that point anticipated.

J. F. W. H.

SLOUGH, *Oct.* 9. 1820.

IV. *On the Chemical Constituents of the Purple Precipitate of Cassius.*

By EDWARD DANIEL CLARKE, LL.D.

LATE FELLOW AND TUTOR OF JESUS COLLEGE; PROFESSOR OF MINERALOGY IN THE UNIVERSITY OF CAMBRIDGE; LIBRARIAN OF THE UNIVERSITY; MEMBER OF THE ROYAL ACADEMY OF SCIENCES AT BERLIN; HONORARY MEMBER OF THE GEOLOGICAL SOCIETIES OF LONDON, EDINBURGH, CORNWALL, &c. &c.

[Read *May* 15, 1820.]

"*LET us then honestly confess with Macquer,*" says ***Proust,*** in closing the account of his elaborate experiments* upon this purple state of Gold, "*that the nature of it is not yet well understood.*" Indeed so little is generally known of its real nature that while some Chemists have considered it as an *oxide of Gold*†, others have believed it to be *gold* in the *metallic* state, and in a state of extreme division mixed with *oxide of tin*. That the oxide of Gold is similarly characterized, as to colour, may be proved by the phenomena attendant upon its combustion when exposed to the flame of the Gas Blowpipe‡. *Pelletier* first shewed that the precipitate which *tin* causes in a dilute solution of the *muriate of gold* is a compound, consisting of the *oxides* of *tin* and *gold*§. *Proust* has endeavoured to maintain a different opinion; namely, that the *gold* in the purple

* Journal de Physique, *Feb.* 1806. Vol. LXII. See also *Nicholson's* Journal, Vol. XIV. p. 340.

† See *Aikin's* Chemical Dict. Vol. I. p. 536. In the Appendix, p. 118, a reference is made to *Proust's* later experiments.

‡ See Gas Blowpipe, Exp. LXXIX. p. 90. Lond. 1819.

§ Murray's Chemistry, Vol. III. p. 103. Edinb. 1807.

powder of *Cassius* is in the *metallic* state; and that a purple colour is natural to *gold* whenever it exists in a state of extreme division. For the latter part of the observation he confesses himself to be indebted to *Macquer;* and he ascribes to the French chemist the honour of the discovery*. But *Macquer* only adopted the opinion of others; and the opinion itself, respecting the *metallic* state of the *gold* in the purple powder, not only remains to be proved, but the experiments made with this precipitate are decidedly adverse to the fact; and more especially the refractory nature of the precipitate when exposed to the action of heat before the common blow-pipe. That chemists should still remain in doubt, not to say in ignorance, respecting the chemical constituents of a substance so long known†, and so highly valued from its application in the arts, may well stimulate an enquiry into its real nature. *Professor Thomson* of *Glasgow*, in the last edition of his valuable System of Chemistry‡, says, that the proofs which *Proust* has afforded of the metallic state of the gold in the *purple of Cassius*, do not appear to him to be quite convincing; though they certainly render the opinion plausible; "there can be no

* See Journal de Physique, as before cited from *Nicholson's* Journal.

† This precipitate is said to have been discovered in the middle of the seventeenth century by Dr. Cassius (*see Aikin's Chem. Dict. &c.*) and applied to the art of tinging glass of a transparent ruby colour, the red glasses of earlier date, such as we see in old Churches and Cathedrals being only superficially painted. *Kunckel* carried the art to such perfection that he made a chalice of this ruby glass for the Elector of Cologne, of an uniform tint throughout which weighed 24 pounds; and he says that he used for the colouring constituent the precipitate of *gold* made with *tin*. But it is very uncertain when this precipitate was first applied to the purpose of colouring glass. In a curious work printed at Florence in 1612, entitled "*L'arte Vetraria*," written by *Antonio Neri*, the process of colouring glass red, so as to imitate the *ruby*, is distinctly stated. "*Si calcini l'oro, che venga in polvere rossa, et questa calcinatione si faccia con acqua regis, più volte, ritornaldola adossoli per cinque o sei volte, poi questa polvere d'oro, si metta in tegamino di terra a calcinare in fornello tanto che venga polvere rossa, che seguira in più giorni, allora questa polvere rossa di oro data sopra il vetro fuso*, &c. &c. *farà allora il vero rosso trasparente di Rubino.*" (Cap. 129. p. 108. In Firenze, 1612.) And *Libavius*, in his *Alchymia*, printed in 1606, speaks of the ruby colour which may be communicated to *glass*, by means of *gold*.

‡ Vol. II. p. 254. 5th Edit. Lond. 1817.

doubt," he adds "that the two constituents of this powder are chemically combined." According to *Proust's* experiments, the *purple of Cassius* is a compound of one part of gold and three parts peroxide of tin*. "Aqua Regia," observes *Professor Thomson*†, "dissolves the gold and leaves the tin; on the other hand muriatic acid dissolves the tin and leaves the gold." As some experiments which I have lately made myself with the *purple precipitate* do not altogether correspond in their results with the accounts given of it, and moreover have been attended with circumstances that may throw some light upon its history, I conceive myself justified in making the examination of this substance the subject of the first chemical essay which has been read to the Society.

Supposing, from what *Proust* and others have affirmed, that the gold were in the metallic state although in a state of extreme division, *mercury* when agitated with the *purple powder* would extract the whole of it; which is not the case. It would moreover be easy to exhibit a more perfect revival and aggregation of the metallic particles before the common blow-pipe. It was with this view that I placed some of the powder, which had been carefully washed and dried, within a charcoal crucible, and exposed it to the blow-pipe. Finding it to be altogether refractory, I endeavoured to accomplish its fusion by adding *borax;* but did not succeed. I then attempted to fuse it with *nitre*, but also failed. Thirdly, I mixed the *nitre* and *borax* together, when an easy fusion was effected; the charcoal becoming covered with innumerable minute dingy-looking metallic beads‡ which were not easily made to flow together, so as to become of sufficient size for the purpose of cupellation upon the tube of a tobacco-pipe.

* Journal de Physique, *Feb.* 1806. Vol. VI. *Nicholson's* Journal, XIV. 336.

† System of Chemistry, Vol. II. 5th Edit. as above cited.

‡ They were brittle, but became partly malleable by further fusion with platinum foil, forming a triple compound of platinum, tin, and gold.

Having placed one of these beads upon pipe-clay, and urged its further fusion, with the aid of a common blow-pipe, and a little borax, it became gradually diminished in bulk, sending forth white fumes, in consequence of the combustion of the *tin*, and leaving upon the pipe-clay a residue, without any metallic lustre, covered with a whitish oxide. Finding it to be impossible, by this process, to separate the *gold* from the *tin*, and being convinced that the *gold* (if any existed in the compound) must be in a very small proportion, I had recourse to another experiment, by which I was enabled to form an alloy comprehending the whole of the *tin* and the *gold* in the *purple powder*, and afterwards from the analysis of this alloy, to ascertain their relative proportion with regard to each other.

A. Having mixed together, in a porcelain mortar, a small quantity of the *purple powder* with equal proportions of *nitre* and *borax*, I placed this mixture within a small capsule of porcelain, and exposed it to a red heat for about an hour. At the end of this time the capsule was taken from the fire and cooled; when I perceived a brilliant globule of metal at the bottom of the vessel, having the colour and lustre of pure silver. It weighed $\frac{8}{10}$ of a grain.

B. The metallic globule mentioned in the preceding experiment, and which I believed to consist of *tin* and *gold*, was placed in *muriatic acid*, and boiled during one quarter of an hour, under an expectation that the acid would dissolve the *tin* and leave the *gold*. It produced however no change it its appearance: when taken from the acid, and washed, it weighed, as before, $\frac{8}{10}$ of a grain; its lustre being unimpaired.

C. The same globule was then exposed to the action of *nitro-muriatic acid*, mixed in the proportion of four parts of *muriatic acid* to one of *nitric acid;* which began to act upon the alloy even when cold; and, being heated, speedily dissolved the whole of it; leaving no residue.

D. The solution being evaporated almost to dryness, and distilled water added, the liquor still preserved its transparency; but as soon as it became heated, a white flocculent substance was precipitated.

E. The liquor from *D* being filtered, a solution of ***sulphate of iron*** was added to it; when a dark powder was separated, which, being collected, washed, and dried, weighed $\frac{2}{10}$ of a grain. This being placed upon charcoal before the blow-pipe, a globule of pure *gold* was revived, weighing also exactly $\frac{2}{10}$ of a grain.

F. The supernatant fluid filtered from *E* after the separation of the *gold*, yielded no precipitate of *tin* to the *corrosive muriate of mercury;* and as it was probable that the *tin* had been separated in the white flocculent precipitate mentioned in *D*, to this precipitate were added two or three drops of *muriatic acid;* whence, a single drop being detached, precipitated *platinum* from its dilute solution in *nitro-muriatic acid.* Hence it was evidently *muriate of tin.*

These experiments are sufficient to prove that the binary compound, which had been analyzed, consisted of the oxides of *tin* and *gold*, and contained those *oxides* chemically combined in the exact proportion of three parts of *tin* to one of *gold*: and that the alloy of the two metals, obtained by the fusion of one hundred parts of the *purple powder*, would yield

Metallic tin	75
Metallic gold	25
	100

Because $\frac{8}{10}$ of a grain of the alloy yielded,

Metallic tin	0.6
Metallic gold	0.2
Total	0.8.

In the foregoing experiments no attention had been paid to the weight of the purple powder used in the analysis; because I had supposed that this would always bear the same proportion to the weight of *alloy* obtained. That having the weight of the *alloy* the weight of *oxygen* requisite in the formation of the *purple powder* would always follow in a constant ratio; the chemical combination being always the same; but this is by no means true. The proportion of *gold* in the *purple powder* varies in every precipitation; which is in fact the cause of the disappointment experienced by artists, who complain that in the application of this *purple powder* to the art of colouring glass, the colour is rarely in two instances the same. Much depends upon the age and the degree of concentration of the *muriate of tin* used in the experiment; also upon its temperature when added to the dilute solution of *gold*. In one instance, having used a recently prepared *muriate of tin*, almost at a boiling temperature, the precipitate had a *black* colour, which, however, afterwards became of a deep *purple*. Having washed and dried $7\frac{9}{10}$ grains of this dark precipitate, and exposed it in a porcelain capsule to a strong red heat during a quarter of an hour, with a view to drive off any remaining *water* or *acid*, I mixed it in a mortar with three times its weight of *nitre* and *borax* in equal portions, and kept it exposed, in a porcelain capsule, to a uniform red heat for an hour. During this experiment the minute globules of *alloy* might be seen forming upon the surface of the flux, and running about in small brilliant particles, like sparks of ignited matter, which afterwards fell to the bottom of the vessel. From the whole of the $7\frac{9}{10}$ grains of powder, a globule of *alloy* weighing $5\frac{4}{10}$ grains was obtained. It had a more *golden* colour than the alloy which I had before obtained from the *purple precipitate;* and, being dissolved in *nitro-muriatic acid,* the solution yielded a much more considerable proportion of *gold* to the *sulphate of iron.* The *gold* in this instance weighed $2\frac{5}{10}$ grains, and a quantity of *peroxide of tin* was separated in diluting the *muriate of gold,* after expelling the excess of acid, which, when washed and dried, weighed $3\frac{8}{10}$ grains, a little water probably remaining, as this *peroxide* had been dried on a filter in the open air. When exposed to a powerful heat it weighed only $3\frac{7}{10}$ grains.

Hence it is therefore evident that the two metals which are chemically combined in the *purple powder of Cassius,* do not exist in a constant relative proportion with regard to each other. That the *tin* sometimes exceeds the *gold* in the proportion of three to one, and in other instances that the two metals exist in nearly equal portions. Perhaps in other examples the quantity of *gold* thrown down may exceed that of the *tin;* but in whatsoever proportion the *gold* may exist with regard to the *tin,* in the *purple precipitate of Cassius,* there is not evidence to warrant the opinion of its being in the *metallic* state. There are, it is true, some experiments, so problematical in their results, that the chemist, in making them, is liable to be misled by appearances. A brief statement, therefore, shewing what these appearances are, and endeavouring to account for them, may now terminate this enquiry; by which it will perhaps be satisfactorily proved that the *gold* in the *purple powder of Cassius,* is at a minimum of oxidation; and perhaps also that it is liable, after precipitation, to that spontaneous decomposition, and to those changes, when exposed to the action either of light or heat, or even of simple moisture, which the *protoxide of gold* has been said to undergo; namely, that of dividing itself into two parts, one portion parting with its oxygen to the other, and becoming revived in the metallic state*. An illustration of this may be afforded by an amusing and very striking experiment. If the *purple precipitate*, after being washed and while it is in a moist state, be agitated in a glass vessel, so as to be made to adhere to the interior surface of the vessel, and be then left to become dry, a portion of the *gold* will become revived and will appear in the *metallic* state. This will take place the more readily if the vessel be exposed to light in a window, or to the full action of the Sun's rays. But a portion of the precipitate will still retain its original colour; and will be found to contain *gold* which has not been thus revived; thereby apparently confirming the observation of *Berzelius*, referred to by the author of the "System of Chemistry" as before cited. Such an appearance, resulting from the change which the *protoxide of gold* has sustained after its precipitation might give rise to an opinion that the metal had been originally thrown down in the *metallic* state. There is another appearance yet more delusive; it results from the following pleasing experiment.

The *purple precipitate*, after being washed, and being yet in a moist state, is to be agitated in a phial with mercury. Some of this mercury is to be placed in a watch-glass over an argand lamp, and volatilized, when a film of *metallic gold*, will remain upon the glass. Four grains $\frac{5}{10}$ of *mercury* which had been thus agitated with the *purple powder* left a residue of $\frac{1}{10}$ of a grain of *metallic gold*. This appearance might lead to the conclusion that the whole of the *gold* in the *purple powder* existed in the metallic state, which is not true; for upon examining the powder whence the $\frac{1}{10}$ of a grain of metallic

* "In a short time this *protoxide* divides itself into two parts. One-third deprives the other two-thirds of the whole of this oxygen and becomes *peroxide*, while the two-thirds are reduced to the metallic state." (*See Berzelius, Ann. de Chim.* 83. 166.) "Berzelius thinks that there exists an intermediate oxide, (between the *protoxide* and the *peroxide* of *gold*) which constitutes a component part of the *purple of Cassius*. But he has not established its existence by decisive experiments." *Thomson's System of Chemistry*, Vol. I. pp. 486, 487. *London*, 1817.

gold had been thus separated, by exposing it to the action of *nitro-muriatic* acid, and afterwards evaporating the excess of acid and adding distilled water, it was found to contain *gold*, which was thrown down, from the *muriate* thus formed, by the usual tests of *sulphate of iron* and *muriate of tin*. The most curious thing to be attended to in separating the portion of *metallic gold* by means of *mercury*, in the foregoing experiment, is this; that the success of it depends upon the moist state of the precipitate after being washed with *water;* but whether the revival of the *gold* be owing to the *hydrogen* of the water, or to the cause assigned by *Berzelius*, of the spontaneous decomposition of the *protoxide* of the metal *, others may determine. Twelve grains of the *purple powder*, which had been previously exposed to a red heat in a porcelain capsule, were agitated with well dried *mercury;* but, after the volatilization of the *mercury*, no film of *gold* remained, as in the former instance; nor any residue, whatsoever, to alter the weight of the watch-glass in which this trial of the dry powder had been made. The same dry powder, after the removal of the *mercury*, being placed in *nitro-muriatic* acid, and the excess of acid expelled, and distilled water added, yielded a solution, from which *gold* was precipitated by the usual tests.

From all the preceding observations it may be inferred that in precipitating the *purple powder of Cassius* from the *muriate of gold*, by means of the *muriate of tin*, the two metals *tin* and *gold* are thrown down as *oxides;* which however do not chemically combine in a constant relative proportion to each other; that the quantity of *tin* always exceeds that of the *gold*; and that the difference observable in the hues of the precipitate made at different times, is to be ascribed to the different proportions in which the *oxides* of the *two metals* have combined together, and perhaps also to their different degrees of oxidation.

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* See a former Note.

V. *Observations on the Notation employed in the Calculus of Functions.*

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Amongst the various causes which combine in enabling us by the use of analytical reasoning to connect through a long succession of intermediate steps the data of a question with its solution, no one exerts a more powerful influence than the brevity and compactness which is so peculiar to the language employed. The progress of improvement in leading us from the simpler up to the most complex relations has gradually produced new modes of shortening the ancient paths, and the symbols which have thus been invented in many instances from a partial view, or for very limited purposes, have themselves given rise to questions far beyond the expectations of their authors, and which have materially contributed to the progress of the science. Few indeed have been so fortunate as at once to perceive all the bearings and foresee all the consequences which result either necessarily or analogically even from some of the simplest improvements.

The first analyst who employed the very natural abbreviation of a^2 instead of aa little contemplated the existence of fractional negative and imaginary exponents, at the moment when he adopted this apparently insignificant mode of abridging his labor. So great however is the connection that subsists between all branches of pure analysis, that we cannot employ a new symbol or make a new definition, without at once introducing a whole train of consequences, and in defiance of ourselves, the very sign we have created, and on which we have bestowed a meaning, itself almost prescribes the path our future investigations are to follow.

Such being the power and influence of those symbols* by which mathematical reasoning is carried on, it cannot be considered as unimportant either as regards the particular branch, or with reference to the science in general, to examine some of the bearings of the notation which has been employed in the calculus of functions, and to resolve some of the unusual questions which it presents.

That the results to which such an enquiry will conduct us are of a nature purely speculative, is an objection to which every attempt to improve notation is liable; it can however never be considered an useless task to examine and strengthen that which essentially contributes to the power of an instrument, which enables us so wonderfully to trace the connexion between the phenomena of nature.

When it became convenient to express without performing the repetition of an operation, whose characteristic is f, the method which first presented itself doubtless was similar to that which had been adopted with such advantage for the exponents of quantities, and $f^2(x)$ was written instead of $ff(x)$; it now followed without any other convention that $f^3(x)$ and $f^n(x)$ represented $fff.(x)$, and $fff.$ (n times) (x) and also that

$$f^{n+m}(x) = f^n f^m(x) \ldots\ldots (A),$$

when n and m are whole numbers.

* Euler, to whom analysis is so much indebted, appears to have been fully aware of the power and importance of notation; "Summa analyseos inventa maximam partem algorithmo ad certas quasdem quantitates accommodato innitantur." Specimen Algorithmi singularis. Acad. Petrop. Comm. *Nov.* 1762.

At this point of generalization a question occurred as to the meaning of f^n when n is a fractional, surd, or negative number, and in order to determine it, recourse was had to a new convention not inconsistent with, but comprehending in it the former one. The index n was now defined by means of the equation (A) and was said to indicate such a modification of the function to which it is attached that that equation shall be verified.

From this extended view of the equation (A) several curious results follow; if $n=0$, it becomes

$$f^m(x) = f^0 f^m(x).$$

This informs us that f^0 is such an operation that when performed on any quantity it does not change it, or putting $f^m(x)=y$, it gives

$$f^0(y) = y,$$

a result which is analogous to $x^0=1$.

Let $m=-1$, $n=1$, we have

$$f^0 x = f^1 f^{-1}(x), \quad \text{or } f(f^{-1}x) = x;$$

$f^{-1}(x)$ must therefore signify such a function of x, that if we perform upon it the operation denoted by f it shall be reduced to x. The number of functions possessing this property will depend on the nature of f; thus if $f(x)=x^n$, let $r_1, r_2, \ldots . r_n$ be the roots of $v^n-1=0$; then $f^{-1}(x)$ may be either of the n quantities

$$r_1 x^{\frac{1}{n}},\ r_2 x^{\frac{1}{n}}, \ldots . r_n x^{\frac{1}{n}};$$

for if we perform the operation f upon any of them, or raise it to the nth power, the result is x.

Here then we find

$$f(f^{-1}x) = x,$$

in all cases; but if the negative index is attached to the first functional sign, we have

$$f^{-1}(fx) = r_i x,$$

and one only of these values gives $f^{-1}fx=x$.

It was more necessary to make this observation, because several errors have arisen from not attending to it, and because that particular form of f^{-1} which gives $f^{-1}fx=x$ possesses peculiar properties: $f^{-1}(x)$ is then the inverse function of fx; and if we have the equation $f(x)=y$, we may indicate its resolution thus

$$x=f^{-1}(y).$$

Having established the connexion between positive and negative indices in functions of one variable, I shall now proceed to those containing two.

If in the function $\psi(x,y,)$ we substitute at the same time $\psi(x,y,)$ for x and y it becomes

$$\psi\{\psi(x,y),\ \psi(x,y)\},$$

and for the sake of brevity this has been denoted thus

$$\psi^{\overline{2,2}}(x,y):$$

similarly, if in this we wrote $\psi(x,y)$ for x and y we should have $\psi^{\overline{3,3}}(x,y)$, and a few steps would lead us to the equation,

$$\psi^{\overline{n,n}}\{\psi^{\overline{m,m}}(x,y),\ \psi^{\overline{m,m}}(x,y)\}=\psi^{\overline{n+m,n+m}}(x,y)\ldots\ldots(B).$$

The same reasons which in the former instance induced us to generalize the first definition, now point out the propriety of assuming this as the definition of simultaneous functions, and of the modifications implied by their indices. The first step is to discover the value of $\psi^{\overline{0,0}}(x,y)$; for this purpose put $n=0$, then

$$\psi^{\overline{0,0}}\{\psi^{\overline{m,m}}(x,y),\ \psi^{\overline{m,m}}(x,y)\}=\psi^{\overline{m,m}}(x,y),$$

and substituting v instead of $\psi^{\overline{m,m}}(x,y)$, we have

$$\psi^{\overline{0,0}}(v,v)=v.$$

If we had put $m=0$, $n=1$ instead of $n=0$, we should have found

$$\psi^{\overline{1,1}}\{\psi^{\overline{0,0}}(x,y),\ \psi^{\overline{0,0}}(x,y)\}=\psi^{\overline{1,1}}(x,y),$$

which shews that $\psi^{\overline{0,0}}(x,y)$ is such a function of x and y that when simultaneously substituted in $\psi(x,y)$, for x and y, it shall give either x or y: it may have different values like all other inverse functions.

If in the function $\psi(x, y)$, we put $\psi(x, y)$ instead of x it becomes $\psi\{\psi(x, y), y\}$ which is written thus $\psi^{2,1}(x, y)$, and continuing such substitutions we arrive at

$$\psi^{n,1}\{\psi^{m,1}(x, y), y\} = \psi^{n+m,1}(x, y) \ldots\ldots\ldots (C),$$

or if the n^{th} function relative to x, and then the m^{th} function relative to y be substituted, it would be

$$\psi^{n,1}\{x, \psi^{1,m}(x, y)\} = \psi^{n,m+1}(x, y) \ldots\ldots\ldots (D).$$

These two equations are now considered as the definition by which the meaning of the indices is known, and we proceed to enquire their values in particular cases: let $n = 0$ in the first and we have

$$\psi^{0,1}\{\psi^{m,1}(x, y), y\} = \psi^{m,1}(x, y);$$

put

$$\psi^{m,1}(x, y) = v, \text{ and it becomes}$$

$$\psi^{0,1}(v, y) = v, \text{ or } \psi^{0,1}(x, y) = x \ldots\ldots\ldots (E).$$

If $n = 1$ and $m = 0$ in the latter,

$$\psi^{1,1}\{x, \psi^{1,0}(x, y)\} = \psi^{1,1}(x, y),$$

whence it follows that

$$\psi^{1,0}(x, y) = y \ldots\ldots\ldots\ldots\ldots\ldots (F).$$

If $n = -m = 1$, (D) becomes

$$\psi^{1,1}\{x, \psi^{1,-1}(x, y)\} = \psi^{1,0}(x, y) = y,$$

hence $\psi^{1,-1}(x, y)$ expresses such a function of x and y that when substituted in $\psi(x, y)$ for y it reduces it to y, or if

$$\psi(x, y) = v,$$

then

$$y = \psi^{1,-1}(x, v) \text{ and } x = \psi^{-1,1}(v, y) \ldots\ldots\ldots\ldots (G).$$

From (C) we may readily deduce as consequences,

$$\psi^{0,n}(x, y) = x, \text{ and } \psi^{n,0}(x, y) = y.$$

The same reasoning which has been employed in discovering the meaning of the indices of functions of two variables applies with equal facility to those of many variables; without repeating it, it is sufficient to observe that

$$\psi^{0,1,1,\dots}(x, y, \dots) = x, \quad \psi^{1,0,\dots}(x, y, \dots) = y, \text{ \&c.}$$

and that of

$$\psi^{1,1,1,\dots}(x, y, z, \dots) = v;$$

then

$$y = \psi^{1,-1,1,}(x, v, z, \dots).$$

Amongst the questions which arise from this notation there are two which are altogether different from any which have occurred in others, and although their solution is not attended with any very great difficulty they furnish an enquiry of some curiosity.

If the expression $\psi^{n,m}(x, y)$ be fully written out, we may seek, first, *how many times will either of the quantities* x *or* y *be repeated;* and secondly, *how many times will the symbol* ψ *occur*.

I shall begin with some of the more simple questions, and first

PROB. I.

How often does the quantity x occur in the expression

$$\psi^{n,n}(x, y)?$$

Suppose it occurs u_n times, then in

$$\psi^{\overline{n+1, n+1}}(x, y) = \psi^{\overline{n,n}}\{\psi(x, y), \psi(x, y)\},$$

it occurs twice as many times as it does in the preceding; hence

$$u_{n+1} = 2u_n, \text{ or } u_n = C.2^n;$$

if $n=1$, $u_1 = 2C = 1$, hence $C = \frac{1}{2}$, and $u_n = 2^{n-1}$, or x occurs 2^{n-1} times in $\psi^{\overline{n,n}}(x, y)$.

PROB. II.

How many times is the symbol ψ repeated in $\psi^{\overline{n,n}}(x, y)$?

Let u_n be the number of times; then it is found u_{n+1} times in $\psi^{\overline{n+1, n+1}}(x, y)$; but in going from the first of these to the second we augment the number of times ψ occur by 2^n, because wherever x

occurs, we introduce ψ by putting $\psi(x, y)$ for it, and as x occurs 2^{n-1} times we by this means add 2^{n-1} times ψ, and similarly, on account of y we add 2^{n-1} times y, so that

$$u_{n+1} = u_n + 2^{n-1} + 2^{n-1} = u_n + 2^n,$$

$$\Delta u_n = 2^n, \text{ whence } u_n = 2^n + C,$$

if $n=1$ $u_1 = 2 + C = 1$, or $C = -1$,

therefore ψ occurs $2^n - 1$ times in $\psi^{n,n}(x, y)$.

PROB. III.

How often is x_1 repeated in $\psi^{\overline{n,n,\cdots}}(x_1, \ldots x_i)$?

Suppose it to occur u_n times, then in going from the n^{th} to the $n+1^{\text{th}}$ simultaneous function wherever $x_1, x_2, \ldots x_i$ occur, we introduce x_1 once, but each of these occurred u_n times, and as there are i of them, we have

$$u_{n+1} = iu_n, \text{ or } u_n = Ci^n;$$

but if $n=1$, $u_1 = Ci = 1$, wherefore $C = \frac{1}{i}$, and x occurs i^{n-1} times.

COR. As $x_i, \ldots x_k$ are all similarly involved, they each of them occur i^{n-1} times.

PROB. IV.

How often does ψ occur in $\psi^{\overline{n,n\cdots}}(x_1, x_2, \ldots x_i)$?

Let it occur u_n times; then in the $(n+1)^{\text{th}}$ besides the u_n times that it occurs in the n^{th} we introduce an additional ψ wherever $x_1, x_2, \ldots x_i$ occur, or since there are i of these quantities, and each occurs i^{n-1} times, we have

$$u_{n+1} = u_n + i^n, \text{ whence } u_n = \frac{i^n}{i-1} + C,$$

$$\text{if } n=1,\ u_1 = \frac{i}{i+1} + C = 1, \text{ hence } C = \frac{-1}{i-1};$$

$$\text{and } \psi \text{ occurs } \frac{i^n - 1}{i-1} \text{ times in } \psi^{n,n,\cdots}(x_1, \ldots x_i).$$

Prob. V.

How many times do x and y occur in $\psi^{n,1}(x, y)$?

In passing from the n^{th} function to the $n+1^{\text{th}}$ we change x into $\psi(x, y)$; this does not increase the number of times x occurs, and as the same reasoning applies to the $\overline{n-1}^{\text{th}}$, $\overline{n-2}^{\text{th}}$, ... down to the first it follows that x only occurs once in $\psi^{n,1}(x, y)$.

Again, in passing from the n^{th} to the $n+1^{\text{th}}$ we introduce y once, if therefore u_n represent the number of times it occurs, we have

$$u_{n+1} = u_n + 1, \quad \text{or} \quad u_n = n + C,$$

if $n=1$, $u_1 = 1 + C = 1$, or $C=0$, and y occurs n times in $\psi^{n,1}(x, y)$.

And similarly, x occurs n times, and y once in $\psi^{1,n}(x, y)$.

Prob. VI.

How frequently does ψ occur in $\psi^{n,1}(x, y)$?

$$\text{since } \psi^{n+1,1}(x, y) = \psi^{x,1}\{\psi(x, y), y\},$$

each step introduces ψ once, it will therefore be repeated n times.

Prob. VII.

In $\psi^{n,m}(x, y)$ how often are x and y repeated?

$$\psi^{n,m}(x, y) = \psi^{n,1}\{x, \psi^{1,m-1}(x, y)\}.$$

In the right side of this equation x occurs once, and in $\psi^{n,m-1}(x, y)$ it is found $(m-1)$ times; now in each of these last x occurs $m-1$ times by Prob. 5, so that on the whole it appears $1 + n.(m-1) = mn - n + 1$ times.

Again, y occurs once in $\psi^{1,m}(x, y)$ and this latter is found n times in $\psi^{n,m}(x, y)$, so that y occurs n times in the same expression.

Prob. VIII.

How many times does ψ occur in $\psi^{n,m}(x, y)$?

In $\psi^{n,1}(x, y)$, ψ is found n times by Prob. 6; and y is found n

times; if for y we put $\psi^{1,m-1}(x, y)$ which contains ψ, $m-1$ times repeated, we shall have

$$\psi^{n,1}\{x, \psi^{1,m-1}(x, y)\} = \psi^{n,m}(x, y),$$

and the number of times ψ occurs is $n+n(m-1)=nm$ times.

PROB. IX.

How often do $x_1, x_2, \ldots x_k$ occur in $\psi^{a,b,c\ldots}(x_1, x_2, \ldots x_k)$?

First, let us consider $\psi^{0,1,1,\ldots}(x_1, x_2, \ldots x_k)$, and let x_1 occur u_a times then since

$$\psi^{a+1,\ldots}(x_1, x_2, \ldots x_k) = \psi^{1,1,\ldots}\{\psi^{a,1,\ldots}(x_1, x_2, \ldots x_k), x_2, \ldots x_k\},$$

the number of times x_1 occurs in the first side of the equation is u_{a+1}; in the second side it occurs u_a^1 times, therefore $u_{a+1}=u_a$, or $u_a=C$; but if $a=1$, $u_1=C=1$, therefore $u_a=1$, and x occurs only once. Again, let u_a now represent the number of times x_2 occurs, then in the second side x_2 occurs u_a times in $\psi^{a,1,1,\ldots}(x_1, x_2, \ldots x_k)$, and also once besides, so that

$$u_{a+1}=u_a+1, \text{ or } u_a=a+C,$$

if $a=1$, $C=0$, and the same result will be found for any other quantity x_i except x_1, hence in $\psi^{a,1,1,\ldots}(x_1, x_2, \ldots x_k)$,

$$\left.\begin{array}{ll} x_1 & \text{occurs} \quad 1 \\ x_2 \ldots\ldots\ldots\ldots & a \\ \ldots\ldots\ldots\ldots\ldots & \\ x_i \ldots\ldots\ldots\ldots & a \end{array}\right\} \text{times} \ldots\ldots\ldots\ldots\ldots\ldots (1).$$

Let us next consider $\psi^{a,b,\ldots}(x_1, x_2 \ldots x_k)$,

$$\psi^{a,b,1,\ldots}(x_1, x_2, \ldots x_k) = \psi^{a,1,1,}\{x_1, \psi^{1,b-1,1,\ldots}(x_1, x_2, \ldots x_k), x_3, \ldots x_k\}.$$

On the right side of this equation x_1 occurs in two places first by itself in which state by (1) it is only found once; and secondly, it occurs in the function $\psi^{1,b-1,\ldots}(x_1, x_2, \ldots x_k)$ where by (1) it is found to recur $b-1$ times, but that function itself is repeated a times, therefore the whole number of times x_1 is repeated is

$$1+a(b-1)=ab-a+1:$$

x_2 only occurs under the last mentioned function, and there it is found only once, but as that function is repeated a times x_2 must occur a times: x_3 occurs in two places; in the first it is repeated $a(b-1)$ times, and in the second a times, so that on the whole x_3 is found

$$ab-a+a=ab \text{ times.}$$

x_i is found the same number of times.

Therefore in

$$\psi^{a,b,1,\ldots}(x_1, x_2, \ldots x_k),$$

$$\left.\begin{array}{ll} x_1 \text{ occurs} & ab-a+1 \\ x_2 \ldots\ldots\ldots & a \\ \ldots\ldots\ldots\ldots & \\ x_i \ldots\ldots\ldots & ab \end{array}\right\} \text{times} \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

by considering the equation,

$$\psi^{a,b,c,1,\ldots}(x_1, x_2, \ldots x_k)=\psi^{a,b,1,\ldots}\{x_1, x_2, \psi^{1,1,c-1,1,\ldots}(x_1, x_2, \ldots x_k), x_4, \ldots x_k),$$

we shall find that when there are three indices a, b, c,

$$\left.\begin{array}{ll} x_1 \text{ occurs} & abc-a+1 \\ x_2 \ldots\ldots\ldots & abc-ab+a \\ x_3 \ldots\ldots\ldots & ab \\ \ldots\ldots\ldots\ldots & \\ x_i \ldots\ldots\ldots & abc \end{array}\right\} \text{times} \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

a similar process applied to $\psi^{a,b,c,d,1,\ldots}(x_1, x_2, \ldots x_k)$ would show that in it

$$\left.\begin{array}{ll} x_1 \text{ occurs} & abcd-a+1 \\ x_2 \ldots\ldots & abcd-ab+a \\ x_3 \ldots\ldots & abcd-abc+ab \\ x_4 \ldots\ldots & abc \\ \ldots\ldots & \\ x_i \ldots\ldots & abcd \end{array}\right\} \text{times} \ldots\ldots\ldots\ldots (4),$$

and in $\psi^{a,b,c,d,e,1,\dots}(x_1, x_2, \dots x_k)$,

$$\left.\begin{array}{ll} x_1 \text{ occurs} & abcde-a+1 \\ x_2 \;\dots\dots & abcde-ab+a \\ x_3 \;\dots\dots & abcde-abc+ab \\ x_4 \;\dots\dots & abcde-abcd+abc \\ x_5 \;\dots\dots & abcd \\ x_i \;\dots\dots & abcde \end{array}\right\} \text{times} \dots\dots\dots\dots (5)$$

the law which these expressions follow is easily discovered from those which have been given, and by their assistance it may be shewn that in the expression

$$\psi^{a,b,c,\dots}(x_1, x_2, x_3, \dots x_k),$$

ψ will be repeated $abcd\dots$ times.

If in a function of two variables we wish after taking the $a, b, c, \dots{}^{\text{th}}$ functions relative to the variables $x_1, x_2, \dots$ in order, again to take the p^{th} relative to the first, the q^{th} relative to the second, &c. some modification of our notation becomes necessary. I have proposed in the Philosophical Transactions to make use of two rows of indices the upper to signify the number of repetitions, and the lower to denote the quantity for which the substitution is made, thus

$$\psi^{2,\,2,\,1}_{2,\,1,\,2}(x,y)=\psi\left\{\psi\{x,\psi(x,y)\},\ \psi\left[\psi\{x,\psi(x,y)\},\ \psi(x,y)\right]\right\},$$

when these indices become numerous it is desirable, for the sake of facility in printing, to have them on a level with the rest of the symbols, and this will become almost indispensible if another or possibly two other rows of indices should be employed: the further extension of the calculus may require such additions to indicate modifications of a different kind from those yet considered. There appear to be four circumstances connected with the indices of functions whose relations it may ultimately be desirable to express by means of them: the two first of them, namely, the number of repetitions and the quantities for which substitutions are made are already pointed out by the two rows. It may become necessary to substitute instead of one of the variables, not the original function but some modification of it such as $\psi^{1,2,}(x, y)$, and this might be only substituted for one of the variables in certain particular places not universally; such changes would require two additional rows.

The alteration which I would propose in all cases where many indices are concerned is extremely simple: it consists in merely bringing the indices down to the level of the functional sign and inclosing them between two bars; the expression last-mentioned would be written thus

$$\psi\left|{}^{2,}_{2}{}^{2,}_{1}{}^{1,}_{2}\right|(x, y).$$

This would also possess some advantage in the case of a function of many variables being after the performance of given operations reduced to a function of a less number, (by means of some assigned relation between some of them) and then new functional operations being performed, or considered as a function of the reduced number of variables, thus

$$\psi\left|{}^{2,}_{1}{}^{1,}_{2}{}^{1}_{3}\right|{}^{2,}_{1}{}^{2}_{2}\left|(x, y, z)\ldots\ldots\ldots\{z=f(x, y)\}\right.,$$

which signifies that the second function of $\psi(x, y, z)$ is taken relative to x; $f(x, y)$ is then substituted for z and the second function of the result considered as a function of two variables is taken first with respect to x, then with regard to y.

The method I have pointed out for the determination of the number of times the quantities under the functional sign would be repeated if they were written out at length is perhaps the most direct and unartificial which could be proposed; I cannot however terminate this paper without pointing out another method of a character completely opposite which promises in more complicated enquiries of this nature to be of considerable use. It bears a strong resemblance to a very elegant artifice employed by M. Laplace in order to determine the numerical coefficients of Σu, and was in fact suggested by it.

Since the number of times any variable is repeated is independent of the form* of the function, that number must be the same for all functions. If therefore we can find it for any particular function, we have it for all others. Let us then select the function $x_1+x_2+\ldots x_n$ and take those functions which the index requires, we shall have the number of repetitions of each variable expressed by the coefficient attached to it.

One great advantage of this plan is that we always have it in our power to take any function however complicated of $x_1+x_2+\ldots x_n$; as an example let it be required to find the number of repetitions of x and y in $\psi^{a,b,}(x,y)$;

$$\text{if } \psi(x,y) = vx + uy,$$

$$\psi^{a,b}(x,y) = \left(v^a + uv\frac{v^a-1}{v-1}\cdot\frac{u^{b-1}-1}{u-1}\right)x + u^b\cdot\frac{v^a-1}{v-1}y;$$

if $u=v=1$, this becomes

$$\psi^{a,b}(x,y) = (1+a.\overline{b-1})x+ay = (ab-a+1)x+ay.$$

Or x will be found repeated $ab-a+1$ times, and y will occur a times, which coincides with what was proved in Prob. 7.

The surprising condensation of meaning comprised in small space and yet exempt from even the slightest tinge of obscurity is nowhere more conspicuous than it is throughout the calculus of functions: and the solution of the problems contained in this paper enables us to give numerical results which will be viewed with surprise even by those who are best acquainted with the power of general signs.

The equation,

$$\psi^{\overline{10,10,}}(x,y) = \psi(x,y),$$

is one whose solution presents no great difficulties and may be

* In whatever manner the original function may involve the unknown quantities it must in this point of view be considered as containing each only once.

accomplished in a few lines. To any person acquainted with the notation employed in the doctrine of functions the question is comprehended at a single glance; yet if we apply to it the rules discovered in Prob. 1 and 2, we shall find that if it were written out at length, x and y would each be repeated 512 times, and ψ would occur 1023 times; so that the whole expression would consist of 2047 letters, and it may be added, that if it were so developed it would require a much longer time merely to comprehend the enunciation of the problem than it would to understand and solve it in its contracted form.

CHARLES BABBAGE.

Feb 26, 1820.

VI. *On the Reduction of certain Classes of Functional Equations to Equations of Finite Differences.*

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THE reduction of functional equations to those of finite differences was the means by which their resolution was originally attempted and though applicable only to particular classes of them, affords very ready solutions in those instances in which it can be practised, and these solutions have the advantage in general of indicating at the same time the number and nature of the arbitrary functions they involve. I propose therefore in the following pages to apply this method to a class of pretty considerable extent, in which the function to be determined is one of two or more variables, but where the condition expressed by the equation assigns to one of them a value or values dependent in a known manner on that of the other. Mr. Babbage, in the second part of his paper on Functional Equations (Phil. Trans. 1816.) has noticed equations of this nature, and has given solutions of certain cases of the higher orders. With these I shall not at present concern myself, the method which I propose to exhibit extending only to equations of the first order, of which it affords the complete solution in all cases. To proceed regularly, it will be necessary to premise the following Problems, the object of which is to determine the nature of the arbitrary functions we shall be obliged to introduce.

PROB. I.

Required the most general form of a function $\psi(x, y)$ of two variables x, y, which remains the same whether P or Q, (two given functions of x) be substituted for y, or to resolve the equation

$$\psi(x, P) = \psi(x, Q).$$

Since the substitution of P for y renders $\psi(x, y)$ a certain function (fx) of x, it is evident that in its general state $\psi(x, y)$ can only differ from fx by a quantity which vanishes when y becomes P, and of course $\psi(x, y) - f(x)$ must necessarily have $y - P$ for a factor. Again, since $\psi(x, y)$ reduces itself to the same function $f(x)$ by the substitution of Q for y, the quantity $\psi(x, y) - f(x)$ must in like manner have $y - Q$ for a factor, and we must therefore have

$$\psi(x, y) - f(x) = (y - P)(y - Q) . \chi(x, y)$$

or

$$\psi(x, y) = f(x) + (y - P)(y - Q) . \chi(x, y).$$

Let this be substituted in the equation $\psi(x, P) = \psi(x, Q)$, and the whole vanishes. This value of $\psi(x, y)$ therefore satisfies the equation independent of any particular forms of the functions f and χ, which therefore remain arbitrary.

PROB. II.

Required $\psi(x, y)$ a function of x and y, which retains the same value when each of the functions P, Q, R, &c. is severally substituted for y; P, Q, R, &c. being given functions of x.

By reasoning exactly similar it will appear that

$$f(x) + (y - P)(y - Q)(y - R), \text{ \&c. } \chi(x, y),$$

is the most general form of the function sought, $f(x)$ and $\chi(x, y)$ being arbitrary functions, the former of x, and the latter of x and y; observing however that $\chi(x, y)$ must not be so taken as to become infinite of the first or any higher order by the substitution of any of the quantities P, Q, R, &c. for y.

PROB. III.

Required the most general form of a function which shall reduce itself to a given function Q when y becomes equal to another given function P, or to resolve the equation,

$$\psi(x, P) = Q.$$

Since $\psi(x, y)$ becomes Q when y becomes P, it is evident that $\psi(x, y) - Q$ must have $y - P$ for a factor, and that

$$\psi(x, y) = Q + (y - P) \, . \, \chi(x, y),$$

and χ is shewn as before to denote an arbitrary function provided only it do not become infinite by putting P for y.

These cases being premised, we shall now proceed to the solution of the equations we proposed to consider.

PROB. IV.

To begin with a simple case, let the equation proposed be

$$\psi(x, x) - \psi(x, 0) = a.$$

Assume

$$\psi(x, y) = \phi\left(x, h + \frac{y}{x}\right),$$

h being a quantity independent on x or y, and therefore to be regarded as an arbitrary constant in the expression of $\psi(x, y)$.

This supposition being made, we have

$$\psi(x, x) = \phi(x, h + 1)\,; \ \psi(x, 0) = \phi(x, h),$$

so that our proposed equation becomes

$$\phi(x, h + 1) - \phi(x, h) = a.$$

Now h being independent on x and y, this may be regarded as an equation of differences in which the auxiliary letter h is the independent variable, and its integration immediately gives

$$\phi(x, h) = ah + C,$$

in which C may be any function which does not change when h changes to $h+1$, that is, which retains the same value whether we put x or 0 for y: now we have already seen, Prob. 1, that the most general form of such a function is

$$fx + y(y - x) \cdot \chi(x, y).$$

But we assumed,

$$\psi(x, y) = \phi\left(x, h + \frac{y}{x}\right)$$

$$= a\left(h + \frac{y}{x}\right) + C.$$

Hence if we substitute for C its value, and suppose the constant ah included in the arbitrary function fx, we get finally,

$$\psi(x, y) = a . \frac{y}{x} + f(x) + y(y-x) . \chi(x, y).$$

Some objection may be raised against the generality, or even the legitimacy, of the above solution, on the ground that in assuming $\psi(x, y) = \phi\left(x, h + \frac{y}{x}\right)$ we in fact limit the possible forms of the function ψ; for although it be true that by the combination of the elements x, $h + \frac{y}{x}$ with each other and with constants it is possible to form any assigned function of x and y, yet to render this assertion general, the quantity h must be admitted as one of those constants, and therefore our assumption should have taken notice of this circumstance, and have stood thus,

$$\psi(x, y) = \phi\left(x, h, h + \frac{y}{x}\right).$$

Now this will very materially affect the process which follows, as the equation will then become

$$\phi(x, h, h+1) - \phi(x, h, h) = a,$$

which is not an ordinary equation of differences in h, the first term not being altogether the same function of $h+1$ that the second is of h. To this however it may be answered that the equation in question may legitimately be resolved as an equation of partial differences in which only the last element varies. In fact it is evident that if we can any how determine a form of $\phi(x, i, h)$ regarded as a function of three variables x, i, and h, absolutely independent of one another, which shall satisfy the equation

$$\phi(x, i, h+1) - \phi(x, i, h) = a,$$

it will certainly follow that the function $\phi(x, h, h)$ found by putting h for i will satisfy the same equation in the particular case of $i = h$, because the symbols i and h destroy each other independently in the first member. But without going into these considerations, it is evident that if we have got such a form of ϕ as shall satisfy the equation

$$\phi(x, h+1) - \phi(x, h) = a,$$

this will be sufficient, for $\psi(x, x)$ being equal to $\phi(x, h+1)$ and $\psi(x, 0)$ equal to $\phi(x, h)$ by the original assumption (right or wrong) of $\psi(x, y) = \phi\left(x, h + \frac{y}{x}\right)$ this equation is in fact identical with the proposed, and the form of ψ so found must be satisfactory.

PROB. V.

Let the proposed equation be

$$0 = F\{x, \psi(x, P), \psi(x, Q)\},$$

P and Q being any functions of x given in form.

Suppose we had $\psi(x, P) = \phi(x, h)$,

$$\psi(x, Q) = \phi(x, h + 1),$$

then would our equation become

$$0 = F\{x, \phi(x, h), \phi(x, h+1)\},$$

which being resolved as an ordinary equation of differences regarding x as constant and h as the independent variable gives the form of $\phi\,(x, h)$. The whole difficulty then is reduced to the discovery of the form of $\psi\,(x, y)$ from the known form of the function ϕ. To this end conceive $\theta\,(x, y)$ a function such that when $y=P$, $\theta\,(x, y)$ shall vanish, and when $y=Q$, $\theta\,(x, y)$ shall become unity, then if we assume,

$$\psi\,(x, y) = \phi\,\{x, h + \theta\,(x, y)\},$$

the values of $\psi\,(x, P)$ and $\psi\,(x, Q)$ will be those we have supposed.

It only remains to assign $\theta\,(x, y)$ so as to have at once

$$\theta\,(x, P) = 0\,; \text{ and } \theta\,(x, Q) = 1.$$

Now, by Prob. 3, the former of these gives

$$\theta(x, y) = (y-P)\,.\,\theta_1\,(x, y),$$

$\theta_1\,(x, y)$ being an arbitrary function. This being substituted in the latter gives

$$(Q-P)\,.\,\theta_1\,(x, Q) = 1,$$

when the arbitrary function $\theta_1\,(x, y)$ is determined. This is again a particular case of Prob. 3, and its solution is

$$\theta_1(x, y) = \frac{1}{Q-P} + (y-Q)\,.\,\chi\,(x, y),$$

so that we have finally

$$\theta\,(x, y) = \frac{y-P}{Q-P} + (y-P)\,(y-Q)\,.\,\chi\,(x, y),$$

$\chi\,(x, y)$ being any function of x and y which does not become infinite when P or Q is put for y.

The several steps in the solution of the proposed equation will therefore be as follows.

Integrate the equation of differences,

$$0 = F(x, u_h, u_{h+1}),$$

x being regarded as a constant, and h the independent variable, and let its integral be

$$u_h = \phi\,(x, h, C),$$

C being the arbitrary constant introduced by integration ; then will the value of $\psi\,(x, y)$ be

$$\phi\,\{x, h+\theta\,(x, y), C\},$$

where $\theta\,(x, y)$ is the function above determined, and

$$C = f(x) + (y-P)\,(y-Q)\cdot\chi_1\,(x, y),$$

$\chi_1\,(x, y)$ being an arbitrary function of x and y and $f(x)$ one of x ; this value of C being found by Prob. 1, from the consideration that C must retain the same value whether P or Q be written for y.

PROB. VI.

In general, let

$$0 = F\{x, \psi\,(x, P), \psi\,(x, Q), \psi\,(x, R), \&c.\}$$

This will be reduced to the equation of differences,

$$0 = F\{x, \phi\,(x, h), \phi(x, h+1), \phi(x, h+2), \&c.\}, \ldots\ldots (a)$$

if we take

$$\psi\,(x, y) = \phi\,\{x, h + \theta\,(x, y)\}$$

$\theta\,(x, y)$ being a function so determined as to give at once

$$\theta\,(x, P) = 0\,;\ \ \theta\,(x, Q) = 1\,;\ \ \theta\,(x, R) = 2, \&c.$$

Now first, the two first of these conditions give, as in the last problem,

$$\theta\,(x, y) = (y - P)\,.\,\theta_1\,(x, y)$$

$$= \frac{y-P}{Q-P} + (y-P)\,(y-Q)\,.\,\theta_2\,(x, y).$$

Again, the condition $\theta\,(x, R) = 2$ gives for the determination of $\theta_2\,(x, y)$,

$$(R-P)\,(R-Q)\,.\,\theta_2\,(x, R) = 2 - \frac{R-P}{Q-P}\,;$$

whence

$$\theta_2\,(x, y) = \frac{1}{(R-P)\,(R-Q)} - \frac{1}{(P-Q)\,(P-R)} + (y-R)\,\theta_3\,(x, y),$$

and so on, so that finally we have

$$\theta(x, y) = A(y-P) + B(y-P)(y-Q) + C(y-P)(y-Q)(y-R) + \\ + \&c. + (y-P)(y-Q)(y-R), \&c. \times \chi(x, y)$$

$\chi(x, y)$ being a function quite arbitrary, provided the substitution of P, Q, R, &c. for y do not render it infinite, and A, B, C, &c. being the series of coefficients above determined.

The law of these coefficients does not readily appear, and as their formation one from the other is rather complex, I shall observe that the value of $\theta(x, y)$ may be expressed at once by means of a very elegant theorem proposed by Lagrange as a formula of interpolation. It is evident from the progress of the steps above detailed that (the arbitrary term excepted) $\theta(x, y)$ is a rational integral function of y of the dimension $n-1$, n being the number of the letters P, Q, &c. The question then reduces itself to finding such a rational integral function of y of this degree as shall become $0, 1, 2, \ldots (n-1)$, when P, Q, R, &c. are put for y in succession. The theorem alluded to gives for the value of such a function *.

$$1 . \frac{(y-P)(y-R)(y-S), \&c.}{(Q-P)(Q-R)(Q-S), \&c.} + 2 . \frac{(y-P)(y-Q)(y-S) \ldots}{(R-P)(R-Q)(R-S) \ldots} + \\ + 3 . \frac{(y-P)(y-Q)(y-R) \ldots}{(S-P)(S-Q)(S-R) \ldots} + \&c.$$

Let this be called Y, and we have

$$\theta(x, y) = Y + (y-P)(y-Q)(y-R)(y-S), \&c. \times \chi(x, y),$$

which it may be observed is a more extensive formula of interpolation than the preceding, and includes every other that can be devised.

If we reduce the function Y to a series of powers of y, and compare it with the series produced in like manner by expanding the terms of the expression

$$A(y-P) + B(y-P)(y-Q) + \&c.$$

it will be found after all reductions that the two expressions are

* Lacroix. Elementary Treatise, Eng. Transl. Appendix.

perfectly identical, the values of A, B, C, &c. being those before found, viz.

$$A = \frac{1}{Q-P},$$

$$B = \frac{1}{(R-P)(R-Q)} - \frac{1}{(P-Q)(P-R)}, \text{ \&c.}$$

Having thus determined $\theta(x, y)$ it only remains to consider the arbitrary functions which will be introduced under the form of constants in the integration of the equation of differences (a). These constants must be such functions as retain the same value when h changes to $h+1$, $h+2$, &c. that is, when y is either equal to P, Q, R, S, &c. Hence by Prob. 2, their most general form will be

$$f(x)+(y-P)(y-Q)(y-R)\ldots\text{\&c.} \times \chi(x)y,$$

and it therefore appears that the solution of the proposed equation afforded by the process here delivered will involve $n-1$ arbitrary functions of x alone, and n of x and y subject only to the restriction of not becoming infinite when P, Q, &c. are put for y.

PROB. VII.

Let the proposed equation be

$$0=F\{x, \psi(ax, \beta x), \psi(a_1x, \beta_1x), \text{\&c.}\}$$

ax, βx, a_1x, β_1x, &c. being given functions of x.

Assume as before $\psi(x, y)=\phi\{x, h+\theta(x, y)\}$, and to determine $\theta(x, y)$, we have

$$\theta(ax, \beta x) = 0; \ \theta(a_1x, \beta_1x) = 1, \text{ \&c.}$$

For x in the first of these write $a^{-1}x$ (the inverse function of ax) in the second $a_1{}^{-1}x$, and so on, and putting

$$\beta a^{-1}x = P; \ \beta_1 a_1{}^{-1}x = Q, \text{ \&c.}$$

we have

$$\theta(x, P) = 0; \ \theta(x, Q) = 1, \text{ \&c.}$$

which are precisely similar to what were treated in the preceding problem.

When the unknown function in the proposed equation is relative to more than two variables, the same artifices may be employed. I will give a single instance to shew the manner of proceeding, it being unnecessary to dwell at length on this case.

PROB. VIII.

Let the equation be

$$0 = f\{x, \psi(x, P, p), \psi(x, Q, q)\},$$

P, Q, p, q, being functions of x.

Take as before

$$\psi(x, y, z) = \phi\{x, h + \theta(x, y, z)\},$$

and determine $\theta(x, y, z)$, so that

$$\theta(x, P, p) = 0; \quad \theta(x, Q, q) = 1,$$

when the equation will be reduced to the equation of differences,

$$0 = F\{x, \phi(x, h), \phi(x, h+1)\}.$$

The most general forms of $\theta(x, y, z)$ and of the arbitrary constant, or function of x, y, z which has the same value for $y = P$ and $z = p$ as for $y = Q$ and $z = q$, are then to be determined, and substitution being made the function required is found.

I will merely add one instance of the application of the method pointed out in the foregoing problems. Suppose the proposed equation were

$$\psi\left(\frac{1}{x}, x\right) = 2\psi(x, x^2).$$

We first assume $\theta(x, x^2) = 0$, which gives $\theta(x, y) = (y - x^2)\,\theta_1(x, y)$,

Again,

$$\theta\left(\frac{1}{x}, x\right) = 1, \text{ or } \theta\left(x, \frac{1}{x}\right) = 1.$$

This gives

$$\left(\frac{1}{x} - x^2\right).\theta_1\left(x, \frac{1}{x}\right) = 1.$$

whence,

$$\theta_1(x, y) = \frac{x}{1 - x^3} + \frac{xy - 1}{x}.\chi(x, y).$$

The x in the denominator may be included in the arbitrary function. This done, we get by substitution,

$$\theta(x, y) = \frac{x(y - x^2)}{1 - x^3} + (xy - 1)(y - x^2) \cdot \chi(x, y).$$

Taking then

$$\psi(x, y) = \phi\{x, h + \theta(x, y)\},$$

we get

$$\phi(x, h + 1) = 2\phi(x, h)$$

and integrating,

$$\phi(x, h) = C \cdot 2^h,$$

whence

$$\psi(x, y) = C \cdot 2^{h + \theta(x, y)},$$

or simply

$$= C \cdot 2^{\theta(x, y)},$$

where $\theta(x, y)$ has the value above found, and

$$C = f(x) + (xy - 1)(y - x^2) \cdot \chi_1(x, y);$$

and the simplest function which satisfies the condition is

$$\psi(x, y) = 2^{\frac{xy - x^3}{1 - x^3}}.$$

J. F. W. HERSCHEL.

SLOUGH, *Feb.* 5, 1820.

VII. *On the Physical Structure of those Formations which are immediately associated with the Primitive Ridge of* DEVONSHIRE *and* CORNWALL.

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[Read *March* 20, 1820.]

CONTENTS.

§. 1. *Red Sandstone, Conglomerate, and Greywacké of Somersetshire, &c.*

THE observations which I have the honour to present to the Cambridge Philosophical Society, are principally compiled from memoranda made in the summer of the year 1819, during a tour in Cornwall and some of the western parts of Devonshire. In examining the most interesting portions of that country, I was accompanied by the Rev. W. R. Gilby, Fellow of Trinity College, to whose active assistance I am happy in having it in my power thus publicly to express my obligation.

It may perhaps appear useless to bring together only such notices of this part of our Island as can be made during a hasty tour. But no regular survey has yet been made of this district by persons qualified at the same time to explain its general structure, and to exhibit the phenomena presented by its more minute features. Such a survey we may indeed expect from the combined labours of the Cornish Geological Society. Until, however, it is completed and given to the public, notices like the present may not be without their advantage. As an additional reason for submitting this paper to the University, I may observe, that during the last year, several hundred specimens have been placed in the cabinets of the Woodwardian Museum; many of them selected from the tract now under consideration. But as a mere catalogue, stating the locality and mineral character of the several specimens, can by no means give all the information they are intended to convey; it is proposed, by this Memoir, to confer an additional value on a portion of our collection, by explaining the views under which it was selected and arranged.

Before entering on the primitive region, which it is the more immediate object of this paper to describe, I devoted some time to an examination of the sandstone and conglomerate which are so widely diffused among the schistose rocks of Somersetshire. Many portions of that deposit are described with great fidelity by Mr. Horner in the Geological Transactions*. I therefore refer my hearers to his Memoir, and to the specimens from the same deposit, which are placed in the Woodwardian Museum, and accompanied by a descriptive catalogue. Similar deposits may be traced in almost uninterrupted succession to the base of the Mendip Hills; and still farther north they are seen resting in the same unconformable position on the coal strata in the neighbonrhood of Bristol. In the

* Geological Transactions, vol. III. p. 342, &c.

vallies of the eastern parts of Devonshire they occupy a wide extent, and, as far as I observed them, appear always to bear the same relation to the rocks with which they are associated. The quarries in the neighbourhood of Heavitree and Upton Pyne, and the red sandstone of the valley of the Ex, have the undoubted characters of belonging to the same epoch. On the whole then, it appears, that the red sandstone and conglomerate of Somersetshire and Devonshire are members of the new red sandstone formation, which is so widely extended in many parts of this Island.

It is not intended to deny, that a sandstone, coeval with that which crops out from beneath the mountain limestone on the banks of the Avon, may be found among the schistose rocks of Devonshire. What has been said refers only to those parts examined by myself, and from which the specimens in our *Museum* have been selected *.

The slaty rocks associated with the red sandstone and conglomerates before mentioned, first make their appearance on the west side of the great alluvial plain of Bridgewater. They soon rise out in gentle elevations, and may be traced, almost without interruption, through the commanding ridge of the Quantock Hills. To the west of this ridge, mountain masses composed of the same rock extend in uninterrupted succession into the northern and eastern parts of Devonshire. This tract of country, almost throughout its whole extent, is singularly diversified; presenting a rapid succession of those undulations which are so characteristic of this beautiful portion of our Island. Diluvian action, and the unequal decomposition of the mineral masses which form the subsoil, have been mentioned among the causes of these singular inequalities. It

* These observations were made in consequence of a mistatement which the Author of this paper had remarked in the best Geological authorities with which he was at that time acquainted. He is happy to find that his own views have been confirmed in the admirable Geological Map of England published by Mr. Greenough.

is however to the constitution of the rocks themselves that we are principally to look for the explanation of this appearance. Throughout the greater part of their extent they exhibit most extraordinary contortions. In many parts of the coast of Somerset and North Devon, where we have the finest natural sections of these schistose masses, the strata do not preserve the same direction for many feet together; but are continually deflected, and coiled on each other; presenting in their course lines of every possible curvature. The same vertical section often exposes a series of beds, one portion of which is disposed in curves convex, and another portion in curves concave to the horizon; and so situated in respect of each other, that no force whatever, acting in a given direction, could produce the structure out of masses originally in an horizontal position. When the fundamental rock is thus constituted, the country must present a corresponding variety of surface.

The whole formation has generally been classed with the greywacké rocks of the German school. Many beds are of silky lustre, and even when viewed with a lens, appear of homogeneous texture. But in the cliffs, and other places where the formation is best exposed, we find the finest grained beds alternating, often without any apparent order, with rocks which exactly agree with the definition of greywacké. The term itself, therefore, as long as it shall be retained in the barbarous nomenclature of Geology, may be applied to this formation with sufficient propriety.

It is not my intention to enter into any details respecting this formation; I therefore refer to the Geological Transactions*, and only add, that among the characteristic specimens, placed in the Woodwardian Museum, will be found the following varieties†:

1. Quartz rock. 2. Silicious sandstone, coarse-grained. 3. The same coarse-grained silicious sandstone containing splinters of slate.

* Vol. II. p. 495, and vol. III. p. 338.

† See the specimens arranged under the Greywacké of Somersetshire.

4. The same substances with the trace of an argillaceous cement. 5. A rock, where the base is distinctly argillaceous with imbedded pieces of quartz and splinters of slate*. 6. The same compound but much finer grained, of slaty texture and generally micaceous. 7. A schistose amygdaloid; the base a variety of clay-slate. 8. The fine homogeneous slate; surface silky and of various cloudy colours; in some instances micaceous, &c.

The characters above-mentioned would by some be considered at once sufficient to determine the place of these rocks in the transition class. The absence of all organic remains from, at least, the greatest part of them, and the uncertainty of classifications deduced from the mere consideration of mineral character, might throw some doubt on this conclusion, if we were not assisted in our determination by many calcareous masses, which are irregularly imbedded in the greywacké, and which constantly present most indisputable traces of organic remains. Several specimens have been selected from these calcareous beds; and from their external characters and geological situation, as well as from a consideration of their organic remains; I think that they may be referred to a formation distinct from the mountain limestone, and belonging to an earlier epoch.

The existence of organic remains in calcareous beds, which alternate with rocks where some of the other earths predominate, and in which we trace no vestige of previous animal existence, is a phenomenon by no means unusual, even in much more recent formations. Water contaminated by a large portion of silex, either in a state of mechanical mixture or chemical solution, was probably unfit for the support of animal life. We must recollect too, that calcareous matter was necessary to the very existence of these inhabitants of the ancient bed of the ocean. They could therefore be abundantly propagated, only where the sea held a sufficient quantity of calcarious matter in solution.

* These specimens, were it not for their intimate association with the finer beds might be easily mistaken for varieties of old red sandstone.

§. 2. *General sketch of the Structure of the Country between Dartmoor and Land's End.*

It is well known, that in Dorsetshire and the south-western parts of Somersetshire, we meet with rocks of much more recent date than any I have yet mentioned. Even as far west as Haldon Hills, on the road from Exeter to Plymouth, we find an alluvial cap containing numerous fragments of common chalk flint; under which, are the remains of the green sand formation and of the beds with which it is usually associated.

From this elevation we command, on the eastern side, the rich woodlands of the valley of the Ex. On the south-west we have a country equally diversified and of the same general aspect, though less exuberant in vegetation. To the west and north-west, however, the face of nature is completely changed. A succession of ridges, rising to an elevation considerably greater than any of the neighbouring hills, exhibits a singularly broken and ragged outline; and the whole appearance of the contiguous country forcibly impresses us with the idea of its barrenness and desolation. Almost any one, while surveying the outline presented by these elevations, though still seen on the distant horizon, would be led to conclude that this extremity of Dartmoor was of a composition entirely different from any of the hills he had left behind him.

At the eastern end of Dartmoor commences the great granitic ridge, which prevails, though not without considerable interruptions, through the mid region of Cornwall, and at length terminates in the broken cliffs of Land's End. By whatever side we approach the moor, we find it flanked by hills of less elevation and of entirely different structure. The whole upper surface may be considered as making a rude approach to a broken table land of elliptical form, the longest diameter of which is more than 20 miles, and may be represented by a line drawn from Harford to Oakhampton.

From many of the higher parts of its western extremity we have a commanding view of the rich extent of country, which descends to the banks of the Tamer and the Tavy. This beautiful and picturesque region gains a double interest from being contrasted with the barren uniformity of the moor. The schistose rocks to the west of Dartmoor, in some instances, reach the elevation of eight or nine hundred feet. They are intersected by numerous mineral veins which continue to be worked to great advantage, more especially in the neighbourhood of St. Mary Tavy and Beeralston. As I made but a superficial examination of these districts, and brought few specimens away of any geological interest, I shall not detain my hearers by any further notice of them.

After crossing the new bridge, between Tavistock and Callington, to the right bank of the Tamer, we again find the granite breaking out from under the slate; the junction of the two rocks being exposed to view about 150 yards down the river. The fundamental rock does not occupy a country of any considerable extent; so that we reach its termination, and again descend on the schist, at no great distance from its commencement.

In advancing to the west by the high moorlands which prevail throughout the middle of the peninsula, we find that the most elevated portions of the tract are composed of granite. The ridge to the south-east of Camelford, the extended moors to the north of St. Austell, and the granite tors near Redruth, are examples of the truth of this assertion. A few miles from the last-mentioned place the granite tract deflects a few degrees to the south of its general bearing and abuts in the cliffs, between Porth Levan and Peran Uthno. After descending to the comparatively low lands, which extend to Merazion and St. Ives, we again find the soil resting on schistose rocks. But the broken outline and rugged surface of the hills farther west, plainly point out the re-appearance of the granite, which occupies nearly all the remaining extremity of the county.

With the exception of the tracts already enumerated, almost all the country extending from Dartmoor to Land's End, and bounded to the north and south by the Bristol and English Channels, may be referred to one formation. The prevailing rocks of this formation are known in the West of England by the provincial term Killas. When used by a miner, the term may designate slaty rocks, which differ from each other in colour, hardness, and almost every physical property. He uses it merely to distinguish the formation of which we are now speaking, from the various crystalline mineral aggregates which are known to him under the appellation moorstone, or growan, and which in hardly any instance exhibit a fissile texture.

That granite is the fundamental rock of the whole region, cannot admit of doubt. We are not left to form this opinion from analogies deduced from the relative situation of similar rocks in other countries. In passing from the slate to the central masses of granite, we uniformly find the former rock rising up towards the latter, and reposing on it in a position which would generally be considered as conformable. If then we make the tour of any of the granitic tracts, we have an opportunity of examining such phenomena in detail, and may remark the schistose beds dipping in succession to every point of the compass.

A section of the country (from Cape Cornwall, through St. Michael's Mount, to Trewavas Headland between Merazion and Port Leven) which I have now the pleasure of exhibiting to the Society, presents no fewer than six beautiful illustrations of the relative positions of the two rocks.

The evidence for the fact I am endeavouring to establish does not rest here. Numberless excavations have been formed in the mining districts near the junction of the two rocks; and in various instances where those excavations have been carried to a sufficient depth; the whole superincumbent schist has been pierced through, and the operations afterwards carried down into the granite.

Such is the structure of the country I am describing: simple in its general outline, but presenting strange and perplexing phenomena to one who examines its features in detail.

At considerable distances from the granite, we often find the slaty rocks so contorted on the great scale, that it would be impossible to form any correct estimate, either of their dip, or line of bearing. The greater part of the county where they prevail is diversified by gentle undulations which are by no means so striking as those I have mentioned at the beginning of this paper. In some instances, the Killas rocks form the basis of considerably extended plains, which at a distance from the shore present the appearance of table-lands, terminated towards the sea by a broken line of perpendicular precipices. These noble sections of the strata prevail nearly throughout the whole coast of Cornwall; for there are comparatively few places where the cliffs exhibit such a shelving descent to the water's edge as to become the support of vegetation.

Before I enter on the mineral character of the rocks abovementioned, I shall take this opportunity of making one or two observations on the general appearance of the country. All the widely extended moors, more especially those in which the granite rocks predominate, are of a wild and dreary aspect. They are thinly covered with vegetation, and that often of the very worst quality; and in some instances nearly half the surface is occupied by granite bowlders, the remains of larger masses of the same kind which have gradually disappeared through the corrosive action of the elements. After descending from the granite ridge to the Killas, we often find a country almost destitute of foliage, and in few respects more inviting than the one we have left behind. In some of the mining districts, the whole surface is nearly covered with unsightly mounds of rubbish, which have been accumulating for centuries, and are so impregnated with mineral matter that a blade of grass will hardly vegetate in their neighbourhood. The rich tract which is so widely extended to the west of the Tamer; the banks of the Foy river; the lands bordering on the different reaches of the Fal; and the whole country along the extended margin of Mount's Bay, form the most striking exceptions to the general nakedness of the county.

One who is attracted by the grand and more rugged features of nature will find many of the high Tors and masses of decomposing granite, which lie scattered about the moors, well deserving of his examination. The extended line of cliffs, almost always precipitous, often broken into bold headlands and exhibiting in their forms the peculiar characters of the rocks which compose them modified by the progress of decomposition; affords numberless scenes not less delightful to the common traveller than instructive to the naturalist.

§. 3. *Granite and the Rocks associated with it.*

A crystalline aggregate of quartz felspar and mica forms by far the greatest part of the fundamental rock, in the region described in the preceding section. Varieties, arising from the loss of one of these ingredients, or from the addition of some other mineral, are by no means uncommon. As these however form the exception, any further consideration of them will be postponed till we have given some account of the more prevailing rock. Keeping therefore in mind its most general character, the granite of the west of England may be described as coarse-grained, and of a greyish or yellowish colour, derived from the felspar which is the predominating ingredient. When examined on the great scale, it is often found porphyritic; the three constituents forming a granular base in which are imbedded large crystals of felspar. We may observe also that these large crystals often exhibit a bright clear fracture, while the felspar of the base is dull, earthy and decomposing. The large prismatic crystals are not unusually of that structure which Haüy calls hemitrope; and their recent fracture sometimes exposes small specks of mica, arranged within the prisms, in a figure which represents the section of a rhomb, and to which they have, no doubt, been determined by the crystalline forces exercised at the consolidation of the mineral in which they are imbedded. The felspar is often crystallized in forms which are perfectly exhibited. Twin crystals arising from the intersection of two rhombs, and hexagonal tables, are among these varieties. The granite bowlders on the moors afford most favourable opportunities for examining such appearances; but their smooth rounded surfaces make it exceedingly difficult to detach from them illustrative specimens for the cabinet. Of the other two constituents, quartz and mica; the former is, I believe, always amorphous, and the latter generally presents the appearance of abraded fragments, rather than of regular crystals. These phenomena may be considered as the imperfect forms of a disturbed crystallization, and caused by the simultaneous consolidation of the heterogeneous ingredients.

I am aware that in mineral cabinets, specimens of Cornish granite are sometimes exhibited in which the quartz has the prismatic form with two perfect terminations. These specimens, as far as I am acquainted with them, have been procured either from the anomalous rocks of Cligga-point, or from subordinate veins; and therefore do not belong to the present part of my inquiry. The mica is occasionally crystallized in hexagonal plates; and if I have not been misinformed, a decomposing granite has also been found in the county, in which laminæ of mica have been aggregated in prismatic crystals; an appearance nearly analogous to that presented by some interesting specimens brought by Mr. Majendie from the Scilly Isles.

A variety of this rock, of comparatively small grain, and containing a great abundance of silvery mica, is so widely extended on the moors near St. Stephen's as to deserve mentioning in this place.

Nearly the same variety appears to the right of the road leading from Helston to Merazion; and from the facility with which it yields to the chisel has been extensively used in building. But the earthy state of one of its constituents makes it pervious to the moisture of the atmosphere, and therefore ill fitted for the purposes of architecture.

We may naturally expect to find the most striking phenomena, arising from the modes in which the constituents of granite have been aggregated, in the cliffs, which expose a larger denuded surface, and where the masses are, for obvious reasons, less ruinous than the blocks which lie scattered about the country. Some beautiful varieties are found between Trewavas-point and Pra-sands. From the eastern extremity of the latter place I obtained the following specimens*.

1. A rock resembling a fine sandstone; composed of quartz, felspar, and chlorite, with a few specks of mica.

2. A variety, larger grained, containing flakes of bronze-coloured mica.

3. Another coarser grained; with earthy felspar of a greenish colour.

4. A beautiful light-coloured granular aggregate; porphyritic, with large and very brilliant crystals of white felspar. The large crystals sometimes prevailed nearly to the exclusion of the base: and the face of the rock then exhibited a very uncommon appearance.

In some of the irregular masses presenting the above-mentioned characters, we found apatite, crystallized in hexagonal prisms of a bluish green colour, nearly resembling the same mineral at St. Michael's Mount; and, what I consider more unusual, semi-transparent schorl of a green colour.

Among the varieties of aggregation may be mentioned the strange appearance of nodular concretions, which abound in some

* See Granite series, Nos. 32—46.

part of the cliffs west of Castle-Trereen. Were it not for their situation they might be mistaken for rounded masses derived from the ruins of some other rock. A more minute examination proves them to have been contemporaneous with the rock in which they are imbedded, and composed of the same elements. They are sometimes so nearly homogeneous, that it requires an examination with a lens to make out their granular texture. But even in these instances, a fracture will often shew the crystals of felspar, passing from the surrounding granite into the imbedded nodule without any apparent interruption in their form.

It would lead me into unnecessary details to consider at greater length the varieties of granite arising from the modified aggregation of its parts. I shall therefore proceed to consider the peculiarities exhibited in the structure of the larger masses.

Wherever any natural section of the country exposes an extended surface of the granite, we find portions of it divided by fissures, which often, for a considerable extent, preserve an exact parallelism among themselves. These masses are not unfrequently subdivided by a second system of fissures, nearly perpendicular to the former; in consequence of which structure the whole aggregate becomes separated into blocks of rhomboidal form. Fine examples of this structure may be seen a few miles west of Porth-Leven; and still more striking phenomena of the same nature are exhibited in the cliffs near Lemorna-Cove and Tol-Pedn-Penwith.

It was from appearances like these, that De Luc was led to form an opinion that the granite of Cornwall was stratified. Had he indulged less in his favourite hypothesis; and made a more extended examination of the coast, he must inevitably have found that such a conclusion was untenable. If the great parallel fissures be assumed as marking the separation between strata, and as indicating their order of superposition; we shall, in almost every succeeding headland be led to the absurd conclusion, that the same mineral mass has been deposited in beds, in one part parallel, and in another part perpendicular to the horizon; without the least indication of contortion, or subsequent catastrophe, to account for so sudden a change in their position.

The cliffs near Tol-Pedn-Penwith, which in many places make a rude approach to a columnar structure, are divided into prismatic blocks, of such regularity, both in their form and arrangement, that they convey a striking resemblance to some piece of gigantic architecture. This peculiarity of form and structure acts powerfully on our associations; and leads us to do homage to the works of nature by contrasting them with the petty operations of human skill. This separation of the mass by nearly parallel fissures, is considered as indicating the first stage of decomposition.

By the action of the atmosphere, the fissures become enlarged; the solid angles at the points of separation gradually disappear; the rhomboidal blocks approach the spheroidal form, and no longer affording a firm support to each other, the whole mass becomes ruinous, and forms an irregular heap of rounded fragments. Some part of the cliffs between Land's End and Cape Cornwall afford striking examples of this second stage of decomposition. From the upper part of the cliff being more exposed to atmospheric action than the portions immediately below them; we not unusually find these rounded masses resting on blocks which still preserve the tabular form. These spheroidal blocks will obviously rest in that position in which their lesser axes are perpendicular to the horizon; it is also clear, that if any mechanical force be applied to them they will on its removal restore themselves to the position of permanent equilibrium. Many thousand rocks which are thus circumstanced might by an adequate force be made to vibrate on their point of support. The celebrated Loggan-Stone of Castle-Trereen is above sixty tons weight, and poised on so firm a pivot, that it may be made to oscillate through a sensible arc by the mere force of the hand *. Many examples of the forms assumed by granite during its first progress towards disintegration are to be met with among the Tors and higher parts of the interior. But by far the greater portion of these moors exhibit the rock only in its second stage of decomposition, where the soil is continually interrupted by the naked surfaces of great bowlders, which are but the nuclei of still larger blocks which once formed a continuous mass above the present surface.

Nearly all the granite of the West of England which has of late years been so extensively used in our metropolis is procured from these bowlders. The indestructible nature of one of the component parts of granite, and the structure of the whole by which it is preserved from decomposition in one direction rather than another, are circumstances favourable to the duration of buildings formed of such materials. Still, I think that stone procured from rocks which present such evident traces of decomposition ought not to be used without most suspicious examination. In addition we may remark, that many of the houses in Cornwall which have been built of granite are continually damp from the penetration of moisture through the earthy parts of the stone; and this is unfortunately the

* The separation of decomposing granite into regular prismatic blocks, has long excited the attention of Geologists. A remarkable instance of the fact is mentioned by Saussure, §. 1689. Faujas considers these forms as derived from the felspar which is the prevailing constituent. Ramond (Voyage au Mont Perdu) seems to regard the prismatic blocks as true crystalline forms derived from the combined action of all the crystalline forces exercised at the time of the solidification of the mass. He even ventures to point out the primitive form of these crystals of granite. The prismatic forms are not now considered as crystals, but as forms resulting from the original crystalline arrangement of the whole mass about different centers. From this aggregation would arise, on a great scale, a structure resembling that of the orbicular greenstone of Corsica. The aggregation, when further continued, would finally produce a more or less perfect columnar structure.

This hypothesis has been ably supported by Dr. Mac Cullock, (Geological Transactions, Vol. II. p. 66, &c.). It is an agreement with the experiments of Mr. Watt, (Phil. Trans, 1804;) and satisfactorily accounts for the principal phenomena exhibited in the decomposition of granite.

case, even where the greatest possible care had been taken in the selection of the materials and construction of the walls.

Under the thin vegetable soil of the moors, we may frequently find earthy siliceous beds, obviously derived from the granite; which may be considered as an exhibition of that rock in its last stage of decomposition.

It must however be observed that the rock in some instances presents an appearance entirely different from what we have described which may be considered as a decomposition in the mass. An imperfect instance of what is here meant, may be seen in a cave near St. Levan. The most instructive example of this decomposition may be examined in detail on St. Stephen's Moor. For some reason, connected probably with the chemical composition of the rock; but which analysis has, I believe, not yet been called in to explain; the greater part of that beautiful variety of granite which contains so much silvery mica, exhibits the peculiar decomposition of which we are speaking. When this rock prevails, the surface of the ground is uneven, but commonly does not present any of those scattered bowlders which I have before described. Numerous excavations are made in St. Stephen's Moor, exposing to the view a granite of a brilliant white colour intersected by contemporaneous veins of quartz. On a near examination it is frequently found soft enough to be cut with a spade, and is in that state packed up and exported to our potteries; those parts only being rejected which are contaminated by the presence of dark coloured mica*. In other pits on the same moor, the rock is broken down by mechanical force, and a running of water is made to pass through the fragments. The finely attenuated particles of felspar are instantly taken up and carried off in streams, as white as milk,

* In some instances we found it impossible to reduce the fine powder, derived from this decomposing felspar, to a glass bead. This seems to prove, that in the progress of decomposition, the alkaline constituent has been partly carried off.

which are collected in reservoirs; then pumped into cisterns; and evaporated, either by natural or artificial heat. The beautiful white clay resulting from this process enters into the composition of the finest earthenware produced in this country. A good series of specimens, exhibiting this variety of moorstone in every stage of decomposition is now placed in our Geological Cabinets*.

The varied phenomena which I have attempted to describe, convey to the mind a most distinct idea of the constant degradation of some of the most solid parts on the surface of the globe. The milky appearance presented by many of the rivulets which trickle down from the moors, offer a striking illustration of this fact. We perceive these rivulets every instant carrying away the great constituent of the granite; distributing it in the lower regions in beds of plastic clay, or bearing it into the waters of the ocean.

We shall now proceed to describe some of the rocks which are usually associated with the granite. Among the most common varieties may be mentioned, 1st Those which arise from the addition of a fourth mineral, (as for example schorl or oxide of tin) so disseminated as to become a true constituent of the mass.

2d. From the disappearance of one of the component parts. A beautiful example of this may be seen at the foot of Dartmoor between Ivy Bridge and Harford. The rock immediately in contact with the schist is composed of bright red felspar and quartz; presenting some traces of that aggregation which forms the variety called Graphic Granite.

3d. From one of the constituents being superseded by a new mineral. An aggregate of quartz, felspar, and earthy chlorite, is found in contact with the killas at the junction near Polmear Porth. A similar aggregate from the eastern side of Pra-sands has already been mentioned. A still more common rock is composed of quartz, felspar, and schorl.

* See Granite, No. 60.—No. 65.

Schorl rock (that is, a granular compound of quartz and schorl) is by far the most striking of all the mineral masses associated with the granite. I shall here enumerate some of its most common varieties.

1. Granular quartz rock, with deeply striated prismatic crystals of schorl, of a coal black colour, and without regular terminations uniformly disseminated through the mass *. It is most commonly of finer texture than the granite; but varieties may be found, especially on the north side of Dartmoor, in which a very coarse granular base contains crystals of schorl several inches in length.

2. Where quartz prevails nearly to the exclusion of the schorl which only appears in small specks.

3. Where the schorl predominates; sometimes nearly massive; often in nodular corrections; which, when broken, exhibit a beautiful assemblage of divergent crystals. These concretions are sometimes more than a foot in diameter. This variety abounds on some of the moors to the south-west of Roach. Traces of schistose rocks are found immediately to the west of Roach; the schorl rock in question must therefore be placed near the junction of the granite and slate.

4. Where the schorl rock is porphyritic, containing flesh-coloured crystals of felspar. These crystals are often decomposing. In some instances they have disappeared altogether, and the base then resembles a scoria.

Specimens were obtained from the south side of Dartmoor, the moors near St. Stephen's and St. Austell, and the parish of St. Just.

Blocks presenting some of the above-mentioned varieties, lie

* In one instance I saw the striated crystals with regular terminations. They were obtained on the east side of Dartmoor, but I did not find them in situ.

scattered about the surface in many parts of Devonshire and Cornwall, especially near the junction of the killas and granite. They form the whole of that magnificent mass of rock near Roach; and in that neighbourhood are so widely extended, as almost to assume the characters of a distinct formation. In general however we do not find them in situ; but they seem to be undecomposed fragments of veins, or irregular masses which were once imbedded in the granite. This opinion is confirmed by the appearance of the western cliffs, which are irregularly traversed by veins of schorl rock varying from the fraction of an inch to many feet in thickness.

Between Lemorna-Cove and Land's End; we not only meet with these schorl-rock veins, but with some other phenomena of which it is difficult to convey an adequate idea by mere description. Large irregular masses are observed to stand out from the cliffs, which at a distance have the appearance of dykes cutting the granite in a direction nearly perpendicular to the horizon. After a more minute examination, they seem to be the remains of irregular masses of contemporaneous rock, which project from the parts in which they were once imbedded, because their physical texture offers a longer continued resistance to the action of the elements. At their junction with the granite, the latter rock is always in an unusual state of decomposition, which has enabled the waters to cut out from the base of the cliff many caverns of strangely diversified forms. This anomalous rock is principally composed of fine granular felspar of grey, yellowish, or bright red colour, with a few scattered particles of quartz. Throughout its mass may be observed a number of dark spots, which are formed by stellated aggregations of schorl *.

The magnificent funnel-shaped cavern at Tol Pedn Penwith has been formed in the manner before described. The cliffs are there

* See Granite, No. 70, &c.

intersected by many vertical veins, some of which consist of a decomposing granite which readily yields to the action of the waters. One part of the cliffs has, in consequence, been undermined, and the cavern afterwards extended to the surface by the continued degradation of its crumbling roof. Among the veins of true granite are others of far different character, composed of large crystals of felspar of a brilliant red colour, occasionally mixed with divergent crystals of schorl. These veins are singularly tough and difficult of fracture, and obviously differ only in the colour and magnitude of their constituents from some varieties already described.

The enormous open work of Carglaze near St. Austell is an object of no ordinary interest. The traveller may there see the operation of the miner carried on in the light of day, without being compelled to descend a hundred fathoms below the surface of the earth and then to crawl into a dirty dripping cavern. The works are excavated in a variety of decomposing stanniferous granite or schorl rock. Its chief constituents are quartz, felspar, schorl, and oxide of tin, with occasional specks of mica. Throughout the whole extent of the excavation, we may trace a succession of parallel veins of schorl rock which do not in any degree partake of the decomposition of the metalliferous beds, and appear both in their range and dip to correspond exactly with the beds of killas which are seen in the immediate neighbourhood. This schorl rock at the immediate junction seemed to pass into the slate by almost insensible gradations. These phenomena induced me to believe that the whole mass was stratified; but subsequent observations have convinced me that the conclusion must have been erroneous.

St. Michael's Mount is a fine instance of veined granite, and of the varieties of rock which arise from such a texture. It affords also a very striking illustration of the fact, that veins which have every appearance of being contemporaneous, often, for a considerable extent, preserve a parallelism among themselves. It must at the same time be observed, that the largest veins, which range in a direction nearly east and west, are accompanied by fissures, which divide the whole mount into parallel vertical beds. Between these beds are found oxide of tin, wolfram, apatite, the topaz, and some of the rarer minerals of the county. It would be difficult to prove that these fissures are not posterior to the consolidation of the granite. The minerals contained in them may therefore be accounted for on the *Wernerian* hypothesis of infiltration.

It is not however my intention to give any account of the phenomena presented by the metalliferous series of Cornwall, or to venture on any opinion respecting their origin. In these imperfect details, I wish to confine my observations to a description of the great formations of the county. Such a description will necessarily embrace those varieties, which are strictly of contemporaneous origin, whether they present themselves in the form of veins irregular concretions, or imbedded masses. Accordingly, those mineral aggregates only, are described, which have appeared in some of the above-mentioned forms, and are supposed to be coeval with the granite. They might perhaps, without impropriety, be considered but as modifications of the granite; produced at the consolidation of the mass by the prevalence of certain ingredients in one part rather another; or by the anomalous action of crystalline forces, arising from disturbing causes with which we are unacquainted. These opinions seem to gain great confirmation, when it is recollected that perhaps all the ingredients of these anomalous rocks are occasionally found disseminated through the mass, and then appear to form a true constituent part of the granite.

By way of conclusion, it may be proper to observe, that the great extent of the formation here considered, its mineral character, the simple minerals which abound in the veins by which it is traversed, and its relation to the superincumbent rocks, all lead to the same conclusion: viz. that it is a true granite, the oldest primitive rock of the Wernerian series.

§. 4. *Junction of Killas and Granite, Granite Veins, &c.*

Having in the last section enumerated some of the principal characters presented by the granite, I shall now proceed to consider the phenomena exhibited at its junction with the killas. These phenomena may be examined, with some advantage, in the beds of the many rivulets which descend from the high granitic tract, and intersect the line of junction*. Unfortunately, however, in these instances, there is never a sufficient denudation to allow of an extended examination.

In other parts of the interior, where the granite and the schist are not laid bare by such causes as we have mentioned, it is in vain that we look for their immediate contact: for the junction is almost universally obscured by alluvial matter and vegetable soil, which seem in all cases peculiarly to abound near the line of separation of two different formations. Fortunately, we are opposed by none of these difficulties in examining the western extremity of Cornwall. For the cliffs present us with a series of natural sections, in which all the phenomena we are attempting to describe are exhibited, under circumstances most favourable to investigation.

An account of such phenomena, in the order in which they present themselves through the whole line of coast, would far exceed the limits of this communication. I leave such detail with less reluctance, as several parts of the coast I am now considering will be described in the next volume of the Cornish Geological Transactions, by one whose opportunities of investigating this subject have been greatly superior to my own†. A minute account

* See the specimens taken from the bed of the river above Ivy Bridge. Devonshire series, Nos. 12....20.

† Dr. Forbes, Secretary to the Cornish Geological Society, and Honorary Member of this Society.

will be given only of one or two portions of the cliffs which have not yet been described, and such observations will be added as are immediately suggested by the specimens placed in our cabinets.

Before we proceed to these descriptions it will not be improper to enumerate the different points on the coast where the granite and killas may be seen in contact.

1. At Trewavas Head, about two miles west of Porth Leven.

2. About half way between the last mentioned place, and the east side of Pra-Sands, where a patch of slate occupies the base of the cliffs for about 300 feet.

3. At the eastern extremity of Pra-Sands.

4. At St. Michaël's Mount.

5. At Moushole, west of the pier. Only to be seen at low water.

6. About half a mile west of Lemorna Cove.

7. About half a mile farther west near Carn Boscawen.

8. At the end of Whitesand Bay. Covered at high water.

9. Cape Cornwall.

10. Pendein Cove.

11. About a quarter of a mile west of Polmear Porth.

12. Wicka Pool. The cliffs between this and the preceding junction are formed of a band of slate, in some places, especially east of Zennor Cove, of inconsiderable thickness, and traversed by many granitic veins*. That part of the cliffs near Wicka-pool, in which the granite re-appears, is of very small extent. From the headland nearly opposite the Carracles to St. Ives' Bay, the killas rocks prevail without interruption; but the denuded surface is in one or two instances sufficiently near the central mass to be traversed by the veins of granite. With the exceptions of such portions of the coast as are contained within the limits abovementioned, the central granite does not appear in any of the cliffs of the county.

* The island immediately west of Land's-end, on which the light-house has been erected, is said to exhibit a junction of the granite and killas.

In following the line of coast, from the granite to any of the superincumbent masses of slate at the points of junction above enumerated, we often observed those various mineral aggregates, which are described in the preceding section; but we in no instance remarked such a general change in the texture of the fundamental rock, as indicated a passage towards a new formation. The line of contact is indeed sometimes exhibited under circumstances of great confusion. In no case however did there appear to be any thing like a separate formation, making a connecting link between two distinct deposits. When the division between the granite and superimposed slate was perfectly well defined, we remarked an almost instantaneous passage from one rock to the other. A very limited exception to this rule has been observed in the parish of Constantine, where a variety of granite, containing a great abundance of mica and of distinctly slaty texture, is found at the junction with the killas. (See Granite, No. 25.) This appearance is, I believe, of inconsiderable extent; for in passing through that part of the county, I was not able in any instance to find it in situ. The same observations will apply to the whole region between Dartmoor and Land's-end, which may be considered as possessing the same simplicity of structure, and almost entirely deficient in all those primitive formations which geologists have interposed between granite and clay-slate.

It is not my intention here to enter on any details respecting the killas: I may however observe that at its immediate junction with the granite, to which it generally adheres so intimately as not to be separated without considerable force, it contains an unusual proportion of mica, and sometimes exhibits that wavy texture which is so characteristic of many beds of gueiss. This variety is never of any great thickness, sometimes not more than the fraction of an inch; and then passes into a schistose rock of a purple colour; most frequently of an homogeneous texture, though sometimes exhibiting a cloudy or striped appearance, from its intimate association with a variety of compact felspar. This rock is succeeded by and alternates with other schistose masses which will be described in their proper place.

We have before observed, that the slate reposes conformably on the granite. With reference to the general structure of the county, the assertion is undoubtedly true; in considering the structure of any particular district, it must be received with limitation. Thus at all the junctions we have enumerated, we may observe the schist dipping from the great protruding masses of granite; yet we by no means find the inclination and line of bearing of the slaty beds universally to correspond with the surface of the rock on which they rest. St. Michael's Mount affords an excellent illustration of this fact. It is almost entirely composed of granite, which on every side presents a series of abrupt precipices.

In crossing from Merazion, the killas rocks are found suddenly to change their dip and rise towards the mount; at the base of which they may be traced through about one third of its circumference *. Though undoubtedly resting on a rock, the visible face of which is so nearly perpendicular to the horizon, few of these beds reach an inclination of more than ten or twelve degrees, and consequently appear (especially near their western termination) rather to abut against, than repose upon the granite. This circumstance, combined with the appearance of those veins which starting out from the granite traverse the superincumbent slate in all directions, has

* Near Penzance the slate rocks dip to the east, declining from the granite which appears immediately to the west: while the cliffs on the other side of the bay near Perzan-Uthno dip to the west, obeying a similar law with regard to the granite which breaks out farther east. Between the two last mentioned places, the beds in succession dip to all the intermediate points of the compass. With the knowledge of such facts as these, it appears extraordinary that any one should have considered the direction and inclination of the schistose rocks on the north side of St. Michael's Mount as anomalous. They are, I think, exactly what would have heen expected *à priori* by any one who had attended to the structure of the county. See Geol. Transact. vol. I. p. 144.

induced some Geologists of the highest authority to consider the granite of St. Michael's Mount as an example of a secondary formation, posterior to the rocks with which it is associated*. I confess that I could discover no good ground for this opinion. The granite and killas of St. Michael's Mount, present, with such modifications as arise from local circumstances, the same phenomena which may be seen at all the other twelve parts of the coast before enumerated. Still less deserving of attention is the gratuitous hypothesis, that the whole Island has been severed from the main land by some rude convulsion, and that by a consequent change in its position, the slate, which once attached to its southern escarpment, has been buried under the present low water-mark. A mere glance of the eye over the rocks to the north of the Mount will be sufficient to prove this hypothesis to be entirely devoid of foundation.

Still more striking illustrations of the position in which the killas sometimes rests on the granite may be seen at the second junction above-mentioned; viz. in the cliffs between Trewavas Point, and Pra-Sands. A small cove is formed by two projecting masses of granite. On descending, during low water, to the margin of the sea, we find all the intermediate space occupied by nearly horizontal beds of killas which are soft, micaceous, and in a more advanced stage of decomposition than is generally exhibited in similar situations. At their western extremity they are seen reposing on the granite, though not adhering to it; but at the eastern side of the cove they are at once cut off by a projecting mound of granite, in such a manner, that the line of demarcation may be traced, in a direction perpendicular to the horizon, from the base of the cliffs till it is lost in the alluvial cap at the top.

* See Thomson's Annals, vol. II. p. 253.

The formation of slate which commences to the west of Lemorna-Cove and extends to the neighbourhood of Carn-Boscawen, may be considered as another good example of the facts we are now considering. From one end to the other, the slaty beds have nearly an uniform dip to a point between east and south-east, and the line of bearing of the strata does not afford any indication of the very uneven surface presented by the foundation on which they rest. The bearing of the coast is nearly east and west. In consequence of this direction, compared with the direction and dip of the slate, the whole super-imposed mass appears to repose obliquely on the granite, and at its western junction rises into cliffs of most commanding elevation; the upper beds of which spread out over the fundamental rock, while the lower beds appear to lean against rather than repose upon the precipitous face with which they are in contact. At the eastern junction of the same mass the slate beds are again seen resting on the granite; but in such a position, that their great line of cleavage, if produced, would abut against the projecting headlands of that rock, which prevails on the coast, as far as Moushole.

Appearances very similar to those above described (at least as far as regards the position of the slate and granite) may be seen at Moushole and other parts of the coast.

The phenomena hitherto described in this section appeared to me at variance with the Huttonian hypothesis. If the killas rocks had originally existed in an horizontal position, and afterwards been elevated in a state of semifusion, and separated by masses of molten granite urged up by subterranean force; they must have exhibited a series of contortions, nearly corresponding to the uneven surface of the molten mass at the time of its consolidation; and at the line of contact they must have presented an inclination nearly corresponding to the face of the protruded rock, or, at least, have been bent back by the mechanical forces exerted at the moment of eruption. If, on the contrary, we suppose the granite at its first consolidation to have presented a rugged and indented surface, and the schistose rocks to have been quietly deposited upon it from a state of aqueous solution; first, filling up the deep cavities, and afterwards aggregating in successive deposits upon the sides of the more elevated masses, we shall have a more intelligible explanation of, at least, some of the phenomena which result from the relative situation of the two formations.

We have before observed, that the junction of the granite and schist is sometimes exhibited under circumstances of extraordinary confusion. The rocks seem mutually to have penetrated each other, masses of slate appearing involved in the granite, and masses of granite in the slate, in such a way that it is difficult to draw an exact line of demarcation between them. The contiguous parts are sometimes described as resembling beds, which, having once been in a state of semifusion, and mixed together under circumstances of mechanical force, have afterwards become gradually consolidated. And such language, if purely descriptive, and used without reference to hypotheses, is not unappropriate. The appearances in question may be seen to great advantage at Polmear Porth, Pendeen Cove, and the east side of Cape Cornwall. These phenomena have been advanced, by the supporters of the Huttonian theory, as demonstrative proofs of the truth of one part of their hypothesis, and undoubtedly present most formidable difficulties to their opponents.

Veins, starting out from the granite, and traversing the superincumbent slate in all possible directions, most commonly accompany the phenomena last described. We remarked some appearance of them at all the twelve junctions above-mentioned, with the exception of the one near Whitesand Bay, which the state of the tide did not permit us to examine. They are also, as was before remarked, exhibited in several parts of the cliffs between Zennor-Cove, and St. Ives, where the section of the slate approaches sufficiently near to the central mass. These granite veins, from their varied mineral character and their mode of association with other rocks, are well deserving of an attentive examination; and they gain a double interest from the manner in which they have been brought forward in support of favourite hypotheses. The geological traveller would therefore do well to visit all the points of the coast before enumerated; in which the same phenomena are exhibited in every possible variety of modification.

The first junction, near Trewavas Point, exposes a series of granite veins of greater magnitude and more varied appearance than can be seen in any other part of the coast. The base of the cliffs near that headland is easily accessible three hours before low water. Notwithstanding this circumstance, so favourable to a detailed examination, and the vicinity of the coast to the great western road; the junction I am attempting to describe, has, I believe, never yet been noticed: Geologists having generally satisfied themselves with the meagre phenomena presented at St. Michael's Mount and the Bier-head near the village of Moushole.

The clay-slate west of Porth Leven is soft, decomposing, and of a very common character. It is interstratified with one or two inconsiderable beds of greenstone; and from the uniform direction of its dip, plainly points out the part of the coast where the granite may be expected to re-appear. About a quarter of a mile east of Trewavas Point the cliffs are in an unusually ruinous state, and a small brook has excavated a passage which affords an easy descent to the water's edge. On reaching the beach we first found the killas rocks intersected by many contemporaneous veins of quartz. Not many feet farther west we were surprised to observe an appearance of alternation between the slate, on which we were advancing, and several thin beds of granite. One, more especially, which towards its southern extremity was lost under the waters, preserved its thickness and conformity to the laminæ of the schist for more than 100 feet. But its true nature was easily determined in the other direction; for it gave out several smaller veins, then cut obliquely through the laminæ of slate, and at length contracted its dimensions, started entirely from its previous direction, and ran in a flickering line across the perpendicular cliffs. This vein is in no part more than two feet wide; yet it may be traced, from the edge of the water to its termination in the cliff, nearly four hundred feet.

In the cliffs farther west there are several granitic veins, which would be considered of no great interest, if they had not been intersected by two other veins of a different character, which must be classed either with the metalliferous lodes or the cross courses of the county. One of them ranges nearly in the magnetic meridian, is about one foot and a half wide, and underlies east, two feet in a fathom. The other underlies in an *opposite* direction. They both contain quartz, oxyde of iron, and apparently, some fragments of clay-slate. At the time of their formation, the mineral masses which they traverse must have undergone a considerable disturbance; for the broken ends of the schistose beds and granite veins where they pass, are distinctly heaved from their original position *.

Beyond this point, the whole base of the cliffs is, for some extent, covered with huge fragments of veins which have been washed out from the decomposing killas. One of them appears to have been more than 10 feet thick, and many others are nearly of the same dimensions. They are of a brilliant white colour, and

* We before remarked, §. 3. that St. Michael's Mount was intersected by veins running nearly east and west, and that some of them were metalliferous. If we be not mistaken, these east and west veins traverse the granite veins, contained in the schist, on the north-east side of the mount, and are therefore probably of an origin posterior to them.

fine granular texture in their general mass; but occasionally contain within themselves parallel veins of a very contrary character, composed of large crystals of quartz and felspar. In some instances these crystals are six or eight inches long; singularly interlaced; and proved to be of contemporaneous origin, by the long spiculæ of schorl which pass, without interruption, through both the quartz and felspar. To the west of these extraordinary ruins, we advanced along a bed of granite, one foot thick and about forty feet in length and breadth, which passes under the cliff, and appears to alternate with the slate. Every portion of the neighbouring strand, would, at first sight, appear to confirm this supposition. But all such beds are but examples of granite veins, the direction of which nearly coincides with the cleavage of the slate; their true nature being always exposed in the cliffs where the section allows a sufficiently extended examination.

Still farther west we found the rocks beautifully intersected by granitic veins; the higher parts being traversed by innumerable ramifications, while the lower part is cut through by one well-defined vein about a foot thick, which after keeping nearly in the direction of the beds of slate for about 60 feet, suddenly starts off at right angles to its former direction and rises *up* to the top of the cliff. The whole system of veins here described afterwards unites in one trunk, which traverses a projecting ledge of rock, and descends obliquely into a mass of granite which forms the eastern side of the entrance into a singular natural cavern. Both sides of it's entrance are of granite; but the roof is formed by undisturbed beds of killas. The granitic masses, however, soon contract their dimensions and wedge out in the schistose rocks, which form both the roof and walls of the cavern about 50 feet from its commencement.

Immediately beyond the entrance of this cavern, we remarked a mass of most imposing character and dimensions. It seemed to be the root of those gigantic veins which rise from this point, and ascend, in broad white lines towards that part of the cliff which reposes immediately on the central granite. Near this place we observed many large angular masses, resembling splinters of clay slate, imbedded in the middle of the veins. Whatever may have been their origin, they certainly very much resemble fragments, torn off from the parent rock by rude mechanical force, and afterwards entangled in the veins. And such conjecture seems confirmed by remarking, that the ragged edges of the imbedded fragments in some instances appear to tally with each other.

From the very point which is marked by so much confusion, two large veins, separated by a lancet-shaped mass of slate, rise towards the west at an angle of about 15°. Within a few feet of the other two, a third vein starts out nearly at the same angle and proceeds in the same direction. These three veins are throughout nearly of the same thickness, viz. each about five feet. The highest, at some distance from its base, begins to ascend more rapidly, and is lost in the alluvial soil at the summit. The other two preserve their course, without being much deflected, for some hundred feet, and from the place where we first remarked them, disappear behind a projecting part of the cliff. On turning this projecting ledge we suddenly reached a recess, the lower part of which was filled with the ruins from the higher part of the overhanging rocks. The western side of this recess is composed of killas intersected by some small granitic veins. A protruding mass of granite forms the base of the eastern side to the height of twenty-five or thirty feet. It is of a very singular outline, yet does not appear to have thrown the slaty laminæ reposing on it out of their usual direction.

The mound of rubbish in the recess enabled us to ascend more than half way up the cliff, and trace the two large veins before-mentioned into an enormous bunch of granite, which here reposes on the top of the cliff, and is supported by undisturbed beds of slate; the line of demarcation being nearly horizontal, and at an elevation of sixty or seventy feet above the level of the beach. The denuded face of this bunch of granite is thirty or forty feet thick, and, if a section were made farther from the cliffs, would probably be much more considerable: for the ground rises rapidly to the north, and it is impossible even to form a conjecture, how far the cap of granite may extend in that direction.

Two or three veins appear to take their origin from this anomalous overlying mass. One spreads out in minute ramifications towards the part of the cliffs which abuts against Trewavas Point, at the termination of the killas in that direction. Two others descend obliquely, and are lost behind the large mound of rubbish before-mentioned.

Such are the complicated phenomena exhibited at this junction. They are not of a magnitude which can easily escape observation, but may be seen distinctly, at the distance of several miles from the coast. Whatever conclusions may be drawn from them, we must remark, that the direction and inclination of the laminæ of slate, even where the granite veins abound the most, have been very little, if at all, affected by these apparently intrusive members of the formation. The proper conclusion seems to be, that the veins are coeval with the slate itself, however difficult it may be to explain the causes which have produced such very complex results.

It may not be improper to observe, that if we had no other knowledge of this junction than could be obtained by shafts, sunk through all the beds of killas into the granite, we should almost inevitably have been led to conclude, that the two formations alternated with each other. The present state of denudation proves that such a supposition would have been erroneous. This observation may, I think, afford a true explanation of those supposed alternations presented in some of the mines which have been worked on the confines of the granite. Through the kindness of Mr. Rule, one of the active superintendents of the great works of the Dolcouth mine, we had a positive proof, that what had, in those works, been considered as a bed of granite alternating with the killas, was in reality a lancet-shaped mass, proceeding directly from the fundamental rock and wedging out in the killas.

The next junction west of Trewavas Point exhibits some interesting examples of granite veins. That which is best worth observing is about one foot wide, and rises exactly parallel to the remarkable line of demarcation which was pointed out in a former part of this section. We have here therefore the singular appearance of undisturbed beds of slate, not more than three or four feet in length, reposing from the bottom of the cliff to the top between two perpendicular faces of granite.

After the splendid phenomena near Trewavas Head, Polmear-Porth exhibits the most striking assemblage of granite veins on the whole western coast. It is impossible, by mere verbal description, to convey any correct idea of their varied forms, and extraordinary ramifications. We may there also observe a rare appearance of disturbance at the intersection of two true granite veins. As the shift does not appear to have been produced by any change in the collocation of the mineral masses with which these veins are associated, we can hardly consider the phenomenon as militating against the hypothesis of their contemporaneous origin. A similar disturbance has been remarked near the pier-head at Moushole. If I be not mistaken, the shift in the granite vein is there produced by a cross course of quartz, and must therefore be considered as a fact of a different character.

Thin veins of quartz, preserving nearly the same rectilinear direction, are very common near these junctions. They sometimes pass through the granite veins, and in other instances are cut off by them. We could discover no rule respecting such contradictory appearances. Another peculiarity may here be remarked. The veins sometimes suddenly contract to a point, and after an interruption of a few inches again set on, in such a manner, as to give the appearance of an oblique fracture when the interval between the severed parts has been filled up with the schist.

In a great majority of instances we are unable to trace the veins to the point where they terminate in the granite. The nature of such termination can therefore be only made out by analogy. Fortunately, however, some parts of the coast expose the base of the veins in such a way as to leave no doubt respecting their origin. The best examples of this fact may be seen at the last junction near Wicka Pool. Three large veins rise out from the granite into the slate. The first soon disappears; but the other two, after being cut off by the retreat of the coast, re-appear in two or three successive projections of the cliff. The largest of them, at its insertion into the slate, is not less than fifteen feet wide. At their lower termination they are all distinct prolongations of the granite itself, and in composition differ from it in no respect whatever *. They also contain imbedded fragments resembling clay-slate; and at a short distance from their base have the ordinary appearance of the granite veins.

It is undoubtedly true, that, at considerable distances from their commencement, granite veins differ very much from the central mass in which they originate. They are generally much finer grained; sometimes the mica disappears, and they present a beautiful granular aggregate of quartz and felspar. To these component parts schorl is sometimes added. We have already mentioned

* See the specimens of Granite Veins in the Woodwardian Cabinets.

veins of this last variety, subordinate to the large veins near Trewavas Head. In other varieties, quartz prevails almost to the exclusion of the felspar and mica. And in others the mica and quartz have both disappeared, and the whole vein is composed of white granular felspar. In following these veins from their commencements through all the gradations of their passage into those minute threads in which they generally terminate, we never observed such a break in the line of continuity as indicated a change in mineral composition. Still less did we observe any appearance to warrant the conclusion, that different parts of the veins have owed their origin to a different mode of formation.

From a general view of the facts detailed in this section, I think we are warranted in drawing the following conclusions.

1. That in the great primitive ridge, we have, with very limited exceptions, no trace of any formation between the granite and the slate.

2. That we have no well authenticated instance of an alternation between the two formations.

3. That the killas reposes conformably on the granite; or, perhaps more correctly, may be said to conform to an imaginary plane, which would result from the removal of all the irregularities and protuberances presented by the surface of the granite.

4. That the slaty laminæ appear to have little or no disposition towards conformity with the irregularities presented by the surface on which they repose.

5. That in all situations where we have a good denudation at the junction of the two rocks, (and therefore by analogy throughout the whole contact of the granite and the slate,) many prolongations of the central granite pass into the incumbent schist; which prolongations, by contractions of their dimensions and varied ramifications, produce the phenomena of granite veins.

6. That these veins have every possible inclination and line

of direction, appearing in those respects subject to no law whatsoever.

7. That, in one instance, two or three very large veins form, at their common intersection, a great bunch of granite, the perpendicular elevation of which above the central rock is probably not much less than 100 feet.

8. That the veins, with very limited exceptions, appear to produce no alteration in the dip or line of bearing of the schistose masses with which they are immediately associated.

9. That small veins of quartz sometimes traverse, and are sometimes cut off by, these granite veins.

10. That in the few instances in which metalliferous bodies, or cross courses, traverse the portions of the killas which contain the granite veins, the killas and the veins contained in it have undergone the same disturbance.

11. That it is therefore probable that the killas and granite veins, prior to the formation of some of the metalliferous veins, bore the same relation to each other which they do at present.

The importance of these phenomena in illustrating some of the speculative parts of Geology need not here be insisted on. I have entered somewhat more minutely on the description of them, because the accounts which have been given of the granite veins of Cornwall seem imperfect or erroneous.—Dr. Berger presents us, in the Geological Transactions*, with a summary of his observations on granite veins. Some of his opinions agree with what has already been stated. But he ventures to assert, in a manner the most unqualified, that the granite veins in Devonshire and Cornwall are invariably directed from North to South. And he afterwards adds: "I did not find these veins extend very far, "nor rise perpendicularly: on the contrary I always observed

* Vol. I. p. 145, &c.

"those at the surface to be conformable with the planes of "inclination of the ground." These two assertions are directly at variance with the facts presented at every junction in the county of Cornwall. He explains the origin of these veins, by supposing them to be portions of the granite a little more elevated than the general plane of the surface before the deposition of the slate, which afterwards filled up the spaces between them: an opinion which does not require a serious refutation.

It was at one time confidently asserted by the Geologists of the school of Hutton, that granite veins must be posterior to the rocks which they traverse; and that the granite in which such veins terminate must therefore, in its present state, be posterior to the rocks which rest immediately upon it. If the premises be admitted, the conclusion seems founded on evidence not short of actual demonstration, and a fundamental doctrine of the Platonists becomes at once established. It must also be allowed that their explanation of the origin of these veins is direct and intelligible; and satisfactorily accounts for those fragments of slate which appear to be separated from the parent rock, and imbedded in the substance of the granite. My object here is not to combat hypotheses, or to advance any arguments against Geological theories beyond those which arise out of the immediate objects of description. The position in which the beds of killas rest on the uneven surface of the granite, and the undisturbed direction of the beds of slate, even where most traversed by the veins above described, are, I think, facts irreconcilable to the Huttonian hypothesis. We venture therefore to conclude, for we have no other alternative, that the granite veins are contemporaneous with the rocks through which they pass.

It is at present a favourite opinion with some very eminent Geologists, that the order of superposition among primitive rocks, has, in many instances, no reference to succeeding epochs; but that the different formations have originated in a simultaneous crystallization*. Whatever evidence there may be for the justness of these opinions in some countries, they seem not to be applicable to any part of the primitive tract we are now considering. Such an hypothesis would but ill account for the regular collocation of the great formations described in this paper. We may further observe, that the schistose rocks of Devonshire and Cornwall undoubtedly belong to the same system of formation. There is no sudden change in the appearance or position of these rocks, which should indicate a change in the mode of deposit. Now some of the upper rocks of this formation have undoubtedly been formed by successive depositions; for they are interstratified with beds which present undeniable traces of organic remains. We conclude therefore, that the whole series of schistose rocks have arisen from successive depositions upon the granitic nucleus.

When these depositions first commenced; the materials, though generally subject to an arrangement arising out of the gravitation of the parts, appear to have been held in that state of solution which admitted of a considerable development of crystalline forces. These forces, combined with the gravitation of the parts deposited, and other disturbing causes with which we are probably unacquainted, would naturally produce very complex results. Of such results, granite veins are at the same time the most striking and the least susceptible of satisfactory explanation.

§. 5. *Elvan Courses, &c.*

The provincial term Elvan is applied to a set of porphyritic rocks, which are associated with the killas. They sometimes appear in the form of beds, having the same dip and direction with

* See some communications in the Edinburgh Philosophical Journal by Professor Jameson.

the laminæ of schist between which they *are found*. In other instances they assume the more ordinary appearance of veins which pass through the slate, without any indication of a disposition towards conformity. They differ, however, essentially from the granite veins described in the preceding section.

1. They are generally of greater magnitude, being sometimes more than forty feet wide.

2. They preserve a more rectilinear direction, not starting off or ramifying like the granite veins.

3. They occur at much greater distances from the granite; in some instances at the distance of several miles.

4. Their general line of direction is nearly East and West. This rule probably admits of many exceptions. It was however confirmed in almost all the instances in which we personally examined the Elvan courses. The underlie is perhaps subject to no rule.

5. They differ also in mineral character. We must however observe, that the granite veins and Elvans are of such varied appearance, that mineral character alone is perhaps not sufficient to separate them.

The following may be enumerated among the principal varieties of character exhibited by the Elvans.

1. A porphyritic rock: the base of fine granular felspar, with imbedded crystals of quartz. The fracture is often dull and earthy.

2. A porphyritic rock: the base of granular quartz, with crystals of felspar.

3. Hornstone porphyry.

4. Porphyritic granite: the base very fine grained with very little mica.

5. A granitic rock with much chlorite.

6. Schorl rock; rather fine grained.

Among the specimens in the Woodwardian Museum, will be found,

Nos. 18—21 *; belonging to the first variety; from an Elvan about ten feet thick near Pentowan. It ranges nearly east and west, underlies to the north at an angle of about 45°, and appears imbedded in the slate. The beds in contact with it are undisturbed and unaltered.

Nos. 3, 4. From a very beautiful Elvan, more than 40 feet wide, which appears below the high-water mark, at the western extremity of Pra-Sands, near the perpendicular cliffs which form Pedn-du-point. It ranges nearly north-west and south-east, and seems conformable to the killas beds, which are neither disturbed in their position, nor altered in their texture at the junction. The exterior parts of this Elvan pass into the third variety, but the central mass is a porphyritic granite.

No. 5. From an Elvan about forty feet wide, between Camborne and the Dolcouth mine, which ranges nearly east and west, and underlies south. It is of the fourth variety, but not so striking as the preceding.

No. 6. From a very narrow dyke east of Cligga Point. It belongs to the sixth variety.

These Elvan courses are no where seen to more advantage than in the cliffs near St. Agnes †. Some of them are repeatedly cut off by the extraordinary indentations of the coast, and re-appear in the successive headlands, in the line of their first direction.

* It has lately been extensively used in building the pier at the village of Pentowan. Many of the houses in Truro are built of a stone of nearly similar texture, obtained from a large Elvan near that place. See Nos. 15—17. The hewn surfaces of the blocks, quarried from the Elvans, have in many parts of Cornwall, a near resemblance to the building stone derived from the Oolite beds in the midland counties.

† See a paper on this subject by the Rev. J. J. Conybeare, Geol. Transact. vol. IV. p. 401.

It is not my intention to attempt any description of the phenomena which are exhibited at the intersection of the rocks we are now describing with the metalliferous lodes and cross courses. The subject is one of great interest to the practical miner; and will, no doubt, receive every illustration from the labours of the Geological Society of Cornwall. It may however be further observed,

1. That the schistose rocks, even when most intimately associated with Elvan courses, do in no instance appear so changed, in texture and position, as to give the least support to the hypothesis; that these porphyritic masses have been injected into the killas, posterior to its consolidation, by the powerful action of subterranean force.

2. That at the time of the formation of those fissures, which are of such constant occurrence among the metalliferous veins, and which in such numberless instances have broken the line of continuity of the great mineral beds, the Elvan courses appear to have borne exactly the same relation to the killas which they do at present.

3. That in some parts of Cornwall, which are remote from the granite, they are very rare; and at still greater distances, where the rocks are decidedly of a more mechanical origin, they disappear altogether.

The inevitable conclusion seems to be, that the Elvan courses are contemporaneous with the rocks with which they are associated.

We were not able to learn whether, in any instance, the Elvans had been traced into the granite. In the very extended surface of granite, denuded in the western cliffs, we saw no veins exactly corresponding to the Elvan dykes here described. Combining this fact with the appearance presented by the lower termination of granite veins, we may venture to conjecture, that the Elvan courses may, in some instances, be traced down to the granite, but that they are in no instance afterwards continued into its mass.

When the successive beds of killas were deposited, their materials were in that state of solution which admitted, under favourable circumstances, of a development of the powers of crystallization. The resulting phenomena would depend on the actual materials presented by the solvent, whatever might have been its nature, and the greater or less prevalence of disturbing forces. If we admit this principle to account for the appearance of those highly crystalline granite rocks which are associated with the more earthy beds of schist, we are under no necessity to limit its powers of operation. The extent of these powers can only be estimated by an attention to the effects produced. On this account we venture to class the anomalous rocks of Cligga Point with the Elvan dykes of the adjoining cliffs, and to consider the whole promontory as a mere local formation, resulting from the accidental combination of circumstances favourable to the production of such crystalline masses as are above described.

To the north-east of St. Agnes, the coast is singularly broken and diversified : it is also peculiarly deserving of examination from the various stages of decomposition exhibited in the prevailing rocks, and from the mineral deposits with which they abound. About three miles from the last-mentioned place, the cliffs suddenly start off from their mean bearing, and form a bold headland, called Cligga Point, composed of granitic beds, which appear to repose on the killas, and at the junction are nearly parallel to its great line of cleavage. At low-water, one may descend to the base of the cliffs and examine these beds in detail. They are generally found to differ from the central granite, almost as much in mineral character as they do in geological position. The extreme point of the headland, which is several hundred yards from the termination of the killas, very nearly resembles the common granite of the county : but the intermediate parts, which are divided by innumerable parallel fissures, exhibit such varied modes of aggregation, and are frequently in such a state of disintegration, that it is difficult to convey a correct idea of them by description*. They are chiefly composed of quartz, sometimes distinctly crystallized, felspar, mica, and chlorite, in every variety of combination; and they are often porphyritic. We remarked one unusual porphyritic mass, composed of crystals of felspar imbedded in earthly chlorite.

The parallel fissures are metalliferous; and the operations of mining have been conducted in them to such an extent, that some parts of the rock are as open as a honeycomb. These veins abound in the ores of tin, and present some traces of the ores of copper. Wolfram, and some other metalliferous minerals, are also very generally found in them. In one portion of the headland, the parallel beds are slightly deflected, and soon afterwards succeeded by a mass so violently contorted, that all its subordinate beds are convex to the horizon. Even this part of the cliff is metalliferous; and the veins, if I have not been misinformed, exhibit the same curvature as the beds in which they have been opened; a circumstance probably unexampled among all the other mineral deposits of the county.

The killas, at its immediate junction with the granite beds is unusually soft and micaceous; and in that state is continued till it is cut off by an Elvan dyke, not less than forty feet wide, agreeing in mineral character, as well as in the inclination and direction of its mass, with many of the beds which form part of the promontory above described. One fact, first pointed out to me by Mr. Gilby, is I think worth remarking. The separation of the granitic mass of Cligga Point from the killas, is neither parallel to the fissures in the one nor to the great cleavage of the other; but may be represented by a very irregular superficies which is, on the whole, nearly perpendicular to the horizon. In this respect, therefore, the junction of the two formations presents an analogy to the phenomena we have before insisted on.

* See the Specimens from Cligga Point, Nos. 7—14.

§. 6. *On the Killas.*

The wide extent of this formation and the relation of its subordinate beds to the central ridge, have been already described with sufficient minuteness. Some general notion may be formed of the mineral character of these beds from the specimens now placed in our Museum, which were selected for the purpose of general illustration. In describing the phenomena in the western parts of Cornwall we mentioned the micaceous texture of the rock in contact with the granite, and its almost immediate passage into a nearly homogeneous slaty mass, generally of a dark purple colour*. Under similar circumstances we remarked slaty beds of exactly the same appearance on the sides of Dartmoor, the right bank of the Tamer, and some other parts of Cornwall. The more compact homogeneous varieties, when breathed upon, give out a strong argillaceous odour. Their mean specific gravity is about 2. 67. When small splinters are examined with a lens, they are found to have the texture, and greasy-looking surface, of some varieties of felspar. All the specimens exhibit, in the flame of the blowpipe, nearly the same phenomena, and melt into a light transparent glass with some dark stains, seemingly derived from impurities.

After examining the beds of slate as they succeeded in order of superposition, we were not surprised to find that corresponding parts of the formation, in different places, exhibited very different appearances. During a hasty passage over the north side of Dartmoor we remarked several extensive beds of hornblende-rock and greenstone

* At the junction of the granite and slate in the Dolcoath mine we found a porphyritic rock (see Killas, Nos. 101, 102.) which differed from any bed we remember to have seen in a similar situation. In some other instances, in which we descended the mines to examine the contact of the granite and the slate, we were disappointed in our hopes of gaining any general information. The rocks in those parts where they were intersected by the veins, were either in so ruinous a state, or so much mixed with the sparry matter of the vein itself, as to assume an almost entirely new character.

near the confines of the granite*. If we have not been misinformed, similar beds may be traced, on the outskirts of the moor, through more than one half of its circumference. In a similar situation, hornblende rocks abound on every side of the granitic tract between Merazion and Land's End. We should, however, be led into an error if we attempted to generalize the phenomena presented at the eastern and western extremity of the central ridge. For example; at Trewavas Point we find the usual purple schist reposing on the granite; but it is soon succeeded by soft argillaceous beds which prevail in the cliffs without much change in mineral composition as far as Loe Bar. They are indeed interstratified with one or two beds of greenstone; which are, however, too inconsiderable to give any character to the formation. The same observations will apply to the schistose beds, resting on the granite, immediately to the north of the Lizard district, and also in the neighbourhood of St. Austell and Redruth. We did not there observe any of those large masses of hornblende-rock and greenstone, which in other places are so characteristic of corresponding parts of the same formation.

In the cliffs between Penzance and Moushole, we found the ordinary varieties of clay-slate, much intersected by contemporaneous veins of quartz. These rocks were succeeded by, and alternated with, beds of compact felspar, greenstone, hornblende-rock, and the purple schist before mentioned; all resting conformably, and on the great scale exhibiting a slaty texture; although many of the hand specimens derived from them broke into irregular fragments†.

The beds of killas to the west of Lemorna Cove are almost entirely composed of felspar and hornblende. The felspar is generally

* The felspar, which is associated with hornblende on the confines of the granite, is generally more compact than crystalline; in some instances both constituents are crystalline, and the larger grained varieties pass into syenite.

† See Killas, Nos. 63—72.

compact; and in some places so intimately mixed with the hornblende as to give the rock the common appearance of greenstone. In other instances the constituents alternate with each other in thin laminæ. Not unfrequently, the compact felspar and hornblende are irregularly separated from each other, and the whole surface of a recent fracture has a spotted or cloudy appearance. Specimens of the last variety abound near Zennor Cove*.

Between Cape Cornwall and Pendun Cove the killas is much intersected by metalliferous veins; many of which, contrary to the usual course of the productive lodes, have a direction nearly north and south. Among these, the copper mine of Botallock is the most celebrated. Its works are conducted to a great extent under the sea, and the engine by which they are drained is perched on a ledge of rock, mid-way between the base and summit of the lofty precipitous cliffs. From the side of the path leading to the works, and from the accessible part of the rocks below the engine-house, we obtained the following specimens†:

1. Nearly homogeneous hornblende rock.

2. Slaty hornblende rock, with traces of chlorite between the laminæ.

3. The same rock with alternating laminæ of compact felspar. These beds were in some instances much contorted on the small scale.

4. Hornblende rock with veins of actinolite.

5. Actinolite rock.

6. Compact axinite, from an irregular bed.

7. A rock of nearly the same aspect as the preceding, much mixed with titaniferous magnetic iron ore.

8. Garnet rock, from a vein about one foot and a half wide.

9. A decomposing mass with veins of epidote and crystallized carbonate of lime.

* See Killas, Nos. 74—97.

† See Nos. 77—89.

In the cliffs a little farther to the east, we found a variety of hornblende rock, somewhat earthy in its fracture, and in texture nearly resembling common basalt.

It is not without some hesitation, that we venture to class the rocks of St. Cleer Downs, with the conformable beds above described; in which, near the confines of the granite, hornblende is so prevailing a constituent. In crossing the country from Liskeard to St Cleer, we were surprised to find the downs near the latter place covered by rude blocks of a rock which is as sonorous as an anvil; and so tough, that it is impossible to detach from it even a minute splinter, without repeated blows of a powerful hammer. It appears to be exclusively composed of hornblende and hypersthene; the former being the prevailing ingredient. With the exception of some of the beds in immediate contact with it, which are in an unusual state of induration, the schistose masses to the south, appear, neither in texture, nor position, to have undergone any change whatever*. We conceive therefore, that the rude blocks above mentioned, are the remains of the upper surface of a large mass of hornblende rock, irregularly imbedded in the schist. Our examination of this part of the county was, however, too imperfect to allow us to speak with any confidence on the subject.

As varieties of greenstone abound near the granite, and are not found among the greywacké rocks of Somersetshire, and some parts of North Devon, most remote from the primitive ridge: it might be presumed that these rocks gradually disappear as we recede from the granite. The supposition would however lead to very erroneous conclusions if applied without limitations. On the banks of the Padstow river, and in the cliffs between Stepper Point and Trevose Head, we found many beds of greenstone. We also remarked them in the cliffs between Tintagel and Boss Castle; on the road between Launceston and Camelford; and on the east side of Lis-

* See Nos. 115, 116.

keard: in all these cases at very considerable distances from any of the granitic tracts. Their occurrence on the banks of the Tamer, near Plymouth, has been pointed out by Dr. Berger. In all such cases the green-stone was of a coarser and more syenitic texture than the rocks of similar composition in the immediate vicinity of the granite. From their peculiar mode of decomposition, and their accidental position at the top of the cliffs, they might sometimes be mistaken for unconformable overlying masses. They are however, in all cases where we examined them, (unless the rocks of St. Cleer Downs should prove an exception,) subordinate members of a great formation; and are undoubtedly of the same origin as the mineral beds with which they are interstratified.

In many parts of the interior of Devonshire and Cornwall, and in the cliffs between Plymouth and Falmouth, the most prevailing rock is a common variety of argillaceous schist; sometimes separating into rhomboidal fragments which indicate two distinct cleavages; more frequently uneven and rugged in its cross fracture, but in the direction of the strata separating into fine laminæ, which are of a beautiful silky lustre, and exhibit every shade of colour between light grey and bluish black. Contemporaneous veins of quartz are of very common occurrence in it; and in many places, especially where it alternates with beds of a different composition, it is much bent and contorted from its mean line of bearing. In the cliffs and other places, where it is most exposed, it readily yields to the action of the elements, and is not unfrequently soft and decomposing. All the varieties we have tried fuse in the flame of a blowpipe.

More hard and indestructable beds, of very irregular thickness, often alternate with the schistose masses last described. In some of these beds quartz prevails, almost to the exclusion of any other mineral constituent*. Great blocks of quartz rock in some places

* Examples of what is here described, may be seen in the neighbourhood of Lostwithiel, at the Carnes near Veryan, on some of the hills near Menaccan, and on the road between Helston and Constantine.

lie scattered among the alluvial debris on the surface, and are evidently the remains of strata of similar composition, once associated with beds of more yielding materials which have been swept away by the last operations of diluvian action. Some of the alternating beds make a near approach to greywacké. That rock is however rare in the district we are considering. For with the exception of some specimens we found a few miles to the west of Plymouth; and some others we obtained from the cliffs near Mawnan, and from Nare Point, which will be described among the rocks of the Lizard district; we did not see any good example of greywacké on the southern coast of Cornwall. Many of the beds, which on their recent fracture exhibit somewhat of an arenaceous appearance, are, on an examination with a lens, found to possess no trace of that mechanical aggregation which belongs to true greywacké. These beds are not uncommonly amygdaloidal. In the cliffs west of Fowey, we found an amygdaloid containing kernels of carbonate of lime and of an impure steatite. Examples occur near Duporth, where the kernels of pure steatite form the predominating part of the rock.

From Patterbury-top, a hill about two miles north-east of Clicker-Tor, we obtained some specimens of a very singular appearance*. They were derived from superficial beds which had originally been amygdaloidal, but which, in their present state of decomposition, have lost the imbedded minerals; nothing being left behind but a variety of chloritic schist, as light and porous as a piece of pumice.

Our examination only extended to a small part of the north coast of Cornwall. We have before mentioned the striking characters of the cliffs near St. Agnes: they principally consist of a soft

* See Killas, Nos. 33—35.

decomposing variety of killas, which contains so much chlorite that it may be considered as a true constituent part of the rock. Quartzose chloritic veins intersect the slaty beds in every direction. Even in hand specimens, these veins often exhibit in miniature, a series of cross-courses, heaves, and dislocations, which beautifully illustrate the similar phenomena in the great metalliferous lodes*.

Near Padstow we remarked all the ordinary varieties of killas associated with the harder beds, some of which were amygdaloidal. Among these we found some specimens, near Stepper Point, in which the minute vesicles were almost entirely filled with decomposing sulphuret of iron.

In a hasty examination of the cliffs between Tintagel and Boss Castle, we were not fortunate enough to meet with any of those beds containing impressions of shells, which have been described by Mr. J. Conybeare†. The fact, however rare in this part of the country, cannot be considered as extraordinary, when we recollect, that similar impressions, associated with other organic remains, abound in some parts of Wales, where the rocks have quite as ancient a character as those we are considering. The most beautiful roofing-slate of the West of England is obtained from the quarries of Delabole and Tintagel. The whole formation, as far as it is exhibited in those quarries and the neighbouring cliffs, is intimately associated with chlorite; and from the presence of that mineral it appears to derive its colour and its lustre.

Our observations on those parts of the formation which extend round Dartmoor were much too hurried to allow us to glean any details worth recording in this place.

The rocks hitherto described in this section are considered by Dr. Berger as belonging to the greywacké formation; which, according to that author, extends, almost without interruption, on

* See Killas, series Nos. 123, 124.

† Geol. Transact. vol. IV. p. 424.

both sides of the central chain*. To prevent any ambiguity, he first defines greywacké to be a rock formed by a mechanical precipitation and composed of separate silicious particles united by an argillaceous cement with a little magnesia and of iron; and he then divides the formation into common greywacké and greywacké-slate. He afterwards adds—that, in Cornwall, common greywacké is always found higher than greywacké-slate,—that it may be conceived to have been precipitated more slowly, and under a less powerful pressure, which has enabled the mass to assume a more crystalline texture—that it rests immediately upon the granite—that it is much less rich in ores than greywacké-slate, &c. He then states—that the greywacké-slate becomes more perfectly schistose as it is farther removed from the granite—that its base is fine, smooth, and nearly homogeneous—that it sometimes possesses the lustre of satin—that it is to this second variety exclusively that the Cornish miners give the name of Killas, &c.—Lastly, that through a very considerable part of Cornwall, the formation is not interrupted by other subordinate beds of any great extent.

We cannot help considering the whole of this account as inadequate, and in a great measure inapplicable. No one term is sufficient to characterize the various beds of this formation, of which we have attempted only to give a short and very imperfect *sketch*. If we assume, with Dr. Berger, that common greywacké rests immediately on the granite; still it is not true that it is always found higher than the greywacké-slate. It is indeed true, that the great granitic masses often break out through the killas at considerable elevations. It is also true, that on the banks of the Tamer, and in many parts of the west of Cornwall, the granite and killas are seen in contact at very small elevations, and even below the high water-mark. The junction specimens in every instance possess nearly the same characters, which appear to have no connexion whatever with

* See Geol. Transact. Vol. I. pp. 111. 117.

the elevation of the beds. The observation, that the texture of these beds arises from their having been precipitated under a less powerful pressure, is therefore without any good foundation. Again, if the common greywacké be much less rich in ores than the greywacké-slate; then the part of the killas which rests immediately on the granite must be much less metalliferous than some other parts of the formation more remote from the fundamental rock. As a general observation we believe this to be untrue. Some of the richest metalliferous depots in Cornwall are found at the junction of the granite and the killas, and the works by which they have been explored have been carried down from one formation to the other.—But this is not all; we will venture to assert that the rock in immediate contact with the granite (at least in every instance in which we have ourselves examined it) bears no resemblance whatever to common greywacké. With equal impropriety we conceive the term, greywacké-slate, applied to all the finer schistose beds, of silvery lustre, which abound so much in this formation: because, with limited exceptions, we cannot trace these finer laminæ into others of coarser texture, and possessing more evident characters of greywacké-slate; and because we do not find them associated with beds of common greywacké. Lastly, it is not true, that the Cornish miners apply the term killas enclusively to these finer schistose beds.

In that portion of the paper to which we have referred, Dr. Berger seems to have been misled by a supposed analogy between the structure of Cornwall and certain parts of the Hartz. In his description, he appears to have kept in view this forced analogy, and to have attended too little to the facts which an examination of the country must have presented to him.

§. 7. *On the Formation subordinate to the Killas.*

Beds of limestone, of very irregular extent and thickness, are interstratified with the killas, in many parts of Devonshire. They all possess, in a more or less perfect degree, the mineral character of transition limestone; and often pass, by almost insensible gradations, into the schistose masses to which they are subordinate. They generally present such certain traces of organic remains, as prove beyond a possibility of doubt, that all the upper members of the series of beds reposing on the central ridge must be excluded from the class of primitive rocks. These masses of limestone are finely exhibited in the cliffs near Plymouth. We were indebted to the kindness of Mr. Hennah* for an examination of a series of organic remains collected from the quarries in that neighbourhood. They consisted of many beautiful madreporites; two or three encrinites, one of which was of an entirely new species†; and many fine casts both of bivalves and univalves. We speak only from recollection, but we think that these organic remains cannot be identified with the fossils of the mountain limestone.

Alternating masses of limestone are more rare in the *slate* formation of Cornwall. We found some dark-coloured beds near Launceston, of more earthly texture, and less penetrated by contemporaneous veins, than the corresponding rocks of Devonshire. We also examined the calcareous beds which break out near Veryan‡.

The coast near Padstow, between Trevose-Head and Stepper Point, is in geological interest not inferior to many parts of the county. We have already mentioned some specimens obtained from that neighbourhood. In a broken part of the cliffs to the east of Trevose-Head, fifty or sixty well-defined beds of limestone alternate with the killas. The limestone is of a dark bluish colour, much penetrated by white contemporaneous veins, and in this respect closely resembles the calcareous deposit near Veryan. The alternating

* See Geol. Trans. (vol. IV. p. 410.) for a paper by that gentleman on the Plymouth Limestone.

† We were fortunate enough to procure a specimen of this encrinite, from the cliffs near Mill Bay. See Plymouth series, Nos. 22, 23.

‡ For an account of this limestone, see a paper by Mr. Trist in vol. I. of the Cornish Geological Transactions.

schistose masses in some instances effervesce briskly in acids; but never contain so much carbonate of lime as to form intermediate beds of an ambiguous character*. The alternations are perfectly well-defined. In the next headland, the beds inferior to those last described rise nearly at right angles to the horizon, are then bent over the projecting ledge, and again descend to the adjoining strand. They at the same time exhibit extraordinary contortions on the small scale, which might at a distance have escaped observation, had they not been beautifully marked out, on both sides of the promontory, by innumerable thin beds of limestone which alternate with the dark laminæ of the schist, and follow their line of curvature. Some of these beds are so singularly coiled on each other, that their exposed surfaces resemble a set of cylindrical pipes, of various dimensions, ranged regularly above each other.

Curvature of such complexity could never have been produced by a simple upheaving force. Besides a force acting from below would not have exhibited so confined an operation. The adjoining rocks are not contorted. Crystalline forces are, we conceive, quite inadequate to the effects produced; neither are the contorted masses highly crystalline.—Some of the clay-slate which alternates with the limestone is hardly more compact or crystalline than the shale of our coal measures.—As the most contorted laminæ are strictly continuous, without interfering with each other, they seem at one time to have possessed considerable tenacity. If we suppose then, that at the consolidation of the mass its subordinate beds possessed different contractile powers, we shall have a cause which will in part account for that irregularity of curvature we have described. That this cause has, at least, operated among others in producing these phenomena, cannot, I think, be doubted, when we observe

* Near Veryan, some of the slate beds in contact with the limestone have been used as a top dressing for the land. They contain a great proportion of carbonate of lime, and fall to pieces on exposure to the weather. See Nos. 26, 27.

that contortions are most general among schistose rocks, when there is a variety in the mineral composition of the laminæ.

The serpentine rocks of the Lizard district, and the other mineral masses associated with them, we conceive to be strictly subordinate to the great formation described in the preceding section. They form so remarkable an exception to the general simplicity exhibited in the structure of the country, that we purpose to make them the subject of a future communication.

The rocks of Clicker-Tor are in composition nearly allied to some of the varieties of the serpentine of the Lizard. They form a ridge which commences immediately on the north side of the road, three miles east of Liskeard, and extends in a direction nearly east and west about three quarters of a mile. The accumulation of soil on the flanks of this eminence makes it impossible to ascertain its exact breadth, which cannot however be very considerable. In order to make out its geological relations, we examined the country on all sides of it: but the schistose rocks are so little exposed, and in such degradation, that it is difficult to procure any certain evidence on the subject. On the whole they appear both to the north and to the south to have the same direction with the ridge itself, and on all sides dip nearly to the south. We conceive therefore, that the rocks of Clicker-Tor cannot form an overlying mass—that they have not been intruded after the deposition of the slate-beds—and that they are subordinate to the great formation in which they appear. The present elevation of the ridge, will, agreeably to this supposition, be accounted for, by its having resisted the progress of decomposition more effectually than the surrounding rocks. Near the western extremity of the ridge a quarry has been opened from which Mr. Gregor procured the specimens of Tremolite described in the Transactions of the Geological Society*. At the time of our visit to the same place, we could not procure any good specimens of

* See Nos. 105—109.

that mineral. The rocks were in one or two places penetrated by veins of fibrous asbestus*, which gradually became compact and passed into the substance of the stone. Taken in the mass, they have no appearance of stratification, and break into irregular fragments of imperfectly conchoidal fracture. The fresh surfaces always exhibit that peculiar play of light, and that pseudometallic lustre which characterizes hypersthene. When examined with a lens, the small crystals of hypersthene are found to pass into a compact mass which is slightly and irregularly mixed with a light green coloured steatite. All the exterior parts of the ridge are covered by rounded blocks of irregular shape, which generally have a thick covering of moss and lichen. In some instances, when the vegetable coat is wanting, these blocks have the external appearance of rusty cast iron. The decomposition of the mass is very superficial; for good specimens may be obtained from the bowlders, which are for the most part hard and sonorous.

We found specimens in the Lizard district of the same composition with the rocks of Clicker-Tor; differing however in the proportion of the constituents, in as much as steatite was the prevailing part of the base. In that district also, we remarked steatite entering into the composition of a rock, and passing by insensible gradations into veins of fibrous asbestus.

Masses of transition clay-slate and greywacké, occasionally alternating with irregular beds of limestone, are very widely extended on the outskirts of the formation described in the preceding section. The old red sandstone is the next formation in order of superposition; yet I am not aware that it is seen in contact with the schistose rocks in any part of our island described in this paper. In some parts of Yorkshire and on the confines of Westmoreland, where the old red sandstone is wanting, the mountain limestone rests

* Large veins of fibrous asbestus are found on the north side of the rock of St. Cleer Downs, but we did not see them in situ.

immediately on transition slate or greywacké*. In such instances we may have beds of limestone associated with the greywacké brought into immediate contact with the great metalliferous limestone and passing into it by almost insensible gradations. A difficulty may, therefore, in some instances arise in the classification of the older limestones of this Island.—Still we think that it would introduce confusion not to separate the limestone of Somersetshire and Devonshire from the great metalliferous limestone. For, in the complete series of British strata, the two formations are separated from each other by the old red sandstone; in mineral character they are sufficiently distinct; and their organic remains are not identical. Any further remarks on the more recent rocks of England would be foreign to the subject of this communication, which is only intended as a sketch of the physical structure of those formations which are more immediately associated with the primitive ridge of Devonshire and Cornwall.

* See Geological Essays, by G. B. Grenough, Esq. p. 215, &c.

[*To face page* 146.

Cambridge, Nov. 25, 1820.

The Author of the foregoing paper on the Geology of Cornwall, &c. having been absent from the University during its passage through the press, has found it necessary on his return to make the following corrections.

p. 92.	line 13.	*for* an	*read* a.	
—	2 from the bottom,	*for* Silicious	*read* Siliceous.	
93.	Remove the note to p. 92, and place the asterisk before *Siliceous sandstone* line 2 from the bottom.			
95.	24.	*for* tors	*read* Tors.	
—	26.	granite	granitic.	
—	27.	Levan	Leven.	
98.	6.	grand	grander.	
101.	1.	part	parts.	
—	27.	hypothesis	hypotheses.	
102.	2 from the bottom	firm	fine.	
103.	3 from the bottom	Mac Cullock	Mac Culloch.	
104.	11.	cave	cove.	
109.	11.	series	veins.	
—	23.	rather another	rather than another.	
111.	18.	Pendein	Pendeen.	
112.	28.	gueiss	gneiss.	
113.	note l. 2.	Perzan	Perran.	
117.	19.	Bier	Pier.	
122.	5.	Dolcouth	Dolcoath.	
123.	6.	when	where.	
125.	12.	bodies	lodes.	
126.	15.	Platonists	Plutonists.	
127.	14.	have	has.	
128.	1.	*are found*	are found.	
129.	17.	Dolcouth	Dolcoath.	
131.	8.	granite	granitic.	
135.	8.	Pendun	Pendeen.	
140.	4.	and of iron	and iron.	
141.	3 from the bottom	Formation	Formations.	
142.	18.	earthly	earthy.	
144.	1.	when	where.	
145.	4.	of	of an.	

VIII. *On the Laws according to which Masses of Iron influence Magnetic Needles.*

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[Read *May* 15, 1820.]

Several of the phænomena which may be observed on placing a magnetic needle in the neighbourhood of a mass of iron, have been explained on the hypothesis that the iron, through the magnetic influence of the earth, becomes itself a magnet, having its north pole in the upper, and south pole in the lower part of the mass. I have for some time considered that many objections might be urged against this hypothesis, indeed that it was not adequate to the explanation of all the phænomena, and having adopted a new one, undertook a series of experiments as a criterion of its correctness. As the effects produced by the action of masses of iron on compass needles are, in some cases, of serious importance, and as I besides consider, that this subject is connected with the interesting question of the change in the variation and dip of the needle, I trust that this paper will not be unacceptable to the Society to which I have the honor to present it.

It is well known, that if a mass of iron be placed at a *small* distance from *either* end of a magnetic needle, suspended freely, that end will be attracted; but if the distance of the iron be increased beyond a few inches, the end of the needle to which the iron is the nearest will, in some cases, be attracted, and in others repelled. If a bar of iron be held nearly vertically, and the upper end be presented to the *north* end, that is the *south* pole, of a needle, the end of the needle will move towards the iron: if the lower end of the iron be presented to the *north* end of the needle, the needle will move from the iron: and this is accounted for, on the hypothesis of the iron becoming magnetic through the influence of the earth, by saying that the poles of the iron and needle, which are brought together, are of opposite kinds in the first instance, and consequently attract each other, but of the same kind in the second, which causes repulsion. The same phænomena, but in a reverse order, are observed at the *south* end of the needle, and to these a similar explanation is given.

According to the hypothesis in question, the magnetism of the earth is communicated to a mass of iron, in the direction which a magnetised bar takes, when freely suspended by its centre of gravity, that is in the direction of the dipping needle; and the magnetic influence is concentrated near the extremities of a line passing through the iron, in that direction, in two points, which are called the poles of the iron. If then the position of the mass of iron be changed, its poles will, according to this hypothesis, be immediately transferred to two other points; and however suddenly the change of position may take place, the shifting of the poles must be equally sudden, to account at all for the phænomena. To suppose that two points possessed of a quality, which they exert energetically, should be instantaneously deprived of that quality, and that it should be immediately transferred to two other points, by a simple change of position in the body, appears to me rather unphilosophical. But it has been said, that this instantaneous change takes place in consequence of the *softness* of the iron which is employed: it has however been found that the same phænomena, which may be observed on suddenly changing the position of a bar of *soft* iron, equally take place with bars of the *hardest steel,* provided care has been taken that the steel should not acquire any magnetism in the manufacture. As, however, my object in the present paper is not to controvert this hypothesis, but to advance one which offers a ready explanation of the phænomena, and affords peculiar facilities in computing the effects produced, I shall for the present take leave of it, reserving some other arguments for a future period.

It appears to me that there is no necessity for supposing that any part of the mass of iron possesses the power of *repulsion,* and that all the phænomena which take place, may be clearly explained on the simple hypothesis that the particles of iron possess the single power of *attraction,* and exert it principally, if not wholly, on that which appears to be the cause of the direction of the needle, and but slightly, if at all, on the poles of the needle itself. I was first led to think that the iron acted in this manner on the needle, on being informed by Mr. Barlow, who has lately published some interesting experiments on this subject, that he had observed anomalies in the action of a mass of iron on a magnetic needle, for which he could not account; that there appeared to be a plane, passing through the centre of a sphere of iron, in which if the centre of the needle were placed, no effect would be produced in the direction of the needle. He did not at this time inform me what experiments had led him to this conclusion, nor of the angle which the plane made with the horizon; but, on consideration, it appeared to me, that if the iron were supposed not to act on the needle in its horizontal position, but in the same manner as if the needle were inclined to the horizon at an angle equal to the natural dip, then such a plane would necessarily exist, making an angle with the horizon equal to the complement of the dip, since then the perpendicular on this needle, by which the action of the iron would be estimated, would fall on its centre. Another consequence of my supposition would be, that if the perpendicular from the centre of the sphere of iron fell on the *upper*, that is, the *south* branch, of this imaginary needle, then that end of the horizontal needle would deviate towards the sphere; and that the *north* end of the needle would deviate towards the sphere, when the same perpendicular fell on the *lower* branch of the imaginary needle.

Having this idea of the manner in which the iron acted, I witnessed some of Mr. Barlow's experiments, mentioning beforehand what I conceived would result from particular positions of the sphere of iron. In these experiments, the several deviations were of the nature I had predicted, and, as far as we could then judge, their magnitude was such as might be expected on the supposition which I had made. I now therefore considered in what manner this mode of action of the iron could be accounted for, and I was soon forcibly struck with the idea that the needle was guided in its horizontal direction by magnetic particles, passing through its centre in the direction of the natural dip, and that the iron acted principally, if not wholly, on these particles, causing, by their deviation towards it, a corresponding deviation of the horizontal needle. The results of the several experiments, which I afterwards made, perfectly coincided with this view of the subject.

The apparatus which was made use of, consisted of a cast iron ball 12.78 inches in diameter, suspended over the centre of a table in the construction of which iron was carefully excluded. In the middle of the table a circular hole was cut, 13.25 inches in diameter, so that the ball could be let down below the plane of the table, or raised above it, by means of a system of pullies. After the table was rendered perfectly steady and horizontal, the magnetic meridian was accurately ascertained, and being drawn, the table was divided at every 10°, reckoning from the meridian, by lines drawn from the centre to the circumference. The compass being placed on one of the divisions, so that its north and south line coincided exactly with that division, and its centre was at the distance of 12 inches from the centre of the table, the ball was raised until it appeared to have no influence on the needle: it was then lowered, inch by inch, and the deviations at every inch carefully noted, until the ball had descended so far below the table as to cease influencing the needle. This was done with two compasses, at every 10° from the *north* to the *west*, and from the *south* to the *east*.

I first considered, that, if the ball acted in the manner I have mentioned, namely, on magnetic particles passing through the centre of the needle in the direction of the dip, then when the centre of the ball was in the point where a line drawn from the centre of the needle, perpendicular to the direction of the dip, cut the vertical passing through the centre of the table, the ball, attracting equally the particles guiding the north end of the needle, and those guiding the south end, no deviation should take place; that when the centre of the ball was *above* this point, a preponderance would be given to the action of the particles guiding the *south* end, and these being attracted towards the ball, the *south* end of the needle would move in that direction, or the *north* end would deviate *from* the ball; and that the contrary would take place when the ball was below this point, namely, that the deviation of the *north* end of the needle would be *towards* the ball. The annexed diagram will illustrate this. (Fig. 21.) $NESW$ represents the plane of the table, the centre of which is O: NOS is the magnetic meridian, and EOW at right angles to it, passing through the east and west points; C is the centre of the magnetic needle, and sCn, in a vertical plane, parallel to SN, the direction of the dipping needle, in which I suppose magnetic particles to act upon the poles of the horizontal needle. CL, parallel to NS, is the line in which the needle points when uninfluenced by the ball. OZ is a vertical line, from the centre of the table, in which the centre of the ball is moved upwards or downwards; and CB is a line drawn perpendicular to sCn, and meeting OZ in B. According to the view of the subject which I have advanced, when the centre of the ball is *in* the point B there should be *no* deviation of the horizontal needle; when the centre of the ball is *above* the point B, the *north* end of the needle should deviate *from* the ball; and when it is *below* B, the deviation of the *north* end should be *towards* the ball.

To ascertain how near the results of the experiments coincided with these ideas, I computed, for every position of the compass, the height of the point B above the plane of the table, in the following manner. Take the centre of the needle for the origin of three rectangular co-ordinates, x, y, z; the plane of xy being that of the horizontal table; the plane of xz a vertical plane parallel to the magnetic meridian. Calling the co-ordinates to the centre of the ball x, y, z, then $\frac{z}{x}$ is the tangent of the angle which the projection of the line joining the centres of the needle and ball, on the plane of xz, makes with the axis of x; and when the line is perpendicular to the direction of the dipping needle, this angle is equal to the complement of the dip. If then we call the dip of the needle, which is at present nearly 70° 30′, d, we shall have, when the line joining the centres of the needle and ball is perpendicular to the direction of the dip,

$$\frac{z}{x} = \cot d.$$

whence $$z = x \cot d.$$

Or, if we call the line drawn from the centre of the needle to the centre of the table r; and the angle which this line makes with the meridian ϕ, then

$$x = r \cos \phi$$

and consequently

$$z = r \cos \phi \cot d.$$

In this, making ϕ successively 10°, 20°, 30°, &c. and putting for r the distance at which the centre of the needle was placed from the centre of the table, the several heights of the centre of the ball above the plane of the table, or depths below it, at which the deviation ought to be *nothing* are obtained. The following table exhibits these heights in inches, and likewise the heights and depths actually observed at which the deviation was *nothing*, for every 10° from *north* to *west*, and from *south* to *east*, the distance of the centre of the compass from the centre of the table being 12 inches.

Value of ϕ.	Calculated height at which the deviation should=0.	Observed height at which deviation=0. North towards west.	Difference between the observed and calculated heights.	Observed height at which deviation=0. South towards east.	Difference between the observed and calculated heights.
10°	±4.185	−3.95	−.235	+4.35	+.165
20	±3.993	−3.90	−.093	+4.20	+.207
30	±3.680	−3.70	+.020	+3.65	+.030
40	±3.255	−3.30	+.045	+3.25	+.005
50	±2.732	−2.80	+.068	+2.90	+.168
60	±2.125	−2.15	+.025	+2.10	−.025
70	±1.453	−1.50	+.047	+1.40	−.053
80	±0.738	−0.90	+.162	+0.80	+.062

I made similar observations, placing the needle at the several distances of 14, 16 and 18 inches from the centre of the table, for the values of ϕ 40° and 50°, as at these angles the changes in the deviation become very sensible. The following are the results obtained.

Value of ϕ.	Distance of needle from centre of table.	Calculated height at which deviation should=0.	Observed height at which deviation=0.	Difference between the observed and calculated heights.
40°	14	3.797	3.75	−.047
	16	4.340	4.33	−.010
	18	4.882	4.90	+.018
50°	14	3.187	3.20	+.013
	16	3.642	3.70	+.058
	18	4.097	4.15	+.053

That a just estimate may be formed of the degree of coincidence between the *calculated* heights at which, according to the hypothesis I have advanced, the deviation should be nothing, and those actually *observed*, it is necessary to mention the manner in which the observations were made, and the degree of accuracy with which, from the nature of the apparatus, these heights could be observed. In order to estimate the height of the centre of the ball above the compass, a horizontal line was drawn on the surface, as much below the great circle of the ball parallel to the horizon, as the centre of the needle was above the plane of the table; and a scale, having the inches divided into tenths, was erected perpendicular to the plane of the table; so that the height of the above line, measured on this scale, gave the height of the centre of the ball above the centre of the compass. The deviations of the needle, as I have before-mentioned, were observed at every inch in the descent of the ball; and when they became small, the ball was lowered very gradually, the needle being at the same time carefully watched, until it pointed to zero, when the height was observed on the scale. As the scale was only divided into tenths of an inch, when the line on the ball did not exactly coincide with one of these divisions, the difference could only be estimated by the eye, and an error amounting to .025 inch might sometimes easily be made. When the values of ϕ were small, the deviations being so likewise, the changes in them were also small, and there was some difficulty in ascertaining the precise point at which the deviation was zero.

When these circumstances are taken into consideration, I think it must be allowed, that the very near coincidence of the *calculated* and *observed* heights, will authorise me in concluding, that when the line joining the centres of the needle and ball was perpendicular to the line passing through the centre of the needle in the direction of the dip, the horizontal needle was then not affected by the action of the ball; and that, as far as this condition goes, my views of the manner in which the ball acted are just. I should here likewise mention, that, in the observations made from the *south* towards the *east*, the deviations of the *north* end of the needle were first *easterly*, that is, *from* the ball, in which direction they gradually increased, as the ball descended, and attained a maximum: they then decreased to zero; became *westerly;* attained a maximum in this direction; and then decreased, until the needle resumed its original position, by the ball descending so far below the table that it ceased to affect the compass. This was precisely what I had anticipated, since here the ball being at first nearest to the *upper* or *southern* branch of the line sCn, according to what I have before said, the *south* end of the needle ought to deviate *towards* the ball and the *north* end ***from*** it: and this would happen until the ball was equally distant from the two branches of the line sCn, when neither end should deviate towards the ball; but when the ball was ***below*** this point, being then nearest to the ***northern*** branch of sCn, the ***north*** end of the needle should deviate ***towards*** the ball. In the observations made from the ***north*** towards the ***west***, the deviations were, as I had expected, exactly in a contrary order; that is, the ***north*** end deviated first ***westerly;*** then returned to zero, when the centre of the ball was below the compass, in the line of the perpendicular to sCn, from C; after which it deviated ***easterly***.

As a further confirmation, if such be deemed necessary, of the accuracy with which the hypothesis agrees with the phænomena, I may notice, that, in a series of observations which Mr. Barlow undertook for the purpose of determining ***practically*** the inclination, to the plane of the horizon, of the plane in which there was no deviation, the mean of the observations, the compass being at the distance of 20 inches from the centre of the table, gave an inclination of 19° 24′. According to the theory this angle should be the complement of the dip, and it only differs by 6′ from that which I had assumed. It is still nearer to that determined by Captains Kater and Sabine, the difference being, in this case, only 2′. Such errors might happen in taking the angle of the dip, even with the most accurate instrument; or, if we suppose that the dip is correctly 70° 30′, from a small error in placing the compass on the table, or in estimating the height of the ball. What, I think, adds considerable weight to the confirmation thus afforded to the correctness of the hypothesis in this particular, is, that, in these experiments, Mr. Barlow's views were entirely practical, and that, although, before he made them, I had explained to him the manner in which I viewed the subject, yet they were not by any means undertaken with an idea of confirming the hypothesis, but merely as necessary to his ulterior objects.

Having ascertained that the quality of the deviations was such as would be the necessary consequence of my hypothesis, my next object was to discover whether their quantity was such as would fully confirm this hypothesis, or was altogether incompatible with it. As the precise deviation of the horizontal needle must depend on the law according to which the magnetic particles in the line *sCn* were affected by the ball, and on the manner in which these particles acted on the poles of the needle, and as I found there must necessarily, in the first instance, be almost insuperable difficulties in the determination of these laws, I endeavoured to find some further criterion of the correctness of the hypothesis, that should be independent of the nature of these laws.

If the ball acted alone on the particles in the line *sCn*, it was evident that being carried round that line, so that its perpendicular distance from any one point in it should always be the same, then these particles must always be influenced in the same manner towards the ball; and, consequently, a needle in the situation *sCn* ought to deviate by the same angle towards the ball, in the whole of its revolution round the line *sCn*. Hence it would follow, if the hypothesis were correct, that the angle of deviation of the horizontal needle, when referred to the angular deviation of the line *sCn*, should give the same angle during the whole revolution of the ball round the line *sCn*. Thus, let *N'MS'* (Fig. 22.) be in the plane of the table, *N'CS'* being parallel to the meridian line; *C* the centre of the compass; *sCn* the direction of the dip; *ÆQ* a circle perpendicular to *sCn* and passing through the centre of the needle; *lBa* any other circle perpendicular to the line *sCn*, and in which the ball is supposed to be carried round that line. The circle *ÆQ*, that in which we have found the deviation to be nothing, being perpendicular to our magnetic axis, may be termed the magnetic equator; *Æl* will then be the latitude of the ball and *BsÆ* the complement of its longitude, reckoning from the intersection of *ÆQ* with the horizontal plane *N′MS′*. Suppose that *S′CM*, or the arc *S′M* is the angular deviation of the horizontal needle, when the ball is at the point *B*; then the deviation of the particles in the line *sCn* will be in the plane of the circle *sBn*, and $s\sigma$ may be considered the measure of that deviation, as causing the deviation *S′M*: $s\sigma$ ought, according to our theory, to be the same whenever the ball may be in the circle *lBa*.

I resolved, therefore, to observe the deviations of the horizontal needle, caused by the ball when in different situations in the circle *lBa*, and reducing the arcs *S′M* to arcs $s\sigma$, see how near they coincided with each other. As, however, the nature of the apparatus could not admit of the ball being carried round the compass, the compass was carried round the ball, in such a manner, that the ball was always at the same perpendicular distance from the same point in the line *sCn*. For this purpose it was necessary to ascertain the relative situation of the compass for every position of the ball in the circle *lBa*. I first computed this in the following manner.

Taking, as before, the centre of the compass for the origin of the rectangular co-ordinates; calling those to the centre of the ball, x, y, z; *Bp* the perpendicular from the centre of the ball on the line *sCn*, p; the complement of the angle which this line makes with the plane of xz, that is, the longitude of the ball, l; and q the part *Cp*, intercepted between the perpendicular and the point *C*: then the position of the ball in the circle *lBa* being given, we shall have for the determination of the situation of the compass, the three equations,

$$(x + q \cos d)^2 + y^2 + (z - q \sin d)^2 = p^2 \qquad (1)$$

$$x^2 + y^2 z^2 = p^2 + q^2, \qquad (2)$$

$$y = p \cos l. \qquad (3)$$

From the equations (1) and (2) we obtain

$$z \sin d - x \cos d = q; \qquad (4)$$

whence

$$z^2 \sin^2 d - 2zx \sin d \cos d + x^2 \cos^2 d = q^2 ;$$

and subtracting this from the equation (2)

$$z^2 \cos^2 d + 2zx \sin d \cos d + x^2 \sin^2 d = p^2 - y^2.$$

Substituting the value of y, and extracting the square root, we have,

$$z \cos d + x \sin d = p \sin l \qquad (5)$$

From the equations (4) and (5) are obtained,

$$x = p \sin l \sin d - q \cos d, \qquad (6)$$

$$z = p \sin l \cos d + q \sin d. \qquad (7)$$

As it was my intention, in the different values which I might give to p and q, to have the ball always at the same distance from the compass, calling this distance ρ, then p or q being assumed, the other was determined from the equation

$$p^2 + q^2 = \rho^2.$$

In the first set of experiments which I made, I assumed $\rho = 14$ inches, $q = 6$ inches, and computed the values of the co-ordinates, from the equation (3), (6), (7), for the values of l, 80, 70, 60, &c. round the whole circumference. The observations were then made in the following manner: I placed the centre of the compass on a pivot on the table to correspond to the values of x and y, with its north and south line in the magnetic meridian, and then lowered the ball, until the height of its centre above the centre of the needle was equal to the corresponding value of z. Allowing the needle to vibrate freely and to become perfectly stationary, I then observed the deviation, both at the north end of the needle and likewise at the south end, in order to avoid any error in the centering of the instrument; and making the corresponding observations on the other side of the meridian, I took the mean of the four, as the deviation of the needle, caused by the action of the ball. If $S'CM$ (Fig. 22.) be this deviation, then in the triangle $sZ\sigma$, are given $sZ\sigma$, the horizontal deviation; Zs, the complement of the dip; and $Zs\sigma$ the complement of the longitude: whence $s\sigma$ may be found. In this manner I computed the value of $s\sigma$ for each of the horizontal deviations; this value, according to the foregoing hypothesis, should be the same at each observation. The following table exhibits the results of this set of experiments.

Diameter of the ball 12.78, $\rho = 14$, $q = 6$, $p = 12.649$.

Value of l	Value of x	Value of y	Value of z	Deviations of the Needle					Computed value of $s\sigma$.
				On E. side of ball.		On W. side of ball.		Mean.	
				N. end E.	S. end W.	N. end W.	S. end E.		
80°N	9.739	2.197	9.814	7°.30′	7°.20′	5°.45′	6°.0′	6°.38½	7°.51′
70	9.202	4.326	9.624	12 .25	12 .15	11 .20	11 .35	11 .54	7 .35
60	8.323	6.325	9.313	16 . 5	16 . 5	15 .10	15 .20	15 .40	7 .19
50	7.131	8.131	8.890	18 .10	18 .10	17 .50	18 .10	18 . 5	7 . 4
40	5.662	9.690	8.370	18 .50	18 .50	19 .20	19 .40	19 .10	6 .46
30	3.959	10.955	7.767	19 .40	19 .20	19 .40	20 .10	19 .42½	6 .35
20	2.075	11.866	7.100	20 . 0	19 .30	20 . 0	20 .30	20 . 0	6 .33
10	0.068	12.457	6.389	19 .30	19 .15	19 .55	20 .15	19 .44	6 .33
0	−2.003	12.649	5.656	19 .15	18 .50	19 .15	19 .35	19 .14	6 .38
10°S	4.073	12.457	4.923	18 .20	18 . 0	18 . 0	18 .30	18 .12½	6 .44
20	6.081	11.866	4.212	17 . 0	16 .40	16 .25	16 .45	16 .42½	6 .47
30	7.965	10.955	3.545	15 . 0	14 .40	14 .25	14 .30	14 .39	6 .42
40	9.667	9.690	2.942	12 .45	12 .30	12 .30	12 .40	12 .36	6 .45
50	11.137	8.131	2.421	10 .30	10 .30	10 .10	10 .20	10 .20	6 .47
60	12.329	6.325	1.999	8 .15	8 . 0	8 .10	8 .10	8 . 9	7 . 6
70	13.208	4.326	1.688	5 .20	5 .20	5 .35	5 .35	5 .27½	7 . 4
80	13.745	2.197	1.498	2 .35	2 .35	3 . 0	3 . 0	2 .47½	7 .13
								Mean	6.57

Although the differences in the values of $s\sigma$, in the last column, are greater than I had expected, yet I can very satisfactorily account for the manner in which these differences may have arisen. After making the three first sets of observations, I found that the centre of the ball had been, when I made them, somewhat to the west of the vertical passing through the centre of the table; but as I had not then the means of preventing the ball taking the same position, if I raised it, I continued my observations, watching this circumstance more attentively than I had before done. This would account for the difference in the corresponding deviations on the opposite sides of the ball; and if the error in excess were greater than the error in defect, the mean would exceed the true deviation. The excess of these deviations, and their difference on the opposite sides of the ball, may also be attributed to another cause, and to its operation I am most disposed to assign them; namely, that a part of the ball might itself possess a small degree of magnetism; and the surface being, at these observations, nearer to the *end* of the needle than at the others, the effects of this magnetism, if it existed, would be here more sensible, than when the ball was at a greater distance from the *end* of the needle. As this was a partial effect to which no theory could be applicable, since it might arise from particular circumstances in the casting of the ball, or from other trifling causes, it had always been my intention to exclude its operation as much as possible, and for this reason, in the experiments which I afterwards made, I removed the compass to a greater distance from the ball.

The values of $s\sigma$ which differ most widely from the rest are the three first and the last. For the excess of the three first I have accounted, and with respect to the last, it may be observed that a very trifling error in estimating the deviation, or in placing the compass, would give this either in excess or defect, since the deviation itself is here so small. Excluding these four sets of observations, the mean value of $s\sigma$, deduced from the others will be $6^{\circ}\ 47'$, and the difference between this and the values of $s\sigma$ is not greater, in any case, than may be fairly attributed to small errors in the observations. It was not, however, my intention that the correctness of the theory should rest on the result of a single set of these experiments; and, although the computations were necessarily laborious, I had determined the co-ordinates for other values of p and q, so as to be able to undertake two or more sets of experiments of the same kind as the preceding: but having found considerable difficulty in adjusting the compass on the table, so that its centre should be at the proper distance from the centre of the table, and its north and south line be at the same time parallel to the meridian, and considering this mode, for that reason, liable to error, I resolved to compute afresh for the positions of the compass, according to a different adjustment.

The method which I now proposed to follow, was, to compute the distance of the centre of the compass from the centre of the table, and the angle made by this distance with the axis x or with the meridian line on the table, so that the ball should have a given position in the circle lBa. This may be deduced as follows from the equations (3), (6) and (7). Let r be the projection on the plane xy of the line ρ, joining the centres of the compass and ball; and the angle which this line makes with the axis x, which may be called the azimuth of the ball, ϕ: or, which is the same thing, r the distance of the centre of the needle from the centre of the table, and ϕ the angle which this line makes with the meridian. Also let λ be the latitude of the ball, or the complement of the angle which the line joining the centres of the ball and needle makes with the line sCn: then

$$x = r \cos \phi, \quad y = r \sin \phi;$$
$$p = \rho \cos \lambda, \quad q = \rho \sin \lambda.$$

The equations (3) and (6) give

$$r \sin \phi = \rho \cos \lambda \cos l, \tag{8.}$$

$$r \cos \phi = \rho \cos \lambda \sin l \sin d - \rho \sin \lambda \sin d. \tag{9.}$$

Dividing the latter by the former,

$$\cot \phi = \frac{\cos \lambda \sin l \sin d - \sin \lambda \cos d}{\cos \lambda \cos l};$$

or, which is more convenient for computation,

$$\cot \phi = \tan l \sin d - \frac{\tan \lambda \cos d}{\cos l}. \tag{10.}$$

Having obtained ϕ from this equation, then the equation (8) gives

$$r = \frac{\rho \cos \lambda \cos l}{\sin \phi}. \tag{11.}$$

Substituting the values of p and q in the equation (7),

$$z = \rho . (\cos \lambda \sin l \cos d + \sin \lambda \sin d). \tag{12.}$$

From the equations (10), (11), (12), I computed the values of ϕ, r and z for the values of l 80°, 70°, 60°, &c. round the circumference; first, when λ was equal to 30°; secondly, when λ was equal to 45°; and lastly, when λ was equal to 60°. In all these I assumed $\rho = 18$ inches, wishing, for the reason I have before-mentioned, to have the compass farther removed from the ball than in the foregoing experiments.

I now made the observations in the following manner: every 10° of the circumference of the table being divided into four equal parts, and lines drawn from the centre to the points of division, I divided the intermediate arc, with a radius of 20 inches, into quarters of a degree on a scale; and by this means, any angle could easily be set off very correctly to within about 5′. In this manner I obtained any particular value of ϕ, on one side of the meridian line reckoning from the south, and on the other side from the north; and by stretching a fine line across the two points, by means of weights hanging over the edges of the table, I had the true direction of the centre of the ball, for that observation. The compass was placed on this line, so that its north and south line exactly coincided with it, and its centre was at a distance from the centre of the table equal to the value of r, corresponding to this value of ϕ: the ball was then lowered so that its height above the needle was the corresponding value of z. I now observed the angle which the needle made with the north and south line of the compass, and, as before, made my observations at both ends of the needle, and likewise on the contrary side of the meridian, taking the mean of the four observations, as the angle indicated by the needle: the difference between this and the angular distance of the compass from the meridian, that is, the value of ϕ, gave me the mean deviation caused by the action of the ball in that particular position. The value of $s\sigma$ was computed from this deviation as before. I now also took precautions that the centre of the ball should descend, as nearly as possible, in the vertical passing through the centre of the table.

The following tables exhibit the results of these three sets of experiments.

I.

Latitude of the ball, $\lambda = 30^{\circ}$, distance $\rho = 18$ inches, diameter of the ball = 12.78 inches.

Longitude of ball or value of l.	Azimuth or value of ϕ.	Distance of compass from center of table or value of r.	Height of centre of ball or value of z.	Observed angles				Mean deviation of the needle.	Computed value of $s\sigma$.
				On E. side of ball.		On W. side of ball.			
				N. end.	S. end.	N. end.	S. end.		
80° N	13°.17′	11.781	13.608	16°.00′	15°.40′	15°.30′	15°.20′	2°.20′½	3°. 42′
70	26 . 16	12.047	13.374	31 . 20	30 . 50	31 . 00	30 . 50	4 . 44	3 . 48
60	38 . 43	12.461	12.990	45 . 50	45 . 30	45 . 30	45 . 30	6 . 52	3 . 51
50	50 . 31	12.983	12.470	58 . 55	58 . 25	59 . 00	58 . 50	8 . 16½	3 . 43
40	61 . 39	13.569	11.829	71 . 05	70 . 40	71 . 15	71 . 00	9 . 21	3 . 38
30	72 . 10	14.181	11.086	82 . 15	82 . 00	82 . 20	82 . 00	9 . 58¾	3 . 33
20	82 . 9	14.787	10.264	92 . 40	92 . 20	92 . 40	92 . 30	10 . 23½	3 . 30
10	91 . 42	15.358	9.387	102 . 25	102 . 5	102 . 30	102 . 20	10 . 38	3 . 32
0	100 . 55	15.876	8.484	111 . 20	111 . 00	111 . 20	111 . 10	10 . 17½	3 . 28
10° S	109 . 54	16.327	7.580	119 . 40	119 . 30	120 . 10	120 . 00	9 . 56	3 . 30
20	118 . 44	16.705	6.704	128 . 00	127 . 50	128 . 00	127 . 40	9 . 8½	3 . 28
30	127 . 29	17.013	5.882	135 . 45	135 . 45	135 . 55	135 . 35	8 . 16	3 . 29
40	136 . 12	17.252	5.139	143 . 15	143 . 15	143 . 25	143 . 05	7 . 3	3 . 25
50	144 . 54	17.426	4.498	150 . 50	151 . 00	151 . 10	150 . 50	6 . 3½	3 . 35
60	153 . 38	17.550	3.977	158 . 00	158 . 20	158 . 30	158 . 15	4 . 38¼	3 . 34
70	162 . 24	17.633	3.594	165 . 30	165 . 40	165 . 40	165 . 25	3 . 9¾	3 . 36
80	171 . 12	17.694	3.359	172 . 45	173 . 00	172 . 55	172 . 40	1 . 38	3 . 42
								Mean	3 . 36

II.

Latitude of the ball $\lambda = 45^\circ$, distance $\rho = 18$ inches, diameter of the ball = 12.78 inches.

Longitude of ball or value of l.	Azimuth or value of ϕ.	Distance of compass from center of table or value of r.	Height of centre of ball or value of z.	Observed angles				Mean deviation of the needle.	Computed value of $s\sigma$.
				On E. side of ball.		On W. side of ball.			
				N. end.	S. end.	N. end.	S. end.		
80° N	16°. 17′	7.883	16.182	19°. 10′	18°. 50′	18°. 35′	18°. 45′	2°. 33′	3°. 54′
70	31 . 47	8.265	15.990	36 . 55	36 . 35	36 . 45	36 . 55	5 . 00½	3 . 59
60	46 . 01	8.884	15.677	53 . 20	53 . 00	53 . 15	53 . 20	7 . 12¾	4 . 00
50	58 . 52	9.558	15.253	67 . 55	67 . 45	67 . 40	67 . 40	8 . 53	3 . 57
40	70 . 27	10.347	14.729	80 . 45	80 . 30	80 . 20	80 . 20	10 . 01¾	3 . 52
30	80 . 59	11.161	14.122	92 . 15	92 . 05	91 . 40	91 . 35	10 . 54¾	3 . 51
20	90 . 42	11.961	13.451	102 . 20	102 . 10	102 . 15	102 . 00	11 . 29½	3 . 52
10	99 . 48	12.720	12.736	111 . 50	111 . 30	111 . 30	111 . 25	11 . 45¾	3 . 54
0	108 . 28	13.419	11.998	120 . 00	120 . 00	120 . 00	120 . 00	11 . 32	3 . 54
10° S	116 . 48	14.043	11.260	128 . 00	127 . 45	128 . 10	127 . 50	11 . 8¼	3 . 57
20	124 . 56	14.589	10.545	135 . 20	135 . 30	135 . 00	135 . 00	10 . 16½	3 . 56
30	132 . 55	15.051	9.874	142 . 15	142 . 20	142 . 00	142 . 15	9 . 17½	3 . 58
40	140 . 49	15.432	9.267	148 . 40	149 . 00	148 . 40	148 . 30	7 . 58½	3 . 56
50	148 . 40	15.733	8.743	155 . 15	155 . 35	155 . 20	155 . 00	6 . 37½	3 . 58
60	156 . 30	15.960	8.319	161 . 20	161 . 30	161 . 04	161 . 30	5 . 00	3 . 54
70	164 . 20	16.121	8.006	167 . 35	167 . 55	167 . 40	167 . 30	3 . 20	3 . 50
80	172 . 10	16.216	7.814	173 . 45	174 . 5	173 . 50	173 . 40	1 . 40	3 . 47
								Mean	3 . 54⅔

III.

Latitude of the ball $\lambda = 60^0$, distance $\rho = 18$ inches, diameter of the ball $= 12.78$ inches.

Longitude of ball or value of l.	Azimuth or value of ϕ.	Distance of compass from center of table or value of $-r$.	Height of centre of ball or value of z.	Observed angles				Mean deviation of the needle.	Computed value of $\delta\sigma$.
				On E. side of ball.		On W. side of ball.			
				N. end.	S. end.	N. end.	S. end.		
80°N	26°. 23′	3.517	17.653	28°. 50′	28°. 30′	28°. 15′	28°. 20′	2°. 05′¾	3°. 22′
70	48 . 02	4.140	17.517	52 . 20	52 . 00	51 . 50	51 . 50	3 . 58	3 . 17
60	64 . 32	4.984	17.296	70 . 40	70 . 15	70 . 15	69 . 50	5 . 43	3 . 17
50	77 . 23	5.928	16.995	85 . 15	84 . 35	85 . 00	84 . 40	7 . 29½	3 . 25
40	87 . 55	6.899	16.625	96 . 45	96 . 20	96 . 25	95 . 55	8 . 26	3 . 19
30	97 . 02	7.853	16.196	106 . 20	106 . 00	106 . 20	105 . 50	9 . 05½	3 . 15
20	105 . 14	8.765	15.721	115 . 20	115 . 00	115 . 20	115 . 20	10 . 01	3 . 23
10	112 . 49	9.616	15.216	122 . 30	122 . 20	123 . 00	122 . 30	9 . 46	3 . 15
0	120 . 01	10.392	14.694	129 . 40	129 . 40	130 . 00	129 . 30	9 . 41½	3 . 16
10°S	126 . 59	11.096	14.172	136 . 20	136 . 20	136 . 30	136 . 10	9 . 21	3 . 17
20	133 . 47	11.714	13.667	142 . 20	142 . 20	142 . 40	142 . 20	8 . 38	3 . 15
30	140 . 28	12.245	13.192	148 . 10	148 . 20	148 . 30	148 . 10	7 . 49½	3 . 18
40	147 . 06	12.693	12.763	153 . 45	154 . 00	154 . 00	153 . 40	6 . 45	3 . 16
50	153 . 42	13.057	12.393	159 . 00	159 . 20	159 . 35	159 . 15	5 . 35½	3 . 16
60	160 . 17	13.399	12.092	164 . 35	164 . 45	164 . 45	164 . 30	4 . 25½	3 . 23
70	166 . 51	13.531	11.871	169 . 30	169 . 50	170 . 00	169 . 40	2 . 54	3 . 15
80	173 . 25	13.632	11.736	174 . 40	174 . 40	175 . 20	175 . 00	1 . 30	3 . 21
								Mean	3 . 18

The remarkably near agreement of the several arcs in the last columns of each of these tables, considered separately, must, I think, be allowed fully to confirm the views with which the experiments were undertaken, and clearly to prove that, in each case, as the ball was carried round the magnetic axis sCn, the particles in that line deviated in the same manner towards the ball, during the whole of its revolution in the circle lBa. Had I made further experiments of the same kind I have no hesitation in saying, that they would all have tended to confirm the hypothesis I have advanced, as I consider that it could not have been put to a severer test than in those I have detailed. As, however, I had an opportunity of making an additional trial of its correctness, I availed myself of it, and I can only regret that time would not allow of my making more experiments with the excellent instrument, a small dipping needle made by Jones of Charing Cross, of which I was favoured with the use, during a few hours.

According to the foregoing principles, $s\sigma$, (Fig. 23.) being the deviation of the particles in the line sCn, which is the direction of the dipping needle, if $\sigma\sigma'$ be drawn perpendicular to the meridian, $s\sigma'$ would be the deviation of the dipping needle when it is placed in the plane of the meridian, since it can then only move in that plane; and $\sigma\sigma'$ would be the deviation of the same needle, when placed in a plane at right angles to the plane of the meridian. Hence knowing the angle $sZ\sigma$, the deviation of the horizontal needle, $s\sigma$ would be determined, and thence, in the right-angled triangle $\sigma s\sigma'$, $s\sigma'$ the deviation of the dipping needle in the plane of the meridian.

It was my intention, had the time during which I could have the use of the above instrument permitted it, to have placed a horizontal compass and the dipping needle in corresponding situations on contrary sides of the meridian, round the whole circumference, and thus to have compared the deviations of the dipping needle, actually observed, with those deduced from the deviations of the horizontal needle; but in consequence of the time which the adjustment of the instrument and the making the experiment necessarily required, I was only able to make the following.

I placed the dipping needle due west at the distance of 18 inches from the centre of the table, and the ball being drawn up, so that the needle was out of its influence, the face of the needle was turned first to the south, then to the north. In each case, had the needle been truly suspended by its centre of gravity, and its centre in the centre of the circle from which the inclination was read off, 90 would have been indicated at each end. The turning the face of the instrument in opposite directions, and reading the inclinations at both ends, were intended to obviate any errors arising from these circumstances; and that they were small in the present case, appears from the mean of the observations: they were as follow.

	Face South.	Face North.	Mean.
Upper end of the needle	88°. 10′	92°. 08′	90°. 12′.
Lower end of the needle	88 . 35	91 . 55	

A horizon compass was likewise placed at the distance of 18 inches, due east, from the centre of the table, and having its centre at the same height as the centre of the dipping needle. The ball was then lowered, when the following observations were made.

Height of center of ball above centres of needles.	DIPPING NEEDLE.					HORIZONTAL NEEDLE.		
	Inclination Face South.	Deviation.	Inclination Face North.	Deviation.	Mean Deviation.	Deviation Observed.	Mean Deviation Observed.	Computed Deviation.
10	Upper 89°. 52′	1°. 42′	94°. 45′	2°. 37′	2°. 05′	N. end 6°. 20′ E.	6°. 10	6°. 13′
	Lower 90 . 00	1 . 25	94 . 30	2 . 35		S. end 6 . 00 W.		
5	Upper 89 . 08	0 . 58	94 . 23	2 . 15	1 . 36	N. end 5 . 10 E.	5 . 00	4 . 47
	Lower 89 . 30	0 . 55	94 . 10	2 . 15		S. end 4 . 50 W.		
0	Upper 88 . 5	0 . 05	92 . 00	0 . 08	0 . 05¾	N. end 0 . 20 E.	0 . 10	0 . 17
	Lower 88 . 30	0 . 05	91 . 50	0 . 05		S. end 0 . 00 W.		

The mean deviations, thus deduced, of the dipping needle, (Fig. 24.) are the values of the arc $s\sigma$, the triangle $sZ\sigma$ being in this case right angled at s, and the deviations of the horizontal needle are the correspondiug values of the angle σZs. In the last column are the values of the horizontal deviations *computed* from the observed values of $s\sigma$ by the formula

$$\cot Z = \sin Zs \,.\, \cot s\sigma.$$

The striking agreement of these with the *observed* horizontal deviations, was highly satisfactory to me, particularly when I con-considered the smallness of the arcs $s\sigma$, from which they were computed, and that consequently a trifling change in these would make a considerable difference in the angles at Z. I now the more regretted having no opportunity of making the experiments I had proposed, as I had no doubt of their results proving equally satisfactory. Seeing then that all the phænomena are the necessary consequences of such an hypothesis, I think we may conclude that, when a mass of iron is removed beyond a few inches from the ends of a magnetic needle, so that they are without the influence of any accidental magnetism in the iron, the deviation of the needle arises wholly from the action of the iron on magnetic particles passing through the centre of the needle in the direction of the dip. I trust, when the labour of the necessary computations, both preparatory and subsequent to the observations, and the tedious nature of the experiments themselves, are considered, that I cannot be accused of having been satisfied on light grounds with the justness of the views I had taken.

I have as yet said nothing respecting the manner in which the action of the iron on the magnetic particles may be supposed to take place, being fully aware that this is a subject of considerable difficulty, and that the mode of action can only be determined by numerous experiments. These I propose making, should I succeed in the construction of an apparatus which I have at present in view. In the mean time I can only offer some conjectures on the subject. We have seen, from the foregoing experiments, that a magnetised needle is guided, in its direction, by particles passing through its centre in a particular direction, and it appears to me, that magnetic particles of two kinds, issue from the centre with great velocity in opposite directions: that the angles which the directions of these particles make with the horizon and meridian vary very slowly at the same place, but differ greatly at different parts of the earth's surface, the directions being in some cases nearly vertical, in others horizontal; in some nearly in the meridian, in others at right angles: and that these particles, by their action on the branches of a needle, cause it to turn, so that if it were freely suspended at its centre of gravity, it would place itself in the line of their direction. I think it not improbable that these particles exist, in a state of equilibrium with each other, in the atmosphere, and that a magnetised bar possesses the property of separating them, so that they then proceed from it, under the influence of some general cause, which gives them their peculiar directions: possibly some atmospherical phænomena arise also from the disturbance of this equilibrium in the higher regions. It further appears to me that every particle of soft iron attracts indifferently both kinds of magnetic particles, but that magnetised iron attracts the one kind and repels the other, from a tendency to restore the equilibrium. Whether experiments will confirm these conjectures must remain, for some time, doubtful, but I do not conceive that the conclusions I have already come to in this paper will be at all invalidated by the result.

The most interesting practical application of the foregoing theory is to the deviations which take place in the compasses employed on board of ships in their navigation; and there can be no doubt, that the results deduced in such cases from this theory would be perfectly accurate, since the greatest care is invariably taken that no iron shall be in the immediate vicinity of the compass, and the disturbance, which it appears has sometimes proved of fatal consequence, arises wholly from distant large masses, necessarily distributed throughout the vessel. The situation of the centre of attraction of the whole of the iron contained in the ship might be found experimentally, from the deviations of the compass at particular places where the dip was known, and the deviations would thence be determined, on any particular bearing of the ship's head, in another part of the globe, provided the dip of the needle were also known at that place; but unfortunately this is a datum by no means easily obtained on board a ship, since the vessel must be perfectly at rest during the observation, and besides, this element would be liable to some error, the dipping needle being itself disturbed by the action of the iron on board. Should however any theory of the inclination of the needle be found to agree with all the observations made in different regions of the earth, as that given by M. Biot, founded principally on the observations of M. Humboldt, agrees with those in certain regions near to the equator, the dip of the needle might then be found from the latitude and longitude of the place of observation, and the deviations of the needle could be determined, on every bearing of the ship's head, from the preceding theory. Another subject, but more of a philosophical nature, to which this theory may be applied, is the changes which have taken place in the variation and dip of the needle. On this I shall not at present enter, since the table of the variations and dip of the needle, which I have been able to procure, for any particular place, is very imperfect. I have however made some computations founded on this theory, and, in the absence of the requisite data, to be derived from accurate observations at distant dates, making certain assumptions, respecting the period of the changes and the alterations in the dip of the needle, find that the variations deduced from the theory coincide, within less than half a degree, with those observed in London, as far as I can judge from the table in my possession, during a period of two hundred years. I am not aware of the dip of the needle having been observed more carefully at any other place than in London, but should I be able to procure a tolerably correct table of the dip and variation of the needle observed at any place, for a long period of time, so as to have more certain data than in the computations I have already made, I shall resume the enquiry, and the result may form the subject of a future communication.

Royal Military Academy, Woolwich,
May 10, 1820.

IX. *An Account of some Fossil remains of the Beaver, found in Cambridgeshire.*

By JOHN OKES, Esq. of Cambridge.

HONORARY MEMBER OF THE SOCIETY, MEMBER OF THE COLLEGE OF SURGEONS, &c.

[Read *March* 6, 1820.]

From all that has been collected by naturalists relative to the abode and habits of the beaver, as well as its anatomical peculiarities, we may not only conclude that the *fossil* remains of that animal found in this and other countries, are of the same species, but also that the beaver has once been indigenous to Great Britain. In addition to the facts already published in support of this opinion, many of which have been detailed in the first number of the Edinburgh Philosophical Journal, I will relate the following account of some fossil remains found in this county, the only specimens, as it appears, that have been yet discovered in England. They consist of the left halves of two lower jaw-bones, which were dug up by a labourer two years ago about three miles south of Chatteris, in the bed of the Old West Water, formerly a considerable branch of communication between the Ouse and river Nen, but which, according to the traditions of the fen people, has been choked up for more than two centuries*. These bones, the only remaining portions of four skulls, are nearly equal in size though not equally perfect, and like most other mineralized remains taken from a peat soil are stained a dark brown colour, arising perhaps from the great commixture of vegetable matter with the soil. The long and very powerful incisive tooth belonging to each half-jaw is perfect, and of the four grinding teeth proper to each in a complete state, the last only has been lost. It is from the singular structure of these teeth, that Cuvier has derived one of the distinguishing features of this tribe of gnawers (rongeurs); he says, "le caractere generique des molaires de castor, est d'avoir l'email de leur couronne replié de maniere de former trois lignes rentrantes du bord externe, et une seule de l'interne a la machoire superieure et precisément l'inverse a l'inferieure. Leur nombre est partout de quartre, dont la premiere seule est susceptible de changer." The more perfect of our fossils, is only defective in a part of the coronoid process, the other having lost both the coronoid and condyloid processes, as well as a great part of the incisive canal.

Besides these bones of the beaver, it appears from a communication, for which I am indebted to Mr. Girdlestone of Chatteris, that in a stratum of clay, about half a mile eastward of that town, has been found part of an elephant's skull, which the labourers broke to pieces, preserving only the two grinding teeth that were contained in it; and that near the same spot was dug up

* The accuracy of this tradition respecting the old West Water, is proved by the following extract from an Order of Council quoted in Dugdale's History of the Fens.

Anno 1617. 9 *Maii.* 15 Jac.—"That the rivers of Wisbeche and all the branches of the Nene and West Water be clensed, and made in bredth and depth as much as by antient record they have been."

It is important to shew the antiquity of the river from whose bed the fossils were removed, for by distinguishing it from those artificial and comparatively recent channels by which the fens have been drained, we refer its existence to a period, when the animal may with great probability be supposed to have been indigenous.

part of the horns of a species of deer, measuring in length two feet, and in circumference at that end by which it is attached to the skull, ten inches. This, from its magnitude, must evidently belong to the celebrated extinct species found in Ireland, and denominated by Cuvier the fossil Elk of that country, of which a minute account is given in the Philosophical Transactions by Dr. Molyneux. In his description of this animal, the circumference of the horn at its root, was eleven inches.

But these last mentioned fossils, it may be observed, have no connection whatever with those of the beaver, for they belong to a stratum of an antiquity of which we can form no idea, but by comparing it with the subjacent strata ; whereas those of the beaver belong to a stratum, which, if the conclusions to be drawn from our account be well-founded, may be referred to a period not very distant even in the history of this country. Indeed, to corroborate this opinion of the probable date of these fossils and the still more recent date of the stratum containing them, I need only recur to the authority of the distinguished geologist mentioned before, who among the several general laws which he has laboured to establish, concerning the relations of organized remains and the strata which contain them, has arrived at the following important conclusions: "that the bones of species which are apparently the same with those that still exist alive, are never found except in the very latest alluvial depositions, or those which are either formed on the sides of rivers, or on the bottoms of ancient lakes or marshes now dried up, or in the substance of beds of peat, or in the fissures and caverns of certain rocks, or at small depths below the present surface, in places where they may have been overwhelmed by *debris,* or even buried by man ; and although these bones are the most recent of all, they are almost always, owing to their superficial situation, the worst preserved."

X. *On the Position of the Apsides of Orbits of great Excentricity.*

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[Read *April* 17, 1820.]

THE problem of the determination of the path which a body will describe when acted upon by a force tending to any center is, as is well known, easily reduced to a differential equation. In order to learn the form and properties of the curves described, it would be necessary to integrate this, which integration can be effected only in particular cases. The cases for which this is possible, if the central force be supposed to vary as a simple power of the distance, are the cases of nature, that is, when the force varies inversely as the square of the distance, the case when the force varies inversely as the cube, and that when it varies directly as the distance*. In these instances the orbit is known, and in two of them it may be a figure returning into itself, namely an ellipse. In the other cases we cannot accurately delineate the curve described, as we could if it were expressed by means of an algebraic equation: we know, however, in some degree, the form of the path. It will generally be a curve running round the center, and alternately

* Besides these cases, we can integrate when the velocity is that which would be acquired in falling from infinity, whatever be the power according to which the force varies; and, under certain conditions, when the force varies inversely as the fifth power of the distance.

approaching to and receding from that point in loops perpetually similar; *not* returning into itself, but making its farthest excursions from the center, every time in a different direction. From this account it will be seen, that we should have a general idea of the curve, if we knew, in each particular instance, the proportion of the greatest and least distances from the center, and the angle contained between them.

When the velocity and direction are very nearly those which are required for the description of a circle, the angle between the greatest and least, or *apsidal*, distances, has been determined by Newton and other writers on Mechanics: but in other cases, where the orbits are more *excentric*, as it may be called, we have nothing but analogy and conjecture. These however can only enable us to judge very imperfectly of the form of the orbit. For instance, we know that in the cases of forces varying directly as the distance, and inversely as the square of the distance, the angle between the apsides is the same whatever be the excentricity. Are we therefore to conclude that the same will be true, or approximately so, in other instances? so far as can be conjectured, the probability is rather against this, since the principle of the approximation depends on supposing the excentricity small. To determine whether or not this is the case, and if not, to obtain limits within which the true value lies, is the object of the present paper. The question may be considered as of some importance, for it is manifest that if it became necessary actually to determine the orbit of a body under given circumstances, it would, in far the majority of cases, fall out of the bounds of the method of approximation above mentioned. The solution of the problem will also enable us to decide how far Newton was correct in the assumption that the angle to which we tend when we make the excentricity indefinitely small, may be taken for its value when the excentricity is small but finite. And if this supposition be inaccurate, we may see in what direction the error lies, and form some idea of its magnitude.

It appears allowable to take for granted, that, knowing the angle between the apsides when the excentricity is indefinitely small, if we can also determine it when the excentricity is indefinitely great, it will for all intermediate excentricities have a value between these two. We shall proceed therefore to find it for the latter of these two cases.

Suppose a body to be projected in a direction perpendicular to its distance from a given center of force. If the velocity of projection be nearly equal to the velocity in a circle at the same distance, the body will revolve, continuing always nearly at the same distance from the centre. But if the velocity of projection be very small, it will (except when the force varies in a high inverse ratio) pass very near the center and then rise again to its former distance, having described an angle round the center which varies with the law of force, and, as appears probable, with the velocity of projection. We are now seeking this angle when the velocity of projection is indefinitely diminished.

First, suppose the force to vary directly as some power of the distance. Let a be the distance of projection, and at x, any other distance, let the force be equal to $\frac{f x^n}{a^n}$. Also let $2q$ to $\surd(n+1)$ be the ratio of the velocity of projection perpendicular to the radius to the velocity in a circle at the same distance. Then, if θ be any angle described about the center, and x the radius vector of the orbit, we shall easily find that

$$d\theta = \frac{q\, a^{\frac{n+3}{2}}\, dx}{x \surd\{(a^{n+1} - x^{n+1})\, x^2 - q^2 a^{n+1} (a^2 - x^2)\}} \ldots\ldots\ldots (1).$$

In order to find the nearest distance of the body from the center, we must have $\frac{dx}{d\theta} = 0$, and therefore

$$(a^{n+1} - x^{n+1})\, x^2 - q^2 a^{n+1} (a^2 - x^2) = 0 \ldots\ldots\ldots (2).$$

the roots of which equation are the apsidal distances.

One root of this equation is obviously a, and hence this is an apsidal distance, which agrees with the conditions of projection. Also, if n be odd, $-a$, is a root of the equation; but it is obvious that no negative quantity can answer our purpose. Now if we take the limiting equation of equation (2), we shall find that its possible roots are $x = 0$; x = a positive quantity; and, in the case when n is odd, x = a negative quantity. Hence the roots of (2) are a, and, if n be odd, $-a$, and besides these a positive and a negative quantity, of which the first is the other apsidal distance.

Now when $q = 0$, equation (2) becomes $(a^{n+1} - x^{n+1})\, x^2 = 0$, which has two roots, $x = 0$, $x = 0$. Hence the two values of x in equation (2) which we are seeking, are those which arise from the two just mentioned, by introducing q. And when q is very small, it is clear that these will be very small; and we may thus approximate to them. By dividing by $a^{n+1}x^2$ the equation becomes

$$1 - \frac{x^{n+1}}{a^{n+1}} - \frac{a^2 q^2}{x^2} + q^2 = 0\,;$$

now when q and x are very small, the second and fourth terms of this are necessarily very small, and therefore the first and third must destroy each other approximately; that is

$$1 - \frac{a^2 q^2}{x^2} = 0, \text{ nearly; or } x = \pm\, a q\,*$$

of these $x = a q$ gives the lower apsidal distance.

Hence a factor of equation (2) is $x^2 - a^2 q^2 + \beta$; where β involves only q^4 &c.

* A nearer value is $x = \pm \frac{a q}{\sqrt{(1 + q^2)}}$. In fact, if we consider the first side of equation (2), as composed of two factors $[x^2 (1 + q^2) - a^2 q^2 + \delta]$ and $a^{n+1} - x^{n+1} + A q^2 + B q^4 + C q^6 +$ &c. we shall find that $A = - x^{n-1} (a^2 - x^2)$; $B = - x^{n-3} (a^2 - x^2)^2$, &c. And δ will not involve any powers of q lower than q^{n+3} when n is odd, and $q^{n+2} x$ when n is even: and hence the value $x = \pm \frac{a q}{\sqrt{(1 + q^2)}}$ is accurate as far as quantities of the order q^{n+2}.

If we call the other factor Q we have

$$(x^2 - a^2 q^2 + \beta) \,.\, Q = (a^{n+1} - x^{n+1})\, x^2 - q^2 a^{n+1} (a^2 - x^2),$$

Hence

$$d\theta = \frac{q\, a^{\frac{n+3}{2}}\, dx}{x \sqrt{\{(x^2 - a^2 q^2 + \beta) \,.\, Q\}}} :$$

and if b be the positive root of $x^2 - a^2 q^2 + \beta = 0$, we must, in order to find the angle between the apsides, integrate from $x = b$ to $x = a$; b being, when q is very small, very nearly equal to $a\,q$. The factor Q vanishes when $x = a$, and, if n be odd, when $x = -a$, but for no other values of x.

Now since the value of $d\theta$ involves q as a multiplier, if q be very small, $d\theta$ will be very small for all points except when the denominator also is very small. But, supposing x to begin from b, the factor $x^2 - a^2 q^2 + \beta$ will be small, and $d\theta$ considerable, so long as x is not much larger than b. When x becomes larger, both the factors $x^2 - a^2 q^2 + \beta$ and Q are considerable, and therefore $d\theta$ very small; and this continues till $x = a$ nearly, which gives $Q = 0$ nearly. And it is to be observed that when x is nearly equal to a, $d\theta$ is much less for a small variation of x than it is for the same variation when x is nearly $= b$. For on the latter supposition the factors of the denominator, x, and $\sqrt{(x^2 - a^2 q^2 + \beta)}$ are both very small and of the order $a\,q$, the variation being supposed to be of that order; whereas the denominator when x is nearly equal to a, will, on the same supposition, be of the order $\sqrt{a\,q}$.

Hence it follows that when q is exceedingly small, by far the most considerable part of the integral is that which is contained between the values $x = a\,q$ and $x =$ any small quantity c, considerably larger than $a\,q$.

The same conclusion may be deduced, and perhaps more simply, from geometrical considerations. In Fig. 25, let $SA = a$

and $SB = b$ be the two apsidal distances, and let $SC = c$ be any other distance, which, when SB is indefinitely small, becomes very small compared with SA, but indefinitely large compared with SB. Then it is manifest that the angle BSC is the integral of $d\theta$ from $x = b$ to $x = c$. And when the excentricity of the orbit is increased, and SB diminished indefinitely, the angle ASC will vanish, and the angle BSC may be taken for the whole angle ASB. Hence the problem becomes, to integrate the expression for $d\theta$ between the values $x = b = aq$ and $x = c$, a quantity much larger than b. If, after the integration, we suppose q indefinitely small, we have the ultimate value of the angle ASB.

Now the integral being taken between the values $x = b$, and $x = c$, both being very small quantities with respect to a, it is manifest that though the factor $x^2 - a^2 q^2 + \beta$ varies considerably, because these quantities are of the order aq, the other factor Q, which consists of factors such as $a - x$, $x^2 + hx + k$, &c. a, k, &c. being quantities of considerable magnitude, will not much vary; and ultimately, when we consider q, and therefore b and c, as indefinitely small, Q may be considered as continuing constant in the variation from b to c.

Hence we have ultimately

$$\theta = \frac{a^{\frac{n+3}{2}}}{\sqrt{Q}} \int \frac{q\,dx}{x\sqrt{(x^2 - a^2 q^2 + \beta)}}.$$

And, neglecting the terms involving β, which will in this case vanish,

$$\theta = \frac{a^{\frac{n+3}{2}}}{\sqrt{Q}} \int \frac{q\,dx}{x\sqrt{(x^2 - a^2 q^2)}}$$

$$= \text{arc}\left(\sec = \frac{x}{aq}\right) + \text{const.}$$

since $Q = a^{n+1}$ ultimately. And, taking the integral from $x = a q$ to $x = c$,

$$\theta = \text{arc}\left(\sec = \frac{c}{a q}\right);$$

and supposing c indefinitely greater than $a q$, as has been said, to obtain the ultimate angle between the apsides,

$$\theta = \text{arc}\,(\sec = \infty) = \frac{\pi}{2}.$$

Hence it appears, that whatever be the value of n, the angle between the higher and lower apse is ultimately a right angle.

This solution is manifestly applicable so long as q^{n+1} is a very small quantity, that is, so long as n is greater than -1*.

Next, let the force vary inversely as any power of the distance, the former denominations remaining, suppose the force be equal to $\frac{f a^n}{x^n}$. Then we may prove, in the same manner as before, (the ratio

* It may be observed, that the same conclusion may be deduced by more direct reasoning in the case when $n=0$, or the force is constant. We have then

$$d\theta = \frac{q a^{\frac{3}{2}} d x}{x \sqrt{\{(a - x) x^2 - q^2 a (a^2 - x^2)\}}} = \frac{q a^{\frac{3}{2}} d x}{x \sqrt{\{x^2 - q^2 a x - q^2 a^2) (a - x)\}}}$$

$$= \frac{q a d x}{x \sqrt{(x^2 - q^2 a x - q^2 a^2)}} \cdot \left\{1 + \frac{1}{2} \cdot \frac{x}{a} + \frac{1 \,.\, 3}{2 \,.\, 4} \cdot \frac{x^2}{a^2} + \ldots\right\}$$

$$\theta = \text{arc sin} = \frac{2\sqrt{(x^2 - q^2 a x - q^2 a^2)}}{x\sqrt{(q^2 + 4)}} + \frac{q}{2} \text{ hyp log } \{2x - q^2 a + 2\sqrt{(x^2 - q^2 a x - q^2 a^2)}\} + \&c.$$

The integral is to be taken from $x=b$ to $x=a$, b being a root of $x^2 - q^2 a x - q^2 a^2 = 0$; hence $b = \pm q a \sqrt{\left(1 + \frac{q^2}{4}\right)} + \frac{q^2 a}{2}$; and the positive sign is to be taken.

And hence for the angle between the apsides

$$\theta = \text{arc sin} = \frac{2\sqrt{(1 - 2q^2)}}{\sqrt{(4 + q^2)}} + \frac{q}{2} \text{ hyp log } \frac{4 - 2q^2 + 4\sqrt{(1 - 2q^2)}}{q\sqrt{(4 + q^2)}} + \&c.$$

all the succeeding terms involving q &c. And when q becomes indefinitely small

$$\theta = \text{arc}\,(\sin = 1) = \frac{\pi}{2}.$$

of the velocity of projection to that in a circle being $q\sqrt{2}$ to $\sqrt{n-1}$,) that

$$d\theta = \frac{q\,a\,dx}{x\sqrt{\{(a^{n-1} - x^{n-1})\,x^{3-n} - q^2(a^2 - x^2)\}}}$$

$$= \frac{q\,a\,dx}{x\sqrt{\{a^{n-1}\,x^{3-n} - (1-q^2)\,x^2 - a^2 q^2\}}}.$$

And to find the apsidal distances, we have the equation

$$a^{n-1}\,x^{3-n} - (1-q^2)\,x^2 - a^2 q^2 = 0; \qquad (3).$$

or, dividing by $a^{n-1}\,x^{3-n}$,

$$1 - \frac{x^{n-1}}{a^{n-1}} + \frac{q^2\,x^{n-1}}{a^{n-1}} - \frac{q^2\,a^{3-n}}{x^{3-n}} = 0.$$

We shall suppose n greater than 1 and less than 3. Hence to approximate to the roots, we may observe that when q, and therefore x, is very small, the second and third terms of this equation become very small, and we must therefore have approximately,

$$1 - \frac{q^2\,a^{3-n}}{x^{3-n}} = 0, \text{ and } x = a\,q^{\frac{2}{3-n}}.$$

And hence, we may suppose the first side of equation (3) composed of two factors $(x^{3-n} - q^2 a^{3-n} + \beta)$ and Q, where Q does not vanish for any positive value of x except $x = a$, and β is small compared with q^2.

Hence

$$\theta = \int \frac{q\,a\,dx}{x\sqrt{\{(x^{3-n} - q^2 a^{3-n} + \beta)\,.\,Q\}}};$$

And, as before, neglecting β, and supposing Q constant;

$$\theta = \frac{1}{\sqrt{Q}} \int \frac{a\,q\,dx}{x\sqrt{\{x^{3-n} - q^2 a^{3-n}\}}};$$

which may be integrated. Let $y^2 = \dfrac{x^{3-n}}{q^2\,a^{3-n}}$;

$$\therefore\ \theta = \frac{2}{(3-n)\sqrt{Q}\,a^{3-n}} \int \frac{a\,dy}{y\sqrt{(y^2-1)}}: \text{ (since } Q = a^{n-1} \text{ nearly,)}$$

$$= \frac{2}{3-n}\,\text{arc}\left(\sec = y = \frac{x^{\frac{3-n}{2}}}{q\,a^{\frac{3-n}{2}}}\right) + \text{const.}$$

and the integral being taken from $x = q\,a^{\frac{3-n}{2}}$ to $x = c$, we have for the angle between the apsides

$$\theta = \frac{2}{3-n} \text{ arc } \left(\sec = \frac{c^{\frac{3-n}{2}}}{q\,a^{\frac{3-n}{2}}}\right).$$

which gives, when q becomes indefinitely small,

$$\theta = \frac{2}{3-n} \text{ arc } (\sec = \infty) = \frac{2}{3-n} \cdot \frac{\pi}{2} = \frac{\pi}{3-n}.$$

This applies to all cases where n is greater than 1 and less than 3. When n is very little greater than 1, the angle is very nearly $\frac{\pi}{2}$; as n becomes 2, θ becomes π, which is the proper value, the orbit being then an ellipse; this value is not confined to the ultimate form of the orbit. As n becomes nearly equal to 3, the angle becomes greater and greater, and finally infinite when n is 3. Beyond this value of n, the orbit, as is known, has no second apse.

Hence, we have the following values of the angle between the apsides in orbits which are infinitely excentric.

When the force varies directly as any power of the distance, the angle is 90°.

When the force varies inversely as any power whose index is less than 1, the angle is 90°.

When the force varies inversely as the distance, the angle is 90*.

When the force varies inversely as any power when index is between 1 and 2, the angle is between 90° and 180°.

* The case when the force varies inversely as the distance gives the formula

$$d\,\theta = \frac{q\,a\,d\,x}{x\sqrt{\left\{x^2 \text{ hyp log } \frac{a}{x} - q^2\,(a^2 - x^2)\right\}}}$$

but without attempting to approximate to the integral of this expression, the law of continuity indicates sufficiently that the angle in this case will be 90°.

When the force varies inversely as any power whose index is between 2 and 3, the angle is greater than 180°.

By the ninth section of the first book of the Principia it appears, that when the excentricity is indefinitely small, the angle between the apsides is $\frac{180^\circ}{\sqrt{(n+3)}}$ if the force vary directly as the n^{th} power of the distance; and $\frac{180^\circ}{\sqrt{(3-n)}}$ if it vary inversely as the n^{th} power. By comparing these with the preceding results we have the following conclusions.

When the force is in any direct ratio of the distance greater than the simple power, the angle between the apsides increases as the excentricity increases; viz. from $\frac{180^\circ}{\sqrt{(3+n)}}$, its value when the excentricity is 0, to 90°, its value when the excentricity is infinite.

When the force varies as the distance, the angle is the same for all excentricities, viz. 90°.

When the force varies as the n^{th} power, n being a *proper* fraction, either negative or positive, the angle diminishes as the excentricity increases; viz. from $\frac{180^\circ}{\sqrt{(3+n)}}$ to 90°. The same is true when the variation is inversely as the distance.

When the force varies inversely as the n^{th} power, n being between 1 and 2, the angle diminishes as the excentricity increases; viz. from $\frac{180^\circ}{\sqrt{(3-n)}}$ to $\frac{180^\circ}{3-n}$.

When n is 2 the angle is 180° in all cases.

When n is between 2 and 3, the angle increases with the excentricity, viz. from $\frac{180^\circ}{\sqrt{(3-n)}}$ to $\frac{180^\circ}{3-n}$.

The dependance of the angle between the apsides upon the excentricity is, as appears from this recapitulation, somewhat anomalous. There is no very obvious reason why a diminution of the projectile velocity should in some cases carry the apse forwards, and in others draw it backwards. When the angle in the circular orbit is less than 90° we may see in some measure why it becomes 90° in the excentric orbit, because if it were smaller there would be points of inflexion in the curve. But it becomes 90° also in cases where it is greater in the orbit nearly circular, as for instance when the force is constant. There will of course be corresponding irregularities in the form of the orbit for intermediate excentricities; but till we can obtain our information more immediately from the differential expression, we must be content with such indications of their nature as are supplied by the few cases which admit of solution.

W. WHEWELL.

Trinity College,
March 18, 1820.

NOTE.

AS the reasoning by which the results in the preceding paper are deduced may be considered as offering some difficulties, it may be worth while to shew how the same conclusions may be more directly obtained. We shall take the case where the force varies inversely as x^n; a similar process is easily applicable in the other case. We shall also make $a = 1$. We have then to find

$$\theta = \int \frac{q\,dx}{x\surd\{x^{3-n} - q^2 - (1-q^2)x^2\}} \begin{bmatrix} x=1 \\ x=b \end{bmatrix}$$

The brackets containing the limits of the integration, and b being a small positive root of

$$x^{3-n} - q^2 - (1-q^2)\,x^2 = 0.$$

Let $\dfrac{1}{\surd\{x^{3-n} - q^2 - (1-q^2)\,x^2\}} = \dfrac{X}{\surd\{x^{3-n} - q^2\}}$; X being a series,

$$\therefore \quad X = \sqrt{\frac{x^{3-n} - q^2}{x^{3-n} - q^2 - (1-q^2)\,x^2}}$$

$= \left\{1 - \dfrac{(1-q^2)x^2}{x^{3-n} - q^2}\right\}^{-\frac{1}{2}}$; and if $1 - q^2 = k^2$, $x^{3-4} - q^2 = z^2$;

$$X = 1 + \frac{1}{2}\cdot\frac{k^2x^2}{z^2} + \frac{1\,.\,3}{2\,.\,4}\cdot\frac{k^4x^4}{z^4} + \ldots$$

$$\therefore \theta = \int \frac{q\,dx}{x\,z}\cdot\left\{1 + \frac{1}{2}\cdot\frac{k^2x^2}{z^2} + \frac{1\,.\,3}{2\,.\,4}\cdot\frac{k^4x^4}{z^4} + \ldots\right\}$$

Now $\displaystyle\int \frac{q\,dx}{x\,z} = \int \frac{q\,dx}{x\surd\{x^{3-n} - q^2\}} = \frac{2}{3-n}\ \text{arc}\left(\cos = \frac{q}{x^{\frac{3-n}{2}}}\right)$

(between the limits) $\quad = \dfrac{2}{3-n}\left\{\text{arc}\,(\cos = q) - \text{arc}\left(\cos = \dfrac{q}{b^{\frac{3-n}{2}}}\right)\right\}.$

But $b^{3-n} - q^2 - (1-q^2)\,b^2 = 0$; $\therefore\ \dfrac{q}{b^{\frac{3-n}{2}}} = \surd\{1 - (1-q^2)\,b^{n-1}\}$;

hence, when q and b become very small, we have

$$\int \frac{q\,dx}{x\,z}\begin{bmatrix} x=1 \\ x=b \end{bmatrix} = \frac{2}{3-n}\{\text{arc}\,(\cos = 0) - \text{arc}\,(\cos = 1)\} = \frac{2}{3-n}\cdot\frac{\pi}{2}\ \text{nearly:}$$

and it is to be shewn, that all the other terms of θ, involving $\displaystyle\int \frac{q\,x^{2m}\,dx}{x\,z^{2m+1}}\begin{bmatrix} x=1 \\ x=b \end{bmatrix}$ will vanish.

Let $P = \frac{x^{2m+n-3}}{z^{2m-1}}$; and since $z^2 = x^{3-n} - q^2$, $dz = \frac{3-n}{2}\,\frac{x^{2-n}\,dx}{z}$;

$$\therefore \quad dP = (2m+n-3)\,\frac{x^{2m+n-4}\,dx}{z^{2m-1}} - \frac{(2m-1)(3-n)}{2}\cdot\frac{x^{2m-1}\,dx}{z^{2m+1}};$$

$$\therefore \int \frac{q\,x^{2m-1}\,dx}{z^{2m+1}} = -\frac{2}{(2m-1)(3-n)}\cdot\frac{q\,x^{2m+n-3}}{z^{2m-1}}$$

$$+\frac{2(2m+n-3)}{(2m-1)(3-n)}\int\frac{q\,x^{2m+n-4}dx}{z^{2m-1}};$$

and, between the limits, $= -\frac{2}{(2m-1)(3-n)}\left\{\frac{q}{k^{2m-1}} - \frac{q\,b^{2m+n-3}}{(b^{3-n}-q^2)^{\frac{2m-1}{2}}}\right\}$

$$+\frac{2(2m+n-3)}{(2m-1)(3-n)}\int\frac{q\,x^{2m+n-1}}{z^{2m-1}}.$$

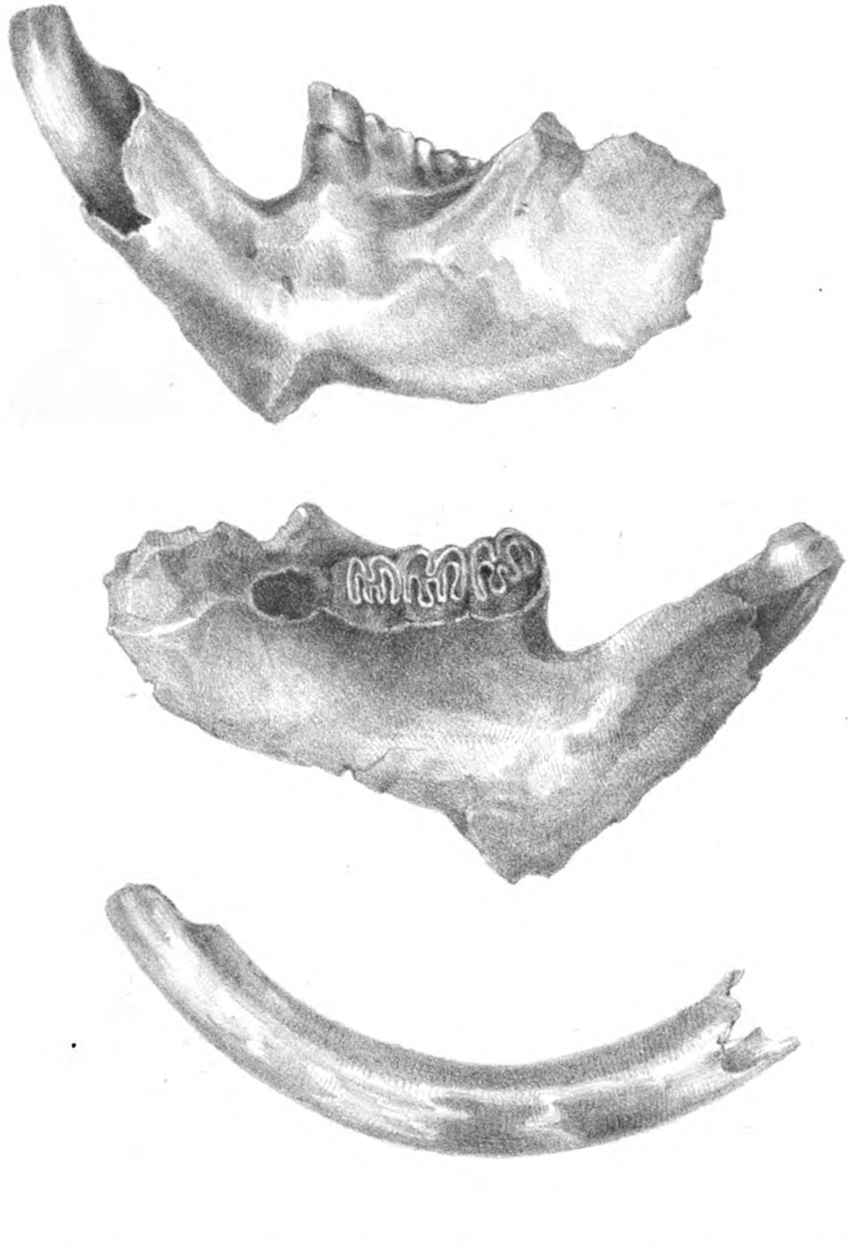
Now $b^{3-n} - q^2 = k^2 b^2$; hence $\frac{q\,b^{2m+n-3}}{(b^{3-n}-q^2)^{\frac{2m-1}{2}}} = \frac{q\,b^{n-2}}{k^{2m-1}}$;

and, since $b = q^{\frac{2}{3-n}}$ nearly, $\qquad = \frac{q\cdot q^{\frac{2(n-2)}{3-n}}}{k^{2m-1}}$;

$$= \frac{q^{\frac{n-1}{3-n}}}{k^{2m-1}}.$$

Hence, the term which is freed from the sign of integration will involve $\{q - q^{\frac{n-1}{3-n}}\}$, which, since $n-1$ and $3-n$ are both positive, will vanish when q vanishes. Similarly $\int \frac{q\,x^{2m+n-4}\,dx}{z^{2m-1}}$ &c. may be integrated in part, and the terms so obtained will involve $\{q - q^{\frac{3(n-1)}{3-n}}\}$, $\{q - q^{\frac{5(n-1)}{3-n}}\}$, &c. and therefore vanish when we make $q = 0$. Thus the integrals after the first, in the series for θ, may be reduced to a series of terms, each of which becomes indefinitely small when q does. And hence, the limit of θ when the orbit approaches indefinitely near the center will be found by making $q = 0$, which reduces it to its first term. That is, ultimately,

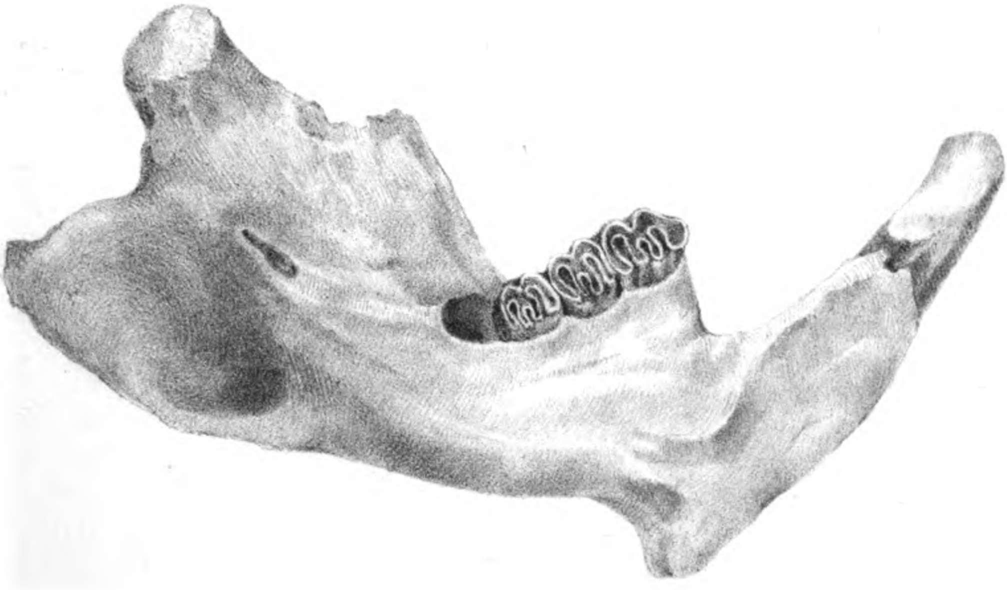
$$\theta = \frac{\pi}{3-n}.$$



FOSSIL BONES OF THE BEAVER FOUND IN CAMBRIDGESHIRE.

Designed from the Original Specimens in the possession of Professor E. D. Clarke of Cambridge, by Mrs E. Clarke.

Drawn on Stone by M. Gauci. *Printed by C. Hullmandel*



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Drawn on Stone by M. Gauci. Printed by C. Hullmandel.

Fig. 21.

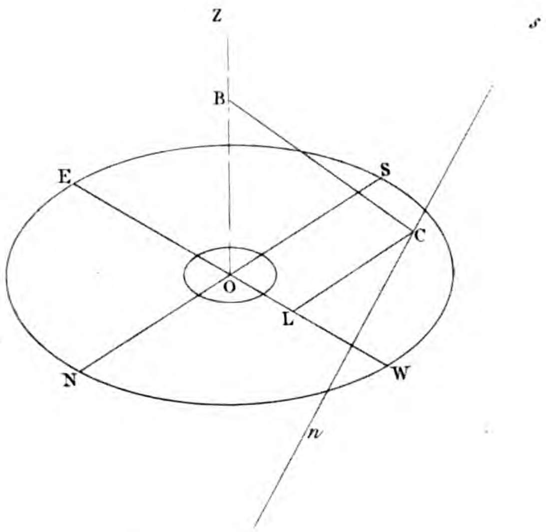


Fig 22

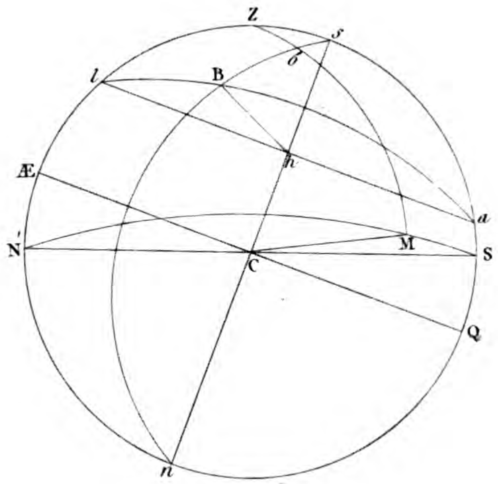


Fig. 23

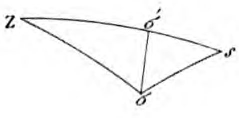
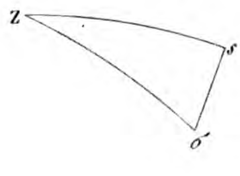


Fig 24



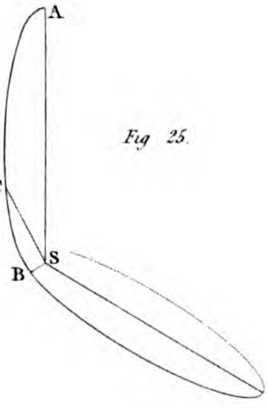
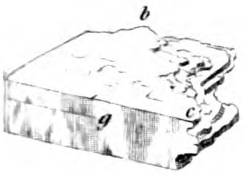


Fig 25.

Fig. 13.



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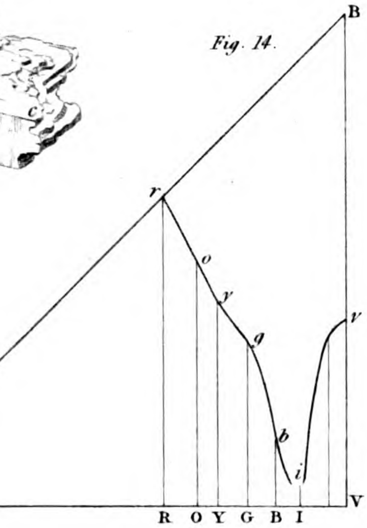
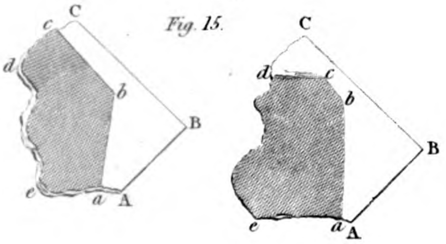


Fig. 15.



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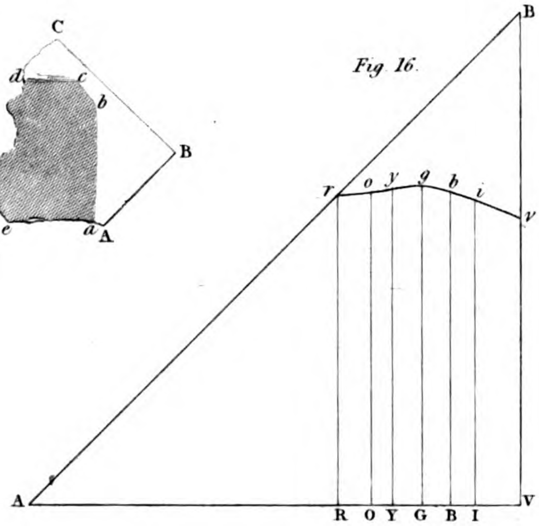

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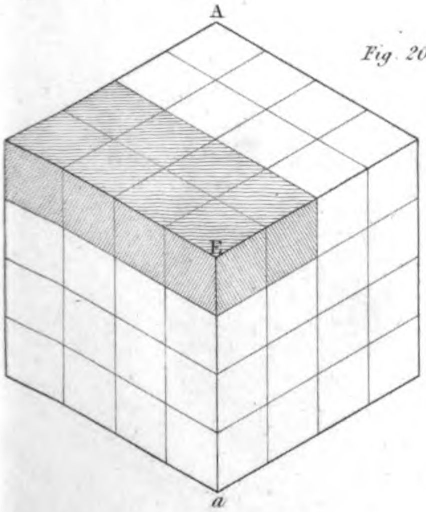
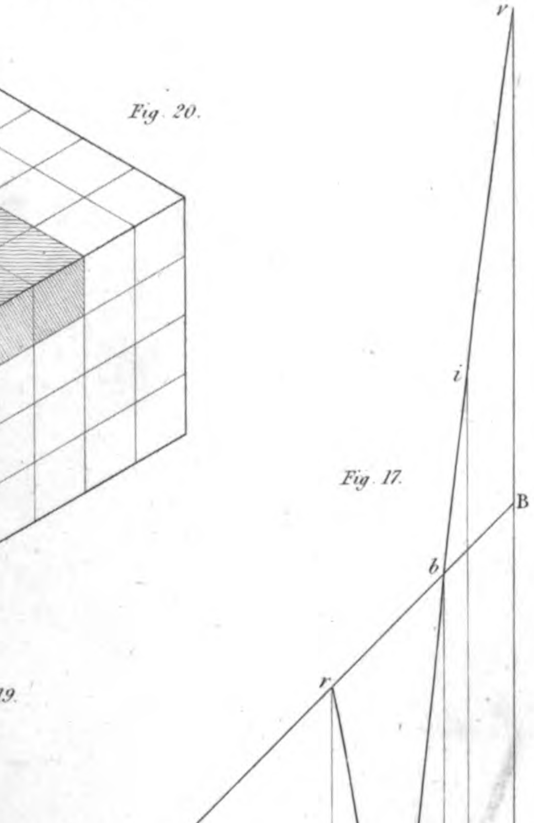


Fig. 17.



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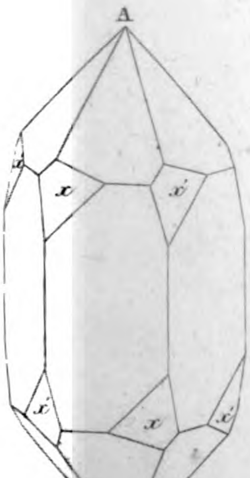

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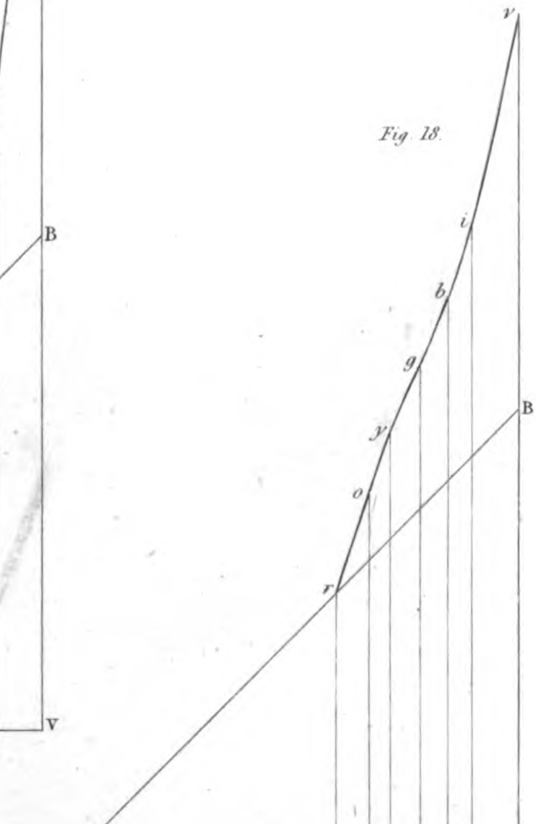

I F W H delin.

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Fig. 10.

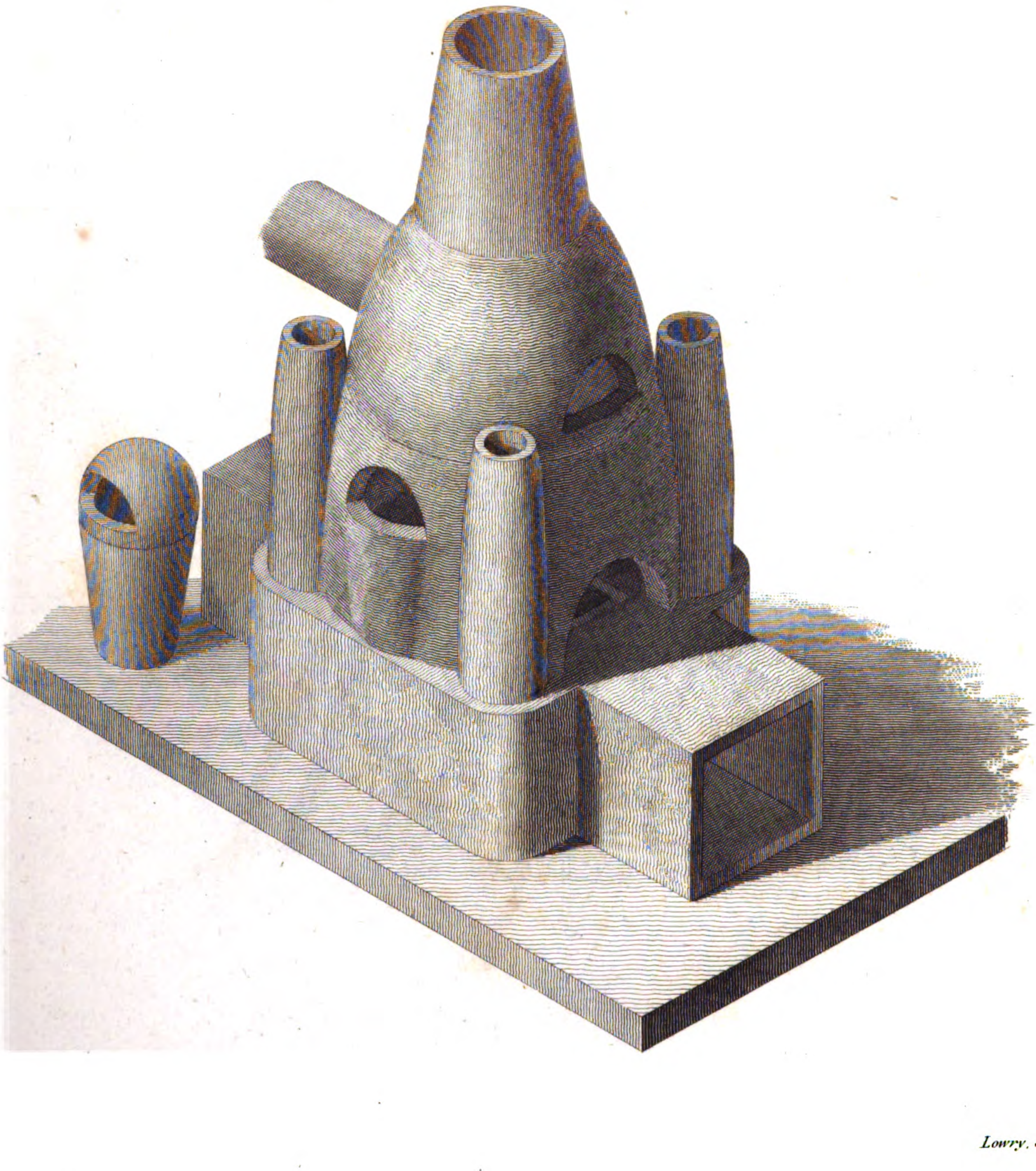

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Fig. 9.

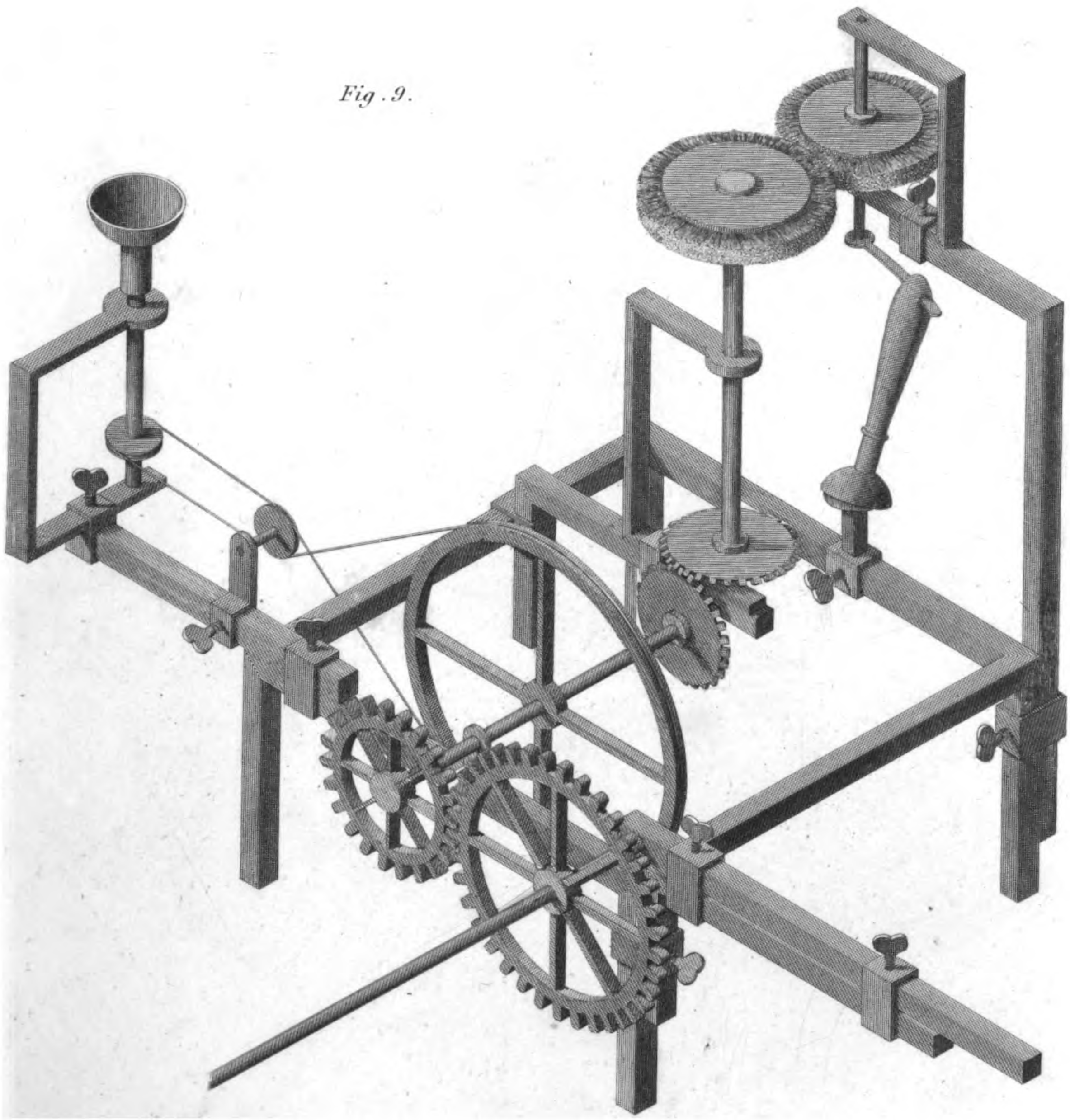

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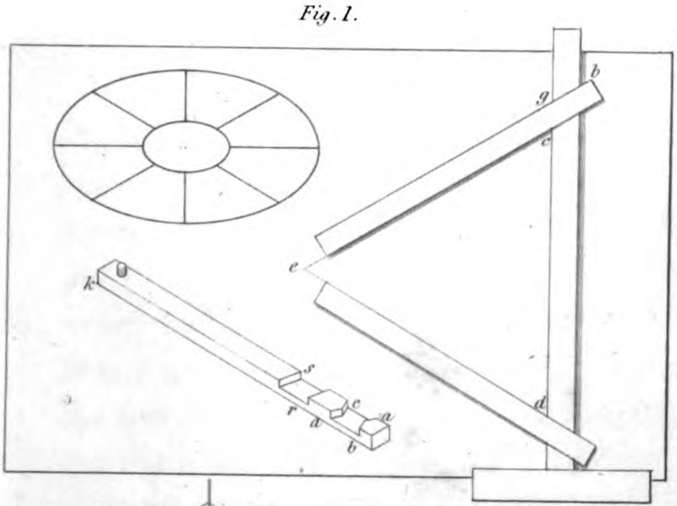
Fig. 1.



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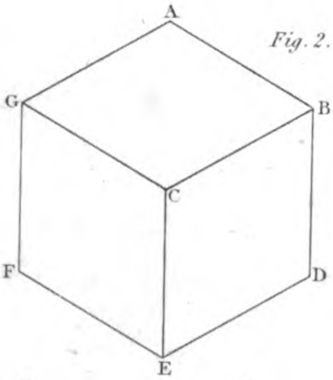

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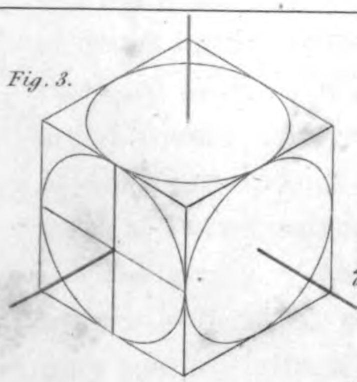

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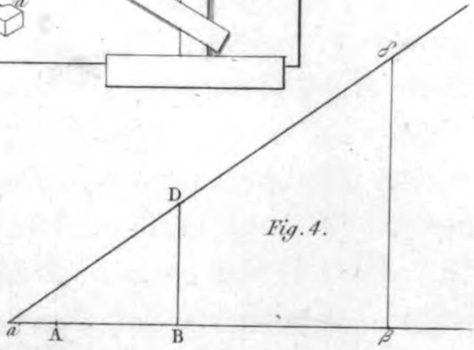


Fig. 6.

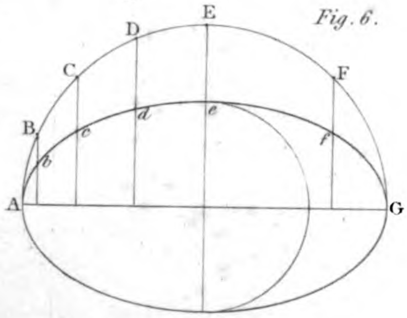


Fig. 5.

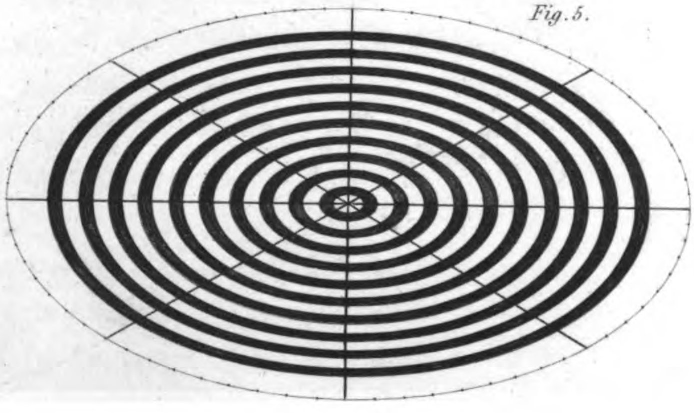


Fig. 8.

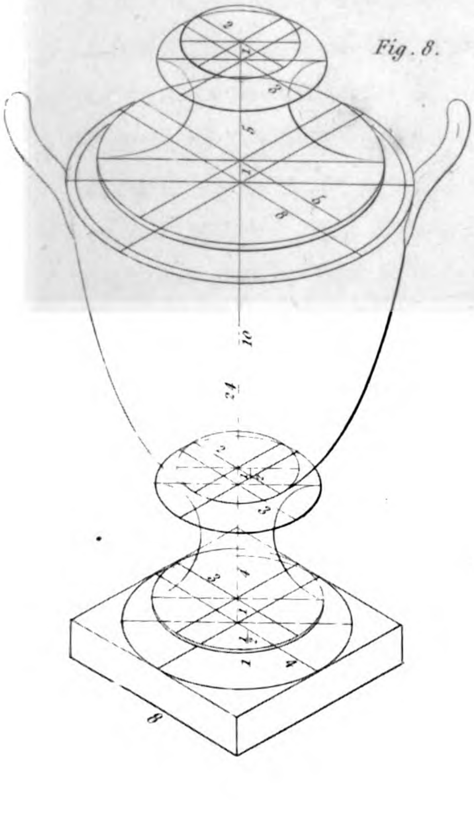
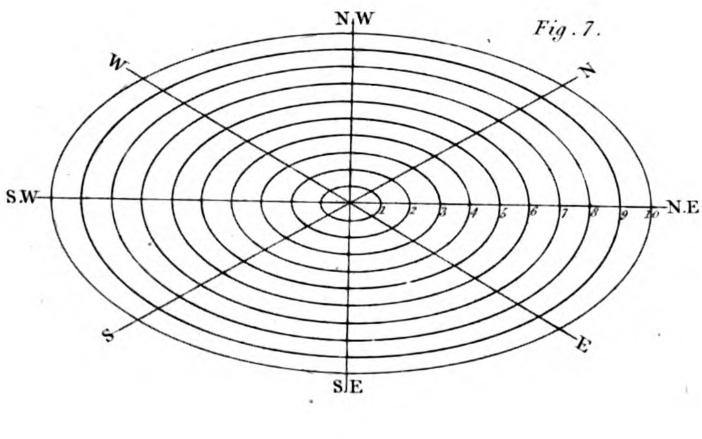


Fig. 7.



wholly of a *siliceous* nature, a deposit of *natron* should have taken place, so remarkable as this noticed by Dr. *Wavell* within the interior of the tower, where the decomposition of the stone has proceeded to such a length, as to have given rise to the cavities which he has described. In a second letter which he has addressed to me upon this subject, he says, " The church is large and antient; the tower, a very fine one, is a sea-mark; and, in a direct line, is not more than half a mile from the sea. I observed no appearance of decay in the stones of the *exterior* of the tower; it seemed wholly confined to those of the *interior*. How have these stones been thus acted upon; and whence originates the salt with which their cavities are laden? Many from their honey-combed appearance seem to have resolved themselves into this salt."

The origin of the salt and its chemical constituents have been already sufficiently explained. The only doubt, as to its formation, may possibly attach to the source of the *carbonic acid* which has combined with the *soda;* i. e. whether it were derived from the small quantity of the *carbonate of lime* which the mortar contains, or has resulted from the action of atmospheric air. There is something also paradoxical in the nature of the action which has produced such a remarkable instance of decomposition in the stones of the tower; and this only upon the interior walls. Further observations made upon the spot, may perhaps clear up these points. For the present, having already trespassed long enough upon the attention of the Society, any additional remarks upon this subject may be reserved for future consideration.

EDWARD DANIEL CLARKE.

Cambridge,
Nov. 15, 1820.

XI. *On a remarkable deposit of Natron found in cavities in the Tower of Stoke Church, in the Parish of Hartland, in Devonshire.*

By EDWARD DANIEL CLARKE, LL.D.

LATE FELLOW AND TUTOR OF JESUS COLLEGE; PROFESSOR OF MINERALOGY IN THE UNIVERSITY OF CAMBRIDGE; LIBRARIAN OF THE UNIVERSITY; MEMBER OF THE ROYAL ACADEMY OF SCIENCES AT BERLIN; HONORARY MEMBER OF THE GEOLOGICAL SOCIETIES OF LONDON, EDINBURGH, CORNWALL, &c. &c.

[Read *November* 27, 1820.]

In the Chemistry of Nature, the mutual decomposition of bodies, by their action on each other, and the new synthetical results which follow this analysis, may be justly deemed among the most interesting phenomena offered to our view; and they are, perhaps, never more strikingly developed than in the formation of the native Salts, when they are found efflorescing and crystallizing upon the surface, and in the interstices, of minerals, which did not originally contain them. It has often happened to me to point out these changes, in my public lectures, to the University, and to call the attention of mineralogical Students to the operation whereby in a successive series of analysis and synthesis the eternal energies of the creative agency are continually manifested. To the attentive observer of Natural Chemistry, these phenomena are highly important; because, while they are calculated to illustrate the origin of some of the most remarkable substances in Nature, their consideration fills the mind with astonishing ideas of the activity, and renovating powers of that ceaseless Cause, which ordains new and beautiful forms, out of the decay and ruin of pre-existent beings. Many such phenomena might be here enumerated; but for the present I shall confine myself to one; namely, to the formation of *native natron;* under circumstances which were communicated to me by Dr. WAVELL of *Devonshire;* so well known to the scientific world by his former discovery of the *phosphate of alumina;* called, in honour of him, by the name of *Wavellite.*

Dr. WAVELL transmitted to me a small parcel of *a white salt,* which he had lately found in the Tower of *Stoke* Church, in the Parish of *Hartland,* in *Devonshire;* desiring me to examine it. The description of the manner in which it was deposited, shall be given from the letter which accompanied this *alkaline* substance, in his own words.—"Many of the stones, in the interior of the tower, were hollowed out, and the cavities nearly filled with the Salt. Upon other stones there was merely an efflorescence. Some of the cavities were only large enough to admit my hand; others would nearly receive my head. I send you a small fragment of the stone, which I broke off with difficulty; for although the stones appear much decayed, they are very hard."—

The stone in question, is evidently a slate-coloured *sandstone;* but unlike any *sandstone* I had before seen. Perhaps it is nearly allied to the *Graiiwacke* of the Germans, but of a purer siliceous nature. The grains of sand are so minute, and withal so intimately aggregated, as to be imperceptible to the naked eye. It preserves its colour when first acted upon by the common blowpipe; but when wrapped in platinum foil, and exposed for half an hour to a white heat in a coal fire, its colour becomes reddish white. Exceedingly minute particles of silvery *mica* may then be discerned with a lens. The action of heat produces hardly any magnetic property; the smallest particles being scarcely affected by the magnet afterwards. Its specific gravity equals 2.625, which alone proves it to be nearly pure *silica;* the specific gravity of *Quartz* being 2.6. It scintillates freely with steel. Placed in dilute *muriatic acid* it yields no effervescence; but the acid being boiled, causes it to exhibit an almost imperceptible effervescence. The same acid being afterwards evaporated to dryness, and distilled water added, *oxalate of ammonia* detected a trace of *lime*. *Carbonate of soda* also threw down *carbonate of lime* from the same solution, but with a beautiful reddish hue owing to the precipitation also of *oxide of iron* by means of the alkaline body. Hence it is manifest that some *carbonate of lime* had existed in this *sandstone;* probably as a cement; but the stone having been corroded and decomposed in the formation of the salt, I thought it right to see if any *carbonate of lime* existed in the *salt* itself, which proved to be the case; and this I ascertained in the following manner.

I dissolved a portion of the *salt* in distilled water; decanting the supernatant solution so long as it continued to change the blue tincture of vegetables to a green colour. When all action upon the vegetable tincture had ceased, and the insoluble residue had been repeatedly washed with many volumes of distilled water, I poured upon it some *muriatic acid;* when a visible and somewhat violent effervescence ensued; particles of the effervescing body being carried up and down in the liquid. That these particles were *carbonate of lime* is evident from this circumstance; that the acid being now decanted into a filter and collected in a watch-glass, and evaporated to dryness, and distilled water added, the presence of *lime* was fully attested by *oxalate of ammonia*.

My attention was now given more immediately to the *salt* itself; in the examination of which I proceeded as follows:

Its taste is very slightly alkaline. Cast upon burning coal it exhibited neither deflagration nor phosphorescence. Placed in the flame of a candle it rapidly melted like ice; giving out *water* and *carbonic acid,* as will further appear in the sequel. To *nitric* and to *muriatic acid* it yielded a violent effervescence. The *gas* being collected precipitated *carbonate of lime,* from *lime* water. Having saturated distilled water with a portion of the *salt* and filtered the solution, there remained at the point of the filter a regular hexagonal crystal of considerable magnitude, the termination of which could not be accurately ascertained, because the crystal had been formed by an aggregation of parallel spiculæ, the points of which projected irregularly at its termination*. When the rest of the solution of the *salt* had passed the filter, a drop of it was suffered to fall into a solution of *platinum,* but caused no precipitation; hence, it was evidently not a salt of *potass.* To prove therefore that it was a salt of *soda, muriatic acid* was added drop by drop until all effervescence ceased. This *muriate* was then placed over an Argand lamp, and with very gentle heat evaporated; cubic crystals of *muriate of soda,* beginning almost instantly to form upon the surface and fall to the bottom, which process was continued until the whole of the liquid became crystallized in highly transparent cubes, having the taste of common salt; exhibiting also indented cavities, as of inverted four-sided pyramids, where the crystallization had affected the regular octahedral form.— That this was a *muriate of soda* seemed clearly shewn; however to put this matter out of all doubt, *nitric acid* was afterwards added,

* This form in *carbonate of soda* has not been before noticed. The mode in which a regular hexagonal prism results from an octahedron, of which the principal section is 120° and 60°, is thus explained according to the common modes of truncation. It is shewn by cutting off the four edges of the principal section and the two acute angles at its extremities. Further, this prism would have right bases if the apex of each rhombic pyramid were truncated.

instead of the *muriatic*, to the solution of the *salt* as sent by *Dr. Wavell*, until all effervescence ceased; and the *nitrate* being left to crystallize exhibited transparent crystals of a rhomboidal form. The filter through which the *nitric* solution had passed being placed in the fire, exhibited the same deflagration as touch-paper, which has been made with the *nitrate of potass*. When exposed to the air the crystals of the *nitrate* attracted moisture.

From all the preceding observations it is therefore plain, that the *salt* discovered by *Dr. Wavell* in the very act of forming in the tower of *Stoke* Church is *native natron;* and it is also proved to be a *bi-carbonate of soda* from its action when exposed to a red heat, in passing from the state of a *bi-carbonate* to a common *carbonate*, by the loss of one half of its acid*. Like the *natron* of *Egypt* † and of *Hungary* ‡, it contains both *sulphate* and *muriate* of *soda*, besides the *carbonate;* which may be proved by adding a drop of solution of *silver*, to the solution of this *salt* in a watch-glass, as a test of the presence of *muriatic acid;* and a drop of *barytic* water, as a test of the presence of the *sulphuric;* in both instances a white precipitate is caused, which in the latter case is insoluble in dilute *muriatic acid*, and in the former, where the test for *muriatic acid* is used, turns brown and afterwards black by the action of light; and is, therefore, evidently, a *muriate of silver*.

Having thus ascertained the nature of the curious discovery made by *Dr. Wavell*, I shall next proceed to account for the very singular circumstance of the formation of *natron* in the situation which he has assigned for it.

* See the opinion of *Dr. Wollaston* as cited in Thomson's Chemistry, fifth Edit. vol. II. p. 440. Lond. 1817.

† Klaproth's Beiträge zur Chemiscen, &c. b. 3. s. 80. Jameson's Mineralogy, vol. II. p. 123. Lond. 1816.

‡ Reuss, Lehrbuch der Mineralogie, &c. b. 3. s. 5. Ibid.

Stoke Church is situate upon the sea-coast of *Devonshire,* upon that promontory which goes by the name of *Hartland Point,* a little to the South West of *Hartland,* in the neighbourhood of *Hartland Quay.* As the distance, inland, to which the salt spray of the sea is carried by winds, is well known to those who reside in maritime districts; being often deposited upon the window-glass of houses, fifteen or twenty miles from the shore; it will not appear at all marvellous, that the *muriate of soda* is perpetually acting upon the stones of the tower of *Stoke* church, which in a direct line is not more than half a mile from the sea. The cavities in these stones, as we have shewn, are found to contain a certain portion of *carbonate of lime;* whether derived from the mortar used in the building, or not, is uncertain; as the stones themselves contain hardly any of this substance. This is of no consequence; because it is only necessary to prove the existence of *carbonate of lime,* in contact with the *muriate of soda;* which has been done already. Whenever these two bodies lie in contact, being also subject to continual changes of moisture and desiccation, it is a fact generally admitted that their mutual decomposition ensues. The *alkali* parts with its *acid,* which forms a *muriate of lime;* and the *carbonic acid* of the *limestone* entering into chemical union with the *alkali,* forms a *carbonate of soda,* or *native natron;* which is the identical *salt,* now under consideration. Yet as this double decomposition of the two compounds is necessary to its formation it is rather a rare deposit in nature. The places where *native natron* has been discovered in any abundance are all of them foreign to our island. The best account of them, is given by *Professor Jameson* in his System of Mineralogy*. The crystallization of natural *carbonate of soda* is unknown; that of the artificial *carbonate* is supposed to be an

* See vol. II. p. 312. Edinb. 1816.

octahedron * of which the common base of the two pyramids is a rhombic plane, whose angles, as nearly as can be determined by the eye, without the aid of a Goniometer †, measure 120° and 60°. The obtuse angle of the rhombic crystals of the *nitrate of soda* is much less; being about 98° or 100° ‡, which gave rise to the erroneous appellation of *cubic nitre* as applied to this kind of salt. The rarity of *native natron* in our island, gives to *Dr. Wavell's* discovery an additional interest. Its usual occurrence is as an efflorescence on the surface of decomposing rocks; in which state it appears among the old lavas of *Vesuvius*, where I myself found it nearly thirty years ago, during all which time this salt has been in my possession without exhibiting the slightest deliquescence or alteration in consequence of atmospheric changes. I shall therefore now present it to the Society that it may be placed with *Dr. Wavell's* specimen in their collection of Natural History, and with an earnest hope that it may serve as the beginning of their Cabinet of Mineralogy; to which I am well assured contributions from all quarters will be made. *Natron* is also found in certain lakes that annually become dry, and to which salt-waters have access; as in the *natron lakes*, to the west of the *Delta*, in EGYPT; which were visited a short time before I arrived in *Egypt*, by the celebrated *Berthollet*, together with other Frenchmen of the corps of *Savants* then in that country, accompanied by a military escort under the command of General *Andreossi*. I well remember the importance which the members of the French Institute attached to the result of

* *Dr. Thomson* states this as a general conjecture with regard to the primitive form of the *carbonate of soda* of commerce; "but" he adds, "I am not aware that this form has ever been met with. At least, I have never seen it myself, although I have examined several hundred fine crystals of this salt." *See Thomson's Chemistry*, vol. II. p. 440. *Lond.* 1817.

† This is the apparent inclination of the spiculæ which form during the crystallization of the *salt* sent by *Dr. Wavell*, after it has been dissolved in distilled water and left to evaporate in a watch-glass.

‡ Also conjectured from the ocular examination of crystals in a watch-glass.

that expedition; first, because it gave rise to the theory of *Berthollet* respecting the formation of *Natron,* which is now in general acceptation among Chemists; secondly, on account of the difficulty of penetrating to those lakes, in consequence of the dangers arising from predatory tribes of Arabs, and from other accidents to which travellers in *Egypt* were then exposed. An account of this journey was published by *Andreossi* in the *Decade Egyptienne* printed at *Cairo,* of which three volumes are extant*. *Berthollet* also himself published a separate memoir upon the *natron* of those lakes. According to him they are six in number, of which they examined the smallest, near a ruined fort, called *Kasr,* which is built of blocks of *native natron;* "of itself shewing," says *Andreossi*†, "that the fall of rain in this country cannot be considerable." The lakes comprise a surface of about six leagues in length, by six or eight hundred metres in breadth; they are fed by springs of brackish water containing *muriate of soda,* falling from the tops of small creeks abundantly during three months in the year, when they begin to fail, and some of the lakes become dry. The bottom of the lake which they examined consisted of "argillaceous mud‡ mixed with sand." *Berthollet* also observes in speaking of the soil between the lakes, that if the soil be too *argillaceous,* no *natron* is found, but only *sea salt.* If it be too *siliceous,* no *salt* at all is yielded; it is therefore the more remarkable that in the tower of *Stoke* church where the stones, exclusively of the mortar, are almost

* Mémoire sur la vallée des Lacs de Natron, et celle du Fleuve sans Eau, d'après la reconnaisance faite les 4, 5, 6, 7 and 8, pluviôse, l'an 7[e] de la République Française, par le Général Andreossi. *Voy. La Décade Egyptienne,* Tom. II. p. 93. *Au Kaire* An. VIII.

† Ce qui annonce que les pluies ne sont pas considérables dans cet endroit. *Ibid.* p. 96.

‡ Unaccountably rendered *Chalk* by an English translator of Gen. *Andreossi's* Memoir. *See Memoirs relative to Egypt,* p. 260. *Lond.* 1800. There can be no doubt both from the observations of *Berthollet* and of *Andreossi,* that the stratum below the sand of the Desert, in this part of *Africa,* is of *limestone;* but the words here are: "*le fond du lac est de boue argilleuse, mélée de sable.*" Ibid. p. 98.

XII. *Analysis of a native Phosphate of Copper from the Rhine.*

By FRANCIS LUNN, B.A. F.R.S.

OF ST. JOHN'S COLLEGE, CAMBRIDGE.

[Read *March* 5, 1821].

Among the Analyses of ***Klaproth**** is one of a ***Phosphate of Copper*** from the ***Firneberg*** near ***Rheinbreitenbach*** on the Rhine: the mineral had long been mistaken for Malachite from its external resemblance. The German chemist obtained as his result

Oxide of Copper......68.13
Phosphoric Acid......30.95.

And this Analysis has been adopted by Haüy—Brogniart—Thomson—Jameson—Phillips, and in short copied into every Mineralogical classification which has appeared. Its accuracy has been doubted†, it is true: for water to the amount of 15 per cent. is overlooked; but the rarity of the substance has prevented chemists from subjecting it to a new examination.

Having lately received some copper ores brought from a mine at ***Erpel*** near the town of ***Bonn***‡, among these were specimens

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* Beiträge zur Chemiscen, III. 206.

† L'Analyse de M. Klaproth n'indique pas que l'eau entre dans la composition de ce phosphate, cependant il en conteient une quantité assez considérable; &c. &c. Cette circonstance jette doute sur l' exactitude de l'analyse de Klaproth; elle mérite bien d' etre répétée Berzelius. Nov. Syst. p. 246. Paris 1819.

‡ For these very fine specimens, I am indebted to George Samuel Kett, Esq. Brooke House, Norfolk.

of the mineral in question. In mineralogical characters it agrees with the description of Klaproth.

In colour it is emerald green, but shaded and streaked with black green, and to this colour the external natural surface approaches; it is opake, its powder is verdegris green, it has a diverging striated texture and a silky lustre, the specific gravity of one very pure fragment was 4.2, its hardness is rather beyond that of Malachite. It was in no instance crystallized, although on the external surface of some specimens an imperfect tendency to crystallization was perceptible. It occurs massive in a white opake quartz rock, in places slightly tinged by oxide of iron; and it is soluble in nitric acid. By exposure to a red heat in a close crucible it becomes of a dark olive green colour, and the powder increases considerably in bulk. Before the blow-pipe on charcoal it readily fuses into a reddish black slag adhering to the charcoal, and by the addition of carbonate of soda it is reduced to a bead of pure copper.

In some specimens it is accompanied by crystals of phosphate of lead.

Although the elements of this mineral are not numerous, yet wherever phosphoric acid enters, considerable caution is necessary to ensure correct analytical results: nothing can more fully prove this than the discordancies between the results obtained by two of the most expert analysts, Professors Thomson and Berzelius, and yet both have exerted their utmost skill on this very subject.

It was necessary to make several previous trials to find out a precipitant which might be depended upon; or rather, to find out the mode of using any of the old ones which would produce accordant results. These trials were made upon anhydrous phosphate of soda by barytes, lime, and the salts of lead. I need not repeat a tedious course of experiments, but may mention the results: the objection to the earthy salts is that unless the solution be most strictly neutral, or even rather alkaline, a very small quantity of the phosphoric acid enters into insoluble combination; these therefore would not answer the intended purpose, because at the very point when the re-agent would be useful the original salt was itself precipitated.

To the salts of lead then we must have recourse: the muriate appears to have the preference with Berzelius*, and with this salt accordant results may be obtained; but both the saline solutions must be most strictly neutral, and the very low degree of solubility of muriate of lead after it has once been crystallized, is a considerable practical inconvenience. With the nitrate of lead I could obtain unvarying results; it is easily crystallized, and when carefully washed and redissolved is perfectly neutral and of high solubility.

In both the above methods it is advisable, to ensure accuracy, that no more of the solution of the salt of lead be added than is necessary to separate the phosphoric acid; and the precipitate must be boiled in water, by which means the combination of acid mentioned by Berzelius† may be avoided.

ANALYSIS.

A portion of the mineral free from any foreign ingredient was reduced to a fine powder; this after being dried at the temperature of 212°, was of a verdegris green colour, and weighed 28.7 grains; by subjecting it to a low red heat in a platinum crucible it became olive green, more bulky, and lost 2.15 in weight, which was water driven off; it was not adviseable to let it remain long at that heat, for it is capable of being volatilized, which appeared by some condensing on the lid of a crucible. The whole was now dissolved in dilute nitric acid, and formed a clear blue solution; from this as much water and excess of acid was driven off as possible by

* Annales de Chimie, II. 159. † Ibid.

a long continued gentle heat. The whole was now very carefully neutralized with a weak solution of potash so as just to avoid the reprecipitation of the salt: nitrate of lead from fresh dissolved crystals was carefully added, avoiding excess, which was shewn by the clear liquor above the white precipitate undergoing no change from sulphate of soda nor hydriodic acid. The precipitate boiled, well washed and dried was after a red heat = 31.23 grains, equivalent to 6.246 of phosphoric acid.

A solution of caustic potash was added in excess and boiled upon the black precipitate formed; this when separated and dried at a heat below redness weighed 18.1 grains, and was Copper in the same state of oxidation as in the mineral*.

Hence,	Phosphoric acid...........	6.246
	Per-oxide of copper.......	18.1
	Water...................	2.15
		26.496
	Loss.....................	2.304
		28.8

Now this loss would appear considerable, if we do not take into account the impossibility of having driven off all the combined water, for reasons above stated. If we consider that loss to be water, the result will stand thus,

Phosphoric acid....	6.246	=	21.687	per cent.
Per-oxide of copper	18.1	=	62.847	
Water............	4.454	=	15.454	
	28.8		100.	

* The analysis was also accomplished in another manner, by adding hydrate of ammonia in such excess as to redissolve the precipitate at first formed. The phosphoric acid was then precipitated by cautiously adding nitrate of barytes, and after the liquor had been rendered acidulous by sulphuric acid, the copper was separated by a plate of iron. The method described in the text has, however, practical advantages.

Now it is fair, at least, to compare all theory with experimental results; if we consider the mineral as composed of 1 atom of phosphoric acid, 1 atom of per-oxide of copper, and 2 atoms of water, the quantities per cent. will stand as below; and by the side I have placed the experimental result for comparison.

	Theoretical Composition.	Experimental Result.
Phosphoric acid	22.222	21.687
Per-oxide copper	63.492	62.847
Water	14.285	15.454

It will be seen that the difference is in no case equal to unity except in the water*.

If we were to represent the constitution of this mineral by the symbols of Berzelius, which being derived from the Latin are more general than the English initials of Thomson, but adopting the opinion of the latter with regard to the constitution of phosphoric acid,

Its chemical sign would be $\ddot{\mathrm{C}}\mathrm{u}\ddot{\mathrm{P}} + 2\,\mathrm{Aq}$.

Its mineralogical ——— $CuP + 2Aq$.

There can be no doubt of Chenevix's artificial phosphate being a bi-phosphate, as stated by Thomson†; and it is rather singular that a neutral combination which has not hitherto been formed in the laboratory of the Chemist, should be the very substance formed by a natural process in the earth.

* Throughout these calculations I have made use of the atomic weights recently laid down by Thomson, because in some trials of verification I found them to accord best with experiment.

† Thomson's System of Chemistry, Vol. II. p. 607. 5th edit.

XIII. *Upon the regular* CRYSTALLIZATION *of Water, and upon the form of its primary Crystals; as they were naturally developed in Cambridge, January 3, 1821, and were seen during the two following days.*

BY EDWARD DANIEL CLARKE, LL.D.

LATE FELLOW AND TUTOR OF JESUS COLLEGE; PROFESSOR OF MINERALOGY IN THE UNIVERSITY OF CAMBRIDGE; LIBRARIAN OF THE UNIVERSITY; MEMBER OF THE ROYAL ACADEMY OF SCIENCES AT BERLIN; HONORARY MEMBER OF THE GEOLOGICAL SOCIETIES OF LONDON, EDINBURGH, CORNWALL, &c. &c.

[Read *March* 5, 1821.]

THE frost which took place towards the end of the last and beginning of the present year (1821), was particularly favourable for the exhibition of a phænomenon Naturalists have been often anxious to witness; namely, the perfect *Crystallization of Water*. This happened in Cambridge, under circumstances worthy of notice; because it exposed to view the primary form which *Hydrogen oxide* assumes in the solid state; and because it is a commonly received opinion, although erroneous, that to observe any appearance of this nature we must visit distant regions, liable to a much greater diminution of temperature than any part of the Island of Great Britain; such as might be found in Latitudes where *Water* is constantly maintained in the solid state.

That the compound of which *Water* consists, does obey the same laws to which the particles of all other *oxides,* and of all other bodies, are liable, when they pass from the fluid to the solid state, is no new discovery—it is even older than the researches of those Philosophers to whom the first dawnings of the Science of *Crystallography* have been usually ascribed. It must have attracted the regard of scientific men as long as the ramified congelations at the surface of glass windows, during the time of a frost, have been offered to their view: the remarkable circumstance of the arrangement of the spiculæ, intersecting each other under constant angles of 120° and 60° would surely not have escaped their observation; indeed, we can prove that it did not; for the same disposition of particles, being exhibited with a striking character of symmetry in Snow, (which sometimes falls in star-like forms, with six radii, bisecting the angles of a regular hexagon,) was noticed, before the Age of *Newton,* by *Descartes* who attempted to explain the phænomenon. *Mairan,* afterwards in his dissertation upon *Ice,* compared the appearance with that of the *Striæ* visible upon the surfaces of some of the crystallized *sulphurets of Iron;* and in connecting it with a result of the laws to which the structure of all Crystals is subjected by that force which disposes the particles of bodies, when in the vicinity of contact, to combine together under geometrical forms, *Mairan* was not far from the truth. The same subject early excited the attention of those celebrated French Chemists, who, towards the conclusion of the last Century, were engaged in publishing an account of their transactions. *Monge,* afterwards President of the National Institute of Paris, in the *Météréological Mémoire,* with which the fifth Volume of the "*Annales de Chimie*" commences, alludes to this beautiful effect of *crystallization* in *Snow;* and he gives the first satisfactory explanation of the phænomenon; illustrating what passes in the vast Laboratory of Nature, by reference to an easy experiment in the Laboratory of the Chemist*. Similar *Snow-crystals* exhibiting an hexagonal disposition of particles, have since been observed and carefully delineated. I have myself seen them in *Russia* and in *England*†; they descend when the atmosphere is calm, and its temperature a little lower than the point of congelation. It is in fact only at this degree of temperature that the regular *crystallization of Water* may be expected; that is to say, at the precise temperature, when the particles of which *Water* consists, not being interrupted by the too sudden agency of the Laws of aggregation, are at liberty to arrange themselves with the most perfect order and exact geometrical precision. If the diminution of the repelling principle be very considerable, this cannot happen; because the consequent encrease of the attractive force is such, that the particles rush together, without any harmonious configuration‡. But the phænomena to which allusion is now made, beautiful as they are, and bearing testimony of the homage paid by inanimate matter to the supreme cause of order in the universe, are but faint expressions compared with those which will presently be noticed: they exhibit, it is true, an incipient *crystallization;* but the full development of the process which ordains that even *Ice* shall put forth its *blossom*, remains for subsequent consideration. That the hexagonal disposition already observed in *Snow-crystals*, might induce an expectation of finding *water* in regular hexahedral Crystals, would have been a reasonable inference from such

* See "Memoire sur la Cause des principaux Phénomènes de la Météréologie," par Monge. *Annales de Chimie, Tome Cinquieme*, pp. 47, 48, 49. *Paris*, 1790.

† See the figure given of those Crystals, *Travels, Vol.* I. *p.* 11. *Camb.* 1810. See also *figs.* 1. 2. 3. representing *Snow-Crystals* which have since been observed near *Cambridge;* and of which an account appeared, at the time, in the *Cambridge Chronicle.*

‡ And this is, in fact, the reason why traces of regular crystallization are rarely discernible in *Meteoric Stones;* which have resulted from the sudden aggregation of particles of matter, in regions where the repelling principle is considerably diminished.

phænomena; and accordingly it happened, that the regular crystals were soon discovered. The first notice of such Crystals occurs in the manuscript Mineralogical Journal of *Monsieur Hericart De Thury,* of which an extract first appeared in the *Journal des Mines**. Another from the same source lately appeared in the *Edinburgh Philosophical Journal*†, describing a subterraneous Glaciere at *Fondeurle,* in the South of *France,* containing perfect *crystals of Ice* in the hexagonal form. The manner in which the regular *crystallization of Water* under a different form was recently exhibited in *Cambridge,* and of which, together with other members of the University, and inhabitants of the town, I was an eye-witness, may now be related.

Upon the third of *January,* at one o'clock in the afternoon, the Mercury in *Fahrenheit's* thermometer then standing only one degree below the freezing point, happening to pass over a bridge, which was fixed against a pair of flood-gates, I stopped to examine a beautiful appearance caused by the most brilliant Icicles I had ever seen, a number of which were hanging abundantly from the sides of the flood-gates and timbers below the bridge, surrounded by falling Water which was continually casting a spray over them. As those Icicles, owing to their dazzling lustre, did not resemble common Icicles, but seemed studded with spangling surfaces like the richest and most limpid cut glass, powerfully refracting and reflecting the rays of light; and instead of being shaped in lengthened cones, with even surfaces, were of a botryoïdal form, with angular points and protuberances, I caused some of them to be broken off, when it appeared that the light reflected from them was transmitted through planes bounded by right lines, and that the several botryoïdal masses were, in fact, so many bunches of Crystal, most of which were perfect rhombi; measuring in their

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* Vol. XXXIII. p. 157. † Vol. II. p. 80.

obtuse and acute angles 120° and 60°. As the temperature of the atmosphere was, at this time, liable to little alteration, I had frequent opportunities of returning to the spot, while the appearance continued, and of having a drawing made of it by an artist who accompanied me thither, and who afterwards at his leisure completed the design which is now exhibited to the Society. I also removed some of those crystalline masses and brought them home with me; where I exhibited them to several members of the University, and frequently, in their presence, measured the angles of the rhombic crystals with the Goniometer of *Carangeau;* the crystals being of such magnitude that they admitted of the perfect application of this instrument with as much accuracy as a rhomb of Iceland Spar. Many of them were more than an inch in length*. Upon the sixth of January a thaw took place; the Mercury in *Fahrenheit's* thermometer rising at twelve o'clock to 39°. Still the same inclination in the planes of the melting crystals, forming angles of 120° and 60°, was generally visible, although the forms of the rhombi were less perfect and the extreme points of the solid angles were rather rounded by the alteration the *Ice* was beginning to undergo†. It was evident, therefore, that a similar arrangement of particles pervaded the entire mass of each crystal; and that a power resisting the agency of the repelling principle preserved a degree of parallelism in the laminæ of the rhombi; the surfaces of superposition being thereby developed almost as perfectly as if they had been disclosed by a series of regular cleavages. Hence it was also evident that the rhomboid with angles of 120° and 60° exhibited the nucleus or *primitive* Crystal of *Hydrogen oxide* or *Water;* and that the hexahedral crystals observed at

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* See fig. 4. representing one of them of the size of the original.

† See fig. 5. shewing the outline of one of the stalactites after the thaw had commenced.

Fondeurle were *secondary* forms, resulting from the juxta-position of such rhombic particles; which also is rendered further manifest by observing the disposition of the spiculæ which diverge from the radii of the star-like crystals of Snow *, shewing the order of arrangement in the rhombic moleculæ from which the hexagonal crystal results.

It is presumed, therefore, that the question respecting the *Crystallization of Water*, may be set at rest by these phenomena; because it is now no longer a mere inference, deducible from observing the intersection and disposition of the spiculæ exhibited by Water when frozen upon the surfaces of other bodies, and in its approach to *Crystallization*, but it is a decided fact, shewn by regular crystals of *Ice*, that the compound we call *Water*, or *Hydrogen oxide*, crystallizes both in *hexahedral prisms* and in *rhombi*, having angles of 120° and 60°; and that the latter is its primary form. The manner too in which these forms have been displayed may guide to the crystalline forms of other bodies, by inducing a careful examination of the surfaces, points, and interstices of all minerals when they are found as *Stalactites*. The *Stalactite* formation is of all others the most likely formation to bear the marks of a regular *crystallization;* because it is the result of a process, in which the particles of bodies are not carried by a too sudden transition from the fluid to the solid state; but gradually approach, and become united, by virtue of their mutual attractions, as the moleculæ of the fluid which had separated them go off by evaporation, or by other causes †. And in further confirmation of this, it may be urged, that when the *Crystallization* of the *Stalactite Carbonate of Lime*, and of other *Stalactites*, especially

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* See figs. 2. 3.

† "On a donné à cette opération le nom de CRISTALLISATION." *Haüy, Traite Elémentaire de Physique, Tome* I. p. 57. *Paris*, 1806.

Fig. 1.

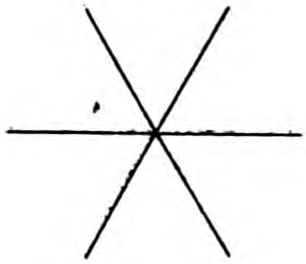


Fig. 2.

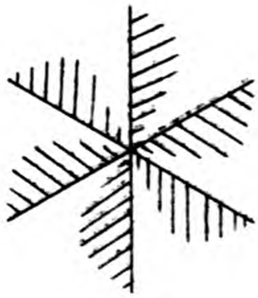


Fig. 3.

Fig. 4.

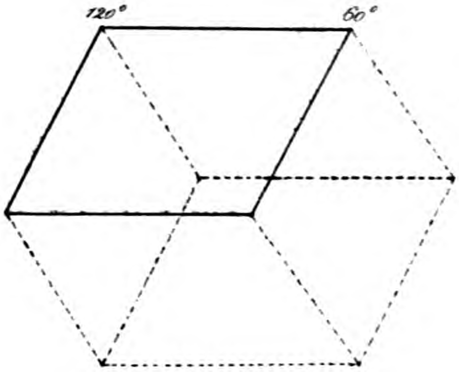
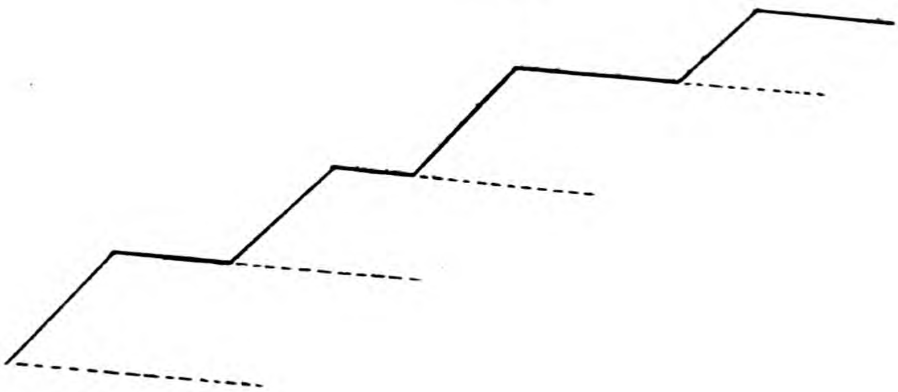


Fig. 5.



G. Scharf Lithog.

Crystallization of Water

Chalcedony, had been considered as impossible formations, contradictory to the laws by which Nature acts in the *Stalactite* process *, yet the primary form of the *Carbonate of Lime* is nevertheless exhibited by the *Stalactites* of the *Cavern of Antiparos*, and the primary form of the *Hydrates of Silica* by the *Stalactites* of *blue Chalcedony* brought from the *Hungarian* Mines.

E. D. CLARKE.

Cambridge,
Jan. 6, 1821.

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* " PIERRES QUARTZEUSES QUI NE CRISTALLISENT PAS. Il y a diverses pierres dans lesquelles la matière quartzeuse domine considérablement, et qui néanmoins *ne cristallisent jamais*, *&c*. Tels sont le *silex*, l' *agathe*, le *cachalon*, la *calcédoine* et ses varietes, l' *opale*," &c. *Patria, Hist. Nat. des Minéraux. Tome* II. *p*. 129. *Paris, An*. IX. The French author, however, seems afterwards aware that his mode of classification was liable to an exception in the instance of *Chalcedony*. " La *calcedoine* (*Ibid p*. 165.) en général ne cristallise pas, non plus que le *silex*, cependant il y a quelques morceaux où la cristallisation semble n'être pas equivoque."

XIV. *On the Application of Hydrogen Gas to produce a moving Power in Machinery; with a Description of an Engine which is moved by the Pressure of the Atmosphere upon a Vacuum caused by Explosions of Hydrogen Gas and Atmospheric Air.*

BY THE REV. W. CECIL, M. A.

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AND OF THE CAMBRIDGE PHILOSOPHICAL SOCIETY.

[Read *Nov.* 27, 1820.]

THERE is scarcely any uniform operation in the Arts which might not be performed with advantage by machinery, if convenient and economical methods could be found for setting such machinery in motion. The extensive application of machinery, therefore, depends much upon the number and various capabilities of the engines which can be employed to produce moving force. Even the most perfect engines at present employed for this purpose, are not capable of being applied universally; but each has a province peculiar to itself, beyond which the use of it cannot be extended with profit or convenience.

Two of the principal moving forces employed in the Arts are Water and Steam. Water has the singular advantage, that it can be made to act at any moment of time without preparation; but can be used only where it is naturally abundant. A steam-engine, on the contrary, may be constructed, at greater or less expense, in almost any place; but the convenience of it is much diminished by the tedious and laborious preparation which is necessary to bring it into action. A small steam-engine, not exceeding the power of one man, cannot be brought into action in less than half an hour: and a four-horse steam-engine cannot be used under two hours preparation.

These limitations exclude the use of water and steam, as moving forces, in all works which are much interrupted and discontinued at considerable intervals, and subject to a change of place.

The engine, in which hydrogen gas is employed to produce moving force, was intended to unite two principal advantages of water and steam; so as to be capable of acting in any place, without the delay and labour of preparation. It may be inferior, in some respects, to many engines at present employed; yet it will not be wholly useless, if, together with its own defects, it should be found to possess advantages also peculiar to itself.

The general principle of this engine is founded upon the property, which hydrogen gas mixed with atmospheric air possesses, of exploding upon ignition, so as to produce a large imperfect vacuum. If two and a half measures by bulk of atmospheric air be mixed with one measure of hydrogen, and a flame be applied, the mixed gas will expand into a space rather greater than three times its original bulk. The products of the explosion are, a globule of water, formed by the union of the hydrogen with the oxygen of the atmospheric air, and a quantity of azote, which, in its natural state, (or density 1), constituted .556 of the bulk of the mixed gas. The same quantity of azote is now expanded into a space somewhat greater than three times the original bulk of the mixed gas; that is, into about six times the space which it before occupied: its density therefore is about $\frac{1}{6}$th, that of the atmosphere being unity.

If the external air be prevented, by a proper apparatus, from returning into this imperfect vacuum, the pressure of the atmosphere may be employed as a moving force, nearly in the same manner as in the common steam-engine: the difference consists chiefly in the manner of forming the vacuum.

We will now estimate the power resulting from such a vacuum, by comparing the effects of equal bulks of steam and hydrogen.

Let the line AB (Fig. 1.) represent any space: this may be formed into a perfect vacuum, by filling it with steam, and condensing: in which case, the steam produces a vacuum nearly perfect, and equal to its own bulk. The same space may be formed into an imperfect vacuum, by exploding in it a mixture of hydrogen and atmospheric air: the bulk of the mixed gas being about one third of the vacuum required, and consequently the bulk of the hydrogen about one tenth. The effect of this imperfect vacuum may be represented, geometrically, by drawing a square $ABCD$ upon AB; taking AE, CF, each equal to one sixth of the side of the square;* and drawing a common hyperbola, through the points E, F, with asymptotes BA, BC. The ordinate GH varies inversely as the abscissa GB, and may therefore represent the density and elasticity of a given quantity of azote confined in the variable space GB; the elastic force of the atmosphere being represented by AD, the side of the square. Therefore HK will represent the excess of the atmospheric pressure above the elasticity of the azote; and the whole effect of the atmospheric pressure upon the imperfect vacuum will be represented by the external hyperbolic area, $EHFD$. And the effect of a perfect vacuum, over the same space AB, is represented by

* The bulk of the azote is .556 of the mixed gas; and the gas by the explosion expands to about 3.4 of the original space; hence the imperfect vacuum thus produced is about six times the space which the azote occupies when reduced to the elasticity of the atmosphere. That is, when the azote occupies a space BI, its elasticity is represented by IF.

the square *ABCD*. But the effects of equal bulks of steam and hydrogen, to produce moving force, are proportional to the fraction, whose numerator is the effect produced, and the denominator, the quantity employed in producing it. Hence the effect of a given bulk of steam, is to the effect of the same bulk of hydrogen, as the area of the square divided by unity, is to the external hyperbolic area divided by the fraction $\frac{1}{10}$; which ratio is as $3 : 5 \times \{5 - \text{hyp. log. } (6)\} :: 3 : 16$, nearly*.

Thus it appears by calculation, that any quantity of pure hydrogen gas will produce more than five times the effect of the

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* Let *BD* be the diameter of the square, which is also the axis of the hyperbola, *ML* perpendicular to *AB*, and therefore equal to *LB*;

$$\text{Then } GH \times GB = LM \times LB = LM^2.$$

$$\text{Let } GH = y, \quad GB = x, \quad LM = a,$$

$$\therefore y = \frac{a^2}{x}, \text{ and } y\dot{x} = \frac{a^2\dot{x}}{x},$$

$\therefore$ the fluent of $y\dot{x} = a^2$ hyp. log. $x \pm$ a constant quantity;

$\therefore$ area corresponding to ordinate $GH = a^2$ hyp. log. $x \pm$ a constant quantity;

——————————— $LM = a^2$ hyp. log. $a \pm$ a constant quantity;

$\therefore$ area between ordinates GH and $LM = a^2$ hyp. log. $x - a^2$ hyp. log. a

$$= a^2 \text{ hyp. log. } \frac{x}{a};$$

$$\therefore \text{area } AEML = a^2 \text{ hyp. log. } \frac{AB}{a}, \text{ but } AB \times \frac{AB}{6} = a^2;$$

$$\therefore \text{area } AEML = a^2 \text{ hyp. log. } \frac{a\sqrt{6}}{a} = \frac{a^2}{2} \text{ hyp. log. } 6;$$

$$\therefore \text{whole hyperbolic area} = a^2 + \frac{a^2}{2} \text{ hyp. log. } 6 + \frac{a^2}{2} \text{ hyp. log. } 6,$$

$$= a^2 . (1 + \text{hyp. log. } 6);$$

$$\therefore \text{external area } DEMF = AB^2 - a^2 (1 + \text{hyp. log. } 6) = 6a^2 - a^2 (1 + \text{hyp. log. } 6)$$

$$= a^2 . (5 - \text{hyp. log. } 6);$$

$$\therefore \text{whole square : external hyperbolic area } DEMF :: 6a^2 : a^2 (5 - \text{hyp log. } 6)$$

$$:: 6 : 5 - \text{hyp. log. } 6;$$

$$\therefore \text{the ratio required is } \frac{6}{1} : \frac{5 - \text{hyp. log. } 6}{\frac{1}{10}} :: 3 : 5 \ (5 - \text{hyp. log. } 6)$$

$$:: 3 : 16, \text{ nearly.}$$

same bulk of steam: and in practice the disproportion of their effects is still greater. It is here supposed, that steam produces by condensation a perfect vacuum equal to its own bulk; but this is far from being the case: much of the power is lost by needless condensation, by the escape of steam through the piston, besides a considerable deduction for working an air pump, and two water pumps, which are necessary to a steam-engine.*

It may be worth while to add in this place an experiment, calculated to obviate any objection arising from the apprehension of danger, as connected with the explosion. If a close cylinder, ten inches long, and two inches diameter, be made of thin tin, seamed up one side, and soft soldered, the ends being well secured, it will easily sustain, without bursting, the whole force of the exploding mixture. The internal pressure against the sides of the vessel, in this case, is about 180 pounds on the square inch; or twelve atmospheres nearly.† From this experiment an idea may be formed, how little strength is necessary for such parts of a gas-engine as are exposed to the pressure of the expanding fluid; a pressure which, as will hereafter appear, bears a very small proportion to the initial exploding force, which is twelve atmospheres.

* The loss of power, from friction, &c. in a condensing steam-engine, even when working with a double stroke, is estimated by practical mechanics at about one-third of the gross power.

† The greatest expansive force was ascertained by filling with mixed gas the cylinder just described, one end being entirely solid, the other being closed with a cork bung, accurately fitted, and confined by several strings, parallel to the axis of the cylinder, and so arranged that the tension might be equally distributed. It was observed how many strings the explosion was able to break, by pressing on a surface of three square inches. The same strings were then transferred to a common steelyard; and it was observed how much weight they would sustain. The results of several trials, differing but little from each other, indicated a pressure of five hundred pounds upon three square inches. If to this be added 45 pounds for the atmospheric pressure on the same surface, the whole being divided by three, gives 180 pounds nearly, for the pressure upon every square inch.

It is already stated, that if hydrogen gas and atmospheric air, mixed in the most explosive proportion, be ignited by an electric spark in a close vessel, the internal pressure upon the sides of the vessel is about twelve atmospheres. But if the mixture be allowed to expand into a space rather more than three times its original bulk, (suppose 3.4,) the initial force is reduced to one atmosphere, or fifteen pounds on the square inch: for the expansion is here at an end; that is, it just balances the elastic force of the atmosphere. This experiment agrees with the hypothesis, that the exploding force varies, during the expansion, inversely as the square of the space occupied by the expanding fluid, and not in the simple inverse ratio of that space;

$$\text{for } \sqrt{12} : \sqrt{1} :: 3.4 : 1, \text{ nearly.}$$

If this law be general, the initial force of any exploding mixture may be known, by observing its greatest expansion.

In large vessels containing hydrogen gas, there is little or no danger to be apprehended, from the unavoidable admixture of atmospheric air in small quantities. In mixtures of hydrogen gas and atmospheric air, if the hydrogen be in excess, the exploding force is very small; but if the atmospheric air be in excess, the exploding force is considerable. If the atmospheric air be only one fifth part of the whole, the explosion, if any, is not sensible; but if the hydrogen be one fifth of the mixture, it will explode with considerable force. The gas-engine about to be described, was found to work very freely when the hydrogen did not exceed one fifth of the mixed gas: but the greatest power was obtained, when the hydrogen was $\frac{2}{7}$ of the mixture. Yet, for the purpose of economy, or that a given quantity of hydrogen may produce a maximum of moving force, it is conjectured that a less proportion of hydrogen would be preferable.

A gas-engine admits of various constructions, but we shall explain at length that model only which is represented in Fig. 2:—

first describing the several parts of it, and then shewing how the motion is continued. The drawings are adapted to a peculiar kind of orthographic projection, digested by Professor Farish into an easy and convenient system of perspective, called the Isometrical Perspective, which is already before the Society. The representation of the central cube ABF', formed by joining the angular points of an equilateral and equiangular hexagon with the centre of the inscribed circle, will serve as a key to the proportion and direction of the other lines in the picture. The dotted lines represent such parts as are not visible, except on the supposition that all other parts are transparent.

ABF' (Fig. 2.) is a cube, having three cylinders, of equal capacity, attached to its sides at right angles. The vertical cylinder is separated from the narrow horizontal ones, by a moveable key or plug $abcd$ in the cube. This plug is hollow, and open at the bottom: it has also two large apertures opposite to each other, one inch wide, and an inch and a half deep; by which, upon turning the handle ef, it causes a free communication from the vertical cylinder $ABCD$, to each of the narrow horizontal cylinders FG, $F'G'$. In the lower part of this plug, and below the level of the large apertures just mentioned, are two small apertures, in the same horizontal plane, and situated eighty degrees apart from each other. One of these c, which is about one tenth of an inch diameter, corresponds with a similar hole c' in the face of the cube ABF', upon turning the handle ef to the left; and by continuing this motion to the left, the aperture c is again closed. If the position of the plug be reversed, by turning the handle ef to the right, as represented in the picture, the other aperture d, which is about half an inch diameter, will be brought to coincide with d', the mouth of the pipe no, which enters nearly at the bottom of the cube, on the side opposite to that which has the small hole c'. Near F is a small hole, one quarter of an inch diameter, which, by means of a trench excavated in the solid side of the plug, admits the atmospheric air freely into the narrow cylinder *FG*, and restores it to an equilibrium with the atmosphere, after the vacuum has performed its office. There is another hole *F′* on the opposite side of the cube, corresponding to *F*, by which the equilibrium is at the same time restored in the cylinder *F′G′*. Hence the plug *abcd* commands six apertures, three of which, namely, the mouth of the pipe *no*, and the two holes *F*, *F′*, all being small apertures, are opened at the instant when the lever *ef* is completing its motion to the *right*. The other three, namely, the two large apertures and the touch-hole *c*, are opened by turning the lever *ef* to the *left;* and of these the small touch-hole *c* is opened just at the *end* of this motion, and immediately shut again. Fig. 3. is a vertical section, at full size, of the cube *AAAA*, the plug *OOOO* in it, and a cap *BB*, which screws into the top of the cube. Through the cap *BB* is a cylindrical hole *DD*, to admit the axis which turns the plug; and in the small cube *CCCC* is a stuffing box and collar of leathers, by which the hole *DD* may be made air tight if required.

The vertical cylinder *ABCD* (Fig. 2.) is closed at the bottom by a cap *CD*, but not so as to exclude the external air: it has also a piston *ghk* connected with a parallel motion *LK*, *L′K′*, causing the piston rod to move in a vertical straight line, nearly.*

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* As this parallel motion is not exactly similar to any of those in common use, and produces a very near approximation to a rectilineal motion, a further explanation of it is here added.

Fig. 4. *A* and *C* are fixed centres, about which the levers *AB*, *CD* are moveable. *B* and *D* are moveable joints; also $\frac{AB}{CD} = \frac{DE}{BE}$. Then the locus of *E* is nearly rectilineal.

When *AB* is parallel to *CD*, *DBE* is at right angles to each of them; and is therefore a common tangent to the circles described by the points *B* and *D*. That the point *E* may continue in the same straight line *FG*, for every position of the point *B*, the deflection of the point

On the top of the piston is a solid conical frustrum, to occupy the hollow of the plug, when the piston is at the top of the cylinder. The horizontal frame *LHN* is connected with a crank on the axle *PQ*, by an upright rod *NO*, jointed at its extremities. A fly-wheel, three feet in diameter, and weighing half an hundred weight, is placed upon one extremity, *P*, of the axle *PQ*, and at the other extremity *Q*, is a crank or handle, situated about ten degrees in advance of the crank *O*, causing the rod *wx*, which slides through a fixed hole at *x*, to oscillate in a vertical plane, parallel to the axis of the cylinder *FG*. When the rod *wx* is vertical, it touches the point *s* of the horizontal lever *qs;* and its angular velocity is then the greatest; and the horizontal levers *qs*, *ef* are moved by it, through a considerable angle, with a motion nearly instantaneous, so as to reach their furthest point to the right, at the instant when the piston becomes stationary at the top of the cylinder. The rod *wx* having passed the shoulder *z*, slides along the bar *zv*, which is at that time parallel to the plane of the rod's motion; and upon its return strikes against the shoulder *y*, causing a rapid motion of the levers *qs*, *ef*, to the left; the motion, which is nearly instantaneous, being *completed* at the instant when the piston

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point *D* from the common tangent, must be greater than the deflection of the point *B*, in the proportion of $DE : BE$; but the deflections, for small arcs of the same length, in different circles, are inversely as the radii;

$\therefore$ rad. AB : rad. CD :: deflection at D : deflection at B :: $DE : BE$, or $\frac{AB}{CD} = \frac{DE}{BE}$.

The arcs described by the points *D* and *B* have the same lineal magnitude *ipso motus initio:* but if *D* describe a finite arc, it will be greater than the corresponding arc described by the point *B*; owing to the increasing obliquity of the line *DBE*. This will occasion the point *E* to continue in the straight line *FG* for a much longer space than might be expected from the preceding theory: and hence it appears, that the correctness of the parallel depends in some measure upon the ratio of *AB* to *DE*. The best proportion of *AB* to *DE* is that which makes the *chords* of the arcs *BB′*, *DD′*, to maintain most nearly a ratio of equality.

The straight line *AC* produced passes through the point *G*, and the curve is symmetrical on each side of the line *ACG*. The point *E* may in practice be made to trace out the whole double curve, by inverting the angle *D*.

becomes stationary at the bottom of the cylinder. After this the rod *wx* slides along the bar *yt*, which is now parallel to the plane of its motion. The angular motion of the plug *abcd* is about 90°.*

The apparatus situated upon the pipe *no*, for mixing the pure hydrogen with any required proportion of atmospheric air, comes next to be described.

UV, *WV*, are two small cylinders, closed at both ends, and separated from each other by a plate of metal between the flanges by which the cylinders are connected at *V*. In this partition is an air-tight metallic valve opening upwards, and moveable by a wire passing through a stuffing box at *U*, and connected with the lever *XY*, whose centre of motion is *X*. At *W* there is another valve, similar to the former, and opening upwards *spontaneously*, as often as there is any rarefaction of the air in the cylinder *VW*. That this valve may open more easily, its weight is partly taken off by a lever parallel to *XY*. This lever also prevents, by its inertia, a rapid saltatory motion of the valve, arising from its conical form, and which retards in some measure the descent of the piston. Into the upper cylinder enters a pipe *lm*, from a gazometer or reservoir containing pure hydrogen gas: and from the lower cylinder, a pipe *no* goes to the engine, and enters at the back of the cube *ABF′* exactly opposite to the small touch-hole *c′*. The lever *XY*, and with

* If the crank at Q were placed exactly parallel to the crank at O, or exactly opposite, that is, 180° in advance of it, the motion of the plug *abcd* would take place while the piston continued nearly stationary at the top and bottom of the cylinder, but it is here required that the motion of the plug may be *completed* at the instant when the piston arrives at its stationary points; for which reason, the crank at Q is placed a little further (about 10°) in *advance*. The crank at Q may also be placed about 170° before the crank at O. In this case the engine will move in the contrary direction; and this latter construction is to be preferred.

it the hydrogen valve at *V*, is elevated by the rod *wx* coming in contact with an obstacle on a fixed axle *RZ*, with which the lever *XY* is connected. This small apparatus, is represented on twice as large a scale as the rest of the engine.

At the end of each of the narrow cylinders *FG*, *F'G'*, is a valve opening outwards, which, for the sake of lightness, is a thin circular plate of brass or sheet copper, upon which is cemented a covering of soft leather, so as to be moderately air-tight when pressed against the end of the cylinder by a spiral spring at the back of the valve: The parts of this valve are seen detached in Fig. 5.

sv (Fig. 5.) is an immoveable brass cylinder, having upon it a spiral spring; *rst* is the valve, having a hollow cylinder *s'v'* attached to it, whose axis is at right angles to the plane of the circle, and passes through its centre.—This pipe *s'v'* is closed at the end *s'* and open at *v'*, so as to slide upon the fixed solid cylinder *sv*. Thus the centre of the valve is confined to move through a small space, ($\frac{1}{2}$ inch,) in a horizontal line, coinciding with the axis of the cylinder *FG*: and the valve may upon this construction be made extremely light, which is a matter of prime importance. The valve may be made still lighter by attaching the leather packing to the end of the cylinder instead of cementing it upon the valve. There is also at the back of the valve an annular cushion of Indian rubber, or some other soft and elastic material, to break the impetus, which otherwise would injure its form, which is a segment of a sphere, a little flattened at the edge.

At *G'* is represented a flap valve, such as is used in a common pair of bellows. This kind of valve is more simple; and may be as effective, if made light, and pressed close by an elastic cushion.

The engine is represented with the piston descending, and about the middle of its stroke. Let the fly wheel be turned round $\frac{3}{4}$ of a revolution, so as to bring the piston to the top of the cylinder. At this instant, the rod wx will sweep across with a rapid angular motion carrying the lever rqs, and the plug $abcd$ to the *right*, as in the picture. By this motion of the plug, the vertical cylinder *ABCD* will be separated from the horizontal cylinders *FG*, *F′G′*;—the small apertures *F*, *F′*, will be opened, admitting the atmospheric air freely into the horizontal cylinders; and the mouth of the pipe *no* will be opened to the inside of the cube, i. e. to the cylinder *ABCD*. The piston beginning to descend, by the continued motion of the fly wheel, the atmospheric air will rush in at the lower valve *W*, which opens spontaneously, and will occupy whatever portion of the cylinder *ABCD* is relinquished by the descent of the piston. When the piston has descended about $\frac{2}{7}$ths of its stroke, the hydrogen valve at *V* is opened, by the rod wx touching an obstacle *Z* on the fixed axis *RZ*. The lower valve *W* is closed by its own weight, and also by the superincumbent pressure of the hydrogen, which now flows freely into the cylinder *ABCD*; and the quantity admitted is determined by *the space through which the piston descends*, while the hydrogen valve continues open. The hydrogen valve will be closed by its own weight when it ceases to be supported by the rod wx; i. e. when the piston has descended $\frac{3}{7}$ths more of its stroke; the obstacle on the fixed axle *RZ* being properly adjusted. The atmospheric air will now again rush in at the lower valve *W*, till the piston comes within a quarter of an inch of its lowest point, at which time the rod wx strikes against the shoulder *y* of the lever qrs, causing a rapid motion of the plug $abcd$ to the left: by which, first, the pipe *no*, and the two apertures *F*, *F′*, all being small, are closed at the *beginning* of the motion; then the piston finishes its stroke by descending a quarter of an inch *during* the motion of the lever *ef*; and lastly, the touch-hole *c′* is opened and shut again at the *end* of the motion; and there will be a gentle absorption at this touch-hole, *the valves G, G′, being closed,* and the piston having descended a quarter of an inch, between the closing of the pipe *no* and the opening of the touch-hole *c′*. By this absorption the flame of a lamp or gas light constantly burning before the touch-hole *c′*, and supplied with pure hydrogen by a separate pipe from the gazometer, is drawn into the cylinder, and the mixed gas is ignited, and expands so as to occupy the whole content of the three cylinders, as far as *G* and *G′*, the common air in the cylinders *FG*, *F′G′*, being expelled at the valves.

Hence an imperfect vacuum, (density of the air $\frac{1}{6}$,) will be formed in all the three cylinders, and the piston will ascend from *C* to *A* by the pressure of the atmosphere. The plug is now moved to the right by the transition of the rod *w x*, and the piston descends by the momentum of the fly wheel acquired during the ascent, and is followed by a fresh portion of mixed gas drawn in from the pipe *no* as before.*

The principal supports of this engine are two horizontal boards, 8 inches wide, 2 inches thick, 30 inches long, and 15 inches asunder: The plane of the upper board coincides with the base of the cube *ABF″*, which rests upon its upper surface. The same plane supports the uprights belonging to the lever *qrs*; on the under side of the same board, are two cast-iron bearings for the

* The pressure upon the piston, at the beginning of its ascent, is $\frac{5}{6}$ths of an atmosphere; or 12,5 pounds on the square inch: when the piston reaches the top of the cylinder, the pressure upon it is $\frac{3}{4}$ of an atmosphere; or 11,25 pounds on the square inch: supposing the common air to be completely expelled from the cylinders *FG*, *F′G′*, and that the machine is perfectly air-tight. It is evident that a large portion of the vacuum produced by the explosion is turned to no account in working the engine; the residual vacuum, density of the air $\frac{1}{4}$, being destroyed by the admission of atmospheric air at the apertures *F*, *F′*. It is probable, however, that no advantage would arise from employing the residual vacuum, which in practice is very imperfect, unless it could be accomplished without increasing the range and friction of the piston; especially in an engine which works only by a single stroke.

axle *PQ*. The lower board supports the bearings of the fixed axles *LM* and *L'*: also the ring at the fixed point x: the two parallel boards are connected at the ends by two uprights of the same width and thickness.

An engine upon this principle is found in practice to work with considerable power, and with perfect regularity. The advantages of it are; that it may be kept, without expense, for any length of time in readiness for immediate action: that the engine, together with the means of working it, may easily be transferred from one place to another: that it may be worked in many places where a steam engine is inadmissible, from the smoke and other nuisances connected with it: a gas engine may be used in any place where a gas light may be burnt: in places which are already supplied with hydrogen for the purpose of illumination, the convenience of such an engine is sufficiently obvious: it may be added, that it requires no attention so long as it is freely supplied with hydrogen.

The supply of hydrogen is obtained, either from a large gazometer, which may be at any distance from the engine, or from a number of long copper cylinders filled with condensed hydrogen. In the latter case, the engine, with the apparatus for working it, will be transferable from one place to another. For pure hydrogen may perhaps be substituted carburetted hydrogen, coal gas, vapour of oil, turpentine, or any ardent spirit: but none of these have been tried; nor is it expected that any of them will be found so effective as pure hydrogen.

Before the hydrogen enters the engine it is received into a small gazometer, containing about two gallons, and placed at a distance of about twenty inches from the engine. The gazometer has three pipes, each furnished with a stop-cock. Through one of them, the hydrogen passes from the reservoir into the small gazometer, and is regulated by the stop-cock, which is connected with the moveable part of the gazometer, after the manner of a ball and stop-cock. The other two pipes are placed on the opposite side of the gazometer, parallel to each other, and about three inches asunder. One of them supplies the gas light, which burns before the touch-hole *c*; the other is a continuation of the hydrogen pipe *lm*, which enters the small cylinder *UV*. The two pipes must not communicate with each other, but each must enter the small gazometer by a separate aperture; otherwise the gas light will be extinguished by the absorption from the other pipe when open to the engine. The use of the small gazometer, is to supply these two pipes separately with pure hydrogen, under a moderate but uniform pressure.—A column of water three inches in altitude will occasion sufficient pressure for the supply of the gas light.*

The consumption of hydrogen gas may be thus estimated. In the model exhibited to the Society, the capacity of the working cylinder is about thirty cubic inches; which, at the rate of sixty revolutions in a minute, requires 1800 cubic inches of mixed gas, or 450 cubic inches of pure hydrogen; the hydrogen being taken at one fourth part of the mixed gas. This multiplied by 60, gives 15,6 cubic feet of hydrogen for the consumption in one hour: and to this must be added two more cubic feet, of pure or carburetted hydrogen, for the supply of the gas light during the same time, making altogether about 17,6 cubic feet in an hour.

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* In order to ascertain with accuracy the proportion of hydrogen and common air in the mixed gas, for a given arrangement of the valves *V* and *W*, this small gazometer was filled with air: then, the valve *W* being kept closed, and the hydrogen valve *V* being continually open, it was found that twelve revolutions of the fly wheel were sufficient to empty the gazometer. Next, the valves being restored to their natural order, the gazometer was emptied by forty-eight revolutions of the fly wheel. From this it appeared that the quantity of air drawn in from the atmosphere was three-fourths of the mixture, which therefore consisted of three parts of common air, and one of hydrogen. By repeating the experiment with a new arrangement of the valves, i. e. by a fresh adjustment of the obstacle on the axle *RZ*, the gases may be mixed in any required proportion; depending however in some measure upon the velocity of the engine.

The quantity of gas required for the supply of this gas light will not be increased by enlarging the scale of the engine: also the touch-hole will be of the same magnitude, (one tenth of an inch diameter,) whatever be the form or diameter of the engine. The thickness of the metal, through which the touch-hole is bored, should not exceed one quarter of an inch; and if more than this, the hole should be countersunk on the outside, till the metal is reduced to that thickness.

The touch-hole is opened only for a single instant, while the piston is stationary at the bottom of the cylinder: therefore the time, during which it continues open, may be diminished indefinitely by increasing the velocity of the engine. In this case the ignition cannot take place: the velocity of the engine will therefore be limited by a cause not connected with the friction of it: and if the velocity exceed a certain limit, the explosions will take place interruptedly; yet recurring in a certain order. But if the engine be retarded, so as not to exceed 60 revolutions in a minute, the explosions will take place with perfect regularity.

This circumstance supplies a ready method for ascertaining how much of the power of the engine is employed in overcoming the friction. If the explosions should be found to take place alternately, when the engine has acquired its greatest velocity, it will follow that the power, for that velocity, is double the friction: if every third explosion takes place, the power is three times the friction: if every third and every second alternately, the power is to the friction as 5 : 2.

The engine regulates itself by this method, but very imperfectly; for it occasions a waste of hydrogen, and implies too great a velocity. It regulates itself much more completely by another method, connected with the magnitude of the hydrogen pipe *lm*. When the bore of this pipe is diminished, which may be done at pleasure by a stop-cock, the hydrogen is retarded in it's progress from the gazometer; which will occasion a larger admission of common air at the lower valve *W*, which opens spontaneously. If the velocity be increased, the proportion of common air in the mixed gas will also be increased; and a less perfect vacuum will be formed, attended with a decrease of power. The *momentary* regulation of the engine is not produced by an alteration in the stop-cock, but by an increased absorption of common air at the valve *W*, which increases with the velocity of the engine, the stop-cock being unaltered.

If the scale of the engine be considerably enlarged, the admixture of the hydrogen and common air may be less perfect, though the proportion of them may be determined with even greater accuracy than before. Let then the hydrogen valve be elevated twice, instead of once, during the descent of the piston: the gases will be admitted in the following order; common air, hydrogen, common air, hydrogen, common air: this will secure a perfect mixture; but in all cases the common air should be let in *first;* so that the equilibrium may be restored in the horizontal cylinders *FG*, *F′G′*, before any hydrogen is admitted.

That the upright axle, by which the plug *abcd* is moved, may be able to adapt itself to the collar through which it passes at *e*, it must be connected with the plug loosely; yet so as not to admit of any relative angular motion in an horizontal plane. To this end the upright axle terminates in a solid cube at its lower extremity, which is imbedded in the *under* side of the solid metal, (three quarters of an inch thick,) which forms the top of the plug; and the whole is covered and made air-tight by a brass plate screwed, with two small screws, pointing upwards, against the under side of the same solid. See Fig. 3.

The wear and friction of the plug *abcd*, which is nearly cylindrical, are entirely removed, by elevating it about one-fortieth of an inch above its natural position; its whole weight being supported upon the small cube at *e*. It is nevertheless sufficiently air-tight, having its upper surface covered with water, which is supplied through an aperture in the top of the cube *ABF'*. As far as respects the communication of the three large cylinders, it is not at all necessary that the plug *a b c d* should be air-tight: it serves only as a *momentary* partition between two portions of air, each of which is in equilibrio with the atmosphere: but to prevent the influx of common air into the vacuum through the *smaller* apertures, the plug should be moderately air-tight.

A part of the water which covers the plug, thus elevated, is pressed through it by the weight of the atmosphere, and falls upon the piston, which carries it up again, and leaves it in the horizontal cylinders *FG*, *F'G'*, from whence it is expelled at the valves *G*, *G'*, with great velocity by the next explosion, and is received into a cistern placed below. Thus the packing of the piston and of the valves is secured from injury, and the engine is kept cool and clean in the inside. The piston may be packed with soft leather; nor will the packing be affected in the smallest degree by the explosion; for it is completely protected by a lamina of cold water, a quarter of an inch deep, which constantly covers the upper surface of the piston.

In every engine where there are packed pistons required to be air-tight, the friction arising from the motion of these pistons will cause a considerable diminution of the power: and where the pressure on the piston takes place only in one direction, as in the gas engine, the loss of power by friction is twice as great as where the engine works with a double stroke. In every such engine it becomes an object of importance to reduce the friction of the piston as much as possible: and this may be done very effectually by immersing the cylinder *ABCD*, which is partly open at bottom, in a cistern of water. In this case the piston will need scarcely any packing, and the friction will be inconsiderable. A small quantity of water will be forced through the piston by the pressure of the atmosphere upon the vacuum, and will be afterwards expelled at the valves *G*, *G'*, by the explosion. Where this improvement is adopted, it will be found convenient to invert the whole machine; making it to rest upon the four upper corners of the cube *ABF'*. A small cistern is also to be attached to the cap *CD*, and to be kept continually full of cold water.—The water is gradually forced into the engine by the pressure of the atmosphere, and is afterwards expelled at the valves *G*, *G'*. By this arrangement the friction is so much diminished, that the engine will continue in motion, though the hydrogen be so far diluted with common air as to be scarcely explosive.

Among the different constructions which may be adopted for a gas engine, there is one which, on account of its simplicity, should not be altogether omitted. It is represented in Fig. 6. *ABCD* is a long narrow vertical cylinder, divided into two parts at *abd*, so that the upper part *ABab* may be one third part of the whole cylinder. In the partition *abd* is a large circular hole, covered by a choke valve turning upon an axis *ab* which passes through a small stuffing-box at *a* on the side of the cylinder. At the point *e* in the axle *ba* produced, is an upright handle *ef* connected by a cross bar *fr* with the lever *qrs*, moveable about *q*.* In the upper division *ABab* of the cylinder is a piston *ghk*, connected by two upright rods *FH*, *GK*, jointed at their extremities, with the horizontal frame *NLH*, moveable about the fixed axle *LM*. The frame is connected, at the point *N*, with a crank on the axle *PQ*, which carries a fly wheel at *P*. Immediately above the partition *abd*, a pipe *no* enters the cylinder,

* This choke valve performs nearly the same office as the plug *abcd*, Fig. 2; and does not require to be *air-tight*, for the reason already stated.

from a vessel containing hydrogen gas, which is mixed with common air by an apparatus already described. Upon the pipe ***no*** is a stop-cock, which is opened upon the appulse of the piston to the partition ***abd***, and shut again upon its appulse to the top of the cylinder. At ***CD*** is a light valve ***RST*** described above, moderately air-tight, and opening downwards.

The piston, during its ascent, draws in from the pipe ***no*** a charge of mixed gas, which is exploded, on the appulse of the piston to the top of the cylinder, by the flame of a gas light, absorbed at the touch-hole *c*, which is opened for a single instant by the motion of a small sliding plate. The common air is expelled from the lower division ***abCD*** of the cylinder at the valve ***RST***; leaving an imperfect vacuum, density $\frac{1}{6}$, in the whole cylinder ***ABCD***. The piston descends from *A* to *a* by the pressure of the atmosphere, and is raised again by the momentum of the fly wheel, being followed in its ascent by a fresh portion of mixed gas, drawn in from the pipe ***no***. The upper division ***ABab***, is a cylinder of brass, accurately bored: the lower division ***abCD***, requires no accuracy of bore, and very little strength: it may therefore be made of sheet copper with a strong flange at the bottom, presenting a flat face to the valve ***RST***. The smaller contrivances necessary for perfecting this construction, may be learnt by comparing it with the former, which has been described at large: the principle is the same in both.

To remedy the noise which is occasioned by the explosion, the lower end of the cylinder ***ABCD*** may be buried in a well: or it may be inclosed in a large air-tight vessel. This vessel will be filled with condensed air, expelled together with a quantity of water from the cylinder ***abCD***. This condensed air may be made to co-operate with the vacuum in working the engine; and will occasion a considerable increase of power, without adding to the friction.

In the description of a gas engine, the power is shewn to arise from the pressure of the atmosphere upon an imperfect vacuum; and is therefore quite independent of the exploding force of the mixed gas. But an engine might be constructed to work by the exploding force only; or by the exploding force and the pressure of the atmosphere jointly. A small model of this kind was exhibited, about three years ago, at the Philosophical Lectures of Professor Farish. Not to enter into the construction of such engines, which would exceed these limits, it will be sufficient to add, in conclusion, a few remarks upon exploding forces in general, and the manner of applying them, with the least danger, to produce moving force.

It may be laid down as a principle, that any explosion may be safely opposed by an elastic force, (the force of condensed air for example,) if the elastic force opposed has little or no *inertia* connected with it. On the contrary, the smallest quantity of inertia, opposed to an exploding mixture *fully ignited*, is nearly equivalent to an immoveable obstacle. Thus a small quantity of gunpowder, or a mixture of oxygen and hydrogen may be safely ignited in a *large* close vessel filled with air; for the pressure of the exploding substance, against the sides of the vessel, can never be much greater than the elasticity of the air which it condenses.* Again, if a small quantity of earth, or a piece of paper, be inserted in the muzzle of a gun, charged with powder only, the gun will commonly burst upon being fired; for in this case the powder, after being fully ignited, comes to act upon a body at *rest*, having *inertia;* and such a body cannot be moved

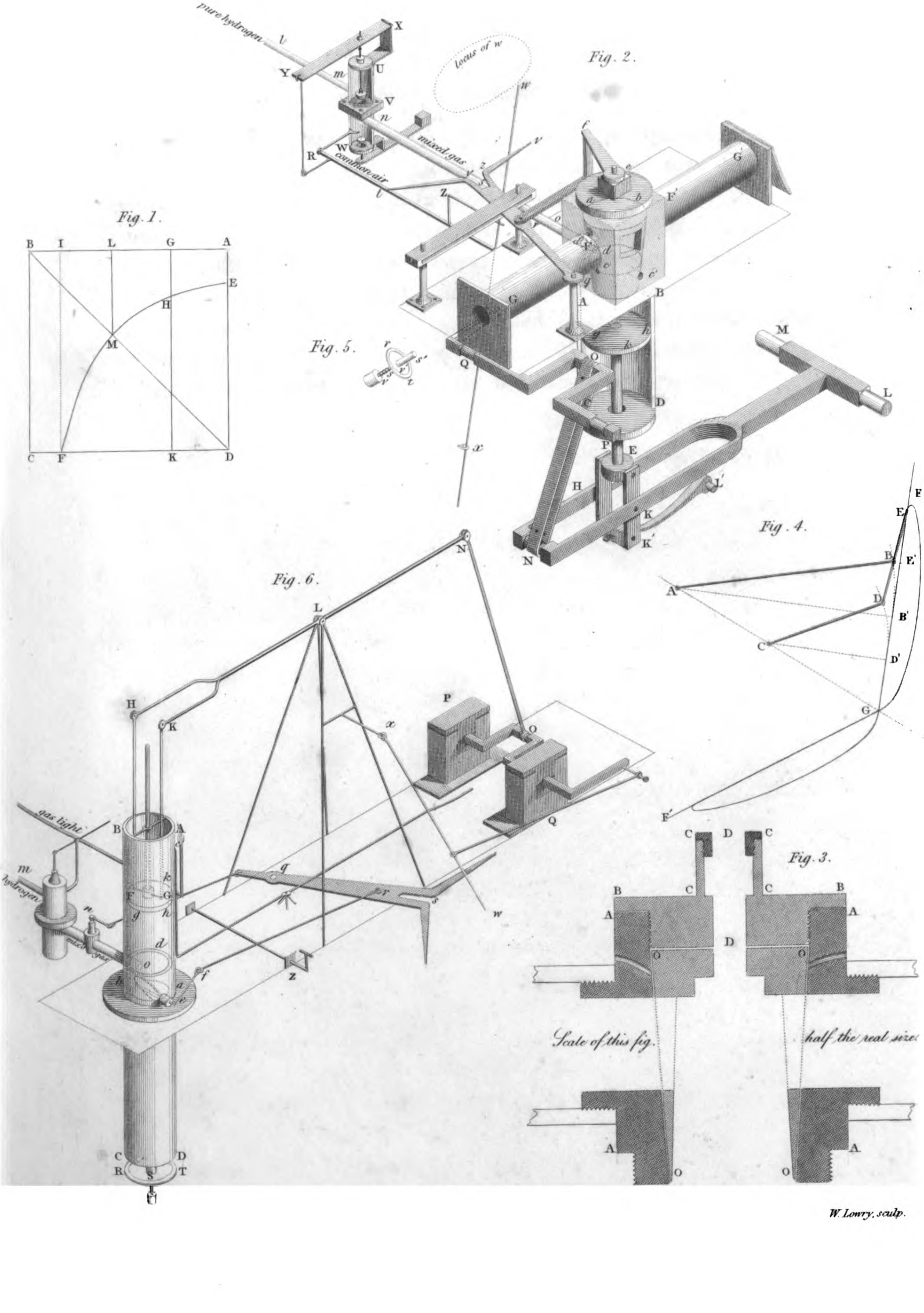
* By a large vessel, is meant one whose capacity is not less than the greatest expansion of the exploding mixture. The case here supposed is exactly what would take place in a gas engine, if the mixed gas were exploded, the apertures at G and G' being permanently closed.

out of the way, in an indefinitely small time, without a force indefinitely great; or it is equivalent to an immoveable obstacle.

Of all exploding mixtures, therefore, having the same field of expansion, those are the most dangerous, and the least adapted to produce moving force, which are ignited with the greatest rapidity. Thus a mixture of oxygen and hydrogen, of which the ignition is extremely rapid, is far less adapted for such purposes than a mixture of common air and hydrogen, which is ignited more slowly.

There is scarcely any exploding mixture which is ignited so slowly as gunpowder. This therefore, notwithstanding its great force and large field of expansion, is peculiarly adapted to produce either momentum or moving force; and, when opposed by a moderate quantity of inertia, is attended with less danger than some other mixtures, which explode with less force, but which are ignited with greater rapidity. But great care must be taken that the mass opposed be placed in close contact with the powder; so that the exploding force may begin to act upon it the instant the ignition commences, and that the action may cease before the ignition is completed. Thus in a common musket, if the ball be placed at a small interval, so that the powder may be fully ignited before it begins to move it, the ball in this case becomes an immoveable obstacle, and the gun will burst. It is here supposed, that the exploding mixture has itself no inertia; or that it is capable of following up the body upon which it acts, with a velocity incomparably greater than that body can acquire.

Upon these principles an engine was constructed which was moved by the exploding force of gunpowder. The gunpowder was employed to contract a very strong but light spring, by a regular series of explosions: and the elastic force of the spring in recovering its former position, formed the moving power of the engine. The danger to be apprehended from an explosion, thus



W. Lowry, sculp.

resisted, depends not upon the strength of the spring so much as upon the weight of it. An engine of this kind may be made to work with regularity for a short time; and the power of it, compared with its whole weight, is extremely great. It is not however proposed with any view to practical utility, being liable to great and obvious objections: particularly from the corrosion of the metals by the sulphur contained in the gunpowder, and by the sulphuric acid which is produced during combustion. It is here noticed merely to illustrate the foregoing principle.

W. CECIL.

Papworth Everard,
Oct. 25, 1820.

XV. *On a remarkable Peculiarity in the Law of the extraordinary Refraction of differently-coloured Rays exhibited by certain Varieties of Apophyllite.*

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[Read *May* 7, 1821.]

DOUBLY refracting crystals have hitherto been divided into two classes; the first comprising those in which the deviation of the extraordinary ray may be regarded as arising from a repulsive force emanating from one or more axes, as in carbonate of lime; and the other, from an attractive, as in zircon. Intermediate between these, and forming, as it were, the limit between both, are bodies devoid of the property of double refraction, as fluor, glass, &c. All these substances, however, act with different degrees of energy on the differently-coloured rays, according to a law which appears subject to great variations in different bodies, and which is directly deducible in any given body, from the series of tints developed by exposure to polarized light. In a former paper* I have instanced some remarkable deviations from the ordinary law of tints exhibited by certain varieties of the apophyllite, but from the mode of experimenting there followed, the most remarkable of the peculiarities

* Transactions of the Philosophical Society of Cambridge, Vol. I. Part I. 1820.

presented by the specimens employed escaped my notice. It is this, that out of the three varieties examined, two appear to belong at once to all the three classes of Media above enumerated; possessing the property of attractive crystals when exposed to the rays forming one extreme of the spectrum, and of repulsive in their action on the other extreme, while for certain intermediate rays, they are altogether void of the property of double refraction, and allow such rays to pass freely through them *in all directions* without dividing them into two pencils.

I was led to a knowledge of this remarkable singularity, by the consideration of the forms of the curves traced in Figs. 14 and 17. (See Plate in Part I. of this Vol.) whose ordinates represent the polarizing energies of the two varieties in question, on the rays whose place in the spectrum is denoted by their abscissæ. It is assumed, without any particular grounds, in my former paper, that these curves lie, throughout their whole extent, on one side of their abscissæ. This was natural enough, being accustomed to regard crystals as necessarily included in one or the other of the great divisions above referred to, and in the mode of experimenting there resorted to, the contrary could not be discerned, the change from attractive to repulsive being marked by no phænomenon. In considering the subject more carefully, however, it struck me that, as the curves in question had been traced to the immediate vicinity of the axis, and when lost sight of were then approaching it more rapidly than in any other part of their course; it was highly probable that they would meet it in that part of the spectrum out of the reach of observation, and if so, must cut it, and the portions corresponding to the two extremities of the spectrum, would thus lie on opposite sides, the absolute lengths of the ordinates given by experiment remaining unaltered.

To put this idea to the test was a matter of considerable delicacy, as well from the imperfections of the specimen, as from its feeble polarizing energy, and the great difference of its action on the different colours. In ordinary cases to determine whether a crystal be attractive or repulsive, nothing more is required than to place a plate of it between crossed tourmalines, so as to view the polarized rings, and then, crossing it with a plate of mica or sulphate of lime, having its principal section 45° inclined to the plane of primitive polarization, to notice in which quadrants of the rings the tints are raised, and in which depressed. If the plate of the substance examined be then removed (without altering the position of the mica plate), and replaced by a plate of carbonate of lime, tourmaline, or any other known substance (which it is convenient to keep as a standard of comparison) it is immediately seen whether the crystal in question be of the same, or an opposite character with the standard; the *corresponding* quadrants of the rings seen in the two substances, being similarly affected in the one case, and the *alternate* ones in the other. So coarse a method proved, as might be expected, unavailing in the present instance, the order of the tints being so completely altered by a plate of mica of moderate thickness, as to be no longer recognized, and I was obliged to have recourse to measures taken in homogeneous light, and on a divided apparatus. The method I pursued was as follows:—Having enclosed the crystallized plate of the second variety described in my former paper, in castor oil, in a proper apparatus for varying its inclination to the polarized beam, and adjusted it so as to revolve in a plane 45° inclined to that of primitive polarization, I noticed the inclinations at which the first minimum of the ordinary pencil on one side of the axis took place. These were as follows:

	Extreme Red.		Violet.	
	19°	16′	25°	55′
	19	48	25	27
	19	5	25	39
	19	48	25	34
	19	5	26	31
	20	10	25	46
	19	5	25	55
	19	5	25	27
	19	5	26	54 .. near the Indigo.
			25	16 .. extreme Violet.
Mean	19°	28′		
			25°	51′

The variations in the observations of the violet rays arise not so much from the imperfections of the specimen, and the difficulty of taking measures in violet light, as from the rapid change of the polarizing energy, as the ray approaches the extremity of the spectrum, and the mean result above set down is, in consequence, that corresponding nearly to the mean violet rays. I now interposed between the crystal and the reflector on which the incident light received its polarization, a plate of mica, so thin as to polarize (alone) a blueish white of the first order; its plane being perpendicular to the ray. My object in using so thin a plate was to dilate or contract the system of rings, by a quantity decidedly smaller than half the interval between two contiguous ones, so as to avoid all possibility of a mistake, in the *order* of the ring brought under examination, by the interposition of the mica plate; the point in question, being not to obtain any precise numerical results, but merely to ascertain whether the change of the inclination corresponding to the minimum or maximum of any given ring, produced by a mica plate of infinitesimal thickness, would have the same or opposite signs for the two ends of the spectrum.

The mica being fixed so as to have its principal section 45° inclined to the plane of primitive polarization (or in azimuth 45°), the minima of the ordinary pencil were now observed to take place at the following inclinations:

	Extreme Red.		Violet.		
	15°	50′	29°	59′	
	18	22	29	10	
	17	38	30	58	
	17	17	32	2	
	16	55	30	14	
			29	53..	Extreme Violet.
Mean	17°	17′	31	41	
			33	29..	Violet bordering on Indigo.
			30°	55′	

The inclination was therefore diminished for the red rays, and increased for the violet—in other words, the interposition of the mica had contracted the red rings in a direction parallel or perpendicular to its principal section, but dilated the violet.

I now (to confirm this indication) turned round the mica plate one quadrant in its own plane, so as to reverse its action on the polarized beam, and then, repeating the measures, found as follows:

Extreme Red.		Violet.	
20°	53′	22°	41′
20	10	24	29
21	14	21	36
21	15	20	31
21	14	21	58
20°	57′	22°	15′

The effect on the measures, as we see, corresponds to the change of circumstances, the red rings being now expanded and the violet contracted, by the action of the mica in the direction in which they were observed. To assure myself still more completely of the identity of the ring examined, I detached the mica, and observed the first evanescence of the *extraordinary* pencil in the extreme red rays, which took place at an inclination of 27° 11′. The whole interval then from the maximum to the minimum of the first red ring embraces an extent of 27° 11′ − 19° 28′ = 7° 43′, while the displacement of the minimum by the mica did not exceed 2° 11′ in one direction, and 1° 29′ in the other. On the other hand, computing the first evanescence of the extraordinary pencil in violet light, from the formula*

$$n\,l = t\,.\,\sin\theta\,.\,\tan\theta$$

which gives $\sin\theta = \left(\sqrt{2\,p\sqrt{1+p^2} - p}\right)$, where $p = \frac{n\,l}{2\,t}$,

we find that it will take place at 38° 12′ of inclination, and the variations produced by the mica in the place of the ordinary minimum being + 5° 4′ and − 3° 36′, are decidedly less than the interval between the maximum and minimum of the first ring which is 38° 12′ − 26° 19′ = 11° 53′.

However to leave no doubt on this head, I interposed an extremely thin plate of mica, which polarized but a feeble blue of the first order, and placing its principal section successively at azimuths 45° and 45° + 90° = 135°, repeated the measures of the inclination at which the first minimum took place, taking in each case, the mean of ten observations to compensate the various irregularities it was found impossible to avoid. I thus obtained the following results:

	Azimuth = 45°		Azimuth = 135°	
Inclination at Minimum of extreme Red .	18°	39′	19°	55′
Ditto Violet	26	15	24	35

* n = the number of periods and parts of a period performed by the polarized ray within the plate.

l = the length of each period. t = the thickness of the plate.

θ = the inclination of the ray to the axis.

The feeble double refraction, joined to the imperfection of the specimen, and the impracticability of cutting it into a prism, with its refracting edge parallel to the axis, (owing to the facility with which the laminæ separate from each other,) have prevented my verifying these results by actual observations on the double refraction. There can be no doubt, however, what would be the result. The spectra formed by the two refractions would appear superimposed on each other, but of different lengths, the indigo spaces of each coinciding. They would consequently appear as one spectrum of diluted colours, and unless examined in homogeneous light, the double refraction would not be noticed at all.

There can be little doubt too that the third variety of apophyllite described in my paper, would exhibit similar phænomena, but I have not thought it necessary to make any experiments on it, the fact which it is the object of this paper to point out, being, I hope, sufficiently proved without it.

J. F. W. HERSCHEL.

Slough, March 31, 1821.

The reader of Part I. of this Volume of Transactions is requested to correct the following *Errata* in my Communications on Polarization.

Page 23,	*line* 5,	*for* their *read* thin.
— 25,	— 1,	*for* their *read* thin.
— *ib.*	— 5	*from bottom, for* any *read* my.
— 26,	— 4	*from bottom, for* their *read* the.
— 51,	— 1	*for* by *read* of.

XVI. *Notice of the Astronomical Tables of Mohammed Abibeker Al Farsi, two copies of which are preserved in the Public Library of the University of Cambridge.*

By SAMUEL LEE, M.A.

OF QUEEN'S COLLEGE;

PROFESSOR OF ARABIC IN THE UNIVERSITY; AND SECRETARY TO THE CAMBRIDGE PHILOSOPHICAL SOCIETY.

[Read *Nov.* 13, 1820.]

In making the following communication to the Cambridge Philosophical Society, I have not so much hope of contributing any thing to the stock of science which is already possessed on the subject in question, as of adding something to the history of its progress, and of bringing before the public the names of some men, who appear to have laboured with success in its furtherance: and, until Mr. Sedillot, as announced by Delambre*

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* Astronomie du Moyen Age, p. 166. "M. Sedillot se propose de donner des notices plus completes de l'Almageste d'Aboul Wefa, du Manuscrit d'Ebn Schathir, de celui de Leyde, et de tous ceux qu'il pourra se procurer."

It may be proper here to point out a very enormous mistake, which it is probable M. Delambre has copied either from Weidler or Montucla. In recounting the Arabic MSS. found in the Library of Merton College, Oxford, he says, 'Mais, pour prouver avec quelle ardour les Arabes s'adonnaient a l'Astronomie, il ajoute, que dans le seul Bibliotheque Mertonienne shall favor the public with his more complete work on the Astronomy of the Arabians, notices, like the present, of such works as are to be found in our Public Libraries, may not be unacceptable. In presenting therefore to the Society a notice of a very scarce and valuable work on Arabian Astronomy, I trust I shall do no more than what some of the most eminent writers on Astronomy have often called for: and, in so doing, it is my intention to avoid prolixity, and to give such details from the Preface of the work in question, and such extracts from the work itself, as may be interesting and useful.

The only notice of the work, here alluded to, is, as far as my researches have gone, to be found in the Bibliotheque Orientale of D'Herbelot, which, from the manner in which it is given, is sufficient to shew that the writer had never seen the work in question. The notice is this, "Zig' Mohammed Ben Abibekr Al-Farsi. Tables Astronomiques composées par Mohammed, &c. pour le Sultan Al-Malik Al-Modhaffer Abou Mansour Joussouf Ben Omar, Seigneur de l'Jemen ou Arabie heureuse.

Cet Auteur dit qu'il a suivi dans son Ouvrage les observations du grand Astronome *Ferideddin Aboul Hassan Ali Ben*

Mertonienne d'Oxford, on conservait plus de *quatre cents* Manuscrits Arabes, tout remplies des doctrines et d'Observations Astronomiques.' Montucla, in his Histoire des Mathemat. Liv. I. Part ii, says, Il nous apprend (i. e. Edovard Bernard) que la seule Bibliotheque de Oxford possède plus de 400 manuscrits Arabes sur l'Astronomie. And, for proof of this, he refers the reader to the Philosophical Transactions for 1694, where not so much as one word is found on this subject. The only work there mentioned, as being connected with Edward Bernard, is a notice of the Catalogus Codd. Manuscriptorum Angliæ et Hiberniæ. I suppose, however, the passage referred to is, Tom. I. Philosophical Transactions, p. 334, which has been cited by Asseman, p. 47, in his account of the Globus Cœlestis Cufico-Arabicus, where, writing to Huntington, Bernard says, "Inter Codices tuos Arabicos in *Musæo Mertonensi* (numeras autem plus quadraginta doctrinæ, et observationis sideralis refertos." The *quadraginta* here mentioned has perhaps been mistaken for *quadringenti*, a mistake certainly of no common magnitude.

*Abdalkerim Al-Schirvani,** dit *Al-Rassed:* l'Observateur. Il cite encore plusieurs autres Tables Astronomiques, dont voici les titres. *Zig' Al-Mosthi, Zig' Al-Moâdel, Zig' Almohakkem, Zig' Al-Zahir, Zig' Al-Mostanfi, et Zig' Al-Olaï Al-Rassadi,* qu'il dit être le dernier de ceux qui ont observé par eux-mêmes, ce qu'il faut entendre jusqu'en l'année 541. de l'Hég. auquel temps cet Auteur a écrit."

This account by D'Herbelot is erroneous in several particulars: for first, instead of the Zig' Al Mosthi, as given by him, the MS. has Zig' Al Moghni. And again, instead of the Zig' Almostanfi, the MS. has Zig' Almostawfi. And, in the third place, instead of An. 541 of the Hegira, according to D'Herbelot, the MS. has An. 541 of the Æra of Yezdigird: from all of which, it is, perhaps, but fair to conclude, that D'Herbelot had never seen the work of Al Farsi.

It is curious enough that excepting this very imperfect notice by D'Herbelot, the work of Al Farsi seems to have been totally unknown in Europe; and, although Astronomical Tables have been composed in Europe upon the Arabian models, yet it is most likely that these were taken from originals, which Al Farsi has shewn to be incorrect; and on which account, he had been compelled to have recourse to observations made long after those of Albategnius, upon which these tables had mostly been constructed.

* Soyuti in his Dictionary of Patronymics, which is preserved in the Public Library in the collection of Mr. Burkhardt, says, الشَّرْوَانِي بالفتح والسكون للراء الي شروان مدينة, &c. That is, Sharwáni, with the vowel *a* before *r*, which itself has no vowel, refers to the city Sharwán. In the MS. above alluded to, the vowel *u* is placed before *r*. And D'Herbelot, as well as the Editor of the Kamoos, places *i* before *r*, so that the word is written, Sharwáni, Shurwáni, and Shirwáni. I prefer the first on the authority of Soyuti, and the Author of the Geographical Dictionary entitled معجم ما استعجم, who writes it in the same way.

Montucla, again, in his History of the Mathematics, notwithstanding his having cited several of the Tables, or Ziges, as given by D'Herbelot, has omitted to mention those of Al Farsi, although he might have seen in D'Herbelot, that they were constructed upon an entirely new set of observations.

It is not, however, my intention here to enter into the merits of the Tables in question:—to attempt to shew in what way they are preferable to those that went before them:—or to institute any thing like a comparison with the Tables of modern times. I shall leave these questions to be decided by those who have more leisure and skill for these pursuits, contenting myself with merely bringing to light the work in question.

It is a remarkable fact that two editions of this very scarce work have lain in the Public Library of this University upwards of 160 years: one of which is the work of Al Farsi, the other an abridged edition by some unknown hand; and undertaken, as the epitomator observes in his preface, for the purpose of facilitating the use of the Tables, by reducing them to the æra of the Hegira, the original work having been calculated according to the Persian æra of Yezdigird.*

I shall have no necessity to appeal to the abridged edition of the work in question, as the other MS. is in very good

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* The title of Al Farsi's work is, كتاب الزيج الممتحن المعروف بالمظفري رصد الحكيم الفاضل الكامل عطارد الارض جاسوس الفلك ابي الحسن علي بن عبد الكريم الشُروانى الراصد المعروف بالفهاد رحمه الله تعالي وتاليف الفقيه اللوذعي المنوّر خاصه السلطان الملك المظفر بدر الدين محمد ابي بكر الفارسي رحمه الله تعالي. The book of the approved Tables, known by the

preservation, and very accurately written; with this exception, that the diacritical points are very generally omitted, which makes the work of decyphering considerable, and the orthography of some of the proper names irrecoverable. As mention however is made of the original compiler of the tables in the preface to this second edition, I shall take the liberty to transcribe it.* "The most elegant work," says this editor, "that has been published on this subject, (namely, Astronomy) according to the longitude of Yemen, is that of the learned and excellent Mohammed Abibeker Al Fársi, which he published for the Treasury of the Sultán Al Malik Al Modhaffer, and entitled 'Al Zig Al Mumtahan Al Khazáyini." i. e. The approved Treasury Tables. And again, speaking of the mean motion of Mercury, and condemning the practice of some who had gone before him, he mentions another work of Al Fársi in the following terms.† "He

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the title Al Modafferi, from the observations of the learned and excellent, &c. Abi Al Hassan Ali Ibn Abd Al Karím Al Shurwáni, the observer, (better) known by Al Fahhád, &c. Published by the eloquent and enlightened Doctor, for the Sultan Al Malik Al Modaffer, Badar Al Din Mohammed Abibeker Al Fársi. The MS. is in large quarto containing about 250 pages, and has the class marks G G. 3. 27. It is said, in a note, to have been bought in Mocha, A. D. 1639, for 200 Ryalls of Eight; and, that it was placed in the Library A. D. 1658, by the Executors of Wm. Bretton, B. D. formerly Fellow of Emmanuel College, and afterwards Rector of Clapton in Northamptonshire.

* وان ابلغ ما صنف في ذلك لطول اليمن كتاب الحكيم الفاضل الكامل محمد ابي بكر الفارسي الذي صنفه لخزانة السلطان الملك المظفر وسماه بالزيج الممتحن الخزائني.

† ومن اراد الوقوف علي حقيقة ذلك فليطالع الكتاب الذي الفه الحكيم محمد ابي بكر الفارسي المسمّي معارج الفكر الوهيج في حل مشكلات الزيج.

who wishes to know the truth of what has been said, may consult the work published by the learned Mohammed Abibeker Al Fársi, entitled, "A step for the ardent mind towards solving the difficulties of the Astronomical Tables:" I cite these particulars merely for the purpose of shewing in what repute our Author was held by his learned countrymen; and to preserve the title of one of his works.

I now proceed to the preface of the work itself, which I shall give as faithfully as possible, from the words of the Author; and then the contents of each chapter of the book; and after that, a few extracts from the Tables.

After a religious preamble in praise of God, and the Prophet, which I shall omit, the Author thus proceeds, "The humble Mohammed Abibeker Al Fársi, relying on the favor of the Almighty, affirms, that the most elevating and ennobling pursuit that can occupy the attention of man, is that of Astronomy and the wonders which it possesses: and since, (adds he), it has been my good fortune to have held an office in the service of our Lord and King, the illustrious and excellent Al Modhaffer Al Mansúri, Al Malik Al Modhaffer,* &c.—Yúsuf Ibn Omar Khalíl, Commander of the faithful,* &c.—And since his favors have been continually and plentifully heaped upon me, it became my wish to publish a set of Astronomical Tables, for the Royal Treasury, unlike any that had gone before, and which should remain unimpaired to the end of time. I therefore took, as the most to be depended upon, the mean motions of the Sun, Moon, and Planets, as given from the observations of the learned and excellent Philosopher Feríd Eddin, &c. Abi Al Hassan Ali Ibn Abd Al

* The parts here omitted consist of the mere repetition of terms of respect, which are altogether uninteresting to an European reader.

Karím Al Sharwâni, the Observer, known by the title *Al *Fahhád*, one of the most celebrated and correct of the learned moderns, and who published several Astronomical Tables, of which the following are the titles: viz. 1. *Al Moghni*, 2. *Al Mohakkam*, 3. *Al Záhir*, 4. *Al Mostawfi*, 5. *Al Moâddal*, and 6. *Al Olăi Al Rassadi*, which is the last published by him from observations. I took this last, on several accounts, because, for instance, the accuracy of the calculations, and the demonstrations on which they were founded, were superior to any that had gone before; and because it was compiled at a time much nearer that in which the observations had been made, than any other. The date of these observations is that of †541 of the æra of Yezdigird. It has been related that Al Sharwâni continued to make and correct his observations on the mean motions of the Planets, through a space of not less than 30 years, which he did by instruments, either made by his own hands, or procured from distant places for that purpose. The instruments alluded to are, the Armilla, which is used for the purpose of ascertaining the longitude and latitude of the Planets. ‡The Dhât Al Shuabatein, with which the (Zenith) distances of the Planets, and their diameters are observed:—and the quadrant, used to ascertain the Sun's declination, which was divided into 5400 minutes, equalling the minutes contained in a

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* Pardum (domans B. in Av.) instituens ad venationem. Castell. Lex. Hept.

† See the above mentioned notice by D'Herbelot.

‡ There is no mention made of this word in any of the Dictionaries or Vocabularies, which are all extremely defective in terms used in the Sciences: the words are ذات الشعبتين i. e. *having two branches:* the etymology of the word, and the description of the uses of this instrument, which is given in the text, clearly shew that it was a species of the instrument invented by Ptolemy for the determination of the Moon's parallax, and which was used by Albategnius in the determination of the obliquity of the ecliptic: it was known to Copernicus and the Astronomers of his age under the name of *Regulæ Parallacticæ*, and was first abandoned by Tycho Brahè.

quadrant of the heavens, used for the purpose of correcting the observations.

Nor did Al Sharwáni depend on the observations of those who had gone before him, seeing as he did the great error and confusion that prevailed among them; and which attached itself, not more to the observations made by Hipparchus and Archimedes, before the time of Ptolemy, than it did to those made by them and Ptolemy himself. The same is true with respect to the observations of Ptolemy and those of the moderns, who followed the Tables called *Almumtáhan, (approved). Now, between the times in which the observations of Hipparchus and Ptolemy were made, there intervened a space of about 260 years; and between the times of the Observations of Ptolemy, and those of the moderns made in the time of Mámoon a space of about 700 solar years. And in the same manner did those who followed the approved Tables disagree, so that one seemed to oppose the other.

Of these Authors were the following: namely, Thábet Ibn Korra: Ahmed Ibn Mohammed Al Nahawéndi the Arithmetician: Isaac Ibn Honein: Hámid Ibn Ali Al Wásiti: †Abu Moasher Al Balkhi: Mohammed Ibn Jábir Ibn Senán Al Batáni (Albategnius): Send Ibn Ali: Khálid Ibn Abd Al Malik Al Marúrúdhi: Ali Ibn Isá Al Astralábi: Abás Ibn Saíd Al Jauhari: Ahmed Ibn Abd Allah the Arithmetician: Ali Ibn Isaac Ibn Kíshoor: Moosa Ibn Shákir, and his three Sons, Mohammed, Ahmed, and Al Hassan: Sáhal Ibn Bashar Al Maháni: Al Kásim Ibn Abd Allah: Ahmed Ibn Abd Allah Habash: Abu Kásim Ali Ibn Al Hosein Ibn Isá Al Sharíf Al Hoseini, known

* By some termed the Tabulæ Probatæ; and by Mr. Caussin, Table vérifiée. Notices et Extr. Biblioth. du Roi. Vol. VII. p. 96. notes.

† There is a work on Astrology with Astronomical tables by this Author in the University Library marked GG. 3. 19.

generally by Ibn Aálam: Al Fadl Ibn Hátim Al *Naïrizi: Mohammed Ibn Ahmed Yúsuf Al Samarkandi: Abu Al Hassan Ali Ibn Amájur Al Turki: Yahya Ibn Abi Mansúr: †Ali Ibn Abd Al Rahmán Ibn Ahmed Ibn Younis: and Abu Al Hassan. The observations of all of whom differed from one another; and each of whom published a set of Tables from such materials as he had before him, and which he considered as sufficiently accurate.‡

§ It is related by Ali Ibn Abd Al Rahmán Ibn Ahmed Ibn Younis, as told him by Send Ibn Ali, respecting Ibn Yahya Ibn Abi Mansúr: namely, that Ibn Yahya's observations could not be correct, nor have arrived to that degree of accuracy that could be wished, as he had seen the Armilla with which they had been made, sold, some time after his death, in the street of the Paper-makers in Bagdad; and that it was divided into parts of 10 minutes each: This, says the Author, is a proof that his observations with this instrument were not perfect, on account of its being divided into parts which were sixths of a degree: but if its divisions had been of one minute each, they would have been perfectly correct.

It is related by the learned and excellent Abu Al Hassan Ali Ibn Abd Al Karím Al Sharwáni the Observer, above mentioned, that he found the mean motions of the Sun and Moon agreeable to the observations of Yahya Ibn Abi Mansúr, and those of Khálid Ibn Abd Al Malik Al Marúrúdhi:—of Abbas

* In the orthography of this name I have followed Mr. Caussin, who says he was a native of Naïriz in Persia, and was famous for his knowledge of Geometry and Astronomy. Notices et Extr. Vol. VII. p. 118.

† Of whose work an ample extract is given by Mr. Caussin in the Notices and Extr. Vol. VII.

‡ From p. 60 et seq. of the Volume alluded to Ibn Younis makes the same remark.

§ The passage here cited from Ibn Younis, is found in Mr. Caussin's edition above alluded to.

Ibn Saíd Al Jauhari, and of Habash, all of which agreed with one another in this particular.

But with respect to the two superior Planets: viz. Saturn and Jupiter, it was found in the Tables called Al Oläí Al Rassadi (composed by Sharwáni) that a conjunction would take place in Capricorn, in which the one would appear to touch the other, and which would happen on the * 14th of Safar, 562, of the Hejira, that is, on the 6th of Bahman Máh, ann. † 535 of Yezdigird: and it so happened; so that the calculation agreed with the fact; which was not the case with any other of the Tables that had been published from observation; but, on the contrary, the event universally contradicted the prediction: which may be sufficient to vouch for the accuracy of Al Sharwáni. ‡

It is further related, that Al Sharwáni observed the mean motions of Mars, through a long space of time, and found them agreeable to the observations of Ibn Aálam. He likewise observed for a long time the mean motions of Venus, when she came in conjunction with the star in the heart of Leo, which he also found agreeable to the observations of Ibn Aálam.

But with respect to the real motions of Venus, and the place of her apogee, he found some difference between his own observations, and those of others who had gone before him: for, according to him, the apogee of Venus would differ from that of

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* Corresponding to Nov. 30, 1166, A. D. which also corresponds to 535 of Yezdigird as given by Gravius in the Epochæ celebriores. See Tables.

† This æra, according to Gravius, Epochæ Celebriores, began A. D. 632, which is the year in which Yezdigird ascended the throne of Persia.

‡ It is worthy of remark that the complaints of Ibn Younis were to the very same effect: viz. that in his day, none of the observations corresponded in time and quantity with the predictions, whence we may infer that the science of Astronomy, had received considerable improvement from the labours of Al Sharwáni. See Mr. Caussin Not. et Extr. p. 122, et seq.

the Sun in degrees, though it would be in the same sign; which is contrary to the general opinion of Astronomers.

Again, with respect to the true motion of Mercury, after repeated observations, he found it to differ from the observations of all but those of Ptolemy, with which it agreed. On these accounts (says Al Fársi) I relied entirely on his observations, because of their great accuracy and the clearness of their demonstrations, and because I had proved them during a considerable length of time, by the conjunctions of the planets one with another, or with one or other of the fixed stars; as, for instance, with the star in the heart of Leo, and others; as well as the quantity and time of duration of the Solar and Lunar eclipses; in all of which I found the prediction to correspond with the event.

I found, moreover, (continues Al Fársi) that most of those who had gone before me, and had composed Tables, had formed them upon the observations of others, as in the case of *Kúshiár, author of the Tables called Al Jámia; Mohammed Ibn Ayúb, author of those styled Al Mofrid; and Ali Al Nasúi, author of those called Al Fákhir;—and Abi Rashíd Al †Barabshi, author of those called Al Kámil, all of whom implicitly relied on the mean motions of the Planets, as given by Al Batáni (Albategnius) taking all the errors and mistakes just as they found them.‡

When therefore I knew the character of the different Tables that had come down to my times, and found none comparable to

* There is a work on Astrology by this Author, bound up in the same volume with the work of Al Fársi.

† It is impossible to be certain of the orthography of this word from the Manuscript, which here omits some of the diacritic points: thus البرابشي.

‡ We have here a further account of Tables of which D'Herbelot has taken no notice when speaking of Al Farsi, which it is most likely he would have done had he ever seen this work: and it is doubtful whether a notice of any one of them is to be found in D'Herbelot.

those called Al Olāí Al Rassadi, either as respects their accuracy, or the nearness of the time of their compilation to that of the observations on which they were founded, I took this, with some degree of confidence, as the basis of my own, which I published as conformably as may be to his models, facilitating, at the same time, the work of calculation as much as possible; and which had formerly been attended with considerable difficulty. I then gave my work the title of Al Zíg Al Mumtáhan Al Modhafferi, i. e. The approved Tables of Modhaffer, according to the name of our Sovereign Al Malik Al Modhaffer, (may his reign be perpetual.)

The epoch of all the elements of the mean motions of the Planets, and of the equations of their apogees in these Tables, I laid down for the beginning of the year 631 of Yezdigird, on the third day of the week at twelve o'clock, which answers to the 17th day of Safar An. Hej. 661.* And the extent of time for which they are formed is An. 1321 of Yezdigird. The place, moreover, according to the longitude and latitude of which these Tables are computed, is the point of the great circle determining the climate of Yemen, the longitude of which eastward from the Canary Isles, is 63° 30′, and the latitude, from the Equator northward 14° 30′, which determines the boundaries of Yemen, upon which these Tables have been formed.†

I further affirm, (continues Al Farsi) that no one has, in our times, published Tables at all to be compared with these, nor will

* Which answers to Dec. 13, A. D. 1262.

† In a note written between the lines in this place of the MS. it is said وهذه البقعة هي مدينة صنعا اليمن لان هذا المذكور طولها وعرضها This place is the city of Sená in Arabia felix, as this is the longitude and latitude given of that place." This, upon referring to the Tables I find to be the case, which is sufficient to determine the place where Al Farsi wrote.

any come hereafter who will equal them, whether as regards their truth, or the accuracy of their construction, excepting only, where some error might have escaped the compiler from absence of mind, either in laying down the numbers in the letters of the alphabet, or in making the computations. My apology is therefore made, and my intention known. No one, it should be remembered, is free from error, especially when beset with difficulties, except the Almighty, whose favor and furtherance I have supplicated in the prosecution of this work, and I am not without confidence that he has answered my requests. I have divided these Tables into 40 chapters, which are as follows.

The number of Chapters in these Tables.

Chap. 1. On Chronology. 2. To find an unknown from a known date, by the Tables. 3. To find the beginning of the Roman, Coptic, Arabian, and Persian year. Also to find the beginning of the year and months of the Jews by the Tables. 4. To find the embolisms of the Arabian and Roman years by the Tables. 5. Explanation of the Elements, to which the mean motions of the Planets, (the Sun and Moon, with their true motions,) are reduced in these Tables; and to find any one for any given time. 6. To rectify the difference of time at any place differing in longitude from that wherein these Tables have been composed, which is in the climate of Yemen. 7. To find the length of Day and Night, for any given time by computation and the Tables. 8. Explanation of the requisites for a calculator in using the mean motions of the Sun, Moon, and Planets, and their equations, as laid down in these Tables: also their true motions. 9. To find the Sun's place. 10. To find the Moon's place. 11. To find the place of the Nodes. 12. To find the places of the five Planets. 13. On the retrograde motions of the Planets:—and their being stationary. 14. To find the latitude of the three superior Planets. 15. To find the latitude of the two inferior Planets. 16. * To find the Sun's declination: also to find the first and second declination by calculation. 17. To find the Moon's latitude. 18. To find the times of the Conjunctions and Oppositions. 19. To find the places of the Conjunctions and Oppositions. 20. To find the Phases of the Moon. 21. To find the sine, the arc being given; and *vice versa*. 22. To find the versed sine, the arc being given; and *vice versa*: also to find the chord, the arc being given, and *vice versa*. 23. On the ascension in a right sphere. 24. On the ascendant, and how to find the parts of the hours of day. 25. To find the Sun's altitude from the tangent and cotangent of observation; and *vice versa*: also to find the reversed shadow (i. e. the cotangent) commonly in use. 26. To find the Equation of the time of day (at any given place): also the places of the Sun and Planets by computation and the Tables. 27. To find the latitude of any place by an observation of the Sun's altitude, and by the Tables. Also to find the longitude of any place and its meridian. 28. To find the ascendant; also the circle of the Heavens corresponding to the latitude of Yemen, from the observed altitude of the Sun. 29. To find the ascendant; also an arc of the Heavens from the observed altitude of the Planets. 30. To find the parts of the ascendant: also the point of the Ecliptic that is upon the Meridian, the common and sidereal time being given. 31. To find the time when any point of the Ecliptic comes to the Meridian, either at a place having latitude, or in one that has none. 32. To find the Equation for the centre points of the twelve signs of the Zodiac. 33. To determine the cases wherein the solar Eclipses take place,

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* For an explanation of what is meant by first and second declination, see Delambre Ast. du Moyen Age, p. 158.

by computation and the Tables. 34. To calculate a solar Eclipse. 35. To calculate a lunar Eclipse. 36. On the *Comet; and to find its place with respect to the Ecliptic. 37. To find the hours of the day as equated for the latitude of Yemen, by the Tables. 38. To find the greatest Meridian altitude for the latitude of Yemen, by the Tables. 39. To find the conjunctions of the Planets one with another: also the times of the conjunctions of the Moon with the Planets. 40. To find the places of the fixed Stars for the epoch of these Tables, i. e. for the beginning of the year 631 of Yezdigird: also to find the places of the 28 stars of the Ecliptic from their original places: which ends the Tables.

The following are two Tables giving the mean places of the Planets, and their Apogees, which may have been influenced by the observations of Sharwâni.

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* The word used in the text is الكبد, of which the Author himself says, اعلم ان الكبد من كواكب ذوات الاذناب وليس هو في افلاك الكواكب وموضعه في الفلك الاثير ما دون فلك القمر Observe that الكبد is one of the stars having a tail, not situated in the firmament of the stars: but having its place in the etherial heaven, below that of the moon. I have therefore supposed it must mean a Comet, no assistance whatever, in this, as well as innumerable other instances, being to be obtained from the Dictionaries; but the Author speaks of this comet as if it were a solitary phænomenon, and subject to the same laws of motion as any of the planets; he has given tables of its mean place in the ecliptic for intervals of 1 year, of 10 years, and of 100 years; a proof, if any were wanted, of the very little attention which was paid to observation in the construction of their tables.

Table of the MEAN PLACES *of the* PLANETS, *for the beginning of the Year* 631 *of Yezdigird, for the Longitude of* 60° 30′ *from the Canary Isles, Eastward.*

Planets.	Signs.	Deg.	Min.	Sec.
The Sun's mean place	6^s	28°	38′	22″
The Moon's ditto	5	2	14	29
Its true place	5	27	34	22
The Nodes	11	38	7	6
Saturn's mean place	4	12	39	8
Its true place	9	5	28	14
Jupiter's mean place	4	8	30	13
Its true place	11	19	55	9
Mars' mean place	2	25	23	57
Its true place	2	16	5	25
Venus's mean place	7	10	14	22
Its true place	1	38	45	52
Mercury's mean place	2	26	49	22
Its true place	11	55	7	31

Table of the APOGEES *of the* PLANETS, *for the year above mentioned.*

Planets.	Signs.	Deg.	Min.	Sec.	Thirds.	Fourths.
The Sun....	*Pisces	2°	29′	12″	30‴	5^{iv}
Saturn......	Sagittarius..	8	9	23	30	0
Jupiter	Virgo......	5	29	5	30	5
Mars	Leo	4	16	6	30	0
Venus	Gemini	2	17	16	30	0
Mercury	Scorpio	7	0	41	30	0

* This is evidently a mistake in the manuscript, as the right sign Cancer is always mentioned in other parts of the Tables.

The positions of the Apogees given in this Table do not accord with those given by Ibn Younis in the year 220 of Yezdigird, and much less with their true places for that time, as determined by modern tables: and, the case of the Sun excepted, their planetary theory would necessarily give results essentially different from the true ones.

The obliquity of the ecliptic is always made 23° 35′, the determination of it given by Albategnius, and adopted by all subsequent Arabian Astronomers. The Sun is said to be vertical at Sena when he is in the 9th degree of Taurus, and its latitude is stated to be 14° 30′: this would give a value of the obliquity much less than the preceding: but no inference can properly be drawn from hence, as we know not whether these results were connected with each other.

It may perhaps be unnecessary to give any further extracts from the Tables, I shall therefore only remark, that in the original work they occupy 96 pages; in the abridgement 70. The chapters moreover in the abridgement are confined to 30. It was my original intention to give a list of the principal places in the East with their longitudes and latitudes from the Tables above mentioned: but, as I intend to present to the Society some extracts from the Geography of Abulfeda, of which a very valuable copy, written by Erpenius, is deposited in the Public Library, and which has never yet been laid wholly before the public, I now defer that part of my design to some future day, when the list of Al Farsi, and the extracts from Abulfeda may appear together.

SAMUEL LEE.

Cambridge,
Nov. 5, 1820.

P. S. I must not omit to mention, that I am indebted to the Rev. Mr. PEACOCKE, the present Secretary of the Society, for several valuable hints, during the preparation of this Paper for the Press.

XVII. *On Sounds excited in Hydrogen Gas.*

BY JOHN LESLIE, ESQ. F. R. S. E.

CORRESPONDING MEMBER OF THE FRENCH INSTITUTE, PROFESSOR OF MATHEMATICS IN THE UNIVERSITY OF EDINBURGH, AND HONORARY MEMBER OF THE CAMBRIDGE PHILOSOPHICAL SOCIETY.

[Read *April* 2, 1821.]

IT is well known that the intensity of Sound is diminished by the rarefaction of the medium in which it is produced. We might therefore expect the sound excited in hydrogen gas to be feebler than what is, in like circumstances produced in atmospheric air. But the difference is actually much greater.

A small piece of clock-work, by which a bell is struck every half minute, being placed within the receiver of an air-pump, a successive rarefaction was produced, and after the air had been rarefied 100 times, hydrogen gas was introduced. But the sound, so far from being augmented, was at least as feeble as in atmospheric air of that extreme rarity,—and decidedly much feebler than when formed in air of its own density, or rarefied ten times.

The most remarkable fact is, that the admixture of hydrogen gas with atmospheric air has a predominant influence in blunting or stifling sound. If one half of the volume of atmospheric air be extracted, and hydrogen gas be admitted to fill the vacant space, the sound will now become scarcely audible.

These facts, I think, depend partly on the tenuity of hydrogen gas, and partly on the rapidity with which the pulsations of sound are conveyed through this very elastic medium. The celerity of the transmission of sound through common air is the same in every degree of rarefaction; but in hydrogen gas it is more than three times swifter. The bell therefore strikes a medium which is at once thin and fugacious; fewer particles are struck, and these sooner escape from the action of the stroke. To produce undulations similar to what are excited in atmospheric air, or to cause equal reciprocations in the tide of sound, it would require the impulse to be as the square of the celerity, or ten times greater than in common air. If this view of the matter be just, I should expect the intensity of sound to be diminished 100 times, or in the compound ratio of its tenuity and of the square of the velocity with which it conveys the vibratory impressions.

When hydrogen gas is mixed with common air, it probably does not intimately combine, but dissipates the pulsatory impressions before the sound is vigorously formed.

It would be desirable to prosecute such observations with different gases, and at various degrees of rarefaction. But I have not yet found time, and merely throw out these hints for subsequent examination and research.

JOHN LESLIE.

Edinburgh,
March 13, 1821.

XVIII. *On the Connexion of Galvanism and Magnetism.*

BY THE REV. J. CUMMING, M. A. F. R. S. M. G. S.

PROFESSOR OF CHEMISTRY
IN THE UNIVERSITY OF CAMBRIDGE.

[Read *April* 2, 1821.]

IT has been remarked of the Pile of Volta that it stands unrivalled in the history of Philosophy, as its discovery was not the result of accident, but the fruit of preconceived theory, without which it might have for ever remained unknown. But this, though the first, was not the only instance of the kind in the history of Galvanism.—The decomposition of the alkalis and the discovery of the close connexion, if not the identity of Galvanism and Electricity, were the results of experiments, which were not undertaken fortuitously, but successfully deduced from theoretical views. —Another instance has recently been added of the verification of hypothesis by experiment, in Professor Œrsted's discovery of the action of the Voltaic Pile on the Magnetic Needle. In repeating his experiments, I have been led to some results, which may not perhaps be unworthy of the notice of this Society. Some years before the identity of Lightning and Electricity were suspected, it had been observed that the Magnetism of the Compass Needle was not only destroyed, which might be attributed to heat, but that it was reversed by Lightning; the same effects were afterwards produced by artificial Electricity: this seems to have been the first step in this discovery. It was noticed by Halley, and afterwards more accurately by Dalton, that the beams of the Aurora Borealis were always parallel to the Magnetic Meridian, and that the direction of the Magnetic Needle deviated considerably during their continuance.

These two facts seemed to prove an intimate connexion between Magnetism and Electricity, and when afterwards a similar connexion was observed between Electricity and Galvanism, it was an obvious inference that these three powers might possibly be identical.—Several fruitless attempts were in consequence made to communicate Magnetism to Steel Bars by placing them in the Galvanic circuit, and, excepting by the experiments of Ritter, there appeared no confirmation of this supposition. His experiments, and the conclusions he deduced from them, were too singular to be passed over unnoticed. By placing a Louis d'or in contact with the extremities of a Voltaic circuit, he caused its opposite sides to exhibit, the one the positive, the other the negative electricities, and this even after having been in contact with other metals; in this respect having acquired polarity similar to that of a magnet. Pursuing the analogy, he galvanised a gold needle, which shewed the dip and variation, and was attracted and repelled by a magnet. The conclusion he deduced from these experiments, was, that a magnet was similar to a pair of Galvanic plates, and that the affinity of Galvanism with Magnetism was still greater than that with Electricity. From some unaccountable circumstances his experiments either were not attempted, or did not succeed with others. In a work published by Œrsted in the year 1807, the subject is again resumed, and the hypothesis brought forward which conducted him to a successful result. After describing some analogies between Magnetism and Electricity, he arrives at this conclusion: in Galvanism the force is more latent than in Electricity, and still more so in Magnetism than in Galvanism; it is necessary to try whether Electricity in its *latent* state will not affect the needle.—It seems to have been upon this principle that he founded his process. A magnetic needle was placed within the influence of a wire connecting the extremities of a Voltaic battery, and was found to deviate in different directions, varying according to its position with respect to this connecting wire.—Subsequent experiments have proved, that this wire, of whatever metal it may be composed, becomes during this process magnetical; that two such wires possess the power of attracting or repelling each other, and that permanent magnetism may be communicated to steel by placing it within the Galvanic influence.—As your Council have done me the honor of desiring me to repeat these experiments before you, I have thought it proper to give this short account of their origin, which otherwise, as they are detailed at length in the different Scientific Journals, might have been thought unnecessary. In many of the results which I obtained in examining these phenomena, I found, as might have been expected, that I had been anticipated by others; I shall therefore mention only those which I believe to be new, or which, though previously discovered by others, yet in consequence of my using an apparatus more suitable for the purpose, I obtained by more simple methods. The apparatus employed was a single pair of zinc and copper plates, having a surface of $2\frac{1}{2}$ feet, and conducting copper wires of $\frac{1}{15}$ inch diameter, with two light magnetic needles, the one moving horizontally, and the other vertically. For examining the direction in which the magnetic force of the connecting wire acted on the needle, a thick brass wire was used, bent into a circular form, leaving an interruption in its circumference of about an inch; the ends of this wire being connected severally with the zinc and copper wires of the Galvanic plates. The ring being placed horizontally with the needle beneath it, the deviation was, in every azimuth of the compass, such that the needle made an angle of nearly 90° with the direction of that portion of the ring which was immediately over it. This deviation is mentioned by Œrsted as being about 45°; but it was shewn that its ultimate direction was at right-angles to the wire; in some cases by using a very light needle, in others by fixing it at nearly 90° by a small magnet; when, on making the connexion, it was impelled towards the right-angle, on which ever side of it the needle had been placed previously. The consequence of this was, that the needle made right-angles with the meridian, when under that part of the ring which was due North and South; and that where it was East and West the needle continued in the Meridian; but in one instance its magnetic intensity appeared to be increased, the North end still pointing towards the North, in the other its poles were reversed.—It was obvious from Œrsted's experiments that when the needle was placed *over* the ring the effects would be similar, but in opposite directions, and that when in the plane of the ring there would be apparently no effect produced. In this case a horizontal needle was used having a vertical motion. This was first placed without the ring, the direction of the needle making right-angles with that part of the ring to which it was opposed.—It was found, that, that end of this needle which was impelled upward in one position, was similarly impelled in every azimuth whilst without the ring, but on being placed within it was in every position impelled downwards.—On reversing these needles the effects were in all cases exactly opposite. When instead of using a common compass as in the first case, a needle was applied to the wire, suspended vertically below its axis, that end which moved to the right of the wire in any one point of its circumference, moved to the right in all; but on being suspended in a similar manner over it, moved to the left of the wire in all positions.—From these experiments it is evident that the force exerted by the connecting wire on the magnetic needle, is in every case in the direction of a tangent to the circumference of the wire, drawn from that point of it towards which the pole of the needle is directed; and that the direction of these tangents, with reference to the wire, is always the same. This may readily be conceived, by imagining the Galvanic fluid, (if it be a fluid) to revolve in a close spiral line from one extremity of the connecting wire to the other. From the opposite effects of this current on the opposite ends of the magnetic needle, it is obvious either that its particles attract one pole and repel the other, or that two electricities proceed, at the same time, from the extremities of the connecting wire, in opposite directions; the one acting upon one pole of the needle solely, the other on the other.—To separate these effects from each other, I used a needle, one end of which was steel, the other brass. The effect of the connecting wire on this double needle was, as I had imagined, considerably less than that on the common needle, but similar. . . . . To ascertain the direction of the supposed Galvanic current with reference to the magnetic needle, we must have recourse to the case where the connecting wire is at right-angles to the Meridian. When that end of it which was connected with the zinc plate was East, the needle beneath it remained immoveable, its magnetic intensity being increased; when the same extremity was connected with the copper plate, the poles of the needle were reversed; in the first case then the Galvanic force coincided with, in the second it was opposed to, that which gives magnetism to the needle.—And therefore the effects of the connecting wire upon the compass needle are precisely similar to what would have been produced by placing over it a magnetic bar at right-angles to the connecting wire, that is, parallel to the needle; having in the first case, its poles in the opposite, and in the second case, in the same direction as those of the compass needle.—In both these cases the direction of the magnetic current in the needle, being at right-angles to the connecting wire, was either from North to South, or from South to North. I concluded therefore that if the Galvanic circuit were completed through a magnet, its force would be increased or diminished, as the Galvanic force coincided with or opposed the magnetic.

On connecting the two poles of a small horse-shoe magnet,* to which a weight of 12 grains was suspended, with a pair of Galvanic plates, the weight fell when the zinc plate was connected with the South end of the magnet, and on reversing the poles it was drawn upward with a strong vibrating motion, indicating increased attraction.—As when that end of the connecting wire which proceeded from the zinc plate was placed in the magnetic Meridian over the North end of the compass, in the former experiments, the needle went to the right, and when under the compass to the left; it follows, from comparing this with the above-mentioned experiment, that the current which issuing from the zinc plate proceeds along the wire from right to left, answering to what would be called a left-handed screw, corresponds with the magnetism which influences the needle of the compass.

Similar experiments to those with the brass ring placed horizontally, were made with it suspended vertically, in different azimuths. As they chiefly served to verify the direction of the supposed Galvanic current as deduced from the former experiments, it is unnecessary to repeat them.—One result however was obtained, which, as I have found it practically useful in magnifying the Galvanic force on the needle, I shall mention. When the ring is placed in the magnetic Meridian, the upper and lower parts of its circumference may be considered as horizontal lines passing over and under the needle,

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* Since this was read to the Society I have discovered the cause of this phenomenon to be different from what I then suspected, I have therefore assigned the true cause in a subsequent paper.

and the East and Western sides as vertical lines drawn in its plane, and at right-angles to its poles. From what has been said as to the direction of the Galvanic current, it is evident that the effect of that part of the ring which passes over the needle is doubled by that beneath it, in the same manner the effect of the East side of the ring is doubled by the Western; in addition to this the effects of the horizontal and vertical portions conspire together. If therefore the ring become an ellipse, or what is more convenient in practice, the connecting wire be made in the form of a parallelogram inclosing the needle, the effect will be nearly quadruple that of a single wire passing over it. By means of this arrangement I have produced a deviation of 20° on a common pocket compass, by a battery so small as to be excited by a single drop of fluid.—By diminishing the size and increasing the delicacy of suspension of the needle there seems every probability that this may become a more delicate Galvanometer than any we as yet possess.—After mentioning the effect produced by so small an apparatus, it may seem singular that in Professor Œrsted's earlier experiments the effects were barely apparent, owing, as he imagined, to the feeble power of his battery. The reason of this he afterwards discovered to be, that the magnetic effect was dependant not on the intensity but the quantity of Galvanism evolved; but he does not seem to be aware of the extent to which this observation may be applied.—My first experiments were made with a battery of 220 double 6-inch plates possessing very powerful effects both electrical and chemical; yet its influence on the needle was scarcely perceptible. One of these plates taken separately caused a deviation of nearly 80°. It is evident then, that, though the circuit be complete, much of the magnetic influence is destroyed by the same circumstance which generates the electrical effect. This can be no other than the tension produced, in consequence of the obstruction presented to the free passage of Galvanism, by the fluid interposed between each pair of plates.—Magnetism cannot therefore be properly considered as the effect of Voltaic Electricity, but of Galvanism in its original form.

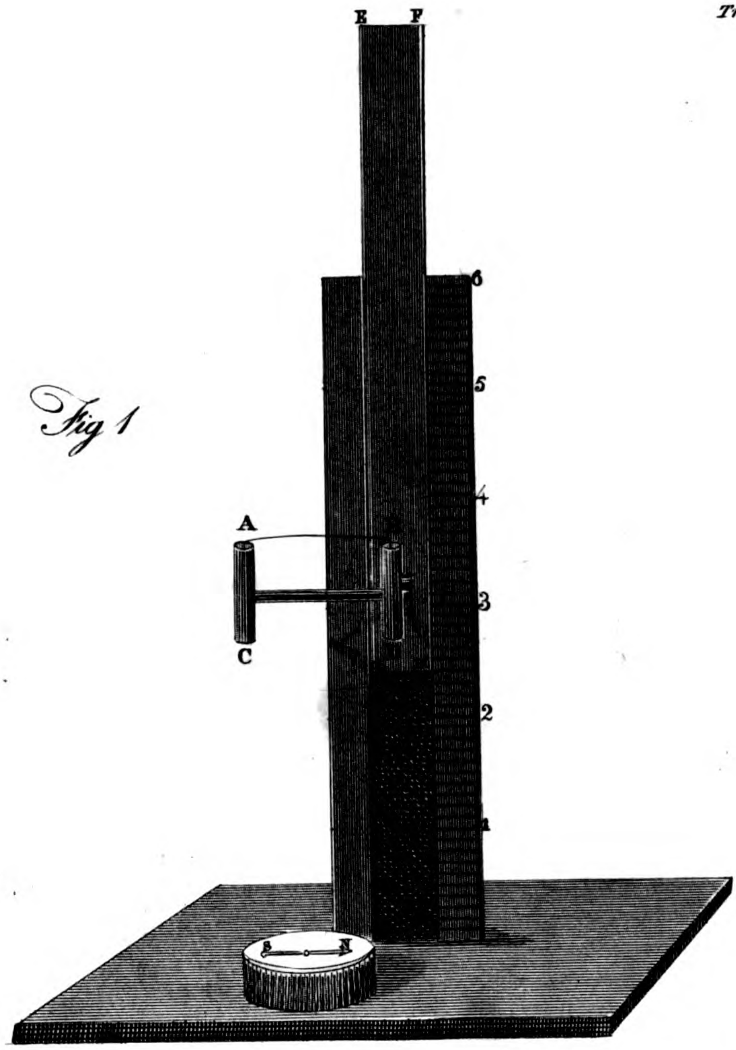
In examining the difference between Electricity and the Magnetic effects produced by Galvanism, I was induced to try the powers of wires of different lengths and diameters in conducting it. Electricity, it is known, is conducted almost entirely by a wire however small, provided it be not fused; and if the circuit be completed at the same time through two wires of different lengths and diameters, a very small portion of Electricity is transmitted through the larger wire, provided the smaller be considerably shorter.—The law by which the Magnetic influence of Galvanism is conducted is precisely the reverse.—A needle which deviated between 80° and 90° when placed under a connecting wire of $\frac{1}{15}$ inch diameter, deviated less than 20° when placed at the same distance from a wire of $\frac{1}{200}$ inch; when wires of different diameters were used, the deviation increased with the diameters, although their lengths increased at the same time; and this law continued, even with a single pair of plates, until the wire was larger than $\frac{1}{30}$ inch.—As it might have been supposed that this effect was owing solely to the smaller wire presenting a less surface to the needle beneath it, I placed a large connecting wire over the compass, and interposed the smaller wire in another part of the circuit, but the effect was still the same. I obtained however a still more decisive proof of the difference of the laws by which Electricity and Galvanic Magnetism are conducted. The connexion was made at the same time by means of two wires, one of which was $\frac{1}{200}$ inch diameter, and 3 inches long, the other $\frac{1}{15}$ inch, and 5 feet in length; the needle of a compass placed under the former deviated only 10°, that of a similar compass under the latter had a deviation of nearly 80°.—That the smaller wire was capable of conducting more of the Magnetic force, was shewn by removing the larger wire when the deviation under the smaller increased to nearly 20°. This influence had therefore, contrary to that of Electricity, chosen the longer passage through the larger wire, even though the smaller had not transmitted all it was capable of conducting.

As in some of these experiments I had inclosed the small wires in tubes filled with water and different acids, without finding there was any increased effect produced, I concluded that these fluids would not conduct the Galvanic Magnetism; nor where a single pair of plates was used, however nearly the connecting wires were brought together, was there any effect produced either chemical or magnetical.—On placing a small copper wire, in a tube filled with nitric acid, over the needle, the deviation was gradually diminished as the wire was corroded by the acid, and when a separation of continuity took place, there was no deviation. The experiment was reversed by inclosing two copper wires in a tube filled with acetate of lead; the extremities of these wires being brought very near each other, and the tube placed in the Galvanic circuit over the needle, there was at first no deviation, but when the arborescence produced by the revival of the lead formed a metallic contact between the wires, a small deviation appeared, which gradually increased as the contact became more extensive.—That in using large wires the surface alone does not transmit this magnetic influence, and that therefore in this respect it differs from electricity, was shewn by filling the above-mentioned connecting tube with mercury, and afterwards removing the mercury, and coating it with metallic foil. With mercury the effect was the same as with a wire of the same diameter; but on removing the mercury and coating the tube with gold leaf the deviation was very inconsiderable, not more than from 5° to 10°;—with platina foil, which was much thicker, the deviation was greater, yet far inferior to that of a solid wire of the same diameter.

Having ascertained the difference between Galvanic Magnetism and Electricity, as to the power of being conducted, it seemed desirable to discover whether there were any thing analogous in common magnetism.—For this purpose I placed beneath the iron pendulum of a small clock, a horse-shoe magnet, whose force, coinciding with that of gravity, would accelerate the rate of the clock, by the going of which a measure would be afforded of the magnetic force exerted upon it. When the poles of the magnet were uncovered, the rate of the clock was accelerated from 10′ to 12′ in 24 hours, when they were connected by a piece of soft iron the gain was not more than from 1′ to 2′; on filing away the middle of the iron the rate was gradually accelerated, and when the central part was reduced to a fine thread the acceleration was nearly the same as when the poles were uncovered.—When the poles were connected by a piece of iron bent down beneath the legs of the magnet, so that the length of the circuit between the poles was considerably increased, the rate of the clock was still but little affected. It appears from this, that the poles of the magnet were much more completely neutralized when the connexion between them was made through the longer but more capacious circuit, than when through the shorter and less capacious; and that in this respect commmon magnetism is analogous to that excited by the Galvanic apparatus.

I have already trespassed so long on the attention of the Society, that I must defer to another meeting, an account of some experiments, to which I was led, by observing the facility which the Magnetic influence of Galvanism affords, for detecting its presence and measuring its effects.

Fig 1



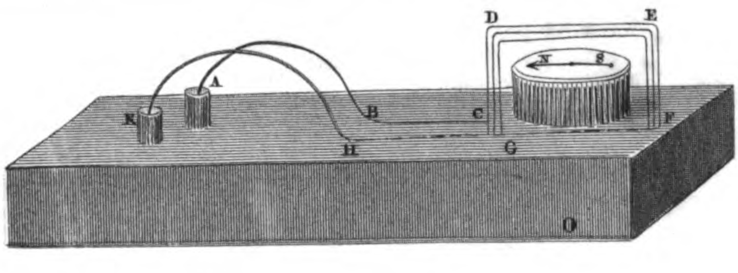


Fig 2

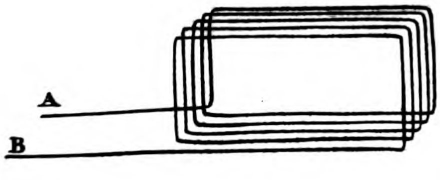


Fig 3

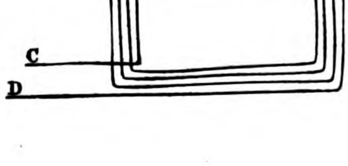


Fig 4.

Roe, Engraver Camb.

EXPLANATION OF PLATE XIV.

The great bulk of the intestines is raised towards the chest, bringing into sight

L—Part of the under surface of the Liver.

K—The Kidneys.

U—The Ureters.

B—The Bladder.

R—The Rectum.

XIX. *On the Application of Magnetism as a Measure of Electricity.*

BY THE REV. J. CUMMING, M. A. F. R. S. M. G. S.

PROFESSOR OF CHEMISTRY
IN THE UNIVERSITY OF CAMBRIDGE.

[Read *May* 21, 1821.]

THE methods hitherto in use for ascertaining the Quantity and Intensity of the Electricity produced either by Friction or by Galvanic action, are (independently of the shock on the animal frame, which obviously affords no definite measure,) derived from its power in decomposing water, or fusing metallic wires.—When the Electricity is either small in quantity, or of low intensity, there are considerable difficulties in the practical application of either of these methods.

The fusion of platina wire by the elementary battery of Dr. Wollaston, proves that the quantity of Electricity developed by very minute metallic surfaces is considerable; yet, exclusively of the difficulty in soldering wires that are barely visible, it is almost impossible to ascertain their length with any precision.—The other mode, that of measuring the quantity of water decomposed by a pair of small Galvanic plates, is impracticable.—The recent discoveries of Professor Œrsted have enabled me to construct two instruments, one for discovering, the other for measuring Galvanic Electricity, with a delicacy and precision that seem scarcely to admit of limitation.—The construction of the former instrument I have mentioned in a communication I had the honor to make to this Society sometime since;—I shall now describe a few of the experiments I have as yet been enabled to make with it.—A wire of zinc and another of platina, each $\frac{1}{10}$ inch diameter, were coated with sealing wax, so as to have merely their extremities exposed: on immersing them in a dilute acid, the circuit being at the same time completed through the Galvanoscope, the needle deviated so decidedly, as to leave no doubt that a visible effect would have been produced by wires of less than half the dimensions of those I employed.—As the compass though small, was by no means delicate, we may, I think, conclude from this experiment, that the Electricity developed by two metallic surfaces, each $\frac{1}{500}$ of a square inch, may be detected, and their relations to each other ascertained, by this instrument.

The minute surfaces, and consequently small quantities of exciting fluid required for experiments with this instrument, offer the means of examining Galvanic effects that have hitherto been unnoticed.

Of the acids whose Galvanic effects I believe have not been examined, I have found, with small disks of zinc and copper, that the oxalic and hydriodic have considerable power; the phosphoric and acetic much less.—The action of strong sulphuric acid was inconsiderable, the needle being scarcely affected, but on adding a drop of water it deviated through more than half a right angle.—Were the Galvanic action owing solely to the Electricity developed by the metallic contact, the fluid acting merely as a conductor, according to a generally received hypothesis, the effect should be greatest when the stronger acid is used, concentrated sulphuric acid being a far better conductor than when diluted; on the other hand, since zinc or iron are readily oxidated by the action of dilute acid, though with difficulty when it is concentrated, this experiment seems to prove, that the Galvanic action depends, not on the conducting, but on the oxidating power of the interposed fluid.—Hitherto I have not had the leisure to form that complete series of the electric relations of the metals towards each other, which this instrument affords the means of doing; yet the effects I have observed in two instances, are, I think, so remarkable, that I ought now to mention them.—On using two disks, one of iron, the other of steel, there was produced a decided deviation; since then the only difference in the metals arises from an alloy of from a $\frac{1}{60}$ to a $\frac{1}{140}$ part of the whole, it appears that this is sufficient to alter their electric relations.—The powerful affinity of potassium for oxygen, made it highly probable, that, in the Galvanic circuit, it would become strongly negative with all the metals. On my first trial with disks of potassium and zinc, the Potassium took fire before I could observe the effect; this difficulty I afterwards obviated by alloying it with mercury; on making the contact the needle deviated through nearly a right angle: The same effect was produced with copper; it was needless to try it with the other metals, for being negative with respect to zinc, and zinc being negative with respect to all the other metals, there can be no doubt that in the Galvanic circuit, potassium is the most strongly negative metal with which we are acquainted.—It is perhaps scarcely necessary to remark, that, if any proof of the metallic nature of potassium were wanting, this experiment would have afforded it.

In using the magnetic needle as a measure of Galvanic effects, we may either observe the deviation at a standard distance of the connecting wire from the needle, or assume a standard angle and measure the distance.—The latter method seems to have the advantage, as enabling us to use a smaller and therefore a more delicate needle, with this additional convenience, that the scale is increased in proportion as the length of the needle is diminished.—I therefore constructed an instrument, having a connecting wire fixed upon a moveable slide divided into inches and tenths, to which a vernier might be added if necessary. My first object was to ascertain the divisions on the scale, corresponding to variations in the angle of deviation;—for this purpose, the moveable wire was placed at different distances from the needle, increasing in arithmetical progression, and the corresponding deviations were observed. As the effects decrease very rapidly during the Galvanic actions, the experiments were made as quickly as possible, proceeding from a distance of $\frac{1}{2}$ an inch to $10\frac{1}{2}$ inches, and again returning to the first distance. On taking the mean of several trials, made in this manner, I found that the tangent of the deviation varies inversely as the distance of the connecting wire from the magnetic needle.

It is well known that in a Galvanic arrangement, intensity is given by the number, quantity by the magnitude of the plates; but I am not aware that any notice has been taken of the effects produced by varying their distances from each other.—On placing a moveable plate of zinc opposite a fixed copper-plate, I found, that, on diminishing the distance, the deviation of the needle placed under their connecting wire continued to increase, until they were in actual contact. The law of that increase, ascertained by the method I have just mentioned, was such, that the tangent of deviation varied inversely as the square root of the distances of the plates. In the construction of a Voltaic series composed of many plates, the advantages to be obtained by placing them very near each other, would be counterbalanced, by the risk of their intensity becoming sufficient to penetrate through a small distance; but in using large plates, with Electricity of low intensity, it is obvious, that provided they are not in actual contact, they cannot be placed too near each other. By availing myself of this observation, I have been enabled to repeat, with a single pair of plates, the experiments of Ampère and Arago, which were originally performed with a battery of twelve pairs.—Of these, one of the most singular, is that by which a spiral connecting wire is made to communicate permanent Magnetism to a steel wire placed within it.*—This experiment I find may be varied, by using a straight connecting wire, and twisting round it a small steel bar; the zinc and copper ends of the bar receiving the Northern or Southern Magnetism respectively, according as its spiral is from right to left, or the contrary. The repetition of this experiment led me to discover the cause of a singular effect, which I had the honor of exhibiting to this Society. The magnet, which was deprived of its attractive power when its North pole was connected with the zinc wire of a pair of Galvanic plates, had been placed in the circuit, by twisting the wire round its poles from left to right; on making this spiral from right to left I reversed the effect; and when the spirals round its two poles were in opposite directions, the weights suspended from them were oppositely affected at the same time, the attractive power of one pole being increased when that of the other was destroyed.

The singular effects produced by using a large conducting wire, I have mentioned in my former paper on this subject, and the analogy it forms between the Galvanic and the common form of Magnetism.—In the further examination of this diffusion of the Magnetic influence, I have found it to be far more extensive than I had at first imagined.—On making the connexion between a pair of plates containing about $1\frac{1}{2}$ foot of surface, through a copper globe of more than a foot diameter, and therefore containing full 4 square

* In these, as in the previous experiments, I find that if the spiral be made of large wire it is much more efficacious than if of small.

feet of surface, every part of it exhibited Magnetic effects, either upon a horizontal or a vertical needle.—The same effects were manifested whatever were the forms of the surfaces interposed between the Galvanic plates.—On varying the experiment by connecting both extremities of the plates with each other, by means of small wires, so that there was a metallic circuit throughout, (in which case it is generally conceived that all Galvanic effect ceases), I found that every part of this circuit affected the Magnetic needle.

The Magnetism of the connecting wires was examined in the usual mode; that of the plates themselves by immersing in the exciting fluid a small compass in a glass case, made impervious to the water. It is perhaps premature to form any theoretical opinions upon these few facts, which seem to me adverse to the received opinion, that the Galvanic effects are produced by the decomposition of an electric fluid circulating between the positive and negative plates; yet, if ever the mysterious agency of Galvanism is to be detected, it must be by examining it in its simplest form; and this, the discovery of the connexion between Galvanism and Magnetism, and the delicacy of the instruments it enables us to apply, seems to promise, more readily than any modes yet tried, the means of accomplishing.

Since this paper was read to the Society, I have had an opportunity with the assistance of Dr. Clarke and Mr. Lunn, of trying the Magnetic effects of Atmospherical Electricity.—A wire of about 100 yards in length, connected with a Kite, readily magnetised a steel needle inclosed in a spiral wire, but caused no deviation in a compass placed beneath it.—I have obtained the same results in repeating Sir H. Davy's experiments both with the Leyden Jar and with sparks taken from the conductor of an Electrical Machine.—It seems that the Galvanic Magnetism is most readily made sensible by the deviation it causes in the compass needle; but the Electrical by its power of communicating permanent Magnetism.

The experiment on Atmospherical Electricity suggests an easy method of ascertaining, from time to time, the prevalent Electricity of the air; by inclosing small steel bars in a spiral wire connected with a conducting rod, and examining the Magnetism induced in them.

XX. *A Case of Extensive Solution of the Stomach by the Gastic Fluids after Death.*

By JOHN HAVILAND, M. D.

VICE-PRESIDENT OF THE CAMBRIDGE PHILOSOPHICAL SOCIETY, AND REGIUS PROFESSOR OF PHYSIC.

[Read *Dec.* 11, 1820.]

THE subject of the following observations was a young man under 20 years of age, of sedentary and studious habits, who had previously to his last fatal illness enjoyed good health.

The case came under my care on the 12th of December, 1819, the patient having been taken ill on the 5th with symptoms of fever, for which he had been bled, and had undergone appropriate treatment under the direction of Mr. Okes.—When I first saw the patient there were still present symptoms of cerebral determination, though by report these had considerably abated, nevertheless I applied leeches to the temples, and a blister between the shoulders, and employed small doses of purgative medicines; under the use of these remedies the symptoms abated. On the 18th he unexpectedly became worse, the pulse was weak and small, though not more frequent than 100 beats in the minute: there was an increased tendency to low delirium, especially at night: I then had the head shaved and kept moist by a cooling application.—From this time till the 22d, the day of his death, the strength of the patient gradually declined without the occurrence of any remarkable symptom: the skin was generally moist, and latterly profusely so: the bowels were moderately open, with about two evacuations daily, which were loose, but not otherwise unhealthy. There was no tumefaction or tenderness of the abdomen. The respiration was frequent and quick, but not particularly laborious till within a few hours of death.—The appetite, as is usual in fever, was throughout the whole course of the disease almost entirely lost, but the patient took occasionally light broths and vegetable decoctions, to which he had no dislike. He also took at intervals a small quantity of port wine and water. Once, about twelve hours before his death, he asked for food, and swallowed a few spoonsfull of calves-foot jelly with apparent relish.

He complained of pain no where but in the head, and that especially in the early part of his illness.

The body was opened about 12 hours after death by Mr. Okes in my presence, and the following appearances were noticed:—

The pia mater exhibited a slight increase of vascularity. The substance of the brain was firm and healthy. The ventricles contained about 12 or 14 drams of a serous fluid.—On opening the cavities of the abdomen and thorax at first nothing unusual was perceived, the viscera appeared entirely free from disease: the intestines were somewhat distended with flatus, but contained no feculent matter.

On raising the stomach and examining the little omentum, we were surprised by the appearance of a dark-coloured fluid, which seemed to escape from the former viscus. A most careful search was now made, and a large opening was perceived in the stomach on the upper and back part, near the cardia. The stomach was then detached, with a portion of the æsophagus and duodenum, when a large perforation of the diaphragm came into view, in the muscular part, corresponding precisely to, and communicating with the hole in the stomach: so that a portion of the contents of the latter organ had escaped into the cavity of the chest. This part of the diaphragm was next removed. A careful examination of the other abdominal and thoracic viscera did not lead to the detection of the slightest diseased appearance. There was no where the smallest evidence of previous inflammation, no adhesions or ulcerations of any part of the viscera. The fluid which had escaped appeared to be nothing more than the contents of the stomach, of which the wine and water formed a part, and probably gave it the dark colour.

The stomach on being examined after its removal from the body, afforded the following observations. The mucous membrane appeared to be more red and vascular than usual throughout its whole extent, and here and there were small spots of what seemed to be extravasated blood, lying below the mucous coat—for these spots were not to be washed off, nor to be removed by the edge of the scalpel. There were two holes in the stomach, the larger very near to the cardiac end of the small curvature, and on the posterior surface: this was more than an inch in length, and about half that breadth. The other not far from the former, also on the posterior surface, about the size of a sixpence. The edges of these holes were smooth, well defined, and slightly elevated. The coats of the stomach were thin in many other spots, and in one in particular nothing was left but the peritoneum, the mucous and muscular coats being entirely destroyed. The hole in the diaphragm was through the muscular portion, where it is of considerable thickness, and was large enough to admit the end of the finger. There was no appearance of ulceration or of pus adhering to the edges of this perforation of the diaphragm.

There can be little doubt, I presume, that the appearances I have now described, were the effect of the solvent powers of the fluids of the stomach, acting upon the solid parts in contact with them, after the death of the patient. It appears to me that the facts are deserving of being recorded, first because they confirm the observation originally made by Mr. J. Hunter, that the secreted fluids of the stomach do sometimes possess a solvent power, sufficient to enable them not only to corrode the parietes of this organ itself, but even the thick muscle of the diaphragm, and that within the space of 12 hours after death. A fact which has sometimes been controverted, and which nevertheless should be distinctly known, it being of great importance with reference to the examination of the bodies of persons who may have died under the suspicion of having swallowed certain mineral poisons. But secondly, the most striking part of the case is, that such an extensive dissolution of the stomach should have occurred in the body of a person who had died from fever, and that one not remarkably rapid in its course. This patient had certainly taken no solid food, and but little of any description, for many days before his death, which was preceded by all those symptoms of debility which are common to the last stage of fever. The occurrence seems irreconcileable with the generally received notions of the pathology of fever,—which disease is usually characterised by an extreme want of energy in the performance of all the functions, but more especially of that of digestion. In this case it would appear that the activity of this function, at least as far as depends on the solvent powers of the gastric juices, was unusually great.

XXI. *On the Physical Structure of the Lizard District in the County of Cornwall.*

BY THE REV. A. SEDGWICK, M. A. F. R. S. M. G. S.

WOODWARDIAN PROFESSOR;

FELLOW OF TRINITY COLLEGE; HONORARY MEMBER OF THE GEOLOGICAL SOCIETY OF CORNWALL; AND SECRETARY OF THE CAMBRIDGE PHILOSOPHICAL SOCIETY.

[Read *April* 2, and *May* 7, 1821.]

IN a paper which was read before the Society in the course of last year, I stated that the Lizard district differed so essentially from every other part of the county of Cornwall, that I intended to make it the subject of a separate communication. I do not however even attempt to give a complete mineral history of the country I am describing. This communication, like the former one, must only be considered as a compilation from such memoranda as were made by Mr. Gilby and myself, during our passage round the coast. The Geological collection which we formed during the same part of our tour, will, it is hoped, be sufficiently complete to convey a correct notion respecting the character of the great mineral masses which successively presented themselves to our observation. Extent of the country described.

Our examination of the cliffs commenced near the mouth of the Helford river, and terminated at Loe-Bar. To the north of a line drawn between the two last-mentioned places, the country is composed of those slaty rocks, which I described in the former paper under the general name of Killas. Immediately to the south of this line the soil rests on the same formation. For the demarcation between the Killas, and those rocks which more immediately characterize the Lizard, commences at Porthalla, and passes in an undulating line, on the whole considerably convex to the north, till it reaches the western side of the promontory in a small cove called Bolerium, not far from the village of Mullyon.

External appearance.

It will always be a matter of interest to trace the connexion between the physical structure of any country and its external form. When seen from the high granitic ridge near Constantine, the southern part of the Lizard district appears to be composed of a table-land, elevated some hundred feet above the level of the sea, and presenting hardly any indication of rupture or contortion throughout the whole extent of its outline. Farther north, the whole country descends rapidly from this elevated plain, and exhibits that undulating and broken surface which so often marks the presence of schistose rocks. It is at the same time intersected by a system of small vallies which generally terminate in the Helford river. The view of the same region from the western shore of Mount's-Bay, is still more striking and characteristic. The upper surface seems so exactly horizontal, that one might almost be led to conjecture, that every projecting ledge of rock had been planed down until the promontory resembled a great artificial terrace. The peculiar dark colour and precipitous face of the cliffs are at the same time sufficient to distinguish them from any other part of the coast of Cornwall.

On entering the table-land from the north, we remarked many partial inequalities in the surface which had before been hidden from the view. We found at the same time that the country declined considerably on the eastern flank of the peninsula; in consequence of which, the cliffs on that side had a much less commanding elevation than those on the other. On the whole, however, the region had an aspect of dreary and barren uniformity.

Structure of the cliffs.

The structure of the cliffs abundantly compensates for the want of interest in the interior. In many parts of the coast they rise out of the sea in one perpendicular ascent to the level of the neighbouring country. In other places, the mineral beds are cut through by deep ravines which descend rapidly to the edge of the water. The peculiar constitution of the rocks, which has favoured the excavation of these ravines, has also enabled the sea to encroach on the mean bearing of the coast. Hence, these lateral openings in the cliffs generally terminate in small coves or creeks, each of which affords a site sheltered on almost every side from the fury of the elements. We were not therefore surprised to find in such situations as these, some of the principal villages of the district.

Of the table-land, &c.

An extended coast presenting the finest natural sections must evidently afford ample means for studying the structure of the country. It must, however, be always difficult to trace the separation of formations through a district which presents an unbroken surface of a tabular form. But even this difficulty was on some accounts less than we had anticipated. The greater part of the table land rests on beds of porphyritic rock, and of serpentine. The presence of the porphyry is indicated by innumerable bowlders composed of the hard nuclei of masses which were once spread over the surface. Almost with equal certainty, the extent of the serpentine is marked out by the brown scanty vegetation with which the face of the country is still imperfectly covered. The limits of these formations are therefore traced with considerable accuracy in Mr. Majendie's map of the district, published in the first volume of the Transactions of the Geological Society of Cornwall.

Extensive masses of green-stone are also associated with the serpentine, and often so intimately interlaced with it, that it would be next to impossible to trace their line of separation, even in the vicinity of the cliffs. The task has not yet been successfully attempted: nor would much information be gained by the completion of it, unless it lead to the discovery of some general law respecting the direction of the several formations, so as to enable us to connect together the phenomena presented in the opposite coasts of the promontory.

From my own observations I doubt the existence of any such connexion. They were, however, almost exclusively confined to the coast, and to the order in which the mineral beds were associated in the cliffs. My memoranda are too imperfect, especially at this distance of time, to enable me to represent this order in a suite of colours on an outline map. The following notice will indeed be sufficient to shew that even such a limited task would not be very easily performed on any chart of ordinary dimensions. I have as far as possible adopted the orthography of the Ordnance Map. Still I have in more than one instance found great difficulty in describing the locality of certain phenomena in such a way as to enable any one to observe them who may hereafter visit the coast.

North of the Helford river.

In descending to the country which borders on the north side of the Helford river, we found, (about two miles to the south-west of Falmouth,) several bowlders of granite, containing such an unusual quantity of mica as to exhibit a slaty texture. Such a locality as this would certainly not be worth mentioning, except in a country where a formation of gneiss is almost unknown. On the northern margin of the river, near the village of Durgans, the cliffs were much contorted; but even at that distance from the central ridge, the rocks shewed no positive indication of a mechanical origin. On reaching the cliffs near Mawnan we soon perceived that the schistose masses were greatly changed in external character, as well as in composition. The larger beds were of a coarse granular texture, and even the finer beds were dull, glimmering, and meagre to the touch, and possessed none of that silky lustre which so generally distinguishes the Killas. These rocks were traversed by many contemporaneous veins; some composed of quartz, and others of ferriferous carbonate of lime. Some small cavities were coated with fine spicula of arragonite; and a much rarer substance, (which on a chemical examination by Mr. Gregor proved to be a subcarburet of iron) was found in thin plates among the laminæ of the schist. Through the assistance of Mr. Rogers of Mawnan, we were enabled to procure a specimen of the last-mentioned mineral.

Nare point and Menacchan.

Our examination of the coast afterwards led us to Nare point, on the south side of the Helford river. Immediately on landing, not many hundred feet from that headland, we found a low cliff, chiefly composed of yellow siliceous sand, containing many fragments of slate, obviously derived from the detritus of the adjacent district. The base of this ruinous cliff was occupied by a conglomerate composed of quartz pebbles mixed with rolled and angular pieces of clay slate, all held together by a coarse argillaceous cement. An appearance so very unusual in this County, might have led to some mistake respecting the date and origin of these masses; had not the denudation of the coast proved beyond all doubt, that the conglomerate passes almost imperceptibly into common greywacké, which in its turn passes into, and alternates with still finer beds of greywacké slate, differing very little from those we had before remarked in the cliffs near Mawnan. As all these beds, both in range and dip, are strictly conformable with the mineral masses in the neighbourhood, they prove that some portions of the formation are decidedly of mechanical origin.

On a subsequent occasion we crossed the country between Helston and St. Kevern, afterwards descended to the village of Menacchan, and from thence returned by the south bank of the Helford river. In the whole of this route we saw no rocks so well characterised as those of Nare point. We however observed repeated instances of a fine grained and somewhat ferruginous sand-stone. Masses of this kind are the constant associates of a greywacké formation, and are to be considered as examples of that rock where the argillaceous parts have nearly disappeared. The blocks of this sand-stone which were scattered about the surface, gave no obscure indication of the true nature of some of the finer and more decomposing schistose beds which were hidden beneath the vegetable soil.*

On the south side of Nare point the cliffs continued for some way to present obvious traces of a mechanical origin. We afterwards found some hard dark-coloured varieties of clay slate, and among them some beds of hornblende slate. Before we had descended to the village of Porthalla, we observed that some of the last beds of the formation were intersected by innumerable veins of carbonate of lime, apparently of contemporaneous origin. It may be proper

* We found several of these blocks of fine sand-stone on the hills south of Menacchan. The small rivulet which runs near the village has become remarkable as the locality of one of the ores of Titanium, which appears to exist in considerable abundance; for we found no difficulty in procuring some specimens of it during the few minutes we employed in seeking it near Tregonwell mill. The Menacchanite may easily be separated from the fine sand of the rivulet by help of a magnet, after the coarser impurities have been carried off by a streaming process, similar to that which is so often used in preparing metallic ores for the smelting house. Mr. Majendie (Geological Transactions of Cornwall, Vol. I. p. 37,) conjectures that this mineral is derived from the decomposition of the diallage rocks which form the hills to the south from which the stream derives its source. We were never able to find a specimen of diallage rock containing any substance which we could identify with Menacchanite. The subsequent discovery of that mineral at Lanarth, appears however to confirm the conjecture. It is there found among sand and other impurities, immediately below the soil, in front of the house of Colonel Sandys, and may be separated by the usual process.

here to remark, that the portion of the formation we have been describing, when considered on the great scale, ranges nearly east and west; dips, at a considerable angle, towards a point within a few degrees of the south; and therefore appears to pass under the north-eastern part of the great table land of the Lizard.

The small valley of Porthalla is excavated in some very soft ruinous beds, which are placed between the Killas and the formation of serpentine and green-stone, which succeeds immediately to the south. It was the first illustration in this district of a fact of very common observation; that those mineral masses which occur at the junction of two formations, or in parts of the same formation where the mode of aggregation undergoes any sudden change, are often in an advanced stage of decomposition. These decomposing beds extend to the cliffs south of the village; but were in such a state of degradation that we could not see their immediate junction with the serpentine. They are intersected by some veins of fibrous carbonate of lime, and are so ferruginous, that some of the fragments have the colour of hematite. Many portions of these beds are somewhat unctuous to the touch, and contain a great abundance of mica. In consequence of these characters, they have been confounded with talcose schist, from which they ought to be separated. Porthalla.

Immediately beyond these crumbling masses, we met with the first rocks of the serpentine formation; which extends along the base of the cliffs nearly as far as Dranna Point. They are difficult of access from above; but a boat may at any time be procured from Porthalla, which will enable the Geologist to examine their extent, the different quarries which have been opened in them, and the manner in which they support those blocks of green-stone which form the upper part of the escarpment. This serpentine is of a more homogeneous texture, and has more the character of a simple mineral, than that of any other portion of the peninsula. Its prevailing colour is dark green; and it is throughout intersected Serpentine of Porthalla, &c.

by many minute veins; some of which are superficial, while others penetrate deep into the mass. Nearly all of them are filled with steatite in different states of induration; or with asbestos, the fibres of which are at right-angles to the fissures. The blocks have a splintery fracture, and break into very irregular fragments. In the planes of fracture, we sometimes observed small green-coloured radiating spicula, of which we were not able to make out the species with certainty, as our specimens were almost microscopic. From their mode of aggregation, silky lustre, and extreme brittleness, we conjecture them to belong to one of the varieties of Tremolite; which is the more probable, as that mineral has been found in the rocks of Clicker-Tor. Our specimens were too minute to enable us to make any observation on their chemical properties. We found the serpentine, as we expected, very untractable in the flame of the blow-pipe. After being acted on for some time, the edges of minute splinters became white, and presented a glazed surface. Fragments, which had remained some time in dilute muriatic acid, were superficially deprived of their deep colour, and exhibited a number of minute brilliant specks of magnetic iron ore. These particles are seldom brought to light by a recent fracture of the rock; yet we think that they must be very generally diffused through it, as every mass which we examined acted very sensibly on the magnetic needle. In the whole of this formation we thought that we observed obscure indications of stratification, and of a dip, to a point between east and south-east, which brought all the beds under the low-water-mark near Dranna Point.

Green-stone. The green-stone in the upper part of the cliffs did not present many varieties. It consisted principally of rude shapeless blocks, which shewed no distinct cleavage. Near Porthalla we however found, immediately over the serpentine, some beds which are principally composed of compact felspar; and are marked, superficially, by a number of fine green lines, in the direction of which they may be separated, though not without some difficulty, into parallel laminæ. These green lines penetrate into the substance of the stone in the direction of the planes of cleavage, and seem to be formed by many minute specks of granular diallage. Beyond Dranna Point the whole formation passed into well-marked green-stone slate, dipping to a point between west and south-west; a direction very different from what we should have expected. In one place we were able to descend to the beach, where we found this slate beautifully intersected with veins of fibrous carbonate of lime. Along these beds, dipping as we have mentioned, we descended to the village of Porthowstock; and remarked on the way, no change of composition in the prevailing rock, beyond the occasional appearance of small crystals of diallage, mixed with the hornblende and the felspar.

Porphyritic rocks south of Porthowstock.

The small valley of Porthowstock does not mark out the exact separation between two distinct formations; the cliffs on both sides of the cove being composed of the same ingredients. In their modes of aggregation, they, however, exhibit a striking difference: for in following the cliffs to the south, all trace of schistose texture immediately disappears, and the rocks soon after assume a porphyritic structure; having a base of compact felspar, in which both hornblende and diallage exist in the form of imbedded crystals. In the proportion, as well as in the magnitude, of these constituents, there was such an unusual variety, that we were almost led to conjecture, that during the deposition of the mass, many conflicting principles had been in action, not one of which was long able to gain the mastery over the others. There were many large blocks, which in one part resembled a fine green-stone, and in another a coarse porphyritic diallage rock. Within the distance of a few feet, these varieties were observed repeatedly to alternate; sometimes in the form of stripes; but more frequently in amorphous concretions, separated from each other by lines which were perfectly defined : so that the whole mass was like a substance derived from the consolidation of heterogeneous materials in a state of imperfect mixture. When the structure of a formation is thus varied, we may always expect to find portions in every possible state of disintegration. The aspect of the cliffs confirmed this observation: for we found among them some hard unaltered beds, mixed with others which were crumbling and ruinous. The broken reef of rocks, called the Manacles, has undoubtedly arisen from this irregular structure. Had the cliffs been uniform in their composition, they would probably have opposed a longer resistance to the inroads of the sea ; and when worn down by the constant attrition of the waters; beds of sand, or of mud, would have resulted from their ruins. The reef in question is at the same time a monument, marking out the extent to which the sea has been able to intrude upon the ancient boundary of the coast.

On the beach, and in the low cliff nearly opposite the Manacles, we met with some beautiful varieties of porphyritic rock. One of them exhibited crystals of diallage in bright rose-coloured compact felspar. Large bronze-coloured crystals of resplendent diallage also abound in many low masses of rock which extend under the high-water-mark. No part of the Lizard district shews that mineral in greater perfection. Near the varieties last described, we met with a granular rock in which the porphyritic structure had entirely disappeared. It was composed of perfectly crystallized felspar and hornblende, with some diallage; and the three constituents were held together without any general connecting principle. The remaining part of the coast presented a repetition of the same phenomena in a less striking form, until we descended along a gentle declivity to the beach in Coverack Cove. This declivity is capped by a thick alluvial bank of sand, containing fragments of diallage rock and of serpentine, and some rolled masses of white quartz.

Though we had not known that the serpentine re-appeared in the next headland, we should have concluded with perfect confidence, from the existence of the cove, and the general aspect of the coast, that the rocks on which we had been descending, were about to be superseded by some new formation. The whole strand was covered with fragments of rocks, such as have been before described, mixed with others perhaps peculiar to this locality. Some varieties arose from the mutual penetration of the constituents, which in part disguised the porphyritic structure: a still larger number were characterised by the various colours reflected from crystals of resplendent diallage. Of these crystals, some were coal black, others olive green, others brown, and many were bronze coloured, and possessed a high degree of metallic lustre. In order to examine with advantage the junction of the diallage* rocks and serpentine, which takes place on the south side of the cove, it is necessary to visit this part of the coast about the time of low water. Near this junction we found a black bed, composed of hornblende, with a very small proportion of diallage and compact felspar; and in almost immediate contact with the serpentine was a rock, in external appearance very like antique porphyry. On a minute examination, its base proved to be nearly allied to the serpentine; and the white spots on the surface did not arise from imbedded crystals; but from small nodules of compact felspar. When viewed through a lens, they appeared to communicate with each other by very minute veins, which ramified through the whole mass. The true serpentine which succeeded, was of a dingy red colour, Coverack Cove.

* By this term I understand a rock, generally of porphyritic structure, with a base of compact felspar. The imbedded crystals may be composed of any of the varieties of diallage described in works on Mineralogy. In the former paper on Cornwall, p. 145, I inadvertently used the word hyperstène, which is appropriated to that variety of resplendent diallage commonly called Labrador hornblende. Had I been present when the impression was struck off I should have adopted the more general term diallage. The term compact felspar is used in this paper with some latitude, and includes one or two subspecies; among which Saussurite (feldspath tenace) is not unfrequent.

and contained many small crystals of olive green diallage. But beyond the first line of junction, very fine specimens of porphyritic diallage rock re-appeared, in the form of thin alternating beds. Before we had passed the pier, we, however, observed that the porphyritic serpentine prevailed to the exclusion of the other formation.

I may perhaps have been thought too minute in describing these phenomena. But all observations are important, which tend to illustrate the relations between the diallage rocks and the serpentine of this district. Some of the beds near the junction appeared to have characters common to both deposits; which seemed to shew that they originated in the same system of formation. In the southern part of the cove, there were some ambiguous indications of a separation into strata which had a considerable angle of inclination, and dipped to the south-east. A farther examination of the coast convinced us, that no general conclusion respecting the order of superposition could be deduced from such obscure indications.

The mineral beds between Porthowstock and Coverack did not in general produce any sensible effect on the magnetic needle; but a recent fracture of the blocks very often exposed a number of irregular spots of a steel grey colour, which always acted on the needle with greater or less intensity. These metallic spots sometimes passed into a dull earthy substance of a brick red colour, when they ceased to act on the magnet. In those parts of the formation which abounded in the resplendent diallage, we always remarked that the finest specimens existed near the surface of the blocks; and therefore concluded, that the pseudo-metallic lustre was not natural to the mineral, but due to a certain alteration arising out of the progress of decomposition.

We twice crossed the high downs* to the north and north-west

* White quartz pebbles abound in the alluvium which caps some portions of the downs.

of Coverack. But among the many bowlders which were strewn over the surface, no varieties differed so much from those rocks I have already enumerated, as to require a separate description.

We now entered on the great formation of serpentine, which stretches from the east to the west coast, through a distance of six or eight miles, and occupies, in superficial extent, about one-third part of the peninsula. The cliffs between Coverack and the next headland, abounded in a black, and highly magnetic variety; which in texture as well as colour, made a near approach to basalt. Its surface was much corroded, so as to resemble a rusty scoria from an iron furnace; and it was occasionally traversed by thin steatitic veins, containing crystals of diallage. We remarked also, that the cliffs were divided by a double system of fissures, which separated the larger masses into blocks of nearly cubical form. One set of these fissures occasionally disappeared, and the masses then became separated into many parallel beds; the local appearance of which has led to mistaken and contradictory opinions respecting the stratification of the whole formation. Commencement of the great serpentine formation.

The most prevailing serpentine, as we continued to follow the line of coast, was of a dull red colour, with many shades of green, and much mixed with brown and olive green diallage. As we had not been taught to expect any appearances of peculiar interest, we hastened to the south-west, and for some time did not pause, except to admire the magnificent black promontories which seemed to bid defiance to the heavy swell which was continually rolling against them. Our subsequent experience made us regret that haste, in consequence of which we may have overlooked several interesting and important facts.

After we had descended to a deep ravine, which is cut down nearly to the level of the beach, not far from Pedn-boar point; we were informed that a copper mine had lately been opened in Copper mine.

the neighbourhood. We immediately ascended to the point where the works had commenced, but were not fortunate in meeting with any one in whose information we could place much reliance. A quantity of grey copper ore, mixed occasionally with fibres of native copper, appears, from what we could learn, to be intimately mixed with the substance of the serpentine: but neither to have that regularity of direction and of thickness, nor that continuity, which indicates a true vein. We obtained some specimens of the ore, which, though of no great beauty, possess considerable interest. They are composed of noble serpentine, common serpentine, steatite, bronzite, vitreous sulphuret of copper, and carbonate of copper; all intimately blended together. A copper mine was opened some years since near Mullyan, but soon afterwards abandoned. The geological relations of that deposit appear to have been the same with those above mentioned. In both instances the sulphuret and native copper are probably contemporaneous with their matrix of serpentine, and not continued in regular veins which are analogous to the metalliferous lodes of the county.

Diallage rocks, Saussurite, &c.

Having ascended from the copper mine to the high table land on the west side of the ravine, we continued our hasty passage near the coast, until we reached a point where the whole character of the cliff was so completely changed, that we again descended to the most accessible parts of the escarpment, and commenced a minute examination of its features. After passing some singularly shattered beds of serpentine, we crossed a slope formed by many earthy decomposing masses, to which it is not possible to give any definite character. They were succeeded by a rock, in which compact felspar, and hornblende mixed with diallage, were arranged in distinctly undulating layers, resembling, in their mode of aggregation, the coarser varieties of gneiss. Among these beds were some veins containing minute specimens of scaly talc of a pearly white colour, with various shades of green. These phenomena were soon superseded by diallage rocks of a more usual form; which were continued under different modifications several hundred yards to the west. In one part of the formation, the crystals of diallage disappeared, and the cliff was occupied by large amorphous blocks of Saussurite. The hardness and tenacity of that mineral are well known; it was not without long continued efforts that we broke off the specimens now placed in the Woodwardian Museum. On the surfaces, exposed by recent fracture, were many light green shades, which were at first supposed to arise from the presence of granular diallage, (smaragdite.) Where these shades of colour prevailed, the mineral had an oily aspect, and a crystalline texture; and in the blow-pipe melted with a slight ebullition, like the other parts of the rock, into a pale glass. The limits of the sub-species of compact felspar are not well defined. When crystalline form is either wanting, or imperfectly developed, the determination of species can only be established by a frequently repeated analysis; the separation by external characters being in such cases liable to error.

As we expected that the rocks last described would have been succeeded by an extensive formation of green-stone, we were surprised to find them suddenly cut off by the re-appearance of serpentine. This induced us to retrace our steps to the former junction; which enabled us to pronounce with some confidence, that the whole mass (composed of diallage rock, saussurite, green-stone, &c.) was wedged in between two nearly perpendicular faces of serpentine; and that there was no indication whatsoever, of stratification or order of superposition.

Having satisfied ourselves on this point, we continued to advance, for about half a mile, on the high terrace of serpentine, until we reached the eastern side of Kennick Cove. The high cliffs are there abruptly cut off, and succeeded by a low bank of sand, occasionally interrupted by some broken beds of serpentine, which mark out the old direction of the escarpment. All these rocks abound

Kennick Cove.

in very splendid crystals of diallage of a deep blood-red colour; a variety I do not recollect to have seen in any other part of the district. We felt assured, from the experience of facts so many times repeated, that this complete degradation of the cliff must have been connected with some alternation among the masses which entered into its composition. We were not, therefore, surprised, on reaching the western side of the cove, to find a bed of green-stone porphyry resting on serpentine; their plane of separation dipping to the south-east, at an angle of about forty degrees. This junction is seen within a few feet of the point where the road, leading to the village of Ruan Minor, ascends from the beach. With some difficulty we passed to the south side of the projecting ledge of rock; and found, not many feet beyond the junction, the serpentine cut through by a nearly vertical dyke of granular felspar, not more than three feet wide. This dyke is of a dull red colour, and of a somewhat porphyritic structure; and has a very minute portion of earthy hornblende irregularly mixed with the base. The state of the tide did not permit us to extend our examination any farther. But the phenomena were of such interest, that we next day revisited this part of the coast at low water; and were enabled to pass along the base of the cliff, and to observe every change of structure in its component parts as far as Callean Cove.

Cliff between Kennick Cove and Callean Cove.

I lament my inability to convey, by verbal description, any thing like an adequate representation of the striking phenomena which rapidly succeeded each other. I shall therefore confine myself to a notice of such facts as seem to throw light on the natural history of the whole formation. A black magnetic decomposing serpentine, studded all over with small crystals of diallage, of a bright golden lustre, extended about forty feet on the western side of the dyke. The dazzling effect produced by this contrast, was greatly heightened in those parts which had been exposed to the action of the waves. The attrition of the waters had worn off the earthy decomposing crust, and produced a natural polish on the surface of these splendid porphyritic blocks. A small dyke of felspar porphyry, contracting its dimensions as it ascended in the cliff, again intersected the serpentine; which was afterwards continued for more than one hundred feet, and a third time interrupted by a dyke, about ten feet wide, in constitution nearly resembling the other two. All these dykes inclined a little to the south-east; but the arrangement did not seem to have had any connexion whatsoever with the gravitation of the several parts at their time of deposition. Beyond the third dyke, were many amorphous and nearly vertical masses of serpentine, separated by irregular planes, which did not underlie in any fixed direction.

For about two hundred feet, these masses were only interrupted by one vertical bed of green-stone; which contained a subordinate vein, three or four feet wide; filled with decomposing materials, from which we separated asbestos, steatite, and some small specimens of foliated talc. Beyond this point, an extensive series of beds, composed of granular felspar, felspar porphyry, granular diallage rock, green-stone, and green-stone porphyry, occupied the cliff for several hundred feet. I have applied the term green-stone to those blocks which take their colour from the hornblende. I have, however, comprehended under the same term, many masses which contain minute crystals of diallage. The several minerals are so intimately associated, that it would be impossible to describe all the modifications of aggregation, without long, and I think unnecessary details. The green-stone was also sometimes penetrated by a variety of indurated steatite, which was only seen in parts exposed by a recent fracture. Some rocks of green-stone porphyry possessed a high degree of beauty, from the contrast between the uniform dark colour of the base, and the brilliant white colour of the imbedded crystals. But a continual change of structure, which is always accompanied with a certain liability to decomposition, unfits all such masses for the purposes of architectural ornament.* The granular felspar rocks exhibited the same varieties of structure; but were less striking from the want of contrast in the colour of the materials.

All these different mineral aggregates alternated in masses, between which there seemed to be no fixed relation. They sometimes mutually penetrated each other; so that one bed might be considered as a felspar porphyry, traversed by innumerable contemporaneous veins of green-stone; while, in the contiguous portion of the cliff, the green-stone so far predominated, that the granular felspar rock was only seen to pass through it in minute ramifications. In some instances, the varieties were divided into parallel layers, represented on the face of the cliff by alternate red and black stripes. In other instances the veins formed a system of zig-zag lines, and re-entering curves, which gave the appearance of one rock enclosed within the substance of the other. These phenomena we considered of great importance; in as much as they seemed to imitate, on a small scale, the geological relations of the successive formations we had been examining. A few garnets were scattered through the substance of one of these complicated masses. The locality is worth recording; because we saw that mineral in no other part of this coast, though it is abundant in some formations of serpentine. It is worthy of remark that the granular rocks were in no instance observed to pass insensibly into serpentine. The separation between the species was generally complete; and well defined, by a series of fissures, or of decomposing veins.

As we advanced to the south-west, we observed a well marked vertical bed of felspar porphyry, rising out of the cliff. It was succeeded by a bed of serpentine, penetrated in all directions by

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* The same observation applies to all the porphyritic diallage rocks between Porthalla and Coverack.

veins of felspar porphyry; which in this instance, bore the same relation to the serpentine, that it had before done to the green-stone.

It would be an useless task to attempt an enumeration of all the alternations of green-stone and granular felspar rock. I may however remark, that they continued to be interrupted by some beds of serpentine; one of which was not more than three feet wide; and might therefore be considered as a dyke of serpentine in a formation of green-stone. Before we reached Callean Cove the serpentine once more predominated over its associates. One bed of green-stone rose up by the side of a great mass of serpentine; was then coiled over its upper surface; and finally descended, on the opposite side, until it wedged out between two blocks of the same formation.

Within a few feet of the projecting reef which forms the eastern side of Callean Cove, we found a vein, about eight inches wide, which cut obliquely through the cliff, and was filled with felspar and bronze coloured resplendent diallage. The latter mineral was of extraordinary lustre; and in some places formed the whole substance of the vein. Callean Cove.

We were here once more compelled to ascend from the beach, and to confine our examination to such portions of the precipice as were accessible from above. A hard black serpentine, often separated by a double system of parallel fissures, prevailed almost all the way to Innis Head. If these fissures be considered as the marks of stratification, they will often, even in different parts of the same mineral mass, lead to conclusions directly opposed to each other. Near Innis Head, we observed a vertical bed of green-stone passing into a granular felspar rock; and still farther to the south-west, near the promontory called Kildown, we found another bed or dyke of similar structure. Close to these points of alternation, the serpentine was penetrated by many talcose veins.

Cadgwith.

A lofty and finely indented cliff was prolonged to the west, and continued almost inaccessible, until it was cut through by a deep ravine, which terminated in a small sheltered cove close to the village of Cadgwith. Some time before we reached the village, the serpentine had disappeared, and was succeeded by well defined beds of green-stone slate; which had a slight inclination to the north. As this slate re-appeared in the same position on the western side of the ravine; we should, in any other place, have concluded that the chasm had been formed by a vertical excavation in a continuous schistose mass. But our acquaintance with the district led us to form a contrary opinion. A further examination of the ravine afforded the most convincing evidence, that the whole opening had once been filled with serpentine, of which a few crumbling blocks were still to be seen *in situ* above the village.

After we had crossed the high cliff on the western side of the cove, we descended into a magnificent natural amphitheatre; formed by the decomposition of an irregular mass of serpentine, which had again intruded on the green-stone. During high water, the sea rushes into the lower part of this amphitheatre; and at the same time undermines its walls and carries off the ruins, which are continually falling down from the decomposing face of a rock nearly two hundred feet high. Above that portion of the cliff, where the sea has forced a passage into the chasm, a hard mass of serpentine stretches right athwart the gulf, and affords a natural bridge, by which we passed over to the west.

For nearly two miles we advanced along a high terrace, bounded towards the sea by a cliff which was precipitous and unbroken, except in two or three places where the green-stone was interrupted by serpentine. The alternations were marked by the usual appearances of decomposition. We afterwards descended to the beach by a road recently excavated in some rocks which seemed to belong to the green-stone formation. One part of them contained much resplendent diallage; another part was composed almost exclusively of fine granular felspar; and we were surprised to find associated with them, some masses into which granular quartz entered as a constituent.

Alternations, such as I have before described, are continued as far as Balk Head, which is the last locality of the serpentine on the eastern side of the Lizard promontory. Before we reached that headland we met with an alluvial cap, containing much siliceous sand, and some quartz crystals with double terminations. We were informed that it had been used successfully as a top dressing for the land. At the immediate termination of the serpentine, the whole strand was covered with prismatic blocks, derived from the crumbling cliff, which generally exhibited a dull fracture, and a decomposing texture. This decomposition often penetrated deep into the substance, even of those masses where the rugged angular forms continued very little altered; a circumstance which would make it necessary to exercise great caution in the selection of such materials for the purposes of ornamental architecture. Large sound blocks, possessing extraordinary beauty, from the admixture of greenish black and bright red colours, might, however, be extracted from the cliff; if the public taste offered sufficient encouragement for the undertaking. **Balk Head.**

On a review of the phenomena we had hitherto observed on the south side of the Helford river, we were led to conclude, that the great plateau of the Lizard was not composed of stratified rocks. We have, indeed, pointed out some obscure indications of an order of superposition near Coverack and Porthalla. But they are too uncertain to be opposed to the clear evidence offered in the south-eastern parts of the coast; where the alternating masses of greenstone and serpentine so often appear, like great wedges driven side by side into the escarpment, without any order of arrangement whatsoever. **Recapitulation, &c.**

Those who contend for the stratification of the serpentine, may perhaps consider the dykes of felspar, and the vertical masses of green-stone, as intrusive members of the formation; and therefore of more recent origin. To this objection we need only reply; that in many parts of the coast, the vertical masses of serpentine might with the same propriety be considered as intrusive members of a formation of green-stone. To us it seemed impossible to account for such phenomena, except on the supposition of the contemporaneous consolidation of a mass, in which the elementary parts had been irregularly distributed; or their mode of aggregation affected by the local action of disturbing forces. On the other hand it must be conceded, that the green-stone, where it is not immediately interrupted by foreign beds, generally exhibits somewhat of a schistose texture; and at considerable distances from the serpentine, not unfrequently passes into a beautiful green-stone slate.

According to the hypothesis we have adopted, the serpentine can hardly be considered to arise from any elements besides those which enter into the composition of the granular rocks associated with it. It may therefore be regarded as the result of the intimate union of felspar, diallage, hornblende, magnesian earth, and magnetic iron ore. A continually varying proportion of these materials will account for the different appearances exhibited by a rock, which in many instances is not sufficiently homogeneous to be included in the class of simple minerals. Every part of it on the eastern coast, between Coverack and Balk Head is porphyritic; but this structure can only be considered as accidental; for we lose all trace of it in the greatest part of the patch of serpentine which occurs near Porthalla.

Veins in the serpentine, &c.

I have already mentioned the veins which traverse many parts of this formation. We found them very abundant on both sides of Kennick Cove; still more so in the ruinous cliffs between

Kennick Cove and Callean Cove; and we remarked some, of very unusual dimensions, among the crumbling masses which had fallen into the great amphitheatre west of Cadgwith. In some instances they ascend along the face of the cliff in well defined lines; and may, therefore, have originated in fissures, formed by a retreat at the moment of consolidation, and subsequently filled by infiltration. Most frequently their direction is ill defined, and they ramify into minute threads; often filled with steatite, occasionally seeming to pass into silky transverse fibres of asbestos. Sometimes the smaller veins are filled with small laminæ of talc. Their pearly lustre, unctuosity, and want of elasticity, seemed to determine their species. In the flame of the blow-pipe they continued to exfoliate, until there remained only a minute atom which melted with difficulty into a light brown enamel. In the larger veins we often remarked among much decomposing matter, coarse asbestos; in which the fibres were arranged longitudinally, associated with impure varieties of fibrous and indurated talc. The whole substance of the vein would sometimes pass into an unctuous ligniform mass, disposed in undulating laminæ, which very rarely alternated with thin layers of noble serpentine. Sometimes these veins were divided into several parallel portions, by the intervention of carbonate of lime; while other parts of the mass were studded over, and mixed with beautiful minute rhombs. The outer part of the vein was occasionally coated over with a kind of steatite, and studded with small botryoidal masses, which had a stellated fracture. These globules, if we mistake not, are formed by the aggregation of minute scales of silvery talc. In a single instance we found the interior of a small vein coated with small transparent crystals of felspar.

Our examination of the coast was too much directed to general facts to allow us to enter into minute details. What we have just stated, can, on that account, only be considered as a sketch of such phenomena connected with these veins, as are of obvious occurrence.

Green-stone slate of Lizard Cove, &c.

Beyond Balk Head commences the finest formation of green-stone slate in the whole district. From some quarries beyond Lizard Cove we obtained specimens capable of being divided into laminæ as thin as paper. In the eastern side of the cove, there were three or four small veins filled with magnesian carbonate of lime, deeply tinged with oxide of iron, and occasionally exhibiting a very unusual and complex crystallization. These minerals were also partially mixed with quartz and iron glance. The schistose beds were slightly inclined to the east; but in the next cove, where they were intersected by many contemporaneous veins of carbonate of lime, the great planes of cleavage dipped to the north. On the south side of this cove, near the road which has been excavated in the naked face of the rock, the cliff is cut through by a vein six or eight feet wide, which underlines to the south-east. As its bearing is nearly the same with that of the coast; it may be traced, for a considerable extent, near the foot of the escarpment. When we ascended from the beach it was inaccessible, but from the ferruginous colour of its materials we supposed them to have been nearly the same with those last described.

Hot Point.

On both sides of Hot Point the formation continued to be characterized by a fine slaty texture; and the beds, on the whole, had a slight inclination to the north-east, though not without some exceptions, arising out of partial contortions. All the more elevated portions of them were externally coated with lichens, which we observed constantly to invest the beds of green-stone slate, whenever that rock prevailed in the upper part of the cliffs.

The want of variety in the mineral character of these larger masses, was compensated by their continual change in external form. It would lead me into details inconsistent with the object of this paper to attempt a description of all the features of this magnificent coast. In some places the perpendicular escarpment is interrupted by projecting ledges of rock which resemble the buttresses of a gothic temple: and where the sea has made greater inroads, the broken masses, separated into nearly horizontal layers, make a still nearer approach to the forms which are exhibited by the mouldering ruins of a castle. The effect of such appearances is greatly heightened, from their being seen in profile from the lofty projections of the coast.

We in one place found the green-stone slate cut through by a system of nearly vertical fissures; but the beds soon regained their more usual inclination, and were continued as far as a recess immediately below the eastern light-house. There they abruptly terminated, and were succeeded by some earthy decomposing masses, which obscured their junction with the singular formation which occupied the most southern point of the Lizard promontory. These earthy materials very much resemble the filling up of a great *fault*. We are however disposed to class them with those ruinous beds which are so often interposed between two distinct formations where there is no appearance of dislocation.

Junction with the slate of Lizard Point, &c.

On the western side of the recess above mentioned, was a thick alluvial cap, resting on some slaty beds, which dipped to the north-east; but at so small an angle, that we could not infer, with any certainty, that they passed under the green-stone slate. The very imperfect evidence on which it had been attempted to establish the relation between the two formations, was not observed by us without some disappointment. For we had ventured to conclude, from the best accounts which we had seen, that the rocks peculiar to the district, had been deposited in a trough or basin of the killas; and that the schistose beds, forming the extreme point of the promontory, would be found distinctly to rise from under all the other formations.

The ruinous state of the cliff, below the first light-house, enabled us to descend to the beach; but the height of the water prevented us from reaching the termination of the green-stone slate. After passing along the strand, for two or three hundred feet, towards the west, we were again compelled to ascend to the top of the cliff, by a road which had recently been cut in the face of the rock. The whole denudation shewed a system of beds possessing two distinct characters. In the upper part of the escarpment they were composed of shining folia, and resembled the commonest varieties of mica slate. At the base they were of a dull glossy green colour, and had a foliated structure. The small layers did not, however, exhibit any long continuous undulations, but were throughout puckered and contorted.

The first variety has generally been classed with mica slate. It contains very little quartz, and the interposed laminæ are so unctuous and difficult of fusion, that they may be perhaps composed of a mixture of talc and mica. The second variety I refer, though not without some doubts, to chlorite slate. It fuses, with great ease, into a black glass, which acts powerfully on the needle. Near the new road we observed two dykes, ranging east and west, which were probably filled with alluvial materials.

Old Lizard Head, &c.

On ascending the hill leading to Old Lizard Head, we found the cliff much contorted, and formed of decomposing beds, nearly resembling the chloritic schist of St. Agnes. In one place it had been rent asunder, and the chasm replaced by a mound of rubbish which resembled the upfilling matter of the two former dykes. The crest of the hill was composed of hard indestructible masses, separated into distinct strata, which dipped to a point between east and north-east. The great constituents were compact felspar and chloritic schist, which alternated with each other ; occasionally in distinct beds, but more frequently in thin laminæ. Their planes of separation were sometimes irregularly covered with small spangles of silvery talc, which made them feel as unctuous as a piece of soap. All these varieties exist in the highest parts of the great headland, and with them a dark coloured felspathic slate; exhibiting, like the other beds, some spots of silvery talc in its planes of cleavage. These formations must once have extended into the sea far beyond their present limits. For the base of the escarpment consists of the softer talcose beds, which are easily worn away by the action of the water. The more indestructible beds above are therefore successively precipitated into the sea for want of an adequate support. This we conceive to have been the mode of formation of the dangerous broken reef which stretches out so far to the south-west.

Beyond Old Lizard Head the face of the country slopes away to the north; we therefore soon descended from the rocks of slaty felspar, and advanced along a decomposing cliff, formed by the inferior beds, until we reached the point where it is cut down by a small rivulet, almost to the level of the beach. Within a few hundred feet of this point the serpentine re-appears in the cliff.

Re-appearance of serpentine.

We were so desirous of seeing all the phenomena presented at the junction, that we visited this part of the coast on two successive days; and in the latter instance, were fortunate enough to reach it at the time of low water. All the lower beds were soft, tough, and of very difficult fracture. Many of them were ill characterized; but they seemed chiefly to be composed of soft chloritic schist, alternating with varieties of indurated talc, and occasionally penetrated by irregular veins of felspar. As they approached the serpentine, they were so much contorted that we could not decide either upon their dip or bearing. They were sometimes made up of regular curved laminæ; and not unfrequently, the planes of separation were marked, on the surfaces of the harder masses, by zig-zig lines, which imitated the salient and re-entering angles of a fortification agate. Before they reached the serpentine, one portion of them was so far decomposed as to exhibit nothing but a mound of rubbish deeply tinged with oxide of iron; and the next portion, seemed only to be held in its form by the innumerable veins of hard striated carbonate of lime, which intersected it in all possible directions, like a great work in filigree. These decomposing masses, were supported on one side by soft talcose slate, which seemed to dip to the south-west; a direction exactly opposite to that which would have carried them under the serpentine. On the other side they seemed to abut directly against the serpentine. We could not discover the least indication of their passing under it.

On the day preceding, we had found a patch of green-stone slate (exactly similar to that which we had left behind, near the light-houses) stretching from the neighbourhood of Lizard Town towards the west, and terminating near the place where the cliff was cut down by the rivulet. From its position, as well as its dip, it seemed, at least in part, to rest conformably on the slate formation of Lizard Point. Combining this fact with the assertions of Berger (whose habitual inaccuracy we have before found occasion to mention) we had expected to see the same slate formation distinctly supporting the serpentine. We have already seen that this is not the case: and our surprise was still increased when we found, in a part of the beach below the high-water-mark, and within thirty or forty feet of the junction, the very same kind of green-stone slate dipping to the east, a direction which carried its beds under both the formations which were in contact.

From the mineral character of this slate formation of Lizard Point, as well as from its relation to the rocks with which it is in contact; we venture to conclude that it is not part of the substratum of the great Table Land, but rather one of its component members; being evidently coeval with some beds which are interlaced with unstratified masses of serpentine.

The western coast of the Lizard district abounds in grand and picturesque features; yet in variety of composition, and in the interest which arises out of the junction of rocks of different characters, it is greatly inferior to the eastern side of the peninsula. As far as Kynan's Cove there is an uninterrupted cliff of serpentine, with the exception of one portion, which is cut through by a felspar dyke. The contiguous rocks are in such a state of decomposition that many parts of the dyke are buried in their ruins. It does not possess the small granular base, and the porphyritic structure which we had previously remarked; but it seems to be formed by the irregular adhesion of imperfect crystals of felspar. The intervals between the crystals are frequently empty; sometimes filled with steatite; and occasionally coated with soft unctuous folia of talc. In some of the larger cavities are considerable nests of mica. Quartz is also irregularly associated with this dyke in the form of veins, rather than as a true constituent. We therefore found all the component parts of granite assembled together; but in a state of aggregation altogether different from that rock.*

Features of the western coast, &c.

Among the magnificent scenes exhibited on the coast of Cornwall, Kynan's Cove has long been justly celebrated. The sea has there made such inroads on the cliff, that one very large mass of serpentine is entirely severed from the main land, and all the neighbouring rocks are worn down into forms which are strikingly diversified. Phenomena like these can only arise from partial decomposition. In the low sandy beach are two protuberances of a very fine grained felspar rock. In appearance many parts of the mass are nearly homogeneous; but when examined with a lens of high power, granular quartz, and a few specks

Kynan's Cove.

* Specimens of agate and jasper have been found near this locality; but we were not fortunate in meeting with any.

of mica are found to be associated with the felspar. On the north side of the cove, a large mass, apparently of the same materials, is sticking like a wedge, midway in the face of the cliff. I think that the wedge must have been formerly continuous with one of the masses on the beach; and that the serpentine formation had been originally penetrated by large dykes or veins of the granular rock. Such a structure, from the whole analogy of the district, would favor that partial decomposition, from which the striking character of the cove has probably resulted. If this account be true, the dykes of felspar must have wedged out in the serpentine; and the mass which is sticking in the cliff must have been the termination of one of these dykes. We have already mentioned some examples of a similar arrangement; and, no doubt, they would have been much more numerous, had we been able to trace the alternating masses of green-stone and serpentine in the line of their direction.

Among the rocks of the cove were many veins of noble serpentine. The porphyritic structure was on the whole less apparent than usual. There were, however, some varieties, which contained so many minute crystals of diallage, that they exhibited a near approach to a granular texture; and have sometimes been considered as forming a connecting link between serpentine and greenstone.

Downs of serpentine soap-rock, &c.

From the cove we ascended to the high dreary downs which extend for several miles to the north and the north-east. On their western side they are cut down into a cliff which is for a great extent absolutely inaccessible; and in many places presents a smooth vertical escarpment, here and there coated over with steatitic matter, which at a distance might be mistaken for a calcareous incrustation. Where the windings of the coast enabled us to see the face of the precipice, we could not discover any marks of stratification. In the interior, however, where the rock is but partially covered with vegetation; we remarked some obscure and contradictory indications of that structure.

After following the irregular deviations of the coast for about two miles, we descended into a deep ravine by which the rocks were once more cut down almost to the level of the water. I have no doubt but that this opening has been occasioned by a decomposition connected with the presence of a dyke of felspar, or a great wedge of green-stone. At a short distance from the sea, it divides into two branches; and in the northern branch, a granular dyke of quartz and felspar, with an excess of the former mineral, may be distinctly traced among the rubbish which has accumulated in all the lower parts of the ravine.

It is from this locality that the greatest part of the Cornish soap-stone has been extracted. The history of its formation is not difficult. Where vertical masses of different structure are associated together, we may suppose that considerable fissures would be formed at the moment of their consolidation, from the unequal contraction of the adjacent parts. It is also a fact, established on general experience, that such associations are often productive of partial decomposition. Nothing, therefore, could be more probable than the existence of a vein filled with materials derived from the neighbouring rocks, and running along the side of a dyke such as we have just described. Unfortunately for us, the work had been abandoned before we visited the district. The dyke and soapy vein were so deeply covered with earth, in the direction in which they had last been excavated, that the value of the material would not pay the expense of its extraction.

Green-stone and serpentine, &c.

In ascending from the soap-rock valley to the northern Table Land, we observed something which resembled a separation into distinct beds, which had a regular inclination towards the east. On the downs we found a very coarse kind of serpentine, which had a decided cleavage, and the direction of the layers was marked by parallel streaks on the weathered surface of the blocks. I think it right to notice these facts, especially as they seem to militate against some opinions which I have already ventured to express. The cliff continued of the same general aspect, and had the same bold perpendicular escarpment until the formation was succeeded by green-stone. At the junction there was the usual decomposition, without any indication of regular superposition among the contiguous masses. The green-stone soon passed into green-stone slate of a light colour from the great proportion of whitish felspar. Like all the other varieties of the same rocks, it was cloathed with great quantities of lichen; and when struck with a hammer, it gave out a strong argillaceous odour. At a considerable distance to the north of this junction, we remarked a grassy slope which intruded on the rugged face of the precipice: and we were not surprised to find that this sudden change in the character of the cliff, arose from the presence of an inconsiderable bed of serpentine; which seemed to rise, in the form of a dyke, through the prevailing rock. The slaty green-stone was afterwards continued, without any apparent interruption to the western side of Mullyan-cove, where the cliff was once more composed of serpentine.

Mullyan Cove.

Many parts of the neighbouring coast are of grand elevation, and broken into the noblest forms; but we shall only attempt a description of such of its features as appear to be connected with the geological relations of its component parts. The island on the south-western side of the cove was evidently, at one time, a prolongation of the serpentine; and its present separation from the main land has arisen from the irregular retreat of the coast, connected with the decomposition of those beds which were in contact with the green-stone. The corresponding parts of the cliff consisted of a coarse variety of dull green and black serpentine; which exhibited occasional traces of a slaty structure, and contained many very small olive-green crystals of diallage. On approaching the eastern extremity of the cove, the escarpment gradually diminished; and the lowest part of its degradation marked out the spot where the green-stone once more appeared. Before we descended into the cove, we had from the southern heights observed a fine projecting mass of rock, which formed the opposite headland, and was nearly cut off by the deep indentations of the coast. The south side of this projecting ledge was covered with some large prismatic blocks, like those at Balk Head, and some other parts of the eastern coast. This induced us to believe that the serpentine would appear to the north of the cove, and be there associated with green-stone. We were not disappointed in these anticipations: for on the north side of the cove, within three hundred yards of the path leading up from the fish houses, there are three distinct alternations of green-stone and serpentine.

I lament that I had no opportunity of revisiting this cove, and of ascertaining, as far as possible, the extent and range of the several formations. The valley which ascends from the cove, affords a very favourable opportunity for making out these relations. It has been asserted that the serpentine and green-stone are here distinctly stratified. Our observations, as far as they were confined to the cliffs, would not lead us to that conclusion.

Native Copper, &c.

Small pieces of native copper are occasionally found in the cliffs near the cove. We saw one specimen, more than an ounce weight, which had been taken out of a solid block of serpentine. We have already mentioned the copper works which were formerly opened in this neighbourhood. Soap-stone has been extracted from a vein near Mullyan, but the works were deserted when we passed through the country. Specimens have been obtained from them, in which coal-black crystals of hornblende are scattered through the steatitic mass. As an example of analogous structure, we may mention a thin vein, west of Coverack Cove, composed of greenish steatite with crystals of diallage.

End of the serpentine formation.

The last mass of serpentine which appeared to the north of Mullyan Cove, did not occupy the cliff for more than sixty or seventy feet, when it was succeeded by a coarse green-stone, which was continued to Bollerium. The cliff there disappears, and a small valley ascends from the sandy beach towards Mullyan Church-Town; commencing exactly at the demarcation of the green-stone and the killas. In the alluvial cap, which rested on several parts of the cliff near Mullyan Cove, we had observed many fragments of clay slate. This seemed to indicate that we were approaching a new formation; and at the same time to prove that the last current which had swept over the high southern terrace, must have set in from the north. Immediately on the south side of Bollerium, the cliffs were very ruinous, and much intersected with veins, containing ferriferous carbonate of lime: these veins were in some cases as ruinous as the beds which they traversed. The larger masses, however, distinctly belonged to the green-stone formation. A little farther south they were better characterized, and cut through by many fissures, without appearing to be stratified.

Killas from Bollerium to Loe-Bar.

On the north side of the same cove the most common variety of killas rose from under the strand at an angle of thirty or forty degrees. The beds dipped to the south-east, a direction which would carry them under the green-stone: but the contact of the two formations was concealed by the same causes which obscured the first junction at Porthalla. The whole coast between Bollerium and Loe-Bar, is composed of beds belonging to the great slate formation of Cornwall; which have, on the average, an inclination towards a point between the east and south-east. There are few places in the west of England where we have a more magnificent exhibition of this formation, and of the peculiar features arising out of the disintegration of its subordinate beds. In a cove about a quarter of a mile north of Gunwalloe church, there are many contemporaneous veins of quartz, and some very complex instances of contortion. The beds in the lower part of the cliff are twisted into a system of gothic arches, and the upper portions exhibit a similar curvature in an inverted position; so that the lancet shaped masses from above are supported in the interval between the lower system of arches. We do not recollect to have ever seen a curvature more difficult to account for by the ordinary action of mere mechanical forces.

Our observations on this part of the coast, enable us to enter upon no details: but the formation may be described generally as a coarse variety of clay slate; presenting alternations of soft silky beds, and hard quartzose masses, both of which occasionally pass into other beds, in which there are indications of an arenaceous texture. We saw no well characterized greywacké like that of Nare Point. At the same time there can be no doubt but that the slate between Loe-Bar and Bollerium, is coeval and continuous with the formation which stretches from the Helford river to Porthalla. Comparing all these strata with certain portions of the great killas formation, which contain beds of lime-stone full of organic remains; we conclude that the slate on the northern skirts of the Lizard district belongs to the class of older transition rocks. It must however be conceded, to those who hold a contrary opinion, that no beds have yet been met with on this part of the coast, containing traces of beings which possessed an organized structure.

Our observations on the coast ended at Loe-Bar; which is chiefly remarkable as forming the only boundary between the sea and an extensive fresh-water lake. Between that place and Helston we saw nothing worth recording except the occurrence of one or two conformable beds of green-stone, in position and texture Loe-Bar.

exactly resembling many of those I described in a former paper.

Natural sections.

As the bearing of the stratified rocks on the north side of the peninsula is nearly east and west, it is obvious that the denudation of the coast must expose the several beds in their order of superposition. But in other parts of the district where the subordinate masses resemble irregular contemporaneous aggregations, formed in a common solvent, it is not to be expected that any two parallel sections should present the same succession of formations. Hence arise the separate phenomena of the eastern and western coasts; which, however nearly related in their leading circumstances, differ entirely in their details.

Recapitulation.

From a general review of the facts already stated, it appears that a section made from the heights above Constantine, to the mouth of the Helford river, and from thence to Old Lizard Head, in the general direction of the coast, would exhibit a series of formations nearly in the following order:

1. Granite containing an excess of mica at it's junction with the slate.
2. Clay slate.
3. Clay slate associated with greywacké slate, and containing subordinate parts, in which are conglomerate, common greywacké, and fine grained sand-stone.
4. Serpentine surmounted by granular diallage rocks, and amorphous green-stone passing into green-stone slate.
5. An extensive porphyritic formation, composed of felspar, diallage, and hornblende.
6. Nearly compact masses formed of the same constituents, associated with a very large grained diallage rock, and alternating with serpentine.
7. Serpentine irregularly associated with saussurite, diallage rock, green-stone, green-stone porphyry, green-stone slate, and granular felspar.

8. Green-stone slate.
9. A formation apparently interlaced both with the green-stone slate and the serpentine, and composed of chloritic slate, (in one place associated with some thin beds of mica slate,) talcose slate, and slaty felspar.

A similar section, formed in the direction of a line drawn from Old Lizard Head to Loe-Bar, and prolonged to the granitic ridge, would not include the serpentine (No. 4.); and would pass to the west of the porphyritic formation (No. 5.). In other respects the leading facts would very nearly correspond.

In the preceding details I may have been led into some inaccuracies, by the imperfection of memoranda which were not made with a view of their becoming the foundation of any subsequent communication. I have, however here advanced no opinions which are at variance with those I formed on the spot; and I may, at the same time, express a hope that no essential fact has been misrepresented. Conclusion.

In those great beds which form the lower part of the crust of the earth, and have taken their present form, rather from crystalline arrangement, than from the action of mechanical forces, we shall never, perhaps, discover any certain order of collocation or superposition. But enough has been discovered to prove that nature has at all times acted by general laws. We may, therefore, be justified in referring two such formations, though existing in parts of the globe, which are remote from each other, to the same epoch; especially if their general circumstances of association be the same. To such an end, details like those which are given in this paper, may be eventually subservient.

Geologists have described two formations of serpentine, one belonging to primitive, the other to transition rocks. I have already expressed an opinion that the Lizard serpentine belongs to the latter class. The limits between primitive and transition rocks are so ill defined, that many of the formations which are now separated may hereafter be brought together, when the different eras in the natural history of the earth are better understood. On this subject I think the observations of Berger of considerable importance.* The masses of serpentine which exist on the Italian side of the Alpine chain are too well known to be insisted on. The Woodwardian Museum has lately been enriched by a series of Geological specimens, brought from the Isle of Elba by Professor Clark of Trinity College. A suite might be selected from them, composed of granite, gneiss, clay slate, diallage rock, iron-stone, and serpentine, in such a way as to form a counterpart to most of the mineral beds between the central granite of Cornwall and Lizard Point.

To Von Buch we are indebted for our knowledge of the country which extends on both sides of the great Scandinavian chain as far as North Cape. From his description of the rocks near Jockulsfiord †, the order of superposition appears to be as follows: — 1. Gneiss; 2. Mica slate, passing into quartz-rock; 3. Green-stone, and occasionally diallage rock. He then observes that diallage rock is seen near Bergen, resting both on mica slate, and on clay slate. From all which he concludes, that the diallage rock of Norway may be placed in the neighbourhood of clay slate. Again (chap. 7.) he describes the succession of formations near Altengaard to be, 1. Quartz rock; 2. Granular limestone; 3. Clay slate; 4. Quartzose sand-stone; 5. Granular hornblende; 6. Grey diallage, and white felspar. The quartz rock sometimes passes into a sand-stone, with which one might expect greywacké to be associated. In some instances greenish black diallage, unmixed with felspar, reposes on the other beds.

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* See Geological Transactions, Vol. I. p. 131, &c.

† See the English Translation of Von Buch's Travels in Norway, p. 232—234.

From these details he concludes, that the suite belongs to the clay slate formation, but *that it does not rise up to the transition formations of more southern latitudes.* Lastly, in ascending from Altengaard towards the south, p. 334, &c., he observed, 1. Quartz and quartzose sand-stone; 2. Mica slate; 3. Clay slate with beds of diallage rock; 4. Pure diallage rock. I do not recollect that this celebrated naturalist observed serpentine in connexion with any of the beds above enumerated. But from all I have seen, as well as from the best authorities with which I am acquainted, I am disposed to consider certain varieties of serpentine as a modification of diallage rock* rather than as a formation distinct from it.

It is always delightful to trace analogies between the great phenomena of nature, even in cases where no certain conclusions can be drawn from them. There is, I think, more than a mere fancied resemblance, between certain parts of the formations in Norway, and in the Lizard; enough perhaps to justify us in referring the diallage rocks of both localities to the same epoch in the physical history of the world. Von Buch's opinion that the diallage rocks of Norway are *only on the confines of the transition class,* can hardly be opposed to this conclusion, as perhaps no two naturalists would agree in fixing the exact demarcation between primitive and transition rocks. Moreover the evidence on which I have attempted to determine the age of the serpentine formation of Cornwall, may be considered by many as inconclusive.

It was at one time my intention to have added some remarks on the alluvial formations of the county, and to have noticed some of the sections exhibited in the stream works. Many of these

* The term is here used, in the sense before adopted, for an aggregate of felspar and diallage.

sections are highly instructive, and shew the extraordinary rate at which alluvial matter will sometimes accumulate. I wished also to have noticed the formation of recent sand-stone on the north coast; which appears to have been well known to some of those who collected for Dr. Woodward, as I find several characteristic specimens of it in the old cabinets of our Museum. But this communication has already extended to so great a length, that I shall not trespass any further on the attention of the Society.

XXII. *On Double Crystals of Fluor Spar.*

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[Read *Nov.* 26, 1821.]

Every one who has noticed the specimens of Fluor Spar, of which a great number have lately been brought to Cambridge, and generally designated by the name of Aldstone Moor Fluor, although they are, I believe, found in a district more extensive than that designation would imply, must have observed the peculiarity of their crystallization. The crystals of this substance, are, in their most common form, cubes: but, in the specimens now referred to, these figures are almost universally aggregated in pairs with a certain uniformity of appearance. The cubes seem to intersect and enter each other obliquely; as the proportions of the parts, and number of the angles developed are different, the appearances undergo variations; so that we see sometimes a large cube, with only one corner of a smaller one appearing above its surface; and at other times, two crystals, nearly equal, seem to penetrate and pierce through each other in a very curious manner, which is best understood by specimens. The effort towards this kind of aggregation, at the time of the formation of these crystals, appears to have been exerted almost universally, and in some places it is rare to find a single crystal which has escaped its influence. And so far as the eye can judge, the angles made by the planes and lines of these crystals, are the same in all cases, however different the general form and proportions.

The number and uniformity of these appearances induced me to examine the mode in which the crystalline particles are arranged to produce them, and the result at which I have arrived, though perhaps not very difficult to obtain, may be worth notice, as marked with the simplicity and beauty which nature every where exhibits in the laws which regulate her crystalline productions. To explain my view of the subject, let Fig. 1, represent a double crystal or macle, as it is sometimes called, in the form of most usual occurrence, and which may be considered as the representative of all others. $ABCD$ is the face of a cube, and through this protrudes $EFGH$ the corner of another. It will be observed that so far as the eye can estimate, the pyramid $EFGH$ is similarly situate as to angular position with respect to AB and AC: EGH is an isosceles triangle, and EG, EH make equal angles with AB, AC respectively, so that GH makes angles of 45° with DB, DC. Also the dihedral angles which the planes EFG, EFH make with $ABCD$, will be equal, and, as has already been observed, these are apparently equal in all our specimens of this substance.

To learn the constitution of these crystals we must examine their planes of cleavage. It is well known that in a cube of fluor we may with ease split off each of the eight corners of the cube, so as to cut off from each a regular pyramid, and this division may be carried on so as to produce either a regular tetrahedron or a octahedron. Now it will be found in all cases that one of these planes of cleavage is common to the two associated cubes.

This plane may be distinguished from the others in this manner; it will cut off that corner (A) of the more complete cube ($ABCD$), towards which is pointed the vertex (E) of the isosceles triangle (EHG), on which the pyramid ($EFGH$) stands. It will be found that plates parallel to this plane may be split off through both cubes, and generally without any interruption to mark the transition from one to the other. All the other planes of cleavage which pass through the first cube, it will be found do not belong to the other, and *vice versâ*. If to this observation we add what has already been mentioned, that EF makes equal angles with AB and AC, which is also confirmed by the other fissures of the two crystals,* we shall be able to explain their relation.

Let the plane of cleavage LMN, Fig. 2, pass through the point E, making $AL = AM = AN$, and LMN an equilateral triangle. Conceive the cube, of which F is the visible corner, to be produced within the other, so that O may be the corner which is cut off by the common plane LMN, and therefore OE, OP, OQ equal and EPQ an equilateral triangle. And EO will cut LM at right angles; hence EP and EQ make angles of 60° with LM, and therefore if we suppose E to bisect LM, P and Q will bisect LN and MN. Now the triangles LMN, QPE may be considered as corresponding faces of the tetrahedrons to which the two cubes may respectively be reduced. And the sides of EQP make angles of 60° respectively with those of LMN. Hence it appears that the relative position of the two tetrahedrons is such, that if we conceive a face of one of them to revolve in its own plane through an angle of 60°, it will come into a position parallel to the other.

* It is found that if after splitting the crystals by the plane which cuts off A, we split off the corner F and the one diametrically opposite to D, the new planes of fissure will cut the former plane in parallel lines.

This will, perhaps, become more intelligible in the following manner. A line Aa, joining two opposite corners of the cube, will manifestly be perpendicular to the surface LMN or EPQ. Hence the diagonal of the cube O, &c. is parallel to Aa; and this cube O, &c. may be conceived to have removed into its present position by revolving round this diagonal through an angle of 60°, from a position parallel to the first cube.

Here, as in all other parts of crystallography, it is the angles only which planes and lines make with each other, and not their magnitudes or places, which we must consider. The point E may be situate any where in the plane $ABCD$, as at A; and the points G and H may be in DB and DC. Also whatever has been said of the angle F of the *parasite* cube, if I may be allowed to call it so, is true of any other angle, which might appear on the other surfaces of the principal cube. We may then suppose the two cubes equal, their diagonals coinciding, all their angles developed, and we shall have them in such a situation as is represented in Fig. 3. The two cubes may be supposed at first to have exactly coincided, and then one of them having revolved through one-sixth of a whole revolution, would come into its present position, in which the position of its faces and edges, with respect to those of the other cube, are exactly what are found to exist in what I have called the parasite cubes, with respect to the principal ones, in fluor spar.

From this mode of conceiving the constitution of these crystals, we can easily calculate the angles of the different planes, &c., and compare them with those obtained by measurement. It is to be observed, however, that this comparison is not so much to be trusted as the results obtained by cleavage, because the surfaces, when of any extent, are not accurately plane, as may be seen by inspection, and also, because the form in most cases, is not, strictly speaking, a cube simply; but each face of the cube is replaced by a very flat square pyramid; so flat indeed, as scarcely to destroy the cubical appearance to the eye, but sensibly affecting the measured angles. With allowances for these irregularities, the results of my measurements agree as nearly as could be desired with calculation: the difference being generally under 30 minutes.

Having at first found some difficulty in measuring the re-entering angles of crystals of this kind, it may be of service to mention, that such angles may easily be found by means of the reflecting goniometer, by using an object of considerable elevation. If no other can be found, a candle may be placed near the cieling, and brought to coincide with a mark on the floor. In this case, to insure accuracy, it ought to be ascertained that the candle, the mark, and the crystal, are in the same vertical plane, which may easily be done by looking at them all at once along a plumb-line: the goniometer being as usual supposed to turn round a horizontal axis. In crystals which are too large for the application of the reflecting goniometer, the angle may be determined by placing them at some distance from a candle, and bringing the eye to two points at which the reflection of the light from the two surfaces is visible. These two points and the crystal form a triangle, of which the angle at the crystal is double of the angle made by its planes.

To calculate the angles, join AE, NE : produce AE, which will bisect GH in K, and join FK.

$$LN = AN\sqrt{2}, \therefore EN = LN\frac{\sqrt{3}}{2} = AN\frac{\sqrt{3}}{\sqrt{2}}, \text{ and } AE = \frac{AN}{\sqrt{2}};$$

$$\therefore \sin. AEN = \frac{AN}{EN} = \frac{\sqrt{2}}{\sqrt{3}}; \cos. AEN = \frac{1}{\sqrt{3}}.$$

Hence $AEN = 54° \, 44'$, and $ANE = 35° \, 16'$.

Also the angle which OE makes with the plane QEP must be equal to that which NA makes with the plane MNL,

$$\therefore \sin. AEO = \sin. (AEN - OEN) = \sin. \{AEN - (90^\circ - AEN)\}$$
$$= \sin. (2AEN - 90^\circ) = -\cos. 2AEN$$
$$= 1 - 2\cos.^2 AEN = 1 - \frac{2}{3} = \frac{1}{3},$$
$$\therefore FEK = AEO = 19^\circ\ 28', \text{ and } FKE = 70^\circ\ 32',$$

which is the angle made by the planes $ABCD$ and FGH.

Also since $\sin. FEK = \frac{1}{3}$, $FK = \frac{EK}{3}$, $\therefore FE = EK\frac{2\sqrt{2}}{3}$,

and $KG = FK$, $\therefore \tan. GEK = \frac{1}{3}$, and $GEK = 18^\circ\ 26'$,

$\therefore$ the angle which GE makes with AB is $26^\circ\ 34'$. Also $\cos. GEK = \frac{3}{\sqrt{10}}$;

hence $\cos. GEH = -\cos. 2GEK = 2 \cdot \frac{9}{10} - 1 = \frac{4}{5}$,

and $\cos. FEG = \frac{EF}{EG} = \frac{EK}{EG} \cdot \frac{2\sqrt{2}}{3} = \frac{2}{\sqrt{5}}$, and $FEH = FEG$.

If with the centre E we describe a sphere meeting EF, EG, EH in α, β, γ, the sides of the spherical triangle will measure angles already found; and to find the angle β which is the inclination of the planes EFG and $ABCD$, we have,

$$\cos. \beta = \frac{\cos. \alpha\gamma - \cos. \alpha\beta \cdot \cos. \gamma\beta}{\sin. \alpha\beta \cdot \sin. \gamma\beta} = \frac{\frac{2}{\sqrt{5}} - \frac{2}{\sqrt{5}} \cdot \frac{4}{5}}{\frac{1}{\sqrt{5}} \cdot \frac{3}{5}} = \frac{2}{3}, \therefore \beta = 48^\circ\ 11'.$$

If EI be drawn parallel to AC, meeting GH produced in I;

$$KI = EK, \text{ and } EI = EK\sqrt{2}.$$

$$\cos. FEI = \frac{FE}{EI} = \frac{EK\frac{2\sqrt{2}}{3}}{EK\sqrt{2}} = \frac{2}{3}, \therefore FEI = 48^\circ\ 11',$$

and FC makes the same angle with AB.

These angles are calculated on the supposition that the faces of the cubes are accurately developed. In comparing them with observation, allowance is to be made for the modifications and irregularities already mentioned.

One of the most remarkable circumstances with respect to the specimens which have been the occasion of this investigation, is the apparent want of symmetry in the way in which the two crystals are aggregated. From what has already been said, it will be seen that this defect of simplicity is only apparent. The face EPQ of the tetrahedron belonging to one cube, may be considered as the face LMN belonging to the other, in a position exactly inverted. All the tetrahedrons belonging to one cube will of course be in positions parallel to each other; and if in Fig. 4, $LMNS$ be one of these, $EPQS$ will be the position of the tetrahedron belonging to the other cube; PQ being parallel to LM. Whatever be the forces by which the crystalline particles are aggregated and retained in the forms in which we see them, it is easy to conceive that if they would produce equilibrium when the tetrahedrons are all in similar positions, they would also produce it when some of them are in this inverted position; just as a pillar which would stand upon its base, would also, mathematically speaking, stand upon its vertex. If the position of the crystals with respect to each other had been any other than it is, this difficulty would have been perplexing, as it would have indicated in the crystals the uniform choice of a certain angle, without any thing in their constitution to distinguish it from any other. By considering the subject in this point of view we may infer, that if we find in any substance pairs of the crystals associating with each other in relative positions which are always the same, the nuclei of each of one set of crystals will be in symmetrical positions with regard to those of their companions respectively, one set being put in some regular inverted position.*

* I have examined several double crystals of fluor for the purpose of discovering how far each cube penetrates the other, and what is the form of the surface which separates the

I have not yet had an opportunity of examining any other substance in which this uniformity in the juxta-position of crystals takes place. Probably, however, there are others, and I will therefore explain a process, by which, whenever this regular law is found to exist, we may ascertain the relative positions of the nuclei of the conjoined crystals.

When two crystals penetrate one another, we may conceive one of them, which I will, as before, call the parasite crystal, to have come into its position, (having been originally parallel to the principal crystal,) by revolving about a certain axis through a certain angle. This axis and angle are what we have to determine.

Let CAO any plane, (Fig. 5,) revolve about an axis OP passing through a point O, so as to come into the position caO: and let OQ be the intersection of the first and second position. If we suppose a plane perpendicular to OP in the point P to cut the planes in the lines AQC, aQc, respectively, APa will be the angle through which the plane has revolved about the axis OP. Also if we suppose PM, Pm to be perpendicular to AC, ac, we shall have $PM = Pm$, $\therefore$ $MQ = mQ$, and $MPQ = mPQ$.

$$\text{Let } AOM = aOm = \delta,\ MOQ = \phi,\ POM = \mu,$$

$$APa = MPm = \theta;\ \therefore\ MPQ = \frac{\theta}{2}.$$

$$\tan.\ \phi = \frac{MQ}{MO} = \frac{MQ}{MP}\cdot\frac{MP}{MO} = \tan.\ \frac{\theta}{2},\ \sin.\ \mu.\ \ldots\ldots\ldots\ldots \quad (1)$$

$$AOQ = \delta + \phi;\ aOQ = \delta - \phi,$$

$$\therefore\ \delta = \tfrac{1}{2}\,(AOQ + aOQ);\ \phi = \tfrac{1}{2}\,(AOQ - aOQ)\ \ldots\ldots \quad (2)$$

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the parts of the crystallized substance belonging to each. So far, however, as I have yet observed, there is no regularity in the proportions or division of the crystals; the transition is completely abrupt from the part which allows division by the planes of one tetrahedron to that which does not, but the lines of separation are quite irregular.

Let a sphere QRr be described with centre O and radius OQ, cutting AO, aO in R, r. If AO be considered as unity, we shall have,

knowing $QR = AOQ$, $Qr = aOQ$;

and angle RQr = angle of planes AOC, aOc;

to find Rr = angle $AOa = \alpha$;

$$\cos.\ \alpha = \cos.\ RQr\ .\ \sin.\ RQ\ .\ \sin.\ rQ + \cos.\ RQ\ .\ \cos.\ rQ. \quad \ldots\ldots (3).$$

Again, in the plane triangle AQa, the angle $AQa = MPm = \theta$;

$$\text{and } \cos.^2 \tfrac{1}{2}\,\theta = \frac{(AQ + aQ)^2 - Aa^2}{4\,AQ\,.\,aQ}$$

$$= \frac{(2\,AM)^2 - Aa^2}{4\,AQ\,.\,aQ}.$$

Now $AM = AO \sin.\ \delta$, $Aa = 2\,AO \sin.\ \tfrac{1}{2}\,\alpha$,

$$AQ = AO\,.\,\frac{\sin.\ AOQ}{\sin.\ AQO} = AO\ \frac{\sin.\ (\delta + \phi)}{\cos.\ \phi};$$

$$\text{similarly } aQ = AO\,.\,\frac{\sin.\ (\delta - \phi)}{\cos.\ \phi}.$$

$$\text{Hence } \cos.^2 \tfrac{1}{2}\,\theta = \frac{(\sin.^2 \delta - \sin.^2 \tfrac{1}{2}\,\alpha) \cos.^2 \phi}{\sin.\ (\delta + \phi) \sin.\ (\delta - \phi)} \quad \ldots\ldots (4).$$

Hence if we know the angles AOQ, aOQ, and the angle made by the planes AOC, aOc, we can find the axis and the angle described about it.

For by (2) we know δ and ϕ.

Then by (3) we find the angle α.

And by (4) we find θ.

From which by (1) we find μ.

Knowing $AOM = \delta$, and $MOP = \mu$, we know the position of the axis OP, and θ is the angle described about it.

If now the planes AOC, aOc instead of cutting the axis in O, be removed parallel to themselves to any distance from the axis, the lines AO, aO also retaining their parallelism, the same properties as before will be true of the plane and dihedral angles made by them. Hence, if we suppose these planes to be homologous faces of a crystal, and AO, aO to be any homologous lines in these faces, the above formula will give us the axis and angle of revolution by which one crystal might come into the position of the other, supposing that we observe the angle made by the homologous faces at their intersection, and the angles made by AO, aO with this intersection. AO, aO may be any corresponding lines in the two faces, as for instance, similar edges of each face, or lines of fissure in each. From what has been said, it is to be expected that when we find by this means the axis of revolution, it will be some principal line in the nucleus of the crystal. In the case of the tetrahedron, it appeared to be a line perpendicular to one of the faces; in a parallelepiped it would probably be a diagonal, and similarly in any other case.

We might apply these formulæ to the case of fluor spar, and in such a figure as a cube, where the sides are not distinguished from each other by their configuration, we should have more than one way of considering the problem. Either the face EFG or FGH may be considered as homologous to $ABCD$. On the former supposition, we find, as before, that the parasite crystal has revolved round its diagonal through 60°. On the latter hypothesis we shall find that this crystal has revolved round an axis parallel to GH, through an angle of 70° 32′, the angle between two planes of a tetrahedron. In the former case the revolution is about the axis of the tetrahedron, in the latter about one of its edges; and it is easy to see that after both these changes the new position of the solid is the same. In Fig. 3, we may either imagine that by revolving round the axis Aa, the corner B comes into the position F; or that by revolving round an axis passing through the bisections of two opposite sides, namely, a line through X parallel to BC, A comes to F.

Before I quit the subject, I will make an observation respecting the constitution of crystals. Hauy seems to have been in doubt whether to consider the tetrahedron or the octahedron as the *integrant molecule* of fluor. If the integrant molecule be defined to be the *simplest* form at which we can arrive by mechanical division, the tetrahedron ought to be taken, for that solid is bounded by the four planes according to which the crystal is divisible, whereas in the octahedron, each of these planes is used twice. The results of the preceding investigation may be said to prove the same thing, for the symmetry in the position of the inverted molecules, considered as tetrahedrons, is less easily explained by considering the nucleus as an octahedron. It appears, however, to me, that the term *integrant molecule* is applied with considerable vagueness, and used in consequence of an erroneous supposition. According to the obvious meaning of the words, it would imply that the whole crystal is made up of such similar molecules. Now at the first sight it was no doubt a very natural idea, that the reason why crystals split in certain directions, rather than others, is because those planes pass along the surfaces of the small component particles; and are, as Hauy calls them, the *joints* of its structure: and on this supposition it followed that the ultimate results of mechanical division give the form of these component particles. This supposition, however, seems to be completely overthrown by the single observation, that the forms thus obtained are often, as in fluor, such as will not fill space. Tetrahedrons or octahedrons cannot make up a crystal, without leaving interstices; and accordingly, Hauy, in describing the structure of the substance before us, has been obliged to conceive these solids hanging together by the edges in a way which makes this cease to be a *simple* explanation of their splitting by the faces of these particles. The inconclusiveness of the inference I have mentioned may be perhaps conceived more readily in the case of a plane figure. If a thin plate of matter of any kind were easily divisible by lines at right angles to each other, we might suppose this to arise from its being made up of small rectangles. If it were divisible in *three* directions, making angles of 120° with each other, we might imagine it to be made up of equilateral triangles. But if it were divisible in *five* directions, making equal angles with each other, we could not infer it to be made up of regular *pentagons,* because these could not fill a plane surface; and to suppose it made up of pentagons combined with other figures, would be to abandon the simplicity on which alone the probability of the supposition is founded.

The ultimate fact, therefore, to which observation conducts us, is, that the crystals in question are divisible according to the four planes of a regular tetrahedron: and the phrase "*integrant molecule*" is erroneous when it implies more than this. The causes of this divisibility are probably those forces exerted by the crystalline particles by which their aggregation has been determined. We may suppose, with Dr. Wollaston, that these particles are spherical; but this alone will not account for the facts, and some additional supposition is requisite: We may imagine, for instance, that the forces reside in centers at the angles of a regular tetrahedron inscribed in one of these spheres. This would make their effects conceivable, but is mere hypothesis; and the recent discoveries with respect to magnetic and galvanic action, seem to indicate that the whole stock of forces by which nature arranges the particles of matter, does not consist merely of repulsions and attractions tending to *centers.*

W. WHEWELL.

Trinity College,

Nov. 25, 1821.

Fig. 1.

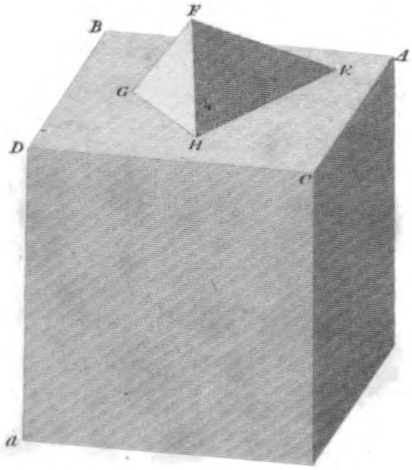


Fig. 2.

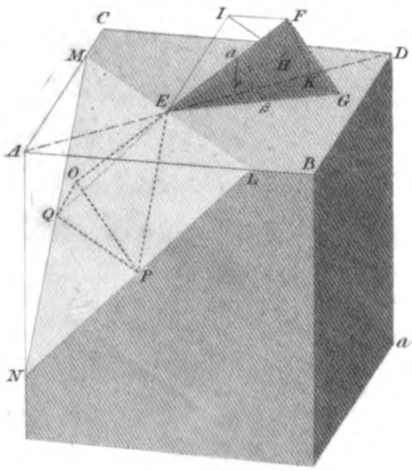


Fig. 4.

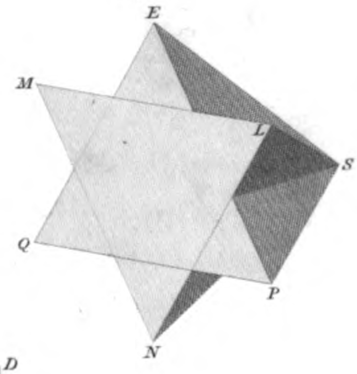


Fig. 3.

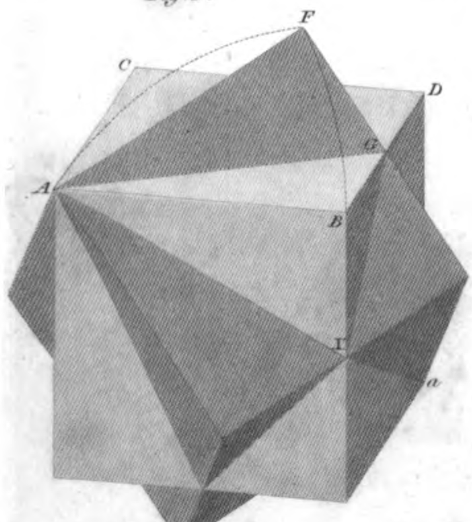
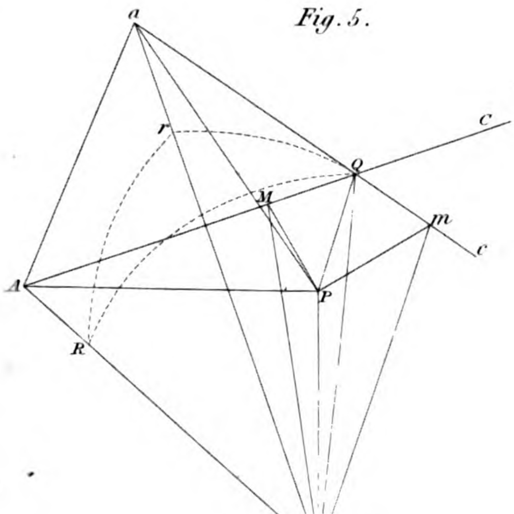


Fig. 5.



W. Lowry, sc.

XXIII. *On an Improvement in the Apparatus for procuring Potassium.*

By WILLIAM MANDELL, B. D.

FELLOW OF QUEEN'S COLLEGE.

[Read *Nov.* 26, 1821.]

On repeating the late Professor Tennant's experiment for procuring Potassium,* (which differs from the similar one first made by the French chemists, Gay-Lussac and Thenard,† principally in being more simple and commodious for practice,) it occurred to me, that one part of the apparatus made use of, might, with advantage, be still further simplified: and as every circumstance, however apparently obvious or trivial in itself, which, in any degree, tends to facilitate the production, in greater quantity, of so powerful a chemical agent as potassium, is of importance, I have thought that the mode of operating which I pursued might not be wholly unworthy the notice of this Society.

It is well known that the grand difficulty in successfully performing the experiment in question, consists in protecting the gun-barrel from the effects of that extreme and long-continued

* Philosophical Transactions for 1814, p. 578, to which the reader is referred for the detail of the process.

† Annales de Chimie, tom. 66, p. 205.

heat, which is necessary to decompound the alkali, and to volatilize its base. The usual practice hitherto has been to surround with a *lute,** that portion of the gun-barrel which is introduced into the fire. This operation, however, is always tedious; and although it be conducted even with the greatest care, it is found extremely difficult to prevent fissures in the coating, particularly when the heat is much increased in the course of the experiment. Hence, if eventually the fire have direct access to the barrel, through any crevice which may be formed, the fusion of the denuded part is generally the consequence, and the whole labour of the experiment is lost.

This, then, being the common cause of failure, it occurred to me that, if there were substituted for the luting, a thin, but sound and well-burnt *tube* or *hollow cylinder* of Stourbridge clay, of such dimensions as just to cover that portion of the barrel which is subjected to the fire, the unfortunate result, which I have alluded to, might possibly be avoided.

A tube of this description was accordingly procured; and, in order to guard against the hazard of its cracking, by reason of exposure to a sudden increase of temperature, it was, in the first place, gradually and with caution, heated to redness.

The remaining part of the experiment was then performed with entire success; and a very considerable quantity of potassium obtained.

It may be proper to remark that the hollow cylinder, and that portion of the gun-barrel which it incloses, should be of such

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* "On couvre cette partie moyenne d'un *lut* infusible." Gay-Lussac et Thenard, Ann. de Chimie, tom. 66, p. 207.

"The *lute* which I have found most effectual .... was composed .... of Stourbridge Clay .... &c." Tennant, Phil. Trans. for 1814, p. 582.

"It (the gun-barrel) is then covered with an infusible *lute*." Brande's Manual of Chemistry, p. 184. Ed. 1819.

relative diameters that, when cool, their corresponding surfaces are not quite in close contact; otherwise, the cylinder will be in danger of bursting, not only on account of its own contraction, but also on account of the simultaneous expansion of the gun-barrel, from the effects of that very high temperature, to which, in this state of combination, they are submitted.

Moreover, the whole apparatus should be supported accurately in the same position, throughout the experiment, (by means of rests made of Stourbridge clay,) and should be so situate in the fire, that the materials operated upon, may during the whole process be subjected to its greatest intensity.

With due attention to these precautions, and to some minor circumstances in the manipulation of the experiment, which I shall not take up the Society's time in detailing, it is believed that the decomposition of potash, by means of iron, might in every instance be effected with almost entire certainty, and potassium be obtained in great abundance.

XXIV. *Notice of a large Human Calculus in the Library of Trinity College.*

BY THE REV. J. CUMMING, M.A. F.R.S. M.G.S.

PROFESSOR OF CHEMISTRY

IN THE UNIVERSITY OF CAMBRIDGE.

[Read *Nov.* 26, 1821.]

IN the Forty-Sixth Volume of the Philosophical Transactions an account is given of a remarkable Human Calculus in the possession of the Society of Trinity College.—Its history, weight, and specific gravity are the only circumstances mentioned in this notice; for, being unsawn, no knowledge of its composition could then be obtained, even had the state of Chemistry at that time permitted it. As, in their internal conformation and in the arrangement of their strata, Calculi present varieties far more important than can be exhibited by their external properties, I requested permission to have this Calculus sawn asunder, which was done with such care and skill by Mr. Okes, that as a specimen it has received little if any injury. Its structure is such as, taken conjointly with its magnitude, to make it, perhaps, the most curious and instructive Calculus in this kingdom, since it presents the characters of not less than four distinct species. The nucleus is lithic, to this succeeds a considerable portion of the oxalate of lime variety, this is followed by layers of the triple crystals, covered by a thick coating of lithic, which is occasionally broken by a layer of the triple crystals, and the external surface is principally composed of the fusible Calculus.—Its present weight, after being sawn, is 32 oz. 7 dr.; the specific gravity 1.756, which after being two days in water became 1.768.—It measures 15 inches in circumference in one direction, and $13\frac{1}{2}$ inches in the other.

The largest Calculus in this kingdom, is, I believe, that which is described in the Philosophical Transactions for 1809, which weighs 44 oz.; but it is composed entirely of the phosphates, and, from its structure, seems rather a number of calculi cemented together, than one formed, in the usual manner by concentric layers.—In the description of this Calculus by Sir J. Earle, is given a quotation from Fourcroy, of which it afforded a confirmation, that all the very large Calculi are composed of the Phosphates.—The Calculus which is the subject of this paper, is a remarkable exception to the general rule, as nine-tenths of it at least are lithic.

I have been induced to give this brief notice of it to this Society, that, if you think it worth publication, so interesting a specimen may be withdrawn from the obscurity in which it has lain for upwards of a century.

As an appendix to this paper I request your attention to another, and in some respects a similar specimen, presented to me for examination by Dr. Thackeray.

It is a concretion formed in the intestines of a horse, weighing upwards of 64 oz., and measuring $37\frac{3}{4}$ inches in the largest circumference, and $26\frac{1}{2}$ in the least. Its composition, as might be expected, is principally of vegetable matter, but mixed with a considerable portion of the phosphates.

Its enormous size makes it a subject for curiosity, though fortunately, the absence of such concretions from the human frame, divests it of the painful interest we cannot but feel in the former specimen.

Fig. 2.

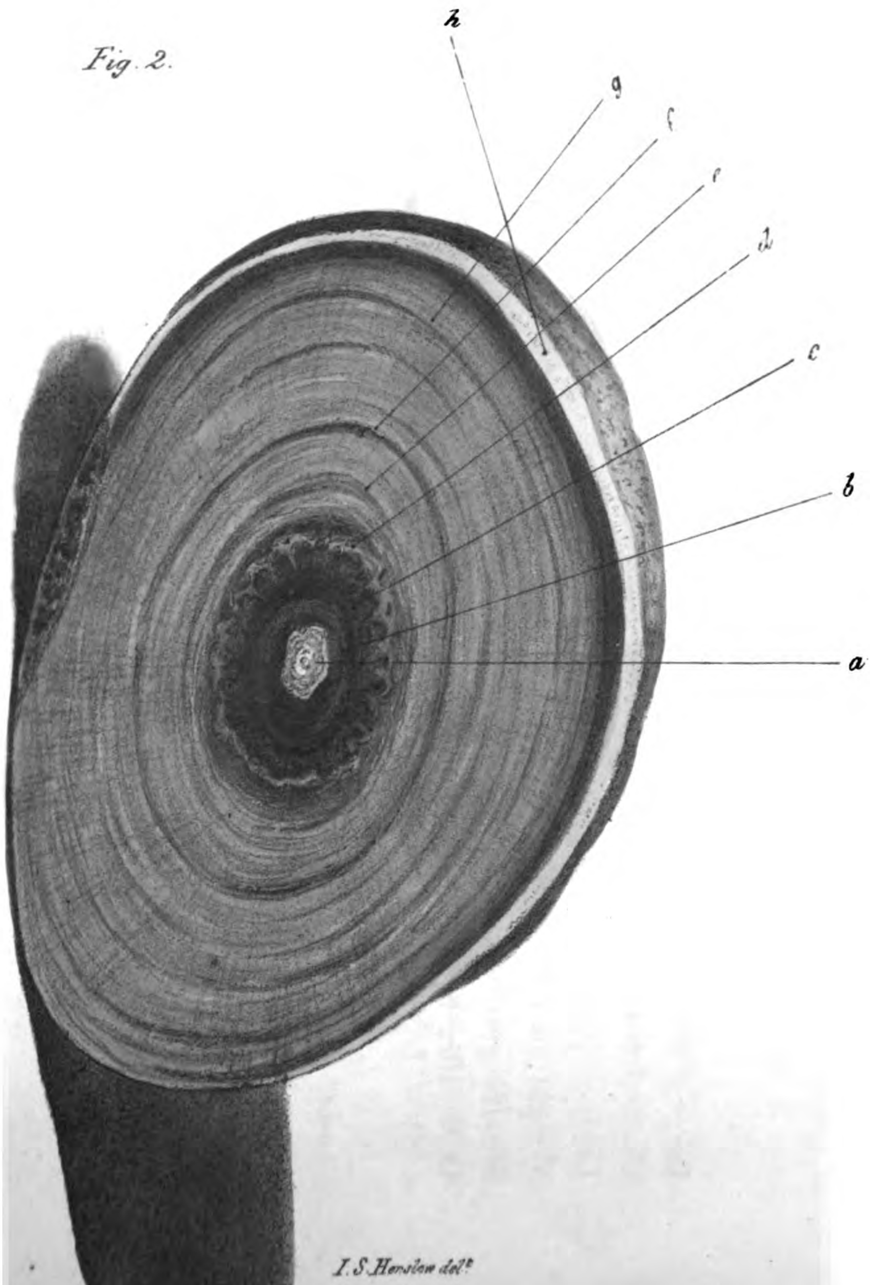
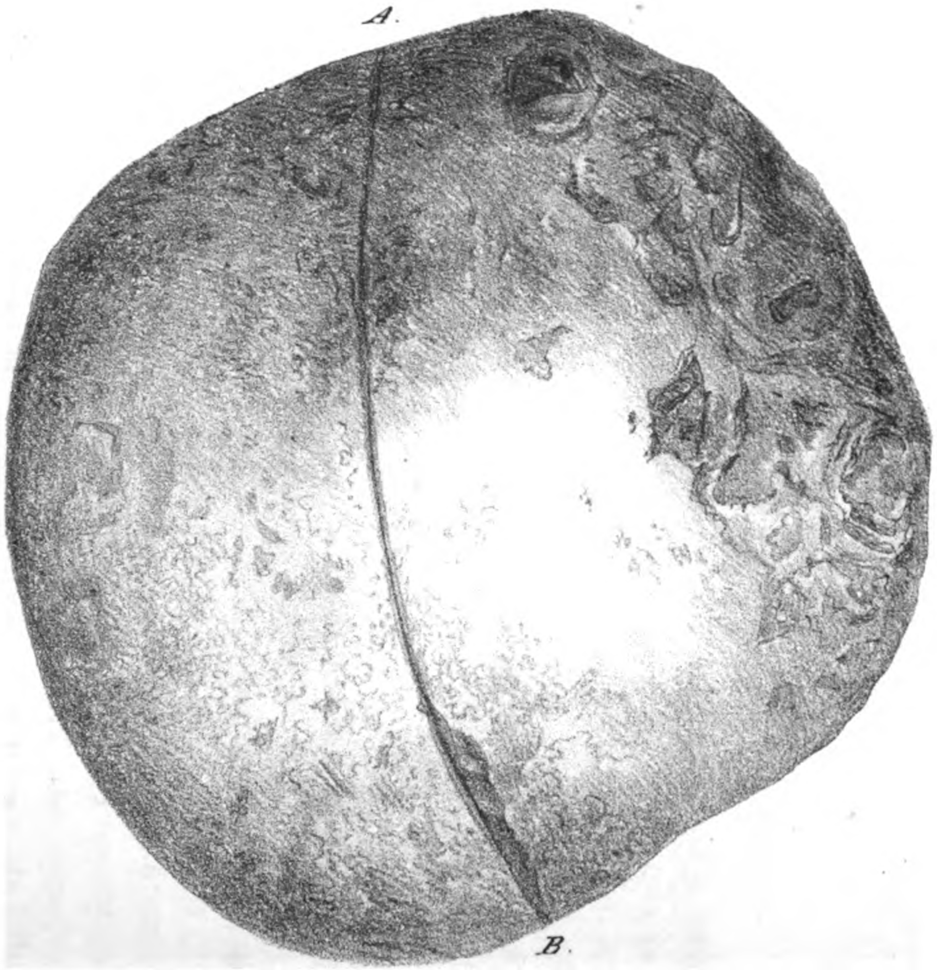


Fig. 1.



I. S. Henslow delt.

Printed by Rowney & Forster London.

DESCRIPTION OF THE PLATE.

Fig. 1. Exterior of the Calculus; the size of the Original.

A. B. The line of section.

Fig. 2. Section of the Calculus.

a. Lithic nucleus.

b. Oxalate of lime.

c. Ditto, mixed with sparkling triple crystals.

d. Triple crystals with a little lithic.

e. Lithic, with minute layers of fusible Calculus.

f. Triple crystals, (four thin layers).

g. Lithic.

h. Fusible.

	Inches.
Largest circumference	15.
Circumference of the section	13.1
Least circumference	11.7
Weight after being sawn, (exclusive of the dust),	32 oz. 7 dr.
Specific gravity	1.756
Ditto, after being two days in water	1.768

XXV. *On a Dilatation of the Ureters, supposed to have been caused by a malformation of their Vesical Extremities.*

By JOHN OKES, Esq. of Cambridge.

HONORARY MEMBER OF THE CAMBRIDGE PHILOSOPHICAL SOCIETY,
MEMBER OF THE COLLEGE OF SURGEONS, &c.

[Read *November* 12, 1821.]

Although extensive dilatation of the ureters consequent upon obstruction be by no means rare, yet it cannot be said to occur frequently, particularly to the degree remarked in the instance which forms the subject of this paper. It is not however the magnitude, so much as the cause of the derangement, which deserves our notice in the case about to be related. In those upon record, the causes of obstruction have been generally ascertained to be calculi and tumors compressing the tubes. Sabulous, purulent and mucous accumulations have been thought by some, sufficient to obstruct those passages. Of the first and most common kind Monro mentions an instance, in which "the lower aperture (of the ureter) being filled up by a stone, the kidney was distended to a monstrous size; and the ureter was so large, that, at first sight, he mistook it for a piece of intestine*." A dilatation of equal extent was found by Morgagni, in a person who died from a large stone in the bladder. "Pure autem et urinâ pleni erant renes et ureteres; immò hi tam distenti ut Ilei intestini diametrum æquarent†." A still stronger instance of the extensibility of the ureters occurred to Ruysch‡. He precedes his history by a remark, in which he is by no means singular: that the unnatural distension which membranous tubes undergo, is accompanied by a proportional thickening of their substance.

Malformations of the ureters, at their junction with the bladder, may be reckoned among the causes of their enlargement. But examples of this kind are of very rare occurrence, and may be easily confounded with the effects of disease upon these ducts. The least doubtful instance, next to that I am about to describe, is one that fell under the observation of Ruysch§. The obstructing cause consisted in a membranous

* Monro's Works, 4to. Ed. 1781, p. 542.

† Morgagni opera, (Neapoli 1762.) tom. 3. p. 314.

‡ "Nil magis admiratione dignum crediderim quàm vasa membranacea, quò magis distenduntur, eo magis sæpe ab humore heterogeneo incrassari. —— Ureteres aliquando ita esse dilatatos, ut digitum admittant, rarum non est. Rarissimum tamen et inauditum, ureterem pintam materiæ purulentæ continuisse; —— In ureteris dextri infimâ parte supra insertionem in vesicam calculus hærebat nucis avellanæ magnitudine. —— Pars media dicti ureteris ita erat extensa, ut pintam ad minimum contineret." *Ruyschii* Observatio XCIV.

§ "Vogelesangh, chirurgus diligentissimus, ad dissectionem duos nobis attulit renes ovillos, ita extensos et humore aquoso repletos, ut duas ferè pintas uterque contineret. Ureteres admodum tortuosi et tantæ erant capacitatis ut radicem majorem pastinacæ admitterent. Utraque renum tumentium extremitas substantiam naturalem glandulosam non amiserat, spatium verò intermedium constabat ex membrana. Intrinsecè tubuli pelvis cellulas magnas repræsentabant, tantæ capacitatis, ut nucem juglandem viridi cortice obductam admitterent. Urinam in vesicâ urinaria contentam facili negotio exprimebam versùs ureteres et renes, verumenimverò ab ureteribus et renibus versùs vesicam non nisi vi adhibitâ idque parcissimè per exiguum foraminulum in medio cujusdam clausuræ membranaceæ, quam vesicam inter et ureteres inveniebam. Talis, inquam, erant constitutionis dicta foraminula, ut è vesicâ urinaria versùs ureteres et renes satis liber esset urinæ transitus, expansion stretched over their apertures into the bladder, and perforated in such a manner, that the urine passed through them out of that cavity, much more freely than into it. It may reasonably be doubted, whether such a membrane would be the product of inflammation falling upon a mucous surface. Upon this point Ruysch has expressed no opinion.

The instance which came under my own inspection, occurred in a patient of mine at Addenbrooke's Hospital in Cambridge, a boy of eleven years old. About ten days after his admission, he complained when taking his usual exercise in the garden, of great pain in his body, numbness in his legs, and faintness. He was immediately conveyed to his bed, and, in a few minutes, expired. At the time of his admission into the house, it was thought that some of his symptoms resembled those of stone in the bladder, until an examination by the sound, induced a contrary opinion. Although not greatly emaciated, his appearance was far from healthy; he was of a diminutive stature, pale complexion, and very weak. The unnatural size of his abdomen, led to a frequent and careful examination of it, more particularly as he had complained of pain in that part: but it was always, even when most distended, so soft, as to yield freely to pressure. Sometimes during these examinations, I was inclined to think that a fluctuation was perceptible, yet the idea of a dropsical tendency was abandoned from its being somewhat irreconcileable with the abundant secretion of urine, that had for a long time existed. Again, the figure of the abdomen led to the supposition, that the intestines might be the seat of the enlargement; though this was at variance with the regularity and healthy state of his evacuations, and some cathartic medicine was

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situs, contraria verò compressio ab ureteribus et renibus versùs vesicam maximâ ex parte erat frustranea, unde dubio procul oborta fuit urinæ regurgitatio, et temporis progressu talis renum et ureterum expansio." *Ruyschii* Observatio XCIX.

directed, but with no other result, than that of adding to his excessive debility; for the large and pendulous form of his body continued the same. His urine, when first passed, resembled water rendered turbid by a small quantity of milk, and after cooling, afforded a copious deposit of pus, entirely devoid of the ropy mucous sediment secreted by a bladder under the irritation of a stone. This had been the state of his urine since he was a year old; it had never been known to be tinged with blood, nor to contain any calculous matter; neither had he ever after that age less power of retaining it than the generality of children, but on the contrary, though the desire to discharge it was very frequent, the effort often proved unavailing. To this distressing circumstance his mother attributed his general unhealthy condition as an infant. It was among her observations as well as those of the Hospital nurse subsequently, that the inclination to make water was not so incessant during the night as in the day; and that he would pass many hours in the day-time upon his bed, and even upon the floor, as though he had discovered from experience, that the recumbent was the most efficacious posture for allaying that continual desire to make water by which, for hours together, he was tormented. So severe indeed was the distress which he usually endured, that it seemed scarcely probable his existence could have been so long protracted, without the discovery of some such means of temporary alleviation. He had, however, intervals of comparative ease; these he had occasionally enjoyed for two or three successive months, when he used to recover rapidly, to a certain degree, his strength and spirits. Such were the observations I had partly made and collected respecting this inexplicable case, when, the boy suddenly dying, an opportunity was afforded of investigating still further, its peculiarities. That the urinary apparatus was the seat of the derangement, there could be little doubt, but the train of symptoms was such, as could not be referred to any one of the known diseases, to which these organs are liable.

Dissection.—Nothing remarkable presented itself to notice, until the omentum and intestines were raised from their natural situations in order to obtain a view of the kidneys. It then seemed as if the intestines were adhering to the iliac regions instead of being easily moveable almost from one side of the body to the other, and, as there were no marks of inflammation to be seen, we were at first incapable of accounting for so unusual an appearance. Upon closer inspection I perceived that besides the intestines, I had also attempted to lift up the ureters, which, owing to their extreme enlargement, had been mistaken for intestine. Pursuing the examination, we found the two ureters of nearly equal dimensions, describing in their course convolutions not very unlike those of the intestines, and containing in their lowermost part a large quantity of urine, that flowed freely into the bladder, or back again into the ureters, according as the position of either was varied. The figure and external appearance of the bladder were perfectly natural, but the ureters, instead of taking an oblique direction through its coats, described a curve that placed their extremities almost at right angles to that organ*. The kidneys bore strong marks of disease; their collapsed sides consisting of little more than their own proper tunic, shewed the almost total destruction of their glandular substance, and thereby confirmed the only conjecture which so singular an assemblage of symptoms could

* The transparency of the dried preparation affords a view of the apertures of the ureters into the bladder, which are large enough to admit a common sized goose-quill. These parts, as well as the bladder, exhibit no other proofs of deranged structure. The kidneys are almost entirely destroyed; there remains of glandular substance, in each, a portion equal to about $\frac{1}{30}$ of the whole gland, the other part consists of cells, perhaps thirty in number, which, if solid, would give it the appearance of the fœtal kidney.

reasonably justify. The urinary organs thus exposed, were then brought still more into view by inflating them through the urethra, that a plaister cast might be taken of them. Nothing else occurred in the examination worthy of notice. The cast represented in plate No. 14. and the inflated preparation afterwards made of these organs, were placed in the Anatomical Museum of the University.

The result of this dissection is such as fully to explain the symptoms, but whether it will justify the opinion I have formed, that the malady had its origin in a deficiency of that structure, by which the coats of the bladder act as a valve upon the ureters, remains for consideration. The earliest remarks upon the health of this child occurred during his infancy, and led, even then, to the supposition of some derangement in the urinary passages, and that too of so serious a kind, as to be regarded as the cause of his unthrifty condition. His symptoms, though occasionally intermitting and varying in severity, continued in after years to preserve such a general uniformity of character, that little doubt could be entertained of their connection with those of his infancy, and still less of their appertaining to some disease of the urinary organs. It is therefore most probable that the conjectures which, in his earliest illness, attributed his symptoms to some disease of the urinary apparatus, were so far correct, and that the appearances disclosed by the dissection were the consequence of that primary affection. That the valvular connection of the ureters with the bladder was destroyed in the first instance by obstructions from calculi, may be justly doubted; for his symptoms commenced at so early an age, that had calculi ever passed, they could not have escaped the observation of his mother. Besides, it is unfavourable to such an opinion, that both ureters should present the same appearances, although, on the other hand, it may be said, that a disposition to calculous concretions would be manifested equally in both kidneys. It is certain, however, in this case, that no tendency to this disease was ever discovered, though the attention of the mother had been directed to it from his earliest age, from the belief that his disorders were situated in these organs. As to the suppurative process in the kidneys having been the cause of obstruction to the ureters, it should rather be regarded as the consequence of it. But to explain our own views of this case, let it be supposed that this malformation of the ureters did actually exist at the time of birth. It would then follow, that the urine flowing *guttatim* into the bladder would at length accumulate until it caused that degree of contraction which, in a perfect bladder, would not be sufficient for micturition, though in the instance before us, sufficient to repel it into the ureters; it would therefore be driven back towards the kidneys, and remain in the ureters as long as the action of the bladder lasted. But when the useless effort of that organ ceased, the urine would descend again into its cavity, and the same ineffectual contraction be repeated, until it had at length accumulated so much beyond the capacity of the ureters to contain it, as to acquire from the bladder an impulse sufficient, with that from the abdominal muscles, to overcome the resistance of the sphincter vesicæ. In the natural construction of these parts, the muscular power of the bladder is thought sufficent to finish the evacuation of its contents, unaided by the abdominal muscles, they having first assisted the bladder to overcome the resistance of its sphincter; in the case before us however, there would be this difference, that unless that pressure upon the ureters by the abdominal muscles were continued after the sphincter vesicæ had yielded, no more urine could necessarily be propelled *per urethram* than the excess above what the ureters were capable of holding. It must then be manifest according to this view of the case, that, although the ureters would occasionally be evacuated of part of their contents by this simultaneous action of the bladder and abdominal muscles, still they would not only be often greatly distended, but in process of time would become the ordinary reservoir for the urine.

In the examination of this child it occurred to me as very remarkable, that so abundant a secretion of urine should be capable of being carried on by so small a portion of the kidneys as that which remained. I then regretted that his urine had never been submitted to chemical analysis during his residence in the Hospital; for, from its appearance, I should conjecture that it differed very much from healthy urine in the proportions of its constituent parts, and that it might even have been found to be entirely destitute of some of them.

JOHN OKES.

Cambridge,
Sept. 10, 1821.

EXPLANATION OF PLATE XIV.

The great bulk of the intestines is raised towards the chest, bringing into sight

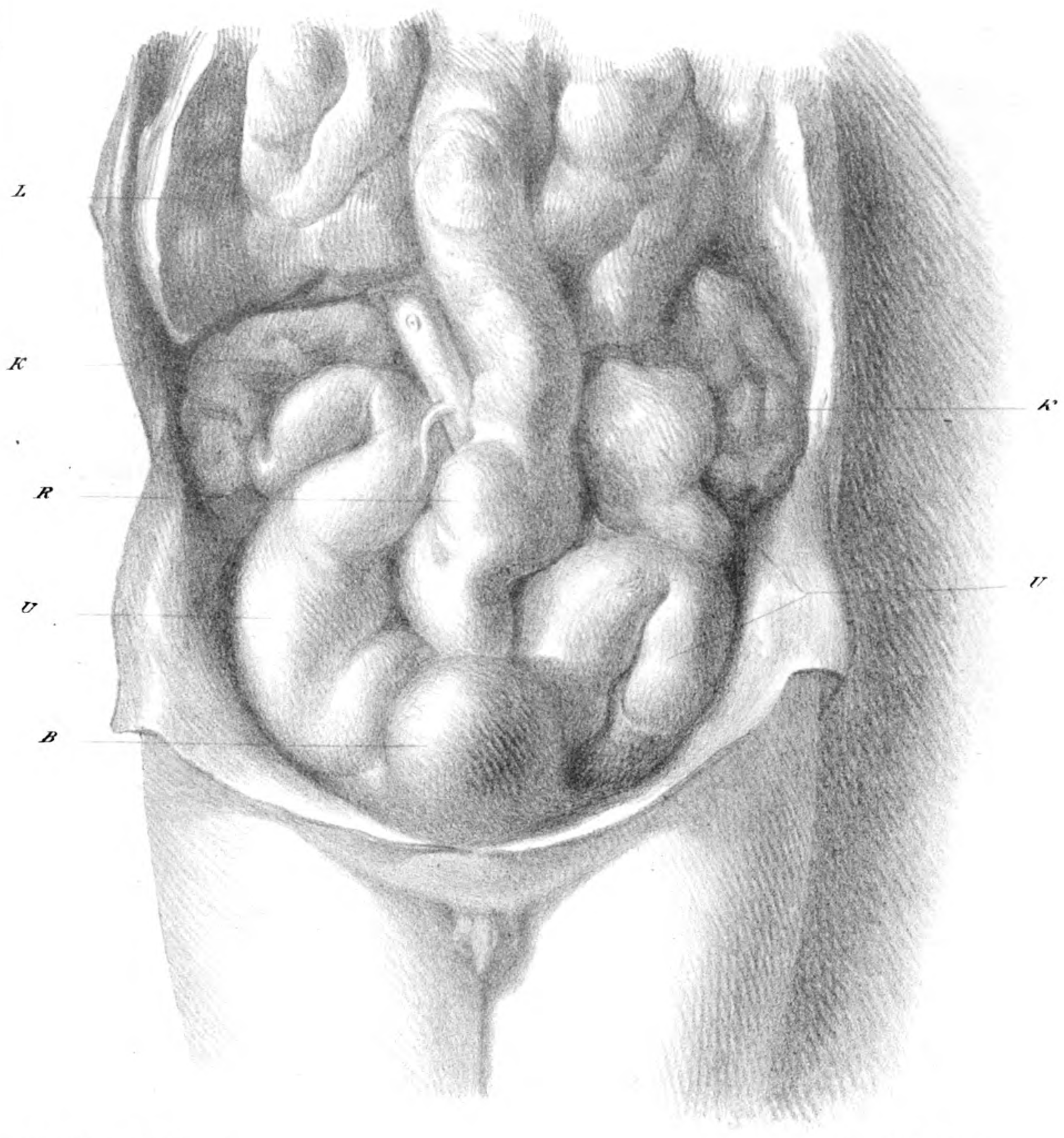
L—Part of the under surface of the Liver.

K—The Kidneys.

U—The Ureters.

B—The Bladder.

R—The Rectum.



Drawn from Nature by R. P. Farrauen

On Stone by G. Scharf

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XXVI. *Geological Description of Anglesea.*

By J. S. HENSLOW, M.A.; F.L.S.; M.G.S.

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[Read *Nov.* 26, 1821.]

To accompany the present Memoir, I have formed a collection of the rocks of Anglesea, which has been placed in the Woodwardian Museum. This collection is numbered throughout, and the number corresponding to any particular specimen is noted between brackets, whenever any allusion is made either to its locality or to the nature of its composition.

I have to acknowledge my obligations to L. P. Underwood Esq., whose previous visits to Anglesea had enabled him to collect many interesting facts connected with its Geology, and to whom I am indebted for the locality of several trap-dykes, which might otherwise have escaped my observation.

I believe that no good map of Anglesea has yet appeared. The map which accompanies this paper is compiled from two maps of North Wales, one by Furnival, published in 1814, the other by Evans, in 1797. The first of these furnishes, with condesirable correctness, the relative positions of the towns and general outline of the country, but does not pretend to trace the indentations of the coast. Evans has enabled me to give some of the latter, where they affect the geological details; but neither in this respect, nor in the configuration of the surface, could I procure any accurate information. What is here offered must be considered as a very rough approximation.

As the map is rather complicated, it has been thought advisable to adopt an artificial arrangement of the different districts in each formation. By this means a reference can more readily be made to any particular place, without the labour of searching through the several detached portions marked by the same colour. A table explaining this arrangement is placed with the description of the plates; and the references are made on the margin whenever they seem to be required. No other places are noted in the map than those alluded to in the paper.

In the accompanying sections, continuous lines are meant to represent the portions actually exhibited. The dotted lines are either such portions as were not visited, or were too much obscured by the concealed nature of the ground. Where no actual section exists, the junctions are marked by the dotted line, even where the boundary between two formations is sufficiently evident at the surface, and the order of collocation has been either ascertained along the coast, or cannot be doubtful from the characters of the contiguous rocks. As the sections are parallel to each other, a reference may readily be made to corresponding portions, and the spot seen where the order was clearly established.

Anglesea possesses no very striking features. Holyhead mountain, which forms the greatest elevation, reaches only to 709 feet above the sea. With this and two or three other exceptions, the ground is low and undulating, although the surface possesses by no means an uniform character. A further description may perhaps, with greater propriety, be referred to the details of each particular formation.

The plan of this paper will be, first to describe the stratified and then the unstratified rocks.

The greater portion of the stratified rocks has suffered considerable disturbance, and they frequently occur under characters very different from what they assume in their undisturbed state. Several of the details therefore, which would otherwise be included in this division, are deferred to the description of the unstratified masses; when it is to their intrusion that such phenomena can be referred.

Quartz Rock.

{Nos. 1. to 11.}

The term, Micaceous schist, would perhaps by some Geologists, be made to include the whole series of the oldest stratified rocks. These, however, vary considerably in composition, but do not allow of separation into distinct formations, and would scarcely admit of geographical distribution, even in a map of the largest dimensions and most accurate construction.

In one instance an exception may be made in favour of a variety, marked on the map as a quartz rock, which possesses certain peculiarities of structure, though it is not very remote in composition from other varieties included under the general denomination. It occupies two distinct localities, the one in the Q. 1.
northern division of Holyhead Island, lying to the West of a line drawn from Port-Dafreth, to a point on the shore about midway between Holyhead and the mountain. The other, in the Southern Q. 2.
division of that Island, occurs in the neighbourhood of Rhoscolyn, extending along the coast, and bounded by a line drawn from Borth-Wen to Rhoscolyn church, and thence about one mile further to the N.W. In each case this rock rises to a greater

elevation than the surrounding country, and in the first-mentioned situation forms the highest point of all Anglesea.

On the summit of Holyhead mountain, and on the highest point near Rhoscolyn, the term given to this rock is strictly applicable, it being composed of little else than highly crystalline and distinctly granular quartz (1.) firmly cemented. There occur in it a very few minute white specks of earthy felspar. It is much intersected by cotemporaneous veins, and occasionally tinged red (3.). In other places it intermixes with a little mica (4. 5.). The quartz is often finely granular (6.), and associated with larger and distinct crystals of silvery white mica (7. 8.), and apparently also with a little chlorite, the specimens assuming a greenish tinge. Such specimens strongly resemble greywacké, but their crystalline nature is still very distinct.

With regard to the structure of this rock, nothing can be more deceptive than the appearance which it assumes in places
Q. 1. where no extensive section exists. On crossing Holyhead mountain, we seem to be walking over the edges of parallel strata, which dip at a very high angle towards the N. of W., the whole surface consisting of broken rugged lines, running from S. of W. to N. of E. Opposed to the small island called the South-stack, is a perpendicular cliff of two or three hundred feet in height, exhibiting the structure of the mountain in a perspicuous manner. Every trace of the former apparent disposition of the strata is lost, and the whole is seen to consist of broad strata, contorted in a most extraordinary manner, often vertical in position, then returning with a sudden curvature, and forming repeated arches. Strings of white quartz, which occur in and between them, partake equally of these contortions, and also of others more complicated and independent of the general position of the surrounding mass. The effect is rendered still more striking by each stratum assuming a peculiar tint; the colours varying through obscure shades of green, brown, and yellow.

They also vary in texture, which causes the more compact portions to project in relief, and these in weathering exhibit convolutions in which the softer strata do not partake. They are sometimes divided by fissures, generally placed nearly at right angles to the curves, producing the effect of an artificial stone arch. Plate XV. represents about fifty feet perpendicular height of this section. Wherever a convenient opportunity occurs of examining the cliffs along the remainder of this district, the same appearance is repeated.

Near Rhoscolyn the strata are very distinct, and among Q. 2.
them is one of a brick red, contrasted with others of a deep yellow colour. The same deceptive appearance of stratification running from the S. of W. to the N. of E., is seen in this district as well as in the former.

The real structure of this rock, then, consists of a succession of contorted strata rudely conformable to each other. That these were originally deposited in their present position seems impossible, and the whole bears a striking resemblance to the flexures that might be formed in a pasty unconsolidated mass, by the application of a disturbing force.

The deceptive appearance resembling stratification, arises from the parallelism preserved between the scales of mica dispersed through the mass, which causes an imperfect kind of cleavage throughout the whole district. In some cases this may readily be exhibited, even in hand specimens (6.), where the mica has a brown ferruginous aspect, coating over the whole surface produced by cleavage, with a plate too thin to be detached. These laminæ occur about one eighth of an inch asunder, and on fracture exhibit an uneven undulating surface. A few other small scales of white mica are irregularly dispersed through the specimen. In some cases (4.) the laminar tendency is distinct, with the intervention of a very small portion of mica, and on a fracture perpendicular to this direction, its existence is marked by faint lines. In other instances the cleavages, sufficiently apparent on the large scale, would not be noticed in a small fragment. Here (7.) the mica which gives rise to them is dispersed at intervals over their surface, and is scarcely to be seen upon a transverse fracture.

Other cleavages exist in the mountain, at much greater intervals than the former, which more nearly resemble natural fissures. These present smoother surfaces, and are probably the cause of large vertical fissures which occur towards the summit of the mountain, separating the rock into rude rhomboidal and cubical masses, where quartz is almost the sole ingredient, and both the fissile texture and divisions of the strata are scarcely to be detected, though, in convenient situations, each may occasionally be traced.

The exposed faces of these masses (2.) present an even polished surface, the effect of weathering; an action which apparently soon ceases, the fragments retaining their angles as sharp as when first fallen.

Plate XVI. Fig. 1. represents the positions of four cleavages obtained from a projecting mass of curved strata (6.).

A. The curved surface of the stratum.

$$\left.\begin{array}{l} 1 - 2 = \ \ 52^\circ \\ 1 - 3 = \ \ 90 \\ 1 - 4 = 120 \\ 2 - 3 = \ \ 90 \\ 3 - 4 = 136 \end{array}\right\} \text{Rough calculations of the angles at which the several planes are inclined to each other.}$$

Plane 3. is the cleavage which produces the apparent stratification of the whole mountain.

It should seem that these phenomena arise from some effort of crystallization subsequent to the original deposition of the materials, and subsequent also to the present contorted position of the strata. These facts may be illustrated by the appearance presented upon the transverse fracture of a calcareous stalactite, where the original structure arising from successive depositions, is exhibited by concentric circles, whilst a rhomboidal fracture marks the effects of a posterior crystallization. The strict resemblance which some of the strata bear to those of sandstone, points out a mechanical deposition as the most likely mode of formation: their present structure may suggest an idea that crystalline force assisted by moisture and pressure is an agent of sufficient power to have produced the similar, but still more perfect texture of the oldest stratified rocks, without the necessity of imagining any previous solution of the ingredients which compose them.

Chlorite Schist.

{Nos. 12 to 187.}

Under this denomination are included several varieties of schist, of which quartz and chlorite form the principal ingredients. Mica slate and clay slate also occur in the same formation, but each of these passes into chlorite schist by insensible gradations, and I could no where trace a boundary between them, marked either by a rapid change in the mineral character, or by some distinct geological feature. The varieties of clay slate included in this formation appear to consist of nearly the same ingredients as the chlorite schist, and to differ from them in nothing but want of crystalline structure. They are of various shades of green and red, and of a close texture.

The variety which immediately succeeds the quartz rock is crystalline chlorite schist. There are four sections on the coast

C. 1. exhibiting their union. At the spot where this takes place between Holyhead and the mountain, there is a space of eight or ten feet in width, occupied by a rock intermediate in character between the two. At the spot on the beach where the change has become decisive, there occurs a breccia (9. 10.) of quartz rock, and angular fragments of talcose slate; from this a vein issues, which may be traced on the shore for a few feet as far as the cliff, up which it is seen to rise, and become forked near the top (Pl. XVI. Fig. 2.). The vein consists of finely granular materials (11.), with occasional patches of the breccia from which it proceeds. Possibly, the origin of this vein may be ascribed to a fissure in the chlorite schist having been filled from the subjacent rock, previous to its consolidation, by the force of the superincumbent pressure.

C. 1. At Port Dafreth, I could not ascertain whether any sudden change takes place; the strata of the quartz rock gradually be-
Q. 2. come thinner, and appear to pass insensibly to chlorite schist. the West of Rhoscolyn their boundary is more marked, the quartz rock rising nearly vertically, and the chlorite schist resting unconformably against it. A small bay is there formed by the removal of the chlorite schist, so that its Eastern side is composed of quartz rock alone, where a broad stratum presents an undulating and nearly vertical cliff. At certain points of projection, a portion of this is removed, which exposes the stratum next below; a similar exposition of the next takes place, and so on. The nature of this may perhaps be better understood by referring to Pl. XVI. Fig. 3.

The last spot where this junction takes place lies to the South-east of Rhoscolyn, and West of Borth-Wen, where the confusion is greater than at either of the three other places. The quartzose strata intermix with the chloritic, and are seen on the beach like veins twisting among them. In some instances they even appear to occur in an inclined position above them.

From what has been said of the nature of these junctions, it may be a question, whether the quartz rock and chlorite schist are not members of the same formation. For, whilst the junctions at each of the Western boundaries of the former bespeak a nonconformity, those on the Eastern sides present a certain degree of intermixture. Supposing the quartz rock to have been once horizontal, and the chlorite schist reposing upon it, perhaps their present appearance may be accounted for upon the principle of an upheaving force acting obliquely from the East.

Around Holyhead the chlorite schist is greenish grey, and C. 1.
composed of nearly equal proportions of quartz and chlorite, both highly crystalline, and finely granular. Sometimes it possesses but an imperfectly fissile texture (12.), though in general this is sufficiently apparent (14.), and the quartz and chlorite predominate in alternate layers (15.). The scales of chlorite often form one continuous shining plate on the plane of cleavage (13.). There are still finer grained varieties (16.), where the intermixture of the quartz and chlorite is very uniform. These form an intermediate passage between the crystalline chlorite schist, and bright green silky clay slate. Quartz sometimes predominates considerably (17.).

Contortions of the most complicated nature are exhibited in many portions of this series. A large block will often present laminæ waving in regular vandykes, or intermixing in a most confused manner (18.).

The finer grained varieties appear to predominate through the remainder of the chlorite schist situate towards the Western side of the Island. The general character of the same rock on C. 5.
the Eastern side is slightly different, though the composition is similar. Both the grains of quartz and the scales of chlorite are larger, and the colour of a darker green. Lenticular plates of

pure crystalline quartz, lie in the direction of the layers of chlorite, which pass regularly round them (19.). Strings of crystallized quartz and scales of chlorite intermix in irregular layers (21.), which appear to arise from the complicated contortions of thin laminæ. Sometimes the rock is nearly homogeneous, the chlorite being dispersed through the quartz (23.).

Some hard varieties occur in the neighbourhood of a rock
C. 5. upon which there is erected a pillar to the Marquis of Anglesea, near Plas-Newydd. The basis is fine grained quartz, and dark grey chlorite (24.) closely united, and through the mass are disseminated small crystalline patches of light yellow epidote, and others of reddish mica.

The epidote, in some cases, forms a considerable ingredient (25.), and the scales of chlorite are replaced by dark green spiculæ, probably hornblende.

C. 5. Mica slate occurs in the Eastern chloritic district, which lies to the S.E. of a line drawn from Pentraeth to Newborough. This is, however, always contaminated with some portion of chlorite, which may be detected by the earthy smell, even of the purest specimens.

The hill West of Penmynydd, about the centre of this district, on the main road from Bangor to Holyhead, and the Llydiart mountain, at its N.W. termination, afford the most crystalline and genuine examples of this rock (26—29.). The quartz does not always present a distinctly granular appearance; but rather constitutes a nearly uniform mass, through which the scales of mica or chlorite are dispersed. It is not always easy to determine whether mica or chlorite forms the second ingredient. Sometimes both are present, and sometimes the quartz is tinged green by an intimate mixture with the chlorite, and scales of white, or light green, mica are superadded.

On the shore, between the Menai bridge and Plas-Newydd, mica enters in a conspicuous manner as an ingredient of the schist, and forms large thin plates which are irregularly intermixed with an impure chlorite schist (30—32.).

Near Cadnant the scales appear to be intermediate between mica and chlorite, and coat over the whole surface of cleavage (33.).

Other varieties afford an impure mixture intermediate between clay slate and mica slate, where the scales of mica are sufficiently distinct, but the basis no longer retains a crystalline character (35—37.).

North-east of Bodwrog, on the confines of the granitic C. 3.
district, is a variety composed of crystalline white quartz in layers, coated with a talcose variety of mica of a light straw colour (38, 39.). Mica slate occurs to the South of this spot, along the Eastern boundary of the granite, where it does not present a granular aggregate of quartz and mica, but forms a highly crystalline mass of quartz, to which a laminar tendency is given by thin layers of mica, sufficiently distinct on the surfaces of the laminæ, and but faintly marked by lines on the fracture perpendicular to them. Where the rock is weathered smooth, the quartz glistens in the same manner as a polished surface of crystalline marble (40.).

A similar variety is found on the East of Tre-Sgawen (41.), C. 3.
situate towards the North-eastern termination of this district.

The passage from the crystalline varieties of chlorite schist to the more earthy kinds (43—49.), and finally to clay slate (50—64.), is very gradual. The yellow epidote, before-mentioned, also assumes a compact appearance, and runs in irregular strings among the schist (43, 44.).

Some specimens of the clay slate present a silky lustre (50), and fibrous appearance. Patches of deep red occur intermixed with the green.

C. 2. These varieties of clay slate predominate to the North of a line drawn from Llaneilian to Llanfechell. On the coast, from
C. 1. Llanrhyddlyd to the nearest point to Holyhead Island, they intermix with the crystalline varieties of chlorite schist, in the most confused manner. A boundary may once have existed between them, for the transition from one to the other is frequently abrupt, and resembles a series of patches of clay slate scattered over a ground of chlorite schist, sometimes presenting a distinctly laminar tendency, at others not a trace.

The clay slate often assumes a hard jaspideous aspect (59-61.). Some earthy varieties, without a trace of fissile texture, appear to consist of an irregular mixture of chlorite and epidote, with patches of quartz, and carbonate of lime (65—69.), intimately
C. 5. united. These prevail on the coast from Beaumaris to Cadnant, in the neighbourhood of Llangaffo, and also between Trefdraeth
C. 3. and Aberfraw.

Rugged, projecting masses of schist, with laminæ generally much contorted, are scattered throughout the tract on which
C. 1. Holyhead is situate. The average bearing of the laminæ is decidedly towards the N.E. and S.W., and their dip in general to the N.W.

C. 2. In the Northern district round Llanfechell, the appearance is similar, but the laminæ are not so much contorted, and they dip more to the North. Towards Amlwch they nearly regain their former position, and between this place and Llaneilian, the contortions are very complicated.

Where the rock had been vertically and smoothly cut, in a recent excavation opposite to the pier at Holyhead, there was a decided appearance of broad strata, undulating in a manner similar to those of the quartz rock, and also a laminar structure parallel to the seams which marked the stratification.

A similar circumstance occurs in the high ground to the North of Llanbabo; the surface is modified by the undulating nature of the strata, which rest upon each other conformably, and are from two to three feet thick. The schist is very flinty, and possesses but little appearance of fissile texture. C. 2.

In the most Easterly tract of this formation, the denudations inland often appear in small rounded eminences, with smooth surfaces dipping gradually on one side, and presenting a vertical face on the other. With a little attention these are distinctly seen to be stratified in the manner represented (Pl. XVI. Fig. 4.), which is intended for a section of the Pillar rock near Plas-Newydd, and an eminence immediately on its N.E., when viewed from the East. This character prevails on each side of a line drawn from Llandonna to Newborough: but on the coast, from Beaumaris to Cadnant, the dip is South-easterly. C. 5.

Where a separation into laminæ does not exist, the scales of mica or chlorite still preserve a degree of parallelism in the crystalline varieties, which, combined with the curvature of a stratum, produces irregular but parallel lines upon its exposed surface, whose general bearing is still towards the N.E. and S.W.

From these circumstances we may perhaps conclude, that wherever a laminar tendency is found in this formation, it was originally parallel to the planes of stratification. And here there appears to exist a marked difference between this and the quartz rock, in which it should seem, that the laminar tendency has arisen from an arrangement of the particles posterior to the present contorted position of the strata.

In endeavouring to account for any appearance exhibited by these rocks, it is necessary to take into consideration the more nearly homogeneous nature of the chlorite schist, when compared with the very variable strata of the quartz rock.

In some places the chlorite schist is associated with rocks composed of heterogeneous materials confusedly aggregated (70—94.). The schistose character is more or less destroyed, and the argillaceous basis intermixes with crystalline limestone, dolomite,
C. 3. serpentine, and jasper. The largest tract of this description lies about one mile to the West of a line drawn from Llangefni to Trefdraeth. The ground is completely broken up by rugged projecting rocks. Some of these are slaty, but in general they present a hard jaspideous aspect with contorted stripes, which mark the existence of former laminæ. These intermix with homogeneous red jasper streaked and spotted with purple.

The width of this tract may be about one mile, and it is succeeded on the West by contorted chlorite schist, and this by the mica slate already described, which, though confused, decidedly dips from the granite.

C. 4. A similar character prevails in the small detached strip of chlorite schist, which forms a ridge from Caint to Red-wharf bay, passing between Pentraeth and the Llydiart mountain. From Caint, as far North as Llanffinnan, this ridge is composed of green and red glossy talcose clay slate; but immediately North of Llanffinnan, it becomes disturbed, passes to a compact red jasper (58, 59.), and from hence to Red-wharf bay presents a series of broken elevations, composed of fragments of schist cemented by crystalline magnesian limestone, patches of which, as well as of compact limestone and jasper occur through the remainder of this district, intermixed with schistose materials. At its termination in Red-wharf bay, it forms a low but perfectly vertical cliff, facing the N.W., intermediate between red jasper and clay slate (60.), and possessing a fissile texture. Both the common and magnesian limestone present different tints of grey, yellow, and flesh red (88—93.).

In contact, and on the steep side of one of these projecting masses of limestone, is found a calcarious tuffa (94) enclosing fragments of slate, and recent snail shells. I mention this circumstance as it may perhaps tend to shew, that some particles of this limestone have been in a state adapted to solution at no very distant period, although its present position should seem to indicate, that this action has ceased.

Fibres, resembling a coarse asbestos, penetrate the solid jasper (86.), and sometimes appear as small veins, (the fibres perpendicular to the sides) traversing a light porous mass into which the jasper passes.

At the Southern point of the promontory at Llanddwyn, C. 5.
there is another partial formation of a similar nature. At one spot are numerous kernels, about the size of peas, dispersed through the schist (80, 81.). These appear to consist of a light green serpentine, in which lime predominates.

Half way between Beaumaris and Garth-ferry, in the new road, there is a rude projecting mass of rock, composed of red crystalline limestone, and jasper (83.), embedded in, and intermixed with decomposing argillaceous materials. When passing close to this, it appears to form a high projecting point of the cliff, but viewed from the river, it is seen in reality to be situate in the bottom of a gap formed by the schist rising abruptly on either side.

The clay slate, on the S.W. slope, and near the summit
of Bodafon mountain, situate at the Northern termination of the C. 5.
middle district, passes to a compact mass between hornstone and jasper (95—100.). It is irregularly streaked with different shades of green, dull red, and grey. It fuses to a transparent frothy white glass, and probably contains a great proportion of

felspar. Indeed the red stripes actually pass from a compact nature to crystalline veins of felspar, which are occasionally associated with stripes of white quartz. Specks of sulphuret of copper are dispersed through the mass.

Contorted patches, and strings of crystallised quartz and red felspar (121—123.), occur in several parts of the chlorite series, both among the crystalline and earthy varieties. In the
M. 1. new road to Holyhead, S.E. of Llanfihangel-East*, I procured masses of crystallised felspar four inches cubed (123.). The colour varies from deep to light red; the structure is curved-laminar passing to compact.

C. 5. On Red-hill, to the South of Beaumaris, is a bed of crystalline quartz (118, 119.), which is quarried for the Staffordshire ware. Other beds of a similar nature are met with in various parts of this schist.

On the shore at Cadnant are broad veins of quartz, slightly contaminated with chlorite (120.). These veins pursue a direct course, and resemble trap dykes in external character.

G. 1. A broken flinty ridge runs from the N.E. side of the Paris mountain to the S.W. of Llaneilian mountain. A fissile texture is sometimes visible, and the rock passes to a schist (111.). Its fracture and aspect vary from flinty to cherty, and its colours are different shades of light green (113, 114.), grey (115.), and red (116.). Sometimes there are small crystalline specks of quartz and felspar dispersed through the mass (117.), which give it a porphyritic aspect. It is semi-translucent on the edges and fuses to a white frothy enamel. This is, perhaps, more nearly allied to hornstone than that from Bodafon mountain.

The transition to a compact flinty or cherty mass, is found in several other portions of this district (108—110.).

* I have added "East" to the name of this place, to distinguish it from another Llanfihangel situate on the Western side of Anglesea, on the confines of the chlorite schist (c. 1.) to the S.E.

Limestone Beds.

{Nos. 124—132.}

Limestone, in the form of veins and small patches, has already been noticed; it also exists in distinct irregular beds in several places, which are marked in the map by an L. In the cliff, East of the island on which Llangwyfan church is situate, C. 3.
there is a bed of compact white marble mottled with black (124, 125.).

Other beds of the same nature occur on the promontory South of Aberfraw.

Also at Gwalchmai, immediately to the S.W. of the lake. As the limestone passes into the schist, it assumes a fissile character, and scales of chlorite are dispersed over the natural fractures (127.).

A compact dark brown and grey limestone (131, 132.), not unlike some of the more crystalline varieties of mountain lime, has been quarried about Llanfacthlu to a considerable extent. C. 1.
There is an impure shaly substance associated with it (132.), somewhat resembling the shales of the coal measures.

Small caverns occur in this spot, the surface of which are rugged, and contain hollow cavities resembling the exposed portions of a limestone district on the sea shore. No stalactites are to be found in them.

Very considerable beds of a similar limestone extend from C. 2.
Glan-y-Don to Cemmes.

In none of these beds was I able to find any trace of organic remains.

Serpentine.

{Nos. 133 to 187.}

Two districts are laid down in the map, in which the principal masses of serpentine are found. These occur in beds subordinate to the chlorite schist, and do not form one continuous line of rock.

S. 1. In the Southern district, they form a range of detached and nearly tabular masses, which extend from the N.W. of Rhoscolyn church to Llanfihangel, rising through swampy ground, and accompanied by projecting patches of schist which dip in various directions Pl. XVI. Fig. 5. The compact serpentine passes into slaty; and sometimes a tabular mass exhibits this double structure, when viewed at a short distance, Pl. XVI. Fig. 6.

S. 2. The serpentine near Llanfechell is not sufficiently exposed to enable us to trace its connexion with the schist. The patches, in which it is found, have been quarried, and appear to be nearly envelloped by a hard compact variety of chlorite-schist.

The purest specimens are dark green with a semi-translucent greasy lustre (133—135.), but the general appearance is that of a compound rock, in which serpentine and dolomite form an irregular mixture (141—151). Patches of light yellow also occur (145.). A considerable portion of that which is quarried at Llanfechell, consists of very compact dolomite, tinged green (146.) or red (148.); sometimes striped (150.); in which patches of serpentine are embedded. It is here associated with common compact limestone (152.). The red tinge also pervades some of the more slaty varieties (153—155.).

S. 1. Near Rhoscolyn the serpentine is associated with a heavy, compact and granular, black limestone, which does not resemble dolomite, although it will not effervesce in cold acids (161—163.).

Patches and veins of beautifully saccharine and white dolomite are dispersed through each district (159.). This occasionally exhibits a tendency to a fibrous structure (160.), which may sometimes be traced partially through several specimens of the serpentine.

Asbestos forms a thin coat over the natural fissures of the serpentine in the form of mountain leather. It also occurs in thin veins, of a light green colour; the fibres set perpendicularly to the sides of the vein (156.), which sometimes seems to be contemporaneous (136.). Some specimens appear to consist of broken fragments of this substance cemented in a paste of serpentine, in which the direction of the fibrous structure being inclined at different angles to the surface, a polished specimen (157.) has a beautiful appearance, different fragments reflecting the light at different angles of inclination.

Pyrites occurs dispersed through the serpentine (136. 140.).

Small crystals of jet black pyroxene form also a common ingredient (137—139.); but they are so intimately associated with the mass that they can not readily be detected, except upon a weathered surface, over which they are scattered in projecting points.

The schistose portion of the district in which the Rhoscolyn serpentine is situate, varies considerably in composition. On approaching the serpentine, asbestos enters largely as an ingredient. This is intermixed with slaty and chloritic serpentine irregularly laminated, with carbonate of lime (170.). Other varieties approximate to chloritic slate (164—169.). A structure half fibrous half slaty is a common character (171—177.).

Radiating crystals of dark green actynolite are dispersed through a more compact variety, the fibres generally lying on the surface of cleavage (180.).

In the confused schist along the shore South of Lanfacthlu, C. 1
are several appearances which approach the character of the Rhoscolyn district, though no considerable mass of serpentine is seen. This schist is sometimes a mixture of serpentine and chlorite, and in it are beds and veins of compact limestone (186.) and earthy chlorite (187.).

Greywacké.

{Nos. 188. to 264.}

Under this denomination is included greywacké slate, and also a fine grained dark grey or black clay slate, which cannot be distinguished in composition from the green clay slate of the last series. It exists, however, above and also intermixed with the greywacké, in a manner which decidedly places it in the same formation. Whether this class of rocks originally succeeded the former in an uninterrupted order, or whether they were separated by a marked geological epoch, cannot be fully ascertained in Anglesea. Their characters are sufficiently distinct to enable us to trace their boundary on the map.

In a few instances the black clay slate assumes a glossy crystalline appearance, approaching the character of a primitive clay slate (188—192.), which passes insensibly (193—196.) to the earthy varieties (197—207). It is often thin slaty, but the plates are not sufficiently regular to admit of their being wrought. The more common character is that of a shattery schist, breaking into small irregular fragments. In several places this schist is intermixed with a greywacké conglomerate (210, 211.) consisting of angular fragments of slate, embedded in a fine black argillaceous basis, or it is composed of quartzose fragments with the addition of argillaceous matter (212—216.). The black clay slate intermixes also with a grey sandstone (221—229.) which cannot be separated from some of the sandstones of the old red sandstone.

G. 1. In the bed of the river at Dulas, the greywacké approaches a sandstone, and contains small embedded fragments of schist (209.). It cleaves into irregular laminæ about one inch in thickness, intermixed with others of a more shaly character. Between the laminæ are hard nodules (258, 259.), of a concretionary nature, composed of the same materials, which decompose in concentric crusts. The finer slaty laminæ pass round them.

On the Western side of Dulas harbour, the greywacké is intermixed with shaly black clay slate, which forms the greater part of the rocks to the S.W. Upon approaching its termination towards the North, where the conglomerate sets on, and where it is intersected by several trap dykes, the harder laminæ (226.) increase in number until they form the body of the rock, with a very slight portion of shaly matter interposed. Concretionary nodules are also found here which possess a peculiar structure (260, 261.). In shape they approach a spheroid, slightly flattened on one side. Upon examining the more convex surface, the nodules appear to consist of cylinders of different sizes pressed together, so that an imperfectly columnar structure is the result; the termination of the cylinders on the surface forming rounded projections. Upon fracture these cylinders are found to be composed of a succession of cones, each about one tenth of an inch thick, placed one within the other, with their bases towards the convex side of the nodule. The surface of each cone is irregularly wrinkled longitudinally, and marked transversely with faint striæ. One cone runs into another, and the whole is so blended together that it is impossible to detach a perfect cone from the rest. There exists a slight tendency to natural cleavage, inclined to the shorter axis of the nodules at an angle of about 45°, which is also about equal to the inclination of the conical surfaces to the same axis. The major axis of some of the larger nodules is two feet and a half, and the minor one foot and a half; and the conical structure extends to the depth of three or four inches. The direction of the longer axis is placed parallel to the schistose laminæ, which pass round the nodules. There is one hard lamina, fifteen inches thick, nearly vertical in position, which winds among the schist, in a most irregular manner, closely resembling a basaltic dyke in external character. It may be traced for some distance along the beach, and also up the face of the cliff. On one side it is completely studded with these concretions, but in this instance their form is modified, the side next to the lamina being flat, and the conical structure extending through the whole of each. They are generally separated from the lamina by a thin seam of clay, but are sometimes firmly united to it. The concretions are confined to one side of a lamina. These laminæ are frequently striated black and grey with all the regularity of a fine sandstone (226.). The broad one above-mentioned is uniform in character, and consists of finely granular and highly crystalline quartz and felspar, partially blackened by argillaceous matter (222, 223.).

G. 1. In the denuded patches of this series round Llanerchymedd, the greywacké character prevails, the base being a black clay slate, which encloses fragments of quartz and slate. More to the East and N.E. it generally consists of shattery fine grained black clay slate, which is also found throughout the strip extending from Llanbabo to Llanrhyddlad. From the summit of Llanrhyddlad mountain towards Carnel's point, a coarse greywacké occurs (219, 220.), intermixed with patches of conglomerate containing rolled pebbles. At the junction between this and the chlorite schist, on the shore to the West of Monachdy, there are irregular patches and stripes of greywacké breccia (210.) embedded in the fine black slate, and not conforming to the direction of the laminar tendency, which appears to indicate a complete intermixture of the materials at their first deposition, and to shew that the laminæ do not mark any order of superposition.

The Western summit of Llaneilian mountain is a decided greywacké (212—214.); very similar in character to that on the summit of Snowdon, in which the impressions of a bivalve shell occur.

A fine grained black clay slate is found on the shore S.W. of Llanfaelog, and in the new road to Holyhead at the nearest point to Llanfihangel church. The small strip which runs from G. 2.
Bryngole towards the S.W. is of the same nature.

There is a good exposition of the junction of the greywacké and chlorite schist, between Llaneilian mountain and the point. The line of junction may be traced on the horizontal section formed by the beach, and thence vertically up the face of the cliff. The contact is between a fine grained glossy black clay slate of the greywacké series, and a green slate of the chloritic. The laminæ of each dip towards the N.W., and their union presents a most decided example of a fault. Proceeding Eastwards along the cliff, we come to the coarse greywacké already alluded to. The termination of this is distinct, and it is succeeded by fine green slate, which reposes unconformably upon a black clay slate in the manner represented Pl. XIX. Sect. A. This section is here referred to merely for the purpose of exhibiting the nature of the connection between the chloritic slate and greywacké, it will be again alluded to, and an explanation attempted of the phenomena which it presents. The junction of the greywacké and green slate in the middle of the mountain forms an undulating line down the face of the cliff nearly conformable to the direction of the laminar tendency. The transition from one to the other is gradual, the upper bed of green slate containing a few fragments of a rock resembling the hornstone found between the Paris and Llaneilian mountains, fragments of which are also found in the lower beds of the greywacké.

The laminar tendency of this series is universally inclined at a very high angle to the horizon.

In the central district, on which Llanerchymedd is situate, G. 1.

the bearing of the greatest portion is from the E. of N. to the W. of S., and the dip towards the N. of W. The laminæ are frequently vertical, often much shattered, and very thin. Whereever the chlorite schist is exposed, along its Western boundary, it is found presenting the abrupt edges of its laminæ towards the greywacké. It is therefore most probable, that the fault exhibited on the coast, between Llaneilian mountain and the point, is carried directly across the Island.

The principal exceptions to the general direction of the dip are about Dulas. In the harbour, the laminæ, though much confused, dip nearly South, varying to points both to the East and West. In this case, therefore, they appear to dip from the high point of granite on the Llaneilian mountain.

From Llanrhyddlad (on the Western coast) to the Paris mountain, the average bearing is more nearly East and West than in the former case, the dip still towards the North. The cliff formed by this schist to the North of Carnel's point, presents the greatest degree of confusion and disrupture among the laminæ, Pl. XX. Sect. N. To the South their dip is by no means regular, but inclines in different directions to the horizon, always however at a very high angle. Around the point, and again on the shore to the West of Llanrhyddlad, it assumes a yellow decomposing aspect.

From Llanbabo to the South of Llanrhyddlad the appearances along the Northern line of junction are similar to those exhibited between Llaneilian and Llanfihangel. The actual junction on the coast near Monachdy is obscured by a mass of diluvium, but judging from the direction of the laminæ on the horizontal section formed by the shore, the greywacké is unconformable to the chlorite schist, and therefore presents a repetition of the facts exhibited on the Western side of Llaneilian mountain. A few yards to the West of this junction, the greywacké passes to an unlaminated hard rock mottled with patches and veins of white quartz, and finally assumes a green flinty character similar to that of the chlorite schist at the junction. There is a small cavern in the cliff at this point, the roof and Eastern side of which is formed of the flinty portion, but the schist is again found on its Western side. The union of the two is very evident, the flinty mass reposing upon an inclined plane of the greywacké, Pl. XVI. Fig. 7. The cavern does not resemble a hollow excavated by the action of the sea, but appears as though the upper part had been bent from the Eastern side, when in a soft state, so as to form an arch. It may probably be referred to the nature of a fault, but this explanation admits of difficulty.

On the Western side of the Llydiart mountain, there is a G. 4.
black shattery clay slate, the laminæ dip from the mountain at a high angle. In the road near Pentraeth their junction has been cut through to the depth of five or six feet, where they meet vertically, and each rock is broken and confused. Following their line of junction towards the North, the mica slate is seen, near Red-wharf bay, to rise from under the clay slate, and presents a smooth rounded surface without any laminar tendency. Between this and the fine grained clay slate, is a thin bed composed of small angular fragments of slate (217.) and at the actual junction it also abounds in small fragments of quartz (218.) loosely cemented together. By one hypothesis this would be called the abraded portion of the two rocks produced by the upheaving of the mica slate. The greywacké may be traced as far South as Llanfihangel.

A confused patch of shattery clay slate, intermixed with G. 5.
greywacké, is interposed between the chlorite schist and mountain lime, to the East of Llandonna. It does not attain to so great an elevation as either of the formations between which it

is situate, so that it is completely concealed at the spot where the mountain lime sets on (Pl. XX. Sect. P.) In immediate contact the chlorite schist consists of a confused talcose rock. Hardened veins of clay slate intermix with it (234—237.).

G. 3. The greywacké district placed to the West of the coal-measures, from Llangefni to the South of Bodorgon, possesses a different character from the rest (238—250.). That a portion of it consists of greywacké, is evident; but whether it belongs to the present series or to the last, or whether it be not rather a confused intermixture of both, I did not fully ascertain.

From Llangefni to Aberfraw, repeated instances of greywacké occur, to the East of the schist containing jasper, and interposed between this and the coal measures. The schist near the coal-measures presents its abrupt edges to them, but no actual appearance of stratification can be traced, and the indications which exist of a laminar tendency are of a very partial nature. On the N.W. of Llangefni, there is a green talcose clay slate (242.), occasionally enclosing embedded fragments (243.) and scales of mica (244.). It possesses an imperfectly laminar tendency dipping to some point towards the West. Along its Eastern termination from hence towards the North, it assumes a hardened unlaminated character. At Llangefni it passes to a green crystalline quartz rock (245—247.), which possesses faint, but undoubted, traces of globular concretions cemented in a paste of quartz. An occasional fragment of uncrystallized matter is also found embedded.

G. 1. Through the centre of the Paris mountain, and in the direction of its ridge, there runs a bed of grey cherty stone (252, 253.) cutting through the schist partly hardened (254.), and the rest assuming a yellow decomposing aspect (255.), full of blebs and drusy cavities, which also occur in the chert.

The simple minerals found in the extensive and well known copper mines situate in this mountain, are sulphurets of iron, copper (256.), and lead.—Sulphate of barytes.—Native copper in small quantities (257.), and still more rarely the sulphate of lead.

There are two patches laid down towards the East of the Map, as included in this formation. Certain points of resemblance to portions of the districts already described, seem to stamp them as members of the greywacké series. But they are found under such peculiar circumstances, that it is impossible to speak decidedly on this point.

The small patch to the South of Beaumaris is seen near the G. 6.
top of Red-hill, and in Lord Bulkeley's grounds, on the slope of the hill above the ferry-house. It appears to be an unstratified mass sticking upon the steep side of the chlorite schist, which rises very abruptly from hence towards Llandonna. It consists of small angular fragments and nodules of clay slate, highly pellucid quartz, and crystallized felspar, either firmly cemented together (263, 264.), or embedded in a hardened argillaceous paste (265—267.). The fracture sharp, and approaching the conchoidal. A perfectly flinty slate (268, 269.), with an irregular fracture is associated with it. The specimens bear a close resemblance to those procured between the clay slate and mica slate on the N.W. slope of the Llydiart mountain (216—218.); differing from them only in a greater degree of compactness.

The patch which extends from Garth-ferry, about one mile, G. 7.
towards Cadnant, scarcely reaches above high water mark. The chlorite schist rises abruptly on the West, and forms a high ridge of rugged rocks. The rock at the base is formed of small angular fragments of quartz (270—273.) running together and passing to a compact mass, interspersed with specks of earthy felspar, and fragments of slate (274.). This is intermixed with a few irregular patches of black clay slate, and a compact mica-

cious sandstone resembling those in the greywacké about Dulas. (275.) There is scarcely any trace resembling stratification, but the whole rises confusedly towards the chlorite schist.

The greywacké on the opposite coast, immediately South of Bangor, in contact with the coal-measures, seems at first sight to consist of large and small rolled pebbles, firmly embedded in a basis composed of fragments of felspar, quartz and clay slate (280—284.). Upon examination, the rude breccia thus formed is found to possess certain peculiarities of structure, which appear to throw some light upon the nature of a substance found in connection with it, and mentioned in Mr. Greenough's Geological Map of England as "a remarkable steatitic rock, associated with the old red sandstone between Cærnarvon and Conway" (285, 286.).

Many of the pebbles, or rather nodules, are found to indent the surface of a contiguous nodule, as though the latter had been in a soft state, and pressed by the former. The surface of one bed, from which a nodule has been removed, is often abruptly intersected by the surface of another. The surface of the nodules are found to be impressed by the angular projections of the fragments which form its matrix. All the specimens exhibit these facts, and on the natural fracture of one of them (280.), where several contiguous nodules are cut through, they are particularly striking.

These facts admit of explanation, by supposing that the nodules are in reality rolled pebbles, which have been softened in some degree, and pressed, since they were brought together. There are, however, other circumstances which appear to destroy such an hypothesis.

The nodules themselves are found in several instances (281.) to be composed of angular, crystalline fragments, which are often sufficiently apparent towards the surface, but which form a compact and homogeneous flinty mass towards the centre, resembling hornstone, and occasionally containing small pieces of pellucid crystalline quartz. Others are wholly formed of quartz, in different states of crystallization, or are slightly intermixed with compact felspar. The matrix also assumes the same characters.

The bed and surface of each nodule, upon a recent fracture, is coated with a ferruginous or ochreous crust. This crust appears also in irregular patches dispersed through the matrix.

From these facts I am inclined to think, that the appearance of a breccia arises from a concretionary structure impressed upon the same kind of fragmental quartz rock, (intermixed with slate) as that which is found on the opposite shore, and that the steatitic rock to which allusion has been made, is a further result of a similar action. This rock consists of white quartz, partly crystalline and partly compact, formed into irregular nodules which run together, but leave several interstices between them filled with a light green talcose substance (285.). The irregular seams which produce the nodular structure are also talcose and ferruginous. Some of the nodules, especially the more crystalline, which attain to one or two inches in diameter, are distinctly composed of irregularly concentric layers (286.). The surfaces of several of these layers are also partially coated with the talcose ingredient, which on weathering becomes detached, and leaves a hollow space between the laminæ.

The homogeneous character which the whole rock must once have possessed, is evident from the numerous veins of quartz or chlorite, which traverse it, always passing through the nodules, however small, which they happen to encounter in their course (283, 284.).

There are veins of crystalline quartz with patches composed of small fragments embedded in them (287.).

How far this rock extends to the South, I did not examine but between this place and Cærnarvon, the rocks to the East of the coal-measures rise high and abrupt. A specimen (288.) from them, at Moel-y-don ferry, consists of a flinty mass filled with embedded fragments of crystallized felspar and quartz, resembling the internal structure of some of the concretions just described. It is traversed by numerous fissures, which separate it into small fragments, and these also are coated with the same ferruginous crust as the nodules.

As a concretionary structure was not suspected during the investigation of these rocks, it is most probable that specimens might be selected which would better illustrate the facts of the case, than those which were procured under a different impression.

From Garth ferry (on the Bangor side) as far as Aber, the dark clay slate is sufficiently regular. Immediately to the South of the ferry, it reposes upon a confused mixture of hardened clay slate of various shades (276—279.), which terminates in the nodular rock, just described. It should seem then, that this is the lowest portion of the greywacké series; but the junction with the dark clay slate is on too small a scale to enable us to speak decidedly, though, as far as it is visible, the fact of superposition is sufficiently evident.

Old Red Sandstone.

{Nos. 289 to 372.}

This formation varies considerably in mineral character. It occurs as a fine red sandstone, (315—321.), along a narrow strip
O. 5. about half a mile in width, stretching S.W. from Dulas harbour as far as Bryngole. Even here it is intermixed with shades of green (313, 314.), and beds of a coarser description (290, 291.), (295—298.). A few other small patches of a similar sandstone are met with in other parts of Anglesea, but the more common

form is that of a coarse breccia. Between Llanfihangel and O. 1.
Llanfaelog it is generally composed of angular fragments of
slate, intermixed with quartz (289.); a character which prevails
as far North as Gwindu. From hence to Llanerchymedd a
coarser variety is found with pebbles (366.), which on the beach
S.W. of Dulas harbour, form a breccia of the rudest description O. 5.
(293.). The upper beds extend from Bodafon to the mountain-
lime on its East, and consist of a coarse grit, not to be dis-
tinguished from some grits of the coal-measures (299, 300.).
About one mile and a half to the South of Bodafon, and a little O. 6.
to the East of an extensive marsh in that neighbourhood, this
grit reappears for a short space, rising through the limestone
which dips from it in opposite directions.

The fine red sandstone round Bodafon mountain, contains O. 5.
small nodular concretions of carbonate of lime (320, 321.).

The strata generally bear in the same direction as the la-
minar tendency of the last formation, but their average dip is
not so considerable. In the largest district, there is no section O. 1.
sufficiently extensive, which might enable us to ascertain their
nature. In several small quarries about Llechynfarwy, we meet
with a laminar tendency, often thin slaty (308.), inclined at an
angle of 65° towards a point 30° to the W. of N. This
direction of the dip prevails throughout the remainder of the
district. Numerous edges of broad strata, nearly vertical, project
between Llanfaelog lake and Ceirchiog, and generally possess a
slight degree of curvature towards the S.E., which gives them
the appearance of having been the bases of arches gone to decay.
In the greater portion of this district, the subsoil is completely
choaked with large fragments of the strata, and as the black
clay slate is found on the shore to the South of Llanfaelog lake,
it is not improbable that the whole consists of a rapid succession
of faults, which have completely dislocated the old red sand-

stone, and left but few patches which may truly be said to remain in sitû.

O. 5. In the portion between Dulas harbour and Bryngole, the dip is more gradual and reversed, being about 10° towards a point 20° to the N. of E. The strata consist of broad, ill defined beds. In descending the hill to the North of Bodafon towards Dulas, the succession is—a thick bed of green and red sandstone—thin shaly red sandstone—thin beds of green sandstone, with coarse fragments of quartz and slate, and intermixed with partial beds of finer materials—and at the bottom of the valley, the stream to the South of the bridge runs over a shattery black clay slate, the laminæ much confused, but dipping upon the whole at a high angle, in a direction opposite to those of the sandstone strata: an additional reason for supposing these laminæ to be wholly independent of the original order of deposition, and perhaps also for suspecting that the thin slaty beds, mentioned
O. 1. in the quarries about Llechynfarway, may be of a similar description.

O. 3. In the small isolated patch to the N.E. of Llanerchymedd, the strata dip to a point 30° to the W. of N., and are interstratified with thin seams of black clay slate: which appears to indicate a gradual transition from the greywacké to the sandstone. The termination of the strata to the East is remarkably abrupt, and forms the summit of a low ridge running to the N.E. They repose upon a rotten greywacké, confused and of a yellowish brown aspect (251.).

O. 4. In the patch to the S.E. of the Paris mountain, the strata dip 50°, and run from the N. of W. to the S. of E., intersecting the former direction at a considerable angle.

It seems highly probable, that no marked separation exists between the greywacké and the old red sandstone, but that the latter merely presents an extreme case of one common formation.

The greater part of this series appears to have undergone considerable alteration since its deposition. This is particularly O. 1.
the case about Llanfaelog-lake, Llanfihangel, and in the outlying masses round Llanerchymedd (322—350.). By this change both the coarse (322—330.) and fine grained (331—335.), (341, 342.) varieties assume a more compact texture, arising from an intimate union, and greater degree of crystallization, of the several ingredients. In the coarser specimens, there are traces of large pebbles and fragments (322—326.), some of which may still be detached (327.); but others have become a crystalline mass (328, 329.) passing into the body of the rock, which assumes a more uniform aspect. Towards Llanerchymedd, where the quartzose fragments predominate, the rock in some places passes to a nearly homogeneous mass of quartz (341.).

Bodafon mountain affords a remarkable instance of this O. 5.
nature. Without minute investigation, it might be mistaken for an unstratified mass of quartz rock, rising abruptly through the old red sandstone. It is cleft by vertical fissures, breaks into rude shapeless blocks, and presents a barren shattered aspect, not unlike the quartz rock of Holyhead mountain. The summit is subdivided into small elevations, some of which are perfectly rounded and smooth, whilst others are as much the reverse, jagged and splintery. The sides of the fissures which traverse the quartz, are coated with red oxide of iron (345.). The quartz has a flinty semi-crystalline aspect, and is of different shades of red, or mottled with white, grey and green (343—346.). These pass to less homogeneous varieties (347.), in which may be seen distinct traces of a finely granular structure. Others exhibit a coarser texture (349, 350.), and contain quartzose fragments, but so intimately associated with a basis of the same nature, that they cannot always be detected upon a recent fracture. On a weathered surface, however, they are left

projecting, owing to the removal of a portion of the matrix in which they are embedded. Small patches of fine white pulverulent matter, probably silica, (for it is neither fusible nor soluble in acid) are dispersed through the solid rock (348.).

This is the oldest formation in Anglesea, in which I found traces of organized bodies, and these were in three separate localities. At one spot, there are three projecting masses of rock, which rise at a few hundred yards to the South of the o. 1. tenth milestone from Holyhead to Bangor. It is in the mass furthest from the road, and at its Eastern end, that the fossils are to be seen (351—364.). Another locality is where a small rock protrudes in the centre of a field immediately N.E. of Llechynfarwy church, forming the angle between the roads to Llanerchymedd and Llantrisant (365—371.). The third spot is in a quarry on the Eastern side of the road from Llechynfarwy to Llanerchymedd, and about one mile from the latter (372.).

The appearances alluded to, consist principally of the impressions of bivalve shells. In the two last-mentioned localities, the bed is coarse, and partly composed of nothing but rolled quartz pebbles in a gravelly sand (366.). The only species found here appears to be an anomia. It somewhat resembles the common pecten varius (on a small scale), except that the indentations which cause the winged hinge, are in the present instance wanting. The general size is about half an inch wide, but some reach to a full inch. In the first-mentioned locality, the basis of the rock is a finer grained and more compact green sandstone, with partial traces of a slaty structure. Besides the shell already mentioned, it contains the impressions of some other species, which are not in general so well preserved as the former specimens. Among them is one somewhat similar to the last, but the striæ are finer and much more numerous. Another is a smooth elliptical shell (352, 353.). A little of the shelly matter still incrusts some of the casts (354.), which are in general coated over with small scales of mica.

Mountain-Limestone and Coal-Measures.

{Nos. 373 to 421.}

A distinction is made, in the colouring of the map, between the mountain-limestone and the coal-measures, although each is supposed to be a member of the same formation. The term coal-measures is meant to include the upper portion, which consists of grit, sandstone, shale and limestone, interstratified with each other, and occasionally containing subordinate beds of coal.

In the most Westerly and principal district of this formation, no attempt was made to investigate the exact boundary between the two subdivisions, which would have required more time than a subject of such comparative unimportance seemed to merit. All that is intended in the map, is to note their general limits, and by this means mark their relative position to each other. M. 1.

The lowest portion of this series consists of a thick bed of stratified limestone, generally of a compact texture, and dark grey colour (373, 374.). It varies also through different shades of brown (376—379.). Sometimes it is composed of a mass of broken fossils firmly cemented together (380, 381.), each of which being formed of calcareous spar, the specimen often assumes a crystalline appearance (382.). Magnesian beds occur subordinate to these. In Priestholme island they are composed of pearl M. 3.
spar intermixing with the common limestone (384, 385.).

Chert and chalcedony are also embedded in the limestone, even in the lower strata, before the grit sets on. Some large madrepores (419, 420.) from Priestholme Island, are partly composed of dark limestone, and partly of translucent bluish chalcedony, passing to chert. In some places the cellular coating is chalcedony, and the interior, which was limestone, has disappeared.

Black and white chert, intermixed with the limestone (386.), is more abundant after the grit has made its appearance, and quartzose pebbles are occasionally intermixed with the strata (387.). The limestone becomes more argillaceous (388, 389.) and slaty, and finally interstratifies with clay shale (390, 391.), coarse grit (393—396.) and sandstone (398, 399.).

Specks of coal are dispersed through the grit and sandstone,
M. I. in Red-wharf bay, North of Llanffinnan, and at the Menai bridge (400—403.). To the West of Llanfihangel East, and also to the East of Trefdraeth, coal is worked. At the former place I was informed by the overseer of the works, that it is found in three strata, the thickest of which is two yards, the next one yard and three quarters, and the last four feet. It is peculiarly glistening, and does not contain organic remains. In some clay shale from the pit I observed an impression resembling a flag-leaf.

In the limestone, on the Western side of Red-wharf bay, there are large cylindrical holes filled with grit which formed a portion of the superincumbent stratum, and which is probably the lowest bed of the coal-measures. The partial removal of this stratum has exposed the top of these cylinders, in several of which the action of the sea has worn away the outer crust of the grit, and the hollow in the limestone presents a smooth surface. This circumstance appears analogous to what occurs so frequently in chalk countries, where holes of this description are filled with gravel and sand.

Upon this grit is imposed a bed of shale four feet thick, from which the sulphates of iron and alumina effloresce. This is succeeded by a thick bed of grey limestone, traversed by nodules of jet black and white chert, and filled with the impressions of shells—then a brown sandstone 15 inches—clay shale 4 inches—grit three feet and a quarter—clay shale three inches—brown sandstone 14 inches—dark impure argillaceous limestone to the top of the cliff. This enumeration will serve to shew the nature of the alternations which take place among the strata of this formation.

In the grit, immediately South of the Menai bridge on the M. 2.
Cærnarvonshire side, there is a peculiar rock, which appears to form a vertical vein, but the ground is too much covered up to ascertain the point. The basis consists of a coarse heavy red sandstone, containing fragments of quartz, which are also coloured deep red, and through the mass are dispersed numerous small round and oval nodules, from the size of a linseed to that of a small pea (404.). These nodules are composed of concentric crusts of a yellow and brown earthy matter, and exhibit a smooth surface coated with the red oxide of iron. They probably result from some action similar to that which produced the steatitic rock before-mentioned, and which is found at no great distance from this spot.

To the North of Bodorgan, at the Southern extremity of the M. 1.
largest district, the grit is composed of small angular fragments of quartz studded with white earthy specks of carbonate of lime (398.). These specks are frequently arranged in parallel lines, inclined to the direction of the strata: an effort, if so it may be called, to produce a fissile texture in a coarse substance where it could scarcely have been expected. The particles of the quartzose fragments appear likewise to have undergone a partial re-arrangement; for several contiguous fragments possess a common cleavage. Some of the strata are traversed by fissures, which separate them into blocks, and these decompose in concentric crusts marked by different shades of brown. This compound structure is represented Pl. XVI. Fig. 8.

The only exposed portion of this formation which succeeds the old red sandstone conformably, lies to the E. and N.E. of
O. 5. Bodafon mountain. From the Eastern side of Dulas harbour, the mountain limestone stretches towards the S.W. forming a low precipitous cliff, which bounds a marshy ground on its West, as far as Llangefni. From Llangefni to Bodorgan the junction takes place along the side and near the top of an elevated ridge of schist. On the Eastern side of the river, there is another ridge of schist which extends from Caint to Llanddwyn. Between these two ridges there lies a flat swampy ground, beneath which is the only explored coal district of Anglesea.

M. 1. About midway between Pentraeth and Bodafon, the limestone and grit attain to a considerable elevation. The strata are either nearly horizontal, or dip from 5° to 10° to various points between 5° and 40° to the E. of S. Their direction is therefore N. of E., and S. of W. Hence the line of junction from Dulas harbour to Bodorgan must intersect the strata, obliquely to their course, from the lowest upwards in a regular succession.

Between Llangefni and Bodorgan, several opportunities occur of examining the nature of their union with the adjacent rocks. In every case the limestone and grit are confused and broken. The schist also rises in a shattered and abrupt manner, dipping from the limestone wherever there happens to exist any tendency to a laminar structure. In some places it projects in peaks surrounded by the limestone or grit, at others it encloses small patches of the latter. Immediately S.W. of Llangefni there is a quarry of limestone, on the brow of the hill rising from a marshy ground, which presents a section exhibiting the confused nature of this junction, Pl. XVII. Fig. 1. The strata are nearly horizontal, but sensibly bent upwards next the schist on either side. In a small elevation lately cut through in forming the new road from Bangor to Holyhead, on quitting the marshy ground, the limestone and shale dip towards the S.E.

at an angle of 45°, and exhibit a fault by which they are upheaved towards the schist. Similar appearances to these may be seen in different quarries between this spot and Trefdraeth.

At Bodorgan, an isolated patch of schist rises through the confused and dismembered grit. Between the grit and schist there is a loose breccia chiefly composed of angular fragments of the latter (392.), which may be accounted for in the same manner as the breccia interposed between the clay slate and mica slate on the N.W. side of the Llydiart mountain.

On the W. of the Pentraeth river, near Red-wharf bay, the limestone dips 45° to the W. of N. In Pentraeth their inclination reaches as high as 80°. At Caint they are confused, broken, and sometimes contorted without fracture, Pl. XVII. Fig. 2. But on proceeding to the West of these several places, we find the strata nearly horizontal. They present several low cliffs, which are not so abrupt as those on the Western boundary of the series. These facts seem to indicate, that the grit and limestone terminate abruptly against the schist to the East, with the intervention of a few hundred yards of disruptured and broken strata.

East of Llandonna, the limestone presents an abrupt cliff M. 3.
to the sea, the strata are nearly horizontal, their edges reposing on an inclined plane, the summit of which is chlorite schist; but at a lower elevation we find the shattery schist before-mentioned, so that the limestone overlaps this in the manner represented Pl. XX. Sect. P. Large fragments of the limestone strata are scattered over the steep sides of the chlorite ridge between this spot and the sands of Red-wharf bay. This district extends to the East as far as Priestholme island. Near the point to the North of Penmon, some coarse grit sets on. The dip is towards the E. of N. at no great angle or inclination.

The appearance presented by Great-Ormes-Head* Pl. XVII. Fig. 3. on the opposite coast of Cærnarvonshire is such as might lead us to expect a continuation of the same strata at that place. I did not visit the spot, but it is evident from the opposite coast, that a considerable indentation Northwards takes place towards the Eastern extremity of the Head. This must expose each stratum at some point further to the North than its Southern boundary, where (owing to the former dip towards the E. of N.) it will be seen at a less degree of elevation, which would give rise to the deceptive appearance of bason shaped strata exhibited towards the East of the figure.

M. 2. In the tract lying to the S.W. of Bangor, the strata belong to the coal-measures. A little to the South of the spot where they first appear, there is a large limestone quarry, which lies beneath some beds of grit and shale, and is possibly a portion of the series belonging to the mountain-lime. The strata here also dip towards the E. of S., and are in contact on the East with greywacké, and the older rocks dipping also, when laminated, in nearly the same direction. The line of junction is obscured by a cultivated valley. They are bounded by mica and chlorite slate on the West.

The fossils found in this formation are anomiæ, madrepores, trilobites, and others identical with those from the mountain-lime of England (405—421.).

Magnesian Limestone.

{Nos. 422 to 474.}

M. 2. To the South of Plas-Newydd park, there commences a series of limestone and sandstone strata, which overlie the coal-measures,

* This place lies to the East of Priestholme island, but is without the limits of the Map.

and appear to belong to a separate formation. They are better exposed, and may be examined with greater convenience on the opposite coast.

The lowest portion consists of rolled fragments of limestone, cemented together by argillaceous and calcareous matter (422.). To this succeed beds of limestone, grit, and sandstone, variegated with deep yellow and brick red colours. Their order from the bottom is,

		feet
1.	Yellowish brown sandstone (424.)	5
2.	Compact and crystalline grey limestone, with specks and cavities filled with yellow ochre (423.)	5
3.	Bluish shale, (thin bed)	
4.	Compact flinty dark grey sandstone, nearly a pure quartz rock, which separates into rude distinct masses coated by a deep yellow ochre (444). This intermixes with,	10
5.	Fine red, striped sandstone, (442.), containing fragments of broken fossils (436.).	
	The two last beds contain variable portions of lime.	
6.	Thick bed of compact red limestone (427, 428.), which has been quarried to a considerable extent.	

Upon this are imposed other strata of a similar nature to those described, whose order of superposition it is not so easy to ascertain. They are all more or less characterised by containing beds of bitter spar (437—440.). The fossils are generally in an imperfect and shattered state, intermixed with pebbles (434, 435.). The more perfect madrepores are frequently traced in deep red upon a light ground (432—434.). These fossils appear to have belonged to the mountain lime, and may be considered as embedded fragments in the present formation. Although I found no good section, by which any positive information might be obtained of the nature of collocation between this series and the last, still it seems probable, that they lie unconformably to each other. Immediately South of Plas-Coch, the black limestone and shale of the coal-measures dip towards the E. of S., and a few yards to the East of this spot, the red beds of grit are found dipping in a contrary direction. On the opposite coast, to the East, of Plas-Newydd, the lowest strata of the red grit and limestone dip gently to the E. of S., apparently conforming to those of the coal-measures; but suddenly their dip is considerably increased, as if they were reposing upon the brow of a steep hill. As the red beds appear to be entirely wanting over the marshy tract in which the coal of Anglesea is situate, it is not unlikely that in the present place they overlie a considerable body of that formation.

New Red Sandstone.

{Nos. 475 to 482.}

Over the strata of the last series, there occurs a rude mass of argillaceous and sandy materials (475.) intermixed with large fragments derived from the older rocks. The basis is occasionally consolidated into thin laminæ, giving rise to a slight appearance of stratification. The whole is of a deep red colour. It commences a little South of Moel-y-don ferry, on the Eastern side of the Menai, and extends as far as Cærnarvon, but in Anglesea it forms only a small hummock on the North of Tan-y-voel ferry. Both this and the preceding formation terminate to the E. and W. in the same abrupt manner as the coal-measures.

Many of the fragments dispersed through it, are of a large size, and generally consist of quartzose materials. Some are of grit in which the fragments run together and pass to a homogeneous quartz rock (476, 477.), others approach chert (478.) or hornstone (479—481.), and nearly all are tinged red.

A fault in the coal-pit near Llanfihangel East, contains fragments of quartz intermixed with red sand (482.), and may probably have arisen from a portion of this formation having filled up a fissure.

Trap Dykes.

Although these form but inferior members among the unstratified rocks, still it seems advisable to commence this part of the account with their description; since the facts which they present tend materially to confirm the conclusions drawn from phenomena observed in more extensive districts, apparently of similar origin.

As their number is very considerable, and as a detailed description of each would only occasion repetition, a selection has been made of those which are accompanied by appearances of the greatest interest.

Where their course is sufficiently exposed, it is represented on the Map in the usual way, by a particular colour placed between parallel lines. But there are many slight indications of trap, where it is either impossible to trace the course of the dyke, from the concealed nature of the ground, or it only presents an isolated mass rising through the schist. In these cases, the locality is marked by placing a (τ) as near the spot as possible. References of this description will seldom guide a second person to the dyke, but may serve a different purpose, and shew the number and relative situation of the places where trap was actually met with.

Mr. Underwood has submitted specimens of several of these dykes to the examination of Professor Cordier, whose method of analysing the basalts, and accurate knowledge of their mineralogical composition, is too well known to need a comment. I have enriched this account with his description of several specimens, and it will be seen that, judging merely from their composition and texture, and unacquainted with the geological phenomena by which they are accompanied, he supposes them to be of volcanic origin.

The dyke with which I shall first commence, is seen on the shore, immediately South of Plas-Newydd, between two and
M. 2. three hundred paces from the landing place. The phenomena with which it is accompanied are exhibited on a scale sufficiently large, and are besides so unequivocal in their nature, that the results deducible from their examination may be considered as of the greatest importance towards the elucidation of this class of rocks.

The width of the dyke is 134 feet, and it cuts perpendicularly through strata of shale and limestone. The strata on each side form an abrupt cliff, about 15 feet high, but the dyke affords a gradual ascent to the top, arising from the effects of its decomposition. On the beach also the same cause has contributed to produce a slight excavation worn by the action of tide. In fact the decomposition is generally so far advanced, as to render it capable of being dug with a spade, and it is applied to the same purposes as coarse sand, being mixed with mortar as a material for building.

There is no absolute certainty of its further extent Westward, than about forty or fifty feet, through which it may be traced in Plas-Newydd Park, where some person, perceiving its nature to be different from that of the surrounding strata, has been at the pains of driving a level up it, in the fruitless hopes of discovering a metallic ore.

The substance of this dyke is "indubitable basalt, composed of felspar and pyroxene." *Prof. Cordier*.

The effect of decomposition probably does not extend to any great depth, for the workmen soon find the rock become too solid to be used for sand. In the more solid parts the texture is rather coarse, and the proportion between the felspar and pyroxene variable. Sometimes these are nearly equal (483.), but in general the latter predominates considerably (484—486.), and the rock is of a dark colour. Sometimes the basalt is very compact (486.), and does not exhibit any signs of decomposition. Carbonate of lime is very generally disseminated through every part. In the midst of the friable and decomposing portion, there occur irregular, concretionary nodules (487.), about the size of walnuts, which consist principally of felspar rudely crystallized in one mass, through which are dispersed small crystals of black pyroxene. These nodules are remarkably tough.

The dyke is found on the opposite shore of the Menai, but there is no section by which an opportunity might be afforded of obtaining any satisfactory conclusions. Similar varieties of basalt occur in five other places, which bear so nearly in a straight line with the two already mentioned, that it is highly probable they are all portions of this dyke, but the concealed nature of the ground renders it impossible to obtain certain information of the fact. The nearest spot is in a quarry, on the North side of the road which runs South of Plas-Gwyn to Llanddaniel, and at 170 paces East of the bridge over the Braint river.

Two other places, within fifty yards of each other, were lately exposed upon digging the foundation for the new road from Bangor to Holyhead. They lie to the South of Llanfihangel-East, on the brow of the hill to the East of the marshy ground over the coal-measures, and the basalt is continued along the steep Northern bank of a small stream which here crosses the road, and then runs parallel to it on the South. The last spot is on the opposite side of this marsh, about a quarter of a mile to the S.W. of Llanchristiolis, at a spot called Tin-rath.

The cliff which bounds the dyke, at Plas-Newydd, is composed of clay-shale and argillaceous limestone. On the Northern side it may conveniently be divided into four parts. The lowest consists of thin, dark, shaly beds, containing a considerable quantity of lime. In it are found the impressions of small anomiæ common in this formation (490.). Upon approaching the dyke, the shale undergoes various degrees of alteration. At fifteen feet from the contact, it forms a compact bluish grey mass (492.) with spots of a fainter colour. The substance of some fossils, which coat a natural cleavage, puts on a crystalline appearance. In contact, it is of a very compact nature; bluish-green (493.), with irregular streaks of a lighter tinge, fracture conchoidal; not easily scratched. Several small crystalline plates of carbonate of lime are dispersed through the mass. The shaly structure disappears, in a great measure, upon approaching the dyke, but a partial separation into parallel beds is still evident.

Owing to the variable nature of this shale, we cannot expect a gradual passage from its original aspect to the indurated part. Together with the hardened variety just mentioned are patches (at five feet from the dyke) of yellow clay, slightly indurated (494.), and intermixed with fossil shells composed of crystallized limestone (495.). At two feet, a light yellowish clay forms the basis, through which are dispersed patches of dark brown; and black specks are placed in the centres of small spherical kernels of crystallized carbonate of lime (496.). On a weathered surface these are removed, and the rock is indented with the small cavities which contained them.

It is in the next portion, above this, that the more striking phenomena, on this side of the dyke occur. At fifty feet from the dyke it consists of a soft, dark coloured plastic clay shale, which separates into thin laminæ (498, 499.). On approaching the dyke this becomes, at thirty-five feet from the contact, rather indurated (500.). At ten feet, it forms a cherty mass (501.), with a splintery fracture, and of a buff colour, associated with patches and streaks resembling black flint (502). In it are patches of highly crystalline limestone. It scarcely admits of being scratched by the knife.

In contact, it is a hard porcellanous jasper, which readily cuts glass, extremely splintery, and the fragments fly from the hammer in all directions, producing an appearance similar to the effect of fracture on unanealed glass (503—509.). Its colours are light and dark grey, sometimes intermixed in irregular stripes parallel to the former position of the shaly structure. Sometimes the light grey assumes a reddish tinge (505.), and the specimen somewhat resembles a piece of fine porcelain, and is translucent at the edges. The fracture is splintery-conchoidal. Another variety is dull greenish-brown, and more nearly resembles a piece of chert (504.).

The impressions of broken shells, generally anomiæ both large and small, occur in the interior of the solid mass (507, 508.). It does not divide into parallel beds except in one or two instances, where the natural divisions are formed by a crust containing impressions of these anomiæ. This crust has a feruginous aspect externally, but possesses a resinous fracture and lustre within, and effervesces in acids.

There is a circumstance which generally takes place on the surfaces of small natural fractures or flaws, dispersed through hardened shale in contact with this and other dykes in Anglesea. On such surfaces there are small glittering plates (503.) from less than $\frac{1}{20}$ of an inch to full $\frac{1}{4}$ of an inch squared.

Different plates may be exhibited by presenting a surface at different angles of inclination to a ray of light, so that it seems to be entirely composed of them. These plates cannot consist of one uniform facet, for in that case the fracture would present an uneven surface of re-entering angles. Each plate is therefore formed by reflection from an aggregation of several minute polished facets, inclined at a common angle to the surface in the same plate; but this angle in different plates must vary.

The third division of this cliff consists of a dark argillaceous limestone about three feet thick, containing impressions of shells (488.). This is also capable of a partial subdivision into thin laminæ, but does not possess so decidedly a shaly structure as the two last, neither is the proportion of argil so great. In contact it forms a remarkably tough, close-grained mass of a speckled dull green and brown colour (489.).

A similar argillaceous limestone in contact with the dyke, on the opposite coast, is not so much changed. It assumes a hard character without much alteration of colour, and becomes finely granular and crystalline. Through it are dispersed specks of pyrites and impressions of shells (497.).

Above this we find another bed of clay-shale (510.), whose contact with the dyke is not exposed on the Northern side. It constitutes the main body of the low cliff to the South. This shale is also partially converted to a flinty mass similar to that already described. The flinty portions lie in irregular strings of various thickness, parallel to the position of the beds, and the rest of the shale assumes a confused appearance of crystallization and globular structure. The perfect crystals which occur intermixed with the mass, present two decided mineral varieties. A description of the specimens, selected for the Woodwardian Museum, will perhaps be the best method of enabling others to judge of their nature and mode of formation.

(511). Shale, of the consistence of hard clay, passing on one side to a globular structure, of a dirty white, earthy aspect. The globules, from one-tenth to three-tenths of an inch in diameter, run into each other, and are harder than the rest of the mass. It effervesces rather briskly for some time, without falling to pieces.

(512). The whole possesses a concretionary structure. The concretions white, some of the same size, but harder than in the last specimen. These are interspersed with smaller globules, about the size of mustard seeds. The interstices are filled with a soft brown clay. A partial effervescence may be obtained from the mass, but a detached globule affords none. Several of the concretions present crystalline facets of a trapezoidal form.

(513). With irregular concretions three-fourths of an inch in diameter. Upon fracture these are found to consist of an outer crust of more crystalline character, and lighter colour than the interior. The surface of each globule is very rough. Smaller globules occur within the larger.

(514). Several perfect crystals with twenty-four trapezoidal faces (the common form of leucite and analcime) are scattered through this mass, and traces of a crystalline structure are evident in the compact portions. The more friable parts, between the crystals, consist of a white earthy substance which effervesces briskly, but leaves a considerable residue.

(515). Globules and imperfect crystals closely united, and occasionally presenting a compact mass, resembling specimens of the hardened shale. In this specimen there occurs the impression of a valve of an anomia, two inches in width. The crystals are studded over, and pass through it, and small fragments, detached from the shell, lie embedded near it.

(516). Thin plate of hardened shale, striped light and dark grey, studded as in the last. The brown clay is left filling up the interstices between the crystals. Impressions of shells on each side of the specimen.

The original slaty structure of the shale modifies the shape of all these specimens, and the more perfect crystals lie on the sides which were parallel to the position of the beds.

I have great pleasure in adding to this account, an accurate examination, and a minute analysis of the perfectly formed crystals, kindly undertaken by Professor CUMMING.

"They are slightly electric by friction; they scratch glass; they readily vitrify before the blow-pipe, and gelatinize with acids. The specific gravity of some detached crystals was 2.293; that of a mass 2.394. By exposure to a red heat there was a loss of 5 per cent."

"The mineral was examined in the usual method, by repeated digestion with muriatic acid, the residue being fused and boiled with caustic potash. The muriatic solution, dried and heated to redness, to decompose the muriates of iron and alumina, was dissolved in water; a small quantity of lime was separated from the solution, which by evaporation gave crystals of common salt. Silex was obtained from the alkaline solution by muriatic acid; alumina and iron were precipitated by caustic ammonia, and lime by the oxalate. The iron and alumina were separated by boiling with caustic potash, from which the alumina was precipitated by muriate of ammonia. The results were,

Silex	49	100.
Alumina	17	
Lime	12	
Iron	4	
Soda	9	
Water	5	
Loss	4	

"Hence, the crystals appear to be analcime with excess of iron."

Small crystals are found embedded in the soft earthy matter, placed between the globules and the large crystals. They are sometimes beautifully symmetrical, but more frequently their facets are less regularly disposed. Their colour is dull opake white.

The remaining specimens present a crystalline substance distinct from the last, but the general character and mode of aggregation is nearly similar. The crystals here assume the form of the rhomboidal dodecahedron, and are generally found in greater perfection than the former, most of the concretions possessing crystalline faces. They are often pressed together into a confused mass, with somewhat the appearance of Coccolite.

(517). Several good crystals; the largest diameter of the rhombic faces is two-fifths of an inch. These are attached to the hardened shale, which contains thin seams of crystallized limestone.

(518). Mass of the crystallized matter; the diameter of the largest rhomb three-fifths of an inch. The interior of some of the large crystals is made up of minute crystals and globules. A thin coat of carbonate of lime covers some of the faces. The edges of some of the dodecahedrons truncated.

(519). The facets exhibit a satiny lustre; the intervals between the crystals are filled with a dark plastic clay and crystallized carbonate of lime. The internal structure of some crystals presents a series of dodecahedrons, one within the other.

(520). Very minute crystals fill up the intervals between the larger, and scarcely any clay is present.

(521). Some large crystals of the dodecahedron with truncated edges, seven-tenths of an inch in diameter. Facets well defined, possessing a resinous lustre and olive brown colour. These are embedded in a mass of crystalline matter of the same kind, and the whole attached to some hardened shale.

(522.) Crystals on hardened shale. This shale presents a mottled appearance, as though numerous globules, running together, were firmly cemented by a substance of similar nature but different colour.

(523). Hardened grey shale with white globules, more perfect than in the last, embedded but not distinct from the mass, so that the fracture presents white circular patches on a dark ground.

Professor Cumming has examined also the nature of these crystals "but they appeared so decidedly to possess all the characters of the garnet, that it was unnecessary to enter upon a minute analysis. They readily scratch the former crystals; their specific gravity is 3.353; they do not easily fuse before the blow-pipe *."

C. 5. At Cadnant, there is another large dyke of a similar description with the last.

On the opposite shore of the Menai, it cuts through the limestone and shale. The effects which it there produces on the surrounding strata are not so powerful as in the former instance, but the marks of violence by which it is accompanied are more

* I am fortunate in being able to add another instance where garnets have been found under similar circumstances of association. Sowerby, in his British Mineralogy, Vol. II. p. 37. Tab. 120, mentions minute garnets, received from the Rev. J. Harriman, "the crystals from the size of a small pin's head to an extreme degree of minuteness—of the form of the rhomboidal dodecahedron,—mixed with a rough mass of their own nature, which seems to incorporate with some quartz—the matrix of carbonate of lime and a siliceous substance, resembling dull reddish jasper." He neither alludes to their locality, nor to the circumstances under which they were found. Whilst Professor Sedgwick was in the North, during last summer (1821), I wrote him an account of the discovery of the garnets and analcimes at Plas-Newydd. Shortly afterwards, he accidentally heard that garnets had been found, in the Mountain limestone formation, in High-Teesdale, and imagining that their geological relations might be the same, he (directed by Mr. Harriman) visited their locality, and though he did not procure any garnets, found the exact matrix described by Sowerby. This proved to be some altered shale and limestone in contact with a large overlying mass of basalt about half a mile below Caldron-Stuno, on the Northern side of the stream. The fact therefore is doubtless of a similar nature to that above-mentioned, though the crystals are not so well exhibited, and are confined to one mineral species.

striking. Considerable masses of the stratified rock lie completely embedded in the trap, and some portions are partly envelloped by the dyke, which ramifies and passes round them.

The composition is "most certainly dolerite; felspar and pyroxene". *Prof. Cordier.*

The main body approaches to the same earthy state as the dyke at Plas-Newydd, and through it are dispersed patches of a more compact nature (524.). This structure is common to all the dykes of a similar character in Anglesea. The harder portions resemble irregular spheres, pressed together, which decompose in concentric crusts. Sometimes these hard portions run into small columns which break into separate joints (527—529). In some parts we find scales of dark brown mica (525), a circumstance of rare occurrence in the dykes of Anglesea. Carbonate of lime, in small quantities, is dispersed through the rock. In contact with the surrounding strata, to the South, it passes to a dull earthy wacké which separates into prismatic masses (526.). In one spot, on the Southern side and near the top of the cliff, it assumes a peculiar character, consisting principally of crystals of jet black pyroxene with a little felspar and lime intermixed, and through it are dispersed nodules of mesotype with crystallized carbonate of lime.—This portion presents concretionary masses about one foot and an half cubed, and is in contact with an embedded mass of the stratified rock. The natural fissures are coated over with a crust of carbonate of lime, formed into an irregular aggregation of rhombs.

The mesotype is also found in the earthy portion of the dyke, but the radii composing each nodule separate upon removing the specimen.

The entangled strata, just alluded to, form a flinty mass (532.) coated and penetrated by carbonate of lime in a pulverulent state (533.). Other portions consist of hardened sandstone

(534, 535.) intermixed with crystalline limestone (536.), and cherty masses, where the natural fractures are covered with the peculiar glistening plates, formed from an aggregation of small parallel facets, in the manner already described (537.). Small crystals of selenite are found in the fissures of the same specimens.

As might be expected, the effects produced upon the surrounding strata are not so marked in this place as at Plas-Newydd, where the dimensions of the dyke are larger. The alterations, however, which they sustain, are sufficiently striking. On the Southern side, the shale and limestone assume a ferruginous, or ochreous appearance, and the passage of the clay to a flinty character (538.), and of the compact limestone to a crystalline (539.), together with the intermixture of the two (540.), where the stratum is of a compound nature, are quite distinct. In one bed of clay shale, which partly assumes the flinty appearance (542.), there are some portions contiguous to the dyke which are found in an earthy form. They are however in a state of decomposition and consist principally of yellow ochre (542.). The casts of large madrepores, partly composed of chert, and partly of limestone, found in the same stratum, (544.), become distinctly crystalline upon approaching the dyke (543.).

On the Western shore of the Menai, the whole width of this dyke is not exposed; it may be traced for 78 feet, and is seen, in the direction of its course, along the steep Southern bank of the stream which empties itself at this spot. It is much more compact than on the opposite coast, a circumstance probably owing to the nature of the surrounding rock; for none of the dykes which intersect the limestone and shale attain to so great a degree of compactness as the generality of those which are found among the schist.—It is here styled by Professor Cordier, "a true dolerite, having the ingredients, pyroxene, *fer-titané*, and felspar, well characterised." The proportion which the carbonate of lime bears to these, is very trifling (545.). Proceeding inland the dyke is soon lost, Pl. XVIII. Fig. 1. is an ideal section, beyond this, along the direct course of the dyke, the dotted lines representing the concealed portions. Parallel to this section there runs a hollow valley, bounded on the North and South by abrupt elevations of schist, and it is beneath the Southern boundary that the dyke is supposed to take its course. On arriving at the top of the hill, three distinct strata, in the chlorite schist, are seen rising in the contorted manner represented in the figure, and forming a small elevation on the top of which there are large stones arranged in circles, which are said to be the remains of an ancient British town. To the West of this spot the trap again protrudes, by the side of the road leading from Beaumaris to the post-road, and a little further to the West it is once more seen rising through the schist, which is hardened (550.), contorted, and partly changed to ochre (551.).

The central portions of the dyke bear the same character as at Cadnant, but towards the outside it assumes a greater degree of compactness (546, 547.), and in contact, forms a dark grey, and nearly homogeneous mass, very tough, and with a conchoidal fracture (548, 549.). Professor Cordier remarks upon a specimen from this spot, "This is a desideratum; the air-holes, and greater degree of compactness where in contact with the schist, render all further discussion as to its igneous origin perfectly ridiculous." The fact which this dyke presents, of becoming more uniform as it approaches the surrounding schist, is repeatedly to be met with in many parts of Anglesea, and may indeed be said to form a general character in dykes of this description.

There is a dyke, 40 feet wide, at Moel-y-don ferry, to the

South of Plas-Newydd; an horizontal section of which is exposed on the Western shore. It reaches to the opposite coast, rising through a projecting mass of limestone and shale which forms a small promontory to the South of the ferry-house.

Its composition is "felspar and pyroxene. The laminæ composing the crystals of felspar are all in the same direction; a circumstance similar to what takes place in the lavas of Ætna and Tenerif." *Prof. Cordier*.

Parallel to this, on the Western shore, and at twenty-four feet to the South, there is a small string, five or six inches wide, of the same kind of trap; and the main dyke itself ramifies towards the North. Between the two, the limestone is considerably altered. In it are a quantity of madrepores; the whole assumes a crystalline character, being formed of small plates loosely cemented together, which gives the specimens the appearance of a sandstone. The madrepores are traced by black plates, and the basis in which they are embedded by plates of a light colour (554—558.). Some portions of the madrepores are not crystallized, whilst the intervening limestone is; which produces an easy separation at the joints, and furnishes a better opportunity of examining the internal structure of these bodies, than could otherwise have been obtained (554, 555.). Possibly the black plates, which trace out the former space occupied by the madrepores, may owe their colour to the carbonization of these bodies.

Through part of this dyke (553.), and in some others in the neighbourhood (559—563.), there are dispersed small globules of a white transparent mineral, the lustre of which resembles that of stilbite. It occasionally possesses a light blue tinge and opalescent aspect. To a slight depth, on the exposed portions of the dyke, all the globules are decomposed to an ochreous powder. Before the blowpipe it turns black, but does not appear to sustain any further change. I suspect this to be a modification of a substance which Mr. Underwood informs me that he found in the dyke nearest to Plas-Coch, on the S.W. (562, 563.). Mr. Underwood says, "What I took for olivene, (and which, though bright green when I broke it), became black in a few days, (an effect which Cordier had once experienced in green earth), and although it has a vitreous fracture, may yet be scratched with a knife." There can be but little doubt that this is the mineral named chlorophæite by Dr. Macculloch in his Western Islands, Vol. I. page 504.

A dyke, composed of little else than crystals of dark green pyroxene coarsely aggregated (564.), and intermixed with pyrites (565.), intersects the strata at the coal-pit on the S.W. of Llanfihangel East. M.I.

Some dark lead-coloured clay shale (567.), in contact with it, passes to a hard jaspideous mass scarcely differing in colour from the unaltered portion (568.). Other strata of shale, grit, and limestone, sustain alterations similar to those already described. Where the dyke comes in contact with the coal, the latter is converted to a scoriaceous cinder full of air-blebs, and traversed by cracks and flaws, many of which are filled by crystallized carbonate of lime (569.). Upon removing this by an acid, a perfect cinder is exhibited, which will neither inflame nor emit any smoke before the blow-pipe. A rude columnar structure may be traced in some portions of this substance (570.), the prisms being about half an inch in diameter, and this is also visible where the apparent conversion to a cinder is less evident, but where the inflammable matter is equally wanting (571.).

Equiaxe rhombs of crystallized carbonate of lime thickly coat over the natural fissures, both in the dyke (566.) and in the cinder (571.).

Q. 1. Another dyke extends from the neighbourhood of the South Stack to the Southern extremity of Holyhead island. The average width of this is about sixty feet. It first appears to the S.E. of the Stack, forming some dark brown rocks, projecting from the sea, at the base of the cliff. It then cuts through a small headland not less than 200 feet in height, and may be distinctly seen in the cliffs to the East and West, but no trace of its intermediate course is apparent on the surface; shewing how very easily a dyke of this description may escape observation, unless accompanied by a succession of denudations. It again enters the cliff on the S.W. side of Hen-Borth, and at this spot presents a picturesque mass of rock, rising abruptly from the shore, the base of which is surrounded by the sea at high tide. It is then lost until, after crossing some high ground, we arrive near Port-Dafreth, where its course is marked, along a sunken track lying between two ridges of schist, by several portions of the trap projecting through the surface. It is seen in the cliff on each side of Port-Dafreth, and may distinctly be traced to the S.E. through the next promontory. It is then lost as a continuous body until we arrive about half a mile to the S.W. of Borth-Anna. In the intervening space, however, there are numerous strings of trap rising through the schist, one of which exhibits a termination upwards, Pl. XVII. Figs. 5, 6. At the spot where it re-appears to the S.W. of Borth-Anna, this circumstance is remarkably well exhibited. It so happens that there is a vertical section in the very direction of the dyke, and the trap is seen for ninety feet in length, capped by the schist from fifteen to thirty feet in thickness, Pl. XVII. Fig. 7. The surrounding schist is in a most confused and contorted state, and considerable portions of it are entangled in the trap. Immediately beyond this spot the dyke regains its original character, and presents several hard projecting masses, rising between two ridges of schist, as far as the marsh on the North of Rhoscolyn. It is found in three places, after crossing this marsh, which bear in the same direction as before; after which it is concealed until we arrive at its Southern termination, where it runs out to sea along the Western side of a small bay.

The most interesting phenomena exhibited by this dyke, are the various changes which it assumes in its mineral character. These changes are not merely such as are presented by different portions of it, at considerable distances from each other, and where it is possible that some doubt of their perfect continuity might exist, but are such as may be traced in parts of one mass.

In Port-Dafreth, there is a recent section which enables us to investigate this point with considerable facility. The main body of the dyke assumes a dirty brown earthy aspect, as though it were in a state of semi-decomposition, and through it are dispersed small crystals of felspar and pyroxene (602, 603.). Some portions of this are filled with nodular concretions about the size of peas, composed of crystallized felspar interspersed with small crystals of pyroxene. The earthy base becomes washed out by exposure, and the nodules project upon the surface (604.).

The more compact portions of the dyke resist the action of the weather, and, when the softer parts are decomposed and washed away, present projecting masses of bare rock, which enable us to trace its course with greater facility. The usual character is felspar and black pyroxene, intimately associated, and possessing a tough, uneven fracture. Although the individual crystals of each substance are small, there are numerous traces of a laminated structure, common to several of them, scattered in different directions throughout the specimen (605.). In one spot, at Port-Dafreth, this variety is amygdaloidal, containing kernels of white chalcedony (606, 607.).

In the small strings given off among the schist between Port-Dafreth and Borth-Anna, the trap always assumes a more compact character, resembling the varieties found at the termination of the dyke at Cadnant to the West (608, 612—614.).

In the Southern division of Holyhead island, the crystals of felspar and pyroxene are generally larger and more distinct. Professor Cordier considered the specimens from this portion "as belonging to the most ancient dyke in Anglesea. The felspar is whiter, and the pyroxene greener. It perfectly resembles the granitoidal ophites of the Vosges, which in those mountains exists in powerful beds. In the ordinary diorites, the felspar is greener, and the pyroxene blacker. The rock is highly interesting, and merits a very strict investigation." The characters here specified are partial, and the more ordinary varieties of this very dyke have, as he describes, the felspar greener, and the pyroxene blacker (515—520.). Hence it should seem, that the distinctions of age, deduced from mineral character alone, are not applicable to the dykes of this country.

The appearance of alteration impressed upon the rocks in contact with this dyke are not so striking or so general as those afforded by the dykes already described, which intersect the strata of more recent formations. It is possible that many facts of this nature have been obliterated by subsequent decomposition, or may actually exist where we are not sufficiently acquainted with the original character of the rock itself, to be able to determine whether an alteration has taken place or not. It is however evident, that such has been the case in several instances. On the Western side of Port-Dafreth, there is an indentation to the South of the dyke, formed by a re-entering angle in the cliff, and parallel to its course. The thin slaty laminæ of chlorite schist, which project round the sides of this hollow, are remarkably sonorous when struck by the hammer, and consist of compact and rather splintery quartz, translucent, and imperfectly tinged green (622.). The surfaces of the thin laminæ are coated with scales of chlorite (623.).

Where the dyke is contained between parallel walls of the schist, and appears as though it were filling up some large crevice, the effects are never so striking as in those places where it ramifies and becomes intimately associated with the surrounding mass. It is in these cases that the trap assumes a more compact character, especially where fragments of the schist have become entangled in its substance. These fragments entirely lose their original aspect, and present a finely striated and contorted mass, blending with the trap, and forming, as it were, a part of its substance (613.). The line which separates the dyke from the surrounding schist is distinct, and a blow will generally detach them; which renders it difficult to procure a specimen exhibiting their junction.

At the spot where it intersects the serpentine, the dyke ramifies for a short space, but soon re-unites. The mass thus enclosed between the two branches consists of dark argillaceous matter, which shatters into small fragments bounded by most irregular though natural cleavages. Through it are dispersed small crystalline plates (621.).

The dyke which runs, from the North-Eastern side of Holy- Q. 1.
head mountain, towards the S. E., to a spot between Port-Dafreth and Borth-Anna, possesses precisely the same characters as the last. At its Northern termination the trap has been removed by the continued action of the sea, and its original walls, composed of quartz rock, form a small bay about eighty feet wide. In this as well as in the last dyke "there is less *fer titané* than is usually found in dolerite, but there is more pyrites." *Prof. Cordier*. (624—627.). The quartz rock in contact is partially altered, and has become charged with a considerable quantity

of felspar, in a state of decomposition (630—632.). In other places, where it remains hard, it loses its usual crystalline appearance (633, 634.). In the trap, there are several masses of hardened schist (628.), and also irregular strings or veins of breccia, composed of angular fragments of quartz, felspar and schist (629.).

The evidence for the continuity of this dyke is not so clear as for that of the former. From the top of the cliff may be seen a hollow tract, lying between two ridges of schist, stretching in a South-Easterly direction, resembling the valley which accompanies the dyke at Cadnant, and similar to that which is occasionally seen along the course of the dyke last described. A considerable mass of trap is found at the spot where this line is intersected by the road from Holyhead to the South Stack, and another, of precisely the same character, in the road leading from Holyhead to Port-Dafreth (635, 636.), where the schist in contact is flinty (637.). "The pyroxene" is here "completely characterized, the cleavage evident, and the crystals may be extracted. This is a most beautiful specimen of dolerite, the same as that at Mount Meissner." *Prof. Cordier.* I met with similar trap in three other localities, along the line of bearing, but the intervals are interrupted by schist.

The two dykes which lie to the N.E. of this, in Port-Newry, are composed of a coarser and tougher basalt, resembling the hard portions of the dyke at Port-Dafreth. The largest is eighteen feet wide (638.), the smallest only one and a half (639.), and they run parallel to each other, from W. of N. to E. of S., with thirty-two feet of schist interposed.

O. 5. The dykes on the Western side of Dulas habour are composed of small grained white felspar, and black pyroxene, and through them are dispersed patches (not distinct crystals) of brown felspar (572—574.). Some portions are very earthy (575.).

The black slate, in contact, in some places passes to a light grey homogeneous clay-stone (576, 577.), at others it undergoes no alteration. In one instance there are several detached fragments, which lie embedded near the side of the dyke. Pl. XVII. Fig. 4.

There are two dykes at the Southern extremity of the C. 5. promontory at Llandwyn, the basis of which appears to be formed of earthy chloritic matter, not to be distinguished from some of the earthy varieties of the chlorite schist (682.). Through it are dispersed crystals of liver-coloured felspar an inch in length (683, 684.). These dykes intermix with the surrounding schist, winding irregularly among it. The most Southerly of the two is soon lost in the sea, both to the East and West; but the other may be traced through several of the indentations formed along the coast, and is exhibited eight times in the cliff.

It appears unnecessary to enter into a separate detail of any more of these dykes, and I shall now merely subjoin the opinions of Professor Cordier concerning the composition of some others which he examined, and select a few circumstances which may seem the most interesting towards establishing their history (640—681.).

The character which many possess, is that of an irregular vein (681.), from a few inches to some feet in width, winding among the schist, and frequently ramifying in its course. They sometimes unite firmly with the surrounding rock, but in general, the line of separation is perfectly distinct, and a blow will readily divide them.

I detected from twenty to thirty between Beaumaris and C. 5. Garth-ferry, a distance of about two miles. It is very easy to overlook them when the cliff is low, or when they are only exhibited on the horizontal section formed by the beach. Where lichen and algæ coat over every thing, the only distinction is in their smoother surface, and more angular fracture: but this will frequently escape observation where a moment's inattention may carry us across one at a single step.

It will be seen in Pl. XVIII. Fig. 4. at *a* and *b*, that there is a deceptive appearance as though these dykes terminated abruptly downwards; but in these cases the course may be considered as tending upwards, obliquely to the plane of the paper, when placed vertically, and coming from some point behind it. The deception arises from the face of the cliff intersecting the inclined side which bounds the furthest extent of the dyke to the East, a fact which I verified in one instance, by removing the schist from below. There is a marked distinction in this apparent mode of termination, and that which is seen in Pl. XVIII. Fig. 2. at *a*. In the latter case, the fissure containing the basalt, gradually becomes thinner towards the end, in the former, the entire width is preserved.

The specimens examined by Professor Cordier, from this neighbourhood, were "dolerite. The pyroxene very evident, with *fer titané*."

"A basaltic lava, but more felspathic than the others. The felspar has the filamentous character of volcanic products, resulting from the crystals being flattened. To see this, two sides of the specimen must be placed at right angles to each other."

The appearance of the flattened crystals is common to several of the very compact dykes, and may be seen in some parts of the one near Cadnant, towards its Western termination. In the small dyke Pl. XVIII. Fig. 2. *a*, these crystals are few, and extremely minute (642.), the basalt being more remarkably fine grained and tough, than any other which I met with in Anglesea.

An evident intermixture often takes place, between the trap and the surrounding schist, along the line of junction, which sometimes resembles the gradual blending of two different colours in a mass of striped jasper (642.). Small portions of schist are embedded, near the sides of the dyke, which intermix with the trap, and modify its appearance and composition (641, 643.). The schist, in contact, has frequently a blistered aspect, with irregular cavities and flaws (644, 645.).

Dykes immediately to the North of the Menai bridge.

"Dolerite with *superbc* pyroxene." *Prof. Cordier.*

"Felspar and pyroxene with crystals of pyrites (665.). The circumstance of having crystals of pyrites, though rare in streams of basalt, is easily accounted for in a dyke. The extended surface presented to the air by the stream, would enable the sulphur to evaporate, but in the dyke it is condensed. Perhaps also the dyke never came to day." *Prof. Cordier.*

The presence of pyrites, frequently in the form of distinct crystals, is common to *most* of the dykes in Anglesea.

Dykes to the South of the Menai bridge.

"Basalt very rich in felspar." *Prof. Cordier.*

"Basalt poor in pyroxene." *Prof. Cordier.*

On the South-western coast near Aberfraw.

"*Plus travaillée* than the other dykes—blistered." *Prof. Cordier.*

The passage to the earthy traps is perfectly insensible, and portions of the most genuine basaltic dykes are frequently of this nature.

At Llangwyfan—"*Wacké endurcie.* It is full of green earth, C.3.
and ought to become cellular in an acid." *Prof. Cordier.*

Most, if not all, of the varieties of trap included in the dykes of Anglesea are occasionally amygdaloidal and porphuritic. Some contain nodules of crystallized carbonate of lime, which do not always exhibit the usual appearance of a rhomboidal cleavage common to the whole nodule, but possess an uneven fracture, although the specimen is perfectly pellucid, approaching the character of saccharine marble (658, 659.). Embedded crystals of felspar are more common in the compact and earthy traps (661.), than in the crystalline (660.).

The compact portions, of several dykes, assume a confused appearance of crystallization, and break into small fragments, a few inches in diameter, bounded by perfectly smooth surfaces. Several of these form accurate rhomboids (676.), others exhibit this figure modified by a diagonal cleavage (675, 677.); but it generally happens that their figure is less regular, and that no two faces are parallel to each other (678, 679.). The effects of decomposition frequently extend to a considerable depth in the dyke, and we find each of these fragments, partially decomposed, presenting a portion of unaltered trap in the interior (680).

Granitic Districts

(including the Granite and Greenstone).

{Nos. 789 to 844.}

A rock formed of quartz felspar and mica, is found in each of the tracts laid down as including the granite; but the mineral character of the whole district is far from uniform.

Gr. In the Southern portion, about the neighbourhood of Gwalchmai and thence towards Llanerchymedd, the surface is broken by small detached rugged eminences, rising through a marshy ground, which is bounded East and West by an abrupt termination of the stratified rocks.

The external character of all these protruding masses is so very similar, that it is impossible to calculate beforehand on what may be the real composition of any one in particular. On examination they are found to vary extremely; one may be a true granite, the next a pure quartz, the third a greenstone, &c.

A better notion of this variety of composition may be obtained by referring to some of the specimens which were procured in the neighbourhood of Gwindu, within four miles North and South of the Inn.

Among the granitic rocks the quartz is generally white; the felspar is either white (724, 725.), brownish yellow (726, 727.), or flesh-red (728—737.); the mica silvery white (725.), black, or green (730—732.). In the latter case it becomes associated with chlorite, which in many places entirely supersedes it (739, 743.), tinging both the quartz and felspar of a greenish hue (740.). The chlorite also mixes with hornblende (741—744.), and these two substances frequently predominate so much as nearly to obliterate the quartz and felspar (753, 754.). Sometimes the felspar, of a flesh red colour, forms the basis of the rock, and the other ingredients are sparingly dispersed through it (728, 729.), (745, 746.). In other places, chlorite and mica supersede the rest (752.), and we then find only patches and veins of felspar and quartz, completely enveloped in the more trap-like rock (750, 751.). A beautiful variety is composed of dark green hornblende crystallized in large plates, and intermixed with irregular patches of white felspar (755.), which however frequently assumes a greenish tinge (756.). At the same spot there are patches of crystallized carbonate of lime penetrated by yellowish green spiculæ of epidote (757.), a substance pretty generally diffused through the surrounding rock, either in veins (758.), or interlaminated with the hornblende (759, 760.). It occurs also in compact masses, intermixed with quartz (761.). Patches of genuine basalt are scattered throughout the district, completely enveloped by the granite, and possessing the same character as the trap found in the dykes of various other parts of the Island (762, 763.).

All these varieties are highly crystalline; but with them we find rocks of another description, whose composition is more nearly homogeneous. They possess a flinty aspect approaching to hornstone, and are of various shades of white (766, 767.), grey (768.), or green (769.). Here and there a crystalline structure is exhibited, or a few crystalline specks lie dispersed through the compact base.

This variety in the mineral composition is chiefly confined to those parts of the district which present a broken rugged outline. In the elevated ridge which stretches from Gwalchmai to Lanfaelog, the character is more uniformly granitic and the surface of the ground unbroken. The quartz and red felspar have not the distinctly granular appearance which they generally assume in substances of this nature, but are intermixed with a more pasty aspect than usual (734.), and the lustre frequently deadened by a superabundance of the oxide of iron (737.).

Gr. 4. The Northern district occupied by the granite is not so variable in its character; the usual appearance being that of an irregular and large grained intermixture of quartz, white felspar and silvery mica. A greasy lustre is frequently given to portions of this granite, which apparently arises from its being contaminated by a considerable quantity of talc (790—801.).

By referring to the Map it will be seen that there are two districts which consist entirely of greenstone. The general character of the rocks which compose them, is so nearly allied to some parts of the granitic district to the South of Gwindu, and their relation to the surrounding strata so very similar, that little doubt can exist of their belonging to the same formation.

Gr. 3. The district to the North of Llanerchymedd is marked by rugged, and rudely shaped masses, projecting through the surface. These extend from a spot about one mile to the North of the town, on the West of the road to Amlwch, towards the North of East, and pass a little to the North of Llandyfrydog. A prevailing character is that of an hornblende rock, composed of large crystalline plates interlacing in various directions, and cemented together by a little felspar and carbonate of lime (689.). The felspathic cement gradually increases (690.), till it forms a greenish compact basis, through which the crystals of hornblende are dispersed (691.). Other varieties present a more perfect intermixture of these two ingredients (692—694.), with the addition of small shining plates, apparently diallage (695.). White felspar and dark grey hornblende form also a finely granular compound, which resembles some varieties of the trap included in the dykes (696, 697.). Distinct, green crystals of hornblende are embedded in a basis of crystallized white felspar, and it is worthy of remark, that some of these crystals have been broken, and the fragments lie in different directions, surrounded by the felspar, the edges of their corresponding extremities tallying with each other (699.).

The greenstone to the East of Llanbabo is not well exhibited. Its characters are precisely the same as the former (712, 713.).

Having proceeded thus far with the description of the granitic districts, before any attempt is made to establish the probable history of the rocks which they include, it may be here remarked, that the phenomena which accompany them are so very similar to those presented by the trap dykes, that we can have little hesitation in ascribing their origin to the action of the same cause. This circumstance is premised, that the object may at once be seen for which any particular appearance, tending to establish the theory of their common origin, is recorded. From what has been stated, it will readily be conjectured, that the theory alluded to is that which ascribes the formation of these rocks to the influence of volcanic action, and it must be perfectly unnecessary to recapitulate the arguments which have been urged by others in its support, and drawn from appearances similar to those described under the details of the several dykes enumerated in the preceding part of this paper. They are such as will suggest themselves to every one, and some speak so strongly in its favour, that it seems scarcely possible for the most sceptical on this head not to allow the force of their evidence.

In addition to those arguments which may be deduced from such phenomena, it may be stated, that the number of these dykes must be very considerable; for many of those enumerated have become exposed, by mere accident, in the different quarries opened for the purpose of repairing the roads, and it may reasonably be expected that there are very many others concealed beneath the cultivated surface, as well as several which have escaped observation. In no one instance does it appear, that they are in any way associated with a superincumbent mass of the same nature, and indeed the great variety of mineral character which they assume is alone a strong argument against supposing them ever to have formed members of a common body. None of the veins and fissures which contain them appear to terminate downwards, whilst on the contrary it should seem, that, in some instances, their termination upwards has been clearly ascertained. In others, there is every probability, that a considerable part of their course lies beneath the rock with which they are in contact at the surface.

There is one argument brought against the igneous theory which may be supposed to derive weight from the investigation of Anglesea. This is, that the trap, if projected in an ignited state, would have produced results of a more uniform character, whereas in many cases it should even seem that it has produced no alteration whatever upon the surrounding rock. Now, one decided example of alteration should speak more plainly towards establishing the nature of these dykes than any negative argument which might be drawn from those cases in which no such alteration is found to take place; for we know it has been determined by experiment that certain rocks, when fused, will afterwards return to their former state, if placed under those very circumstances which most probably must have existed at the time of their fusion.

This fact may be illustrated by referring to the phenomena which accompany the dyke at Plas-Newydd. The alteration which there takes place in the surrounding rock, although of the most decided nature, is by no means uniform, even in the same stratum. On one side, we have a mass of soft clay shale assuming a hard jaspideous character, whilst, on the opposite side, this alteration is partial, and the rest puts on a crystalline structure; and intermixed with this we also find some portions in an earthy state. That the whole is not crystallized may readily be accounted for, by supposing a superabundance of calcareous and argillaceous particles, above the requisite proportion necessary for the formation of the crystals; still, however, it shews us that in the very spot where the change is the most marked, it is yet possible for some portion to remain unaltered.

If the granite of Anglesea be justly ascribed to the same class of rocks as those which compose the trap dykes, it should seem equally certain, that some portions of it must either have resulted from the fusion of the surrounding strata, or else have been considerably modified by an intermixture with them, and consequently that it is more recent than any with which it is associated.

At the South-western termination of the Northern granitic district, there is a patch of old red sandstone. Although the o. 4.
whole of this appears to have been considerably changed from

its original character, and to have assumed a more compact and crystalline structure, yet at the furthest point West from the granite, it is evidently composed of sandstone mixed with coarse breccia containing pebbles of quartz and slate (784.). The strata run directly towards the granite, and several opportunities occur of examining the alterations which they sustain. Upon approaching the granite, the crystalline character increases, the materials become more firmly cemented, and pass into each other (785—788.), till at length, without any abrupt transition (789.), the strata merge into a crystalline rock (790—796.), in which the nodular concretions of quartz have scarcely lost the aspect of pebbles (790.). Felspar, frequently of a talcose or steatitic aspect (792.), forms the principal ingredient of the resulting granite (798—801.), which contains large, distinct concretions of quartz and mica. Through it there are also dispersed irregular masses of impure adularia, which cleave with great facility (797.). At the spot where the sandstone has first assumed the decided character of a granite, there occur a few specks of galena (796.).

A repetition of similar appearances may be traced along the boundary between the old red sandstone and South granitic district. Towards its Northern termination, immediately to the West of Llanerchymedd, the granite is found in the bottom of a valley which passes between two portions of the sandstone. At the last spot where its effects are distinctly marked, there is a quarry in which the rock may truly be said to constitute the intermediate passage between the two. The remains of a coarse sandstone are evident in some parts of the quarry, and the passage (777—780.) to a perfectly crystalline mass (781.) distinctly visible. The whole shatters into small fragments, and a considerable portion is converted to yellow ochre, which also coats over the natural cleavages in the more solid portions. A vein of crystalline quartz, one inch and an half thick, traverses the decomposing, porous portion of the rock (783.), and with it are intermixed irregular stripes of chlorite, which penetrate the quartz, and are so disposed, as to form rudely parallel lines inclined to the sides of the vein at an angle of 45° (782.). Where the chlorite is not present, the quartz still preserves a tendency to cleave in this direction; a circumstance which bears a striking resemblance to a fissile texture, oblique to the disposition of a bed.

About one mile to the South of this spot, there is one of the localities already pointed out, for the fossils in the old red sandstone. The quarry in which they occur is on the confines of the granite, and the neighbouring mass of rock, which projects a few yards to the East, is in fact completely crystalline. Some parts of the quarry also approach the same structure, and a gradual obliteration of the fossils is the consequence. The impressions are coated with oxide of iron (369.), and as the matrix loses its original character, their position becomes marked only by an irregular cavity, retaining a partial impression of some portion of the cast (370.), till at length the spot where they formerly existed is simply traced by a shapeless ferruginous patch (371.). Having found the impressions of anomiæ in the midst of the altered shale at Plas-Newydd, and even where it had assumed a crystalline structure, it did not seem improbable, that some traces of these shells might also be met with in the neighbouring granite, derived from the altered sandstone. But the search proved fruitless, and indeed we can scarcely expect that any such can exist. The less compact state of the sandstone, and the character of the resulting rock, so much more uniformly crystalline than that of the altered shale, would render it less likely that any appearance of this description could be preserved. It may seem singular that I should have searched in the granite for a fossil, as a circumstance likely to increase the number of arguments in favour of its igneous origin. But what has been stated may serve as a caution against forming any hasty conclusion to the contrary, should such a discovery be ever made.

The altered appearance of the old red sandstone, which lies to the West of the Southern granitic district, was remarked in the description of that rock. The facts which have been just stated seem to point out a cause adequate to the explanation of this circumstance, and there are besides some other particulars connected with its history, which tend materially to
O. I. confirm this supposition. From the lake at Llanfaelog, to Llanfihangel, the surface is swampy and uncultivated, through which many masses of bare rock project. Several of these present an aspect so highly crystalline, that at first sight a question might easily arise, whether we were not still in the midst of the granite, until a second blow from the hammer clears up the doubt, by exposing a mass of hardened sandstone. In short, the state of this sandstone appears to be only a degree removed from the more crystalline structure of the granitic district which lies to the North of Gwindu.

Near Llanfihangel church, on the South, and in the midst of an assemblage of rocks distinctly composed of the brecciated materials, we find a mass of trap (804, 805.). The felspar is sufficiently distinct, and forms the chief ingredient in the basis of the rock, through which a few embedded crystals of the same mineral are scattered, giving it a slightly porphyritic character. The whole assumes a greenish tinge, but the colouring substance does not appear to be of a very crystalline nature, and is probably chlorite. This intermixes with a confused aggregation of hornblende and diallage (807, 808.), passing by insensible shades to the breccia which surrounds it. In the very midst of the more crystalline portion we find small patches possessing a trace of the original character not quite obliterated (809.).

The rock often passes also to a light green felspathic mass, spotted or mottled with dark green. Several such appearances occur in the form of smooth nodules, already alluded to as embedded pebbles, but I strongly suspect that they must be of a concretionary nature, similar to those in the steatitic rock near Bangor.

The whole of the exposed rock to the S.E. of Llanfihangel church, has more nearly the external character of a mass of trap than of any other substance. It possesses no traces of stratification, but is rent by fissures which divide it into prismatic and rhomboidal blocks. One of these is so singular in its appearance, that I have given a sketch of it, Pl. XVIII. Fig. 5. It resembles a basaltic column lying upon its side, and is composed of felspathic and chloritic matter, mottled and blended together (810, 811.).

On the N.W. of the lake near Llanfaelog, there are several instances of a similar passage of the breccia to a trap rock (812.).

This apparent conversion of the schistose breccia, belonging to the old red sandstone formation, to a trap rock, seems more distinctly to connect the greenstone with the granite, and to point out a common origin for the two, which also receives additional confirmation from the examination of the tracts occupied by the former rock. The patch of greenstone to the North of Llanerchymedd is surrounded by greywacké, the basis of which is a glossy black clay-slate. In the immediate vicinity of the greenstone, this greywacké is curiously affected; the embedded fragments of schist assume a yellow decomposing tinge, whilst the quartz becomes more crystalline (701—705.). The next step presents a rock of decomposing aspect, through which are scattered traces of crystalline structure, resulting from an imperfectly formed hornblende, mixed with felspar (706—710.). The latter is distinctly marked, but the crystals of the former bear a strong resemblance to fragments of slate. They are frequently broken transversely, a circumstance which it has been stated also occurs in the genuine crystals of the same substance in the neighbouring hornblende rock.

It does not appear very evident why hornblende should here result from the fusion of schist, and that pyroxene should be a constituent of the dykes which are presumed to be of similar origin. There is, however, one point of difference between them. In the dykes, the fused matter appears to have been injected into a fissure of the superincumbent rock, but in the present instance the alteration has taken place without any progressive motion. There are other rocks, in this part of Anglesea, of which hornblende is an ingredient, where the transition from the schist to the trap is not marked by a distinct line, and where a similar explanation might be given of their origin.

Near the summit of Llaneilian mountain, towards the South, we find masses of this rock, protruding through the greywacké, in which the hornblende is sometimes well crystallized (715.), and at others scarcely to be detected (716.).

At the bottom of the cliff, to the N.E. of the highest point of this mountain, a similar rock is found, but the hornblende is not so distinct as in the former case (717.). Upon ascending the cliff the appearance of a dyke is gradually lost, and it scarcely exhibits a structure sufficiently crystalline to separate it from the schist (719—722.). Through this dyke there run several veins of quartz, which also abound in the surrounding rock, a fact which I do not recollect witnessing in any other dyke in Anglesea. Irregular strings of reddish compact felspar, of a cotemporaneous character, are also found in it (718.). The schist in contact is a fine grained clay-slate (723.), and in the dyke there occur several strings, or thin laminæ, of clay-slate of the same nature.

Patches of glossy crystalline clay-slate are also found among the hornblende rocks to the North of Llanerchymedd.

On the South side of the road from Llanerchymedd to Llechynfarwy, before quitting the former place, there is a quarry which partly consists of clay-slate, and partly of hornblende rock and greenstone, similar to that on the North of the town.

Considering the extensive influence which must have been exerted to form the granitic districts, we might also expect to find the rocks in their vicinity modified by its action. Where the South granitic district joins the older rocks to the East, it is not so easy to ascertain when an alteration has taken place; since we are not always certain of the original character which these rocks themselves possessed. In some places, however, there appears to be little doubt of the fact.

On the sea-shore, immediately South of Llanfaelog lake, the confusion and alteration impressed upon the schistose rocks are of a very marked description. They vary in composition and aspect at every step, and have scarcely a trace of fissile texture remaining. There are slight appearances of a crystalline rock, resembling some varieties in the granite round Gwindu (824.), but the general character is that of an homogeneous flinty mass of different shades of green (825, 826), grey (827.), and brown (828, 829.). Since all these will fuse before the blowpipe, though with difficulty, they seem to approach the character of a hornstone. One of the specimens presents a singular fact, and as the experiment was several times repeated, there can remain no doubt of its accuracy (827.). It forms a dirty white mass between compact and finely granular, and seems to consist principally of quartz, but contains also a little lime disseminated through it. A few faint streaks of green matter, resembling chlorite, are intermixed with the substance of the stone. When the specimen is exposed to a red heat, the green veins immediately turn jet black, assume a laminated texture, and strongly resemble pyroxene. It then fuses, with some difficulty, to a black glass. There are some portions of a more compound nature (830.), intermixed with the homogeneous rock, which appear to be composed of small fragments of quartz firmly embedded in a paste of the same substance (831.), and others in which the embedded fragments are so loosely set, that they might be detached (832, 833.). With these are associated patches of blistered schist, gradually blending itself with the compact mass (834.). Proceeding Eastward along the shore, we find traces of a laminated texture making its appearance. The whole rock still forms a flinty mass, but the smooth surfaces exhibit parallel contorted lines of obscure yellow upon a green ground (835—837.). This character prevails until we arrive at Llangwyfan, after which the rocks become more regularly schistose.

There are numerous trap dykes scattered throughout the whole of this district (813—823.). These vary considerably in character; some form a perfect basalt highly charged with crystallized carbonate of lime, tinged green (813.), but the generality, are of a more earthy nature, and vary through different shades of dark grey and green. In texture and composition, they often resemble clay-slate so closely, that a detached specimen might easily be mistaken for this rock (820—822.). They are generally porphyritic, containing embedded crystals of felspar, and alter their character completely, and suddenly, through different parts of their course. Many of them are seen to terminate in both directions, and some form mere bumps rising through the hardened schist, and are themselves again intersected by smaller dykes of a different character.

There are several other appearances of a similar description impressed upon the schist near the granite, both in the neighbourhood of Llanerchymedd, and of the North granitic district. In one spot, about a mile and an half to the N.E. of the Paris mountain, it is intermixed with veins of a granitic description. They consist principally of dull mica, which is associated with felspar, quartz, and a steatitic substance (802.). The surrounding schist assumes a hardened aspect (803.).

Perhaps we may also ascribe the flinty beds dispersed throughout the schist, to the West and S.W. of this spot, to a change of character impressed by the granite. If so, the chert, which traverses the Paris mountain, will rank with them; and the decomposing schist, which accompanies it on either side, must be ascribed to the more partial influence of the same action. The external character of this mountain is very striking. On the N.W. it slopes gradually from the top, but to the S.E. it presents a precipitous side, from which project the edges of the schistose laminæ, to all appearance as sharp as though they had scarcely sustained the action of the weather since they were first placed in their present position, although the materials of which they consist are in a very decomposing state.

Although the circumstances detailed above seem to indicate that the granite and greenstone have been derived from the fusion of the stratified rocks in their neighbourhood, still, the marks of violence and disturbance which accompany them, tend further to shew, that some portions of these rocks have been protruded from below. The structure of Llaneilian mountain affords an interesting and important illustration of this fact, and forms a prominent feature in the Geology of Anglesea.

In Pl. XIX. Sect. B, we have the greywacké dipping from the granite on the West, and succeeded in order of superposition by the chlorite schist, dipping also in the same direction. Upon referring to Sect A, which is exhibited on the coast, the greywacké is found to be terminated abruptly to the West by a vertical fault, which explains the apparent anomaly of the superposition of the older rock. This greywacké also reposes unconformably upon some black clay-slate of the same series. The explanation which suggests itself is, that the granite has removed the greywacké from its original position, and that the lowest beds of the portion removed, repose towards their termination Northwards upon the superior beds of the same series. The hollow tract which runs across the mountain, between the summit and the highest point of granite, is composed of glossy black clay-slate, intermixed with patches of quartzose rocks, which project in irregular masses. The lowest portion of the removed greywacké is a green clay-slate, which may have formed either the lower beds of the greywacké series, or the upper of the chlorite schist. It is much shattered; a circumstance which causes the alluvial matter to collect, and consequently the line of demarcation, between it and the black slate below, is distinctly marked by the vegetation which covers it. A deep ravine runs from the Northern termination of the granite to the sea-shore, from which part of the removed portion may have been derived. The most Westerly, and therefore the uppermost beds of the disturbed greywacké, are composed of the same black clay-slate as that upon which the lower beds repose unconformably.

Another circumstance which seems to have resulted from the intrusion of the granite, occurs to the East of this spot. Descending from the Eastern summit of the mountain towards Dulas harbour, the ground forms a gradual declivity, broken by projecting hummocks. These, as well as the rocks on the shore, consist of a most heterogeneous mixture (857—867.). Hardened sandstone (863—865.); clay-slate, which shivers into sharp hard fragments, each tarnished with a glossy coat (866, 867.); large masses of quartz and schist, rudely intermixed and bound together by a basis of fragmental matter (859—862.).

Among this confusion there are patches of purely crystalline rock, consisting of red felspar, quartz, and chlorite (857, 858), which appear to assimilate this tract to some portions of the district round Gwindu. This conglomerate is seen, at its Northern G. 1. termination, reposing upon the clay-slate, which assumes a compact quartzose aspect (852.), and contains concretionary nodules (851.). In one spot it consists of crystalline quartz, through which are dispersed numerous fragments of slate (853.). These fragments have, in many instances, sustained an alteration in character, and become blended with the quartz. On a weathered surface they decompose, the quartz assuming a cavernous appearance.

By referring to the sections it may be seen, that the intrusion of the granite in the two principal districts, has produced effects in opposite directions. In the Northern district, the dislocation and tilting of the schist lies on the West, the older members having been upheaved and brought to the surface on that side of the granite, whilst on the East we find the newer rocks comparatively in a state of repose. In the Southern district the reverse is the case, and the upheaving of the mica and chlorite schists has taken place to the East, the old red sandstone being in contact to the West.

Having examined the phenomena which accompany the granite and trap, the next endeavour will be to explain certain appearances where a cause seems to have been exerted, similar to that which produced these rocks, though without the actual protrusion of any volcanic product.

A reference to the localities noted on the Map will be sufficient to shew that there can scarcely be any part of Anglesea which has entirely escaped the influence of an action so general as that which formed the numerous dykes seen bursting through so many parts of its surface, and we may naturally expect that some places must exhibit traces of this influence, where the results are more equivocal than those already described.

At Carnel's Point, the appearances so closely resemble those exhibited on the confines of the granitic districts, that it seems scarcely possible to ascribe their origin to the action of a different cause. Upon approaching the Point, a little to the North, the greywacké is associated with a rock, which at the time I mistook for a conglomerate of rolled pebbles, but which is composed of concretions running together in the same manner as the steatitic rock near Bangor (870.). This passes to a perfectly crystalline mass formed of quartz, felspar, chlorite, and mica (871—878.), in which the traces of a concretionary structure are sometimes evident (871.). In other places the transition to the earthy rocks which are contiguous, is sufficiently marked (880.). The character of the surrounding schist is singular. In part it appears to have sustained no alteration, but the greater portion assumes a yellow decomposing aspect, and in some places it passes to a hard semi-jaspideous mass (883, 884.). Rather large crystals of quartz are found attached to compact masses of the same nature, which are dispersed through these rocks (881, 882.).

Another spot, which has strongly the appearance of having been subjected to some violent disturbing cause of the same nature, occurs at Moel-y-don ferry, on the Cærnarvonshire side of the Menai. The strata of limestone and grit, belonging to the magnesian limestone, are found confused, tilted, and, for several yards, disposed in a most disorderly manner. The alteration which the substances composing the strata undergo, is also of a marked description. The sandstone, which in other places is red, becomes white (452.), hardens, and passes to a compact siliceous stone, resembling white flint (453.). In some places it approaches the common dark chalk-flint (454.). It is intermixed with crystallized limestone and bitter spar (456—462.), and some portions of the specimens are in a pulverulent state. The red limestone either becomes very compact and crystalline (463—467.), passes to a brown bitter spar (469.), or assumes the character of a nearly arenaceous white limestone (470.). About the centre of the disturbed portion, the materials of the several strata are mixed together (471—473.), presenting a singular scoriaceous appearance (474.). The dyke which crosses the Menai at this spot, intersects the line of the disturbed portion at right angles. A little to the North of the ferry where the disturbance ceases, the sandstone, which is fine grained with small pebbles dispersed through it, appears to have been hardened and turned white (451.), and is here quarried as a whetstone.

The present disposition of the stratified rocks, from the greywacké upwards, seems strongly to favour the hypothesis which ascribes the formation of the granite and trap to volcanic action. If we suppose the different portions of each formation to have been once continuous, their original bearing appears to have been from N.E. to S.W., and their dip towards the S.E. In every case they terminate with great abruptness against the older rock, and near the junction they frequently appear to have sustained some violent action.

The singular transition from old red sandstone to quartz rock, on the summit of Bodafon mountain (p. 391.), resting upon hornstone derived from the clay-slate (p. 373.), appears to be the Northern termination of some volcanic influence which extended Southwards to Llangefni, and from thence, towards the S.W. to Aberfraw. Hand specimens cannot convey a just idea of the appearances exhibited in a quarry of this hornstone. The irregular intermixture, which takes place in the different shades of colour, strongly resembles the result afforded by agitating the ingredients of a semi-fluid mass, and the solid hornstone passes to a blistered schist. Proceeding Southwards, we come upon a peculiar variety of chlorite schist, in which the quartz forms a homogeneous basis, and the chlorite or mica lies disposed in parallel laminæ (p. 369.). At the spot where this occurs furthest to the North, it forms a mass of rock scarcely protruding above the surface of the swampy ground on the East of Bryngole, and is not easily accessible. From hence, some patches of schist are found which pass to jasper, and others to the same translucent, green quartz rock, with a globular structure as that at Llangefni, (p. 384.). In an intermediate state, the schist has a fragmental aspect, the fragments drawn out into strings (243.). At Bodorgan, we find a mass of basalt and greenstone protruding in the midst of the small patch of schist which rises through the grit (p. 397.). It should seem therefore, that the disturbing force, which cut off the further extent Westward of the mountain limestone and coal-measures, has acted upon the old red sandstone, clay-slate, mica-slate, and chlorite-slate, and that the respective results are quartz rock, hornstone, homogeneous quartz with scales of mica or chlorite, and jasper or translucent quartz rock. To this list may be added another substance, equally singular. To the West of the spot where the chlorite schist passes to quartz rock, North of Llangefni, the grit rises abruptly to the East of the river, and through it there protrudes a rude tabular mass of white quartz rock (868.), which may be supposed to have resulted from an alteration of the grit, (see Pl. XX. Sect. H).

C. 3. The district lying North and South of a line from Gwalchmai to Llangefni, will, by the above supposition, be included between two distinct modifications of volcanic action, which were probably united beneath it. The result, as might be expected, is the utter confusion and complete alteration of the intervening rocks, the appearance of which has been already described (p. 372.). Among other phenomena which tend to confirm this hypothesis, is the occurrence of several large hummocks of white quartz, scattered over the surface in the neighbourhood of Trefdraeth (869.). They consist of sandstone passing to quartz rock, and are possibly the remains of grit, from the strata belonging to the coal-measures; and if so, it is equally possible, that the hard compact limestone found with the jasper may have been derived from the same source.

A similar explanation will apply to the other districts of this nature, and particularly to the jaspideous ridge which extends from Llanffinnan to Red-wharf bay, (p. 372).

There are a few circumstances connected with the history of the serpentine which render it probable that this rock is the result of an action impressed upon some of the limestone beds, dispersed through the chloritic districts.

The general outline of each of the serpentine districts, presents an aspect of great disturbance, want of stratification, and other appearances usual in a trap formation. At the Eastern termination of the Southern district, the transition from the chlorite schist to the old red sandstone is abrupt, and on the Eastern side of the line of junction we meet with a trap rock, apparently derived from an alteration impressed upon a portion of the latter formation, a description of which has been given, p. 432. The connection between serpentine and greenstone is equally remarkable at Llanfechell. The patches of serpentine run S.W. from the principal quarry, and with them are found some which seem intermediate between that rock and greenstone (589—591.). Others pass from a compact and crystalline variety of the latter, including veins of serpentine and epidote, to a more earthy rock, with a greasy chloritic aspect, containing but few crystals of pyroxene. The chlorite schist in the neighbourhood is much hardened, especially in the high ground to the S.E. of this spot. Veins of epidote are found where the rock approaches the character of greenstone (592—596.).

C. 3. To the West of the pool at Gwalchmai, the chlorite schist is intermixed with limestone, and a dyke intersects the rock close to a small bed of this mineral. The natural fissures of the dyke are coated with an unctuous substance resembling serpentine (584.), and some portions of the dyke itself have the earthy chloritic aspect of the greenstone in the serpentine at Llanfechell (585.). Veins of crystallized carbonate of lime are found in it, and when the primitive rhomb is extracted from them, two of its faces appear finely striated parallel to the longer axis (586—588.).

Conglomerates.

{Nos. 885—913.}

There are two tracts laid down in the Map under this denomination, one of which has been already alluded to, as its connection with the North granitic district appeared to afford an explanation of its origin. The other, which occurs at the most Northerly point of Anglesea, possesses a few characters in common with the former, but there is no evidence to shew that it has resulted from an action of a similar nature. It consists of a most confused intermixture of chlorite schist, greywacké, clay-slate, large masses of quartz, and limestone, with several traces of trap, Pl. XVIII. Fig. 6.

To the East of Cemmes, the cliff consists of yellow ochre and steatite (895.), both of which are there quarried as articles of commerce. They evidently result from the decomposition of the schistose rocks, and the gradual passage from the solid to the earthy state is distinct (892—894.).

The large masses of quartz, which are dispersed through the district, have sometimes an homogeneous aspect (889.), but in general they retain the traces of a coarse breccia (885—887.), or sandstone (888.), from which they seem to have been derived. In the midst of the steatite there are some which possess a porous earthy aspect (896.).

The limestone, which intermixes with this conglomerate, is the same as that about Llanfacthlu, and belongs apparently to the chlorite schist (906—913.). It does not appear to have sustained any alteration, except in one or two places where it is in contact with some trap (908.). In one spot to the West of Cemmes it consists of small irregular black globules firmly cemented in a basis of rather lighter colour, which at first sight resembles the traces of an organic structure (909, 910.). In another spot where it possesses the same shaly character as at Llanfacthlu (912.) there are slight appearances resembling anthracite (913.).

Although the ingredients which compose this conglomerate cannot be said to lie in distinct strata, still there are several places where a rude kind of alternation is visible, somewhat like the arrangement which often takes place in a mass of diluvial matter. These rudely formed beds indicate a considerable dip towards the North; from which it should seem, that the conglomerate succeeded the chlorite schist in order of superposition, and that the present inclined position was impressed upon each at the same time.

Diluvium.

{Nos. 914—980.}

Deposits of diluvial matter are scattered over each of the chloritic districts which bound Anglesea to the West. They occur in the form of very obtuse conical hills, the diameters of whose bases varies from about a quarter to half of a mile, and the surface, in consequence, presents a succession of gentle undulations clothed by cultivation, the subjacent rock being exposed only in the hollows between them. The internal structure of these hills is exhibited in several places along the coast to the South of Llanfacthlu, and also between Monachdy and Wilfa. They consist of fine grained sandy materials deposited in layers, and in several instances it happens, that the coarser ingredients form the uppermost portion. The rolled pebbles are not numerous, and there are a few large blocks of schist, greenstone and limestone, dispersed through them.

C. 5. From Penmon to Beaumaris there is a low cliff of diluvium, through which are dispersed numerous large blocks of limestone and grit, derived from the coal-measures. This terminates immediately to the South of Beaumaris, in a mass about sixty feet thick. The character of this diluvium does not resemble that which is found to the West of the Island (where it bespeaks a succession of deposition), but forms a rude mass in which the materials appear to have been brought together by a single effort. A suite of specimens has been selected from the embedded pebbles. The smallest and most rolled consist of various granites, traps, and the older stratified rocks. Some of the blocks of limestone and of the more recent strata, are of very large dimensions, especially as we approach the mountain lime at Penmon.

Alluvium.

Wherever the coast to the S.W. is low, the neighbouring country has suffered from drifts of sand, which in some places have covered up the soil to a considerable distance inland, presenting a dreary outline, broken only by a few projecting points of schist. This sand is still active in making its annual encroachments, if we may judge from the half buried walls which have been recently built over the low ground on each side of a road from Newborough towards the N.W.

In the preceding pages it has been my endeavour to relate those facts which appeared most likely to facilitate the future investigation of the Geology of Anglesea. It cannot be expected that a first account of any complicated country, should be accurate in all its details; for, in such cases, the time necessarily consumed in obtaining a clue to the examination, will seldom leave sufficient opportunity of accurately verifying all the points of relation which may exist between contiguous formations.

EXPLANATION OF THE PLATES.

Plate XV

Contortions in the strata of the quartz rock at Holyhead mountain. Sketched from the South Stack .... p. 363.

Plate XVI.

Fig. 1. Cleavages exhibited by the strata of the quartz rock... p. 364.

Fig. 2. Vertical section of a mass of breccia (*a*), and a quartzose vein (*b*) connected with it, which rises through the chlorite schist, near its junction with the quartz rock .... p. 366.

Fig. 3. Junction of the quartz rock (*a*), and chlorite schist (*b*) to the West of Rhoscolyn .... p. 366.

Fig. 4. Section of the stratified chlorite schist .... p. 371.

Fig. 5. Serpentine (*a*) rising abruptly through the chlorite schist (*b*), which dips in various directions .... p. 376.

Fig. 6. Massive serpentine (*a*) gradually assuming a schistose character (*b*) .... p. 376.

Fig. 7. Appearance presented by the greywacké slate on the shore near Monachdy .... p. 383.

(*a*) Hard, green, and unlaminated portion, passing gradually on one side to a schistose black slate (*b*), and terminated abruptly against a similar rock on the other.

Fig. 8. Arrangement of particles in the stratified grit at Bodorgan, p. 395.

Plate XVII.

Plate XVIII.

Plates XIX and XX.

(A to M). A series of parallel sections across Anglesea from N.W. to S.E., referred to on the Map by corresponding letters.

(N to O). Two parallel sections from S.W. to N.E., at the North-Western corner of the Island.

(P). Section at the N.E. corner.

A few changes in the mineral character of some rocks included in the same formation are referred to in the following manner:

(*a*) Green clay slate,
(*b*) Black clay slate,
(*c*) True greywacké slate,
(*d*) Micaceous schist,
(*e*) Chlorite schist,
(*f*) Conglomerate of jasper, limestone, &c. in the chlorite schist.

Plate XXI.

Geological Map of Anglesea.

The principal districts included in each formation are artificially divided, for the purpose of easy reference, in the following manner,—(the order of arrangement always proceeding from West to East,) see page 360.

Quartz Rock. (Q).

Q. 1. Most Westerly portion of Anglesea, including nearly half the Northern division of Holyhead Island.

Q. 2. Also in Holyhead Island. To the S.W. of its Southern division.

Chlorite Schist. (C).

C. 1. Includes the greater part of Holyhead Island, and is bounded to the North by a line from Llanrhyddlad to Llanbabo, and on the S.E. by continuing this line through Llanfihangel to the sea.

C. 2. The Northern part of Anglesea—between Carnel's Point and Llaneilian Point.

C. 3. Middle district—from Dulas on the North to Aberfraw on the South.

C. 4. Small strip to the East of the last—between Red-wharf bay and Caint.

C. 5. Western district—from Llandonna to Llandwyn.

Serpentine. (S).

S. 1. In Holyhead Island—from Rhoscolyn to Llanfihangel.

S. 2. Near the centre of C. 2.—to the S.W. of Llanfechell.

Greywacké. (G).

G. 1. Between C. 1. and C. 2., and to the East of each as far as C. 3.

G. 2. Towards the North of C. 3.—a small strip running from Bryngole to the S.W.

G. 3. Bounds C. 3. on the S.E.—from the North of Llangefni, to the South of Aberfraw.

G. 4. Between C. 4. and C. 5.—from Red-wharf bay to Llanfihangel East.

G. 5. Small patch N.E. of the last—at Llandonna.

G. 6. At the Eastern termination of C. 5.—West of Beaumaris.

G. 7. To the South of the last.—At Garth-ferry, and on the opposite coast of Cærnarvonshire, from Bangor to Aber.

Old Red Sandstone. (O).

O. 1. Separates C. 1. and C. 3. at their Southern termination, and runs as far North as Llanerchymedd.

O. 2. A small patch at the N.E. termination of the last—immediately South of Llanerchymedd.

O. 3. A similar patch to the N.E. of Llanerchymedd.

O. 4. Another, to the N.E. of the last—in contact with the Northern granitic district.

O. 5. On the N.E. of C. 3.—From Dulas harbour to Bryngole.

O. 6. A small spot, surrounded by the mountain lime, to the East of the last.

Mountain limestone and Coal-measures. (M).

M. 1. The most extensive district of this formation—from Dulas harbour to Bodorgan.

M. 2. S.E. of C. 5.—From Garth-ferry to Plas-Coch.

M. 3. N.E. termination of Anglesea—including Priestholme island.

Magnesian Limestone and New Red Sandstone.

These lie to the South of M. 2.

Granitic Districts. (Gr).

Gr. 1. Largest district — towards the centre of the Island — round Gwindu.

Gr. 2. Small patch in G. 1., to the South of C. 2.—East of Llanbabo.

Gr. 3. S. E. of the last, and North of Llanerchymedd.

Gr. 4. Northern district—from Llaneilian mountain to Dulas.

Conglomerates.

One of these occurs at the most Northerly point of Anglesea—the other to the East of Gr. 4.

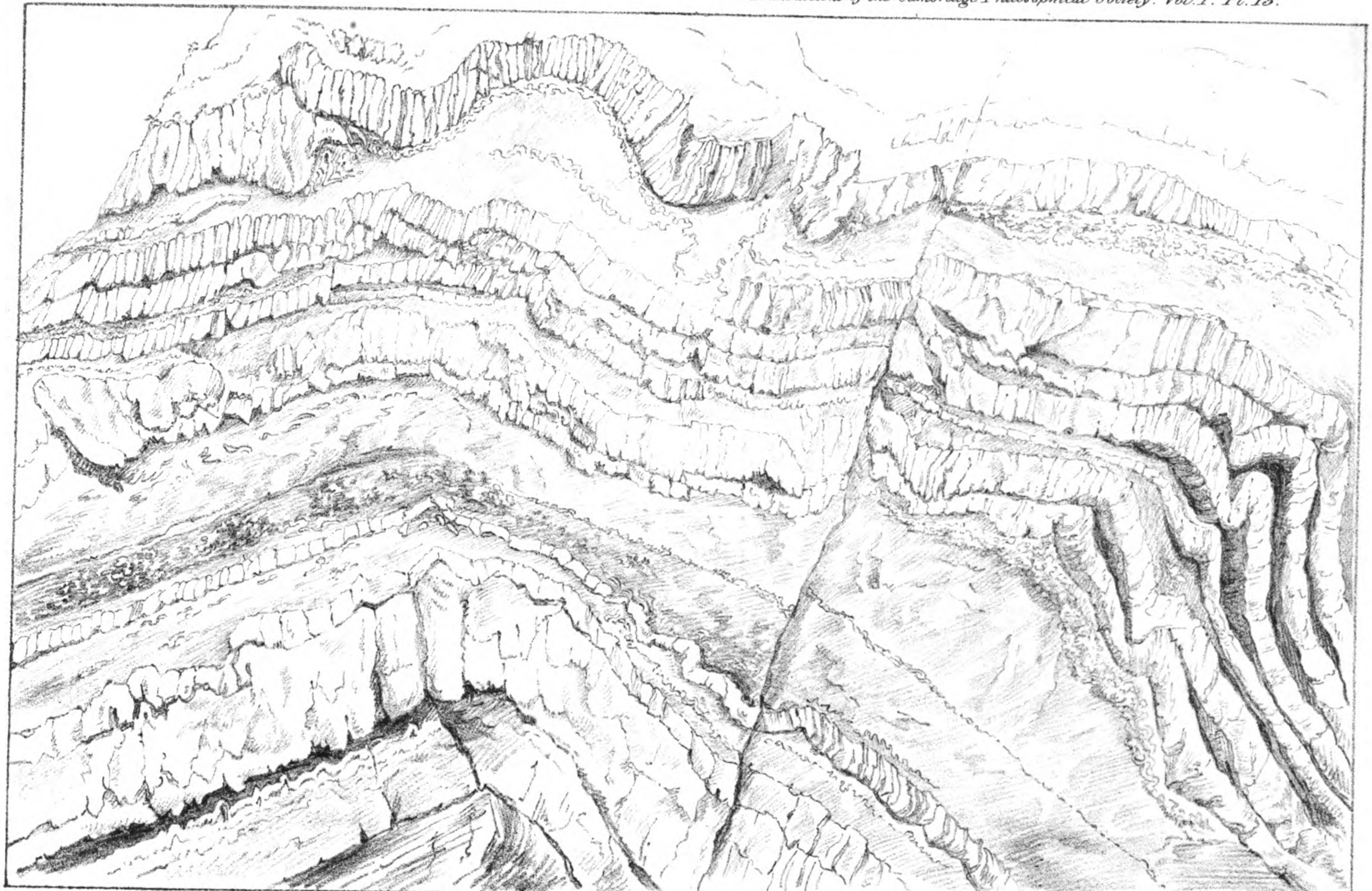
Trap Dykes.

These are referred to the formation in which they occur.

N.B. By an error of the Engraver, the references to these in the Map are made with a (*T*), instead of with a (τ) as mentioned in p. 401.

St. John's Coll.
Nov. 26, 1821.

J. S. HENSLOW.



J. S. Henslow del. G. Scharf Lithog.

Printed by Rowney & Forster.

Quartz Rock opposite the S.th Stack. Holyhead Island.

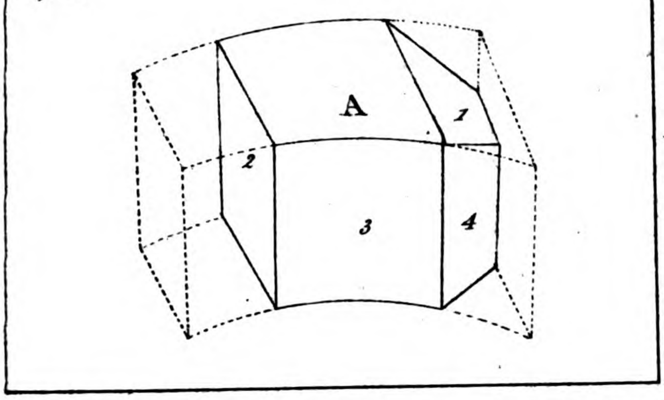


Fig. 1.

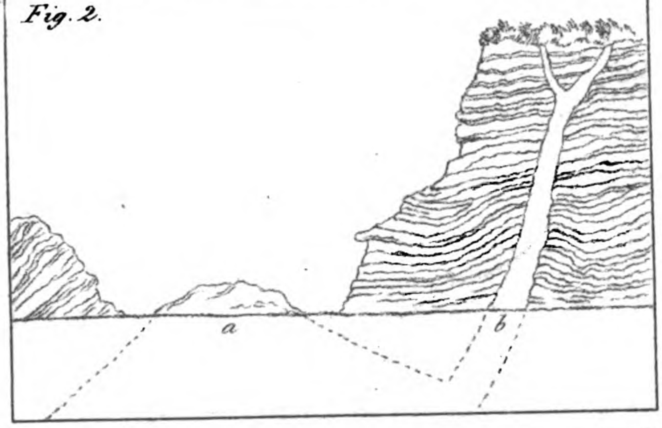


Fig. 2.

Fig. 3.

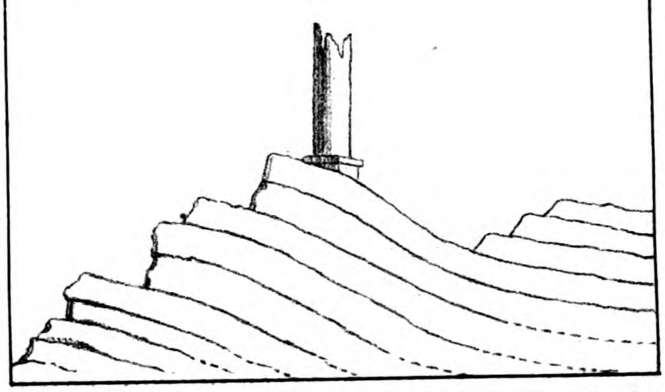


Fig. 4.

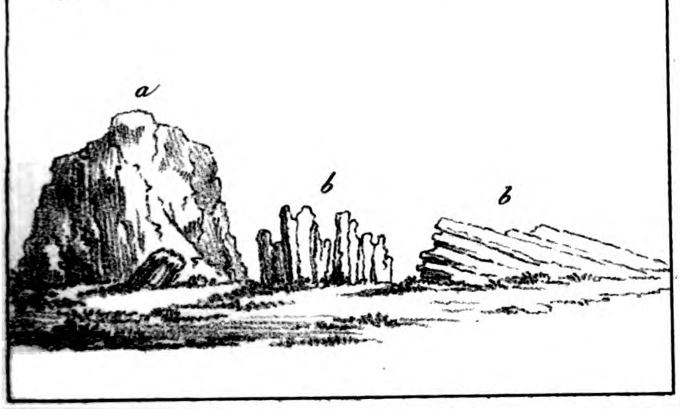


Fig. 5.

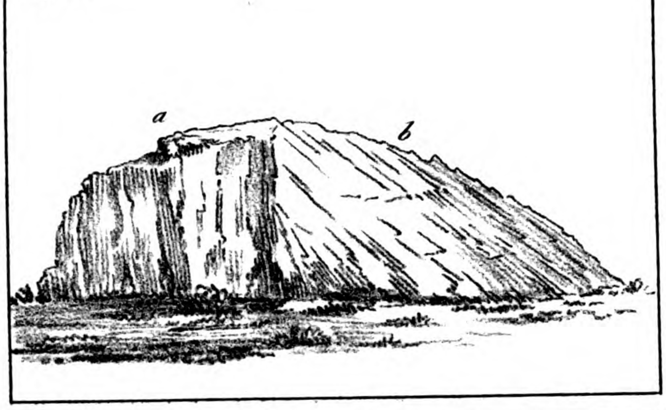


Fig. 6.

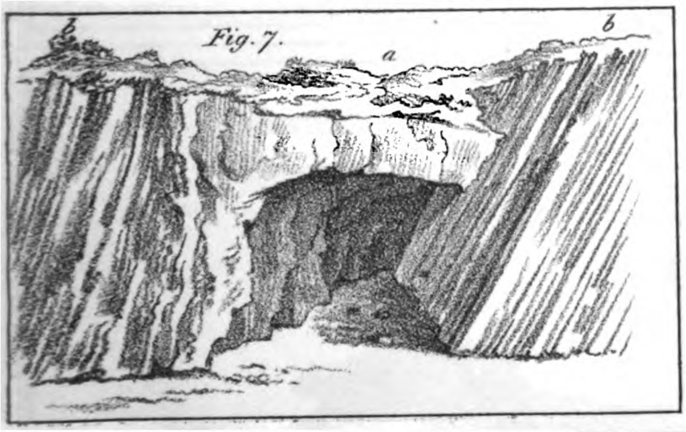


Fig. 7.

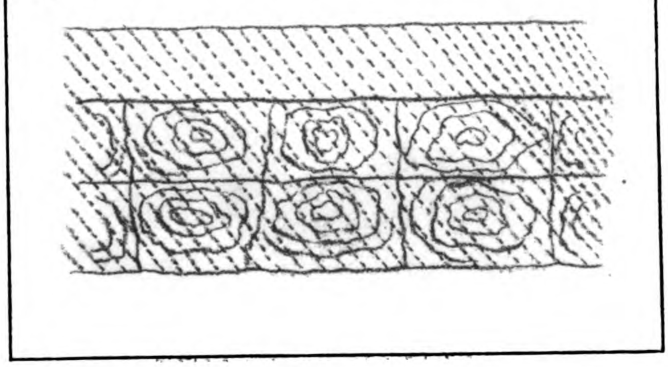


Fig. 8.

I. S. Henslow del. G. Scharf Lithog.

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Fig. 1.

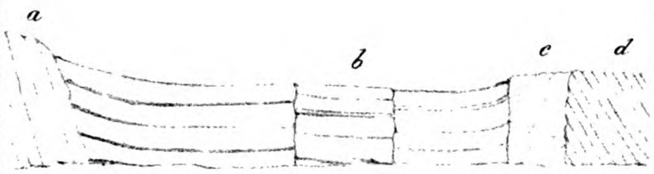


Fig. 2.

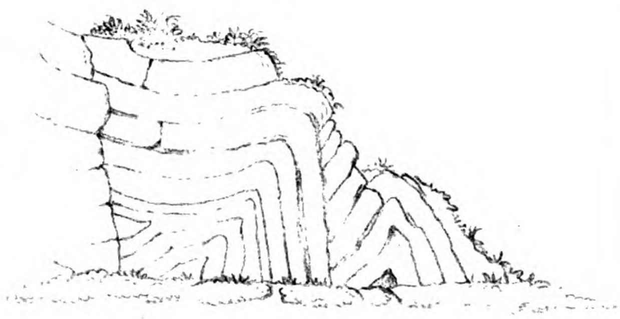


Fig. 3.

Fig. 4.

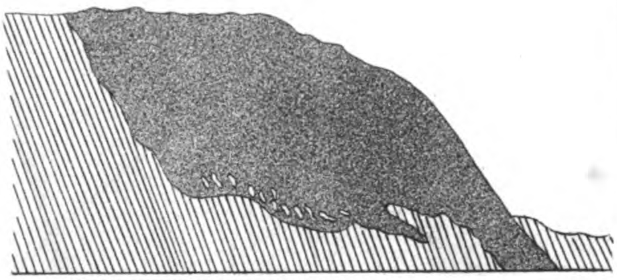


Fig. 6. *Fig. 5.*

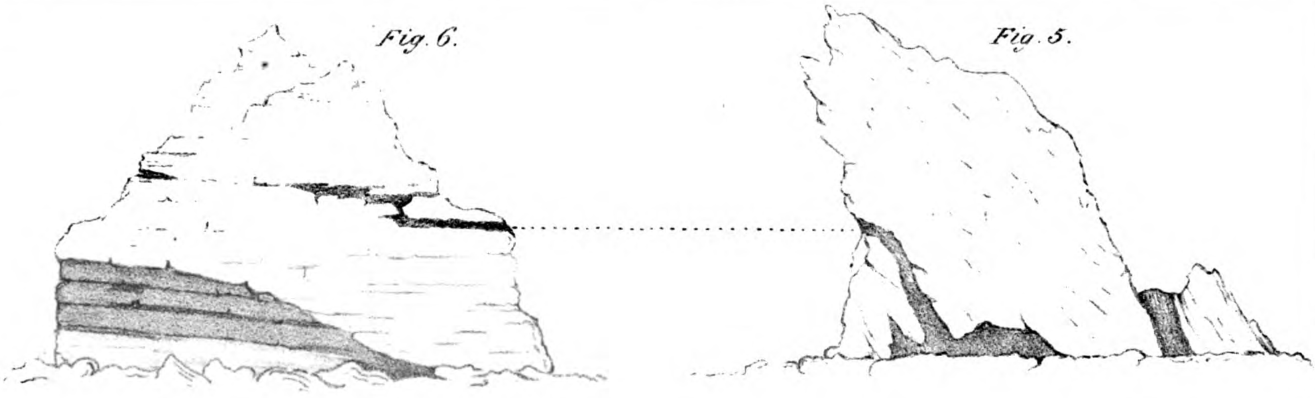
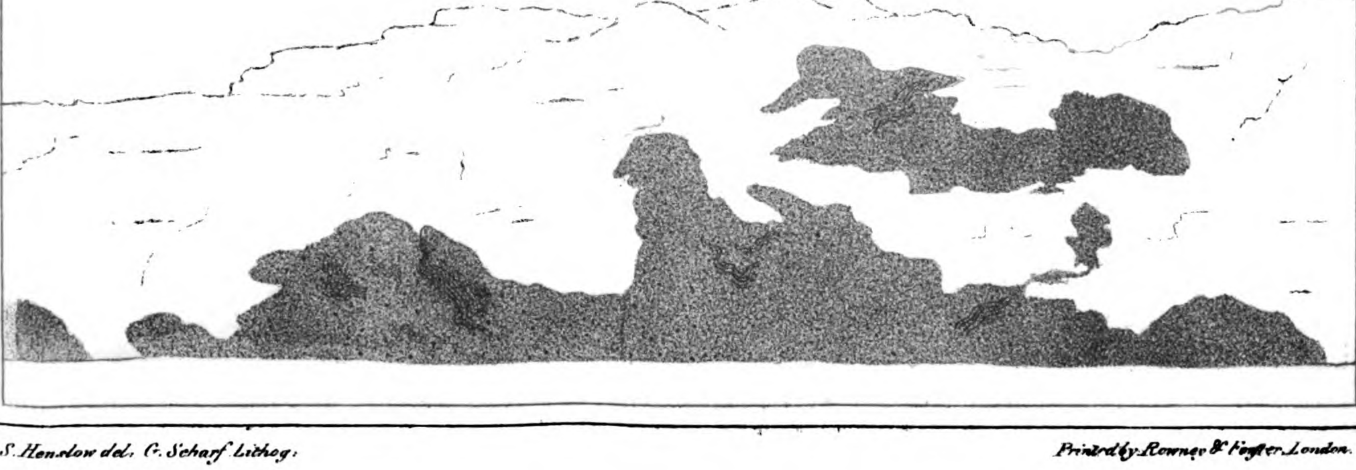


Fig. 7.



J. S. Henslow del. G. Scharf Lithog. Printed by Rowney & Forster London.

Fig. 1.

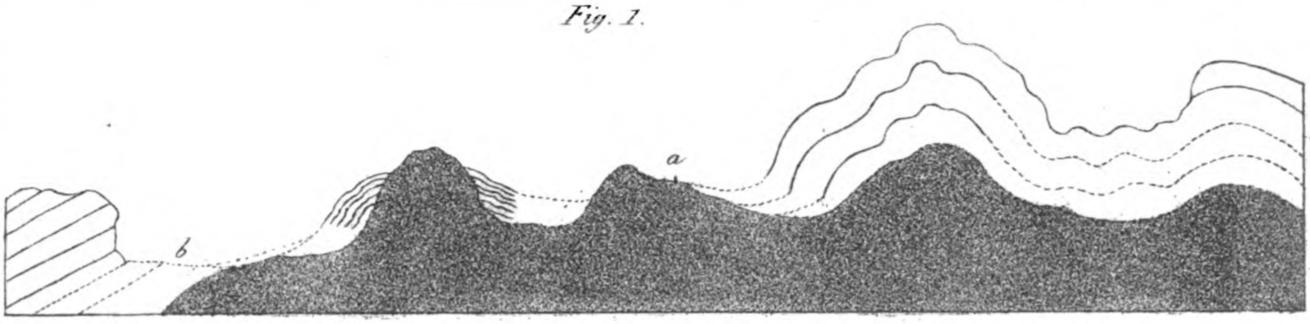


Fig. 3.

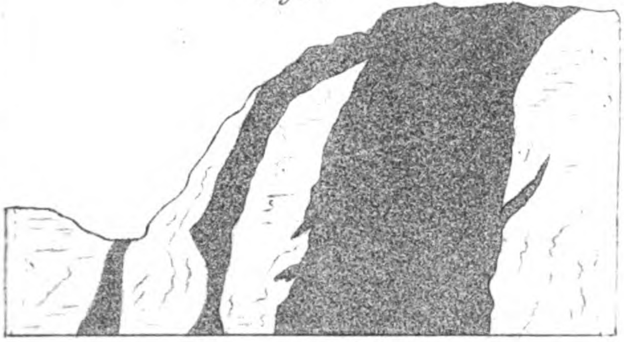


Fig. 2.

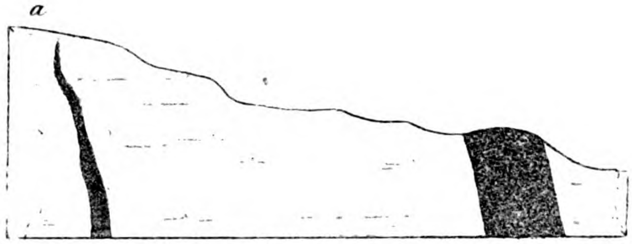


Fig. 4.

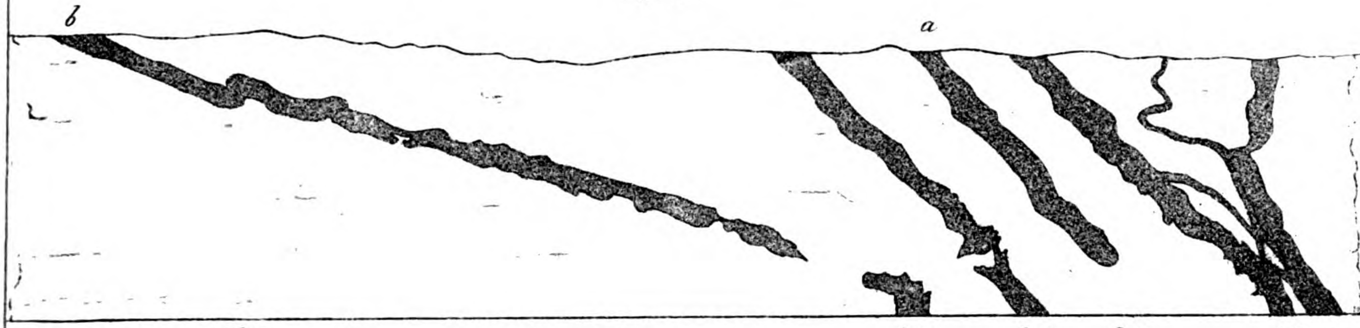


Fig. 5.

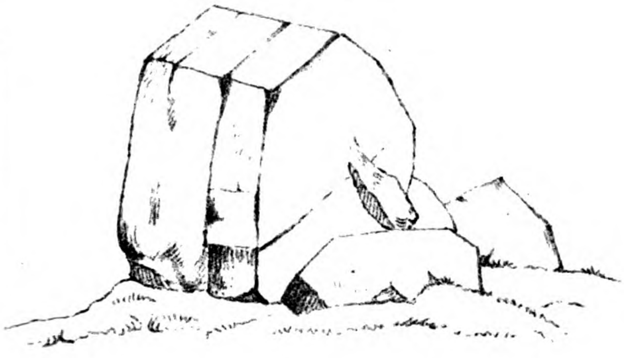
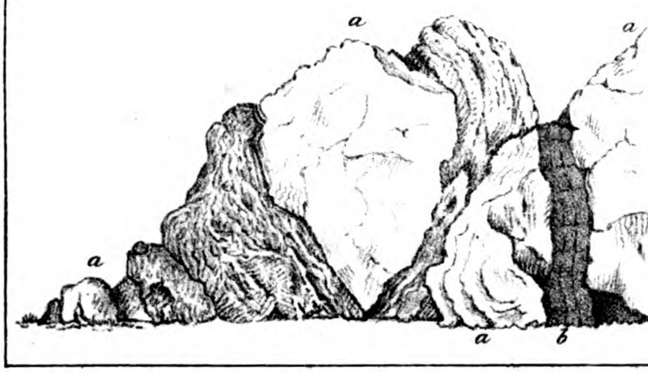


Fig. 6.



J. S. Henslow del. G. Scharf Lithog.

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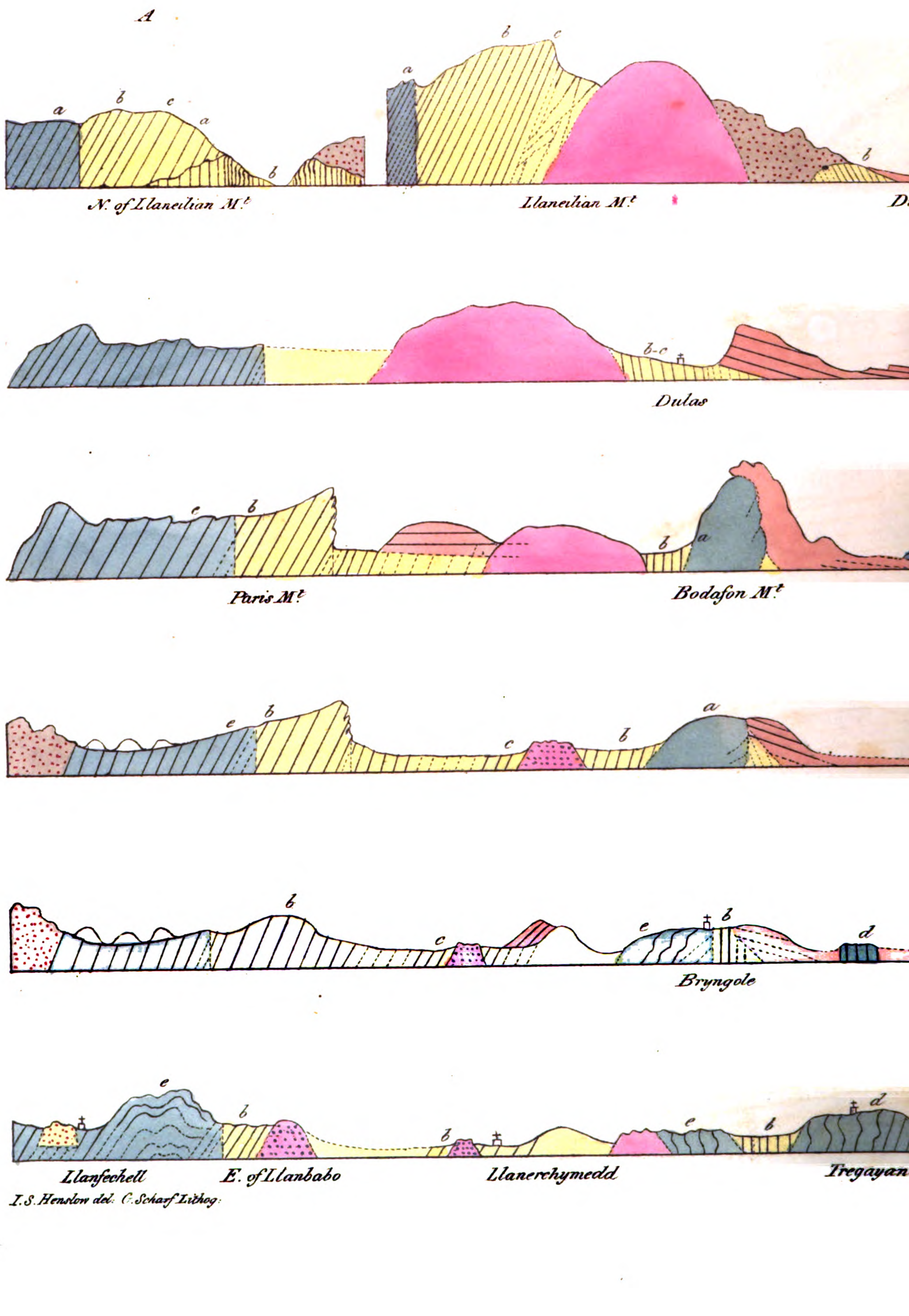

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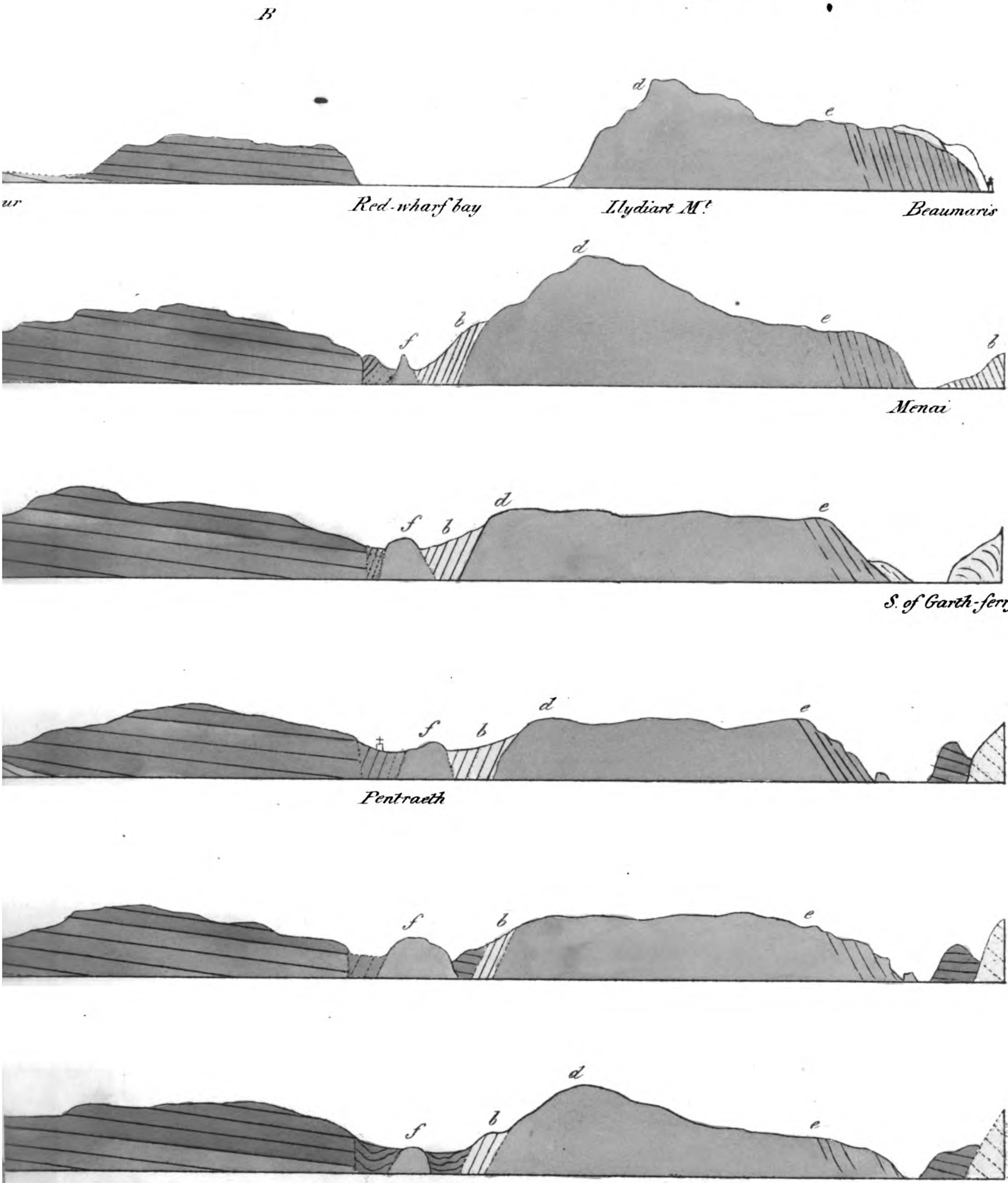

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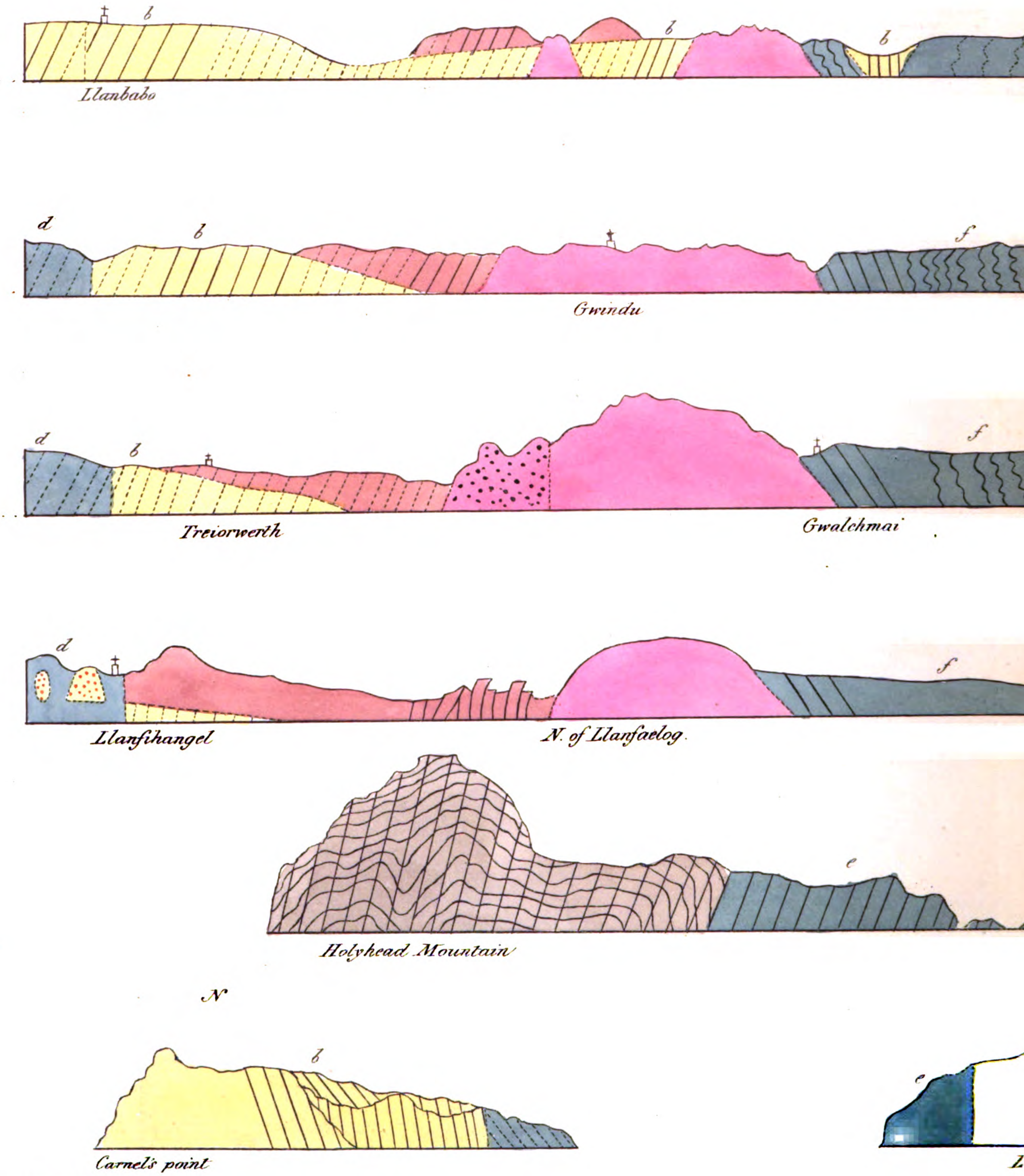
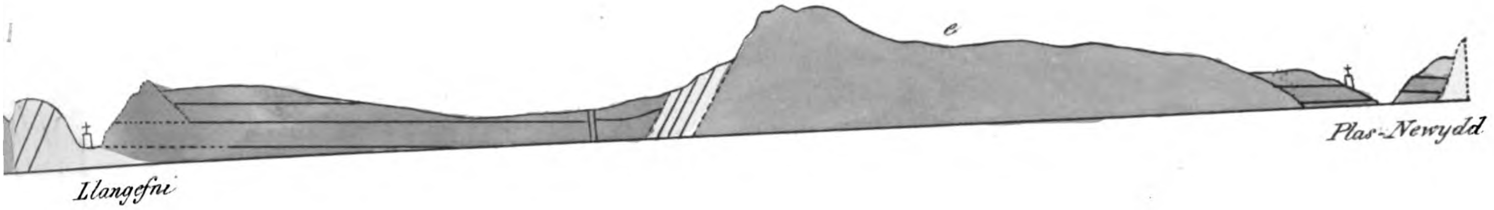
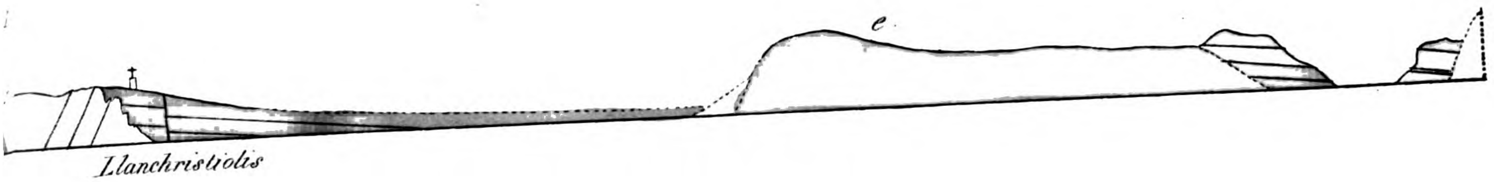
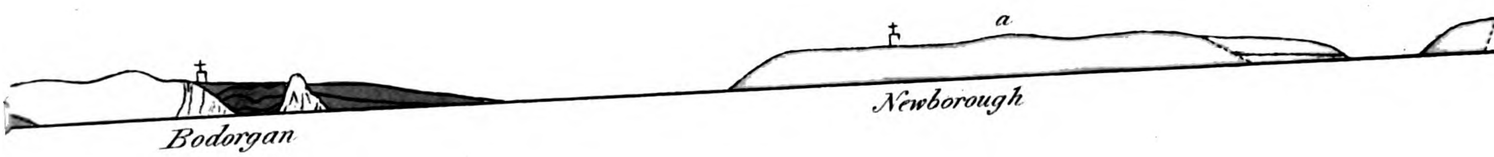
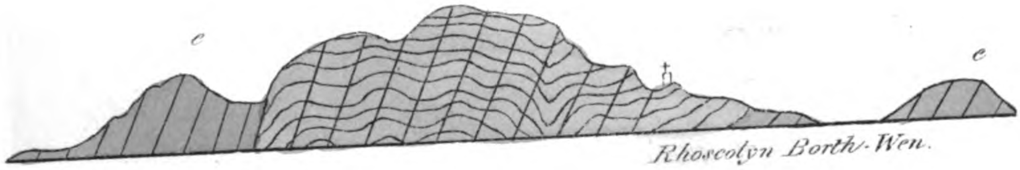


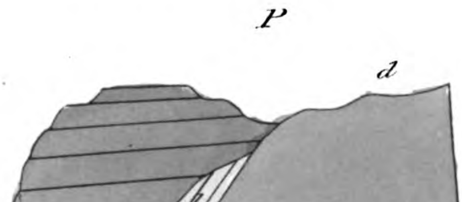
I. S. Henslow del. G. Scharf Lithog.











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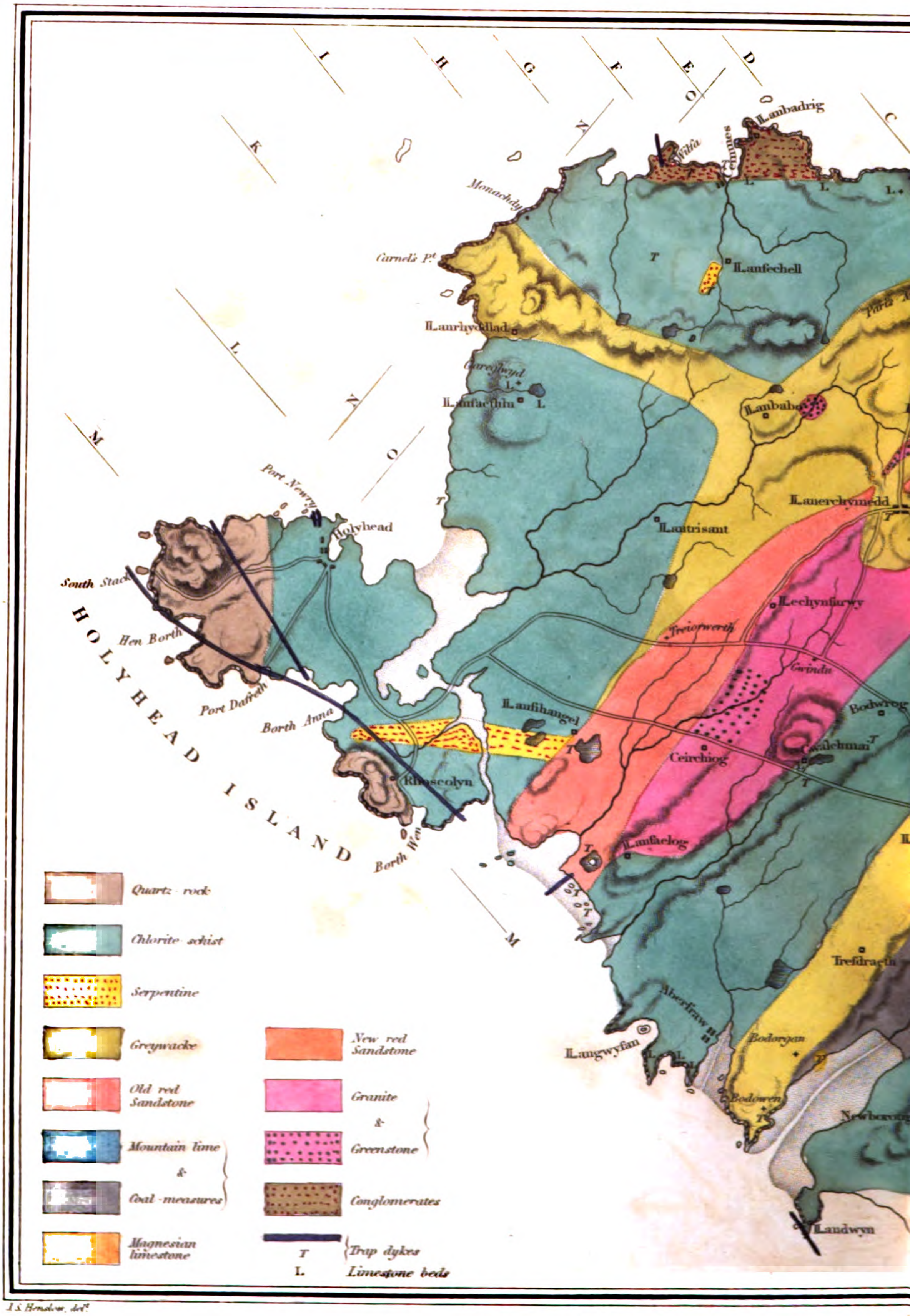
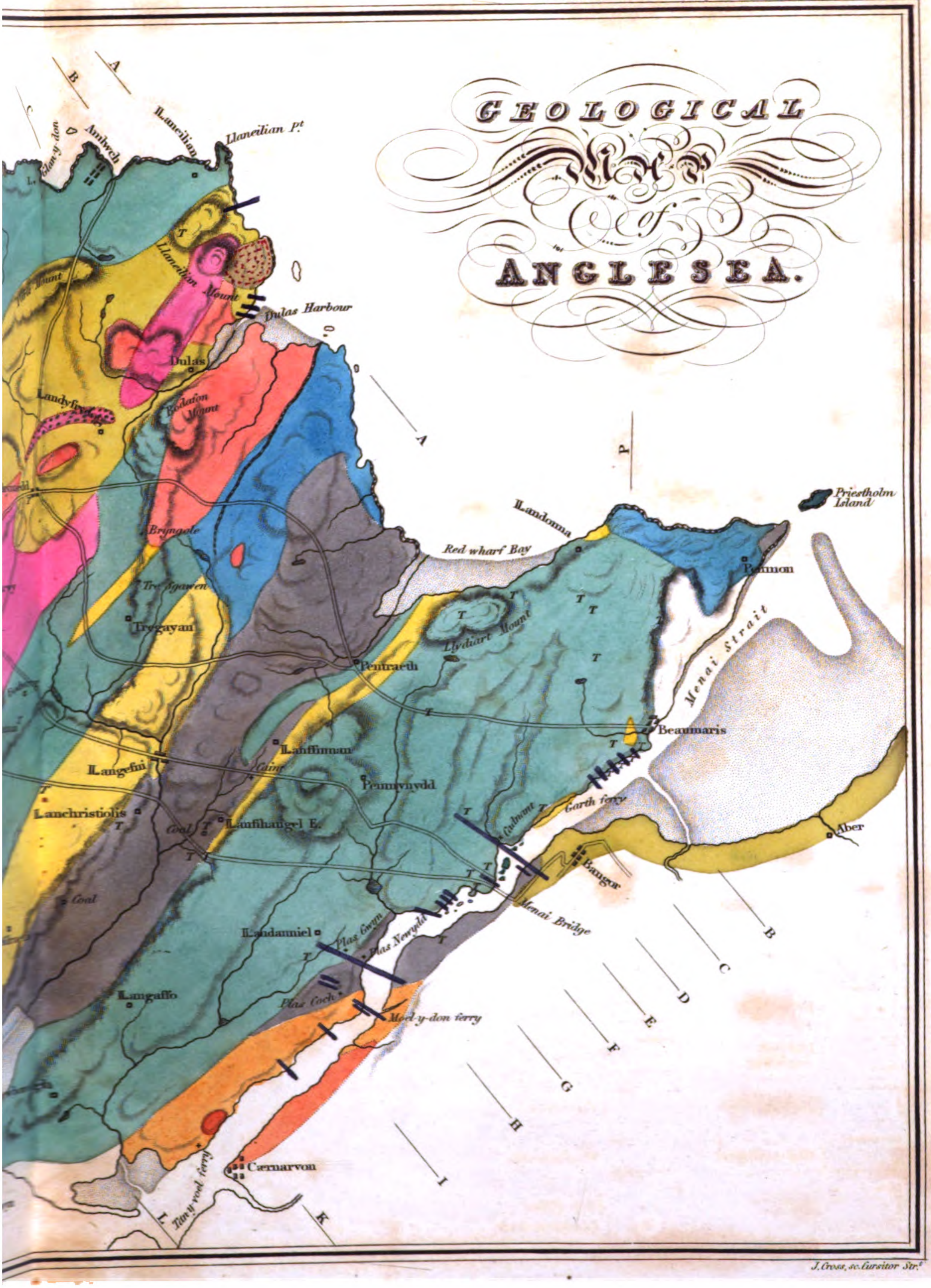


J. S. Henslow, delt.



J. Cross, sc. Cursitor Str.

XXVII. *Some Observations on the Weather accompanied by an extraordinary depression of the Barometer, during the Month of* December 1821.

BY THE REV. JOHN HAILSTONE, M.A. F.R.S.

FELLOW OF THE CAMBRIDGE PHILOSOPHICAL SOCIETY,

LATE FELLOW OF TRINITY COLLEGE AND WOODWARDIAN PROFESSOR.

In a Letter addressed to the Rev. GEORGE PEACOCK, *Secretary.*

[Read *Feb.* 25, 1822.]

Sir,

As the weather during the late winter has been of a very unusual character, I have thought a register of it for the month of December last, might be acceptable to the Society. This register, as will be seen by inspection, consists of observations made on the heights of the Barometer and Thermometer at three several times of each day, viz. at eight in the morning, two in the afternoon, and eight again in the evening. There is also a column which registers the lowest point to which the thermometer had sunk during the night. The quarter from which the wind blew at the time of each observation is also noted. I have not thought it necessary to add the temperature of the mercury in the barometer at each observation, because the instrument stood in a room which varied very little in that respect, not more than from 45° to 50° during the whole of the month. The thermometer hung in an aspect to the North, and about four feet from the ground. The barometer was made by Cary, and is of the portable kind, having been originally contrived and fitted up for the purpose of measuring altitudes. The Gage is not a floating one, but a fixed linear sight to which the surface of the quicksilver in the basin is brought by means of a screw; and it is almost needless to add, that this adjustment was made previous to every observation.

The most remarkable phænomenon in the register is beyond question the extraordinary depression of the barometer, which took place on the 24th and 25th of the month. On the 19th thunder was distinctly heard here proceeding from the N.W., and on the 20th the glass seems to have commenced its fall: it will be seen by the evening observation of the 24th, that it had fallen so low as 28.37, and as it was then still falling, I paid particular attention to it, till at 3 A.M. on the 25th I observed it at 28 inches precisely, a degree of depression I believe I may say almost unprecedented in this climate. The weather which accompanied this unusual state of the barometer was distinguished by violent gales from the W. and S.W. attended with incessant heavy rains.

It appears from the public papers, that this remarkable depression of the barometer has been general through Europe, and at the same period of time. The accounts from Germany state, in addition to the storms of wind, that it was attended with a shock of an earthquake. This was particularly the case at Mayence, where a slight shock of an earthquake is said to have taken place on Christmas day, about half past eight in the evening. At Bamberg and at Francfort about 7 P.M. on the

24th, an igneous meteor was observed of the size and shape of a full moon, which taking a North-Easterly direction, fell to the ground, and disappeared with an explosion as loud as that of a cannon. But it was in Italy that the tempest appears to have been the most violent. In a letter from Genoa, dated the 29th, there is the following passage: "The inhabitants of Genoa have often witnessed ravages occasioned by tempests, but not one so dreadful and prolonged as that which we experienced during the night of the 24th instant. It will ever be memorable in the annals of our State. During several days previously, the air was charged with thick vapours, which vented themselves in torrents of rain; the wind was S.E.; on the 24th at six in the evening it settled in the South, and blew with intense violence; at ten o'clock it had reached its utmost force. The sea rose progressively. At eleven the vehement conflicts betwixt the two elements had the full character of a hurricane, and in the language of the country was a *terremoto di mare*."

Doubtless we may expect farther details and observations of this most unusual state of the atmosphere, and I therefore await the arrival of the various scientific journals published on the Continent with some degree of impatience. From America I have met with no accounts to which I can draw the attention of the Society. It is certainly an object of considerable importance, to ascertain the limits of barometrical phænomena with regard to their geographical position.

Having finished my remarks on what may be considered as the great meteorological feature of the year 1821, perhaps it will not be thought uninteresting, if I add a few observations on the mean temperature of the latter months of that year, as compared with the corresponding months of the year preceding. I estimate the mean temperature of any month, by first finding the mean of each of the four thermometrical columns of daily observations separately, and then taking the mean again of the four results thus found. By this method the temperature of the month of April last, according to a register which I kept, is found to be $48^\circ\frac{1}{2}$, which is also the precise temperature of our springs. And this confirms the truth of a remark which I have heard, namely, that the average heat of the month of April affords a good estimate of the heat of the whole year. Conversely also, the coincidence may serve to confirm the accuracy of the above method of estimating the mean monthly temperature.

The heat of December last, averaged in this manner from the register is $42^\circ\frac{1}{2}$; in the preceding year of 1820, it is only 39° for the same month. Of the months of September October and November last, the mean temperature was $58^\circ\frac{3}{4}$, $49^\circ\frac{1}{2}$ and $46^\circ\frac{3}{8}$, respectively. The corresponding numbers for the same months in the preceding year 1820 were 54°, $46^\circ\frac{2}{3}$, and $40^\circ\frac{1}{2}$. Thus it appears the heat of December last was three degrees and a half above the heat of the same month in the preceding year. And November also when compared with October of the prior year, is in this respect, very nearly equal.

From several experiments made by sinking a thermometer in garden earth to the depth of twelve or fifteen inches, the mean heat during the month of December last was found to be 44°. This portion of the earth's surface comprises the ordinary region of vegetation, which, as appears from these experiments, was in the very depth of winter inferior only by $4\frac{1}{2}$ degrees of temperature to that of the whole year. Such an extraordinary mildness in the season was accordingly very perceptible in all the productions of the garden. The autumnal flowers continued blowing late, till they were superseded by those of the spring, which appeared in the same degree, early. The animal creation felt also its genial influence, and the blackbird ushered in the new year with a carol as loud and as articulate as is usually heard in the months of April and May.

I have the honour to be,

Your very obedient servant,

JOHN HAILSTONE.

Trumpington,
Feb. 10, 1822.

DECEMBER 1821.

Day of Month.	Eight o'Clock Morning.			Two o'Clock Afternoon.			Eight o'Clock Evening.			Night Thermometer.
	Barometer.	Thermometer.	Wind.	Barometer.	Thermometer.	Wind.	Barometer.	Thermometer.	Wind.	
1	29.50	45	W.	29.52	45		29.65	40	W.	42
2	29.80	41	W.	29.82	47	W.	29.90	39	W.	36
3	29.65	50	S.W.	29.60	45	W.	29.65	41	W.	36
4	29.78	38	W.	29.79	47	W.		44		34
5	29.67	47	W.	29.67	48	W.	29.77	42	W.	44
6	30.18	37	N.	30.22	42	N.	30.25	32	N.	37
7	30.07	40	S.E.	29.90	42	S.E.	29.75	43	S.	31
8	29.89	44	W.	30.02	52	W.	30.05	48	W.	42
9	30.07	50	S.W.	30.05	52	S.	30.05	49		42
10	30.03	50	S.W.	29.99	54	S.	29.93	51	S.	48
11	30.20	39	N.	30.27	46	N.W.	30.32	34	N.W.	38
12	30.27	40	S.E.	30.20	44	S.E.	30.18	44	S.	30
13	29.92	45	S.E.	29.90	49	S.	29.93	43	S.	44
14	29.96	35	S.W.	29.95	49	S.W.	29.95	49	S.	35
15	29.95	47	S.	29.95	52		29.92	46		46
16	29.75	49	S.	29.70	55	S.	29.70	49	S.	44
17	29.45	50	S.	29.46	51	S.	29.38	48	S.W.	46
18	29.08	45	S.W.	29.07	50		29.08	46		44
19	29.07	42	S.W.	29.07	48	S.W.	29.20	39		41
20	29.37	36	S.	29.35	45		29.00	39	S.	35
21	28.72	44	S.	29.01	47	W.	29.20	41		39
22	29.44	38	W.	29.30	49	S.W.	29.27	46	S.W.	36
23	28.95	40	W.	29.03	46	W.	29.12	42	S.W.	40
24	28.87	42	S.W.	28.71	45	S.W.	28.37	44	S.E.	36
25	28.14	38	W.	28.35	46	W.	28.48	35	W.	39
26	28.52	34		28.50	40		28.50	38	W.	30
27	28.92	36	S.	28.95	44	S.	29.00	42	S.	32
28	28.87	42	S.E.	28.55	43	S.E.	28.33	44	S.E.	38
29	28.32	44	W.	28.41	45	W.	28.70	45	W.	44
30	29.03	43	W.	29.13	43	N.W.	29.45	40	N.	42
31	29.88	38	N.W.	29.95	47	N.W.	30.00	34	N.W.	38

EXTRACT FROM THE MINUTE BOOK

OF THE

CAMBRIDGE PHILOSOPHICAL SOCIETY.

Nov. 26, 1821.

XXVIII. *Notice of a remarkable instance of Fossil organic Remains found near Streatham in the Isle of Ely.*

By Dr. FREDERICK THACKERAY.

This bone was picked up among the materials for forming the turnpike road in the neighbourhood of Ely: all the natural grooves or channels in which the blood-vessels formerly ran, may be seen, confirming the observation of Cuvier, that these reliques have not been acted upon by attrition in water; and of which many more striking examples occur among specimens lately found in the neighbourhood of Cambridge. In order to account for this, it may be observed, that the finest examples of organic remains, characteristic of beds of alluvium, rather rest upon the line of junction between clay and gravel, than in the gravel itself. The present specimen consists of limestone with a slight impurity of alumina and oxide of iron: the exterior of it retains some portion of phosphate of lime; and (what seems very singular), a minute quantity of animal matter, which was manifested by its peculiar fœtid smell on being submitted to destructive distillation.

A very considerable part of the skeleton of a Mammoth was lately found in a gravel-pit near Chatteris.

A

LIST OF DONATIONS

TO THE

LIBRARY AND MUSEUM

OF THE

CAMBRIDGE PHILOSOPHICAL SOCIETY.

I. *Donations to the* Library.

1820.

	Donors.
Account of Smithson Tennant	Dr. E. D. Clarke.
———— the Jesuits	————
American Journal of Science, Nos. 1, 2, 3, 4 . . .	————
———— Mineralogical Journal, Vol. I. No. 2. . .	————
Carnot Geometrie de position	Rev. B. Bridge.
Christian's Dissertation on the Rules of Evidence .	Prof. Christian.
Deidier Calcul differential et integral	Rev. B. Bridge.
Edinburgh Philosophical Journal Nos. (1—5.) . .	W. Whewell, Esq.
Greenough's Geological Map of England	R. Sheepshanks, Esq.
Lhuilier Elemens d'analyse geometrique	Rev. B. Bridge.
Map of the World on Mercator's projection . . .	J. S. Henslow, Esq.
——— England.	————
——— Europe	————
——— Cambridgeshire	J. Okes, Esq.
Paris on the Physiology of the Egg	Dr. E. D. Clarke.
Physique de Rohault	Rev. B. Bridge.
Quarterly Review, Vols. (1—23.)	Rev. Whitworth Russel.
Rosetta Inscription	Rev. E. D. Clarke.
Sayer's Antiquarian Miscellanies.	————
Stackhouse on the Balsam and Myrrh trees . . .	————

1820.		DONORS.
	Stackhouse de Libanote, &c.	Dr. E. D. Clarke.
	Schweigger de Plantarum Classificatione . .	————
	Vindiciæ Geologicæ	Prof. Buckland.
	Watsoniana	Dr. E. D. Clarke.
Mar. 6.	On the developement of exponential Functions.	J. F. W. Herschel, Esq.
	On circulating Functions	————
	On the application of the Inverse theory of Functions	————
	Consideration of various points of Analysis .	————
	On the action of crystallized bodies on homogeneous light	————
	Isoperimetrical Problems	————
	Method of computing Astronomical refractions	Rev. John Brinkley.
	Method of correcting the approximate elements of the orbit of a Comet	————
May 15.	Annals of Philosophy, Vols. (9—14.)	Dr. E. D. Clarke.
	Nouveau Journal de Medecine, tom. (1—9.)	Dr. Haviland.
Nov. 13.	Viaggio per la Toscana di Georgio Santi . .	Prof. Santi.
27.	Discours sur Nicholas Kopernik	Dr. Slawinsky.
	Liebkneght clarissima testimonia Diluvii .	Dr. Thackeray.
1821.		
Mar. 19.	British and French Expeditions to Teembo .	T. E. Bowdich, Esq.
	Geography of North-western Africa	————
Nov. 12.	Epimetrum de quibusdam monumentis cum Pollionis Historia conjunctis	C. J. Reuvens.
	Elenchus plantarum Hort. Bat.	————
	Transactions of the Asiatic Society, Vols. (6—13.)	Asiatic Society.
	———— of the Royal Society of Edinburgh, Vol. IX. Part. 1.	Royal Society of Edinburgh.
	On the circular polarization of the Amethist .	Dr. Brewster.
	Connection between the primitive forms of minerals and their axes of double refraction	————

		Donors.
1820.		
Nov. 12.	Superstitions of the Egyptians, Abyssinians and Ashantees	T. E. Bowdich, Esq.
	Introduction to Ornithology	————
	Analysis of the Natural Classification of Mammalia	————
	Theory of Equations	Rev. B. Bridge.
	Translation of Cagnoli, on the method of ascertaining the exact figure of the earth	F. Baily, Esq.
	Notice of a paper on the structure of the Alps	Prof. Buckland.
Dec. 10.	History of the Crinoidea	J. S. Miller.
	Observations on the Lituus	Dr. E. D. Clarke.
	Reply to Samuel Lee by John Bellamy . .	Rev. Prof. Lee.
1822.		
Feb. 25.	On the Circular Sterns of Ships of War . .	Sir R. Seppings.
	Contradictions in Park's last Journal explained	T. E. Bowdich, Esq.
	Technical Repository, No. I.	Dr. E. D. Clarke.
	Elements of Conchology	T. E. Bowdich, Esq.
	The Rudiments of Plane and Solid Geometry	N. J. Larkin, Esq.
	Introduction to Solid Geometry	————
April 22.	Transactions of the Astronomical Society Vol. I. Part 1.	Astronomical Society.
	Observations on the Geology of the Isle of Man	J. S. Henslow, Esq.
	Essay on Political Economy	The Author.
	Journal of the Royal Institution (Nos. 1–13.)	M. Ramsay, Esq.

II. *To the* Museum.

1820.		
Mar. 6.	Fossil tooth from the coast of Scarborough	Rev. J. Hailstone.
May 1.	Collection of British Shells and Insects .	J. S. Henslow, Esq.
Nov. 27.	Medal of Copernicus	Dr. Slawinsky.
1821.		
Mar. 5.	Impressions of leaves in coal-shale	Rev. T. Kerrich.

Date	Donation	Donors.
1821.		
Mar. 19.	Quartz and Fluor from Beeralston	Rev. T. Ross, Esq.
	British Insects	Dr. Leach.
	Ditto	F. Stephens, Esq.
	Ditto	J. C. Dale, Esq.
	Chinese and Brazilian Insects	J. S. Henslow, Esq.
	White varieties of the Goldfinch, Sparrow, and Mole	————
	Black-billed Auk	————
	Fossil breccia of Gibraltar	C. Collins, Esq.
Nov. 12.	British Insects and Birds' Eggs	H. Englehart, Esq.
	Collection of Minerals	Rev. A. J. Carrighan.
	Three specimens of a Pinna from Guernsey	Rev. M. Vernon.
	Snakes and Scolopendra from Trinidad . .	Rev. Miles Bland.
	Large specimens of Fluor and Quartz from Alston Moor	Rev. G. Peacock.
26.	Very large Crystal of the Sulphate of Barytes	G. E. Wood, Esq.
	Fossil Bone	Dr. F. Thackeray.
	Specimens of the Areeka nut	Dr. Ingle.
Dec. 10.	Crystallized Carbonate of Barytes from Fallowfield—Northumberland	R. Lyon, Esq.
	Masses of Shale, from the Coal-measures in Anglesea, converted to Garnets and Analcimes, in contact with a trap dyke.	J. S. Henslow, Esq.
1822.		
Feb. 25.	Fossil vertebral Bone	Dr. F. Thackeray.
Mar. 25.	Collection of Foreign Shells and Corallines.	Mrs. Tyrritt.
	Sulphate of Barytes and Fluor from Matlock.	Prof. Cumming.
	Series of Models of Geometrical Solids . .	N. J. Larkin, Esq.
April 22.	Specimens of Scolopendræ	Rev. G. Jermyn.
	Lizard from Bencoolen	Dr. Ingle.

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DESCRIPTION OF THE PLATES.

N.B. *In the* First Part *of the* Transactions, *none of the Plates are numbered; the numbering of the Figures being carried on from* 1 *to* 25, *with the exception of* 11 *and* 12, *which are omitted.—These are followed by two lithographic drawings of the Bones of a fossil Beaver.*

In the Second Part, *some of the Plates are numbered, and, to prevent confusion, the following description of the whole is given, in order that each Plate may more readily be referred to the Paper which it is meant to illustrate.*

In Part I.

Plates I, II, III. include Figs. 1 to 10.—To accompany Professor Farish's Paper, No. 1. on Isometrical Perspective:

I. includes Figs. 1 to 7, representing several perspective views of simple figures.

II. Fig. 9. Perspective view of a piece of machinery.

III. Fig. 10. Perspective view of a furnace.

Plate IV. Figs. 13 to 20.—To accompany Mr. Herschel's Papers (Nos. 2 and 3.).

Plate V. Figs. 21 to 25.—To accompany Mr. Whewell's Paper No. 10.)

Plates VI, VII. Two lithographic drawings of the Bones of a fossil Beaver.—To accompany Mr. Okes's Paper (No. 9.).

VI. contains a single figure.

VII. contains three figures.

In Part II.

Plate VII. B. Crystallization of Water. — To accompany Dr. Clarke's Paper (No. 8).

Plate VIII. This plate is numbered, and refers to Mr. Cecil's Paper (No. 14).

Plates IX, X. These two plates are wanting. It was originally intended to make three plates from the figures included in Plate VIII; but, by an error of the engraver, their sizes were diminished, and the whole placed together.

Plate XI. This Plate is numbered, and contains the Galvanometer and figures described in Professor Cumming's Paper (No. 18).

Plate XII. To accompany Mr. Whewell's Paper on the double crystals of Fluor (No. 22). — The figures in this plate represent the intersections of cubes, &c.

Plate XIII. This plate is numbered, and refers to Professor Cumming's Paper on the Calculus (No. 24).

Fig. 1. The Calculus of the natural size.

Fig. 2. Section of the same along the line *AB*.

Plate XIV. Lithographic drawing of the dilated Ureters described in Mr. Okes's Paper (No. 25).

Plate XV—XXI. To accompany Mr. Henslow's Paper on the Geology of Anglesea (No. 26).

N. B. A description of these plates is given at the end of the Paper.