I. *Researches in Physical Geology. By* WILLIAM HOPKINS, M.A., *Fellow of the Cambridge Philosophical Society, and of the Geological Society, and Mathematical Lecturer of St Peter's College, Cambridge.*

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INTRODUCTION.

NOTWITHSTANDING the appearances of irregularity and confusion in the formation of the crust of our globe which are presented to the eye in the contemplation of its external features, geologists have been able in numerous instances to detect, in the arrangement and position of its stratified masses, distinct approximations to geometrical laws. In the phenomena of anticlinal lines, faults, fissures, mineral veins, &c., such laws are easily recognized; and though, when we consider how large a portion of the surface of the earth remains geologically unexplored, it may appear premature to assert that these are perfectly *general laws*, yet, founding our reasoning on our knowledge, and not on our ignorance, and feeling that confidence which we are entitled to feel in the universality of the laws and operations of nature, we shall, I conceive, be justified, if not in the absolute conclusion, at least in the presumption, that the laws already observed in phenomena such as those above mentioned will be found, by the wider extension and increased accuracy of geological research, to be the approximative *general* laws of those phenomena.

If the legitimacy of this inference be allowed, we are necessarily led to the conclusion, that the phenomena alluded to are referrible not to the particular and irregular action of merely local causes, but to the more widely diffused action of some simple cause, general in its nature with respect to every part of the globe, and general in its action at least with respect to the whole of each district throughout which the phenomena are observed to approximate, without interruption to the same geometrical laws. Between these phenomena and their actual causes necessary relations must of course exist; and in this paper I purpose to examine how far such relations do exist between our observed phenomena and a certain general cause to which they may be attributed. But in the first place it will be necessary to state distinctly the nature of the phenomena to which I refer, though without entering into more detail than may be necessary for my immediate object.

I. *Faults.*

a. In districts where faults abound, two distinct systems are usually found, in each of which the faults approximate to parallelism* with each other.

β. The common direction of one of these systems is approximately perpendicular to that of the other.

γ. The plane in which the dislocation at a fault has taken place is frequently somewhat inclined to the vertical; and it appears that the side of the fault on which the strata are most elevated, is more frequently that *towards* which the plane of dislocation inclines *from* a vertical through the lowest point of a section of the fault, by a vertical plane transverse to the plane of dislocation †.

II. *Mineral Veins.*

A distinct idea of a *mineral vein* is perhaps most easily formed by conceiving a vertical fissure, varying in width from a few inches to a few feet, to have been formed, extending downwards from the surface, and to have been subsequently filled up with matter in the midst of which the ore which properly constitutes the *mineral vein* ‡ is deposited.

* This term must in certain cases be taken in a modified sense, as will be explained hereafter, whatever may be the phenomena to which it is applied.

† See Encyclopedia Metropolitana, *Art.* Geology, p. 541.

‡ This is termed by miners in the Northern districts a *Rake-Vein.* In Cornwall the whole substance contained in the fissure is called a *Lode.*

sometimes in a regular vertical layer, and sometimes in irregular and detached masses. I shall therefore occasionally, without wishing to prejudge the question of the formation of veins, speak of the *fissures* in which they are deposited.

α. The *direction* of the intersection of a vein with a horizontal plane usually approximates to rectilinearity. It is not meant that every short portion of this intersection forms a straight line, but, when considered with reference to its whole extent, these variations are not for the most part considerable.

β. In every mining district the largest and most important veins are divided into two distinct groups, in each of which a very decided approximation to *parallelism* is observable, and of which the directions are nearly perpendicular to each other.

γ. When the veins occur in stratified masses, the *direction* of one of these systems usually coincides with that of the general dip of the strata, the other being consequently perpendicular to that direction*.

δ. A large proportion of the most productive mineral veins are found in the former of these systems. The latter (frequently termed by the miner *cross courses*) carry ore very irregularly.

ϵ. It seems doubtful whether any actual limits of a fissure containing a mineral vein were ever arrived at by the miner, though the division of a large fissure into several small ones not unfrequently seems to indicate a near approach to such a limit in the direction of its length. I know of no case, however, in which such indications have been observed of an approach to both extremities of a large vein. It is probable that their linear extent is frequently much greater than has yet been, or in many cases ever can be, observed. In numberless instances they

* I first observed this relation between the general direction of the mineral veins and that of the dip of the strata in the mining district of Derbyshire. I find on enquiry that the same relation holds in the Alston-moor district, and in Flintshire. In Cornwall also, when the lodes are in stratified rock, I apprehend this is generally the case, assuming the killas formation in the immediate vicinity of the granite to be stratified.

have been traced for four or five miles in the mining districts of this country, and in some cases to the distance of eight or ten miles.

ζ. Their depth appears to be uniformly greater than that to which man has been able to penetrate.

η. The width of the fissures in that system of the two above mentioned which contains the most productive and the most continuous mineral veins, varies in general from a few inches to about 12 feet. In the same vein the width will frequently vary, and sometimes suddenly along the same vertical line. In passing through a horizontal bed of clay the fissure will be sometimes almost entirely closed; and the toadstone of Derbyshire produces the same effect, frequently closing the fissure so effectually that it can only be traced through it by means of small ramifying veins of calcareous spar. The average width however does not appear at all to diminish as we descend*. The strata through which the fissure penetrates generally form well defined though uneven walls bounding it on either side, and perfectly firm and solid, except where the strata themselves cease to be so.

θ. The width of the cross courses is frequently greater than that above stated, and generally much more irregular.

ι. The fact of the strata in one wall of a fissure being higher than the same strata in the opposite one, has been recognized by all miners in some parts of almost every vein of consequence that has been explored, when existing in a distinctly stratified mass. This difference in general does not exceed a few feet, though it has not unfrequently been found to be many fathoms, in which case the vein of course coincides with a *fault*. This is sometimes termed by miners the *throw*† of the vein.

* In the mining district about Alston-moor there appears to be a few exceptions to this rule, as well as to the assertion of the preceding paragraph (ζ), in what are termed *gash veins*. These are comparatively wide at the top, and become gradually narrower as they descend, till they appear to terminate. (See Forster's account of this district, p. 186.) They are probably *rents* the formation of which began at the surface, but are hardly worthy of notice as exceptions to our general rules.

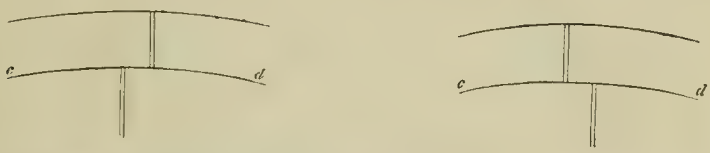
† A *throw* is in fact a small fault.

κ. The *inclination* of the plane of the fissure to a vertical plane, which is frequently termed by the miners of the more northern districts the *hade* of the vein, and by the Cornish miners its *underlie*, is very uncertain, amounting not unfrequently to as much perhaps as 20°, generally, however, to considerably less, though in particular cases to considerably more. It will sometimes vary at different depths along the same vertical line, so that in some instances, when the *hade* is small, it will be in one direction in the upper, and in the contrary direction in the lower part of the vein. Upon the whole, however, the hade is not very great, and tolerably regular in each vein*.

μ. Masses of the adjoining rock, more or less perfectly detached from it, are frequently found imbedded in the matter which occupies the fissure†.

ν. Apparent or real displacements in the position of a vein are frequently observed at its intersection with another vein, or with some particular stratified bed, which is generally found to be a bed of moist slimy clay. These intersections are of various kinds.

ο. First, that of a vertical or nearly vertical vein, with a clay bed horizontal, or nearly so. The displacements in this case are shewn in the figures annexed, which represent vertical sections perpendicular to the plane of the vein.



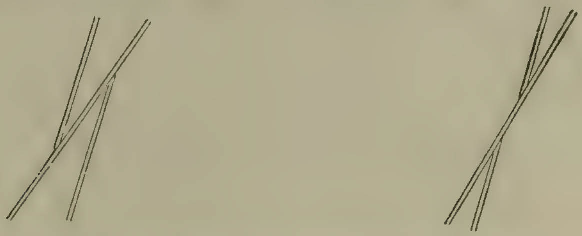
It is manifest that here either the part of the vein above the stratum *cd* has been moved, or that below it, or both, if the two portions were ever in the same plane.

* The underlie of the Cornish lodes is frequently greater, I conceive, than in our other mining districts. It may possibly also be more irregular.

† These insulated masses are frequently termed by miners, *Riders*.

π. Secondly, we may have the intersection of two vertical veins, the planes of which are inclined to each other at any given angle. In such case it frequently happens, that while the continuity of one vein is preserved that of the other is broken, apparently by a relative displacement of the portions on opposite sides of the unbroken vein. This kind of displacement is exhibited in the annexed figures, which represent horizontal sections.

ρ. Thirdly, we may have the intersection of veins the planes of which are inclined, but at different angles, to a vertical plane. If such veins be near enough to each other, their intersection will take place sufficiently near the surface to be within the limits of observation, and if they meet the horizontal surface in parallel lines their line of intersection will be horizontal. If the subjoined figures represent vertical



sections perpendicular to this line, the displacements observed will be such as they exhibit.

These phenomena of faults, and mineral veins, are those which appear to approximate the most distinctly to well defined laws, and therefore afford the best means of testing the truth of any theory of elevation. The following phenomena also bear equally on the investigations contained in this paper, though their characters are in general much less distinct than those of the phenomena already cited.

III. *Anticlinal and Synclinal Lines.*

When two or more anticlinal lines, with the corresponding synclinal ones, are found in the same geological district*, their general directions frequently approximate to parallelism with each other†.

IV. *Longitudinal Valleys.*

a. Along the flanks of elevated ranges, longitudinal valleys are not unfrequently found running nearly parallel to the general axis of elevation ‡.

β. The partial elevations along the sides of an elevated range have usually these escarpments presented towards the central ridge ||.

* I mean by a *geological district*, any tract of country throughout which the phenomena may be regarded as following the same laws without discontinuity.

† If we take two planes coinciding at any proposed point of an anticlinal line, with the portions of the surface of a stratified bed on opposite sides of that line, these planes* of stratification will intersect in a straight line not necessarily horizontal; and the *direction* of the anticlinal line at the proposed point will be determined by the azimuth of a vertical plane drawn through this intersection, or the direction of the intersection of this vertical plane with the horizon. Again, if through the proposed point we draw vertical planes respectively perpendicular to the two planes of stratification above mentioned, their respective intersections with them will be the lines of greatest inclination of the strata, and consequently the azimuths of these vertical planes will determine the *directions of the dip*. The angles between these two latter vertical planes, and the one before mentioned as determining the direction of the anticlinal line, will not generally be equal; they will become so only when the inclination of the planes of stratification on either side of the line is the same; *i. e.* the directions of the dip on opposite sides of an anticlinal line at any proposed point of it will not generally make equal angles with that of the line itself, unless the dip on opposite sides be the same. There is however an exception to this rule, when the direction of the dip on each side of the anticlinal line is perpendicular to it. This will occur when the two planes of stratification first mentioned intersect in a horizontal line.

‡ Saussure, Voyages dans les Alpes, Vol. I. Chap. x.

|| Traité de Geognosie, by D'Aubuisson, Vol. I. §. 24. p. 82.; and Saussure, Voyage dans les Alpes, Vol. III. Chap. x. This rule is probably very general.

V. *Transverse Valleys.*

Deep valleys are sometimes found of which the directions are nearly at right angles to that of the general elevation*.

VI. *Dykes or Veins, and Horizontal Beds of Trap.*

α. The dykes are usually found in nearly vertical planes, and, when they occur in the vicinity of each other, with a general tendency to parallelism.

β Extensive beds of trap are found apparently interstratified with the stratified rocks.

VII. *Granite Veins.*

The form of a vein of this kind is frequently very different from that of mineral or trap-veins, as above described, inasmuch as a section of it does not generally approximate in the same degree to rectilinearity †.

These approximations to general laws have been, I believe, very generally recognized by geologists, and more especially in faults and mineral veins, in almost all cases in which these phenomena exist *throughout districts of considerable extent;* and this appears unquestionably to justify the notion, that they are not to be referred to partial causes, but to some cause general at least with reference to the district throughout which the same laws are observed to hold without breach of continuity. Local and accidental causes may in some cases act with sufficient energy to obliterate all traces of general laws in phenomena such as those above mentioned; but still this will manifestly not invalidate our inference with respect to those districts in which such laws have been clearly recognized. We may moreover

* These valleys may frequently be due in great measure to the effects of erosion. In some instances, however, they appear to have been obviously formed by the elevation of the strata on either side of them. The valley of the Wye, in Derbyshire, offers a beautiful example of this kind of formation.

† Trap veins sometimes assume the tortuous form of a granite vein. See M'Culloch's Description of the Western Islands of Scotland. Vol. III. Pl. XXXIII.

observe, that the law of approximate parallelism which equally characterizes the phenomena of anticlinal lines, faults, and mineral veins, affords, *à priori*, a strong probability that they are all assignable to the same general cause. We may also further remark, that if, with the previous conviction that the stratified beds have been deposited from water, and with a knowledge of the physical impossibility of beds of uniform thickness being so deposited except on planes but little inclined to the horizon,—if, I say, under these circumstances, we examine many of the phenomena above mentioned, it seems impossible not to be struck with the idea of their being referrible to the action of some powerful elevatory force acting beneath the superficial crust of the globe, and thus producing those elevations and dislocations which we now witness. And, accordingly, such is the almost universal impression on the minds of geologists.

It appears, then, that we are arrived at that stage of geological science in which we are able to recognize certain well defined geological phenomena, distinctly approximating to geometrical laws; and we have also a distinct mechanical cause to which geologists, with almost one consent, have agreed in considering them to be assignable. The next step we are therefore called upon to take is obvious—it is to institute an investigation, founded on mechanical and physical principles, of the necessary relations which may exist between our observed phenomena and the general cause to which we attribute them. This investigation I have attempted, and now beg to lay it before the Society. I hope the nature of it will be deemed a justification of my introduction of a new term into the science, that of ***Physical Geology***.

I have conducted the investigation by the methods supplied by mathematical analysis. I am aware, however, that to some persons the application of these methods to geological problems may appear like an affectation of an accuracy which the nature of the subject may not be conceived to admit of; but from this opinion I dissent entirely. We have, as I have before remarked, observed phenomena approximating to well-defined laws, and which we are prepared to regard as the effects of an assigned and definite cause; and to shew that this hypothetical cause is the true one, we must shew that, supposing all local and partial causes with which we are acquainted to be removed, it would produce effects strictly in harmony with those laws to which the actual phenomena are observed to approximate. The most obvious cause of deviation in our phenomena from strict geometrical laws, is irregularity in the intensity of the elevatory forces, and in the constitution of the masses on which they are supposed to act. Abstracting these sources of uncertainty, we have before us a definite problem, viz., to determine the nature of the effects produced by a general elevatory force acting at any assigned depth on extended portions of the superficial crust of the earth, and with sufficient intensity to produce in it dislocations and sensible elevations. To this simple and definite form the problem may be reduced; and at least a correctly approximate solution of it must necessarily be obtained by some means or other, before we can pronounce on the adequacy of the assigned cause to produce the observed effects. The complete solution of the problem presents many difficulties, which, however, are avoided by restricting ourselves to a *first approximation*, which will amply suffice for all practical applications of our results. This approximate solution is what I have now to offer; and I may be allowed to observe, that those who may object to the mathematical resources of which I have availed myself, are at least bound to offer a solution equally conclusive and available by some method more adapted to the general reader. A slight examination however of the problem will suffice to shew that it can admit of no accurate solution independently of reasoning too intricate to be clearly embodied in any language but that of mathematical analysis.

The hypotheses from which I set out, with respect to the action of the elevatory force, are, I conceive, as simple as the nature of the subject can admit of. I assume this force to act under portions of the earth's crust of considerable extent at any assignable depth, either with uniform intensity at every point, or in some cases with a somewhat greater intensity at particular points; as for instance, at points along the line of maximum elevation of an elevated range, or at other points where the actual phenomena seem to indicate a more than ordinary energy of this subterranean action. I suppose this elevatory force, whatever may be its origin, to act upon the lower surface of the uplifted mass through the medium of some fluid, which may be conceived to be an elastic vapour, or in other cases a mass of matter in a state of fusion from heat. Every geologist, I conceive, who admits the action of elevatory forces at all, will be disposed to admit the legitimacy of these assumptions.

The first effect of our elevatory force, will of course be to raise the mass under which it acts, and to place it in a state of *extension*, and consequently of *tension*. The increase of intensity in the elevatory force might be so rapid as to give it the character of an impulsive force, in which case it would be impossible to calculate the dislocating effects of it. This intensity and that of the consequent tensions will therefore be always assumed to increase *continuously*, till the tension becomes sufficient to rupture the mass, thus producing fissures and dislocations, the nature and position of which it will be the first object of our investigation to determine. These will depend partly on the elevatory force, and partly on the resistance opposed to its action by the cohesive power of the mass. Our hypotheses respecting the constitution of the elevated mass, are by no means restricted to that of perfect homogeneity; on the contrary, it will be seen that its cohesive power may vary in general, according to any continuous law; and moreover, that this power, in descending along any vertical line, may vary according to any discontinuous law, so that the truth of our general results will be independent, for example, of any want of cohesion between contiguous horizontal beds of a stratified portion of the mass. Vertical or nearly vertical planes, however, along which the cohesion is much less than in the mass immediately on either side of them, may produce considerable modifications in the phenomena resulting from the action of an elevatory force. The existence of joints for instance, or planes of cleavage in the elevated mass, supposing the regularly jointed or slaty structure to prevail in it previously to its elevation, might affect in a most important degree, the character of these phenomena. To a mass thus constituted, these investigations must not be considered as generally applicable. Vertical or highly inclined *planes of less resistance*, will only be assumed to exist partially and irregularly in the elevated mass.

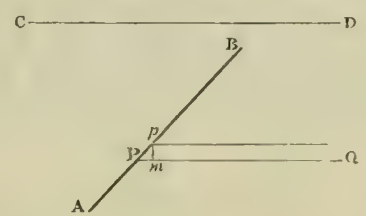
With these hypotheses then respecting the nature of the elevatory force, and the constitution of the elevated mass, I shall proceed in the next section to investigate the directions in which fissures will be formed in it when subjected to given internal tensions sufficiently great to overcome the cohesive power which binds together its component particles. These tensions, so far as this investigation is concerned, may either be supposed to be produced by external forces causing an *extension* of the mass, or by such as prevent that *contraction* of it which might be conceived to result from the loss of moisture or of temperature. It must be understood however that these internal forces are quite distinct from that sort of molecular action on which any kind of laminated or crystalline arrangement of the component particles may depend.

SECTION I.

1. The simplest form of the mass in which we have to consider the formation of fissures, is obviously that of a thin lamina. The investigations therefore of this section will be applied directly to this case, from which the results applicable to a mass of three dimensions are immediately deducible. It will appear that its cohesive power may vary according to any continuous law.

§. *Lamina subjected to one System of Tensions.*

2. Suppose the lamina acted on by external forces, which shall place it in a state of tension, such that the direction of the tension at every point shall be parallel to a given line CD*. Let AB be any



proposed line in the lamina; P any point in this line. Also assume F to be the tension at P, estimated by the force which the tension at that point would produce, if it acted uniformly on a line of which the length should be unity, and which should be perpendicular to CD, the common direction of the forces of tension. Then if we take Pp a small and given element of the line AB, and draw PQ parallel to CD, and pm perpendicular to PQ, the force of tension on Pp in the direction PQ will be measured by $F.pm$, or $F.Pp.\sin\psi$ ($BPQ = \psi$); or the

* The reference will always be made to the figure in the same page, unless stated to the contrary.

tendency of the forces of tension to separate the particles which are contiguous, but on opposite sides of the geometrical line Pp, by causing them to move parallel to CD, will be measured by

$$pm \,.\, F \sin \psi,$$
$$= \delta x \,.\, F \sin \psi \text{ (if } AP = x).$$

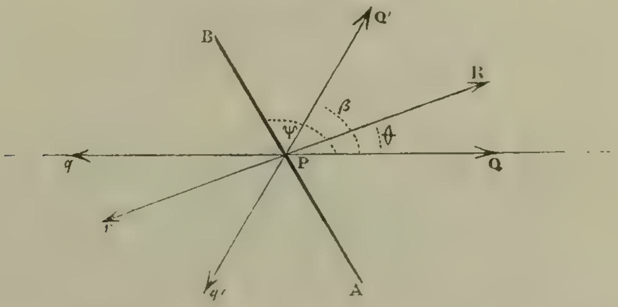
The tendency to separate the particles at P, by causing them to move in a direction making an angle θ with CD or PQ, will be estimated by

$$\delta x \,.\, \cos\theta \,.\, \sin\psi \,.\, F.$$

This is greatest when $\theta = 0$, and $\psi = \frac{\pi}{2}$, as of course it ought to be. AB being then perpendicular to CD.

§. *Lamina acted on by two or more Systems of Tensions—Direction in which their tendency to produce a fissure is greatest.*

3. Let us next suppose a second system of parallel tensions superimposed on the former, their common direction making an angle β with that of the first system. Let PQ, PQ', in the following figure, be the directions of the tensions acting on the element δx, of the line AB at



P, and therefore $QPQ' = \beta$; and let the intensities of these tensions (estimated as in Art. 2.) be represented by F and f. Then if $QPB = \psi$, and therefore $Q'PB = \psi - \beta$, we shall have the forces $\delta x \,.\, F \,.\, \sin\psi$, and $\delta x \,.\, f \,.\, \sin(\psi - \beta)$ acting on the element δx; and to find the tendency of these forces to separate the contiguous particles on opposite sides of the elementary portion δx, of the geometrical line AB, estimated by their tendency to give an opposite motion to these particles along any assigned line rPR, we must resolve the forces in the direction of that line. Let $RPQ=\theta$; then will the sum of the resolved parts of our forces in the directions PR and Pr be

$$\delta x \,.\, F \sin\psi \cos\theta + \delta x \,.\, f \sin(\psi-\beta)\cos(\beta-\theta) \ldots\ldots\ldots\ldots\ldots (A).$$

If the value of this expression, considered as a function of the independent variables ψ and θ be made a maximum, we shall manifestly obtain from the corresponding value of ψ that angular direction of the line AB along which the two sets of tensions we are considering have the greatest tendency to form a fissure.

Differentiating the expression with regard to θ, we have

$$\delta x \,.\, F \sin\psi \sin\theta - \delta x \,.\, f \sin(\psi-\beta)\sin(\beta-\theta) = 0.$$

The left-hand side of this equation is the expression for the sum of the resolved parts of the forces $\delta x \,.\, F \sin\psi$ and $\delta x f \sin(\psi-\beta)$, perpendicular to the line PR. Consequently the equation expresses the condition that PR must coincide with the direction of the resultant of the above forces.

Again, differentiating with respect to ψ, we obtain

$$F\cos\psi \,.\, \cos\theta + f\cos(\psi-\beta)\cos(\beta-\theta) = 0.$$

From the above equations we must determine ψ and θ. If we put $\frac{f}{F}=\mu$, we obtain from thence

$$1+\mu(\cos\beta - \sin\beta\cot\psi)(\cos\beta - \sin\beta \,.\, \cot\theta) = 0,$$

$$1+\mu(\cos\beta + \sin\beta \,.\, \tan\psi)(\cos\beta + \sin\beta\tan\theta) = 0,$$

or, putting $\cos\beta = c$, $\sin\beta = s$, $\cot\theta = x$, $\cot\psi = z$,

$$1+\mu(c-sz)(c-sx) = 0,$$

$$1+\mu\left(c+\frac{s}{z}\right)\left(c+\frac{s}{x}\right) = 0.$$

From the inspection of these equations it is manifest that $z = -\frac{1}{x}$; for putting this value for z, and therefore also $-\frac{1}{z}$ for x, the two equations will only be converted into each other. Substituting in the first equation, we have

$$1 + \mu (c - sz) \frac{cz + s}{z} = 0,$$

which gives

$$z^2 - \frac{1 + \mu (c^2 - s^2)}{\mu cs} z - 1 = 0,$$

$$\text{or } \cot^2 \psi - 2 \cdot \frac{1 + \mu \cos 2\beta}{\mu \cdot \sin 2\beta} \cdot \cot \psi - 1 = 0 \text{..................(1).}$$

4. Let ψ_1, ψ_2 be the two values of ψ given by this equation. Then, since the last term is -1,

$$\cot \psi_1 \cot \psi_2 = -1;$$

which shews that the difference between ψ_1 and ψ_2 is $\frac{\pi}{2}$, or

$$\psi_1 = \frac{\pi}{2} + \psi_2;$$

and if θ_1, θ_2 be the values of θ corresponding respectively to ψ_1 and ψ_2, we have

$$\cot \theta_1 = -\frac{1}{\cot \psi_1}$$

$$= \cot \psi_2;$$

$$\therefore \theta_1 = \psi_2 = \psi_1 - \frac{\pi}{2}$$

$$\text{and } \theta_2 = \psi_1 = \psi_2 + \frac{\pi}{2}.$$

The angle *BPR* is consequently a right angle.

5. Since *PR* coincides, as shewn above, with the direction of the forces of tension acting on the element δx of the line *AB*, the expression (A) is the value of that resultant. Consequently ψ_1 and ψ_2, which correspond to the maximum and minimum values of the quantity (A), determine the position of the line *AB* in which the resultant of the above-mentioned forces of tension is a maximum or minimum.

6. If the two systems of tensions be equal and perpendicular to each other, equation (1) becomes

$$\sin\pi \,.\, \cot^2\psi - 2(1+\cos\pi)\cot\psi - \sin\pi = 0,$$

and is satisfied independently of particular values of ψ. In this case, therefore, there is no greater tendency to form a fissure in one direction than another. If F be greater than f, the equation becomes

$$\sin\pi \,.\, \cot^2\psi - 2\left(\frac{1}{\mu} - 1\right)\cot\psi - \sin\pi = 0,$$

of which the two roots are 0 and ∞, which shews that the greatest tendency is to form a fissure in a direction perpendicular to that of F.

7. The above investigation easily admits of generalization for any number of systems of parallel tensions superimposed upon each other. Let F denote, as before, the intensity of the tension in the direction from which θ and ψ are measured; f_1, f_2, &c. the tensions in directions making respectively angles β_1, β_2, &c. with the direction of the tension F. Then shall we have

$$\delta x \,.\, \{F\sin\psi\cos\theta + f_1\sin(\psi-\beta_1)\cos(\theta-\beta_1) + f_2\sin(\psi-\beta_2)\cos(\theta-\beta_2) + \&\text{c.}\} = \text{max.};$$

and proceeding exactly in the same manner as in the previous investigation, and adopting an analogous notation, we shall manifestly obtain the following equations:

$$1 + \mu_1(c_1 - s_1 z)(c_1 - s_1 x) + \mu_2(c_2 - s_2 z)(c_2 - s_2 x) + \&\text{c.} = 0,$$

$$1 + \mu_1\left(c_1 + \frac{s_1}{z}\right)\left(c_1 + \frac{s_1}{x}\right) + \mu_2\left(c_2 + \frac{s_2}{z}\right)\left(c_2 + \frac{s_2}{x}\right) + \&\text{c.} = 0,$$

and putting, for the same reason as before, $x = -\dfrac{1}{z}$, we obtain

$$1 + \mu_1(c_1 - s_1 z)\frac{c_1 z + s_1}{z} + \&\text{c.} = 0;$$

$$\therefore\ z + \mu_1\{c_1 s_1 + (c_1^2 - s_1^2)z - c_1 s_1 z^2\} + \&\text{c.} = 0;$$

$$\text{or}\ -\{\mu_1 c_1 s_1 + \mu_2 c_2 s_2 + \&\text{c.}\}z^2$$

$$+\{1 + \mu_1(c_1^2 - s_1^2) + \mu_2(c_2^2 - s_2^2) + \&\text{c.}\}z + \mu_1 c_1 s_1 + \mu_2 c_2 s_2 + \&\text{c.} = 0;$$

$$\text{or } z^2 - \frac{1 + \Sigma\mu(c^2 - s^2)}{\Sigma\mu cs} z - 1 = 0;$$

$$\therefore \cot^2\psi - 2 \cdot \frac{1 + \Sigma\mu \cos 2\beta}{\Sigma\mu \sin 2\beta} \cot . \psi - = 0 \ldots\ldots\ldots\ldots (2).$$

The same remarks will apply to this equation as to equation (1).

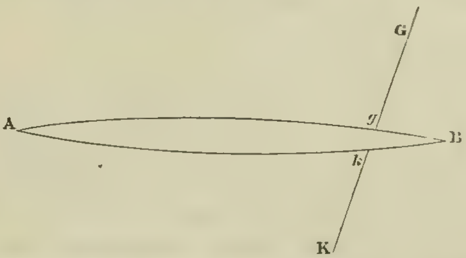
Hence, then, when the directions of the different tensions to which a lamina is subjected, and the ratios of their intensities, are known, this equation will determine that position of the line AB passing through any proposed point P, in the direction of which there is the maximum or minimum tendency to cause a fissure to *begin* at that point. If β be less than a right angle, it is manifest by inspection that the negative root will correspond to the former, and the positive root to the latter case.

8. The actual direction in which the fissure will begin to be formed at P, may, however, be different from that in which the tensions have the greatest tendency to form it; for if there be any particular line through that point, along which the cohesive power of the lamina is less than in any other, the fissure may begin to be formed in that direction, though it may not coincide with that of the maximum resultant tension. If however the cohesive power at the proposed point be equal in every direction, *i. e.* if it vary *continuously* in passing from one point to another, and not suddenly as at a line of less resistance, the direction in which the fissure will begin to be formed, will coincide with that of the maximum resultant tension determined by equation (2). This observation respecting the constitution of the mass to which the investigations of the previous articles are applicable, is important. *The cohesive power may vary according to any continuous law*, as was before stated. (Introd. p. 11).

Direction in which the Fissure will be continued.—Partial System of Tensions imposed on the Lamina about the extremities of the Fissure.—Direction of the Fissure not affected by it in the case proposed.

9. In the preceding investigations the tensions have not been considered necessarily sufficient to produce a fissure. Let us now suppose

their intensity to increase till the resultant tension becomes greater than the cohesive power at any proposed point P. A fissure will then begin to be formed in the direction determined by equation (2), in which the values of μ_1, μ_2, &c. express the ratios of the different tensions at P, at the instant the fissure begins to be formed there. Let us suppose the fissure AB to have been thus formed, and that the cohesive power



of the lamina beyond A and B is sufficient to prevent its further propagation, and let us then consider whether any modification of the tensions will be produced immediately beyond A and B, which may possibly influence the direction in which there will be the greatest tendency to continue the fissure.

10. Let GK be any physical line broken by the fissure. It is obvious that if it pass near the extremity of the fissure, its extension, and therefore its tension, will not be very much diminished; but since this tension is no longer counteracted at g and k by an equal and opposite tension, as in its unbroken state, it is manifest that the force exerted by each portion Gg, Kk, must produce an increased stress upon the portions of the lamina, immediately contiguous to and beyond the extremity of the fissure; and since a similar effect, differing only in degree, will be produced by each physical line broken by the fissure, it is possible that the intensity of the whole additional tension, thus partially superimposed upon the lamina, may be very considerable in comparison with the general tensions impressed upon it.

Now it is manifest, that the direction in which there is the greatest tendency to continue the fissure from A or B, under the circumstances we are supposing, will be determined by the whole tension contiguous to those points, consisting of that superimposed as above described, as well as of that impressed generally on the lamina; and consequently, if we conceive the latter of these tensions, (and therefore also the former) to increase till the resultant tension is sufficient to overcome the cohesive power at A or B, the fissure will not necessarily be continued in the same direction, as if its continuation were independent of the partial system superimposed about its extremities.

It will be observed, however, that in the case just considered, in which the forces are not producing motion in the mass, the whole force exerted by gG, and kK, and similar lines is effective in producing the superimposed system of tension about the extremity of the fissure. We shall shew however, that such is not generally the case during the propagation of the fissure, if propagated in the manner we shall suppose it to be, and that consequently this force will have no material effect on the direction in which the fissure will be continued, and which will therefore be very *approximately* determined by equation (2).

11. For this purpose, let us suppose in the first place, any systems of tensions impressed on the lamina, of which the resultant tension (R) shall be less than the cohesive power (Π), at any proposed point P; and let us then conceive subsequently superimposed on these another system of which the direction is different to that of R, and of which the intensity Φ shall increase continuously with the time t, till the resultant of R and Φ shall be equal to Π, so that a fissure shall then begin to be formed at P. Its direction will evidently depend on R, *and the value* (Φ_t), *which* Φ *shall have acquired at the instant the fissure commences.* If R differ but little from Π, Φ_t will be generally small*, and cannot (however the forces producing Φ may subsequently act on the lamina), produce any material influence on the direction of the fissure, which will therefore, in such case, nearly coincide with the direction in which the tensions whose resultant is R may have the

* If the direction of Φ coincided with that of R, the fissure would manifestly begin to be formed when $R + \Phi_t$ should $= \Pi$, or $\Phi_t = \Pi - R$, which by hypothesis is small. If the angle between the directions of R and Φ be not too near a right angle, it is equally manifest that Φ_t must be small. In the actual case considered in the text, this angle obviously cannot be very considerable.

greatest tendency to form it, *i. e.* it will be nearly perpendicular to the direction of that resultant.

12. Let us now suppose P_1 to designate a point in the lamina, at which a fissure shall begin, and P_2 another point through which it shall be subsequently propagated; and let Π_1, Π_2, denote the cohesive powers of the lamina at those points respectively, Π_1 being the least. It has been already stated, (Introd. p. 11.) that in the case to which these investigations are to be applied, the intensity of the elevatory force, and therefore, of the tensions produced by them, will be assumed to increase *continuously* from the commencement of the action of this force, to the formation of the fissures; we shall here also make an additional assumption, viz., that this intensity shall increase *rapidly*, so that a very small time shall elapse between the commencement of the elevatory action, and the instant when the fissures shall begin to be formed*. The tensions therefore to which our lamina is subjected, will be assumed to increase in the same manner. Let R_t denote the intensity of their resultant at the time t; then if t_1 be the time when the fissure begins at P_1, R_{t_1} must be equal to the cohesive power at $P_1 = \Pi_1$. When the fissure is thus begun to be formed, the partial system of tensions described in Art. 9., will be superimposed about its extremities. Let Φ_t denote its intensity at the time t, and at any proposed point. As the fissure in its progressive formation approaches P_2, this force will be superimposed on the lamina there, in addition to the force R_t *previously acting there*, so that if $t_{\prime\prime}$ be the time when the fissure is first formed at P_2, we must have at P_2, the resultant of $R_{t_{\prime\prime}}$, and of $\Phi_{t_{\prime\prime}} = \Pi_2$. Now, if during the time $t_{\prime\prime} - t_{\prime}$, R_t increases from $R_{t_\prime}$, or Π_1, so that $R_{t_{\prime\prime}}$ nearly $= \Pi_2$, $\Phi_{t_{\prime\prime}}$, must be small at P_2, and therefore can have but little influence on the direction of the fissure through that point, whatever be the direction of that tension, or the intensity it might acquire if the cohesive power at P_2 were sufficient to prevent the propagation of the fissure beyond that point (Art. 11.) In such case therefore the direction of the fissure will be at least very approximately determined by equation (2), p. 18, in which the values of μ do not include the tension Φ,

* This assumption is not absolutely necessary for the truth of the approximation we have to establish or for the proof of it. It renders however the approximation more accurate, and the proof much more simple.

but only the values F, f_1, f_2, &c. of the general tensions, at the instant when the fissure is propagated through the proposed point*.

13. Under the circumstances here supposed, the fissure will be propagated from P_1 to P_2, nearly in the time $t_{\prime\prime} - t_{\prime}$, during which R_t increases from Π_1 to Π_2. Consequently, if the difference between these latter quantities be not great, *i. e.* if the cohesive power do not vary rapidly; or if R_t (heretofore assumed to be the same at the same time at different points of the lamina) increase with rapidity, it follows that the velocity of propagation will be extremely great, becoming infinite, when the cohesive power, and the tension R_t are accurately uniform throughout the lamina.

If R_t be not uniform, it is easy to see that reasoning similar to the above will hold equally true, with respect to the progressive formation of any fissure.

14. The fissure will be propagated in a straight line, if the values of μ in equation (2) remain the same, *i. e.* if the ratios of the tensions at different points be the same at the instant the fissure is propagated through them. If these ratios be different for different points, the fissure will generally be curvilinear; there is, however, an important exception to this rule, when there are only two systems of tension, of which the directions are perpendicular to each other; for in this case it appears by Art. 6, that the direction of the fissure will always be perpendicular to that of the greater of these two tensions.

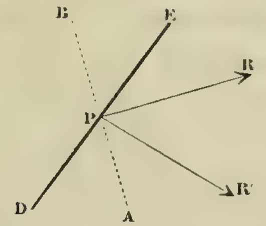
Effect of Lines of Less Resistance on the Direction of a Fissure. Permanent Direction of Cleavage.

15. In the preceding articles, we have supposed the cohesive power of the lamina to vary according to some continuous law. Let us now

* When the cohesive power of the lamina is not sufficient to prevent the propagation of the fissure, the problem presented to us is no longer a statical one. In the case above considered, a small portion only of the extraneous forces producing the tension Φ, is effective in causing an additional tension of the lamina before the formation of the fissure. The greater part is effective in communicating motion to those parts of the mass, the receding of which from each other causes the opening of the fissure. On the contrary, when the formation of the fissure is arrested, the whole of these forces is effective in producing this partial system of tensions.

consider the effect of the existence of *lines of less resistance* in the lamina, in which case the continuity above assumed will no longer exist along these lines.

Let DE be a line of this description, along which the cohesive power estimated in a direction perpendicular to it $= \Pi'$, that of the lamina near to DE being $= \Pi$. Also let R_t, acting in the direction



PR, be as before, the resultant at the time t and at the point P, of the general systems of tensions impressed upon the lamina; and let R_t' denote the tension along PR' perpendicular to DE at the time t. Then if

$$\frac{R_t'}{\Pi'} \text{ be } > \frac{R_t}{\Pi},$$

it is manifest that the fissure will begin to be formed along the line DE, rather than in a direction perpendicular to R_t, in which it would be formed in the absence of a line of less resistance*.

16. Let us now suppose this line to terminate at D and E. When the fissure has been propagated to those points, its progress will be arrested till the tension R_t and that superimposed just beyond the extremities of the fissure, and before denoted by Φ_t (Art. 11), produce a resultant tension greater than the cohesive power Π. The direction in which the fissure will be then immediately continued, will not be known, Φ_t being unknown; but without staying to enquire what this may be, we may observe, that the fissure must very soon in its pro-

* It is assumed in the above condition, that if the fissure be formed along DE, the particles on opposite sides of the fissure in separating would move in lines perpendicular to DE. This would be only approximately true.

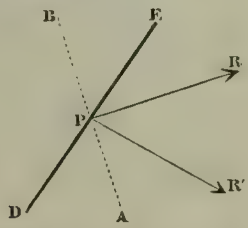
gressive formation, arrive at a point at which R_t will be very nearly equal to the cohesive power, {since that force by hypothesis increases rapidly with t, (Art. 12)}, and where, consequently, the direction of the fissure must necessarily be very approximately that determined by equation (2), as explained in Art. 12. Hence then we may conclude, that under the hypotheses we are taking, whatever may be the direction first given to the fissure by any local cause, its subsequent direction will soon become independent of that cause.

17. If the fissure, instead of beginning at some point in a line of less resistance meet it, in its progressive formation, it will pass along it, or will cross it, according as a condition exactly similar to that given above (Art. 15), be satisfied or not. At the termination of this line, the fissure will soon resume the direction given to it by the general systems of tensions to which the lamina is subjected, as just explained. Such also will be the case at the point at which the line of less resistance, should it be a curved or broken line, may assume a direction in which the condition just referred to is no longer satisfied.

18. The condition given in Art. 15 gives us

$$\frac{R_t'}{R_t} > \frac{\Pi'}{\Pi}.$$

The first of these ratios will in each particular case be a function of the angle RPR' or EPB, the angle between the line of less resistance and the direction AB, (perpendicular to PR) in which the

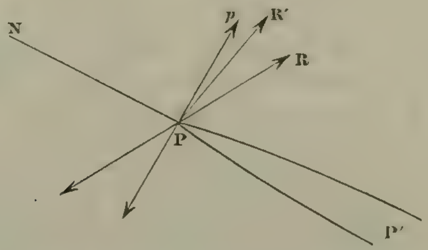


general tensions tend to form the fissure, the value of the function decreasing as RPR' or EPB increases from zero to a right angle, since the resultant tension is a maximum in the direction *PR*, and a minimum in that perpendicular to *PR*. (Art. 5). Consequently, the greater the ratio which the former of these resultants bears to the latter, the more rapidly will R_t' decrease while RPR' increases, and the smaller will be the angle *EPR*, within which the above condition will be satisfied, and the narrower therefore will the angular limits, within which a line of less resistance must be situated, in order that it may cause a fissure proceeding in any assigned direction to deviate from its course. A line through *P* perpendicular to *PR*, may be termed a *permanent line of cleavage*. If the ratios $\frac{f_1}{F}$, $\frac{f_2}{F}$, &c. be the same at every point of the lamina, all such lines will be straight lines (Art. 14) and parallel to each other. A fissure will always have a tendency to resume this direction, when made by any partial cause to deviate from it, and will resume it {taking our assumptions respecting the impressed tensions, (Art. 12)} almost immediately after the cessation of such cause. It will be well to examine this tendency in a few particular cases. It may be considered as measuring what may be termed the *permanence* of the fissure's general direction.

19. Let there be two systems of tensions, the directions of which are perpendicular to each other, and of which the intensities are *F* and *f* respectively, at any proposed point, when they become sufficient to form the fissure there. The greatest of these (*F*) will be the maximum, and *f* the minimum resultant tension, (Art. 6), and therefore the less *f* is, the greater will be the *permanence* of the permanent direction, perpendicular to that of *F*. If $f = F$, there will be no permanence in any particular direction. We have already seen (Art. 6), that there is, in fact, no greater tendency in this case to form a fissure in one direction than another.

20. Again, let us suppose in addition to the systems of tensions, of which the intensities are f_1, f_2, &c., and which have determinate directions, a force acting within the fissure perpendicularly to its direction, and with equal intensity on its opposite sides, exactly as a fluid would act when forcibly injected into a fissure formed in a solid mass.

Let $P'P$ be the fissure. It is manifest that this force (p) will produce a tension on the mass contiguous to the extremity of the fissure, in a direction Pp perpendicular to $P'P$, and must therefore tend to propagate the fissure along $P'P$ produced. Hence it will follow that such

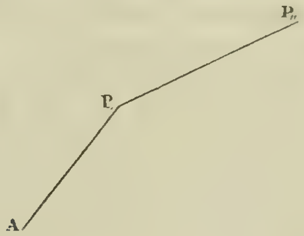


a force cannot affect the permanent direction of cleavage as determined by the tensions f_1, f_2, &c. alone. For, suppose PR the direction of the maximum resultant (R) of these tensions, it is manifest that the whole resultant tension (including that produced by p) immediately beyond the extremity P of the fissure, must be in a direction PR' between Pp and PR; consequently, the direction of propagation from P will deviate from $P'PN$, and approximate more nearly to perpendicularity with PR', and therefore also with PR. For the same reason, the direction of its further propagation will approximate still more nearly to a line perpendicular to PR, till it coincide with it. The permanent direction will therefore be the same as if the force p did not exist.

If however p be large compared with R, it is manifest that the angle pPR' will be very small, and that the tendency to resume the permanent direction, when the fissure has been obliged by any partial cause to deviate from it, will be much less than if p were relatively smaller.

21. If the lamina be subjected to no tension, and the fissure be produced entirely by p, the tendency will be to propagate the fissure in the direction in which it may originally be formed. Suppose $AP_{,}$ to be its original direction, but that from $P_{,}$ it follows a line $P_{,}P_{,,}$

of less resistance; then if we suppose the force p not to act effectively in propagating the fissure, except near its extremity*, its action will not extend beyond the portion $P_{\prime}P_{\prime\prime}$ of the fissure, and consequently



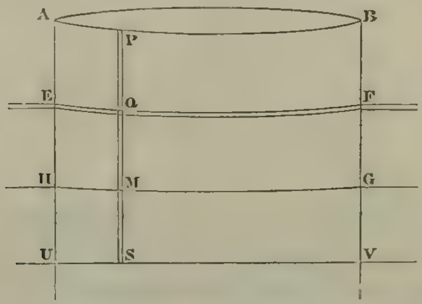
its tendency will be to propagate it in the direction of $P_{\prime}P_{\prime\prime}$ produced, after it has reached the termination of the line of less resistance. There will be no tendency, as in the former cases, to resume any particular direction.

§. *Modification of the Tensions in the vicinity of a Fissure.*

22. Let us now suppose a fissure to have been formed in the manner above described, and extending between two points in the lamina, where we may conceive its propagation to have been arrested either by an increased cohesive power, or by a diminution of intensity in the tensions. It is manifest that the state of tension in the vicinity of this fissure, will become entirely different from that which existed previously to its formation; and that the subsequent formation of any other fissure not very remote from the first, must therefore be influenced by the modification of the original tensions thus produced. It will now therefore be our object to examine this consequence of the existence of a fissure. For the greater simplicity, we may suppose it to be rectilinear. It will also suffice for our immediate purpose, to suppose the lamina subjected to two sets of tensions acting perpendicularly to each other, the direction of the fissure being perpendicular to that of the system of the greater intensity.

* This will be true in the actual case to which it is intended to apply this part of the investigation.

23. Let AB represent the fissure, AU, BV, the physical lines perpendicular to it, and passing close to its extremities, and for the greater distinctness, let us suppose the boundary of the lamina along UV to be parallel to the fissure. Let EF be a physical line originally parallel to the straight line AB. After the formation of the fissure,



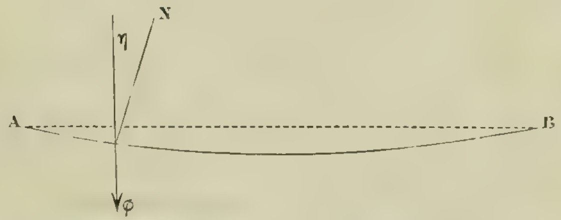
it will evidently assume a curved form resembling that of APB; but its curvature will be less than that of the latter line, since the curvature of all such lines must obviously be smaller the nearer they are situated to the fixed straight line UV, along which it becomes evanescent. If, however, the length of the fissure be considerable, the curvature of APB will be very small, and therefore the variation of curvature in successive physical lines such as EF, will be extremely slow, AU being very large*.

Also, let PQS be a physical line, parallel before the opening of the fissure, to AU. If the form of every such line as EQF were exactly the same, this line would still be accurately straight and parallel to AU, and consequently in the case we are supposing it will be approximately so. The tension of all such lines will evidently be much affected by the opening of the fissure. Since there is no force acting at P, the tension of SP in the direction of its length, will, at that

* If the boundary of the lamina be not parallel to the fissure, UV may be conceived to be a physical line in the lamina, *very distant* from and parallel to the line AB, previously to the formation of the fissure, since the position or rectilinearity of such a line will not be sensibly affected by the opening of the fissure, as appears from the text.

extremity, become evanescent; but since the line is extended, though not by a force at its extremity P, it must at every other point be subjected to a certain tension, and our object will be to compare this tension at any point Q with that acting in the direction EQF at the same point, with the view of ascertaining within what limits another fissure might be formed subsequently to the formation of AB, and parallel to it between the lines AU and BV. Such a fissure could not be formed through Q, by the tensions to which we are supposing the lamina subjected, if the tension in the direction EQF at that point should be greater than that in the direction PS, since the fissure must necessarily be formed perpendicular to the greater of these tensions (Art. 6).

24. In the first place, let us suppose a physical line of indefinitely small width to be attached at its extremities to the fixed points A, B, and then conceive parallel forces to act on each element of this line,



with the same or different intensities at different points, and in directions perpendicular to AB. The line will thus be made to assume a curvilinear form, and if the extensibility be small, as we shall suppose it to be, the curvature will be small, so that if $AQ=s$, and x be the original length of AQ, x and s may be considered as very approximately equal. Let τ denote the tension at Q, ρ the radius of curvature, and ϕ the intensity of the force at that point, ϕ being any function of x. Then the force on the element δs, will be $\phi . \delta x$, and the normal force produced by the tension τ, will $= \frac{\tau}{\rho}$ estimated by the effect it would produce, if it acted uniformly on a unit of the line, so that the normal force acting on the element δs, will $= \frac{\tau}{\rho} . \delta s$, or $\frac{\tau}{\rho}\ \delta x$ very approximately. Consequently, if the normal make an angle $\frac{\pi}{2} - \eta$ with AB, we shall have for the conditions of equilibrium of δs,

$$\frac{\tau}{\rho} . \delta s - \phi . \delta x \cos \eta = 0,$$

$$\delta \tau + \phi . \delta x \sin \eta = 0,$$

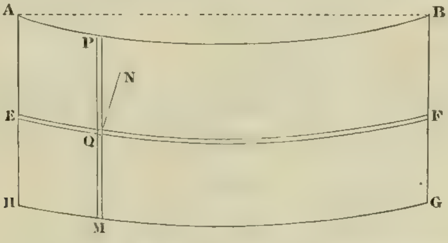
$$\text{or } \frac{\tau}{\rho} - \phi \cos \eta = 0.$$

$$\frac{d\tau}{dx} + \phi \sin \eta = 0,$$

Again, let us suppose another physical line exactly similar and equal to the former, with its extremities fixed to two other points in lines through A and B respectively, and perpendicular to AB, and so that the two lines shall be in contact, when not acted on by any force. When the force ϕ acts in exactly the same manner on both, they will assume exactly similar positions, and those elements of the two lines respectively which were in contact when the lines were straight, will remain so when they have assumed their curvilinear form, and will be in exactly the same relative positions with respect to each other, as if the lines had been united into one previously to their becoming curved. Whence it follows, that there can be no more action between these lines when united, as we have just supposed, than if they were perfectly independent, and therefore the tension of each must remain the same as if this independence existed. If we conceive any number of lines to be united in a similar manner, so as to form a lamina, the same conclusion will apply to each.

25. Let us now take then a rectangular lamina $ABGH$, which we may conceive to be formed in this manner, and which we will suppose to be brought into the position represented in the annexed figure, by the force ϕ acting perpendicularly to AB, and in the plane of the lamina. EF represents a physical line originally parallel to AB; and PM another originally straight and parallel to AH, and therefore, still evidently remaining so, though in a different position, in the curved form of the lamina. Let x be the original distance of PM from AH,

which will be approximately $= AP$, or EQ; then will δx be the original width of the element PM; and if AE, or $PQ = y$, δy will be the width of EQF. Also, if T denote the tension of the lamina at Q, (estimated as in Art. 2.), in the direction of a tangent to EQF at



that point, it is evident that $T.\delta y$ will equal the tension above denoted by τ. Therefore the force produced by this tension in the direction of the normal to EQF at Q, will $= \frac{T}{\rho}.\delta x.\delta y$, acting on the element common to the two physical lines PM and EQF at Q.

Now it is manifest, that the tension T, and $\frac{T}{\rho}$, will remain unaltered so long as the position of every element of the lamina remains so, whatever be the forces by which it is kept in that position. The action of ϕ will be the same at any point Q in PM as at P, since Q and P are similarly situated points in EQF and APB, and by hypothesis this force acts in the same manner upon each physical line, similar to APB. Consequently, the whole force on $PM = \phi.PM.\delta x$. Let us suppose this force instead of acting on each element of PM, to be applied entirely at its extremity M. If this be done to every such line as PM, and the lamina be sensibly inextensible in the direction of these lines, the position will remain undisturbed, and the normal force $\frac{T}{\rho}\delta x.\delta y$, at Q will not be altered. Hence, if T' denote the tension of the lamina at Q in the direction PM, and therefore $T'\delta x$ the tension of PM at that point, and η the angle which the normal there to EQF makes with PM, we shall have for the conditions of equilibrium of the element common to PM and EQF,

$$\frac{T}{\rho} . \delta x . \delta y - \delta (T' . \delta x) \cos \eta = 0,$$

$$\delta (T . \delta y) + \delta (T' . \delta x) \sin \eta = 0,$$

or since $\delta (T' . \delta x) = \frac{dT'}{dy} \delta y . \delta x$, and $\delta (T . \delta y) = \frac{dT}{dx} \delta x . \delta y$,

and η is by hypothesis very small,

$$\frac{T}{\rho} - \frac{dT'}{dy} = 0,$$

$$\frac{dT}{dx} + \frac{dT'}{dy} . \eta = 0,$$

neglecting terms involving η^2.

In the case we are considering, $\frac{T}{\rho}$ is a function of x alone, and therefore the first of the above equations gives

$$T' = \frac{T}{\rho} . y + C$$

$$= \frac{T}{\rho} y \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

since $T' = 0$, when $y = 0$. This is subject to the condition $T' . \delta x =$ force at $M = \phi . PM . \delta x$, or $T' = \phi . PM$.

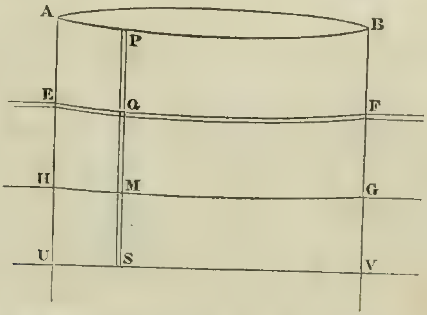
The second equation gives

$$T = \text{const. nearly} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (2).$$

26. If instead of supposing the lamina inextensible in the direction PM, we suppose it capable of small extension in that direction as well as in that parallel to AB, and still assume it to be acted on by forces applied at each point of HMG, so as to keep that extreme boundary in the same position as before, the physical line EF will assume a position differing in a small degree from its former one. Since the angle η will still be very small, we shall still have $T =$ const. nearly. The curvature at Q will no longer be the same as that at M, and ρ will therefore be a function of y, as well as of x. Consequently equation (1) of the

previous Article will no longer be accurately true; but since the variation of ρ as a function of y will be very slow, $\frac{T}{\rho}$ may still, for a first approximation, be considered constant from $y = 0$ to $y =$ a considerable value. Consequently both the equations (1) and (2) of Art. 25 may in our present case be considered as approximately true.

27. The case at which we have last arrived is exactly similar to that of Art. 23, which it is our object to investigate. For a portion $ABGH$ of the lamina, bounded by a line HMG, similar to EQF,



may be considered as being retained in its actual position, by the tensions acting parallel to AU and BV, at every point of HG, exactly in the same manner as that in which we have supposed the lamina represented in the figure in p. 31, to be kept in its position by forces acting at each point of HG in that figure. Also it has been shewn (Art. 23,) that the curvature of any such line as EQF, varies very slowly with its distance from AB. Consequently the variation of ρ, the radius of curvature at Q, is extremely small, considered as a function y (AE). This being the case, it is manifest likewise (assuming the original system of tensions parallel to AB, to have been uniform)* that T (the tension of EF) will vary very slowly with AE; and that therefore $\frac{T}{\rho}$ as a function of y, may approximately be considered constant. Consequently we shall have in this case

$$T' = \frac{T}{\rho} \cdot y, \text{ nearly.}$$

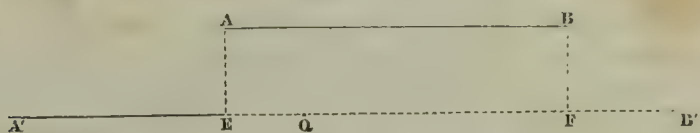
* This is not essential to the truth of our general conclusions.

If the fissure be of considerable length, ρ will be extremely large, and this equation will hold approximately for large values of y, and if y be less than ρ, T' will be less than T.

28. *Hence then it appears, that if the fissure be such that the curvature of its sides is extremely small, the greatest tension at any point within the lines* AU *and* BV, *and not extremely remote from* AB, *will be in a direction parallel to* AB; *and that consequently, if any fissure were propagated through* Q, *by the tension there, it must necessarily be in a direction perpendicular to that line.*

§. *On the Formation of Systems of Fissures.*

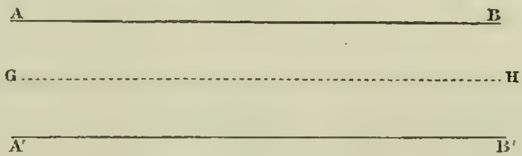
29. The result enunciated in the last Article is important, as shewing the impossibility of forming in succession parallel fissures not far distant from each other in a mass subjected to such tensions as we have supposed. Let us suppose, for instance, a fissure AB to have been formed in a lamina subjected to two systems of tensions, of which the directions are perpendicular to each other. The



propagation of the fissure beyond A and B, may be conceived to have been prevented by a greater cohesive power of the lamina there, or by a diminished intensity of the tensions perpendicular to AB. Let us also suppose another fissure to commence at A', subsequently to the formation of AB, and not remote from it, from the increased intensity of the tensions perpendicular to AB. Its direction AE will be parallel to AB, but it cannot be propagated in that direction from E to F; for the tension at Q along EF (as above stated) will be greater than that in a direction perpendicular to it, and therefore if a fissure be formed at all through that point, it must be perpendicular to EF. Nor would the formation of a fissure from E to F be rendered the more possible by the existence of this fissure through Q perpendicular to AB:

for it will be immediately seen, that this latter fissure together with *AB*, would destroy all tension at *Q*, and would of course prevent the possibility of the formation of any other fissure through that point*.

30. Hence it follows, that in any system of parallel fissures which are not remote from each other, *the fissures could not be formed in succession*. It will be easy however to understand how, in the case above assumed, of two systems of tension perpendicular to each other, any number of parallel fissures may be formed *simultaneously*. Let *AB*, *A'B'* be two such fissures, and let *GH* be parallel to and equidistant from them.

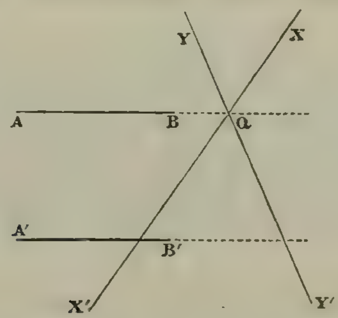


Now if the two fissures begin simultaneously at *A* and *A'*, (the line *AA'* being perpendicular to the direction of propagation,) and be propagated with equal velocity, it is obvious that no point in the physical line *GH* will have any motion communicated to it by the relaxation of the portion of the lamina between the fissures. Hence, if the line *GH* were to become absolutely fixed, the formation of the fissures would not be affected; but in this case the portions of the lamina on opposite sides of *GH* might be regarded as two absolutely distinct laminæ, having that line for a common fixed boundary. Consequently it is as easy to understand the simultaneous formation of any number of parallel fissures, under the circumstances supposed, as that of a single fissure.

31. Let us assume the two systems of tension not to be perpendicular to each other, and suppose *AB*, *A'B'*, two parallel fissures of which the directions are perpendicular to the maximum resultant tension. These fissures would not necessarily be continued parallel to each other.

* It must be recollected that the impossibility here spoken of assumes the tensions not to be produced by *impulsive forces* acting on the mass, the intensity of these tensions being always supposed to increase *continuously*, till sufficient to produce the fissure, and not to acquire that requisite intensity *instantaneously*, as previously stated in the Introduction, p. 11.

For let YY' be parallel to the direction of one system, XX' (meeting the fissure $A'B'$) to that of the other. The opening of $A'B'$ will relax

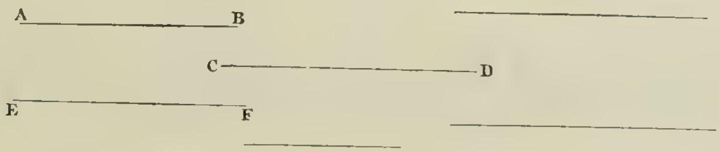


the tension along XX', while that along YY' will not be affected. Consequently the ratio of the tensions at Q will not be the same as originally, when AB, $A'B'$ began to be formed. The direction of propagation of the former will evidently deviate towards perpendicularity with YY', and that of the latter in the same manner more nearly to perpendicularity with XX'. They will not therefore in such case preserve their parallelism.

A finite time, however, will be necessary to produce the relaxation at Q, after the opening of $A'B'$, and therefore if the distance between the fissures be not too small, and the velocity of propagation very great, as we have shewn it may be (Art. 13) AB may be propagated through Q before the relaxation is produced there, and the fissures might under such circumstances preserve, at least approximately, their parallelism.

32. It is evident, however, that in whatever manner a system of parallel fissures may be produced, that, after their formation, the only tension of the mass between them must be in a direction parallel to them. Consequently, *should any other system be subsequently formed, it must necessarily be in a direction perpendicular to that of the first system. No two systems of parallel fissures, not perpendicular to each other, could be formed by causes similar to those of which we have been investigating the effects.* It will appear also, as in Art. 30, that this second system must be of simultaneous origin.

33. From our assumptions respecting the variable cohesive power of the mass, it is manifest that different fissures might commence simultaneously at different points, and be propagated in opposite directions.



Thus, suppose the fissure *CD* to commence at *D*, when *AB* and *EF* commence at *A* and *E* respectively. When the first of these arrives at *C*, as the two others arrive respectively at *B* and *F*, the further propagation of each of them may be prevented by the relaxation of the mass. Consequently a system of fissures might thus be formed similar to that represented in the above figure.

§. *Application of the previous Propositions to a Mass of three dimensions.*

34. These investigations have been applied immediately to the case of a thin lamina, to avoid the complexity which would necessarily have been introduced in their immediate application to a mass of three dimensions. The extension of the preceding propositions, however, to this latter case is sufficiently obvious to require little more than an enunciation of the results, which may also serve as a summary of the most important of those at which we have arrived in this section.

A slight inspection of what has been advanced in Art. 15, will shew that the existence of a line of less resistance in a thin lamina, will have no effect on the propagation of a fissure in a direction perpendicular to it; and similarly, if we suppose any mass acted on by horizontal tensions, it is manifest that a horizontal plane of less resistance will have no effect on the verticality or horizontal direction of the vertical fissures resulting from such tensions. Consequently, the tensions being horizontal, the cohesive power of the mass may be supposed to vary continuously or discontinuously along any vertical line, and, as explained in Art. 8, it may vary according to any continuous law in any horizontal lamina of the mass. The same assumptions are made respecting the continuous but rapid increase of the tensions, as in Art. 12.

I. If this mass be acted on by a single system of horizontal parallel tensions, a fissure beginning at any point will be propagated in a vertical plane perpendicular to the direction of the system. (Art. 2).

II. If the mass be subjected to any number of systems of parallel tensions, the fissure will be propagated through any point in a direction perpendicular to the maximum resultant tension at that point, at the instant the fissure reaches it, (Art. 12.) the horizontal direction being determined by equation (2), (Art. 7). If the ratios of the tensions at each point at the instant of propagation through it be the same, the fissure will, in general, be formed in one vertical plane. (Art. 14.)

III. If there be only two systems of horizontal tensions, and these be perpendicular to each other, the fissure will lie in one vertical plane perpendicular to the direction of the system of the greatest intensity, whatever be the ratio of the tensions at each point in the two systems, provided the tension at each point always remain the greatest in the same system. (Arts. 6, 14.)

IV. Each fissure under the conditions assumed, will be propagated with extreme velocity. (Art. 13.)

V. The tendency of the tensions to propagate the fissure in one particular direction rather than in any other, or the *permanence* of the permanent direction of cleavage, depends on the rapidity with which the magnitude of the resultant tension, estimated in a particular direction, decreases as that direction deviates from that of the maximum resultant tension; or generally, on the ratio which the maximum bears to the minimum resultant tension, which is perpendicular to it. (Art. 18.)

VI. If in addition to a system of horizontal tensions, there be also a force acting on the opposite sides of the fissure, perpendicularly to its direction, and tending to increase its width*, the *permanence* of direction in the progressive formation of the fissure will be diminished, but the permanent direction will remain the same as if there were no other force than the system of horizontal tensions, *i. e.* if the direction in which the propagation of the fissure is taking place be disturbed by any partial cause, it will still constantly tend again to perpendicularity with the directions of the system of tensions; but this tendency will be less than if the force always acting perpendicularly to the fissure did not exist. (Art. 20.) Consequently, deviations from the permanent direction of cleavage will, in the case we have supposed, be greater than if the sides of the fissure were not subjected to the action of this last-mentioned force.

VII. If there be no tension acting on the mass, and a fissure be formed solely by this force, acting perpendicularly to its sides, the fissure will be propagated in the plane in which it begins to be formed, if the cohesive power of the mass vary according to any continuous law. There will be, however, but little permanence in its direction, so that if it be turned from its original direction by planes of less resistance, there will be little tendency to resume that direction, and the fissure may thus assume any form of irregular curvature. (Art. 20.)

VIII. If a fissure commence at, or in the course of its progressive formation meet, a partial plane of less resistance at an acute angle, it will, under certain conditions, be propagated along it; but when from any cause this ceases to be the case, the fissure will almost immediately resume a direction parallel to its original one, supposing it produced by tensions, which, independently of the existence of planes of less resistance, would produce rectilinear fissures. (Arts. 17, 18.)

IX. If the mass be subjected to two systems of parallel tensions, of which the directions are perpendicular to each other, two systems of

* This will be the case if the fissure be filled with any kind of fluid subjected to a great pressure from some external cause.

parallel fissures may be produced, of which the directions will be perpendicular to each other. No two systems of parallel fissures could be thus formed, of which the directions should not be perpendicular to each other. (Art. 32.)

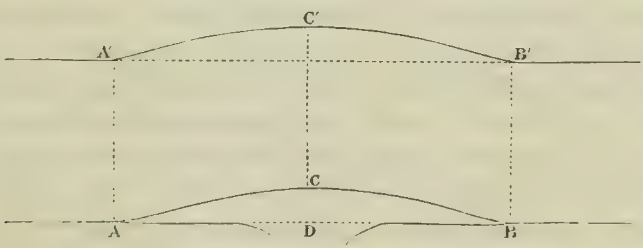
X. If the fissures in either of these systems be near to each other, they could not be formed by such tensions as we have been considering, *in succession*. They must be formed *simultaneously* in each system. One system, however, might be formed at any time subsequently to the other. (Art. 30, 32.)

SECTION II.

35. Let us now proceed to apply the results obtained in the last section to the actual case of a portion of the earth's crust, under the hypotheses respecting the action of the elevatory forces and the cohesive power of the mass, which have been already stated, (Introd. p. 11, and Art. 12.) And, first, let us suppose, for the greater simplicity, the surface of the mass acted on to be of indefinite length, and bounded laterally by two parallel lines. If we first suppose the elevatory force to be uniform, it is manifest that the extension, and therefore the tension, will be entirely in a direction perpendicular to the length; so that its whole tendency will be to produce *longitudinal* fissures, or such as are parallel to the axis of elevation.

§. *Formation of Longitudinal Fissures—Their Position and Width—Complete and Incomplete Fissures.*

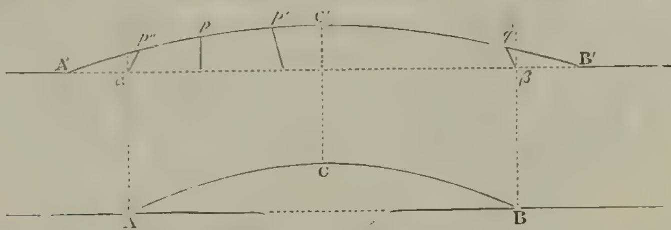
36. Let the annexed diagram represent a transverse section of the elevated mass, and let us suppose it symmetrical with respect to the line CC', and also that the mass below the horizontal line AB remains



perfectly undisturbed. The cavity $ACBD$, containing the fluid through the medium of which the elevatory force is supposed to act on the lower surface of the elevated mass, (see p. 10), may either be supposed to have existed previously to the action of the elevatory forces, or to have been partly produced by them.

If we suppose the mass not to become compressed, and the disturbance not to extend beyond the vertical lines AA', BB', it is manifest that the lengths of the lines ACB, $A'C'B'$ will be equal; and since their original lengths were so, their *extension* will be the same.

It is evident, however, that the force required to elevate the mass $ABB'A'$ will be much greater than that just necessary to overcome its weight, on account of the forces called into action at the extremities of the elevated mass, and that some degree of compression of the mass will consequently exist, which will render the vertical line



CC' shorter than its original length. It is also evident that the disturbance of the upper part of the mass will extend laterally beyond the verticals through A and B, as above represented.

The compression of CC' will clearly make the curvature of $A'C'B'$ less than that of ACB, and will consequently render its *extension* less than it would otherwise be. The greater extent of lateral disturbance in the upper portion will also produce the same effect. For let us suppose the portion $A'p$ of the upper curve exactly similar, and equal in length to pC', then is it easily seen (assuming the extension of $A'B'$ to be uniform throughout) that the line joining the physical point p, and its undisturbed position will be vertical, while similar lines for $p_{,}$, $p_{,,}$ and $q_{,,}$ will be inclined, as in the figure. Hence it immediately appears that the difference between the lengths $p_{,,}q_{,,}$ and $\alpha\beta$ will be less in this case than if $p_{,,}$ and $q_{,,}$ were in the verticals through A and B respectively. We may therefore infer that the same will hold generally, since the condition of the similarity of $A'p$ and pC' will be approximately satisfied when the tangents at A' and C' are parallel, and the curvature small, as we may here assume it to be.

Hence, then, we may conclude that the *extension* of the physical line ACB, under the circumstances supposed, will be at least equal, and generally greater, than that of any similar line in the higher portions of the uplifted mass. It seems also probable, that in cases occurring in nature the *extensibility* will be less in the lower portion of the elevated mass (at least to a certain depth) than in that which constitutes its upper surface.

Now the tendency of any horizontal portion of the mass to separate, so as to form a vertical fissure, will vary directly as the *extension*, and inversely as the *extensibility*. We may therefore safely conclude, that when a mass has been elevated as above supposed, the greatest tendency to rupture will not be in its upper portion; and consequently, that if any fissure be produced, whether by a gradual increase of the horizontal tension, or by any more sudden impulsive action on the mass in its state of tension, *such fissure will not commence at the surface, but at some lower part of the mass.*

37. It appears, from what has been proved in the previous Section, that if we suppose the fissure produced solely by the tensions to which the mass is subjected, the plane in which it will lie will be perpendicular to the direction of the single system of tensions which, in this case, act upon the mass, and will consequently decline as much from a vertical plane as that direction deviates from horizontality. According to the hypothesis we have made, however, of the force acting on the elevated mass through the medium of an elastic vapour, this vapour will necessarily ascend into the fissure, and exert a fluid pressure on its sides, in a direction perpendicular to them, and of which the intensity may bear a considerable ratio to that of the tension. To form a rough estimate of this intensity, let r be the radius of the circle which shall most nearly coincide with the curve ACB (Fig. p. 41), p the pressure of the fluid on a unit of surface, T the intensity of the tension (supposed uniform) of the elevated mass estimated as in the previous section, and b the thickness of the mass. Then the whole tension exerted on a portion of the mass included between two vertical planes perpendicular to the axis of elevation, at a distance unity from each other, will $= bT$, and we shall therefore have

$$p = \frac{b}{r} \cdot T.$$

The value of r, according to the same rough approximation, will be nearly $= \frac{AD^2}{2CD}$, which will always be very large; but as b also is probably large, p may bear a very considerable ratio to T.

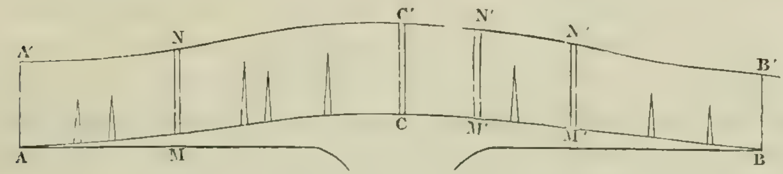
Here then we have the case which has been anticipated in the investigation of Art. 20; and it appears that the action of this force p will greatly tend to increase the effect of any local causes in producing partial deviations in the plane of the fissure from a vertical plane, but that it will not alter generally its position when considered with reference to its whole extent.

38. Again, with respect to the comparative width of the fissure at different depths, it is manifest, taking the case of the Fig. p. 41, where the extension of each lamina is the same, that if the mass, when relieved from its tension by the rupture, return to its original horizontal length, the width of the fissure will be the same throughout its whole depth; and in the case of the Fig. p. 42, the same conclusion might be considered as very approximately true under the same hypothesis. If, however, the different laminæ, which I have supposed to have different powers of cohesion, have also different degrees of elasticity, this difference may materially affect any approximation to this uniformity of width. It seems probable, however, that the *mean* width (at least within certain limits) will rather increase than decrease with the depth.

39. Any number of these fissures might thus be formed simultaneously, (Art. 30.); and this simultaneous formation would be very much facilitated by the action of the pressure p in the interior of the fissure. If it be supposed, however, that partial causes prevent the commencement of the formation of each fissure at the same instant, exactly equal forces will not be exerted in the production of each, and consequently they will not be propagated with the same velocity. Some therefore will reach the exterior surface sooner than others; and when a certain number have thus been formed from the lower to the upper

surface of the mass, the tension of it may become so far relaxed that the further formation of the others shall cease. We may therefore suppose it highly probable that the number of fissures formed in the inferior parts of the elevated mass, will be considerably greater than the number which reach the surface.

40. The phenomena, then, to which our investigation at present extends, may be represented as in the annexed diagram, a few of the fissures being *complete* ones, or running up to the external surface of



the mass, and the others being *incomplete* ones, or rising to different heights, without reaching the surface.

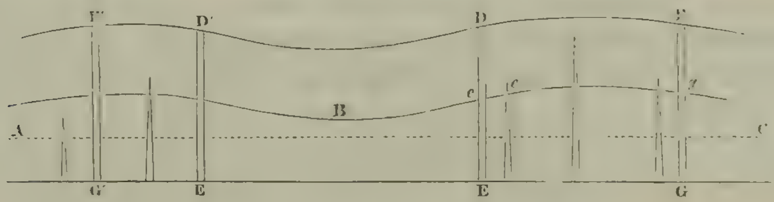
41. If we recur to what has been previously advanced respecting the depths of veins, (Introd. II. ρ.), we shall see the importance of the fact established above, that the formation of fissures produced by the causes we have supposed must necessarily begin in some lower portion, and not at the upper surface of the mass, where it might perhaps at first sight be supposed more probable that they would begin.

42. We may also see, in what has been above stated, one cause of the inclination or *hade* of a fissure. (See Introd. II. κ.)

§. *Formation of Transverse Fissures—Fissures of a Conical Elevation—Modification in the Position of Longitudinal Fissures.*

43. In the case we have been considering, the whole tendency of the elevatory force, acting with perfect uniformity, will be, as we have before remarked, to produce longitudinal fissures; and a vertical

section of the elevated mass parallel to the general axis of elevation, will be bounded above and below by straight horizontal lines. If, however, we now conceive this force to act with greater intensity at particular points along the general line of elevation, the section just mentioned will present such an appearance as represented in the annexed diagram,



in which the line *ABC*, previously to the elevation, was horizontal. In such case we shall have longitudinal extension, (equal to the difference between the line *ABC* and the dotted line *AC*), which, if sufficiently great, will necessarily produce transverse fissures, similar to the longitudinal ones already described, and such as represented in the above section.

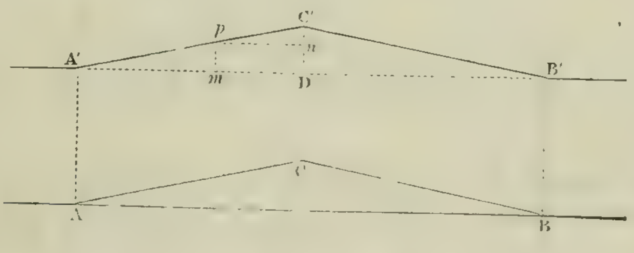
44. We may represent to ourselves this more intense action at particular points, by conceiving an additional force superimposed on a uniform force producing the general elevation independently of the irregularities resulting from this partial action. It is manifest therefore that the tension perpendicular to the line of elevation will result from the sum of these forces, while the longitudinal tension will be produced by the superimposed force alone. The former will therefore, when the partial force is not great, be much the greatest; and we may consequently conclude, that the longitudinal fissures may in such case be formed first, during the continuous though rapid increase of intensity in the elevatory forces, according to the assumption we have made respecting them, (Art. 12.); and when this system is once formed (the fissures in it not being remote from each other), the transverse system must necessarily be approximately perpendicular to it, whether it be formed at the next instant, or at any succeeding epoch, and notwithstanding any irregularity in the forces producing it, provided they do not act impulsively. In this

manner it is easy to understand the formation of a transverse system of fissures approximating to the law of parallelism, though resulting from forces which, acting partially, and under other circumstances, would produce the most irregular phenomena.

45. If however this more intense action at particular points be sufficiently great, and exactly simultaneous with that of the general elevatory force, it may modify materially the position of the longitudinal fissures. To determine the nature of this modification, we must consider the directions of the tensions which would be produced by an elevatory force, acting solely in the vicinity of any proposed point of a mass; because such tensions superimposed upon those produced by a force acting uniformly along the whole range, will be very nearly equivalent to the tensions produced by the simultaneous action of two forces such as those just mentioned.

46. For the greater simplicity, we may take a cone as the approximate type of the partial elevation we have to consider.

Let $A'C'B'$ represent this cone, $C'D$ its axis. Then if we assume the physical line $A'pC'$ to be equally extended, and AD to be its original length, we have



The original length of $A'p : A'p :: A'D : A'C'$,

and therefore,

$$\text{The original length of } A'p = A'p \,.\, \frac{A'D}{A'C'}$$

$$= A'm,$$

mp being parallel to DC'. Consequently, the distance of the physical point p from the axis of the cone, will not be altered by the elevation; and since the same holds for every physical point in the circumference of the horizontal circle whose radius is pn, there can be no tension at any point of the physical line forming that circumference, in the direction of its tangent at that point. This is consistent with our assumption of the equable extension of every part of the line $A'C'$, which will therefore be true*. Similarly, if we conceive the whole mass $AA'B'B$ to be formed by the superposition of similar conical shells, it is easily seen that the same result will hold for every horizontal circle concentric about the axis of the cone. Hence it follows, that if any vertical plane be drawn through the axis of the cone, there will be no tension at any point of the mass in this plane in a direction perpendicular to it. The tension will be entirely in the plane, and parallel to the slant side of the cone.

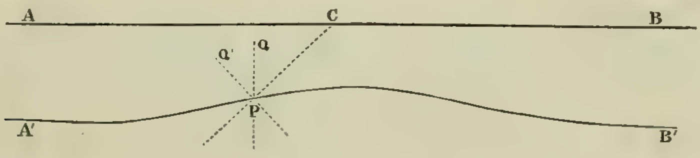
If, then, a fissure which should pass through any proposed point P, were formed according to the greatest tendency of the tensions of the unbroken mass to form it, it would manifestly coincide with the surface of an inverted cone, whose base would be the circle of which the radius is pn, and whose axis would coincide with that of the elevated cone. If p should coincide with C', an orifice would be formed along the axis $C'C$; and if we consider that the force will act, according to our hypothesis, with the greatest intensity at C, it seems highly probable that the first dislocation will usually take place along, or very near to that axis. For the greater distinctness, suppose this to be the case.

47. The instant this has occurred, the conditions of the problem will be entirely altered. The force at C' maintaining every such line as $A'C'$ and $B'C'$ in its state of tension, being now destroyed, the

* Suppose a tension T to exist along the physical line forming the circumference of the circle whose radius is pn. This would produce a force $\frac{T}{pn}$ acting at p in the direction pn, the resolved part of which in the direction pC' would increase the tension of $A'p$. In such case the extension of $A'C'$ would be greatest at A', and our assumption of the uniform extension of that line would not be true.

extremities of those lines at C' will separate from each other by the contraction of $A'C'$ and $B'C'$; and the same will be true for every similar pair of lines. An extension of the orifice at C' will thus be produced, and consequently a tension of the mass contiguous to it in the direction of a tangent to a horizontal section of it, while the tension in the direction of such lines as $C'A'$ will be entirely destroyed near to C', and much lessened at lower points. The whole tension therefore in the upper part of the mass, will be in the directions of the tangents of horizontal circles concentric about the axis; and the tendency to form a fissure there, will be entirely in a vertical plane passing through the axis of the cone. It is easily seen also that the tension at the vertex will be greater than in any other part. Consequently, if fissures be formed under these circumstances, they will commence at the vertex, and be in positions such as that just mentioned.

48. Let us now suppose the elevatory force to act with additional intensity beneath the point C of the annexed diagram, (which represents a horizontal section,) so as to superimpose on the general elevation



a conical one, having its apex at C. In addition to the tension (F) acting at any point P within the bounds of the cone, and in the direction perpendicular to the general axis of elevation, we shall also have another tension (f) acting at P, in the direction PQ' perpendicular to CP, (taking the case of Art. 47.) and the tendency of these tensions will be to form a fissure deviating from perpendicularity with PQ, in a degree depending on the relative intensities of f and F. Consequently, a fissure $A'PB'$ will deviate from parallelism with the line of general elevation, approximating towards C in the manner above represented.

49. If the partial elevation instead of approximating to the conical form, be more nearly spherical, without any such rupture at C, as

above supposed, the principal tension due to it will be in the direction *CP*, instead of being perpendicular to that line, in which case the deviation in the direction of the fissure will be the contrary of that above represented.

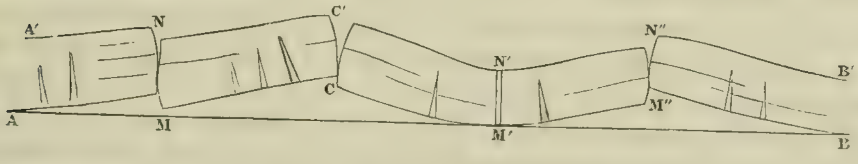
§. *Formation of Longitudinal and Transverse Faults—Anticlinal Lines—Longitudinal Valleys—Transverse Valleys—Comparative Effects of subsequent Movements on the Width of Longitudinal and Transverse Fissures—Throw of a Vein.*

It appears then, that in the case we have considered, and under the conditions assumed, the elevating forces will produce two systems of fissures with a general approximation (subject to certain modifications) to rectilinearity, and perpendicular to each other. Let us further consider what positions the different portions of the mass may assume subsequently to the formation of these fissures.

50. The diagram in page 45, represents a transverse section of the elevated range, immediately after the contemporaneous formation of the complete fissures *MN*, *CC′*, &c. It does not appear probable that the effects of the continued action of the elevatory force will afterwards follow any general law; for the subsequent movements of the different portions of the mass, now rendered in some degree independent of each other by the fissures which separate them, must be constantly influenced by that irregularity in the action of the elevatory force, and those accidental and local causes of which it is now impossible to form any estimate. If the elevatory force be produced by an expansive vapour, or act through the medium of any fluid, as we have supposed it to do, its intensity must decrease after a certain time, thus causing subsidencies in the elevated mass, the degree of which in different portions will probably be in general determined by accidental circumstances. One consequence, however, of these irregular causes, would appear to be necessarily a very general one, viz. a difference of elevation in the adjoining parts of different portions of the mass separated by the fissures, whether longitudinal or trans-

verse, thus producing systems of *longitudinal and transverse faults*, such as described in the Introduction, (I. α, β.)

51. Sections of longitudinal faults which may be thus produced, are shewn in the annexed diagram, which represents one of the forms which, it is manifest, the uplifted mass represented in page 45, may ultimately assume from the causes above mentioned (Art. 50). In such case we shall have an *anticlinal line* through N'', running parallel to the general one through C' in the central part of the elevation; and a synclinal line through N' parallel to the two former ones. The existence also of these longitudinal fissures and consequent irregularities of surface, will obviously tend to direct the action of superficial



agents of denudation along longitudinal courses, and thus to facilitate the formation of *longitudinal valleys*, particularly in the case in which the relative elevation of two adjoining portions of the mass is such as represented at N. If this kind of elevation be continued for a considerable distance longitudinally, a distinct longitudinal valley must be the necessary consequence.

52. It not unfrequently happens that we observe in anticlinal lines a degree of deviation from approximate rectilinearity, which might at first sight appear inconsistent with the mode of formation which this theory would assign to them, assuming that great predominance of general over partial and accidental causes, throughout an extensive area, with which very irregular deviations in the direction of a fissure would not be accordant. It seems, however, highly probable, that this character of anticlinal lines would not, in fact, be the unfrequent consequence of the general causes we are considering. In the first place, we may observe that longitudinal fissures are not necessarily continuous for any great distance, as we have explained in Art. 33, and

therefore an anticlinal line formed along one fissure, may easily be conceived to be continued along another, not exactly in the same line. If we conceive several transferences of this kind to take place from one fissure to another, we shall have a discontinuous anticlinal line, each portion of which will be as rectilinear as the fissure with which it coincides; but if the physical structure of the mass should be placed under that disguise so frequently spread over it by superficial agencies, the geologist, instead of detecting this discontinuous line, consisting of a number of straight ones having parallel directions, will probably only recognize a somewhat ill defined anticlinal line of irregular curvature, and apparently destitute, in a considerable degree, of those characters of rectilinearity and parallelism with the general axis of elevation which this theory might appear to assign to such lines. It may also be observed, that since on the opposite sides of a transverse fissure the movements of the adjoining masses will be in some degree independent of each other, it is easy to conceive that this cause also may sometimes facilitate the transference of an anticlinal line from one longitudinal fissure to another, and thus destroy its apparent rectilinearity.

Similar observations will equally apply to the directions of longitudinal valleys, as far as their formation may be referrible to the causes above mentioned.

53. It has been stated how much the ultimate position of the dislocated mass may generally depend on accidental causes. In particular cases however, and especially with respect to those portions of the mass adjoining the lateral boundaries of the general elevation, there appears reason to expect that the phenomena would, according to our theory, frequently follow a certain law. Suppose the diagram, page 51, to represent the portion of the mass bounded by two parallel transverse fissures, produced as described in Art. 43, by a greater intensity of the elevatory force acting at the point *C*. For the greater simplicity, we may also suppose this force to act symmetrically with respect to the two transverse bounding fissures. Then, after the general elevation has proceeded as far as represented in the diagram, page 45, and the fissures have been formed,

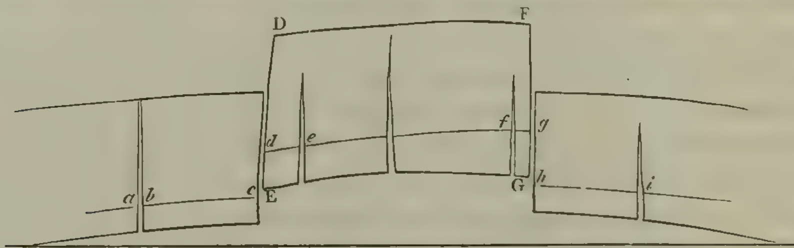
if the elevatory force act at C with a considerably greater intensity than at M, it will communicate to the mass $CC'NM$, together with its general upward motion, a rotatory one, of which the axis will be horizontal and perpendicular to the transverse boundaries. This motion will tend to depress the extremity M, particularly if CM be of sufficient length. No such cause will exist in the adjoining mass $AA'NM$ to lower its extremity N; and moreover it may be remarked, that this mass once elevated is more likely to be supported by the debris produced by a convulsive movement such as we are supposing, and therefore its extremity N will be less likely to subside than the adjoining extremity of the contiguous mass. From these causes it would seem highly probable that these two portions of the general mass should assume the relative positions above represented. A partial elevation and escarpment may thus be produced in accordance with the general fact stated in the Introduction, (IV. β. p. 7.)

We may also observe, that the fault thus formed at N must very generally possess the character mentioned in the Introduction, (I. γ. p. 2.)

54. In the diagram, page 46, $DEFG$ may represent a section parallel to the general axis of elevation of the portion of the mass which we have supposed, in the preceding article, to be subsequently elevated in a greater degree than the portions contiguous to it on either side, as represented in the diagram of the following page. If we conceive the portion also of which the section is $F'D'E'G'$ (p. 46.) to be raised in the same manner, it is obvious that a *transverse valley* will thus be formed between these two partial elevations, such as described in the Introduction. (V. p. 8.)

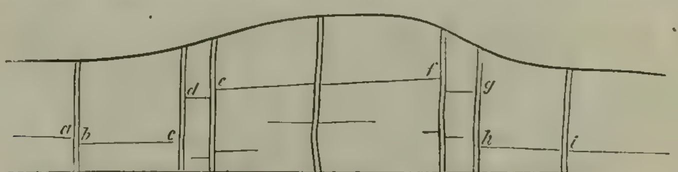
55. A section of one of our partial elevations above mentioned, by a vertical plane parallel to the axis of the general elevation and the longitudinal fissures, will now present an appearance (taking the phenomena as far as we have yet investigated them) similar to that of the annexed diagram, in which $DEFG$ represents the portion of the mass defined by the same letters in the diagram of page 46. The broken

line *cdgh*, supposed to be originally horizontal, indicates the faults along *DE* and *FG*. We may easily conceive, however, a further modification of the phenomena from any irregularity in the action of the elevating force, or in the resistance opposed to it, in adjoining portions of the mass on opposite sides of any one of the incomplete transverse



fissures, similar to that which we have assumed to produce the faults *DE*, *FG*, at complete fissures; for if this inequality of action on two such portions of the mass be sufficient, it may evidently convert the incomplete fissure into a complete one, provided the fissure extend near enough to the surface to weaken the mass so much as to render it unable to counteract the tendency of this unequal action, to give a greater elevation to the portion on one side of the fissure than to that on the other. In such case a fault would almost necessarily be produced, but probably smaller than that which would be produced by the same cause at a complete fissure. In either case, however, the fault may of course be of any magnitude, depending on the intensity of the action producing it.

If then we conceive the phenomena represented in the preceding diagram to be thus modified, and the superficial elevations to have been partially removed by denudation, the actual phenomena may be represented as in the annexed section. The broken line *abcdefghi* is as



before, supposed to have been originally continuous and horizontal, or if the mass be stratified, to represent a line of stratification. *cd* and *gh* are *faults;* the differences of elevation *ab*, *de*, *fg*, are supposed too small to be so designated. Small relative elevations of this kind constitute what is frequently termed the *throw* of the vein. (Introd. II. ι. p. 4.)

56. It is important to observe the different effects which will be produced on the form of the longitudinal and transverse fissures by the movements above described. It has been shewn (Art. 38.) that a fissure immediately after its formation, and before any subsequent movement of the mass has taken place, must offer a certain approximation to uniformity of width; but an inspection of the diagram in page 51, will make it appear very evident, that this subsequent movement must in general destroy, in great measure, this character in the longitudinal fissures, since it must almost necessarily close them in some parts and open them considerably in others; while a movement similar to that described in Art. 53, and represented in the figure, page 54, will not necessarily produce any derangement in this respect in a perfectly uniform fissure, because the motion of one wall of the fissure is parallel, or nearly so, to the other. We should expect therefore, as a necessary consequence of this view of the subject, a much nearer approximation to uniformity of width in the transverse, than in the longitudinal fissures. This is strikingly in accordance with what has been stated in the Introduction (I. θ. p. 4.) a rule to which, I believe, there are comparatively few exceptions.

§. *Proper signification of the term "System of Fissures"—Simultaneous Formation of Systems of Fissures.*

57. I have hitherto spoken of systems of parallel fissures, as if the parallelism of the fissures constituted the essential characteristic of each system; and in the case we have been considering of an elevation of indefinite length, and of which the axis is rectilinear, this parallelism will characterize the two systems at right angles to each other, and which I have designated as longitudinal and transverse. If, however, the axis of the general elevation of indefinite length be not in a right line, the fissures of the longitudinal system (assuming them to be produced in

the manner I have indicated,) will be still parallel to this axis (in the sense in which one curve line may be said to be parallel to another) and every fissure of the transverse system will be perpendicular to each fissure of the former system at the points of their intersections, and consequently the fissures in this transverse system will not be parallel. Again, if we suppose the superficies of our elevated mass to be of finite length, and to be bounded for instance by a line approximating to the form of an elongated ellipse, the directions of the fissures in the transverse system, as we approach towards either extremity of the elevated range, will gradually change from perpendicularity with the major axis (the axis of elevation) till they become parallel to it, at the extremities of the ellipse, always preserving their approximate coincidence with the directions of the lines of greatest inclination of the general surface of the mass. The fissures of the other system will be approximately perpendicular to these lines. In this case then, the two systems will be no longer characterized by any constant relations which their directions bear to that of the axis of elevation, and therefore the terms *longitudinal* and *transverse* will cease to designate them so correctly as in other cases; and still more is this the case, where the elevation approximates to the conical form, in which all the fissures analogous to those we have termed transverse, diverge from the vertex of the cone. I have not, however, thought it necessary to supersede these terms by others, since they are very generally applicable with great propriety. It is highly important, however, as respects the application of this theory of elevation, to distinguish these two systems carefully from each other. It has been pointed out (Art. 56) how much the *transverse* fissures exceed the others in regularity of formation, and it seems not improbable, that this fact may be in some way connected with that of their containing mineral veins, so much more continuous than those found in the more irregular fissures of the other system, (Introd. II. δ. p. 3.) The most general rule will probably be, whatever be the form of the elevated mass, that the direction of a *transverse* fissure approximates to that of the *dip* of the strata, (supposing the mass stratified) the direction of a *longitudinal* one, consequently, approximating to that of the *strike* of the stratified beds. It should be observed, however, that the present form of the elevated mass may in some cases differ materially from that which was originally given to it, by the movement to which the formation of the principal fissures must be referred. The rule would probably be more applicable immediately after this first elevation, than after the modifications in the position of the mass, which may possibly have been produced by subsequent ones.

It will be observed that the law of parallelism, which characterizes alike the phenomena of anticlinal lines, faults, mineral veins, &c., is to be traced, according to the view we are taking of the subject, to the same origin; viz. the formation of the two great systems of fissures, which have been shewn to be, under certain simple conditions, the necessary effects of the elevatory force to which they have been referred. The term *parallelism*, therefore, when used as characterizing systems of any of the above phenomena, must be equally regarded as subject in its interpretation to the exceptions or modifications pointed out in the last paragraph. In fact, if the extent of the mass be comparatively small, and its boundary irregular, this property would cease altogether to characterize the phenomena. If the elevated mass be of great superficial extent, partial irregularities in its boundary will have no appreciable effect on the directions of the fissures; and though two remote fissures of the same system might, in such case, (as appears from the preceding paragraph), be inclined at any angle to each other, any two adjoining fissures would in general be approximately parallel. The law of parallelism, however, in the strict acceptation of the term, could only hold through the whole extent of the elevated mass, in the case above considered of a rectilinear elevation of indefinite length. In other cases, the law must be subject to the modifications indicated above.

58. If the approximate accuracy of our assumptions be allowed, as applied to the crust of the globe, it appears, from our investigations, that an elevated range characterized by continuous systems of longitudinal and transverse fissures, referrible to the causes to which we have been assigning such phenomena, could not be produced by successive elevations of different points, by the partial action of an elevatory force. It has been shewn (Art. 46) that in such elevations

fissures would necessarily diverge in all directions from the central points, so that parallel systems such as above mentioned could not possibly be thus produced. It has moreover been shewn, (Art. 30.) that every system of parallel fissures in which no two consecutive fissures are remote from each other, must necessarily have had one simultaneous origin. Subsequent efforts of the subterranean forces may enlarge these fissures, and propagate some of them to the surface, converting incomplete into complete fissures, but it would seem essential, according to our view of the subject, that their *positions* in the lower portion of the mass, where their formation will commence, (Art. 36.) should be determined contemporaneously.

§. *Formation of Riders—Explanation of the Phenomena at the Intersections of Mineral Veins.*

59. If two systems of fissures were formed by forces acting in the manner we have supposed on a mass without vertical or nearly vertical planes of less resistance, these systems would present to us cases of *intersection* only of nearly vertical fissures with horizontal beds, or with other vertical fissures at right angles to the intersecting ones. It is manifest, however, that the existence of planes of less resistance, combined with an irregularity of intensity in the elevatory force such as we have assumed, may produce some fissures irregular both in direction and inclination to the horizon, though the general phenomena may still present that distinct approximation to the laws we have indicated, which would be the necessary consequence of the great predominance of general over local causes. It is at the intersections of the two perpendicular systems of veins (metalliferous veins and cross courses) that the most important of the phenomena we are about to consider are found, while others occur at the intersections of veins of more irregular formation.

60. Before we proceed to examine these phenomena more particularly, we may notice one probable consequence of this occasional irregularity in the formation of veins, viz., the production of what are usually termed *riders*. If a fissure be propagated through a point in which

two planes of less resistance meet, it is very possible that it may be propagated simultaneously along these planes. These diverging branches may continue separate, and present themselves at the surface as two distinct fissures, or they may meet again, and thus including a portion of the mass in which they are formed, produce the phenomenon above mentioned. If the insulation be perfect, the mass, if not too large, will of course fall, and may descend to any unknown depth; and possibly this may be one cause of the partial irregularities in the width of the fissures of mineral veins. If the insulation be imperfect, or the width of the mass be greater than that of the fissure immediately beneath it, it will be supported in its original position, or it may under other circumstances lodge at a certain depth below it. In either case if such a mass come within the sphere of the miner's observation, he terms it a *rider*, (Introd. II. μ).

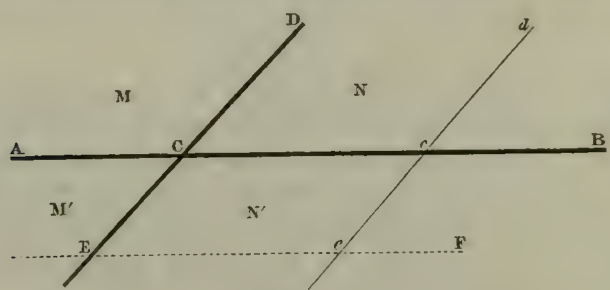
If the rider be originally supported as above suggested, till a sufficient quantity of matter shall have been deposited in the fissure, to afford a support to it independent of its contact with the walls, and the fissure be then increased in width by any renewed action similar to that which originally produced it, the rider may present itself to us supported by the *vein-stuff*, in a state of perfect insulation from the solid mass on either side of the vein*.

61. In the phenomena attending the intersections of veins, described in the Introduction (II. o, π, ρ,) the broken veins are generally supposed to have been originally continuous, and to have been broken by a relative movement of the portions of the mass on opposite sides of the unbroken vein. Adopting this hypothesis, we have not the smallest difficulty in accounting for the appearance represented in the figures, p. 6. (Introd. II. ρ,) since our elevatory force must necessarily produce in many cases that relative elevation of different sides of a fissure, which at once accounts for the phenomena in question. The other two cases above

* This perfect insulation of riders has been recently urged as an objection of the most serious weight against the mechanical origin of veins. It appears to me, on the contrary, to be an almost necessary consequence of the causes we are considering acting on a mass constituted like the crust of the earth.

alluded to, (Introd. II. o, π,) presenting apparent *horizontal* displacements of the mass on one side of the unbroken veins, is not at first sight so easily accounted for, since it can hardly be regarded perhaps as physically possible that any horizontal pressure can have acted on the mass with sufficient intensity to produce an absolute displacement equal in many instances to the apparent one. A very ingenious mode has, however, been suggested* of explaining phenomena of this kind, by referring them to relative *vertical* movements of the masses in which the fissures have been formed. It will not be difficult to convey an idea of the manner in which this may be effected.

62. Let the annexed figure (1) represent a horizontal section at the



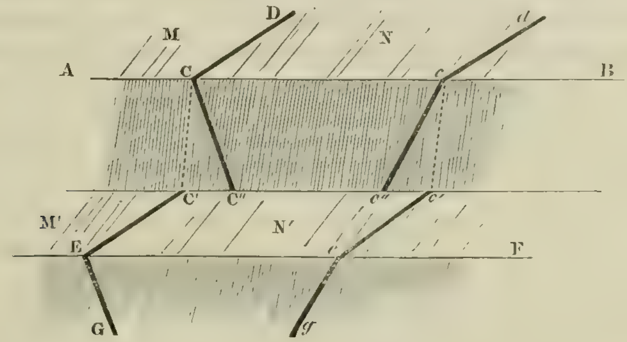
(1)

surface, of two veins which intersect, both being somewhat inclined to vertical planes through AB, ED respectively. Now suppose the portion of the mass bounded by the horizontal surface MN, and the nearly vertical plane ABC' (Fig. 2.)† of the vein AB, to be elevated (or the opposite portion to subside), so that the surface $M'N'$ may be at a lower level than MN. If this change be effected by a movement parallel to the plane ABC' of the vein AB, CE (Fig. 1.) will assume the position $C'E$ (Fig. 2.); and if EFG be a plane parallel to ABC', and intersecting the vein DCE (Fig. 1.) in EG (Fig. 2.) $C'EG$ will be the plane of the vein in the subsided mass, and it will no longer coincide with the plane DCC'', the original plane of the fissure DCE. If we now conceive the higher portion of

* By the late M. Smidt.

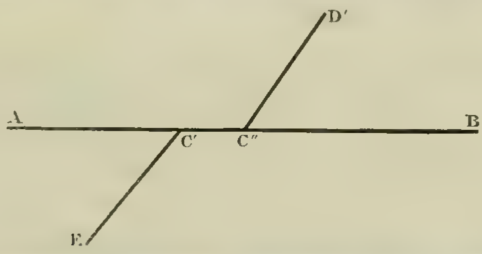
† The same letters denote the same points of the mass in the diagrams (1), (2), (3), (4).

the mass to be removed by denudation, the general surface will coincide



(2)

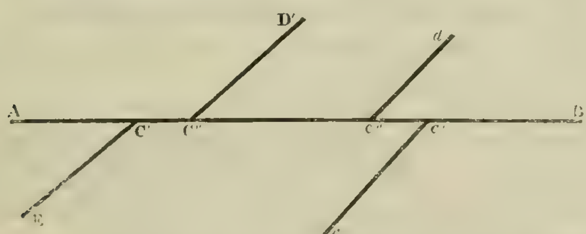
with $M'N'$, and the broken plane of the vein will no longer intersect it in a continuous line, but as represented in (Fig. 3), along the broken



(3)

line $EC'C''D'$; thus producing the appearance of a horizontal movement of the mass on one side of the vein AB, relatively to that on the other.

63. That these phenomena cannot, in some cases, have been pro-



(4)

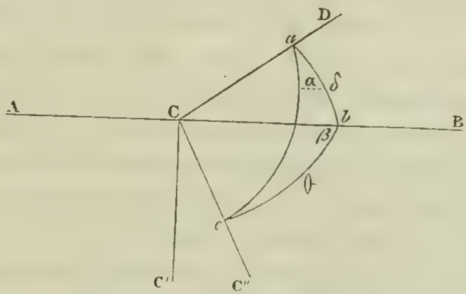
duced by actual horizontal movements, appears to admit of the most demonstrative proof; for it is sometimes found that when two veins intersect a third, both are apparently shifted horizontally, but in opposite directions, presenting the appearance represented in the preceding diagram (4), (a horizontal section), where $C''D'$ and $c''d'$ are apparently so shifted, though it is manifestly impossible that they should be so heaved by any horizontal displacement of the mass containing them.

This case admits, however, of a perfectly simple explanation on the hypothesis of a vertical motion, provided the two veins, which are apparently shifted, *hade or underlie in different directions.* This will be immediately seen by a reference to the diagram (2), where dcc'' represents the plane of the second vein intersected by AB in the higher portion of the mass, and $c'eg$ in the lower. The line cc' being parallel to CC', it is manifest that when C' coincided with C, c' would coincide with c; and consequently, after the denudation above supposed, the intersections of these veins with the exterior surface will present the appearance represented in (Fig. 4).

64. The case just described is admirably calculated to afford a decisive test, as to whether these phenomena have, or have not been produced by vertical movements, or rather by *upward movements parallel to the plane of the unbroken vein.* It is manifest that the explanation above given depends on the fact of the veins CD, cd, inclining in opposite directions, or more correctly, upon their intersecting the plane of the vein AB, in lines inclining towards each other from the parallel lines CC', cc' respectively. Consequently, it may be stated in general terms, that if the two shifted veins incline in the same direction, the above explanation is inadmissible; but if, on the contrary, it be found that these displacements in opposite directions occur only in veins which hade in opposite directions, the truth of the explanation can no longer admit of a reasonable doubt.

65. Other cases also of the apparent displacement of a single vein, may afford most valuable evidence respecting the fact of the kind of elevation of which we have spoken. It is manifest, that whatever the case of displacement may be, the horizontal extent of it must depend on the following quantities: the inclinations of the planes of the broken and unbroken veins to the horizon (the complement of the angles which

measure the hades), the angle *DCB* (Fig. 1.) between their intersections with the horizontal surface, and the length of the line *CC*′, which evidently measures the *throw* of the unbroken vein *AB*, produced by the supposed movement. To express the horizontal displacement of the vein in terms of these quantities, suppose a sphere described with center *C* in the previous diagram (2), {or in the following one in which the same letters denote the same points as in (2)}, and any radius so as to



form the spherical triangle *abc*, by its intersections with the planes of the veins and the horizontal plane. Let

α = angle *bac*, the inclination of the plane *DCC*″ of the broken vein to the horizon.

$\beta = abc$, the inclination of the unbroken vein to the horizon.

$\delta = ab = DCB$ the angle between the intersections of the veins with the horizon.

bc = angle BCC'',

$h = CC'$, the throw of the unbroken vein.

Then shall we have

$$\cot\theta = \cot\alpha \,.\, \sin\beta \operatorname{cosec}.\,\delta + \cos\beta \,.\, \cot\delta;$$

and the apparent horizontal displacement $C'C''$

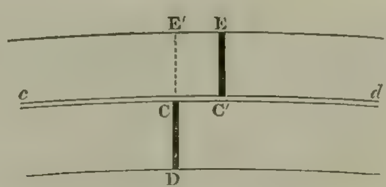
$$= h \,.\, \cot\theta$$

$$= h\,\{\cot\alpha \,.\, \sin\beta \operatorname{cosec}.\,\delta + \cos\beta \cot\delta\}.$$

The quantities $C'C''$, α, β and δ can generally be obtained with very considerable accuracy, as may h also, when the mass in which the veins are formed is distinctly stratified. In such cases therefore, by comparing our observed and computed values of $C'C''$, we might obtain very accurate tests of the truth of the explanation which has been given of these phenomena.

66. The value of the explanation which has been given above of the phenomena we are now considering, consists in the substitution of vertical for horizontal movements, and therefore depends on the approximate verticality of the unbroken vein, parallel to the plane of which the motion is assumed to take place. It not unfrequently happens, however, that a horizontal displacement of a vertical vein takes place at the thin horizontal beds of moist clay, of which so considerable a number is found interstratified with the mountain limestone. The slimy nature of these beds undoubtedly affords a great facility for a relative movement of the masses respectively above and below them; and therefore where the displacement is small, there seems no difficulty in accounting for it on the supposition of this relative motion. In other cases a more probable cause may be found in the following considerations.

67. In the annexed figure let *cd* represent a thin stratum of clay,



of such a nature as to give a considerable facility to a relative horizontal motion of the masses above and below it, and suppose a fissure to have been propagated upwards by the action of horizontal tensions, from D to C. If there were no cohesion whatever between the upper and lower divisions of the mass, it is manifest that the position of DC would not in any degree influence the position of a fissure $C'E$, which might be produced in the same manner and at the same time in the upper portion of the mass, and consequently the point C' would then be determined by the constitution of the upper mass, or some circumstance not immediately depending on the position of DC. In such a case, therefore, there might be an *apparent* horizontal shift of any magnitude. If, however, a certain force, arising from cohesion and friction, should oppose a relative horizontal movement of the upper and lower portions of the mass, a limit will be imposed on the extent of the apparent shift, for it is obvious that this force must be called into action in the formation of $C'E$, (in the progressive formation upwards of the fissure) by the opposite motions of the upper surface of the lower mass, and lower one of the upper mass between C and C', and in no other part. Consequently, if the resistance at C' to the formation of a fissure in the upper mass, together with the lateral force just mentioned, be greater than the resistance to the continuation of the fissure from C towards E', the former fissure cannot be formed in preference to the latter, and thus a limit will be imposed on the distance CC'. It is easy, however, to conceive, from the known constitution of the beds which appear to give rise to phenomena of this kind, that this distance may be sufficient to account very easily for all such appearances of displacement as we are now considering.

68. If we conceive the figure in page 64 to represent a horizontal instead of a vertical section of the mass, and cd to represent a fissure, then, if a fissure $DCC'E$ be propagated across it, it is manifest that considerations exactly similar to the above would enable us to account for the apparent displacement CC' in this as well as in the former case, and it appears highly probable that such appearances may have been not unfrequently thus produced. We may also observe, that if the fissure cd has not been completely filled, and its sides again cemented together, the movements of the masses on opposite sides of it will be in a certain degree independent of each other, so that a fissure DC propagated so as to meet cd at C, might be continued on the other side of cd, from a point C' quite remote from C. In such case DC would appear to terminate at C, and this, in fact, (DC being a small, and cd a large vein) is not of unfrequent occurrence.

69. There is also another manner somewhat different from the above, in which an apparent displacement of a fissure may be produced. It

has been already shewn (Art. 17), that if a fissure in its progressive formation meet with any line of less resistance, it will under certain conditions be propagated along it for a certain distance, and then resume its original direction. If AB (Fig. 3, p. 61) be a line of less resistance, $EC'C''D'$ would represent a horizontal section of the fissure formed in the manner just supposed, and thus presenting the apparent displacement $C'C''$.

It must be remarked, however, that an apparent displacement due to this cause must necessarily be such as represented in the figure just referred to, viz. on the side of the obtuse angle $EC'C''$, or $D'C''C'$, and not on that of the acute angle $ec'c''$, or $d'c''c'$ (Fig. 4, p. 61): and we may also observe, that neither this cause, nor that pointed out in the previous article, appear sufficient to account for the fact, which has been frequently recognized, of two or more adjoining veins being apparently displaced, or heaved, to the *same extent* and in the *same direction* by the same cross course. We see no reason why the apparent displacements of two such veins should be related in either of these particulars, when produced by the cause indicated in Art. 68; and if produced by that mentioned in the preceding paragraph, though the apparent displacements would necessarily be in the same direction, there seems to be no reason why they should be of the same extent. When the heaves, therefore, of adjoining veins appear to be related to each other both in extent and direction, the above two causes do not appear to offer an adequate explanation of the phenomena.

70. It was a notion first propagated, I believe, by Werner, and subsequently adopted by many other geologists and miners, that when two veins meet each other, of which one is heaved, and the other unbroken, the formation of the latter must necessarily have been posterior to that of the former. The theory of elevation, however, which we have been discussing, will not authorize this conclusion. If we assume the modes of producing apparent displacements considered in Arts. 68 and 69, it is evident that we must adopt a rule exactly the reverse of the one just stated; and if we suppose the displacements to be real, it is manifest from what has been advanced in this and

the previous section, that the formation of one or both of the fissures may have been either contemporaneous with, or anterior to that movement of the mass which produced these displacements; and consequently the existence of the heave in the one or the other of two intersecting veins, can afford no test of their relative ages. In cases, however, where several veins are found to have been heaved in the immediate vicinity of each other (as in some of the Cornish veins) indications may be obtained of their relative ages from the phenomena they exhibit, assuming them to have been produced in the manner just supposed.

71. It has been stated (Introd. η, p. 4), that the fissure of a vein is frequently almost entirely closed in passing through a thin stratum of clay. This fact may, I conceive, be easily accounted for from the greater *extensibility*, and less *elasticity* of this stratum, as compared with the masses with which it is interstratified. The former quality would allow it to remain unbroken, with an extension which the general mass could not but yield to, or if broken, it would from the latter property have little tendency to recede to its original extent.

72. It is not my intention to enter into any discussion on the mode in which the fissures of mineral veins have been filled*; but I would remark, that the frequent occurrence of the fact above mentioned seems equally unfavorable to the hypothesis of this process having taken place by superficial agency, or by any species of injection from beneath. The difficulty, however, assumes a far more formidable character when considered with reference to the toadstone of Derbyshire, which, as I have already stated (Introd. II. η.), produces the same effect, in nearly destroying the continuity of the fissure, as the clay beds above mentioned. But in this case, instead of a bed of a few inches in thickness, we find a bed of toadstone of from ten to forty fathoms, through which the vein can sometimes be traced only by mere threads of calcareous spar. How then can we conceive the upper part of such a fissure

* I do not here allude merely to the process by which the *mineral vein* properly so called, (see p. 2.) has been deposited, but that by which the whole fissure may have been filled with the *vein stuff* which now occupies it. The fissure may be several feet wide, while the mineral vein is not an inch in width.

to have been filled from below, or the lower part filled from above? Either the one hypothesis or the other appears totally inadmissible, unless we suppose the communication between the upper and lower parts of the vein to have been formerly very much more perfect than at present. This hypothesis would, perhaps, present no very serious difficulty, because it is very possible to conceive the toadstone to have been so imperfectly solidified at the time of the formation of these fissures, as afterwards to diminish their width, by yielding in some measure under the pressure of the superincumbent mass. But if we suppose the portions of the fissure both above and below the toadstone to have been filled either from above or below, while there existed a wider fissure connecting them through the toadstone, this fissure in the toadstone must also have been filled before its ultimate degree of contraction, in which case it appears almost impossible that there should not be a much more determinate trace of a vein through the toadstone, than is at present observed to exist. We seem almost necessarily driven in these cases to the hypothesis of some process of segregation or infiltration *into fissures previously formed for the reception of the segregated or infiltrated matter.*

§. *On the Formation of Granite Veins.*

73. These veins have been described (Introd. VII.) as distinguished in general by the absence of that tendency to rectilinearity and parallelism in their directions which so distinctly characterize the principal mineral veins in each mining district. The fact of these veins being found only at the junction of masses of granite with other masses of different mineralogical constitution, has naturally suggested the idea of these veins being *veins of injection;* the granite being assumed to be of igneous origin. This opinion seems strictly in accordance with the views which we have been developing. The rectilinearity of mineral veins is due, according to this theory, to the predominance of tensions acting in a particular direction, whereas fissures formed in great measure by the hydrostatic pressure of injected fluid matter, in a mass subjected to no tension very determinate in its direction, might assume

any tortuous course. The irregular and violent action, also, to which the mass through which, according to this view of the subject, the granite is supposed to have been protruded, would have a great tendency, independently of the hydrostatic pressure just mentioned, to form in the broken mass irregular fissures, which would facilitate the injection of the fluid matter, and increase the irregularity of the form of the injected veins.

§. *On the Formation of Trap-Dykes and Veins.*

74. The results above obtained respecting the formation of fissures in the crust of the globe will manifestly hold equally, whether we suppose the uplifted mass acted upon immediately through the medium of an elastic vapour, or by matter in a state of fusion in immediate contact with its lower surface. In the latter case, however, this fused matter will necessarily ascend into the fissures, and if maintained there till it cools and solidifies, will present such phenomena as we now recognize in dykes and veins of trap. The same phenomena would result from the injection of the fluid matter at any period posterior to that of the formation of the fissures as above described. To represent to ourselves, therefore, the phenomena of trap-veins, as referred to the causes to which we are referring them, we have only to conceive the fissures previously described filled with trap. The larger ones will thus form dykes, and the smaller ones veins of that rock.

75. It has been observed by geologists, and particularly by M‘Culloch, that a large proportion of trap-dykes have been formed without producing any sensible disturbance in the ends of the stratified masses abutting against them. And this is precisely what we might expect, if we suppose such dykes to have been injected without excessive violence into fissures formed as above described, whether that injection be supposed to have taken place after the formation of the fissures, or contemporaneously with it. Where injection, however, has taken place in great abundance, and with great violence, corresponding degrees of disturbance might of course be expected to attend it.

The geologist to whom I have just referred, in speaking of the trap-veins of the Isle of Sky, observes: "It is necessary to point out one extraordinary effect which must have resulted from the intrusion of these veins. Whatever proportion, collectively taken, they may bear in breadth to the lateral dimension of the strata which they intersect, it is plain that the whole mass of strata must have undergone a lateral extension equal to that quantity; a motion so great as not to be easily reconciled with the present regularity of the whole. It is also a singular circumstance, that on the opposed shore of Sleat a different effect takes place, and proportioned, it would here seem, to the number of veins; the red-sandstone strata of this coast being often turned from a slightly inclined into a nearly vertical direction, with other considerable marks of disturbance. It is impossible to account for these apparently capricious differences, and we must for the present be content to rank them among the numerous unexplained phenomena in which the science abounds."

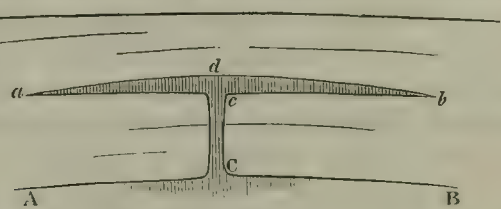
These phenomena present no difficulty except in the apparent lateral displacement of the stratified beds, without any other appearance of disturbance; and if this effect is to be referred to the lateral pressure of the injected matter, it does indeed present a difficulty no less, I conceive, than a physical impossibility. In the first place, it appears inconceivable how sufficient resistance could be obtained from above to produce the enormous lateral fluid pressure necessary to cause this lateral movement, as we have before remarked respecting the horizontal heaves of mineral veins; and in the next place, it is still more inconceivable how this force could have been exerted without indications of such violent action. Under the point of view, however, in which I have regarded the subject the difficulty no longer exists; for it must be recollected that the aggregate width of the veins, or apparent lateral displacement, is not to be taken with reference to the breadth of the mass in which the veins immediately exist, but with reference to the whole extent of the mass, the tension of which may have been relieved by the formation of these fissures. No rational account can be given, I conceive, of such lateral movements of extensive masses, except by referring them to the horizontal tension produced by vertical forces, and the consequent contraction when the mass becomes fractured by too great an extension.

§. *On the Formation of Horizontal Beds of Trap—By Ejection—By Injection—Remarks on some Phenomena observed by M'Culloch—Effect of imperfect Fluidity in Horizontal Injections.*

76. If the quantity of fluid matter forced into these fissures be more than they can contain, it will of course be *ejected* over the surface; and if this ejection take place from a considerable number of fissures, and over a tolerably even surface, it is easy to conceive the formation of a bed of the ejected matter of moderate and tolerably uniform thickness, and of any extent. If the ejection take place over a level surface, these properties of the resulting bed would seem to require a number of points or lines of ejection as a necessary condition, on account of the imperfect fluidity, which, according to analogy, we ought probably to assign to the ejected matter. If there were only a single center of eruption, a bed of such matter approximating to uniformity of thickness, could only be produced on a surface of a conical form, having the point of eruption at its vertex, and an angular elevation depending on the degree in which the fluidity of the ejected mass should differ from perfect fluidity. Where no such tendency to this conical structure can be traced, it would probably be in vain to look for any single *center* of ejection. On the supposition too, of ejection through continued fissures, or from a number of points, that minor unevenness of surface which must probably have existed under all circumstances during the formation of the earth's crust, would not necessarily destroy the continuity of a comparatively thin extensive bed of the ejected matter, in the same degree in which it would inevitably produce that effect in the case of central ejection.

77. I will now proceed to consider the formation of a horizontal bed by *injection*; what limits may be imposed on the probable or possible extent of it, and with what phenomena it may be accompanied, which may serve as tests for distinguishing a bed so formed from one formed by *ejection* over the external surface.

Let us suppose then, that the fluid mass has risen through the fissure of which *Cc* is the section, till it has reached the stratum *adb*. If this stratum have sufficient tenacity and extensibility, and but little adhesion to that on which it reposes, it is easy to conceive that it may be elevated without being broken, if the fluid mass be impelled upwards with sufficient force to overcome the weight of the superincumbent mass. In this case the fluid will necessarily be *injected* horizontally, as represented in the figure, and so long as the lower surface of the uplifted stratum remains perfectly continuous and unbroken, it is very possible that this injection may extend to any assignable distance *without the*

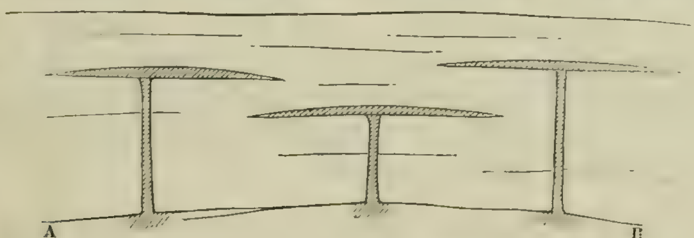


production of vertical dykes, on veins branching from the upper surface of the injected bed. In this case there would appear to be no indications of mechanical action from which the geologist of the present day could ascertain whether such bed had been *injected* among the beds associated with it, or *ejected* over the surface *acb* at a period anterior to the formation of the superincumbent strata.

The most favorable case we can conceive for the kind of injection we are considering, without the production of the vertical veins above mentioned, is that in which we assume the absence of all adhesion between the uplifted bed and that immediately beneath it; but even in this case the condition of unbroken continuity in the lower surface of the superincumbent mass, must be satisfied, not approximately, but accurately; for if the smallest crevice existed in the uplifted portion, the injected matter would be impelled into it with a force proportional to the enormous pressure to which it would be subjected from the weight of the superincumbent beds; and if the injection should take place under the weight also of a deep sea, the probability of this effect would be exceedingly increased by the consequent additional pressure, while the process of injection would not be in the smallest degree facilitated by it. Trap-veins would thus be produced, affording indubitable evidence of injection.

Again, the hypothesis we have made above of the entire absence of adhesion between two contiguous beds, though it may in some cases be true for limited spaces, cannot be uniformly so in cases in nature for spaces of considerable extent. Now in those instances, in which the force of adhesion between the two beds, bears any kind of ratio to that which holds together the component particles of the uplifted portion, an enormous force will be required to overcome this adhesion. And how are we to conceive such a force applied without producing the smallest rupture in the lower surface of the uplifted mass? If there be no adhesion between the beds, no considerable horizontal tension will be produced in this mass; but if the adhesion be considerable, such a tension will be produced, proportional to the increased force of injection called into action. Under these circumstances the smallest break or crevice will be torn open, the fluid matter will enter it, and acting on its vertical sides with an enormous pressure, and with the mechanical advantage of a wedge, will add immensely to the tendency of the horizontal tension to produce a vertical fissure.

78. It may perhaps be thought that the difficulty of conceiving the process of horizontal injection of considerable extent, without the production of vertical veins, may be obviated by supposing the fluid



matter injected from many points simultaneously between the same two horizontal beds. But this hypothesis appears extremely improbable, unless it be also assumed that the want of cohesion between these beds is co-extensive with the injected bed, an assumption, which as I have before remarked, must probably be in general considered as totally inadmissible. The probable consequence of simultaneous injection from different fissures, (supposing the injected matter not in too great quantity), would be the formation of partial and unconnected beds as represented in the annexed diagram.

For these reasons then we cannot hesitate, I think, to conclude, when we consider the general structure of stratified masses, that the absence of numerous trap-veins and dykes, *having their origin in the upper surface of a horizontal bed of trap*, with the want also of very frequent indications of violent mechanical action in the lower portion of the *superincumbent mass*, affords indubitable proof of the fact of such horizontal bed having been ejected over the exterior surface existing at the time of its eruption.

79. The existence of a single vein or dyke such as above described, in rocks incumbent on a horizontal bed of trap, is clearly an indubitable proof of injection; but it must not therefore be concluded, that every trap-vein or dyke in the superincumbent strata affords this unequivocal testimony, since it is manifest that such a vein or dyke might possibly be produced by injection, subsequently to the formation of the horizontal bed, which it may have traversed exactly in the same manner as any other stratum*. The decisive character of the evidence of injection afforded by a vein, consists in its originating in the upper surface of the injected bed. We may also remark, that indications of mechanical action on the beds *beneath* a bed of trap will not necessarily afford conclusive testimony as to the fact of injection, because such appearances might be produced, to a certain extent, by the force of an *ejected*, as well as of an *injected* bed. It is in the superincumbent beds that we must seek for the evidence in question.

80. It is not my object to enter into any detailed comparison between observed facts, and these theoretical deductions, but I think it necessary

* Many instances are given by M'Culloch of veins of trap existing in trap. See "Description of the Western Islands."

to allude to some cases of injection described by M'Culloch in the Western Islands, in which the injected beds assume for considerable distances the appearance of being regularly interstratified, thus seeming, it might be thought, to offer exceptions to the rule I have deduced from theoretical considerations. Four or five only of these exceptions I think have been expressly mentioned by that author. Those on the coast of Trotternish in the Isle of Sky, which appear to be the most striking, are described as follows:

"In one case, which occurs not far from Holme, there is a bed extending for a great way, surmounted by a parallel series of the secondary strata in contact with it; but on a narrow inspection, innumerable veins are seen branching into the strata in every possible direction, illustrating in a very perfect manner the origin of at least one order of veins. In a second case, three beds of trap can be traced in a parallel direction for a considerable space, separated by the regular strata, when suddenly the whole unite into one mass. Had not this occurrence at length betrayed the true nature of these beds, there would have been no hesitation, from a limited observation, in describing them as unquestionable instances of alternation. In the last case which I shall mention, one regular bed of trap may be traced for more than a mile, lying in a parallel and undisturbed continuity between the secondary rocks. On a sudden, however, it bends downwards so as to pass through the strata immediately in contact, and then continues to hold its regular course for a space equally great, with a thickness and parallelism as unaltered as before*."

The first of these instances presents in its branching veins, exactly the phenomena which, I have been contending, must necessarily attend any extensive horizontal injection of a fluid mass. The others seem to indicate the possibility of this injection without such phenomena, for at least the extent of a mile. Nor am I disposed to doubt this possibility, though I should in general consider a horizontal injection of that extent without ramifying veins, as extremely improbable, and especially if the injected bed were not a very thin one. In fact, however, there

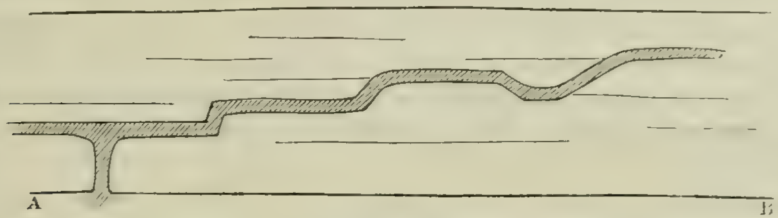
* Description of the Western Islands of Scotland, Vol. I. p. 382.

appears no reason to conclude that such has been the case. The whole of Trotternish is described as consisting of an enormous overlying mass of trap, which appears to have risen in numberless places through the stratified rocks on which it reposes. It extends (if I understand the description rightly) quite to the coast, so that scarcely any stratified rocks are visible, except in the vertical section formed by the steep cliffs along the beach, and in which the appearances above described are observed. Hence it is probable that these horizontal beds are connected with vertical masses of trap, at distances from the visible sections of them, small in comparison with their apparent range along the cliffs, and consequently it is very possible that the extent of horizontal injection may have been much less than at first sight it appears to have been.

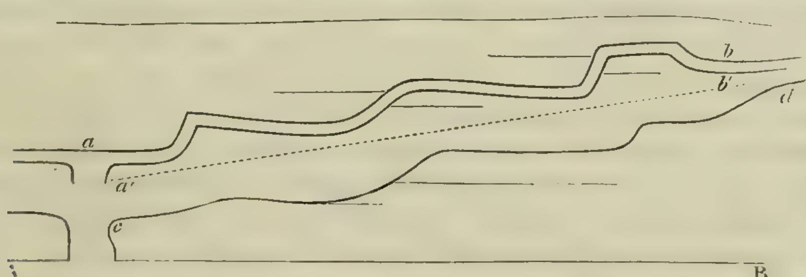
The same observation will apply to the other phenomena of the same kind as described by the author just quoted; and so far from offering any thing opposed to the theoretical views I have been explaining, they may, I think, be considered, when taken in conjunction with numberless cases of vertical dykes and veins, as strongly corroborative of them; since the comparatively insignificant number of these injected horizontal beds, clearly proves them to offer only so many exceptions to the very general rule of verticality in trap-veins, so frequently recognized by M'Culloch himself.

81. In speaking of horizontal injection, I have not yet alluded to the consequences of imperfect fluidity in the injected matter. If we may be allowed to judge of the degree of this fluidity from the analogy which the injected matter may be presumed to have borne to modern lava in its eruption, we may conclude it to have fallen considerably short of that of perfect fluidity. Consequently the lateral pressure communicated by the fluid, would never be equal to the direct pressure impressed upon it, and this, it is evident, would increase the difficulty of horizontal injection in the cases which I have already considered. The most important consideration, however is, I conceive, that this property of imperfect fluidity, would thus impose a limit to the possible extent of lateral injection, supposing the injected matter not to form a bed lying in one plane, but to form an irregular surface, such

that the following diagram may represent a vertical section of it. For suppose the fluid capable of transmitting the $\left(\frac{m}{n}\right)^{\text{th}}$ of a force impressed upon it, in a direction perpendicular to that of the impressed force; then if the pressure be transmitted along a broken line consisting of straight lines at right angles to each other, it is clear that the force transmitted along the first straight portion (supposed horizontal), will be $\frac{m}{n} \cdot p$, p being the impressed force and acting vertically. Along the second portion of the broken line the transmitted force will be $\left(\frac{m}{n}\right)^2 \cdot p$, and generally



along the r^{th} portion it will be $\left(\frac{m}{n}\right)^r \cdot p$. If the different portions of the broken line be not at right angles to each other, or instead of being straight be curved, the diminution of the transmitted pressure must still be calculated on the same principle. It is important, however, to observe that the thickness of the injected bed would probably influence this diminution very materially, as may be illustrated by the following figure. If the section of the bed be represented by the space between



the lines *ab* and *cd*, a straight line may be drawn in it from one extremity to the other, and therefore the transmitted pressure at one extremity would nearly equal that impressed at the other. On the contrary, if the space between the lines *ab* and $a_{\prime}b_{\prime}$, represent the section of the bed, it is manifest that the smallest number of straight lines which could be drawn entirely within this space, so as to form a continued but broken line between *a* and *b*, would be considerable, and that consequently the loss of transmitted pressure would be considerable. The magnitude of the impressed pressure at *a* is limited by the power belonging to the incumbent mass of resisting dislocation there; and when the loss of pressure by transmission is so great, that there is no longer sufficient force to cleave the mass into which the injected matter is penetrating, the horizontal injection will cease. I think it very probable that the limits thus imposed on the extent of possible injection, in the case of a thin bed like that just described, may be much narrower than some geologists seem to have conceived.

§. *Effect of Joints in determining the Directions of Fissures.*

I have stated (Introd. p. 11), that the investigations of Sect. I., are not to be considered as applicable to a mass in which the jointed structure should prevail generally, because the cohesion of the mass being in great measure, or altogether destroyed along the joints, the fissures resulting from any external force, would of course be formed along them. If, however, there should be two systems of joints existing previously to the action of the elevatory forces, in directions respectively parallel and perpendicular to the general axis of elevation, it is evident that the systems of fissures produced by this force, as well as all the phenomena resulting from them, would be exactly the same as those already described. If the direction of these systems should be only approximately parallel, and perpendicular to the axis of elevation, the same would still be true as respects the distinctive characters of longitudinal and transverse fissures, (see Art. 56). If, however, the directions of these two systems of joints should not have approximately these relations to that of the axis of elevation, or should not be nearly at right angles to each other, systems of fissures will result different from those which we have already described as the consequence of a general elevatory force.

Since the existence of joints in rocks appears to be very general, it becomes a matter of interest to enquire what effect they may possibly have had in determining the positions of the lines of dislocation, which we at present observe in the crust of the globe, as already described. Our present limited knowledge of the extent of joints, horizontally and vertically, and of their relative directions, will not enable us to return any direct and definite answer to this enquiry. We may however, observe, (and the observation is important as respects the applicability of this theory) that in those districts where the directions of faults, mineral veins, cross courses, &c., bear those relations to a well defined axis of elevation, which would exist according to these theoretical views, and which observation, so far as it has proceeded, has shewn to hold very generally, it would appear absurd to assign those directions to the influence of joints, unless some cause can also be assigned why the elevatory force should act in such a manner as to give to the axis of elevation, a direction bearing a necessary relation to that of any previously existing system of joints. As it appears almost impossible to conceive any such cause, we may, I think, without hesitation, in the cases above-mentioned, reject the hypothesis of any extensive influence of a jointed structure upon the phenomena in question. Should a general coincidence be hereafter observed in the directions of joints, and those lines of dislocation which follow the laws before mentioned, it would seem far more probable, that the former had been influenced by the latter, than the latter by the former phenomena.

In asserting the generality of the laws above mentioned, it must not be supposed that we are assuming the absence of all exceptions, or that the directions of mineral veins may not, in some instances, have been determined by causes different from those we have been considering. This, I think, has been unquestionably the case in the veins or lodes of St Austle moor, in Cornwall, where we recognize systems of lodes forming acute angles with each other, and obviously referrible to some cause totally distinct from the action of extraneous forces on the general mass. This, however, forms no argument against our theory, as applied to those cases in which the phenomena present to us features entirely different from those just mentioned, and in perfect accordance with our theoretical deductions.

With the causes which may have superinduced the jointed structure in rocks, I have at present no concern, except so far as it might possibly be influenced by the action of extraneous forces. It has been shewn, however, (Art. 32), that such forces could only tend to produce systems of fissures crossing each other at right angles, whereas regular systems of joints appear to meet each other frequently at acute angles, and consequently, must necessarily have been owing to some different cause. I do not therefore conceive that any general tension of the mass produced by extension from elevation, or contraction in the course of solidification, can have had any material effect on the formation of joints. It is probably, I think, to be referred entirely to some kind of internal molecular action.

THOUGH the law of approximate parallelism has long been recognized by geologists as characterizing mineral veins, faults, &c., I am not aware that any attempt has hitherto been made to deduce this important law from the causes to which these phenomena have been referred. In the preceding investigations, however, I have shewn, that under certain simple conditions, such a law is the necessary consequence of a general elevatory force acting in the manner I have supposed; and I have moreover shewn, that this law is entirely inconsistent with the partial action of such a force; because an elevatory force acting thus partially at a particular point, would necessarily produce fissures diverging from that point, so that in a general elevated range produced by the elevation of different portions in succession, there could be no general system of parallel fissures. This deduction appears to me perfectly conclusive as to the respective claims of two theories, one of which should assign the phenomena of elevation, in which the law of parallelism is observable, to the *partial*, and the other to the *general* action of an elevatory force, the terms *general*, and *partial* being taken in the sense in which I have heretofore used them, (see p. 1.) It must not, however, be supposed that our theory would lead us to the conclusion, that the whole elevation of any elevated range must have been communicated to it at once. It requires only that the *first* movement should have been general, and sufficient to produce at least the commencement of the systems of fissures, by which the range may subsequently be characterized, (Art. 58). Elevations, partial or general, may afterwards take place without producing other fissures following any law different from that of the preceding ones.

In the present state of geological theory, this deduction will not, I conceive, be deemed unimportant. It forms no part, however, of my present purpose to examine the merits of the different theories of elevation, which have been propounded by geologists; nor have I entered into these investigations in the spirit of advocacy of any peculiar and preconceived notions. My object has been simply to develope the necessary or probable consequences of certain definite hypothetical causes, and to compare them with those results which appear to be at present best established by observation; but, at the same time, leaving the theory of elevation founded upon our hypotheses, open to that refutation, or more complete verification, which must arise from the comparison of the results of more extended and accurate geological research with those of theory, deduced not by vague and indeterminate methods, from assumptions still more vague and indeterminate, but by accurate methods, from hypotheses the most simple and definite, which the nature of the subject will admit of.

In our own country the elevated range extending from Derbyshire to Northumberland, seems peculiarly calculated to afford us an opportunity of comparing the results of observation with those of the theory we have been investigating. On the slightest inspection of a map of this portion of the island, the direction of the central line of elevation is indicated to us by the sources of the rivers, which pursue their courses from it respectively to the eastern and western coasts. This line appears to be almost straight, running nearly north from its southern extremity to the valley of the Eden, where the well defined ridge of Cross Fell commences, in a direction almost north-west and south-east. On the eastern side of this range, the different formations succeed each other with a general regularity in the order of their superposition, which would appear to indicate the absence of any comparatively irregular action of the elevatory forces in that region; and the existence of extensive mining and coal districts along this range, afford the surest means of ascertaining with accuracy the exact positions of the fissures and lines of dislocations which exist in it. Hitherto these phenomena have not, however, been made the objects of sufficiently careful examination, and if these observations should have the effect of leading to a more detailed investigation of them, one object of my entering into these researches will be accomplished. According to our theory the mineral veins in the southern part of the range above mentioned ought to run east and west, while in the Cross Fell part we should expect them to assume a direction more nearly north-east and south-west. From my own observation I have ascertained that in the mining district in Derbyshire, the phenomena are in this respect as well as in others strikingly accordant with theory, and I have reason to believe that in the coal district lying along the eastern boundary of that country they will be found so likewise. I hope, however, shortly to bring the details of this district under the notice of geologists.

The northern and southern portions of this range present us also with the important and interesting phenomena of extensive horizontal beds of trap, (the toadstone of Derbyshire, and the whinsill of the north) apparently interstratified with the sedimentary rocks with which they are associated. In the preceding investigations, I have entered with considerable detail into the subject of the formation of such beds, from the conviction that the notion of injection with reference to them has been carried by some geologists much too far, and that conclusions have been adopted without a due regard to the necessary effects on the contiguous beds, of that enormous hydrostatic pressure, which the process of injection of an extensive horizontal bed would necessarily call into action. That the toadstone of Derbyshire is not an injected bed, admits, I think, of the most indubitable proof from observation; and if the interstratification of the whinsill of the north, with comparatively thin beds of limestone and shale, be as regular as it is represented to be, I should have no hesitation in coming to the same conclusion with respect to that bed, for the reasons which have been heretofore mentioned, (Art. 77).

In the preceding investigations, I have spoken of the law of parallelism only as recognized in phenomena of faults, mineral veins, &c., comprized within narrow boundaries as compared with those to which it has been attempted to extend it, in the theory of Elie de Beaumont. It is very possible, however, that the physical causes to which I have referred this law, may have had a far more extensive operation than that I have ventured to assign to them. The parallelism of two mountain chains might thus be accounted for as simply as that of two neighbouring anticlinal lines; but it is obvious, that the more remote they should be from each other, the less would be the probability of the fissures to which our theory would refer them, belonging to the same system, and the less satisfactory would our solution become.

I have been anxious to avoid, for the present, any speculations respecting the interior constitution of our globe, beyond what is comprized in the simple assumptions on which these investigations have been founded; we may, however, include in those assumptions, the hypothesis of the elevatory forces having acted in different cases at different depths. The application of our theory, alluded to in the preceding paragraph, would perhaps require the hypothesis of these forces having acted at a much greater depth in such instances, than in those where the resulting phenomena are on a much smaller scale; and we may observe, that if the formation of the fissures should commence very far beneath the surface, it is extremely probable that very few would become complete fissures (see Art. 39), or would ever reach nearly to the surface, in comparison with those which would do so in cases where these fissures should originate at a much smaller depth. The complete fissures would consequently be distant from each other and very large, and all the phenomena of elevation resulting from them might be expected to be of proportionate magnitude. I have no intention, however, of insisting on this extended application of our theory, but merely to indicate its possible extension (should established geological facts appear hereafter to require it) to account for phenomena on a much larger scale than those to which I have considered it essential to refer in the preceding investigations.

W. HOPKINS.

ST PETER'S COLLEGE,
May 4, 1835.