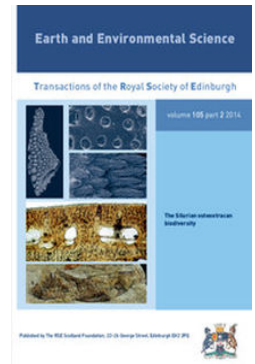


# II. *On the Vertical Position and Convolutions of certain Strata, and their relation with Granite*


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II. *On the Vertical Position and Convolutions of certain Strata, and their relation with Granite.* *By* Sir JAMES HALL, *Bart.* Pr. R. S. Ed. & F. R. S. Lond.

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THE tract of country extending across this island, from the sea-coast of Galloway to that of Berwickshire, consists, with little interruption, of that species of rock, which has of late been most generally known by the German name of *Grauwacke*. But as this rock does not differ essentially from what in Cornwall is called *Killas*, I am disposed, in concurrence with several members of this Society, in particular with Mr ALLAN, who has of late been in Cornwall, and has paid particular attention to that subject, to reject the uncouth term Grauwacke, and adopt that of Killas, as being more congenial to our language.

The continuation is so unbroken, that I believe it would be practicable to walk from one sea to the other, without treading upon any rock but killas; and as its character is identical throughout, we seem to be authorised, in every view of mineralogy, to look upon the whole as one with respect to origin and

and history; so that observations made at any one part of the range, may, with confidence, be applied to the rest.

There are but few exceptions to this general rule, which have come to my knowledge. At the Rae Quarry in Peeblesshire, near the Crook Inn, a Limestone containing shells occurs, interstratified with killas; and in the stewartry of Kirkcudbright, there are three Granitic districts in the midst of this rock, whose relations with it exhibit some interesting facts, which will occupy the second part of this paper. A granite mass also occurs within the range of this same mass of killas, at Priestlaw on the Water of Fasnet, in the mountainous part of East Lothian.

The killas consists everywhere of an assemblage of strata of various thickness, from several yards to the minutest leaf of slate. It is in general of a dark-blue colour, and, when examined, is found to consist of a congeries of fragments, which bear the most undoubted proofs of having been deposited in an horizontal position. The strata lie parallel to each other, but are everywhere far from being horizontal, their prevailing and best known position being vertical, or nearly so. They are often bent, however, at various angles, frequently very acute, and sometimes with the strata nearly doubled upon themselves. In all the inland part of this range, the rock appears so partially, shewing itself only in river-courses, or in quarries, that it is difficult to obtain any correct information as to the position of the strata, which frequently exhibit great seeming irregularity, and which cannot be described, without making use of language which at first sight bears an appearance of contradiction in terms. Thus it not unfrequently happens, that one set shews itself in a position, at the surface, nearly erect, but having a decided dip to the east; and that in the immediate neighbourhood, another

another set occurs in a position similar to the first, but having a no less decided dip to the west.

On the shore of the sea, however, where these rocks are bare, and exposed in such a manner, that our view can embrace at once a considerable extent of the mass, the general structure becomes apparent, and we are enabled to give a rational account of these seeming anomalies.

This opportunity of observation, occurs with peculiar advantage on the coast of Berwickshire, where the lofty cliffs which extend from Fast Castle eastward to Gun's Green near Eyemouth, present to view a cross section of these strata, by which their position is seen to possess much more method and regularity than the inland rocks would have led us to expect. The strata here exhibit a succession of regular bendings, and powerful undulations, reaching from top to bottom of the cliffs, two or three hundred feet in height. These are occasionally interrupted, as might be expected, by the irregularities of the coast, by shifts and dislocations of the beds, and sometimes, as happens at St Abb's Head, by the intervention of whinstone; or occasionally of porphyry.

Notwithstanding these interruptions, I reckoned, (in an excursion to that coast, made last summer with my son Lieutenant Basil Hall of this Society), sixteen distinct bendings, in the course of about six miles, each of the largest size, and reaching from top to bottom of the cliffs, their curvature being alternately concave and convex upwards. Plates I, II and III. are from drawings made on the spot. Fig. 1. Plate I. shews a general view, taken at sea, at some distance off the point of Fast Castle, which appears upon the right hand. Plate II. shews a near view of part of the same scene, representing a spot called the Brander Cove, in which one of these convolutions, concave downwards, is conspicuously seen. The rock

upon the right, on which Fast Castle stands in fig. 1. Plate I., exhibits also one of the convolutions concave downwards, and similar to that of the Brander Cove, seen on the left. Plate III. represents another rock of the same coast, at a place called Whapness, near Gun's Green, in the neighbourhood of Eyemouth. Here there are four bendings; two convex upwards, and two convex downwards, lying close to each other; and fig. 2. Plate I., represents a rock in the same neighbourhood, in which a variety of convolutions are distinctly seen.

We have thus a specimen of that part of the coast which consists of killas; the whole being a succession of similar bendings, alternately concave and convex upwards; and the curvature of the mass is, in general, (as Mr PLAYFAIR has well observed, *Illustrations*, art. 204.) simple; that is to say, these bendings are performed in one direction only, and round axes that seem to lie horizontally, and parallel to each other.

These strata, in common with all those of killas, seem to have been originally deposited in a position nearly horizontal, and many of the particular beds represented in these sketches, possess that peculiar undulation on their surface which we meet with on a sandy beach, when the tide has left it, and which affords the most unequivocal indication of aqueous deposition. There is reason to believe also, that the strata, constituting these convolutions, though now detached from each other, have at one period lain in continuity, and horizontally; that by the exertions of some powerful mechanical force, they have been compelled to assume their present contorted shape; that their continuity still exists below, and would be seen, could we penetrate into the mass under the level of the sea; the interruption of their continuity upwards, having arisen from a removal of part of the rock, by some of those revolutions which have

have every where agitated and corroded the surface of our globe.

In order more fully to illustrate this arrangement, I have drawn in figure 1st, Plate IV. an ideal portion of a coast similar to that which we have been describing; and in figure 2d, the same has been exactly repeated in black lines. But in this last figure, I have introduced a continuation of each of the strata in dotted lines; so that every one of them is rendered completely continuous from end to end.

This theoretical completion of these forms, may be of service in accounting for the anomalous circumstances already mentioned, as belonging to the strata of killas. In particular, we may thus readily account for the abrupt change of dip from east to west. Thus, in figure 1. Plate IV. we see the strata *a b*, and *c d*, dipping rapidly to the east, and those at *e f*, and *g h*, as rapidly to the west; yet, at their *outgoings*, or appearances at the surface, they are very little removed from each other; and if the middle point, where the convolution takes place at *m*, were hid from the view or removed, the appearance would be completely paradoxical.

Making allowance for shifts, and various interruptions, great part of the coast may be thus explained: but this simple curvature, though general, is by no means universal in the killas; as appears in some places upon this coast, to the eastward of Eyemouth, at Gun's Green, where the axis of convolution is very irregular, and is sometimes vertical; and also in Galloway, where the strata present to view much more irregularity. But these anomalies, though more complicated, seem all to be of the same class, and to denote the influence of similar actions, as I shall endeavour to shew in the course of this paper.

In reducing these irregular forms into system and connection, one object, of no small consequence in geology, seems to be obtained; but it would be desirable, if possible, to go a step farther, and to discover by what means this peculiar arrangement has been brought about. For this purpose, it will be necessary to shew, first, That this peculiar conformation may be given to a set of horizontal beds by a mechanical force of sufficient strength; and, secondly, That there are rational grounds for believing, that such a force has been actually exerted in this case. I have now, and formerly, tried to establish the first point by experiment; and I shall endeavour to vindicate the second by a train of geological reasoning, founded upon some volcanic phenomena.

In the year 1788, when I had the pleasure of visiting the coast of Berwickshire, in company with Dr HUTTON and Mr PLAYFAIR, it occurred to me, that this peculiar conformation might be accounted for, by supposing that these strata, originally lying flat, and in positions as nearly level as might be expected to result from the deposition of loose sand at the bottom of the sea, had been urged when in a soft, but tough and ductile state, by a powerful force acting horizontally; that this force had been opposed by an insurmountable resistance upon the opposite side of the beds,—or that the same effect had been produced by two forces acting in opposite directions; at the same time that the whole was held down by a superincumbent weight, which, however, was capable of being heaved up by a sufficiently powerful exertion.

By either of these modes of action, I conceived, that two opposite extremities of each bed being made to approach, the intervening substance, could only dispose of itself in a succession of folds, which might assume considerable regularity, and would consist of a set of parallel curves, alternately convex and concave

concave towards the centre of the earth *. At the same time, no other force being applied, any two particles which lay with respect to each other, so that the straight line joining them were horizontal, and at right angles to the direction of that active force, would retain their relative position, and of course that line would maintain its original straightness and horizontality; and thus the forces exerted being simple, or, if compound, tending, as just stated, to produce a simple result, the beds would acquire the simple curvature ascribed to them by Mr PLAYFAIR, and which belongs to them, in the immediate neighbourhood of Fast Castle; whereas, in Galloway, and in some parts of our coast, particularly near Gun's Green, to the eastward of Eyemouth, where the curvature deviates from that simple character, and becomes in the utmost degree irregular, we must conceive the force to have been more complicated, or most probably to have acted at successive periods.

This conjecture no sooner occurred, than I endeavoured to illustrate my idea by the following rude experiment, made with such materials as were at hand. Several pieces of cloth, some linen, some woollen, were spread upon a table, one above the other, each piece representing a single stratum; a door (which happened to be off the hinges) was then laid above the mass, and being loaded with weights, confined it under a considerable pressure, (fig. 3. Plate IV.), two boards being next applied vertically to the two ends of the stratified

* I am aware, that this expression of parallel curves is irregular; but I can find no other mode of conveying the idea. It is not easy to trace, *à priori*, what form would be assumed by these beds, supposing the whole to be held down by a force so powerful as to prevent any vacuity. It is enough, however, for our present purpose, that the forms of nature correspond with those obtained in an experiment soon to be mentioned.

tified mass, were forced towards each other by repeated blows of a mallet applied horizontally. The consequence was, that the extremities were brought nearer to each other, the heavy door was gradually raised, and the strata were constrained to assume folds, (fig. 4. Plate IV.), bent up and down, which very much resembled the convoluted beds of killas, as exhibited in the craggs of Fast Castle, and illustrated the theory of their formation.

I now exhibit to the Society a machine, by which a set of pliable beds of clay are pressed together, so as to produce the same effect, fig. 5.; and I trust, that the forms thus obtained will be found, by gentlemen accustomed to see such rocks, to bear a tolerable resemblance to those of nature, as shewn in fig. 6., copied from the forms assumed in the machine, by an assemblage of pieces of cloth of different colours.

It still remains for us to consider how this *horizontal thrust* may have been produced. It will be found, I conceive, to arise, as a natural consequence from Dr HUTTON's original hypothesis, according to which our continents have been raised from the bottom of the sea, and elevated to their present positions, by the internal action of the same heat which shews itself externally in volcanoes.

The most obvious mode of investigating these internal actions, in pursuance of the Huttonian view, is to study the external volcanic phenomena, and to consider what variations and modifications would be produced upon these last by the circumstances attending the subterranean action of the same powers.

With this view, I beg leave once more to solicit the attention of the Society, to a scene which I have mentioned in former papers, and to refer to some plates representing it, which I have given in the sixth volume of our Transactions, in my paper

paper "On the Effects of Heat modified by Compression." This scene, as viewed in the *Atrio del Cavallo*, (Plate V. volume VI. figs. 41, 42, 43, and 44.), exhibits in nature a complete section of the old volcano of Vesuvius, now called Somma. The mountain is there seen to be composed of a succession of beds of lava and of cinders, the lava occupying only a fourth or a fifth part of the mass, which is traversed vertically, but irregularly, by numerous rents filled with solid lava; these rents, as I have endeavoured to prove, having undoubtedly served as the pipes through which lateral eruptions have been discharged.

Each of these rents would continue open during the course of the particular eruption by which it was formed, and the lava would flow freely through it; but when the eruptive impulse ceased, it would remain full of the liquid lava, which would congeal, so as to leave the rent, as it now appears, completely filled with hard and solid rock. This new substance welding itself firmly to the extremities of the beds of lava which had been broken across, would bind them together into a species of net-work, and thus the injury done to the mountain by the formation of the rent, would be repaired, and much more than repaired; so that when a new eruption was directed to the same quarter, it would be less able to penetrate than before, and the eruption would be restrained till a fresh rent was effected in some other part of the mountain. A new eruption must thus, in every case, be an act of violence; and we see how a lateral eruption may be followed, as frequently happens, by a discharge of lava from the summit of the mountain, which could not have taken place, had the first lava continued fluid, since it would never have ceased in that case to flow through the lowest aperture, whereas, in consequence

consequence of the congelation of its upper part, that aperture is closed.

What is true of volcanoes, must be no less true of those internal operations, which, according to the Huttonian theory, have been the means of raising all the rocks and mountains from the bottom of the sea into their present situation; and by which the unstratified substances have penetrated the strata, and filled the rents formed in them, producing the veins or dikes so common in this country, just as we have seen the lava of Mount Somma filling the rents through the beds of lava and of cinders.

It cannot be doubted, that the secondary strata must have been greatly strengthened in this way. We may be satisfied of this, by looking at any great dike of whinstone (such as that of twenty or thirty yards in breadth, now opened on the north side of Edinburgh, as a quarry for pavement), crossing and connecting substances of every variety of hardness; also at the two small dikes which appear crossing the loose shale in the bed of the Water of Leith, close to the two mineral springs.

The introduction of this new substance, and the heave of the superincumbent mass, which is its necessary consequence, have been productive of several very important results, which shall be the subject of a future communication to this Society. Let us confine ourselves at present, however, to the convolutions of the killas.

According to the Huttonian theory, that loose assemblage of sand of various qualities, which was destined to give birth to strata of every sort, from gneiss to sandstone, lying originally in a position nearly horizontal, as deposited in beds at the bottom of the sea, and being acted upon from below, on successive occasions, by a heat of great intensity, must be conceived,

conceived, in consequence of the progress upwards of that heat, to have possessed at any particular moment a great variety of intermediate temperatures, between that intense pitch and the ordinary heat of the sea. Owing to these varieties of substance and of temperature, the utmost diversity of character in point of tenacity, from firmness and brittleness, to the most perfect pliability and ductility, must have belonged to the assemblage in various parts.

Let us now suppose a rush to have taken place from below upwards, of any of those bodies in a state of liquid fusion, which on cooling have constituted all our unstratified substances, from granite to whinstone inclusive, and that this fluid was urged by an irresistible force; the consequence must be, that the stratified mass would yield in various modes. Such beds as were in a frangible state, would yield by the formation of rents, and the others, by having their substance forced through and partly dragged upwards. Into these rents and openings the unstratified matter in fusion would enter, and would proceed upwards more or less, according to its fusibility. Whinstone, the most fusible of the set, would flow the farthest, and would even perhaps arrive at the surface, and there discharge itself in the open air as a real lava, or, breaking through the bottom of a deep sea, might constitute a submarine lava, like one of those observed in Iceland by Sir GEORGE MACKENZIE, which, with the characteristics of a lava, have their cavities studded with calcareous spar *. When I met with this ob-



* M. DE LUC, in his Elementary Treatise on Geology, p. 365. art. 311. has undertaken to shew, that my experiments with compression are not applicable to Dr HUTTON's hypothesis. "When calcareous substances," (he says, p. 365.) "are calcined in open air, the fixed air which is produced immediately escapes, "and

servation in Sir GEORGE MACKENZIE's work, it recalled to me what I had seen in Sicily, where the Cyclopian Islands, at the

" and it continues to form until the substance is deprived of its ingredients; but " when a solid body prevents its escape, the particles first formed acquire a de- " gree of condensation proportional to the resistance which they experience, " and they oppose in their turn the same resistance to the formation of other " particles. Under such circumstances, therefore, if the heat be increased, it " produces other combinations of the *fixed air* with the calcareous earth, as in " the experiments of Sir JAMES HALL. But, under *water*, which the particles " of that gass can easily penetrate, in which, collecting in bubbles, they will " rise rapidly, on account of their inferior specific gravity, there can be no im- " pediment to their formation, any more than that of the *aqueous* vapour in wa- " ter, under the pressure of the atmosphere, when the heat is sufficiently in- " tense."

When M. DE LUC says, that in my experiments a solid body preventing the escape of the fixed air, " the particles first formed acquire a degree of condensa- " tion proportional to the resistance which they experience," he must conceive, that during the first application of heat, some fixed air has separated from the lime, and has accumulated in the cavity left in the barrels. But if he will look again into my paper, he will find that I had foreseen this inconvenience, and had guarded against it; that being under the necessity of leaving some cavity, in order to allow for the liquid expansion of the fusible metal, I introduced some water into the barrel, which assuming the gaseous form, and reacting with great power, before the heat had risen to the calcining point, effectually prevented the separation of any *fixed* air. And the same thing would happen at the bottom of a sea that was deep enough. In some of my experiments, made with a compressing force equal to 171 atmospheres, equal to 5693 feet, or about a mile of sea, the carbonate bore the heat of melting gold without calcination, and entered into fusion. Now, it is obvious, that the same result must take place at the bottom of a sea of this depth, and that a shell lying on its bottom, if met by a lava whose heat was equal to that of melting gold, would enter into fusion, and no fixed air would be separated in the form of gas. M. DE LUC's objection, therefore, which is founded on the levity of the substance in that gaseous form, must fall to the ground.

In those experiments which I have made, with a compressing force applied by means of a known and regulated weight, the carbonate has been placed exactly in

the foot of Mount Etna, are possessed of that same character. M. DOLOMIEU considers these and others as having been covered by the sea.

Other unstratified substances would attain, in a liquid state, to positions less and less elevated, as they were more and more refractory; and the granite would be the soonest congealed, being the least fusible of the whole set. In any of these cases, when the opening above was stopt by congelation, the force from below being irresistibly powerful, the liquid, as we have said, must have found room for itself among the strata. This must have been done in one of two modes.

Either, 1st, when the strata were in a hard and inflexible state, in which case, the liquid must have forced itself between stratum and stratum, by flowing horizontally among them, by which means an arrangement would be produced, similar to that of great part of the group in this neighbourhood, consisting of Arthur's Seat and Salisbury Craigs, as well seen from the south-west, where thick beds of uniform basaltic matter, emanating on both sides from the vast massive block in the middle, which rises highest of any, are interposed between thin beds of freestone, lying parallel to each other, and inclined to the horizon at an angle of about thirty degrees.

Or, 2dly, where the strata were soft and pliable, and possessed of considerable toughness. In this case, they would yield on both sides, so as to allow the vein to become wider



in the predicament ascribed to it by Dr HUTTON, when exposed to the same heat under a sea whose pressure is equal to that force.

The fusions, then, which have taken place in my experiments, confirm Dr HUTTON's theory, in so far as it depends upon the action of heat on limestone.

and wider to an indefinite extent, producing a solid unstratified mass. At the same time, they must have made room for that yielding, partly by heaving up the superincumbent mass, and partly by propagating the motion horizontally along their own beds; which last motion will be opposed by their friction and inertia. We should then have three forces more or less opposed to each other; the force of elevation of the liquid, the superincumbent weight, and the friction of the strata. The consequence would be, that the strata, to a certain limited extent, would be thrust horizontally; and so far as that action reached, would be placed in the exact predicament of the pieces of cloth in the old experiment, or of the clay in that before us, (figs. 4. and 6. Plate IV.) We have every reason to expect, then, that our experiments have been a faithful representation of what would happen in a similar case in nature. And the results we have obtained, bearing an exact resemblance to the peculiar forms of the strata of killas, seem to justify that conclusion. If we suppose two such invasions of matter in fusion, to rise parallel to each other, and both under the circumstances above described, their influence exerted in parallel, though opposite directions, would conspire, and the space between them would be still more completely convoluted than where one action alone took place; or would be carried to a greater extent, than merely the double of one of them. Were the neighbouring veins inclined at any angle towards each other, the amount of the effect produced, and the situation of the axes of convolution, would be difficult to calculate; but it is certain, that their effects would still conspire. The complication would be still farther increased along with the amount of the action, if a third vertical burst of liquid matter occurred, so as to enclose a district of the stratified mass within a triangle. We are not possessed of data by which

which the extent of such a triangle may be limited. It seems clear, however, that the greater the superincumbent mass, and the deeper the bed of ductile strata, provided that the force from below were sufficiently powerful, the more extensive would be this influence. And the influence of such a force upon a mass which had, by previous actions, acquired a simple curvature, will account for any deviation from that simplicity. By acting upon a set of beds previously rendered vertical in part, it might thus produce convolutions having a vertical axis, as at Gun's Green.

Let us now suppose, that, after the strata had cooled to such a pitch as to lose their pliability, a fresh quantity of matter in liquid fusion was impelled against them; the whole penetration would now be effected, by rents traversing the convolutions in all directions, and the liquid stone would flow into them, the temperature of the strata not having yet fallen so much as to occasion its immediate consolidation. Some of these rents might penetrate the mass in directions horizontal or nearly so; and these, swelling by the infusion of liquid from below, would form great unstratified masses, and contribute powerfully to the general elevation.

All the junctions of stratified with unstratified matter, which took place during this second stage, would possess a different character from that in the first. In the first, the axes of convolution would of course be parallel to the neighbouring boundary, between the two substances; whereas, in the second case, no such parallelism need be looked for, since the liquid stone would flow in rents, and along surfaces which were produced by the laceration of a frangible mass, in which the axes of convolution would act no part.

According to this view, as all the substances concerned must have lain very deep at the time of the first operation, and as the mass by which this powerful horizontal thrust was performed,

performed, must have been of great bulk and consequent solidity, it seems probable, that the convoluted mass, together with the matter in a liquid state which it had received after its consolidation, would, upon a subsequent application of the elevating cause, be more easily raised than the solid unstratified mass, by whose swellings the convolutions were first effected.

It is natural, then, to expect, that in the various rents and agitations which these masses have evidently undergone, the original mover of the convolution, and the scenes of its meeting with the stratified mass, may very frequently have been left in the deep abyss. In an account which I am now preparing to lay before the Society, of circumstances relating to the revolutions of the earth's surface, I shall have occasion to state a fact, which seems to prove, that the particular mass of killas of which we have been speaking, has undergone one palpable revolution of this sort, by which the mass in its immediate neighbourhood has been left at a considerable distance below it. I must hope, however, that on some occasions, scenes exhibiting the junction of the prime mover with the strata, and in which the axes of convolution shall be found parallel to that junction, may hereafter be discovered, in situations raised up, and well exposed to view; and I recommend this as an object of great interest to geological observers.

Our attention is naturally turned in this case to Granite, as far surpassing in importance every other species of unstratified body; and I have little doubt that it has in fact been the agent of these convolutions. I have not, however, been able to discover any case in which it has performed this function. All the junctions which I have seen belong decidedly to the second class mentioned, and bear marks of an infusion of the liquid granite into hard and brittle strata; and the peculiar junction

junction we have in view, if it does occur at the surface, will most probably be found where granite meets with gneiss or mica-slate, not where it meets with killas *. I have no scruple, however, in presenting these speculations to the Society, although I cannot produce direct evidence in support of them, because I trust that the conjecture is sufficiently plausible to merit some attention; and, above all, because it may be the means of giving rise to much interesting observation, in a department hitherto overlooked, or in which, for want of any connected system, the observations of travellers have been lost.

It will be an object of consequence, that future travellers should attend to this circumstance in the Alps, where a very long ridge of granite is bordered on both sides by strata. The ideas just stated, not having occurred to me till long after I had left that country, I can form no judgment with respect to what inferences may be drawn from the state of facts which are there to be seen. It is certain, that the strata of the Alps are very much convoluted, as mentioned in various places by M. DE SAUSSURE; but whether these forms could reasonably be

* GNEISS is found to pass by insensible degrees into granite; that is, specimens of every conceivable intermediate step have been found. We may then conceive one stage more advanced towards granite than the rest, in which all character of the original stratification is removed, and the mass may have become wholly crystalline, but in which the peculiarity of each stratum may still have left a trace of its character, in the quality of the granite thus produced from it. This seems to explain the nature of a great part of the internal ridge of the Alps, which is possessed, as SAUSSURE mentions, of a stratified character. This mass may, again, be traversed from within by granite in higher heat, and in a state of complete liquidity, which would be more ready than the mass first described, to penetrate into the neighbouring masses. Accordingly, SAUSSURE observes, that those veins, and other masses which, project from the central ridge, and penetrate farthest into the neighbouring strata, are devoid of that stratified character.

be ascribed to the elevation of the central granitic ridge, or whether its arrival at its present place has been connected with their formation, does not appear from any of the facts which I have read an account of, or recollect to have seen. It is probable that the point will not be decided, till that country is visited by a person previously aware of the theoretical views which we have been considering.

A case of such convolutions is mentioned by M. DE SAUSSURE, at a spot which I remember well, the cascade called the Nant d'Arpenaz, on the road to the Glaciers of Chamouni. The strata there consist of limestone, and are bent in such a manner, as to have struck that valuable observer with the utmost astonishment; yet, in our view, they may easily be accounted for by a lateral thrust. In reasoning upon this subject, he finds himself forced to contemplate the possibility of those convolutions having been the work of subterraneous forces, occasioned by internal fire; but he abandons the idea almost as soon as he has formed it, from the reflection that this mountain, and its neighbourhood, shew no indications of the action of fire. After a good deal of argument, he at last (though with seeming reluctance), submits to the idea, that these great results may have been the work of crystallization; the insufficiency of which reasoning, Mr PLAYFAIR, in his *Illustrations*, art. 207. has clearly pointed out.

Since this paper was read in the Society, I have met with a very interesting account of a set of rocks in Argyleshire, whose position and arrangement greatly resemble those which I have been describing, and among which, one fact occurs which seems well worthy of notice. (This account is contained in the Edinburgh Encyclopædia, under the article ARGYLESHIRE, and was written by Mr ARCHIBALD CAMPBELL,

BELL, whose recent death is much to be lamented). The strata there described occupy a great extent of coast, nearly forty miles; they consist of strata of slate and limestone, sometimes alternating, and seem to belong to the class of killas. Their convolutions are less elevated and less abrupt than those we have been describing, but in all other respects exactly resemble them. One circumstance is mentioned by the author as a simple fact, and without view to theory, but which seems, in a striking manner, to accord with what we have endeavoured to establish. "Where the strata (he says) "consist chiefly of limestone, with few, or very thin stra- "ta of slate intervening between them, the thickness of a "stratum is frequently five or six times greater at the sum- "mit of the wave, and at the hollow where it begins ascend- "ing to form the next wave, than at the intermediate point, "where the contrary flexure takes place."

I recollect no such difference as to thickness among our strata; but the circumstance might be expected, upon our theory, to take place, when the beds acted upon by the horizontal thrust were not only flexible and tough like cloth, but also ductile, and capable of being elongated by pressure. For supposing the thrust to have continued, after the folds had, to a certain extent, been accomplished, it is evident, that the horizontal pressure acting in some degree at right angles to the beds, where the contrary flexures took place, and of course where their position was most erect, would tend to elongate and thin them at those places, and would have a contrary effect, if any, at the summit and hollow of each arch, where the stratum for a short space occupies an horizontal position. This unexpected fact tends then, I conceive, in a striking manner, to confirm our theory.

When we undertake to account for the convolutions of the killas, by the forcible invasion of granite, one material point is to show, contrary to the opinion entertained as yet, I believe, by all geologists but those of the Huttonian school, that granite has been the latest formed of the two. The scenes in Galloway, where these substances meet, prove this, I conceive, beyond dispute; but they prove it over much in one point of view, since they show the arrival of the granite at its present place, to have been posterior, not only to the formation of the strata of killas, but also to their convolutions when in a state of softness, and to their subsequent consolidation. It must, therefore, be admitted, that this mechanical effect cannot have been produced by the particular granite there exhibited; but the circumstances which the junction presents to view, authorise us to believe, that another granitic mass, acting in a former period, with the same powers, but when the killas was in a soft state, has been the agent of these convolutions. It becomes, therefore, of great importance in this inquiry, to make a clear statement of the mode in which the introduction of the granite into its present place has been effected in this authentic instance.

In that view, I shall ask permission to lay before the Society, the details of some observations, which, in general terms, I mentioned in a former communication.

In the year 1790, I read an account in this Society of my observations on one of those granitic masses which reaches from Loch Ken to the valley of Palnure, a short abstract of which has been published in the History of the Society at that period. It is there stated, that I had traced the junction of this mass with the neighbouring rock, in a complete circuit of it, which I made in company with the Honourable Thomas Douglas

DOUGLAS (now Earl of Selkirk), and that in "all this extent, "where the junction of the granite with the schistus was visible, veins of the former, from fifty yards to the tenth of "an inch in width, were to be seen, running into the latter, "and pervading it in all directions, so as to put it beyond all "doubt, that the granite of these veins, and consequently of "the great body itself, which I observed forming with the "veins one continued and uninterrupted mass, must have "flowed in a soft or liquid state into its present position."

I have since, on many occasions, visited the same place, and every fresh observation has confirmed my first impression, and has served more and more to convince me, that the granite is posterior in formation to the killas, and has flowed into its present position from below upwards, in a liquid state, whilst the stratified mass was hard, or at least sufficiently so as to break with sharp angles, and to allow the liquid granite to mould itself upon its fractures.

I observed every circumstance that might be expected in such a case. I saw the granite meeting the strata in every possible angle. In one case, which occurs in the bed of the river, at the High Bridge of Dee, I saw the bounding surface of the granite dipping at an angle of 45 degrees from the centre of the granitic mass, and the strata lying upon it, in what (in the Wernerian language) is called a *conformable position* to the granite, and corresponding exactly to what they have held out as the mode in which the granite always meets the strata.

The Hill of Lauren, which occupies the south-west of Loch Ken (on the side of the granitic mass, nearly opposite to the spot last mentioned) presents a junction of these bodies, whose character is as completely different as could well be conceived. At the southern extremity of the ridge, the junction is well seen, characterised by large features. The strata

are here nearly vertical, stretching from north to south. The line of junction, which occurs on the face of the hill, towards its summit, cuts the strata at various angles, sometimes nearly at right angles; and the strata thus abutting endwise against the granite, the two substances are, as it were, spliced into each other. The granite enters among the strata in several large dikes or veins, which at first are a hundred yards in wideness, but which rapidly taper away to a small breadth.

Along the whole line of junction, from this point northward to the burgh of New Galloway, at a distance perhaps of two miles, a scene of almost perpetual interest presents itself, being a repeated display of the penetration of the stratified mass by the granite; and the rock being but thinly covered with soil, these circumstances come frequently into view, and particularly at the spots known by the name of Sight Knoll, and the Hog Knoll. In 1788, I had seen an instance of a dike penetrating the strata, and distinctly emanating from the mass of granite, in such a manner as to convince me that it constituted with that mass one uninterrupted and identical substance. On my return in 1807, when the subject had acquired a peculiar degree of interest, in consequence of the discussions carried on in this Society, the progress of vegetation had been such as to conceal it entirely; but being well convinced of the reality of its existence, I determined to recover it, and employed several workmen to clear away the earth and vegetable matter from the most interesting spots. At various distances, within fifteen or twenty yards from the main granitic mass, several masses of granite, or portions of veins, made their appearance, which I conceived to be emanations from the great mass, although their junction with it was concealed. I was anxious to trace some of these to their source; and after the labour of several days, I at last succeeded with one

one of them, though I cannot tell whether or not this was the same which we saw in 1788. Having in this instance traced the communication between the vein and the main mass, I almost exclusively devoted my attention to it, and, I trust, not fruitlessly. Besides exhibiting by a drawing, (Plate V.), the appearances of this very interesting spot, which is called the Windy Shoulder, I procured a more expressive representation of it in the form of a model, which now lies before us *.

The Windy Shoulder is situated nearly opposite to the point on the other side of the loch, at which the Shirmers Burn enters it; the entry bearing from it E. 10 N. by true bearings.

The strata, which continue here in a vertical position, meet the granite on the surface at an angle of about 45 degrees. The dike runs for about twenty-three or twenty-four feet between two of the strata; it then starts across them, and resumes nearly its first direction, which it pursues for a considerable distance more; making in all ninety feet from the granite.

I was at the greatest pains to examine the circumstances attending the exit of the vein. The earth and vegetation were carefully removed. Some parts of the surface of the rock were dressed by a mason, and a powerful temporary polish was given to that surface by water dashed upon it. All these precautions tended to confirm the identity and continuity of the two rocks, which appeared more and more conspicuously after every fresh exertion that was made to remove the influence of external actions.

Several

* I have also presented one of these models to the Geological Society of London.

Several small veins were found to cross from the dike to the main mass, having an identity of substance throughout. That which is represented in the model, incloses a triangle of killas, whose sides are seven feet by five; the strata being here moved by a small shift. Many other smaller veins occurred of the same kind, and in the same position, which have been omitted as too minute. The dike, near its exit, also exhibits a fine example of another most important and instructive circumstance in geology. The granite actually contains a mass of the stratified body included in its substance, and surrounded on all sides with granite.

In the immediate neighbourhood of the granite, to the distance of a foot or two, and not more, the stratified matter has in many instances assumed a highly micaceous character, so as to deserve the name of Mica-slate, and perhaps of Gneiss.

Every thing seems to indicate that those dikes, which appear on this hill in such abundance, and which have been shewn in this case to be continuations of the same mass, have come from below; and this opinion seems to be strengthened by the fact, that on the north-west side of the same Windy Shoulder, the granite at the junction seems to dip under the killas. From the shape of the ground, sinking rapidly below the line of junction, I expected easily to reach the granite, by blowing up with gunpowder the killas at some point beneath this line. The first blast did not succeed; but a second, near the junction, was very effectual. It rent the mass at right angles with the junction, by which the granite is seen actually to dip under the killas, as at first supposed, with an irregular line.

The surface being dressed at the emergence of one of the small veins from the great mass, the following curious fact presented itself. To the distance of about three inches within

in the junction, the progress of the granite vein was visible through the outer part of the granitic mass; the substance of which last was there in a confused and undefined state: farther in, the vein spread wider, and in the space of a few inches more, was quite lost in the general mass. I account for this by supposing, that the granite near the junction being partly cooled, and partly contaminated chemically by the contact of the strata, is rendered less liquid than elsewhere, and that a quantity of more thoroughly liquid matter occasionally and subsequently forces its way through this barrier, and through the contiguous substances.

We have thus a representation in miniature of one of those events which I conceive to have happened on a large scale in the formation of that mass, which, in its present elevated situation, constitutes the body of our island. One portion of liquid granite, forcing its way among the strata of killas, then lying low and flat at the bottom of the sea, and in a state of softness and pliability from semifusion, has, by its swelling, pressed them into a convoluted shape, and has taken its station among them. By the progress of cooling, this whole assemblage, both stratified and unstratified, has become susceptible of laceration, and has been rent by subsequent forces acting from below. A fresh stream of liquid granite has penetrated into the rents so formed, and has swelled and spread among the convoluted and broken killas, so as frequently to occupy an extent of many miles, constituting one of our external granitic masses. But this last-mentioned invasion, though doubtless producing a comparative elevation, has still, I conceive, taken place at the bottom of a deep sea, where our sandstone strata have since been deposited, on the rock both of killas and of granite; and where the fragments composing that sandstone have undergone the moderate heat by which they have

have been converted into stone. The whole assemblage of granite, killas and sandstone, having been raised into the position which they now occupy, by revolutions of a still posterior date.

The present order of things may thus be accounted for, by a set of progressive steps of elevation, without the necessity of supposing, everywhere, an interposed submersion. Not that I am disposed to deny the occasional occurrence of such submersions; which may naturally be expected to have taken place, in consequence of the voids, which could not fail to be produced by so many undoubted elevations.

The circumstances thus stated are different, as may be observed, on the Hill of Lauren, from those of the junction on the bed of the Water of Dee, as described above; but such differences are perfectly consistent with our view of a liquid forcing its way among a set of beds previously consolidated and indurated.

The conformable junction at the Water of Dee, is the only one which, being ambiguous, does not contradict the Wernerian view of the general system; a view that is completely excluded by the perturbed junction at Lauren. Now, both of these junctions are consistent with the Huttonian theory, according to which, a diversity of this sort was to be expected in such circumstances. It is very obvious, that the substance of a vein must be of newer formation than the rock through which the vein passes; and it is no less obvious, that where the angular fragments of one substance are contained in another, the substance thus contained must be the older of the two. In these observations, we have seen that two veins of granite, which penetrate the killas, do constitute one continuous mass with the great body of granite which lies below, and are of course of contemporaneous formation with it. The conclu-

sion,

sion, then, is irresistible, that the granitic mass of Lauren is posterior in formation to the killas which lies above it. This admits of no other rational solution, but by supposing, as Dr HUTTON has done, that the granite, in a liquid state, has flowed in its present position, and that emanations from that liquid penetrating into the rents of the strata, have formed the veins.

The same general facts which have been observed with respect to the granite of Lauren, and the district of which it makes a part, occur also in the other two granitic masses of Galloway, as I have found by a particular examination of their junctions with the strata.

I was convinced of this as to the mass which crosses Loch Doon, by a circuit which I made of that mass in 1807, accompanied by Mr JARDINE of this Society. In the island upon which the Castle of Doon stands, a fine example occurs of angular fragments of killas, included in the granitic mass near the junction. The dressing which this stone has received from the hand of nature, renders this very conspicuous, as I shall have occasion soon more particularly to state to this Society.

I have at different times, though not with the same regularity, examined various places, where the third granitic mass in Galloway, of which the Mountain of Criffel makes part, meets the surrounding strata; and I have seen dikes of granite near the junction, and other circumstances leading to the same conclusion, particularly on the sea-shore, at a place known by the name of the Needle's Eye, which approaches to the granite boundary; and also on the side of Criffel, which lies directly opposite.

According to a rough computation, each of these three granitic masses occupies a space of about six miles by four.

Their positions, and bounding lines, which are very irregular, are laid down, as nearly as we could guess, in the map of the stewartry of Kirkcudbright, now on the table. There is good reason, I conceive, to suppose, that all granitic masses are related in a similar manner to the neighbouring strata, where such strata are found penetrated by granitic veins. Such veins were first observed, I believe, by M. DE SAUSSURE, in the Valoisine, and also at Lyons and Semur. Dr HUTTON examined them with great care in Glentilt, in Arran, and in other parts of Scotland, and upon these observations founded his bold and original theory with respect to granite. Mr PLAYFAIR has not failed to make ample use of those which he has more recently discovered at St Michael's Mount in Cornwall. All the appearances which I have witnessed in Galloway, as to the relative situation of granite, and the contiguous rock, accord with the doctrine of Dr HUTTON, and tend, I conceive, to confirm his views.

It might be rash to extend universally to all granite those conclusions which have been established by particular observations; yet as no instance warranting a contrary inference has occurred since the subject began to be inquired into, enough seems to have been done to contradict the generality of that leading maxim of the Wernerian doctrine, that the order of position which rocks maintain with respect to the centre of the earth, denotes the order of formation.

It is an important circumstance to observe, that the substance whose formation is thus proved to be prior to that of the granite of Galloway, is the killas, or grauwacke of the German school, which, holding only a middle station among stratified bodies, as to antiquity, is considered, according to their doctrines, or of formation long subsequent to that of any kind of granite. The quality of this stratified mass, from

from one side of the island to the other, seems to be uniform throughout, except in the immediate neighbourhood, or contact of the granite, where it assumes a micaceous character, approaching to the nature of gneiss or mica-slate. This furnishes a most notable indication of the action of heat; since the granite, by its local intensity, has performed the very effect which Dr HUTTON ascribes to the general heat below, as acting upon the lower beds, and converting them into gneiss.

Another circumstance of importance is, that at the Rae Quarry in Peeblesshire, nearly in the middle of this mass of killas or grauwacke, a bed of limestone occurs, interstratified with the killas, and of course coeval with it, which bed contains shells in abundance. Now, as this mass of killas has been proved to be of older formation than the granite of Galloway, it is obvious that granite is here found to be of a formation posterior to the existence of living animals.

The relative age of granite and of sandstone has not been decided in any case that I have had occasion to observe, and is a point of considerable importance in geology. Nothing seems as yet to prove, that granite may not have flowed up against a stratified mass, possessing, in some of its parts, the properties of sandstone; I conceive, however, that these properties will nowhere be found to belong to that part of the stratified mass which lies close to the granite. For we have seen, on the Lauren, that killas near the junction has been changed into gneiss or mica-slate by the heat of the granite, as we conceive; and there is still stronger reason for believing, that a similar change would take place on sandstone in the same circumstances. We ought, therefore, to find, that while a remote portion of the stratified mass retains the properties of sandstone, that which lies but at a little distance from the

granite, has been converted into gneiss or mica-slate, or at least into killas; and this view is confirmed by the circumstance, that no example has been produced of granite veins traversing sandstone.

I expect, then, that granite and sandstone will not be found to occur in immediate contact, unless where the latter has been deposited upon the former. In the junction which is seen in the bed of the river near Jedburgh, and in that at the Siccar point, on the coast of Berwickshire, we see that the sandstone has evidently been deposited in the state of loose sand, on killas then existing as a hard and shivered rock. We may easily conceive, that sandstone has been deposited in a similar manner on the granite of second invasion; and that, in a similar manner, it has been consolidated and elevated.

I have not met with an example of this; but such may be looked for, and will be interesting in geology. I have just learnt from a young friend, member of this Society, who has spent a few days in the course of this year at the Cape of Good Hope, that upon the side of the Table Mountain, a junction occurs of granite with killas, and that, higher up on the hill, the same granite actually meets with sandstone. I hope soon to have the means of laying before this Society the details of these observations.

III.

# PLATE I.

*Fig . 2.*

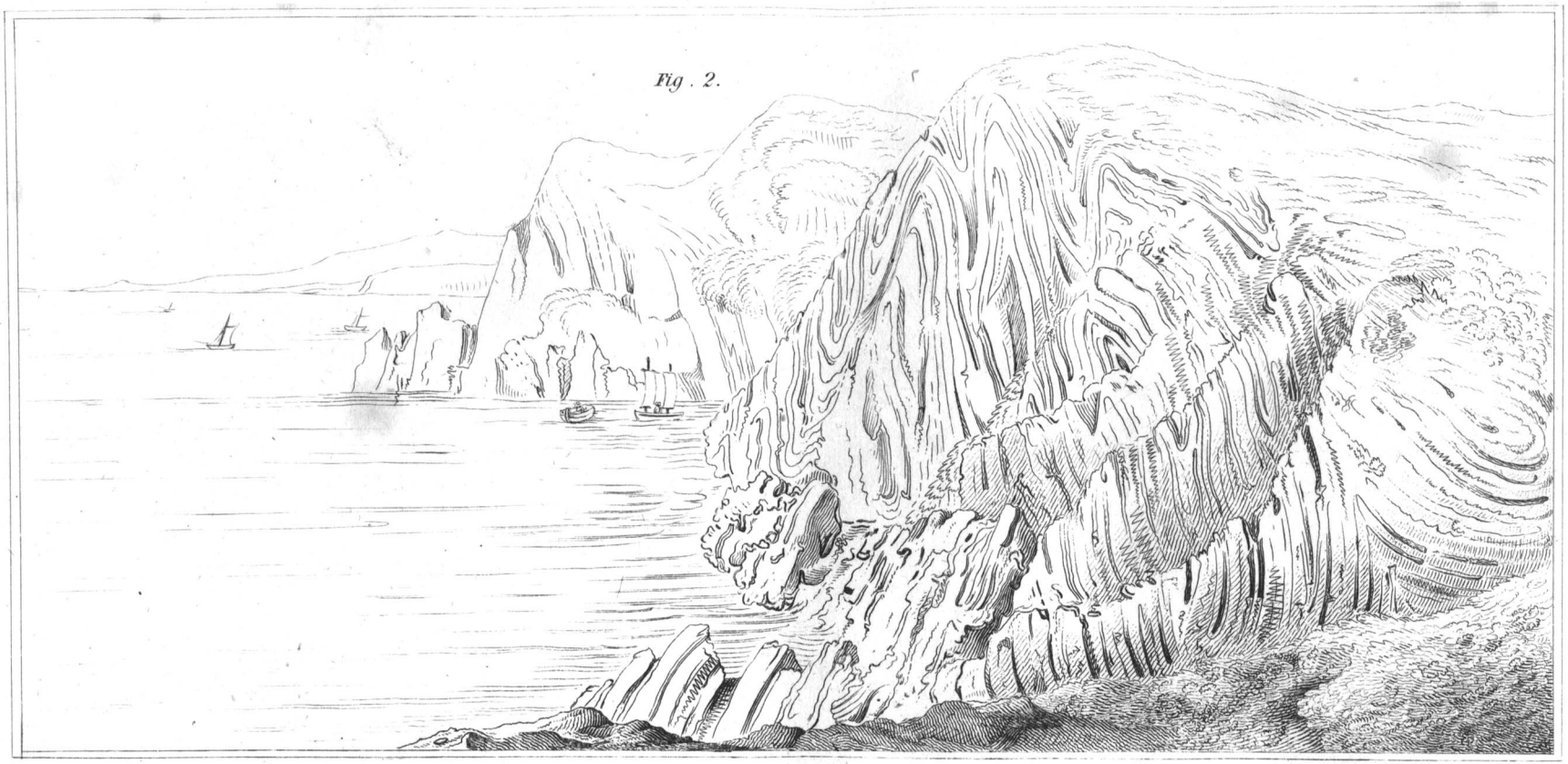
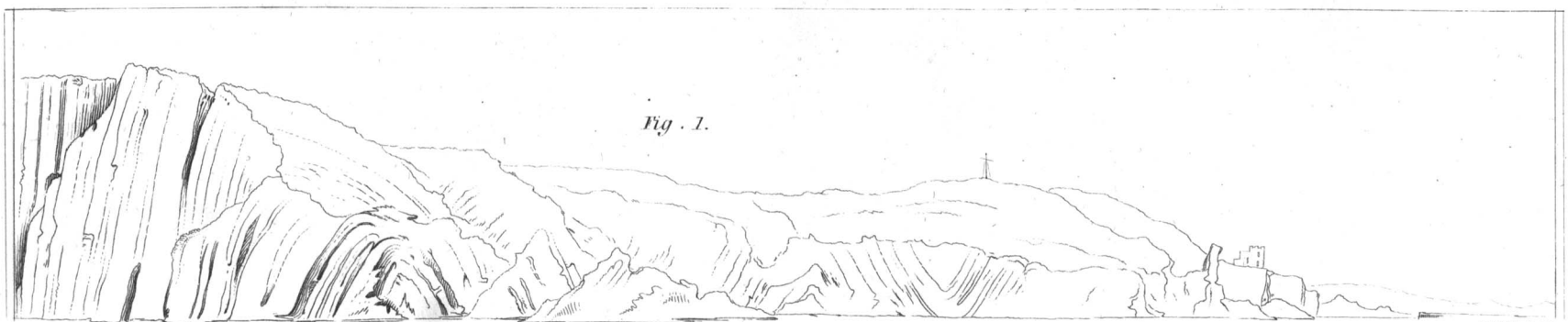


*Fig . 1.*

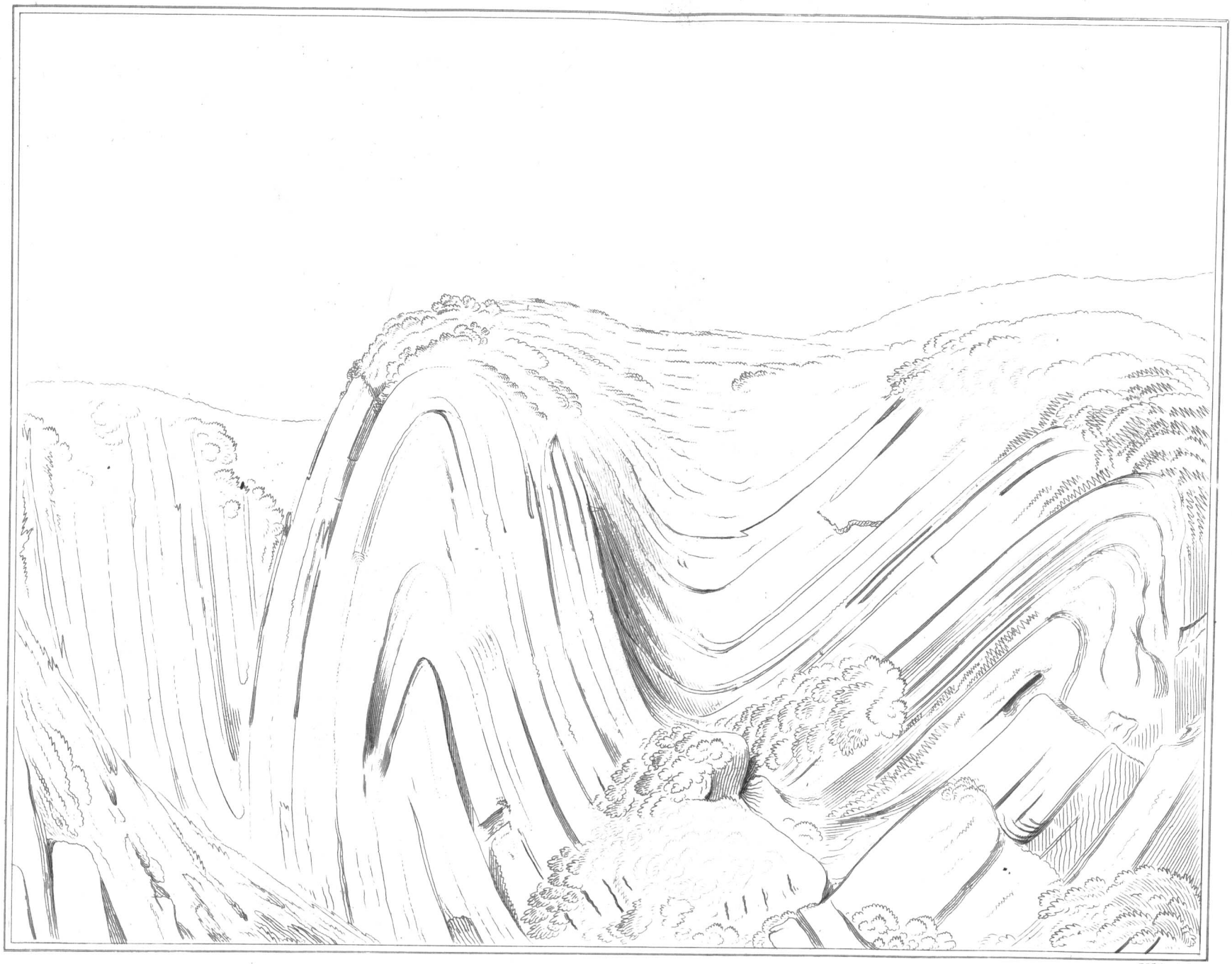


*J. Moffat Sculpt.*

PLATE II.

J. Moffat Sculpt

PLATE III.



J. Moffat Sculpt

PLATE IV.

*Fig . 1.*

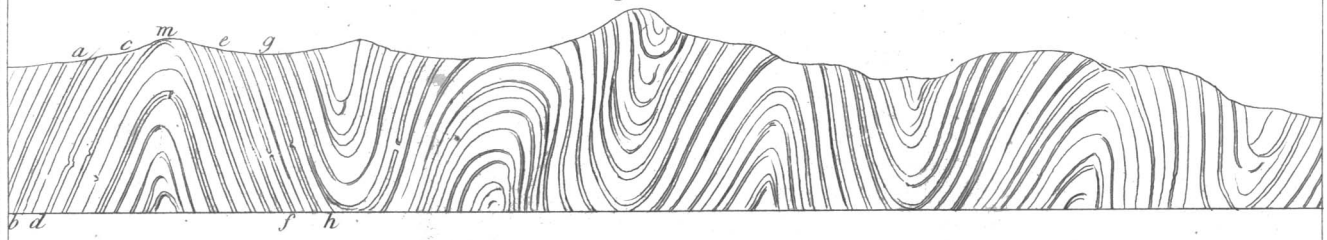



*Fig . 2.*

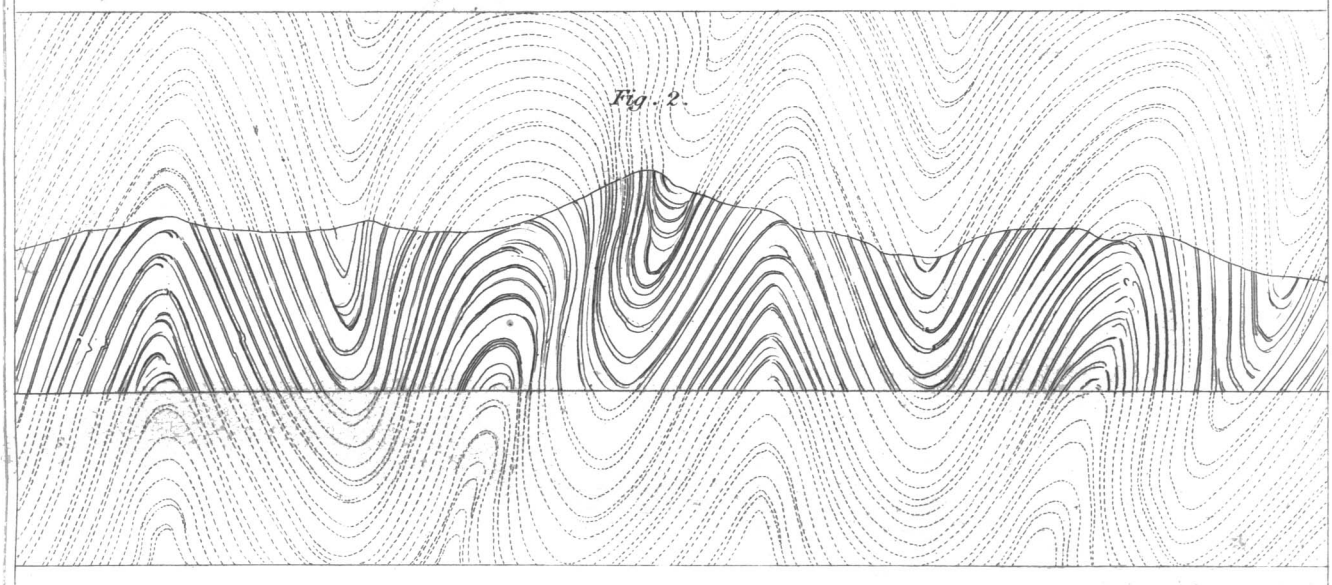
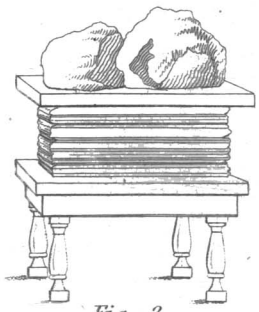


*Fig . 3.*



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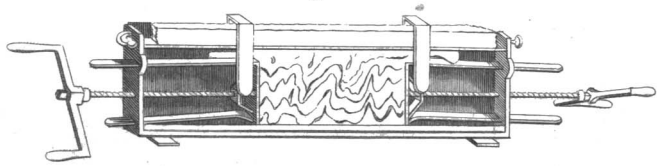

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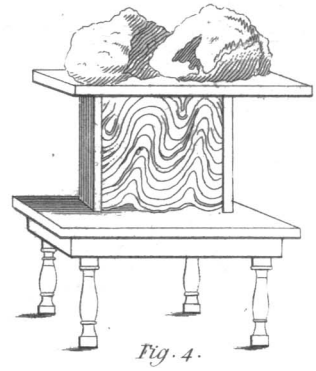
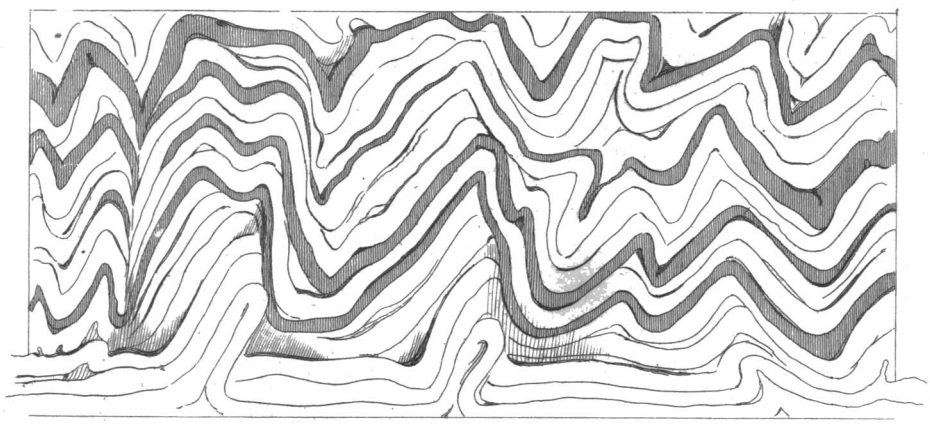
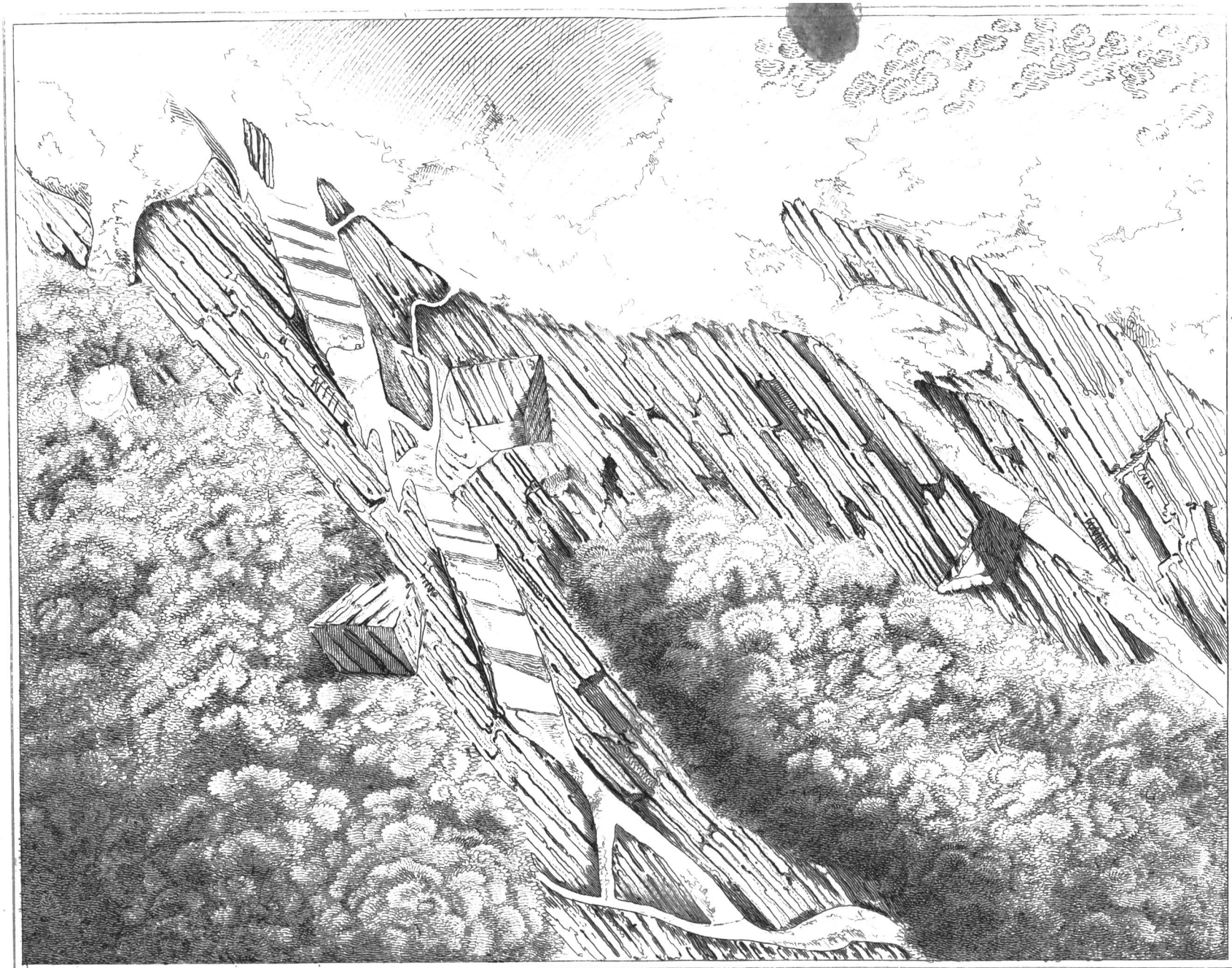


*Fig . 6.*



J. Moffat Sculpt

PLATE V.



J. Moffat Sculp.t