2. *On the CAUSES producing FOLIATION in ROCKS; and on some observed cases of FOLIATED STRUCTURE in NORWAY and SCOTLAND.* By DAVID FORBES, Esq., F.G.S., A.I.C.E.

THE study of the metamorphic and crystalline rocks has of late years attracted much attention, and the researches of Darwin, Sharpe, and others have brought forward many facts particularly interesting and important.

It will probably, however, be admitted, that, notwithstanding the labours of these geologists, great difference of opinion exists as to the formation and structure of these rocks, and that at present we are not in possession of sufficient data to enable us to place the question upon a firm basis. It is therefore of importance that as many observations as possible be laid before geologists working at this subject; and it is consequently hoped that the present communication may not prove unserviceable in advancing the inquiry.

The observations here brought forward have with a few exceptions been made during a residence of some years in Norway, where the foliated rocks play so important a part. The others are the result of some short excursions in Scotland made for the express purpose of comparison.

For a long period, and it may be said until late years, it was the generally received opinion that the lines of foliation in rocks were lines corresponding in direction or identical with the lines of stratification, and were produced by the alteration of these lines by metamorphic action. This view of the case can no longer be considered tenable, and the observations of many geologists have shown that foliation frequently takes place at a different angle to that of stratification.

Darwin seems to consider this as almost invariably the case, and remarks that, even should they correspond in the strike, they would not correspond in the dip; and Ramsay, in his paper "on the Lower Palæozoics of North Wales," considers that there is no doubt that in many cases the foliation of the Anglesea rocks runs much across the dip. Many other observers might be quoted on this point; but, on the other hand, several geologists of high reputation seem to consider these cases as exceptional, and that in general the foliation is developed according to the lines of stratification.

(Case 1.)—As bearing on this point, I observed in the Highlands of Scotland, near Crianlorich, on the road to Tindrum, in Perthshire, regular beds of a blue limestone, resting upon a dark greenish-grey mica-schist, and dipping 32° N.E., with an inclination in the course of the strata of 24° S.E. This limestone was most completely foliated by the introduction of small plates of white mica, so that it often could hardly be distinguished by the eye from gneiss. Here the foliation in the limestone appeared perfectly identical with the planes of bedding, as shown by the coloured bands and large beds of the limestone. This was apparently also the case in the gneiss; but in the crust or stratum above the limestone on the surface of the ground the foliation was very twisted and irregular.

(Case 2.)—At Jægersborg, near Christiansand, in Norway, the foliation of a highly crystalline white limestone in schist was found to be parallel with the apparent lines of bedding (see fig. 1). It

Fig. 1.—Section of foliated limestone and gneiss at Jægersborg, near Christiansand. (See also page 173.)

will frequently, however, be found very difficult to prove satisfactorily when the line of foliation coincides with that of bedding; as in many cases, and particularly in Norway, there are rarely any normal stratified beds in so close contact as to render the matter perfectly indisputable.

Keilhau seems, however, to consider the cases where the foliation does not agree with the stratification as exceptional, and mentions*, evidently with this impression, a case where he has observed in Thelemarken a thick bed of very characteristic gneiss situated amongst other crystalline strata in which the mica and gneiss structure, as a whole, was developed at right angles to the real planes of stratification.

It is possible also that the coincidence of foliation and stratification would be found much more frequently the case, were it not for the very general occurrence of the disturbing influence of a previously existing cleavage-structure,—or of a more or less inclined position of the beds during the time foliation occurred,—or, lastly, of the intrusion or approach of igneous rocks.

* Norske Mag. for Naturvidenskab, New Series, vol. i. p. 70.

Where cleavage is previously existing in rocks, it appears very reasonable to suppose that the folia would arrange themselves along the lines of cleavage, which may be regarded as so many cracks or vacuities extremely convenient for the development of crystalline matter. These spaces probably may be much more diffused than would appear at first sight. For we may suppose matter compressed so as to give it a cleavage-structure, and this pressure then removed or only relaxed: the elasticity of the mass itself (however small) would naturally cause a certain degree of relaxation throughout its entire body, giving it, in consequence, a general porous structure; the pores being of course elongated and flattened in the direction of the planes of cleavage, or at right angles to the compressing force. Afterwards, when the foliating forces, which cannot be other than chemical, come into action in a mass in this state, we may fairly expect that the lines of foliation will be identical with these lines;—which seems to be the reason that we so often find the lines of cleavage and foliation parallel. In case the chemical action here alluded to was so intense as to obliterate the cleavage-planes, then we have no guarantee that the lines of foliation will follow these planes.

In some cases possibly the cleavage may have taken place after foliation, and in some measure accommodated itself to these lines as offering the least resistance.

The superincumbent pressure, likewise, must be taken into account in considering the arrangement of foliation; as it appears likely that this would act against any vertical position of the crystals; and the elongated and flattened appearance generally seen in the crystalline minerals inducing foliation appears doubtless the result of this action.

Foliation and cleavage have both, I believe, been referred by some to electric or magnetic action; but I am afraid that it is too general to refer to these causes effects that we do not at first sight comprehend. If it be found, as I believe to be the case, that electricity traverses more easily in the direction of the cleavage-planes than across them, I think this argument has no further weight than as confirming the porous structure here supposed as consequent on the relaxation of a previously applied pressure; as it seems very probable that the resistance offered to the current in this direction would, in consequence, be less than across the grain,—and we know that most non-metallic mineral substances are very imperfect conductors, whereas space, or air rarefied by heat or exhaustion, are conductors, though not equal to the metals themselves.

Darwin and Sharpe (the latter in his paper on the Highlands) put forward the view that cleavage and foliation are identical,—that is, are parts of one and the same process, the former being but the first stage of the latter. To this I must object, and I believe that they are not only distinct phenomena, but that the causes producing them are also distinct; as in foliation we must have chemical action brought into operation, whilst in cleavage no such action is requisite, and the phenomena admit of a mechanical explanation.

We can only regard the truly cleaved rocks as mechanical aggregates; and the more foliated or crystalline such rocks become, the less perfectly do we find the cleavage-planes developed.

The microscopic researches of Sorby* and others have proved that in slates possessing the most perfect cleavage we have a mass composed of minute rounded grains of mica, decomposed felspar, quartz-sand, phosphate of iron, and other substances, all easily recognizable, and having all the characters of a waterworn deposit, apparently not in any way mineralogically different from the state they were in when originally deposited as a sediment. In fact they are nothing further than a consolidated mud, in which a lamellar structure has been induced by mechanical action; and the synthetical experiments of Sorby on this subject give the most conclusive evidence as to the mechanical nature of cleavage!

Admitting that cleavage and foliation were identical, how inconsistent with the parallel structure of cleaved rocks should we find the numerous cases of complicated and contorted foliated structure, which are so common, and where it is almost impossible to believe that these contortions have arisen from any twisting of the lines, either of stratification or cleavage, as the mechanical forces then brought into play would be so compound as hardly to be conceivable.

It must, nevertheless, be admitted, that the lines of foliation and the planes of cleavage do often agree and are parallel to one another; and several opportunities of confirming this have come under my observation.

(Case 3.)—In Espedalen, Norway, the foliation of the mica-schists and hornblende-gneiss is parallel to the cleavage of the clay-slates of the district, both running nearly E. and W., and dipping N. at various angles from 10° to 50° . The line of bedding cannot be determined, but seems probably to be in the line of cleavage.

(Case 4.)—On the side of Loch Lomond, at Luss, I observed that the clay-slate there quarried has a cleavage-strike of N.E.—S.W., and dip of 70° S.; the stratification being uncertain. A little further north the mica-schist appeared (the points of contact were hidden by the soil), and the strike was found to be 65° N.E.—S.W., with a dip of 60° to S.; which may be regarded as nearly coinciding.

(Case 5.)—In the slate-quarries at Luss we have also instances of the cleavage-lines being bent by coming in contact with quartz-veins, just as described by Mr. Sharpe†; but I found that, where these veins occurred, not only were the ends of the cleavage-planes bent, but around the quartz-vein there was developed a distinct curved foliation, induced by a deep-green chlorite, with here and there a little mica. This foliation sometimes extends for a short distance into both the slate and the quartz, but appears quite independent of the cleavage, though with an evident relation to the curves of the veins themselves, which are very irregular. The quartz itself is

* Edin. Phil. Journal, July 1853.

† Quart. Journ. Geol. Soc. vol. v. p. 117.

sometimes foliated by the chlorite, so as to resemble a green mineral. The annexed diagram, fig. 2, will give an idea of these conditions.

Fig. 2.—Quartz-vein in clay-slate at Luss, Loch Lomond, Scotland.

In general in foliated rocks there is a totally altered structure, and we have many instances where they hardly possess any character in common with cleaved rocks.

Thus, even the parallelism of the lines cannot be considered invariable; we certainly have some cases where the foliation coincides with the bedding and not with the cleavage, and the property of splitting into laminæ in certain directions is often not possessed by foliated rocks at all, particularly if the foliating mineral be not itself of laminar structure.

We find certainly that in considerable districts of country the cleaved rocks are totally different from those in another district, just as one formation might be expected to differ from another; but it is doubtful if we ever find such abrupt and total changes as come in such rapid succession in the beds of foliated rocks.

(Case 6.)—In a quarry on the roadside about two miles from Crianlrich, in Perthshire, I found the strike N.W.–S.E., with dip 30° N.E.; the rock consisted of very thin beds which alternately presented the character of perfect and highly micaceous mica-schist and of extremely quartzzy schist, so that it was not possible to call one single linear foot by the same name. Other cases more unusual will be noticed in the course of the communication.

The production of foliated structure is not confined to the introduction of laminæ of one or two mineral substances, as mica, hornblende, chlorite, &c.; it may be produced by minerals widely different in chemical composition and mineralogical character, and the presence of which is only to be accounted for by the supposition that the constituent elements must have been at hand in the unmetamorphosed rocks, although in a different state of combination.

It is apparently also a necessary requisite in the production of foliated arrangement, that the minerals thus formed be of a different chemical constitution to those composing the mass of the rock itself.

I may here bring forward some instances of very distinct and determinate foliation produced by minerals not usually found under these circumstances.

(Case 7.)—On the heights immediately above Christiansand, in Norway, probably at a distance of two miles from the town, the section represented by fig. 3 was taken. The prevailing rock is here gneiss (*a a*), composed of black mica, white quartz, and white and red felspar, with sometimes specks of black oxide of iron. The strike of the foliation runs nearly N. and S., and the dip varies from

Fig. 3.—Section of gneiss, limestone, and granite, at Stampekjærn, on the Heights above Christiansand, Norway.

30° to 45° East. The strike inclines in course of the foliation about 10° towards S.

The section here represented is E. and W. nearly, or at right angles to the strike; and, coming from the east, we have first the gneiss, which sometimes is slightly granitic, but always preserves its regular foliated structure;—next we find a bed, about 14 feet thick, of coarsely crystalline pink limestone, in which a beautiful foliated arrangement is visible (as shown in the specimens now exhibited), by the presence of numerous small crystals of a green augitic mineral and white scapolite. Sometimes these minerals are so abundant as to present a very striking appearance, at other times we have only single lines of these crystals, with the intermediate limestone free from them; in all cases, however, both in this bed and throughout, they arrange themselves in distinct lines, which are invariably parallel to the lines of foliation of the gneiss itself. No tendency to split along these lines is present. Next we have some small beds (c c) of what may be termed gneiss, but in which the same augitic mineral appears to replace the mica, giving the mass a green appearance. The beds between this and the granite are of limestone, similar to the above, but of white colour and foliated in the same way.

The granite (A), which now shows itself and is about 10 feet thick, is composed of white felspar, quartz, and black mica, is coarse-grained, and follows the general line of the beds. On its sides, where it touches the limestone, it is in some places impregnated to a small depth, but very strongly, with the same green augite; and in cavities at the junction we find aggregations of garnets, scapolite, and augite, sometimes finely crystallized.

Beyond the granite we have beds of white limestone like the former and similarly interstratified, if we may use the term, with beds of augitic gneiss, until we again come to another and larger vein or bed of granite, of similar character to the former band, and under which we again find the regular gneiss, still preserving the unaltered

line of foliation. In the different beds of limestone I did not observe any mica whatever.

(Case 8.)—On the other side of Christiansand, about five miles from the town, west of Torresdale River, we have very extensive beds of a white crystalline limestone, very similar to, and foliated like, the last-mentioned. A section is seen in fig. 4, and represents a quarry near the top of a mountain called Pusaasen.

Fig. 4.—Section of gneiss and limestone at Pusaasen Mountain, near Christiansand, Norway.

- a. Granitic gneiss; not distinctly foliated.
- b. Quartzose, brownish, foliated gneiss.
- c, c. White, crystalline, foliated limestone (about 15 feet exposed).
- x, x. Indeterminable broken and weathered mass, filling joint.

The section is taken about parallel to the strike, or 40° N.W.—S.E. The strata incline towards the south, and dip at 15° S.W. At the top of the section on the north side we have a considerable mass of gneiss (a), without a grain (or nearly granite-gneiss), with no foliated arrangement apparent, very quartzzy, and containing but very little mica. This abuts against a bed of very quartzzy gneiss (b), where the lines of the foliation give the appearance of its having been doubled up. This gneiss contains numerous crystals of iron-pyrites in the lines of foliation, and by their oxidation it has acquired a rust-brown colour. Between these two gneiss rocks we have a joint filled up with a broken, decomposed, and weathered mass (x), of undistinguishable character; but below the whole is a large bed of white crystalline limestone, foliated by lines of augite-crystals, precisely as in the last case; the foliation is here parallel to the upper and lower surfaces, or the foliation, of the gneiss above it. About 15 feet of the limestone bed is uncovered; the lower 3 feet is coarser-grained than the upper 12 feet. At a few spots mica is seen present, foliating the limestone in a similar direction.

(Case 9.)—On the same side of the Torresdale River, and about two miles west of the last locality, can be seen an extremely interesting

case, in which the lines of foliation are carried out quite independently of the nature of the minerals by which they are formed.

It will be understood by referring to fig. 1, p. 167, where we have an overlying granite (A), below this a bed of ordinary black micaceous gneiss (*a a*), sending forth a small arm (*b*), very quartzy and losing itself in the surrounding white, coarse-grained, crystalline limestone (*d*), of which a thickness of about 8 feet is uncovered and is here represented; in this we find several blackish detached patches of gneiss (*c*).

The line (*ff*) crossing the lower part of the section represents an apparent line of bedding, very regular, and showing itself the more strongly, from the foliation of a few inches on the upper side principally being much closer than throughout the rest of the mass. This line, as shown in the section, runs nearly E. and W., or at right angles to the strike, and inclines 20° from N. to S. The strike itself is within a few degrees of N. and S., and inclines 15° to E.

The portions of the limestone marked *e* in the section, fig. 1, are foliated by crystals of blackish-green to light-green augite and white scapolite; in the part marked *ff* the foliation is produced by the presence of laminæ of mica. Now when the lines of foliation are examined, which are well developed and distinct, it will be seen that these invariably run in one direction throughout the mass, no matter what minerals produce the foliation itself; also that this direction coincides with the line of apparent bedding.

Not many yards above, and at right angles to this, the section represented in fig. 5 was made, showing as much as was uncovered

Fig. 5.—Section of granite, gneiss, and limestone at Jægersborg, near Christiansand, Norway.

A. Granite.
a. Granitic gneiss.

b. Ordinary gneiss.
c. Foliated crystalline limestone.

by soil or debris. This presents a much-disturbed appearance; the central part appears to have been broken through by a fault, and we have on the east side, on the surface, granite (A); below this, gneiss (*a*), without grain, passing into regular gneiss (*b*), and then the limestone (*c c*) cut up by granite. On the other side, the granite is absent; and we have gneiss, similar to the former and without grain, at top, and then the limestone, in which rounded masses of granite

are seen, as if protruding from large supplies behind. We also see a small vein of granite, not more than a few inches thick, losing itself in the grainless gneiss at top. We have lastly some gneiss showing itself in a very peculiar shape, and becoming grainless when near the granite. The general foliation of the limestone and gneiss seems to agree. The section, fig. 1, p. 167, would cut across this at the extreme right of the diagram where the distortion is least.

(Case 10.)—Besides the more regular beds of limestone here described, several apparently quite detached pieces (varying considerably in size) may be seen completely surrounded by the gneiss. Fig. 6 represents the shape of one of these detached masses*. The limestone

Fig. 6.—Outline of one of the detached limestone-masses in gneiss at Jægersborg, near Christiansand.

is precisely similar to the other, and is foliated by the same minerals as in the last case; and even here the lines of foliation in the gneiss appear to be carried out without disturbance through these limestone-masses.

(Case 11.)—A very interesting arrangement of the foliated structure, very similar to that of the garnets in mica-schist, was found by me at Lindfild, on the borders of Ongsteens lake, between Bratsberg and Nedeness Amt, in Norway, and apparently extending over a considerable area, probably of some square miles. The rock here is a species of talcy mica-schist, and contains innumerable nodules of dichroit, of a white or bluish-white colour, sometimes exhibiting the

Fig. 7.—Mica-schist with nodules of Dichroit, Ongsteens Vand, Norway.

peculiar and characteristic play of colours. These nodules are nearly of a size, about that of a walnut, and the foliation of the mica bends itself around them, producing a very peculiar appearance from the immense number of the nodules present and the extreme regularity of their disposition, which can be seen at a glance.

The whole would appear as the effect of some arranging force, in conjunction with the ordinary action of foliation.

The cases of foliation which I have hitherto brought forward have been all caused by the introduction of silicates, but in many cases I

* Scheerer also has some remarks on the occurrence of these masses of limestone at Christiansand, N. Mag. f. Naturv. vol. iv. part 2, p. 158.

have observed that the same phenomena have been caused by the appearance of totally different chemical compounds.

(Case 12.)—At Pusaasen, a little north of east of the locality described above, and illustrated by fig. 4, p. 172, we have a bed of limestone, apparently either the same, or one parallel to it, which lies on gneiss, and appears to run in the same direction as the former. Here I found that several feet of the lower part of this bed were foliated by the introduction of the mineral termed chondrodite (a fluosilicate of magnesia), which was arranged perfectly parallel to the micaceous foliation of the gneiss, as well as of that of the limestone. It may be also mentioned that the chondrodite here is associated with the black spinel, precisely as at Sparta in the United States.

I have also observed in Norway many cases of foliation where this structure has been induced by the presence of small laminae or folia of oxide of iron, sometimes to the almost total exclusion of other foliating minerals. I have found this to be the case, on the small scale, in Nissedal, at Langoe, and at Dybsund Holm, near Krageroe. On a larger scale, it appeared at Rønningen, in Drangedal, where the gneiss was often very strongly foliated by scales of oxide of iron, and having a very characteristic red appearance. This foliation appeared not to disturb in any way that of the adjoining gneiss.

The foliation of rocks by means of oxide of iron is not peculiar, however, to Norway. From observations recently communicated to me by Lieut. Aytoun, Bengal Artillery, this is often the case in Hindostan. He states that at one of the small outliers of the Kuptut-good range of mountains a very fine example of this may be seen. The rock is a siliceous talcy schist, and strikes N.N.W., dipping 50° E.; the beds thus foliated are from 60 to 80 feet thick, and extend for several miles. In some hand-specimens received from Mr. Aytoun there are portions of the talcy schist having the talc entirely replaced by scales of black magnetic oxide of iron, which also shows itself particularly well developed along the joints.

In the valley of the Mulpurba, about eight miles south of Belgaum, in the Deccan, Mr. Aytoun has observed many instances of mica-schist and clay-slate running 5° N.W., and dipping 80° E., in which small bands, from $\frac{1}{4}$ to $\frac{1}{2}$ inch thick, were foliated by oxide of iron, and many hand-specimens of which possessed a distinct polarity.

It is often the case in Norway that some strata or parts of strata, extending often for miles, present a peculiar foliated arrangement, due to the introduction or appearance of certain metallic compounds and the greater or less exclusion of the usual foliating silicates. Thus at Kongsberg, near Tvedestrand, in Drangedal, in Espedalen, and several other places I have found various sulphurets showing themselves; and at Modum and Snarum, also at Vena, near Askersund in Sweden, arseniurets show themselves under similar circumstances.

The details connected with these occurrences are particularly interesting, and important also in an economical point of view; but they cannot be brought within the limits of this communication: I trust, however, at a future period to bring some observations on the subject before the Society.

The cases already described show in some measure the wide range and extraordinary difference in mineralogical or chemical composition of the substances producing foliated structure; and I think it must be admitted that we have no such analogous phenomena characteristic of the cleaved rocks, and that these facts would be opposed to the view that cleavage and foliation were the effects of one action.

Mr. D. Sharpe, in his excellent paper "On the Foliation and Cleavage of the North of Scotland*," has brought forward another argument in support of the identity of these two phenomena, namely the arrangement of grand semicylindrical arches in which the lines of foliation and cleavage *together* form the defining boundaries.

My excursions in Scotland were too short to form even a faint idea of these arches. It seemed to be not improbable, however, that these lines, which appear so regular upon Mr. Sharpe's map, might be found continued into Norway, where I was better acquainted with the rock-structure. I could, however, make nothing of them, and must candidly confess that I relapsed into that state of despair described by Mr. Sharpe as "the first impression of an observer entering a district of gneiss or schist in search of order in the arrangement of their folia." The geological map of Norway now produced, and which is by Keilhau, has indicated on it a *résumé* of most observations of strike and dip made in that country prior to 1849, and probably more experienced observers than myself may be able to reduce these lines to a system. I am sorry that time has not permitted me to mark down on the map a great number of observations made by myself or collected from friends, since its publication.

In an attempt to generalize the lines of foliation in the district around Arendal and Krageroe in an examination of that tract made by Mr. Dahl and myself, and published last year in Norway†, we were unable to come to any more definite conclusion than that these lines generally varied from N.W. to E. and W., and were in the main parallel to the line of coast. The dip was found extremely variable at all angles, from 13° to 90°, S.E., S., up to S.W. Contorted arches are of constant occurrence in the gneiss districts in Norway, but they seem to be connected with local phenomena. Some are very interesting, and the arrangement shown in fig. 8 is one difficult of explanation.

(Case 13.)—We have in fig. 8 a section of a ravine near Krageroe (the section being broken in the centre to admit of both sides being shown, otherwise impossible from the scale). The ravine at the bottom is probably not 50 feet across, and the precipice of the side is about 60 feet high. The angles dip in opposite directions on the respective sides of the ravine; on the one side, N.W. at various angles up to vertical; on the other, pretty constant at about 60° S.E. The dotted lines show what may be supposed to have been the continuation of the jagged edges of the strata, and are confirmed by the blocks of similar configuration lying loose in the ravine below.

The central boss *a* represents a mass something between granite

* Phil. Trans. R. Soc. London, 1852.

† See also Quart. Journ. Geol. Soc., No. 42, Part II. Miscell. p. 9, &c.

Fig. 8.—Section at *Lykkens Grube*, near *Krageroe*, *Norway*.

and gneiss, of undefined character; and above is seen a small vein of coarsely grained granite (B) containing numerous crystals of brown titanite. The contorted structure of the foliation here observed is, I think, due to the entrance of the granite-vein and the occurrence of the granitic gneiss, which seems in this case to be nothing more than gneiss into which granite has infiltrated from large masses of this rock, not seen in the section, but which are in the immediate neighbourhood.

Now as to the influence of the intrusion of the igneous rocks on foliation, it seems to me that the two are very intimately connected, and that, in many cases at least, foliated structure seems to arrange itself in planes connected with the configuration of the intruded or underlying igneous rocks.

Mr. Sharpe admits that the occurrence of such rocks has a very disturbing influence on the regularity of his arches; but it may be fairly questioned whether such arches may not themselves be due to the appearance or approach of such igneous rocks.

Looking at Norway, we find no considerable tract of country exempt from the constant occurrence of such igneous rocks; and, as far as my experience goes, these rocks seem generally to have an apparent influence on the lines of foliation.

Fig. 3 (p. 171) gives a good illustration of this; as also fig. 1 (p. 167) and fig. 5 (p. 173).

(Case 14.)—Fig. 9 also represents a similar case at Pusaasen near Christiansand, where we have a granite-vein (A) about 3 feet thick, breaking through gneiss (a) into crystalline limestone (c) similar to that previously described, and foliated by augite, scapolite, and mica; below the small vein of granite (B), the gneiss (b) is more calcareous and augitic; but above, it is of the ordinary character, and does not contain carbonate of lime. The strike is E. and W., and the dip 25° to the South.

Fig. 9.—Section at Pusaasen, Christiansand.

The foliation here, in the gneiss, in the augitic calcareous gneiss, and in the limestone, is parallel in each rock, and to the general run of the imbedded vein of granite.

On the coast near Krageroe we have also numberless instances of the foliation of the gneiss having the same direction as the veins of granite may have on an immense scale. Near Smedsbugten we have, for instance, no less than seven enormous veins, or rather beds, of granite visible on the side of the mountain arising abruptly from the sea, and all of which run N.N.E., dipping to the W. at an angle of about 40° . Between each of these are great beds of gneiss, the general foliation of which is parallel to the beds of granite, and the whole appears to be several hundred feet in height.

In the paper by Mr. Dahl and myself, previously quoted, other instances will be found.

It is frequently also the case, where veins of trap make their appearance, that the foliation is found parallel or greatly influenced.

On the side of the road about two miles from Inverarnon, in Perthshire, I observed a vein of grey porphyritic trap, containing specks of iron and copper pyrites, and running N.-S., with a dip of 20° W.

On both sides of the trap, the mica-schist, which was quartzy and contained black mica, had the same angle of foliation as the imbedded trap-vein.

This I found also to be the case about two miles further north from this, where a large vein of syenitic trap, running nearly horizontal, showed itself. Here, however, as small veins ramified from the main body of trap, the coincidence was not always so carried out as in the previous case.

Similar cases to these were found in Drangedal, at Vedfald, where two veins of mottled serpentine-trap made their appearance.

That the intrusion or approach of igneous rocks is always the cause of foliated structure cannot be insisted upon; and I am aware that many cases occur exhibiting appearances quite different from the above-mentioned: still at the same time it is a circumstance worthy of con-

sideration, as being in some cases the agent in causing as well as modifying foliated structure.

Whatever may be the cause of the arrangement of foliation in certain directions, I believe that most geologists agree in supposing that foliation itself is due to the action of heat, which has reduced the rock *in situ* to a fluid, or at least semifluid state, to which some add the action of gases and pressure.

On this point I would wish to make some remarks; and I may premise by stating, that to me foliation appears to be the result of chemical action in recombining the elements existing in amorphous sedimentary rocks, together with a simultaneous molecular movement of the products thus formed; also, that this action is effected by heat, but has taken place at temperatures lower than even necessary to change the external form of the masses, or to produce any semifusion or even softening.

As corroborative of this, I may refer to fig. 10, which Keilhau

Fig. 10.—Section of the gneiss in the Island of Jomfruland, Norway.

has also observed and made mention of*. It represents an appearance in the gneiss on the island of Jomfruland.

Here we have a vein of hornblendic character running across the gneiss, and disturbed by the fault AB, which throws it downwards.

On examining the lines of foliation, it will now be found that those lines which are most distinct are not at all affected by the fault, and continue throughout with the greatest regularity; so that it can hardly be doubted, that the foliation of the gneiss took place later than the formation and subsequent dislocation of the hornblende vein; and consequently we cannot suppose that the mass could have been in a fused or softened state at the time of foliation without the obliteration of these appearances. Again referring back to fig. 8, p. 177, it will be seen that the fault B, the origin of which apparently was previous to or simultaneous with the granite-vein, has altered the position of the foliation on the one side and bent it upwards. The faults c, d, and e do not effect this at all.

If, however, the rock had been in a semifused state when foliation took place, or when the granite-vein was injected, we should have

* Norske Magazin for Naturvidenskab, vol. iii. p. 175.

expected that the faults would have been obliterated, or that both sides would have been equally affected.

At the limestone quarry on the road to Crianlorich, previously described, p. 166, where the limestone is foliated, we have the foliation affected by faults and curved, and in one place a portion enclosed between two faults had the foliation curved on both sides in a nearly circular direction; so that there is here also reason to believe that the foliation took place subsequently to the faults, which otherwise would not have retained the sharp and defined angles here seen.

In submitting this opinion as to the temperature at which foliation took place, it can be objected, however, with reason, that in the present state of chemical science we have no right to assume that such chemical action and arrangement can take place in solid bodies without external change of form. Chemists will no doubt admit that in *homogeneous* bodies of one composition we may have a complete change of molecular arrangement without any change of form;—thus,

that a mass of bar-iron from being fibrous may become crystalline—

that sugar-candy may from an amorphous state become crystalline—

that large crystals of sulphur may change their structure, becoming an aggregate of small crystals belonging to a different crystalline system—

that the sandstone bed of a blast furnace or the bricks of kiln-walls may by the action of heat acquire a columnar or basaltic structure.

But in all these cases we have no chemical action, no production of other and totally distinct compounds as in foliated rocks,—we have only the results of a molecular arranging force*. It is necessary, therefore, before the view I have brought forward, with reference to the production of foliated rocks at comparatively low temperatures, can be securely established, that we have some data to prove that such action and changes can really take place. I endeavoured, therefore, to procure experimental proof of this with direct reference to the rocks, but met with many difficulties.

Thus, I often could not succeed in regulating the heat to sustain such temperatures as seemed necessary, and found that, the instant a pasty or semifluid state was induced, I could not obtain satisfactory results. The action of the air in oxidizing the iron present as protoxide to the state of peroxide also introduced a new element which would have been gladly dispensed with.

On taking, however, a rock like steatite, which we have in Norway in such quantities as to use it as a building-material,—and which is at once one of the most infusible of rocks, and nearly altogether free from iron,—I was not annoyed by the above difficulties, but found another obstacle in the way.

The results, however, on prolonged treatment of this rock, were so satisfactory as to be very encouraging as a beginning, and I found that a slightly foliated structure was evidently being induced. The

* See also Hausmann on Arsenikglas, &c., Quart. Journ. Geol. Soc. vol. vii. part 2, page 2.

pieces subjected to heat were, however, always more or less broken up and friable, evidently from the unequal expansion and contraction of the mass. To obviate this, it seemed necessary to have the auxiliary aid of pressure; and, in order at the same time to make experiments on a somewhat larger scale, I proceeded as follows.

Having some small blast-furnaces at disposition, I placed slabs or blocks of the rocks in question under the bottoms of them, which were composed of a stamped mixture of clay and charcoal-dust,—and which consequently protected them from the action of the air, whilst at the same time they were exposed to a certain amount of pressure from the slag and metal above them. This pressure varied as the sump was filled with slag or metal, or a mixture of both, and as the former was of average density 3, and the latter 5, and as the depth was about 3 feet, we might have a pressure of from 7 to 12 lbs. per inch. These experiments were made in Norway in a district where no great variety of rocks were obtainable, and as they occupied a very long time I can only here give the results of one or two, which, however, are so far satisfactory.

I exposed large slabs of an impure, rather micaceous clay-slate, about 4 inches thick, 6 feet long, and 4 feet broad, under these circumstances, to the action of heat continued for some months, but which never was so intense as to cause fusion or even softening, as the slabs, even if they had been broken up, retained their original outward form and sharp edges. From the pressure and the unequal distribution of the superincumbent weight, they were very frequently, if not always, broken up, and consequently had to be removed, so that generally some metal or slag is adherent to the pieces;—also it sometimes happened, when little cracks had arisen in the protecting lining of clay and charcoal, that the pieces would be found permeated to great distances with small veins of metallic matter, so fine as to render it astonishing how it could have occurred. In all cases, however, where a softening had taken place, the result was spoiled, and the foliated arrangement, which is otherwise so distinct, would be more or less obliterated or totally destroyed.

From the specimens now shown to the Society it will be seen that the original slate is unrecognizable, and that we have a rock of a white (probably feldspathic) ground, with specks of a black mineral arranged with a distinct foliated structure. The appearances here presented are strikingly like some of the rocks of the district, where syenite comes in contact with mica-slate.

The specimens, though not large, are, I think, quite characteristic.

Again, on repeating these experiments with soapstone, using blocks of this material (which is very abundant and is cut up with axes and saws), I formed the bottom of a furnace of cubes of this stone, 1 foot square, cemented by Stourbridge clay. After several months, under precisely similar circumstances, the blocks retained their external form and their sharp edges precisely as at first; even the axe-marks can be distinguished upon them.

On fracture, however, it is seen that in parts they have all the outward appearance of the chlorite found at Brevigstrand in Norway;

and here and there we observe small aggregations, evidently arising from foreign matters present in the original soapstone, which have separated themselves.

In repeating this experiment with a view to the economical use of soapstone for the bottom of furnaces, I found that the metal had broken through the protecting lining (which in this case was not so thick), and had gone right through the substance of the soapstone blocks, which had acted as a filter. The blocks themselves retained their form completely, and were perfect at the joints; but below them was found a large mass of metal which had percolated through them; and the blocks themselves were converted into heavy semi-metallic masses, much resembling in appearance the magnesian rocks impregnated with metallic ores found in the veins of this district. It was also easy to see that an arranging force had likewise come into play, as the sulphurets of the various metals previously existing in the *matte* as a homogeneous compound, were here separated and showed themselves distinctly crystalline.

Many other experiments of a similar character were made; but, as they were principally connected with the formation of minerals, they are not so immediately related to this subject.

The above facts are, however, I think, sufficiently conclusive to show that we may have an altered chemical, as well as molecular, arrangement at temperatures below that at which softening is produced.

That we may, however, sometimes have an arrangement analogous to foliated structure in rocks generally considered as of igneous origin, and which have been fluid, must be admitted. The structure of graphic granite illustrates this well; and Sedgwick mentions that the granite of St. Austell in Cornwall has a grain. Keilhau mentions*, that in a granitic rock at a place called Salmelic, in Norway, he found a parallel structure, sufficiently distinct to determine a strike and dip, induced by the presence of crystals of flesh-coloured orthoclase.

This arrangement cannot, however, I think, have anything in common with that found sometimes in volcanic rocks, and which is often seen in slags and glass, produced artificially, and which seem probably due to similar causes as those producing the ribboned structure of glacial ice. In the specimen of glass here produced we have an arrangement evidently due to this cause and to a subsequent crystallization superadded, in which the crystalline arrangement has followed the striæ of the glass, previously invisible. Some rocks certainly igneous may have been formed in a similar manner; but here, in the case of the glass, we do not have the chemical action as in the production of foliated rocks; since the glass is only to be regarded as a homogeneous body, modified by crystalline forces, according to pre-existing lines.

It will be found that many minerals apparently possess in themselves a certain independent arranging power. Minerals do not only

* Norske Mag. f. Naturv. vol. ii. p. 372.

show themselves in the same crystalline form, but have likewise a tendency to arrange themselves preferably in certain figures. Thus crystals of grossular from Brevig, in Norway, almost always occur as hexagonal rings of single crystals, the interior and surrounding mass being only the matrix. Crystals of augite from the Canary Islands were found to arrange themselves parallel to the long axis of the prism. Many other instances might be cited that are doubtless quite familiar.

I have now only to notice some points regarding the chemical composition of the foliated rocks, as compared with the other truly sedimentary beds.

This has by some been considered so different as to preclude the idea that foliated rocks have been formed from rocks similar to the present formations, without supposing that some ingredients must have been added to, or taken away from such.

Thus the amount of alkali has been supposed much greater. On examining the later analyses by Taylor of the carboniferous rocks, Hunt's analyses of the lower and upper Silurian rocks, and others, it will be seen that when we subtract the organic matter and other volatile substances, as carbonic acid, &c., we have then no greater difference than that usually found in different series of the foliated rocks. In fact, many of these contain but very little alkali.

Bischoff makes hornblende-schist to contain only 1·45 per cent. of potash and soda together, and the averages of two analyses of mica-slate give 6·67 per cent. of alkali; but, considering that the quartzzy schist contains so much less, the average will probably not be more than we find in the fossiliferous strata. Thus Hunt found in the upper and lower Silurian beds of East Canada 5·05 and 5·59 per cent. of alkali respectively.

In the clayslates (azoic) of Norway, Kjerulf has found* between 5 and 6 per cent., and some of the slates analysed by Bischoff gave up to $8\frac{1}{2}$ per cent.; but whether fossiliferous or not, is not mentioned. I think, therefore, there is no necessity for supposing with Forchhammer that the alkali in the foliated rocks is derived from the vapours of potash and soda exhaled from the melted granite. This view is so extremely Plutonic, that I think it ought only to be accepted when we can find no more moderate doctrine. It seems to me more probable, that, if there really was a deficiency of alkali (which I doubt) in the strata before being metamorphosed, or rather foliated, in Norway (as Forchhammer especially alludes to the Norwegian rocks), we should rather seek to account for its subsequent presence by the supposition that these strata have been changed whilst submerged, and by the infiltration of sea-water and consequent decomposition of the salt by silica.

This is consistent also with the known upheaval of the land in Norway.

Keilhau has advanced the idea of a silicification of the limestones as they approach the crystalline rocks. I have analysed several;

* Norske Mag. f. Naturvid. vol. viii.

namely, from Stampekjærn, Jægersborg, and Pusaasen, near Christian-sand, from Boedalen, in Gulbrandsdalen, and dolomite from several localities near Krageroe, as well as crystalline calc-spar veins near Arendal; but in none of these specimens have I found this the case; and no silica was present except that contained in the mechanically inter-mixed minerals. In fact, the limestone, on the contrary, seems generally purer than that found in fossiliferous strata; and this is accounted for by the tendency which the chemical action producing foliation has to separate and recombine all extraneous matters.

In one of these limestones and in several of the azoic rocks, I have found considerable per-centages of carbon present. This has also been found to be the case by Kjerulf, who has found as much as $4\frac{1}{2}$ per cent. of carbon in some of the clay-slates of Norway.

I have also observed the frequent occurrence of graphite (which may be looked upon as foliated carbon) in these rocks, often developed on the sides of the joints, as in Svadsum, Gusdal, Opdal, and other places.

Again, anthracite occurs in the gneiss, at Kongsberg, and near Arendal; at the point of junction with the gneiss at Narestoe I have found it in nodules in the granite. Phosphate of lime is also frequently present in the gneiss.

From these facts it would appear not unreasonable to question whether many of the metamorphic rocks of Norway may not originally have resulted from the alteration of fossiliferous strata, without at the same time at all deviating from Sir Roderick Murchison's views in his admirable exposition of the Norwegian Silurian system; as we may suppose that this very system may have covered considerable areas of the country, and by its destruction given rise to at least some part of the present metamorphic or crystalline rocks. In fact, Sir Roderick Murchison has described in his paper* a case where a portion of the Silurian system near Christiania has actually undergone a change into gneiss by contact with granite.

Without going further into detail as to the chemical relations of this part of the subject, I think that the observations and remarks which I have just laid before the Society would tend to strengthen the evidence in favour of the following views:—

1. That foliation and cleavage are two distinct processes not necessarily connected; and that those cases where they are parallel or identical generally result from previously induced cleavage-structure.

2. That foliated structure is the result of chemical action combined with a simultaneous arranging molecular force, developed at heats below the fusion or semi-fusion of the rock-masses; and that, when we find a similar structure induced in rocks which are known to have been previously in a fused state, this has been developed subsequently to the solidification of such rocks.

3. That the arrangement of foliation is often due to the presence or proximity of igneous rocks, and has a tendency to follow the direction

* Quart. Journ. Geol. Soc. vol. i.

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of any lines present in the rocks, whether of cleavage, of stratification, or of striæ of fusion,—following preferably those lines offering least resistance ; and lastly, that there are considerable reasons for supposing that the foliated rocks, even of Norway, may be chemically altered fossiliferous strata.

In conclusion, I have but to add, that, in laying these remarks and observations before the Society, I have hoped that they might not be altogether unworthy of notice, notwithstanding that they may in some points differ from the views already set forth by very eminent geologists.

FEBRUARY 16, 1855.

Annual General Meeting. [For Reports and Address, see the beginning of this Volume.]

FEBRUARY 21, 1855.

Edward Hull, Esq., A.B., was elected a Fellow.

The following communication was read :—

On the Occurrence of ANGULAR, SUBANGULAR, POLISHED, and STRIATED FRAGMENTS and BOULDERS in the PERMIAN BRECCIA of SHROPSHIRE, WORCESTERSHIRE, &c. ; and on the PROBABLE EXISTENCE of GLACIERS and ICEBERGS in the PERMIAN EPOCH. By ANDREW C. RAMSAY, F.R.S., F.G.S.

Introduction.—The sedimentary strata which contain the fragments of striated and polished rocks to which I am about to call attention belong to the inferior portion of that which has been defined as the “Permian Group” by Sir Roderick Murchison, the true geological horizon of which in England was first explained by Professor Sedgwick, in his celebrated memoir, “On the geological relations and internal structure of the Magnesian Limestone and the lower portions of the New Red Sandstone series,” &c. It is of the last-named division of this series that they probably form a part.

The speciality of the subject of this memoir scarcely requires me to enter upon points connected with descriptive geology further than may be needful to explain the true position of the Breccias alluded to ; and the detailed sections subsequently given, having that object in view, should therefore be considered chiefly as explanatory of the general relations of the subdivisions of the Permian and Bunter strata to each other. It is, however, proper to state that the general position of the Permian rocks skirting the coal-fields of North Wales, Coalbrook Dale, and Staffordshire was first indicated in Sir Roderick Murchison’s Map, published in 1839*. They are there coloured as Lower Red Sandstone with subordinate calcareous conglomerates ; and their lower boundary he defined by the outcrop of the Coal, while the upper he shaded off into the New Red or Trias

* ‘Silurian System.’