III.—ON SOME QUARTZ-SCHISTS FROM THE ALPS.

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A THICK mass of bedded schists, as I have described in more than one paper,¹ occupies the highest position among the so-called metamorphic rocks of the Alps. With the exception of some gneisses—so far as I know of a porphyritic character, and almost certainly intrusive granites modified by pressure—and various green schists, which, in part at least, are basic igneous rocks, similarly affected,² the group, which may be traced from one end of the chain to the other, consists of altered sediments. Calcareous mica-schists are its most abundant members. The commonest types are dark schists varying from lead colour to black (the *Thon-schiefer* or *Thonglimmer-schiefer* of many Continental authors) from which the calcite sometimes disappears, and greyish schists in which there is not much mica (the *kalkhaltig glimmer-schiefer* of the same, which locally becomes a white marble³). Quartz-schists also occur, sometimes merely as laminæ alternating with the darker mica-schists—like sand and clay in certain stratified rocks—sometimes in beds. These, so far as I know, are of moderate thickness and white in colour.

That the various schists are associated exactly as are shales, limestones, and sands in ordinary stratified masses cannot, I think, be doubted.⁴ The persistence of lithological types over large areas is often remarkable; even the peculiar black mica-schist with dark garnets can be traced, to my knowledge, for more than thirty miles along the general strike of the group.⁵ Still changes occur, especially in the transverse direction. The group of dark-coloured mica-schist, of which the above-named garnet-bearing rock is a member, occupies a broad strip for some miles E.N.E of Monte Leone, but for a considerable distance west of that mountain the rocks become lighter in colour, and the darker type is restricted to the northern margin. We perceive the change if we ascend towards the Simplon Pass from the Rhone Valley; it is even more marked, if we extend our examination up the Vispthal as far as the outlying masses of the same group near the range of Monte Rosa.

The quartz-schists, so far as I know, are not always present and are generally of subordinate importance. But they occur at intervals over a considerable part of the chain. My collection contains specimens from the neighbourhood of Windisch Matrey (*i.e.* very near the Gross Glockner) to the district of the Great St. Bernard.⁶ But I purpose to restrict my description mainly to the quartz-schists which occur in the neighbourhood of Saas-Fee, since here I have studied them in more detail. In this neighbourhood

¹ Q.J.G.S. vol. xlii (Presid. Address) xlv. p. 67; vol. xlv. p. 187.² Q.J.G.S. vol. xlix. p. 94.³ Sometimes dolomitic.⁴ I have examined them more or less minutely, over various Alpine regions, from the Viso to the Gross-Glockner.⁵ Q.J.G.S. vol. xlvi. p. 199, etc.⁶ I have not been east of the former among the crystalline schists, nor found them west of the latter in any journey made since I began to pay minute attention to the Alpine schists.

the calc-mica-schist group is obviously folded up in a very complicated fashion between the underlying gneissose rocks.¹ The gigantic undulations rise and fall for thousands of feet. It is no exaggeration to say that an active climber in a single day might touch the schists at points separated by a mile vertical. I know of outcrops on the same path which differ in elevation by full 3000 feet.² But to describe in detail either these folds or the varieties of the calc-mica-schists³ would occupy too much space; on the present occasion I must restrict myself to the quartz-schists.

This is a rock macroscopically very well characterized. It is a compact white quartz-rock,⁴ containing a variable quantity of silvery mica, which is sometimes grey coloured. The latter mineral not seldom is almost absent from bands an inch or so thick; then it may become abundant, forming sometimes a layer hardly thicker than a sheet of letter paper, sometimes distinct bands in thickness, running up to about half an inch (seldom reaching one inch), when the rock, strictly speaking, consists of alternating layers of white quartz-schist and lead-grey or greenish-grey mica-schist. In weathering it shows a marked tendency to break up into slabs. This, for instance, is very conspicuous in the quartz-schists which crop out on the craggy slopes west of the hotels at Saas-Fee. The talus below is strewn with slabs about as thick as the tiles used in flooring an outhouse. The laminae of mica determine their separation, so that the surface sparkles with little scattered flakes of this mineral, and the thicker blocks may be further split up with the hammer. The basset edges of the rock can be recognized at once by their peculiar "flaggy" aspect and sharp, almost rectangular, jointing. In this section, as usual, the quartz-schist is associated with varieties of the calc-mica-schist, in which the mica is generally subordinated as much as in the quartz-schist. The change from the one rock to the other is rapid, but the calc-schist is often more micaceous in the immediate vicinity of the quartz-schist. The former becomes in places an almost pure marble; sometimes also it is quite "slaty," fine-grained, crumbling, and of a bluish-grey colour, at first sight very like some of the Mesozoic limestones of the Alps. The resemblance is the result of pressure;⁵ the real difference becomes apparent on careful examination.

The general relations of these schists are readily determined, but some minor questions are by no means easy to settle. It is quite clear that the mass, as a whole, is infolded between moderately coarse rather micaceous gneiss, of a type common in the district. The latter, often considerably crushed, may be seen cropping out in places both below and above, extending in the latter direction right

¹ It was my intention to give some particulars of these gneisses, but they would make the article too long, so I reserve them for a future communication.

² Between Saas-Fee and Saas im-Grund and on the peak of the Mittaghorn.

³ Many details are given in the papers to which reference has already been made.

⁴ I avoid the term quartzite for reasons which will presently appear.

⁵ Other instances may be found both in this district and elsewhere in the Alps. The effect of pressure in crystalline limestones is discussed in this *MAGAZINE*, 1889, p. 483.

up to the mountain crests;¹ but it is difficult to ascertain the exact nature of the fold. In one place—just west of the hotels—we found only two outcrops of the quartz-schists; but further away to the south (working towards the shoulder overlooking the stream from the Hochbalm Glacier) two other bands of quartz-schists made their appearance, one seemingly above and one below the higher of the former outcrops. Have we here a double fold or are some other beds intercalated? There is something to be said for each view, and as the matter is of little moment I did not attempt to work it out in detail.² On the opposite side of the above-named stream we find, at the base of the mountain-buttress corresponding with the one just described (in descending order), calc-mica-schist, and below this two bands of quartz-schist, the higher about 10 feet, the lower about 8 feet thick, separated by about 3 feet of calc-mica-schist, very micaceous in lower part, saccharoidal, with thin mica-layers, in upper. As the bands of quartz-schist mentioned in the previous description at least are many yards apart, one of them (probably the highest)³ appears to be locally split up by a calcareous band; lower down, after some more calc-mica-schist, is another band of quartz-schist. The same rocks also occur on the Fee-Gletscher alp—further to the south-west.

Another section occurs on the opposite side of the valley in which Saas-Fee stands, which requires some description. This is on the north-eastern part of the Mittaghorn.⁴ Here we found in one place the quartz-schist separated from the gneiss by a fairly thick zone of calc-mica-schist; the latter then thins gradually out (as the path *descends*) till the quartz-schist is in contact with the gneiss. After this has happened the quartz-schist is thrown into S-like curves, and in one place a mass of calc-schist only a few feet thick remains infolded in the top part of the letter. The quartz-schist in contact with the gneiss is micaceous, contains some elongated spots like a felspar, and seems as if it passed rapidly into the gneiss, which is somewhat affected by pressure, is not a coarse-grained variety, and contains (in larger amount) a similar mica. The annexed section may serve to make the relation clearer. Evidently the quartz-schist

¹ It is indicated as correctly as the scale permits on the Swiss map, sheet xxiii. Here the gneiss above is distinguished from that below. There are some differences, but I think that we may regard them as of minor importance, and the gneiss broadly as one group.

² To give an idea of the possible complication I may mention that in one place we found a small patch of a cavernous, yellowish, soft, calcareous rock, containing numerous fragments from the calc-schist group. It *might* have been a tufa; but the position made this interpretation improbable, and I strongly suspect it was the last remains of an infold of rauchwacke (Trias). This rock is mapped as here and there in the middle of the crystallines in this part of the Pennines, always in mere strips, and with the once overlying Jurassic rocks wholly gone.

³ I refer only to the *apparent* position.

⁴ The path from Saas-Fee ascends and crosses the northern spur of the Mittaghorn and then runs for some little time along the eastern face at a height probably of rather more than 3000 feet above the Saas-thal. The sections described are found soon after the corner is turned, but the calc-mica-schist and quartz-schist can be also seen for some distance running obliquely down the western slope of the mountain.

is unconformable with the gneiss, so the question to be determined is whether the latter is an older rock than the former, or is an intrusive granite which has been afterwards crushed into a gneiss. The quartz-schist certainly becomes more micaceous as it approaches the gneiss, and I thought that here and there I could detect in it indications of larger quartz grains.

G Gneiss.

A Gneissose Quartz-schist (?)

B) Quartz-schist.
C)

D Calc-schist.

G seems to quadrate in A and A into B the last and C are varieties of quartz-schist and certainly pass one into the other; the passage from C to D about the dotted line is quick.

Specimens were secured for microscopic examination, which may be now described. It will be convenient to take first the normal quartz-schist, such as occurs at c in the section, and with this specimens of similar rock from other localities may be included. These flaggy quartz-schists consist almost entirely of quartz and mica, with an occasional grain of felspar, which, however, is sometimes all but absent.¹ The quartz grains vary in size in the different specimens, but are commonly less than .02". Usually they are distinctly longer in the direction of the foliation, their outline is irregular, sometimes ragged, giving a characteristic "clotted" look; occasionally, if the nicols be used, one tint, especially where the grains run small, seems to predominate in the slide. No trace of a nucleus can be detected in the grains, which exhibit the peculiar mosaic structure often seen in the more quartzose layers of the mica-schists of the same group. Minute fluid cavities with relatively small bubbles are rather numerous.² They are more abundant near, but not restricted to, the junction of grains. The mica flakes range from about .04" downwards in length, being frequently about .03", though in some slides smaller scales, say about .01", are common. With transmitted light, they vary from a slightly olive-grey to colourless. Dichroism, if any, is very faint; they are, in the former case, a little greener with vibrations parallel to the basal plane. The ends are often rather irregular, but sometimes the flakes

¹ Small zircons, occasional grains of iron oxide, probably also of zoisite, may be detected, but on these it is needless to dwell, as they have no apparent bearing on the history of the rock.

² Most of these require a one-eighth objective and many can only just be seen with that; some are irregular in form, the majority oval.

are a little lenticular in outline, as if slightly nipped. In a specimen from the south side of the Lukmannier Pass, where thin laminæ of mica alternate repeatedly with layers of quartz, and the rock macroscopically shows beautiful flexures, it is clear that the folding took place after the foliation had been produced. The grains of felspar are often a little larger than the quartz, but of the same general form. As a rule they are more or less decomposed, but not seldom are in fair preservation, showing characteristic twinning, etc.

In regard to the other specimens collected from the Mittaghorn; two were taken respectively 6 feet and 10 feet from the one already mentioned; the second near to the seeming passage of the quartz-schist into the gneiss. They are more micaceous than the former one, and the first is rather gneissic in aspect, as if some felspar were present. On microscopic examination that proves to be the case. The felspar grains, far from numerous, are irregular in outline like the quartz, and are rather decomposed. Two or three of them are about .07" in diameter, while the quartz grains seldom exceed and are often less than .01". The second specimen only differs from that already described in being distinctly more micaceous, and in having its quartz grains a shade smaller. In this but little felspar is recognizable though a disseminated brown dust gives the slide a less clear aspect. A fourth specimen was taken at a distance of about 100 yards, very close to the junction with the gneiss; the precise line of demarcation, as already said, being impossible to determine.¹ Here the constituents are decidedly more variable in size. Much of the mica (abundant) is about as large as that in the other slides, but there are many flakes barely .01" long. The quartz is occasionally about the same diameter, but as a rule is much smaller. Very little felspar can be recognized, but occasional clouds of brown dust suggest that it may have been present, and the slide as a whole is dirty.²

Next as to the relation between the present structure and the pressure which these rocks have undoubtedly undergone. In the cases under immediate consideration, the fissility and the foliation are parallel to the banded structure, so the modifying pressure must have acted at right angles to it. The constituents of the rock do not suggest shearing forces of importance, nor indeed so much "flattening out" as one would anticipate. In some cases no doubt a peculiar clotting and mixing of grains and granules may indicate something of the kind; but in these specimens from the Saas-thal only a moderate amount of mechanical disturbance is suggested. The condition of schists which belong to the same group and occur as fragments in the Rauchwacke (Trias) indicates that the foliation was anterior to the Tertiary mountain-making, so that in all probability these rocks had very nearly arrived at their present

¹ Thus labelled in the field: "seems to be the base of the quartz-schist, just against wrinkled gneiss."

² In these slides a few rather irregular grains of a clear mineral are present, which is probably zoisite, and in one garnet (one or two grains of rather fragmental aspect) is probably present.

condition prior to Mesozoic times, and the uprearing of the present Alpine chain only rendered them more fissile and produced occasional flexures.

But in none of these quartz-schists can original fragments be distinguished with certainty. Here and there a clastic structure may be suspected. Here and there an inequality in size may suggest that the larger quartzes either are not authigenous or, if so in a certain sense, only represent the remains of grains which have escaped better than the rest in a general catastrophe. There is nothing to intimate that the mica in its present form is derivative. Like the quartz, it seems either to have formed or at least to have acquired its present outline *in situ*.¹ The few grains of felspar in one specimen most nearly resemble fragments. I cannot detect any structural difference, allowing for the altered proportion of the constituents, between these quartz-schists and some of the mica-schists, such as are found in the same group, and the latter correspond more nearly (though by no means identical) with certain laminated sediments altered by contact metamorphism² than with any other rocks known to me.

But these quartz-schists are markedly different from ordinary quartzites.³ In these either the original sand-grains, though surrounded by an aureole of secondary quartz, can be readily recognized, or the comparatively regular granular structure suggests a clastic origin. So too does the mica, when it occurs. No marked reconstitution of constituents has taken place. A felspar fragment still remains as a fragment; rotten perhaps, but not, as it were, inosculating with a mosaic of quartz and white mica. These quartzites, also even after being subjected to pressure, do not put on, so far as I know, the aspect of *quartz-schists*⁴—in the former the fragmental character of the rock, the cause of its modified structure, are at once apparent. Not so in the quartz-schists; that they were once sandstone, though doubtless true, is only a matter of conjecture; how far they have been affected by pressure is a matter of uncertainty.⁵

¹ The structure of these schists sometimes recalls that of certain of the rocks on the Eastern Gneiss near Kinlochewe, but the structure is coarser, the fragmental character (due in the latter to crushing) is less distinct, as if mineral reconstitution had been more complete in these Alpine rocks.

² See Q.J.G.S. vol. xlv. p. 11.

³ I have not a few slides in my collection, representing, among others, the 'Durness,' Wrekin, Hartshill, Lickey, Stiperstones, Cherbourg, and Ardennes quartzites.

⁴ I am indebted to the kindness of Messrs. Peach and Goodchild, and the favour of Sir A. Geikie, for the opportunity of examining a fine specimen of the 'piped' quartzite (Basal Cambrian) from Glendhu, Sutherlandshire, which has become, through great pressure, slabby and schistose. It exhibits a structure with which I was already familiar from other rocks affected by the great thrust faults of the N.W. Highlands, and this is so different from that of the quartz-schists described in this paper that I could distinguish the one from the other at the first glance through the microscope.

⁵ I except, of course, the cases where the rock exhibits flexures. Here it may be added that since the first notes of this paper were written I have had the opportunity of seeing the quartz-rocks near Clifden (Connemara)—a prolongation westward of the Twelve Pins. These in the field reminded me frequently of the Alpine quartz-schists, and always appeared to differ from the Durness quartzite; they seem to be

Again, though these quartzites, just enumerated, are separated from the quartz-schists by distinctive characteristics, we find occasionally rocks which may be said to occupy an intermediate position. Of these I possess only a few examples. Some of the Huronian quartzites, which show no signs of pressure, are now quartz-mica rocks, in which, as I have said,¹ we cannot determine what portion of either mineral is allothigenous, and are led to believe that their present forms were assumed *in situ*. I have found the same structure in a pebble from the basal Cambrian conglomerate at St. David's,² and may add that small fragments of quartz-schist are often not uncommon among the oldest coarse grits and conglomerates.

But on grits and shales which have been exposed to the action of important earth movements—such as those which come from the Alps themselves—pressure has produced but moderate effects. Certain of the more minute constituents have undergone micro-mineralogical change; but, generally, of the larger constituents, though certain of the more unstable have been altered, most of them are little affected; even fragments of organisms can still be recognized. In the crystalline masses, zones doubtless occur, here and there, where the effects of crushing are very conspicuous; where, for instance, granitic rocks have been converted into fissile fine-grained mica-schists; rocks also there are (such as some of the pyroxenic group), the constituents of which seem exceptionally unstable under pressure, but many large masses are comparatively little affected. On what grounds, then, when the sedimentary rocks have emerged from the pressure with so little loss of personal identity, are we justified in assuming that the crystalline masses have been completely re-constituted, and that the cases just mentioned, instead of indicating the extreme effects of pressure, represent really its partial effects, that is to say, where crushing has been followed only by partial re-constitution. For any such assertion I cannot find the slightest grounds in the Alps.

So the specimens of quartz-schist discussed above (1) give no proof that their structure was caused by pressure; (2) show that if they have been crushed, great molecular changes have since occurred; (3) afford indirect proof that their structure is pre-Tertiary; (4) are not like Palæozoic rocks which have been crushed. In short, pressure is a most important agent of change, but it is far from being the only one. Dynamometamorphism is a fine-sounding term, but "comfortable words" are more suited for old women than for scientific men.

associated with crystalline schists. Also the quartz-schists in the district near Braemar; some of which occur near to calc-mica-schists, very like those of the Alps, others pass into mica-schists or a kind of gneiss. In microscopic structure both rocks agree in the main with these Alpine quartz-schists. The gneissoid bands seem likely to confirm the idea expressed above that one kind of gneiss may result from the alteration of a quartz-felspar grit, but I must verify some points before I can venture to say more.

¹ Q.J.G.S. vol. xliv. p. 32.

² GEOL. MAG. Dec. III. Vol. VI. (1889), pp. 315-318.