of a decimetre diameter, *composed of macropegmatite, enveloping a porphyritic Carlsbad twin of potash-feldspar* (orthoclase or microcline), that occur in the granite of the Riesengebirge, repeat, on the large scale, the microscopic characters of the micropegmatite of certain quartz- and granite porphyries (the granophyre of Rosenbusch). *All these phenomena compel the assumption that at least a part of the pegmatites are of indubitably eruptive origin*, and arouse in us the question whether this structure is not to be brought into connection with the origin of the gneisses.

(5) What are the differences between the *primary structures* (*due to consolidation*) of the plutonic and volcanic rocks and the *structures* of (*a*) the crystalline sediments, (*b*) the metamorphic rocks in contact with granite, (*c*) the crystalline schists?

(6) What *reliable* characters have we, to distinguish crystalline grains developed *in situ* from clastic grains, in cases where they occur, side by side, in one and the same rock?

The answer to this question has already frequently been attempted, among others in the most praiseworthy manner by A. Wichmann. It requires, however, a fresh solution based on the latest experiences. The safest test of the authigenic, non-clastic nature of a grain is doubtless the presence in it of enclosures of minerals that are also present in the rock as authigenic constituents. External form and internal molecular relations, in consequence of pressure-phenomena, can, however, be very misleading. Hard minerals, especially, occur in clastic sand in very sharp crystals (quartz, tourmaline, zircon, &c.).

(7) Are the views of those authors justifiable, who conceive certain gneisses or porphyroid crystalline schists to have been produced by the injection of a granitic magma, *in discontinuo*, between the schists (*Schiefer*)?

(8) If the views expressed in the preceding question are justifiable, how are the gneisses and porphyroids, produced by the addition of granite *in discontinuo* to slaty sediments, to be distinguished (*a*) from true eruptive granite or its porphyritic modification, both having, under the influence of pressure, undergone a "phyllitic" modification; (*b*) from slaty sediments in which aggregates or crystals of silicates have been deposited from water (quartz and feldspar)?

(9) What differences can be established in mineral composition and structure between a true eruptive granite and an indubitably stratified (not simply jointed or cleaved) so-called "*Lagergranit*" or granite-gneiss?

An *amalgamation of eruptive granite* with *the mineral aggregates of the rocks in contact* has, according to my experience taken place in some cases; but I have not yet observed an undoubted discontinuity in such granitic material. It is much to be desired that the French geologists (for instance, Michel-Lévy and Charles Barrois), who defend the views formulated in Questions 7 and 8, would enlighten us by good drawings of macro- or microscopic sections, as to how far in this difficult question *an incontestable separation of injected eruptive granite from metamorphic gneiss* is possible. This would, without doubt, facilitate the solution of Question 9. Unanimity on this point will scarcely be obtained without a careful structural diagnosis, which, of course, must be supported by serviceable material, self-collected in the field.

(10) Are there any *absolute* material and structural differences between metamorphic rocks of the granite contact-zone (hornstones, cornéenne, &c., cp. Question 1) and rocks affected by regional or dynamic (*Dislocations-*) metamorphism? or are such differences only *relative*, and what are they?

The exact solution of this question requires, above all, the assumption that only such occurrences shall be submitted to consideration that are unmistakably connected with *visible* eruptive rocks. It should also not be forgotten that rocks which have originally undergone contact-metamorphism have, in some cases, *subsequently* lost their peculiar characteristics in consequence of the influence of regional metamorphism. With this qualification I am personally inclined to concede only a *relative* and not absolute differences. I am guided in this, not only by my experience in the Hartz, which has made me acquainted with the rema kable variation of the metamorphic rocks in contact with granite, according as they occur just outside the contact-zone or in its outer, middle, or inner division; or again according as they belong to the unpenetrated but eroded mantle of the eruptive cores, or to masses, of greater or smaller extent, that have sunk deep in between the eruptive masses and have been covered up by them. The rocks occurring thus differently vary between a phyllitic clay-slate and gneiss, while the main mass of the slate- and grauwacke-hornstones present little resemblance to the crystalline schists. In the classic region of the Erzgebirge, however, there occur, according to the careful investigation of our Saxon colleagues, *compact hornstone-like or even conglomeratic greywacke gneisses* (the mica-trap of older writers) that present this analogy in a complete degree. The same analogy is presented by Gosselet's Lower Devonian "*cornéite*" (to be distinguished from *cornéenne*, the product of contact-metamorphism) from the regionally metamorphic Ardennes of Belgium. Again, *the Lower Devonian fossiliferous sediments* of the Ardennes, *containing garnets, hornblende, and graphite*, that are so well known through A. Renard's admirable descriptions and drawings, remind one of hornstone, although no contact with eruptive rocks has been observed affecting either them or the *Cambrian garnetiferous* "*Wetzschiefer*" of Vielsalme. The association of such hornstone-like rocks with those of the usual phyllitic type of regional metamorphism recalls the occurrence of lime-silicate-hornstones in the outermost zone (beyond the zone of the "Knotenschiefer" around the granite of the Rammberg. Whatever explanation of these phenomena may be given—Gosselet is decidedly in favour of dynamic metamorphism as opposed to a latent contact-metamorphism—at least this is evident, that important contributions to the question, here formulated, can be furnished by the Ardennes.

ON THE CLASSIFICATION OF THE CRYSTALLINE SCHISTS.[1]

THE most important constituent of the earth's crust—the crystalline schists—has remained, with respect to their field-relations and their origin, the most shrouded in darkness. The difficulties that bar the way are quite exceptional. We have frequently to deal with rocks that have undergone subsequent alteration, without being able to determine their original constitution, and without being able to explain the nature of the change. We have, as it were, to deal with an equation with two unknowns—we cannot solve it.

At the present time we meet with a number of attempts to classify the crystalline schists, mainly according to petrological characters, in stratigraphical groups. I regard these attempts as premature, for this reason: microscopists are unfortunately very behindhand in the exact investigation of the crystalline schists, and of the half-clastic, half-crystalline sediments. The purpose of these lines is to direct attention to another difficulty which has not yet received sufficient consideration, but which bars the way to every attempt of that kind—namely, *the mechanical metamorphism during mountain-formation.*

That, by the plication of the Alps, the constitution of the rocks has been completely changed, is most directly proved by an examination of the sedimentary rocks; because the latter can be also studied in an unaltered condition in adjacent localities. The commonest changes met with here in connection with folding are:—

Deformation of fossils, pebbles, or crystals (compression in one direction, extension in another).

Cleavage (*Transversalschieferung*).

Cleavage with linear extension.

Puckering.

Internal formation of breccias and cementing of the same by secretions.

Internal formation of innumerable slickensides, so as to change the whole structure.

Scaly structure, produced by the compression of oolitic structure.

Alteration of hematite and limonite into magnetite, in connection with cleavage.

Marmorosis of the limestones.

Formation of confusedly "kneaded" structures (*Knetstructuren*).

Development of new minerals (garnet, staurolite, mica) in places that have undergone crushing.

Now, sedimentary rocks, metamorphosed in the above way, are frequently found in extremely narrow synclinal zones, nipped in between rocks belonging to the crystalline schists. The

[1] "Zur Klassification der krystallinischen Schiefer," von Prof. Dr. Albert Heim. "Etudes sur les Schistes Cristallins." Published by the International Geological Congress in London, 1888. (Translated from the German by Dr. F. H. Hatch.)

Alpine zones, which consist mainly of crystalline schists, are termed *central massifs.* Such intercalations of mechanically metamorphosed sediments with the crystalline schists are very frequently to be observed at the ends of the strike of the *central massifs,* and between the *central massifs*; they are not rare even in the interior of the *central massifs.* The crystalline schists and metamorphosed sediments not only present the same stratigraphical position, but also similar characters in other respects. The cleavage of the sedimentary rocks may be continued in the same direction into the crystalline schists; and similar contortions may traverse both: in the latter, as in the former, a marked linear extension in the same or but slightly deviating direction may be present: calcareous patches in the crystalline schists are crystalline and granular, and contain layers of mica-scales which have undergone extension, precisely as in the neighbouring Jurassic limestones, &c., &c. From these facts we see that in these crystalline schists we have not to deal with rocks of original constitution, but that both these rocks and the sediments have undergone similar mechanical metamorphism. The only difficulty in dealing with the schists is contained in the fact that we are never in a position to describe the original appearance of the rock before it underwent the mechanical metamorphism.

Now it is in the crystalline schists that the plications of the earth's crust are most potently developed. The isoclinal and fan-shaped folds, the wedging and "kneading together" at the contact with the sediments—in short, all these high forms of dislocation, which are the earliest to modify the inner structure of rocks, are to be found in the crystalline zones of the Alps. They are most highly developed in the northern series of the *central massifs* (Mont Blanc, Aiguille Range, Finsteraar-*massif,* Gotthard-*massif,* Silvretta-*massif,* &c.).

At first sight it appears as if the crystalline schists and the true sediments, in the Alps, were separated by a constant unconformity; but frequently even recent sediments are found folded in, parallel with the crystalline schists. Again the sediments often take the position of a *central massif;* indeed, it seems as if a great part of several of the *central massifs* consisted of Palæozoic sediments. On the other hand, in the southern *central massifs* of the Central Alps, we see the crystalline schists lying in all respects like the sediments.

Those who have worked in these parts of the Alps will have remarked how often the mechanical crushing undergone by the rocks obliterates the limits of stratigraphical and petrographical characters, and how many rocks have become confused thereby in their development (*Ausbildungsweise*). Such changes can sometimes be directly proved to be the result of local crushing; sometimes, however, they are regional, and then passages into the unaltered rock are difficult to trace. All degrees of change by earth-movements are to be found, from a slight alteration of the structure up to complete metamorphism. In hundreds of places one does not know whether one has to deal with the residual traces of original bedding or with a cleavage (*Transversalschieferung, Quetschungsschieferung*) that has completely obliterated the original structures. In many cases it is impossible to distinguish between a schistose structure (*Schieferung*), superinduced by earth-movements, and one that is original. Schistose structures which cross one another are by no means rare. Whether the more pronounced or the less definite one is then the original is often not to be decided. Even an exact microscopical examination will often not suffice to distinguish between structures resulting from crushing and lateral deformation; and the fluxion-structure of an eruptive rock. It is certain that a structural modification by earth-movements has everywhere taken place where linear extension abounds. The latter is never original. In such crystalline schists with linear-parallel structure there are often elongated, ragged mica-scales. The linear extension can go as far as the development of rod-like separation (*stenglige Absonderung*).

Are there any rocks left in the *central massifs* of the Alps which have undergone no change in structure during the orogenetic processes?

The metamorphism can penetrate still deeper.

Enormous zones, for instance, in the interior of the Finsteraar-*massif,* that were formerly held to be true crystalline schists, prove to be originally clastic rocks of the Carboniferous period that have been squeezed into schists, and pervaded by secondary mica. Conglomeratic rocks of the Verrucano group, and clay-slates, nipped into the *central massif,* have become crystalline, schistose, and even gneissose. They can scarcely be distinguished, in the field and in the hand-specimen, from crushed gneisses pervaded by sericite. Granites can be proved, locally and perhaps also regionally, to have been compressed into gneisses. Gneisses, having a different position relatively to the pressure, have locally become granitoid. Massive eruptive felsite-porphyries have become felsite-schists. Mica-schists have been dragged out; their quartz grains ground down; and the whole converted into a rock that one would be inclined to describe as a sandy clay-slate. Even Liassic slates with fossils have been converted into garnetiferous mica-schists, staurolite-schists, &c. The boundary between the old crystalline schists and real sediments in the Alps has, by such processes of dynamic metamorphism, been obliterated, and the proper character of the rock so altered as to render recognition impossible. When we see, in true sediments, new minerals developed by the progress of the mechanical metamorphism (magnetite in the crushed Oolitic ironstone of the Windgälle, garnet in the Belemnite-slates of Scopi), the question arises, for the crystalline schists of this and neighbouring regions—Which minerals are original, and which have been produced subsequently, by orogenetic processes?

We arrive at this conclusion:—*The constitution of the crystalline schists in the Alps has been much changed by the orogenetic process* (dynamic metamorphism). *Original material and material mechanically produced at a later period, are often not to be separated from one another.*

Besides these, the Alps present other difficulties that stand in the way of the recognition of a stratigraphical grouping of the crystalline schists. The field-relations are frequently so intricate, that often it is very difficult to decide what originally lay under and what above; and whether the enormous thickness, for instance, of many gneiss-complexes, is real, or merely produced by repetitions of the folding, the folds being concealed by cleavage.

It follows that, if, on the basis of petrographical relations, a general stratigraphy of the crystalline schists is to be attempted, *this must never take place as the result of observations made in plicated regions of the earth's crust: districts must rather be chosen which are not influenced by disturbances of the Alpine character.* In the question of the stratigraphy of true crystalline schists, the Alpine geologist is not in the position to furnish material of essential value; he must rather wait for the results of the workers in other regions, in order to be able to apply them to his own district. The dislocations of fractured regions have, in the main, left unaltered the constitution of the rocks. There, then, the crystalline schists can be studied in their unaltered condition. There also they lie in flatter and more regular bedding; and a stratigraphical sequence is sooner to be found than in the Alps.

ON THE ORIGIN OF THE PRIMITIVE CRYSTALLINE ROCKS.[1]

IN this paper the author briefly summarizes the ideas prevailing on the origin of the crystalline schists, and throws a doubt on the current opinion that the primitive rocks have been formed by the *direct* crystallization of their constituents. He divides his treatise into two parts: (1) stratigraphical considerations; (2) the mode of association of the component minerals.

(1) *Stratigraphical Considerations.*—The primitive crystalline rocks form the fundamental floor upon which lie the earlier detrital deposits, their schistosity being often parallel to the stratification of the latter.

Although composed mainly of acid gneisses, the primitive rocks present countless variations in chemical and mineralogical composition; they include very basic representatives, such as the amphibolites, pyroxenites, peridotites, cipolines, and dolomites, &c. These intercalations are always parallel to the schistosity: they form elongated lenticular patches, of which the greater axis is in the direction of the general banding.

At the same time, their relative homogeneity in composition is shown by comparison of sequences established, not only in Europe, but also in the United States and the rest of the world. Acid gneisses predominate at the base; then come frequent intercalations of mica-schists and leptynites, with which are

[1] "Sur l'Origine des Terrains Cristallins Primitifs," by M. A. Michel-Lévy, Bull. Soc. Géol. France. 3e série, t. xvi. p. 102, 1888. Published by the International Geological Congress in London, 1888. (Abstracted from the French by Dr. F. H. Hatch.)