The type of rocks characterized by orthoclase, appearing in the fundamental granite and the granitoid gneisses of the Laurentian, is again found in the quartziferous porphyries of the Arvonian, in the Montalban gneisses, and, though less distinctly, in the feldspathic rocks of the Taconian. The non-magnesian micas, rare in the fundamental granite and the Laurentian gneisses, appear abundantly in the Montalban gneisses and mica-schists, as well as in the lustrous schists which are found in the Huronian and the Taconian, and which predominate in the latter. It is further to be remarked that the simple silicates of alumina, such as andalusite, cyanite, fibrolite, and pyrophyllite, as yet unknown in the more ancient terranes, are abundant in the Montalban, and are also found in the Taconian. At the same time, crystalline limestones, oxides of iron, and calcareous and magnesian silicates, are met with in every terrane above the fundamental granite.

The chemical and mineralogical differences between these various terranes are more remarkable than the resemblances, a fact which, however, has not prevented some observers from confounding the younger with the older gneisses. Again, the resemblances between the Huronian and Taconian terranes led the late Prof. Kerr, in North Carolina to refer the latter terrane to the Huronian. Moreover, in the vicinity of the Lakes Superior and Huron, where we find alike Laurentian, Norian, Huronian, Montalban, and Taconian, the outcrops of this last were confounded with the Huronian by Murray and by other observers. In 1873, however, the author, distinguishing between the two, gave to the Taconian in this region the provisional name of the Animikie series. It was not until later that he recognized the fact that this series, which is here found in certain localities resting unconformably upon the Huronian, is no other than the Taconian. Emmons, on the contrary, who had long known the existence in this region of what he called the Lower Taconic, believed that the terrane to which the author gave, in 1855, the name of Huronian, was identical with this same Lower Taconic or Taconian. The differences between these two terranes in the basin of Lake Superior, first noted by Logan and later by the author, are clearly brought out by the recent studies of Rominger.

Upon all these different terranes, including the Taconian, there rests in discordant stratification in this region a vast series of sandstones and conglomerates, with contemporary basic plutonic rocks, the whole remarkable by the presence of metallic copper. This series, which had been alternately confounded with the Huronian and the Taconian on the one hand, and with the trilobitic sandstones of the Cambrian on the other, was for the first time separated by the author in 1873, under the name of the Keweenaw group, a term changed by him in 1876 to that of the Keweenian terrane. It still remains to be decided whether this series, upon which rest unconformably these same trilobitic sandstones, should form a part of the Cambrian, or should constitute a distinct terrane between the Taconian and the Cambrian.

§ 11. In submitting to his colleagues of the International Geological Congress this summary of his conclusions, based on over forty years of study, the author takes the liberty to state that the notions here advanced as to the origin, the chemical and mineralogical history, the subdivision, and the nomenclature of crystalline rocks, are for the most part the generalizations of a single observer. He now offers them as a first attempt at a classification of the indigenous rocks, and at the same time as an exposition of his crenitic hypothesis, and of the mineralogical evolution of the globe, which he conceives to have determined the succession and the chemical nature of the masses which he has named crenitic, as well as those of plutonic masses. He feels at the same time that his work is far from complete, and that to others must now be left the task of correcting and finishing it.

As a large part of these results, so far as regards geognostic classification, appeared for the first time in the Reports of the Geological Survey of Canada, the author may be permitted to say, in closing, that the first publications made by that Geological Survey on the crystalline rocks of Canada—that is to say, the reports of progress for the years 1845 and 1846, were prepared by him, and published in 1847, from the notes and the collections made by Logan and by Murray in the two years previous. Moreover, all the statements relating to the mineralogy, the lithology, or the chemical composition of the rocks of Canada, which are found in the official reports from 1847 to 1872, when the author resigned his position as a member of the Geological Survey of Canada, were written by him or under his personal direction.

T. STERRY HUNT.

SOME QUESTIONS CONNECTED WITH THE PROBLEM PRESENTED BY THE CRYSTALLINE SCHISTS, TOGETHER WITH CONTRIBUTIONS TO THEIR SOLUTION FROM THE PALÆOZOIC FORMATIONS.[1]

THE question of the "crystalline schists" still presents so many unsolved difficulties, and the views of contemporaneous fellow-workers diverge herein so widely, that an attempt at unanimous agreement on the points at issue must at present be regarded as premature. This assuredly does not prevent our taking counsel together, interchanging observations, and endeavouring to gain solid ground, whence a future solution can be aimed at. Each geologist will approach such a consultation in a way differing in accordance with his own experience.

I can only contribute experience gained by the study of the metamorphic crystalline schists, belonging to the *Palæozoic* formations, that have been proved to have resulted from the action of contact or dynamic metamorphism on eruptive or stratified rocks, the latter including the tuffs. The *direct* application of this experience to *all* Archæan crystalline schists appears to me premature—*i.e.* rather a *thema probandum* than *probatum*. Doubtless there are cases—as, for instance, in the so-called flasergabbros or zobtenites, which, apparently, must be regarded as quite analogous to the alteration of the diabases in the Palæozoic formations. Indeed, the same essential features which Lehmann has described in the development of the Saxon "flasergabbros" have been demonstrated by Teall in the Lizard gabbros, G. H. Williams in the Baltimore gabbros, and Hans H. Reusch in Norway. But Hans H. Reusch also mentions *bedded gabbros*[2] as well as eruptive flasergabbros, differing thus from Lehmann; while Credner and Roth appear by no means willing to concede all that is contained in Lehmann's book. This fundamental difference must, however, be noticed: Lehmann holds the Archæan schists half for metamorphosed sediments, half for interbedded or injected eruptive rocks; and although I cannot agree with or follow Lehmann in every detail (and, above all, lay more stress upon the altered tuffs), still on the whole I can but support him in this view. Roth, on the other hand, holds all the Archæan crystalline schists—limestones, quartzite, gneiss, mica-schist, amphibolite, &c.—for *schistose, plutonic* (only in form not eruptive) rocks (*Erstarrungskruste*); finally, Credner holds the majority of the crystalline schists, including granite-gneiss and flaser-gabbro, for the *normal stratified* sediments of a primæval ocean, their crystalline nature being essentially not due to metamorphism.

I have dwelt thus at length on this point in order to demonstrate that there exist numerous controversies even on those questions that admit of solution by reason of the *most undoubted pseudomorphic changes* (hornblende after diallage, hypersthene, augite; zoisite, epidote, actinolite, quartz, albite after lime-soda feldspar), and by reason of the presence of the *original eruptive structure*.

My stand-point is identical with that expressed by Carl Friedrich Naumann in the following words: *My task above all else is to study the metamorphism, with respect both to substance and to structure, of the fossiliferous sediments and the eruptive rocks, together with the tuffs intercalated therein.* Much has already been done, especially with respect to contact-metamorphism, which is more sharply defined than regional or dynamic metamorphism. There remains, however, much to answer, especially as the primary structures of original schistose eruptive rocks and the structure and substance of certain very common sedimentary rocks (as, for instance, the greywackes, the so-called greywacke-schists, or the majority of the tuffs) are still too little known to afford a firm basis for the study of metamorphic processes.

Still the detailed solution of the following question would be of no little value for the study of the Archæan schists:—

(1) What material agreement or difference exists between the

[1] "Einige Fragen zur Lösung des Problems der krystallinischen Schiefer, nebst Beiträgen zu deren Beantwortung aus dem Paläozoicum," von Prof. Dr. K. A. Lossen. "Etudes sur les Schistes cristallins," 1888. Published by the International Geological Congress in London, 1888. (Translated from the German by Dr. F. H. Hatch.)

[2] Giving a somewhat wide meaning to the word "gabbro"; he now says, "dioritic rock," "altered gabbro and diabase." In the Hartz the interesting gabbro-district of Hartzburg presents, among numerous other varieties, some which show layers alternately richer in plagioclase and diallage (bronzite) or present *flaser*-structure with biotite, and possess thus a *bedded-like* but not a true *bedded* parallel structure. These rocks are true eruptive gabbros.

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results of metamorphism due to the contact of granite with fossiliferous sediments and the eruptive rocks intercalated therein, on the one hand, and the Archæan schists on the other?

For such a comparison useful data are furnished by the *Hartz*. These mountains, consisting of fossiliferous sediments and the most diversified eruptive rocks, already plicated at the Coal-measure period, represent a fairly average section of the earth's crust, *i.e.* although there is no axis of crystalline schists, the strata, together with diabases, keratophyres, and the accompanying tuffs, are considerably depressed between highly elevated plutonic rocks (granite, gabbro, &c.).

The *contact-zones around the gabbro and granite* present the following authigenic *minerals*: quartz, orthoclase, albite, plagioclase, biotite, muscovite, hornblende, actinolite, augite, bronzite, chlorite, epidote, garnet, vesuvian, tourmaline, axinite, wollastonite, cordierite, sphene, spinel, andalusite, rutile, magnetite, hematite, titaniferous iron ore, magnetic pyrites (pyrothine), and other sulphur ores, calcite, fluorite, apatite; and continued investigations will easily add others to the list, as, for instance, anatase, zoisite, lithionite, lepidolite, corundum, sillimanite, cyanite, graphite—indeed, the four last-mentioned minerals have already been detected in certain mineral aggregations in post-granitic dykes of the Hartz, that probably are to be referred to metamorphic influence. But not only *do these minerals show great resemblance to those which are most frequently present in Archæan crystalline schists; their combination to definite mineral aggregates and rocks also makes the analogy even more complete.* In the *normal gneisses*, which are derived, with great diversity of structure, from the *culm-greywackes and the greywacke schists of the Oberhartz*, in contact with granite and gabbro, are intercalated *cordierite- and garnet-gneisses and augite- (or bronzite-) bearing gneisses*, which are produced by the alteration of schistose and calcareous sediments. *Saccharoidal quartzites* are clearly produced by the recrystallization of *Carboniferous* or *Devonian lydites* (*Kieselschiefer*); and it is very difficult to distinguish these from rocks produced by the contact-metamorphism of nearly pure quartz-sandstone (*Quarzitsandsteine*). *Hornstones* (*cornéenne*), which contain garnet, amphibole, augite (or bronzite), schorl, andalusite, apatite, as well as orthoclase and plagioclase, are found replacing *mica-schists* and phyllites. The thin *limestone-seams in the Lower Devonian* (*Hercynian*), Upper Devonian, and the Culm-measures, are partly metamorphosed to compact or phanero-crystalline "*lime-silicate-hornstones*," containing garnet or other allied silicates—vesuvian, epidote, malacolite, cordierite, amphibole, sphene, &c., in places also fluorite or axinite, and corresponding to the garnet-rocks, epidote-rocks, pyroxenites, ecklogites, &c., of the Archæan formation.

In part, however, they have undergone *marmorosis*, while being impregnated with garnet or other silicates and locally with ores; even anthraconite is not altogether absent from these marbles. Amphibolites are in part also derived from *calcareous sediments*; those, however, that contain felspar (plagioclase) in any essential quantity can be demonstrated to result from the *contact-metamorphism of pre-granitic, Devonian, and Carboniferous diabases that have been plicated and metamorphosed in common with the strata.* Further, there are, in the granite and gabbro contact-zones, *alteration-products of the diabase* that are *rich in biotite*; and other pre-granitic eruptive masses, such as the *augite-keratophyres* and the *augite-orthophyres*, show a great abundance of biotite, which is associated with a recrystallization of the orthoclase and of a part of the augite. This biotite is certainly developed at the expense of chlorite derived from augite or primary hornblende.

Schistose rocks with more abundant biotite, that are locally present among the more dominant massive rocks, bear the strongest resemblance to garnetiferous *mica-schists*. In the *porphyroids of the Hartz*, which occur both within and without the contact-zones, we mainly find *sericitic muscovite*; beyond the contact-zone it occurs in such abundance as to produce very schistose sericite rocks, which, on the other hand, are here also derived directly from the porphyritic massive rocks. These porphyroids I regard, from my present stand-point, as the metamorphosed pre-granitic tuffs of quartz-keratophyres and quartz-porphyries. To these tuffs are perhaps related certain *hornstones, very rich in orthoclase*, which occur in the granite contact-zone with Devonian and Carboniferous siliceous schists (equivalents of Adinole?).

Other questions are:—

(2) What differences exist in the *order of crystallization* of the minerals which compose granites, quartz-diorites, gabbros, diabases, in short holo- and phanero-crystalline eruptive rocks, and that of the secondary minerals produced in the contact-metamorphism of these eruptive rocks?

This question must be the more carefully answered, as, in spite of the rich material so excellently collected and cleverly arranged for the use of science by H. Rosenbusch, the order of crystallization of the eruptive rocks is not yet firmly established. A certain degree of regularity is undeniable; but, on the one hand, the chemical law is, as Lagorio has demonstrated, more intricate than that formulated by Rosenbusch; and on the other, the order varies quite unaccountably with alterations in the physical conditions of consolidation (compare granite and pegmatite).

(3) Is the ophitic (diabase-) structure under all circumstances the structure of an eruptive rock, or are there undoubted sedimentary rocks possessing a similar structure?

(4) It has been proved that graphic granite, as micro- and macro-pegmatite, forms an integral part of true eruptive rocks, especially of granite and its porphyritic modification. Since graphic granite is very common among the gneisses, the question arises whether it is to be regarded as a true eruptive rock, or whether such occurrences can be proved to have been produced by thermal action, or even lateral secretion, in the sense of a partial solution of the neighbouring rocks.

Even if it be admitted that all minerals can be produced, by a suitable variation of the conditions, either by consolidation, by separation from aqueous solutions, or by sublimation, still it does not follow, to my mind, that all the structures that combine minerals to regular aggregates, can be produced in like manner in these three modes of formation. It seems to me that such structures—as, for instance, the ophitic (diabasic) or the pegmatitic (to say nothing of the structures which are developed in rocks containing glass or other base)—that have been demonstrated to be *characteristic of rocks of undoubted eruptive origin, must rather be regarded as indicating an origin by consolidation from a magmatic condition, so long as contrary proofs are not forthcoming.* No one, to my knowledge, has ever maintained that the ophitic or diabasic structure can be of sedimentary origin; but gabbros have been claimed—wrongly, as I believe—as sediments, in spite of the close relation of their structure to that of the diabases.

As regards *graphic granite* (or *macro-pegmatite*), the case is somewhat different.

The frequent occurrence of such masses in gneiss has created the notion that they are integral components of the *sedimentary* gneisses. And this view is maintained, although a considerable portion of these pegmatitic masses can be clearly seen filling vein-like cavities, while another part make up lenticular patches that follow, more or less, the dip and strike of the schists. The occurrence of simple aggregates of quartz and feldspar, that are of *thermal* origin, must, then, in accordance with one's experience of regional and contact-metamorphism, be unconditionally conceded; while the absence of such aggregates in the greywackes appears to me to absolutely disprove a development by lateral secretions. It is therefore not inconceivable that the pegmatitic aggregates represent, so to speak, the quintessence of the gneiss, exuded into primary cracks. At the same time, great caution is to be recommended; for, since the introduction of the microscope, *micropegmatite* has, little by little, been recognized as an essential constituent of numerous acid and basic (with SiO_2 per cent. as low as 48) rocks. The veins of graphic granite in the Hartzburg gabbro have been held by some for segregation-veins. They are, however, demonstrably apophyses of the eruptive granite; indeed, the principal mass of granite in the Brocken *massif* is, in the main, micropegmatitic. The *banded structure, with bilateral symmetry*, of many pegmatites, which has been compared to that of many mineral veins, is no proof of their non-eruptive nature. The augites, felspars and other minerals of lavas present banded structures with variable chemical composition: banded structure with a chemical composition varying from that of diabase to granite-porphyry, is shown by compound eruptive dykes, as has lately been well shown by Bücking, in the Thüringerwald ("Jahrb. d. kgl. preuss. Geol. Landesanst. f. 1887," p. 110, *et seq.*). Even the *drusy character and the richness in minerals presented by the central portion of many pegmatite-dykes* finds its analogy in the external shells of true eruptive granites, which may, however, be complicated by the influence of thermal actions, accompanying, or subsequent to, eruption. *Giant spherulites*,

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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.)

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