5. *On* CERTAIN ALTERED ROCKS *from near* BASTOGNE,[1] *and* THEIR RELATIONS *to* OTHERS *in the* DISTRICT.

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CONTENTS.

I. INTRODUCTION.

MUCH has been written about the exceptional rocks of the Ardennes, but the petrographical work has been treated, in some memoirs, apart from the field-evidence. This, indeed, owing to the limited occurrence of the most peculiar specimens, is not easy to obtain. It seemed then that a detailed study of a few interesting examples of the rocks, and of their relations in the field, might be worth a brief record. Further, eminent authorities have expressed different opinions as to the cause of the alterations. André Dumont in his famous monograph[2] described numerous observations, and inclined to the view that the structures were the result of contact-action. Prof. Barrois,[3] from comparison of specimens with those of Britanny, supported this theory. A. von Lasaulx[4] added the important evidence that a granite occurs in the Hohe Venn. Other authorities, however, have described the folding, contortion, and faulting of the rocks, and attribute the changes to mechanical influences. This opinion is advocated by Prof. Renard in a valuable petrographical paper,[5] and by Prof. Gosselet in his exhaustive memoir on the district.[6] Thus I became interested in the question, and, at the desire of Prof. Bonney (as he was unable at that time to undertake the

[1] [Bastogne is a small town in the extreme north-east of the Belgian Ardennes, a few miles away from the frontier of the Grand Duchy of Luxemburg.]

[2] 'Mémoire sur les Terrains Ardennais & Rhénan' p. 232. [See also Mém. Acad. Roy. Belg. vol. xx, 1847.]

[3] Ann. Soc. Géol. Nord vol. x (1883) p. 205. The comparison here is drawn, however, with the porphyroids.

[4] 'Der Granit unter dem Cambrium des Hohen Venn' Verhandl. Naturh. Ver. Preuss. Rheinl. vol. xli (1884) p. 418. See also E. Dupont, Bull. Acad. Roy. Belg. ser. 3, vol. ix (1885) pp. 110–114.

[5] A. Renard, 'Les Roches Grenatifères & Amphiboliques de la Région de Bastogne' Bull. Mus. Roy. Hist. Nat. Belg. vol. i (1882) pp. 33–39.

[6] 'L'Ardenne' (1888) p. 762. See also Eugen Geinitz, 'Der Phyllit von Rimognes in den Ardennen' Tscherm. Min. & Petr. Mittheil. vol. iii (1881) pp. 533–40.

investigation) I visited the district in 1898, and collected many specimens. After careful study of these, I made a second expedition in the summer of 1899, and gained observations over a wider area of country.

In the course of this investigation I have received much valuable help from Prof. Bonney, who has examined all the specimens, and has made many important suggestions. I have had also the advantage of the loan from his collection of many slides of rocks, from this and other localities, for comparison.

The rocks of the district are classed as Cambrian and Devonian. The former, according to the map, occupies four patches:—two larger, Stavelot and the Meuse; two smaller, Serpont and Rocroy. The Cambrian rocks are generally blackish, and include shaly micaceous grits, shales, slates, and strong compact rocks, often quartz-veined, which in the hand-specimen resemble quartzites, but under the microscope have the appearance of a quartz-grit. The different species sometimes graduate one into the other, as along the road at Trois Ponts, where they alternate repeatedly, while they form a much-folded series by the railway-station below. Under the microscope, we see scattered mica, partly or wholly secondary, within the gritty groundmass, and often squeezed dark carbonaceous streaks.

The Lower Devonian slates and grits extend over wide areas of the country, exhibiting at places alterations which I shall describe later. Lithologically they bear much resemblance to the Cambrian with similar micromineralogical change, a resemblance which is found also in Britanny in the 'grès feldspathiques,' the 'grès armoricains,' and in the later (Devonian) rocks.

II. Mineral Modifications.

(1) Results of Pressure.

The district of the Ardennes is familiar to all geologists as an example, both in Cambrian and Devonian, of the results of pressure, which has caused a very general slaty cleavage, while foldings and overthrust-faults have been described and figured from many places.

A much-crushed quartz-felspar rock occurs at several localities, as at Lamersdorf, south of the village, where it is described by A. von Lasaulx.[1] In these quarries the base of the series consists of a dusty pale-banded argillite followed by a layer, containing large fragments of quartz, which is almost certainly a grit, although the quartz has some resemblance to a broken-up vein. Bosses of the quartz-felspar rock succeed, and it is found in a road-cutting on the hillside below. All these rocks exhibit an imperfect cleavage dipping roughly south-eastward. On examination with the microscope, we see in all of them fragments of quartz dispersed in a groundmass

[1] Verhandl. Naturhist. Ver. Preuss. Rheinl. vol. xli (1884) pp. 445–48.

of minute filmy mica and elongated grains of secondary felspar. It is difficult to decide with certainty the nature of the overlying quartz-felspar rock; on the whole, it seems more probably a crushed grit than a porphyroid, although some of the quartz has the aspect of corrosion by a magma such as is often seen in a quartz-felsite. The rock differs, however, from the porphyroids of the district in not containing the large, much-corroded felspar-crystals.

The rocks bear a strong resemblance to those from the Llanberis section, North Wales, which include porphyroids and crushed felspathic grits. Near Salm Château certain crushed rocks occur, which probably have an origin similar to those of Lamersdorf.

In other cleaved rocks some of the minerals are certainly secondary, including microlithic white mica, and possibly the better-defined crystals of ilmenite, ottrelite, etc. The micromineralogical development is doubtless the result of pressure. For instance, in a gritty phyllite (from St. Pierre) consisting of angular fragments of quartz (with one or two of white mica, biotite, tourmaline, and possibly a zircon), minute crowded mica-films are developed mainly along the cleavage-planes. Of the better-defined secondary minerals, ilmenite-crystals, usually small, occur,[1] frequently along cleavage or strain-slip planes, as if their development also might be connected with pressure. The origin of the well-known ottrelite offers some difficulty. It may be partly a result of contact-action, but some indirect evidence rather connects it with pressure-results. It occurs generally in crushed rocks—for instance, one schistose greyish grit from near Viel Salm, crossed by shining micaceous crush-planes, contains ottrelite-crystals (about 1·5 mm. broad) with rich brown cleavage-faces. The crystals (in this and other rocks) when seen under the microscope have the parallel sides and irregular ends shown by Prof. Renard,[2] as if they had grown through the crushed material, like the biotite and hornblende described by Prof. Bonney.[3] The last-named author has noticed a mineral resembling one of the chloritoid group in a Nufenen rock, where there is neither proof nor any probability of contact-action.[4] In many slices of the Ardennes rocks patches of ferrite are associated with the ottrelite, as if the isolated crystals may have originated from scattered grains of iron-oxide, which borrowed constituents from the surrounding mass.

[1] See A. Renard, 'Recherches sur la Composition & la Structure des Phyllades Ardennais' pt. ii, Bull. Mus. Roy. Hist. Nat. Belg. vol. ii (1883) p. 127.

[2] 'Note sur l'Ottrélite,' A. Renard & Ch. de la Vallée Poussin, Ann. Soc. Géol. Belg. vol. vi (1879) p. 61 & pl. ii, figs. 1–2. Compare the similar form of chloritoid described by Barrois, 'Note sur le Chloritoïde du Morbihan' Bull. Soc. Minéral. France, vol. vii (1884) p. 39.

[3] 'On a Secondary Development of Biotite & of Hornblende in Crystalline Schists from the Binnenthal' Quart. Journ. Geol. Soc. vol. xlix (1893) p. 104.

[4] 'On the Crystalline Schists & their Relation to the Mesozoic Rocks in the Lepontine Alps' Quart. Journ. Geol. Soc. vol. xlvi (1890) p. 234.

(2) Probable Contact-Alterations.[1]

It would be interesting if we could trace exactly the distribution of the more and the less modified types among the altered rocks of the Ardennes; but quarries are far apart, and the country between is generally a rolling plateau, sometimes thickly wooded. The modifications, however, are found chiefly over the 'zone of Paliseul,' as Dumont termed the country extending from west of the Meuse to east of Bastogne.[2] In this tract the chief alterations occur around certain centres (as, for example, Libramont, Bastogne) over areas of a few miles. Thus the distribution of these rocks is such as might be expected, if an important igneous mass occurred below the surface.

Further, we can trace progressive alteration in specimens collected in certain districts, and sometimes even in those from a single quarry. For instance, some rocks with faint spots (as from near St. Pierre) show under the microscope a matted, minutely crystalline mass of quartz or secondary felspar and white mica with some biotite. In a more gritty band (from near Mont St. Etienne west of Bastogne) the quartz and felspar-grains are coarser, surrounded by minute greenish films with some graphite, and the flakes of biotite are larger and clustered. Other types have more numerous or more scattered films; or more abundant biotite, in nests and groups. In others, streaks of biotite and associated minerals (some sphene, iron-oxide, etc.) give the grit a banded appearance. In all these, the micromineralogical change is not greater than is often found in pressure-modified rocks; but the microliths are not connected with pressure-planes, and the development of biotite (especially in clusters) is suggestive of contact-alteration. It has the indented or interrupted form of, and a general similarity in colour and appearance to, the mica in undoubted contact-rocks.[3]

The change in the rocks described above is slight and chiefly traceable under the microscope, but previous observers have obtained stronger evidence. Thus Von Lasaulx found a granite in the Hohe Venn beneath upheaved Cambrian strata.[4] Although the granite is not exposed in other localities, yet at many places veins occur of quartz, sometimes with felspar and mica, such as would often be connected with a granite-mass. Further, M. Dupont obtained from near Libramont crystals which he identified as doubtless chiastolite, and this would be considered, as he points out, certain evidence

[1] Excluding the garnetiferous and hornblendic rocks.

[2] The ottrelite-rocks of Salm, and the granite of Lamersdorf in the Hohe Venn, are from other and distant localities.

[3] Such as those from Glendalough (Ireland), slices from which were kindly lent me by Prof. Bonney; or those from Andlau in the Vosges.

[4] The railway-cutting where this was exposed is grassed over, and I could not examine the adjoining schists described by Prof. Gosselet. Close by, near the bend of the road, is quarried a pale brownish muddy rock containing grains of quartz, possibly fragmental, but the mass is quite decomposed.

of 'the proximity of a granite.'[1] I examined from this place many specimens, among which I could trace under the microscope stages of increased alteration. In two adjacent quarries, I found veins of quartz, felspar, and mica. If these are not connected with a granite but are only mineral veins, their occurrence among the fine-grained mudstones is at least singular.

Specimens of the sedimentary rocks (taken at various distances from the veins) are sometimes slightly spotted, but do not otherwise suggest contact-alteration, although such effects may be masked by the dusty decomposed condition of the material. The microscopic constituents, however, are mostly recrystallized. Among the specimens from one quarry, I find :—Firstly: at about 16 feet from the vein, a brown-stained argillite, slightly indurated in one band. The groundmass, crowded with narrow plates of iron-oxide, is composed mainly of matted micaceous flakes of uniformly small size (average often ·03 mm. in length), generally with an orientation. Occasionally a prism of hornblende or tourmaline occurs. Secondly: at about 2 feet from the vein occurs an iron-stained mudstone with minute dark spots. A thin slice shows rather large quartz-grains irregular and agglutinated, large mica without orientation (often about ·05 mm. long), and, in a finer-grained band, minute garnets. Thirdly: at about 1 foot from the vein comes a dark, strong, ferruginous grit, of clear quartz, pale green chlorite (probably altered biotite) in larger flakes, generally grouped (often ·2 mm. in length), and numerous minute garnets. The latter are partly rounded, and much cracked within. Some iron-oxide and an occasional grain of (?) staurolite occur. Thus the abundant development of minute garnets and the coarser-grained crystallization are found nearer to the vein.

In a neighbouring quarry I observed, on my first visit, branching veins resembling rotten granite, which, however, in 1899 were no longer visible. Specimens taken from this pit are much weathered; but on examining thin slices under the microscope, it is seen that the flakes transitional from biotite to chlorite (brown or greenish to almost colourless) are very large and frequently in clusters. One specimen (to which a fragment of a vein adheres) contains flakes often ·15 mm. long, embedded in a clear quartz-felspar mosaic including some grains of (?) corundum. With this, we may compare two other specimens from a third quarry close at hand. One consists of clear grains parted by thin micaceous strings, and contains some iron-oxide and a few minute garnets. A second specimen, traversed by three subparallel veins (about $\frac{1}{3}$ inch broad), consists mainly of minute mica-flakes at right angles to the veins, and contains abundant minute garnets. All these facts at any rate show increasing alteration such as granite produces, as one approaches the veins.

[1] E. Dupont, 'Sur l'Existence de Roches Mâclifères dans le Terrain Dévonien Inférieur de l'Ardenne Belge' Bull. Acad. Roy. Belg. ser. 3, vol. ix (1885) pp. 110–14. Andalusite was described also from veins in the Cambrian rocks of Stavelot, from strata near Laifour (Cambrian), and from ejectamenta in the agglomerates of the Eifel.

(3) The Garnetiferous and Hornblendic Rocks.

Previous observers have called attention to the very limited distribution of these rocks in the field. Dumont noticed many examples,[1] which, as later authorities state, cannot now be seen. Prof. Gosselet quotes Dumont, and figures some drawings showing their mode of occurrence.[2] They are sometimes in rather short, generally lenticular bands, sometimes in 'nodules.'[3] Thus they are quickly worked out in the quarries, and loose fragments of them are few and scattered, preserved doubtless only by their superior hardness.

The petrographical characters of hand-specimens have been exhaustively described by Prof. Renard. The minerals, which he enumerates[4] as seen under the microscope, in the garnetiferous and hornblendic rocks and the 'phyllades,' are :—

(1) Graphite as fine dust, or as hexagonal scales; (2) iron-oxide often plate-like (hæmatite or ilmenite); occasionally magnetite is present; (3) titanite? (4) zircon; (5) apatite; (6) quartz; (7) white mica.

In the 'phyllades': (8) rutile, (9) tourmaline, (10) ottrelite (with sillimanite, pyrite, pyrrhotine), (11) and biotite, similar to that which I have described in the previous section, p. 59.

(12) Garnet often in sharp well-developed dodecahedra, with regularly arranged enclosures. I have also found garnet interrupted by much of the groundmass in a manner somewhat resembling micropegmatite.

(13) Hornblende in sheaves or tufts.

To these I would add the following minerals, some of which I have identified with hesitation in the absence of certain distinctive characteristics; and where the minerals are mentioned by name in succeeding pages, this must be taken only as the most probable identification :—

(14) Felspar (described by Prof. Gosselet).

(15) A mineral which forms crystals with straight sides, ragged ends, and a parallel cleavage, resembling mica or more closely an ottrelite: the crystals sometimes develop incurving tufts like the hornblende. The mineral always includes grains of the groundmass, which are sometimes so abundant that the crystals are scarcely more than suggested. Except for an occasional yellowish tint, probably iron-staining, it is practically colourless, but, on close examination with a high power, shows a very slight green. It is not at all, or very faintly pleochroic; and with crossed nicols its polarization-tints are so low as often to be barely perceptible—then dull greenish or yellowish-green. It has polysynthetic twinning like plagioclase, the above-named colours being striped with dull grey, green, or leaden blue. The mineral has at least one very well-marked cleavage, sometimes mica-like but more usually separating lath-shaped films; besides cross-cleavages which make with this an angle difficult to determine, because of the curvature. The twinning-stripes are occasionally transverse to the perfect cleavage. The mineral includes granular opacite, sometimes scattered irregularly, but generally aggregated along the cleavage-

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[1] 'Mémoire sur les Terrains Ardennais & Rhénan' p. 305.

[2] 'L'Ardenne' (1888) pp. 787–91.

[3] *Ibid.* p. 785. Prof. Gosselet says that the 'metamorphic rock' occurs generally as 'nodules.' Prof. Renard says that it occurs .... 'en lits' .... 'en bancs minces' .... 'sous la forme d'amas couchés' .... 'sous la forme de nodules:' see Bull. Mus. Roy. Hist. Nat. Belg. vol. i (1882) p. 7.

[4] 'Les Roches Grenatifères & Amphiboliques de la Région de Bastogne' Bull. Mus. Roy. Hist. Nat. Belg. vol. i (1882) pp. 1–47; 'Recherches sur la Composition & la Structure des Phyllades Ardennais' *Ibid.* p. 215 & vol. ii (1883) p. 127.

planes and often between the laths.[1] The characteristics on the whole agree best with ottrelite, by which name it is hereafter designated.[2] The hornblende in the slides is usually green, shows distinct pleochroism from green to pale straw, and gives bright colours with crossed nicols; it is sometimes intercrystallized with the mineral described above as 'ottrelite.'

(16) Grains which show with crossed nicols the rich colours or bluish tints usual in epidote.

(17) Small grains, colourless, with high refraction, showing with crossed nicols a drab colour or pale pink and green. They have no marked cleavage, but sometimes a parallel twinning, are usually irregular in outline, with a tendency to a wedge-shape or scalenohedron, are undoubtedly secondary, and have even formed an irregular border along certain faces on one or two garnets. I have failed to identify this mineral.[3]

The next two minerals occur in a few cases in rock adjacent to the nodules:—

(18) Grains, colourless, not highly refractive, with bright polarization-colours, having one marked cleavage, and extinguishing straight; these may be scapolite.

(19) Grains (some rounded), colourless, crossed by two cleavages, highly refractive, showing often low interference-colours, extinguishing parallel to the long axis of the grain. I incline to identify this mineral as probably corundum, occurring often in what resemble fragmental grains.

The examples of garnetiferous and hornblendic rock to be described are from near Bastogne. North or north-east of that town, a rounded ridge formed of a flattened anticlinal has been cut, by both the road to Longwilly and the railway to Kautenbach, and quarried extensively for ballast along the railway to Gouvy. The quarries at the last-named locality have been probably cut back since Prof. Gosselet made a drawing of one nodular mass,[4] but I found in them two examples of the garnetiferous or hornblendic rock; and by the road to Longwilly, three.

I will begin by describing one of the last-named instances. This occurs in a craglet about 5 or 6 feet high, which consists of compact sedimentary rock with almost horizontal greyish bands and blackish

[1] I presume this mineral to be that figured by Prof. Renard in the 'Taunusian garnetiferous rocks' Bull. Mus. Roy. Hist. Nat. Belg. vol. i (1882) pl. i, fig. 2, and included by him in the variety of amphibole. In his earlier paper, Ann. Soc. Géol. Belg. vol. vi (1879) pp. 55, 65–67, he gives a full description of it and reasons for referring it to ottrelite rather than hornblende; but in 1882 (Bull. Mus. Roy. Hist. Nat. Belg. vol. i, pp. 19–22) he withdraws the previous identification, and accepts Dumont's reference to actinolite, remarking, however, that the large amount of alumina present in it is a difficulty.

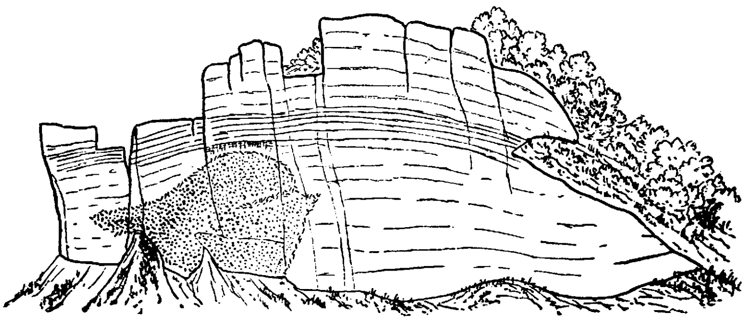
[2] The mineral agrees with the ottrelite of Dana, and differs from chloritoid in being feebly or not at all pleochroic. But the distinction of closely allied species is not clear:—Prof. Iddings places chloritoid under the ottrelite-group; M. Michel-Lévy and Dana (in an earlier text-book) place ottrelite under the chloritoid-group; Dana (in his 'System of Mineralogy,' 6th ed. 1892, following Tschermak) describes chloritoid and ottrelite as two species of the clintonite-group, but, speaking of the chloritoid in schists or phyllites, occurring in fan-shaped or sheaf-like forms, says that 'most of what has been called ottrelite probably belongs here' (*op. cit.* p. 642); Mr. G. Barrow, 'On the Occurrence of Chloritoid in Kincardineshire' Quart. Journ. Geol. Soc. vol. liv (1898) p. 154, suggests 'that chloritoid, ottrelite, etc. . . . . have really the same composition, if we could only obtain pure material to work upon.'

[3] It has been suggested to me that this might be sphene. We had considered the possibility, but were not very satisfied with that identification.

[4] 'L'Ardenne' (1888) p. 769 & fig. 208.

streaks. A patch seen on one joint-face is doubtless the section of a nodular mass; it measures about 56 × 36 inches, is nearly circular above, but projecting at the side as shown in the diagram, and shaped rather like a sprouting bulb lying on its side (fig. 1). The layers of the sedimentary rock directly above are slightly arched, and divided by small joints into lath-like structures. The 'nodule' and the surrounding mass are cut by vertical joints; and other joints mostly occupied by quartz-veins, tailing off below, occur between this 'nodule' and the next. The rock is spotted along certain lines, and seems indurated, weathering into ridges and furrows near to the nodule. This has an outer zone, about 1 to 2 inches thick, pale grey, crowded with sheaves and tufts of green hornblende without orientation. The next zone, brown, speckled, crowded with

Fig. 1.—*Craglet about 6 feet high, showing a nodular patch which measures 3 × nearly 5 feet: north-east of Bastogne, by the road to Longwilly.*



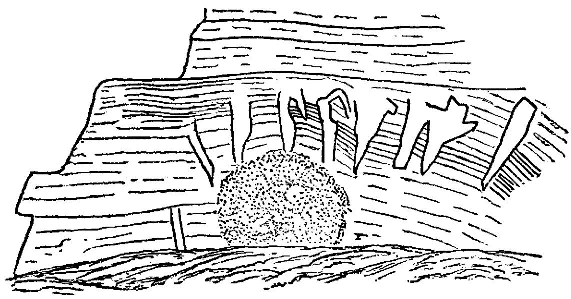
[The margin of the nodule, about 1 to 2 inches broad, is grey, the interior being black from abundant carbon. The nodule throughout is rich in hornblende-tufts, which, however, are seen more clearly in the greyer outer zone, and are specially well developed in two small included bands.]

hornblende, has a fairly sharp boundary which can be traced across the stratification. The central area is dark, even blackish, and is dusty and crumbles easily. Further, a harder band (about ¾ inch thick) projects into the 'nodule' from one side; it is black, and crowded with crystals of hornblende; another enclosed band somewhat lenticular, about ¼ inch thick, is of a pale greyish colour.

On examining the sedimentary rock under the microscope, it is found to vary from a compact quartz-grit to an imperfect slate, sometimes crowded with filmy microliths. Grains of corundum (?) occur, possibly tourmaline; and biotite (sometimes bleached) is found not infrequently either in patches, or in flakes which may represent original fragments with subsequent enlargement. The secondary modifications, although all somewhat slight, do not always increase nearer to the nodule. The differences may be partly due to the original nature of the layers; but the hand-specimens are all fine-grained, grey, rather dusty, faintly laminated, with no evident distinctions.

The rock directly adjoining the nodule, when examined under the microscope, is seen to consist mainly of clear quartz, and altered or secondary felspar, with abundant greenish microliths; biotite, chlorite, (?) epidote, and some zircons occur, all small. The external zone of the nodule has a clearer groundmass without the microliths or small flakes, though with small (?) epidote, but secondary minerals of more conspicuous size now appear. Sheaves and tufts are formed mainly of a green actinolite,[1] while certain highly refractive colourless granules often aggregated are probably epidote. The next browner zone seems to owe its colour to hæmatite, which forms either minute patches (sometimes within the hornblende) or a surface-deposit on grains of the groundmass. The colour of the centre is caused by the preponderance of black dust, probably carbon, which sometimes saturates the felspar as if formed from a carbonaceous mud. Thus successive zones are characterized by :— (i) clearer crystalline grains of the groundmass with microliths; (ii) still clearer groundmass; crystals of hornblende, some granular epidote; (iii) in addition, deposit of iron-oxide (hæmatite, etc.); (iv) in addition, deposit of carbon.

Fig. 2.—*Banded rock including a garnetiferous nodule; north-east of Bastogne, by the road to Longwilly.*



[The nodule measures about 2 feet across; is black, with a greyish margin; and contains small reddish garnets and small 'ottrelite.' The laminæ above the nodule are interrupted and slightly disturbed, along cracks filled by quartz-veins, narrowing downward.]

The projecting band previously mentioned is more compact and less carbonaceous, and contains actinolite-tufts, some of which grow into it from the adjacent rock. In the thinner $\frac{1}{4}$-inch band, the tufts are even clearer, projecting inwards or curving along the surface. They apparently grow more readily through fine-grained material,[2]

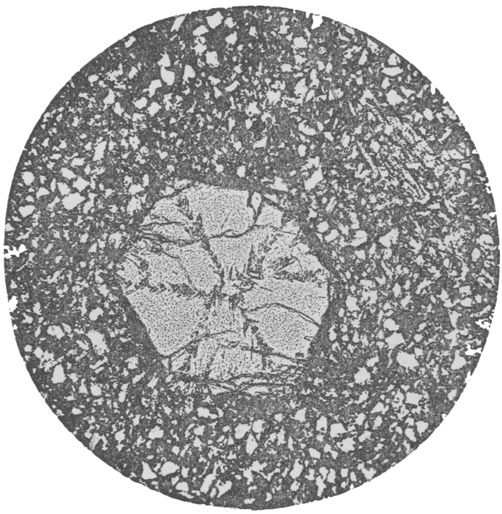
[1] See Bull. Mus. Roy. Hist. Nat. Belg. vol. i (1882) pl. i, fig. 2, pl. ii, fig. 1, & pl. iii, fig. 1.

[2] T. G. Bonney, 'The Garnet-Actinolite Schists on the Southern Side of the St. Gothard Pass' Quart. Journ. Geol. Soc. vol. liv (1898) p. 371. See also Proc. Roy. Soc. vol. lxiii (1898) p. 220.

which forms a streak in the band and contains blackish plates of ilmenite or hæmatite, with rather abundant small epidote (?).

A few yards away, where the cliff nearly reaches the road, is a second nodular mass of rounded outline about 2 feet across (fig. 2, p. 63). The rock here is grey, banded, finely laminated, sometimes showing current-bedding. The laminæ can be traced up to the sides of the nodule, and even into it (seen in thin slices), while above it they are slightly faulted and displaced, with a number of quartz-veins, all more or less wedge-shaped and pointing downward. At a lower level, and a few feet in front, are a banded indurated grit and a little slate. The margin of the nodule is blackish, weathering to slate-colour; it is crowded with crystals, steel-like when fresh, brown when weathered, and contains scattered reddish garnets, about 1 mm. in diameter. The mass of the nodule is similar, jointed

Fig. 3.—*Part of a slice for the microscope (× 40) taken from the nodule (by the road to Longwilly) shown in fig. 2, p. 63.*



[A garnet and a small imperfect crystal of 'ottrelite' are seen embedded in a carbonaceous groundmass. The garnet is mostly sharp-edged, with regularly arranged inclusions along crystallographic planes.]

somewhat rhomboidally, is firmer towards the exterior, but in the centre becomes dusty, crumbles away from around the small garnets,[1] and blackens the fingers when rubbed.

The marginal zone is seen under the microscope to consist of a mosaic with carbon-dust, and with curving sheaves of the supposed ottrelite. These, although apparently continuous, are really crowded with enclosed grains of the groundmass. In the next zone garnets appear, generally with a border of opacite (fig. 3).

[1] See A. Renard, Bull. Mus. Roy. Hist. Nat. Belg. vol. i (1882) p. 9.

They are sometimes imperfect, and crystallized against a patch of ottrelite.

The interior of the nodule consists of the same minerals with some small sharp-edged crystals, probably white mica, some of mineral No. 17 (see p. 61), small epidote, and patches of hæmatite or limonite sometimes embedded in the ottrelite. In a squeezed part, the sheaves of ottrelite grow across the planes of schistosity.

This garnetiferous nodule appears isolated; but about 2 feet away, an irregular step left in quarrying shows altered rock, which may have been previously a prolongation of the 'nodule.' The mass is a compact greyish grit (with silvery mica along pressure-planes) forming indurated, dark, somewhat speckled bands above and below; while the central portion (about 1 foot thick) is more altered, crowded with the supposed ottrelite, and similar to the rock last described.

Thin slices of the upper and lower bands are crowded with minute greenish films and carbonaceous dust, and contain ilmenite or hæmatite, with occasionally a minute flake of biotite. This opacite is especially abundant along certain blacker layers. The altered central band contains much carbon, crystals of iron-oxide, sheaves of ottrelite, and small crystals of white mica which terminate irregularly and fit on to adjacent grains, and thus evidently are of secondary origin; garnets, however, are absent.

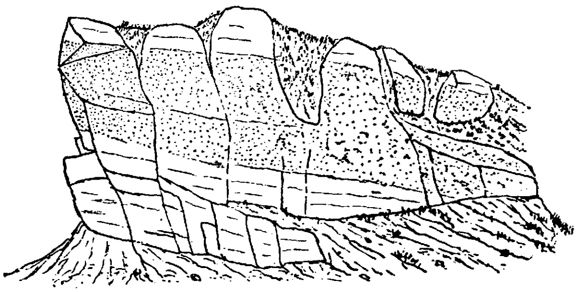
The cutting along the road extends for 100 yards or more, and exhibits grits, often banded and very fine-grained, containing sometimes (in various specimens) filmy chloritic patches, iron-oxide, white mica, possible scapolite, and a little biotite. The groundmass occasionally forms a clear recrystallized mosaic containing rounded grains of corundum (?), and sometimes lath-shaped crystals of mineral No. 17 or possibly a carbonate, which in one slice have grown across the cleavage of included wedges of slate.

In the quarries along the line to Gouvy, the strike of the rocks is roughly parallel to the railway. The rock is a greyish compact grit or an imperfect slate, developing structure-planes only in weathering. On examination with the microscope it is seen to have similar characters to that by the Longwilly road. The general dip is about 20° north-westward or west-north-westward.

Towards the south, above a slope of débris, is a boss somewhat trapezoidal in shape, partly isolated by quarrying (fig. 4, p. 66), its stratification dipping gently south-eastward. Here the mineral changes are mainly restricted to a band roughly about 1 foot thick, while the adjoining layers are hardly more than indurated and of flinty appearance, with a greyish mudstone beyond, which at one part below is jointed into small rhomboids. In the hard bands, nearly vertical joints together with the almost horizontal bedding-planes form cuboidal, or, in the upper part, imperfectly spheroidal blocks which weather externally into platy flakes.

Taking a section across the layers from above downward, one finds:—A fine-grained quartz-felspar grit crowded with microliths, with some graphite, biotite, pyrite, and iron-oxide. Next comes a banded rock, containing tufts of hornblende and of the supposed ottrelite intercrystallized, and abundant graphite. Small garnets begin to occur, and then become more numerous, being especially aggregated at the junction of adjacent bands. The garnets contain inclusions along crystallographic planes[1] (see fig. 3, p. 64); they are sharp-edged but often imperfect, especially where the lines of inclusions start; and they interfere mutually in their growth where a group has formed. Then comes the central banded rock more altered and rather clearer, with some hæmatite occasionally associated with the tufts, and containing but seldom mineral No. 17 (see p. 61), sometimes clinging to a well-formed garnet. The next band contains incipient hornblende or ottrelite, and incipient garnets. These are ill-formed and incomplete, being in places almost entirely occupied by interspersed crystalline grains. Then a blacker band containing graphite and incipient hornblende is followed by a greyish band including

Fig. 4.—*Band about 1 foot thick, containing garnets (often aggregated near planes of weakness) and hornblende or ottrelite; north-east of Bastogne, in quarries along the railway to Gouvy.*



[The rock is markedly stratified, and much jointed.]

much biotite. In the rock below, greenish films are abundant, opacite is less important, hæmatite or ilmenite-plates occur, and much biotite. Thus the rock, as we approach the central band, seems to show successively:—(1) minute greenish microliths, small biotite, scattered iron-oxide; (2) incipient hornblende or ottrelite with graphite; (3) in addition incipient ill-formed garnets; (4) hornblende (sometimes with ottrelite) better developed, and well-formed garnets.

Another patch of altered rock, seen on a joint-face,[2] measures about 18 × 3 inches, is irregularly wedge-shaped, weathering whitish,

[1] See A. Renard, Bull. Mus. Roy. Hist. Nat. Belg. vol. i (1882) p. 15 & pl. i, fig. 1.

[2] The patch *a* represented in fig. 208 of Prof. Gosselet would agree somewhat in position with that above described, but it differs in shape and in being garnetiferous, and has probably been quarried away.

I found in a talus-heap near here a loose specimen containing garnets, some of which are about 5 mm. in diameter.

with green acicular hornblende often in tufts. The boundary seems clear, but under the microscope it is found to be a slightly brownish zone, containing scattered iron-stained films. Beyond this edge, the hornblende-tufts extend for a few inches within a strong indurated compact rock, which passes into a pale-grey dusty-looking grit. The patch is probably a section across the crust of a garnetiferous nodule, either still concealed or removed by quarrying.

Examination with the microscope shows tufts of hornblende, some biotite, iron-oxide, pyrite, and probably garnet, having a somewhat pegmatitic structure. In the grey rock (at about 2 inches from the patch) hornblende-tufts are absent, but biotite, iron-oxide, and small interstitial colourless garnet occur with greenish microliths. At about 9 inches are more abundant microliths, and larger and more numerous flakes of biotite, together with ilmenite, along the margin of an included fine-grained band.

It may be worthy of observation that the patches of altered rock are either black, containing carbon [1] and garnets accompanied by ottrelite or hornblende; or they are greyer, more compact, crowded with tufts of hornblende without the sharp-edged garnets. Both rocks are fine-grained grits, but the latter is rather coarser, with a texture approaching that of a quartzite.[2]

In each of the cuttings described the strata form a very flat, slightly undulating anticline, each cusp which points downward corresponding with a vertical joint, filled by secondary quartz, thinning out below.

III. Theoretical Considerations.

As to the causes which have affected these rocks, Prof. Gosselet maintains that the metamorphism is explained almost entirely by mechanical action, except in the sahlbands of the porphyroids and of the granite. The formation of new minerals was due, according to him, to the heat produced by arrest of movement, compression, and friction. The movements continued over a long period. Some rocks enclosing crystals produced by an earlier metamorphism were laminated by later pressure ('phyllades aimantifères' of Deville). In others which were already 'phyllades,' crystals were developed by a second metamorphism (as, for example, the ottrelite-schist of Bogny). The chapter which advocates this view [3] is a most valuable statement of facts and observations; but, for reasons of which the following is a summary, I am not convinced by the arguments:—

The author maintains that the 'corneite' is due to a more intense pressure, where the rocks are folded over to the north, yet he

[1] See Bull. Mus. Roy. Hist. Nat. Belg. vol. i (1882) pp. 15, 17. The graphite, as described by Prof. Renard, is often disseminated as a fine dust.

[2] Compare the classification by Prof. Renard into quartzites, grits, and 'phyllades;' *op. cit.* p. 7.

[3] 'L'Ardenne,' 1888, ch. xxv. p. 759.

expressly says that the corneite is not found only in this position (*op. cit.* p. 771). Thus it seems more probably a coincidence, than a relation of cause and effect.

If the metamorphism of the 'corneite' were due to these causes, how could it be intercalated among grits which are not much metamorphosed (as at Serpont, etc.)?

It is difficult to understand how the movements which produce such undulations as are figured (*op. cit.* p. 769, fig. 208) could have caused the formation of the secondary minerals. These are often well-defined crystals, while in other districts far greater compression and folding has resulted only in microlithic development.

Even in the Ardennes, strata which are much more intensely contorted do not show any marked metamorphism.

No explanation is offered as to how pressure could have caused the metamorphism of 'nodules' or 'nodular patches' (*op. cit.* pp. 769, 789 & figs. 208, 216, etc.).

Prof. Gosselet refers the more marked metamorphism to movements of five different kinds :—(*a*) anticlinal, (*b*) synclinal, (*c*) near the sides of a fault, (*d*) along a fault, and (*e*) gliding-planes. But there can hardly be any locality here which does not exhibit one (or generally more) of these disturbances. Yet the chief secondary minerals are limited in their distribution.

When we consider what causes may have acted in the district, it is clear that the alterations include successive phases, one at least of which was due to pressure. Doubtless, as maintained by Dumont and by Prof. Gosselet, the pressure was of more than one epoch.

The altered rocks, so far as I have studied them, may be grouped as :—

1. Crushed quartzose grits ('arkose porphyrique'), with micromineralogical development (as, for example, Lamersdorf, Salm Château).
2. Rocks containing ilmenite, biotite, ottrelite, chlorite, with recrystallization of quartz. All these minerals are found over wide areas.
3. Garnetiferous and hornblendic rocks in limited patches.

Of these, the first and some of the second group doubtless exhibit pressure-effects, including possibly the development of ilmenite and of ottrelite; while the chlorite may be derived from biotite, or indirectly from hornblende.

Other results, such as the development of biotite; the recrystallization of quartz and felspar; and, even more important, the development of chiastolite described by M. Dupont, show such resemblance to the effects of somewhat slight contact-metamorphism that they are probably due to an igneous mass coming near to the surface in certain areas. We may compare the rocks with some of those from Andlau, or more closely with those from New Galloway collected by the late Samuel Allport.[1] In the latter, even in the less

[1] I have to thank Mr. L. Fletcher, M.A., F.R.S., and Mr. G. T. Prior, M.A., of the British Museum (Natural History), for allowing me to examine and compare the slides of these rocks.

altered examples, the biotite is generally more abundant, but the greatest amount is in one specimen from Libramont, and in all it is similar in character. Again, the small microscopic garnets in rocks from Libramont are rounded or subrotund, rather like those in contact-specimens from Glendalough and from New Galloway, although in the former the garnets have a grey centre and are contained in a fairly coarse mica-schist.[1]

Thus a resemblance is exhibited to contact-metamorphic rocks from other localities. As to the cause, it is true that, as Prof. Renard says,[2] the veins of porphyry and diorite in the Ardennes do not occur where the metamorphism is intense, but such intrusions as these would not cause much change. If the metamorphism in Brabant is due to them (as claimed by Dumont), it probably is only where the change is slight. Further, the existence of a subjacent igneous mass is surely not a 'gratuitous hypothesis,'[3] when evidence of its results can be given as stated above, and when in one district a granite has been shown to be exposed.

At the same time, the development of garnet and hornblende is so local and limited, that we seem forced to attribute them to a somewhat different cause. In regard to these, the following facts may be established:—

The stratification passing almost horizontally above the top of the 'nodule' belongs to a low, somewhat undulating anticline (although compression has given rise to slaty cleavage in some layers at a short distance). Thus the metamorphism cannot be due to folding or mechanical disturbance of the rocks, and the 'nodule' could not be a curiously contorted part of a band. Though the line of demarcation seems rather sharp in the field, and suggestive of a junction of an igneous and metamorphic rock, microscopic examination shows a gradual passage, with continuous lamination. The 'nodule' is part of the surrounding rock metamorphosed.

The 'nodule' is always very limited, generally a few feet across, and surrounded by normal, or but slightly altered, sedimentary rock. It is not likely to be a projecting knob of an ordinary contact-zone around a subjacent igneous mass, for such is nowhere exposed,[4] and its position within the surrounding rock makes this almost impossible.

Further, the secondary minerals differ from those of an ordinary contact-zone in certain respects, although resembling them in others. We note, for example: (1) the absence of any large andalusite; (2) the tufted growth of the hornblende; (3) the sharp outline of the garnets in a comparatively unmetamorphosed groundmass; (4) their peculiar internal structure; and (5) the frequent presence

[1] The garnets of the Brazil-Wood gneiss have a sharper outline, and exhibit internal cracks; but the rock is of a different type.

[2] See Bull. Mus. Roy. Hist. Nat. Belg. vol. i (1882) pp. 35, 36.

[3] 'L'Ardenne' 1888, p. 761.

[4] By the road from Bastogne to Longwilly no ignĕous rock is seen in the lowest part of the quarry, as already stated; and I searched the lower cutting by the railway, and the craglets south of the valley, but found none.

of carbonaceous material. Yet the recrystallized groundmass often resembles an early stage in contact-altered rocks. It frequently contains some of the characteristic biotite, which sometimes may be abundant even in a rock crowded with hornblende-tufts.

Thus we have to account for small limited patches often comparatively undisturbed, showing gradual alteration, with a marked line of change at one part, yet without any exposure of an igneous rock to cause the modification. I believe that the true solution will be found in the suggestion, made by Prof. Bonney in 1890,[1] that we see here results due to hot springs. They would modify the sedimentary strata, so that we should expect to trace a gradual transition. At the same time, a line of division would be marked around the central mass, often crossing the banding: just as a deposit from ordinary infiltration may end almost abruptly. The alteration would occur over limited areas,[2] which might appear in section as 'nodules,' or lenticular patches, or partial bands.

Mineral differences are sometimes exhibited along zones in the nodules, or along bands in the altered layers. This might be due to the marginal effects of the heated water. Even in a lava-flow minerals may be sublimed and deposited at one part of the layer. Thus Scrope pointed out that

'the specular iron, so frequently met with in lava-rocks, is evidently sublimed by [the intense heat of the lava] and . . . . is always found in the upper parts of the bed or current; while the lower parts of the rock . . . . have obviously lost all or the greater part of their iron by sublimation . . . . Or, as in many of the currents of Etna, the upper parts . . . . contain much specular iron, ... the lower and compacter division abounds in magnetic iron, in grains or octahedral crystals.' ('Volcanos' 2nd ed. 1862, p. 144.)

In the Ardennes 'nodule' the central and main part contains generally garnets, and often ottrelite, and is crowded with graphite. The last named substance (abundant only here) might have been deposited from the decomposition of a hydrocarbon contained in the waters of a hot spring.[3]

The peculiar character of the garnets (so different from those ordinarily found in schists or even in igneous rocks), their very

[1] 'On the Crystalline Schists & their Relation to the Mesozoic Rocks in the Lepontine Alps' Quart. Journ. Geol. Soc. vol. xlvi (1890) p. 214 note.

[2] Compare the cherty nodules of Stotfield which Prof. Judd attributes to 'purely chemical agencies,' Quart. Journ. Geol. Soc. vol. xxix (1873) p. 136. In Cornwall patches of altered rock occur, which also may be compared. Here the tourmaline, doubtless a result of infiltrating waters, has the same interrupted granular appearance as the biotite or hornblende; like these, it is sometimes developed along lines, and commonly forms tufts. I am indebted to the authorities of the Natural History Museum for facilities of studying slides from the Mousehole, Penzance.

[3] Just as the hot springs of California have deposited silica and sulphides of metals in accretions or disseminated through the rock, as described by J. A. Phillips, Quart. Journ. Geol. Soc. vol. xxxv (1879) p. 390. See also Geol. Surv. California, vol. i (1865) pp. 92, 94. In slides at the Natural History Museum, belonging to the collection of that author, from a rock of Steamboat Springs (Nevada), an opacite-dust is scattered, reminding me of the distribution of carbon in the Ardennes rocks, although in the Nevada slide the opacite is probably a metallic ore.

regular shape, and regularly-arranged inclusions[1] point to some special action. Doubtless favoured by the slow growth of well-formed crystals, inclusions accumulated along crystallographic planes, and material from the groundmass was pushed to the exterior, so that a border of carbonaceous dust, or sometimes of secondary crystalline mineral, is found. Larger garnets or groups of them are sometimes developed along joints or planes of bedding. Either the infiltrating waters may have permeated more readily here, or crystallization may have started from the divisional surface.

The tufted growth of acicular or platy minerals (such as actinolite) has been shown in other rocks to be due to crystallization overcoming the resistance of a crushed or a fine-grained powdery mass.[2] But here we claim an initial aid to crystallization in the presence of heated waters. Even the friable earthy character of the interior might be caused by the later effects of vapours and solutions decomposing the mass.

Further, the numerous joints and the quartz-veins, narrowed downward towards the altered rock, might be due to chemical action. The expansion of the rock caused in such changes would slightly lift the overlying strata, forming a low arch, with joints as described above.

The solfataric theory may claim, to a certain extent, the support of Prof. Gosselet, since he emphasizes the important part which he believes that superheated water has played[3]; but I cannot adopt his view that the heat was developed through mechanical disturbances.

Thus we consider that this district exhibits modifications due to different kinds of action. Compression and folding, probably at more than one epoch, produced slaty cleavage, schistose structure (including that of the peculiar squeezed porphyroids), and even initiated the development of certain minerals. Contact-metamorphism, due to subjacent masses (like the granite which at Lamersdorf rises actually to the surface), probably acted over a certain area; while the local action of hot springs induced the development of the peculiar garnetiferous and hornblendic rocks.

Discussion.

Gen. McMahon remarked that the beautiful lantern-illustrations shown on the screen seemed to him to be quite typical examples of contact-metamorphism acting on fine-grained sedimentary rocks.

[1] We may compare the sharp form of couseranite within a slightly-changed ground; also the sharp-edged pyreneite (in a blackish limestone) which has similar regularly-placed inclusions. This latter is described by M. Ed. Mallard as corresponding to a group of orthorhombic pyramids, Bull. Soc. Minéral. Franc. vol. xiv (1891) p. 293.

[2] See T. G. Bonney, Quart. Journ. Geol. Soc. vol. liv (1898) p. 371; Proc. Roy. Soc. vol. lxiii (1898) p. 220; T. G. Bonney & C. A. Raisin, 'On Varieties of Serpentine & Associated Rocks in Anglesey' Quart. Journ. Geol. Soc. vol. lv (1899) pp. 294–97.

[3] 'L'Ardenne' 1888, p. 762.

Hot springs were potent factors in the metamorphism of rocks. He had studied their effects in the Himalayas, and found that the rocks in their vicinity—especially basalts—had been intensely metamorphosed. It was sometimes difficult, however, to distinguish between the results of contact-metamorphism and the results produced by hot aqueous agents circulating through rocks underground. Geologists were aware that the quartz of granite abounds in water-vesicles, and water was usually supposed to contribute by its presence to the fluidity of molten granite. An appreciable part of the contact-action of granite is due to the superheated water, or steam, emanating from the fluid magma; and the resulting metamorphism is sometimes not distinguishable from the action of water caught up in, or percolating through, sedimentary beds, and brought within the influence of underground heat and pressure. Some minerals, such as mica and hornblende, are known to be the products of contact-action and also of the simple percolation of water below the surface of the earth.

Prof. WATTS referred to the brief account, published in the Annual Report of the Geological Survey, of the metamorphic areas of the Isle of Man. These areas showed what appeared to be typical examples of contact-metamorphism associated with masses of granite and other intrusive rocks; but it has been found by Mr. Lamplugh that the metamorphism had no relation to the intrusive masses, indeed it was visible in the intrusive masses themselves. Minerals similar to those described by the Authoress occurred in the Isle of Man. The hypothesis of the action of mineral springs was one which would have to be carefully considered in the Isle of Man as well as at Bastogne.

The PRESIDENT and Prof. SOLLAS also spoke.

Prof. BONNEY, replying on behalf of the AUTHORESS, said that as the Isle-of-Man rocks, mentioned by Prof. Watts, were not yet really described, she could not be expected to refer to them. The Wicklow rocks he had seen, under the kind guidance of Prof. Sollas, and had examined with the microscope; but they were markedly different in more than one respect from those in the Bastogne area. Here the chief peculiarity was, that remarkably well-formed garnets occurred in a comparatively unaltered matrix. In ordinary contact-metamorphism (examples of which, as the Fellows had just seen, did occur in the Bastogne area) the garnets were seldom well-shaped, and only appeared when the matrix was greatly changed. So far as his own experience went, the Bastogne rock was almost unique, and its mode of occurrence was difficult to explain, either as the result of contact- or of dynamic metamorphism. As to the last, undoubtedly work produced heat; but the question was, how much? If the crushing was sudden, there might be a considerable rise of temperature, but then the vicinity should show great disturbance; if it were slow, there would be no effective rise of temperature.