

The Geognosy and Mineralogy of Scotland.

BY PROFESSOR HEDDLE.

SUTHERLAND.—CONTINUED.

The Upper Gneiss.

WHILE agreeing with those writers who affirm that many of the members of this series are of the nature of schists,—sometimes almost flaggy schists, still, even when examined throughout their multitudinous varieties, it has to be affirmed that they are all *gneissic* schists; and, however fissile some of these members may be, this is far from a sufficient reason for attempting to dispense with a time-honoured appellation;—one moreover which is more fittingly applied to them, than to the somewhat *more generally hornblendic* rock to which alone it has been proposed to confine its use.

As perfect a gneissic structure, nay, even a more perfect gneissic structure is to be seen in the rocks between Tongue and Farr,—in Strath Oikel, or at Strath Virick, as in any part of the “hornblendic gneiss”; and the gradual transition of such rocks (generally as we ascend on the series,) into readily cleavable flat flags,—whether gritty, micaceous, or aluminous,—shews the latter to be but lithological allomorphs.

Changes quite as marked, both as regards proportional increase of one or other ingredient, and as regards structural modifications, are found to obtain in this upper system of rocks, when we track them *along their strike*;—even when we are kept rigidly thereto by restricting ourselves to an examination of that basement layer which is in contact with, or immediately succeeds to the upper quartzite.

Sooth to say, it becomes very much of an enigma, if we suppose that layer to have been deposited upon anything approaching to a level ocean-floor, how rocks so very dissimilar as those which we find in different districts along this line, can have been simultaneously laid down.

Over the quartzite at Whiten Head, may be seen at the Bodach-Derg, a dark-green rock, coarse in structure, and largely formed of what

was possibly hornblendic mud. This rock is generally so similar to parts,—especially to decomposed parts of the hornblendic gneiss, that it is not altogether to be wondered at that they were at one time considered to be the same.

This Whiten Head rock has by one observer been called “chloritic schist.”

While it is *chloritic* in the sense of being *green*, it certainly is very different from the true chlorite-slate of Ben Lomond, and the south-west of Scotland. The colouring ingredient seems to be a mixture of pounded hornblende with minute scales of muscovite. Very possibly it is a repetition in force, of the schistose green beds which at many points underlie the Logau rock.

As we pass southwards we come, in the neighbourhood of Hope Lodge, to beds of a quartzose character. These, considered along with others which lie between the Hope Ferry and the limestone of Heilim, may be taken as supplying fair ground for holding *that the quartzite there passes upward by a system of separated beds into the upper gneiss*; and as entitling us to refer both to the same epoch.

The uppermost of these beds lies about a fourth of a mile to the east of the Lodge, and it differs markedly from the rock last noticed. It might, from its extremely schistose character, be termed *paper-quartz*. Its appearance, which is somewhat that of a mica-schist deprived of its mica, conveys the impression that it is an example of pseudomorphism in a rock mass.

Still further southward, an increase in the quantity of mica beyond that of the Bodach-Derg Rock, gives us the “Oyster Shell Rock” of Craig Vercan. This larger amount of mica is here asserting itself in the attempt to form crystals; but the associated hornblendic mud, may, by distorting these, have produced the curvilinear “oyster-shell” structure.

Still further south, the total removal of the dark-coloured ingredient gives us, at Leiter Mussel, a mica-slate, which cleaves into plates as thin as a writing slate. In the Loch More and Loch Merkland district, it has become a clay-slate, dark in colour, merely glistening with mica;—not far from the *phyllade* of the French.

On the eastern side or end of the ridge of Ben More, there is so small an amount of the sand-grains that the rock, when wet, works into a plastic clay. East of Loch Ailsh, the silica has returned in such quantity and with so much coherence, that some would term the flags quartzite.

On the road between Knockan and Ullapool, it looks like a clay-slate, with some bands largely made out of a mud of comminuted horn-blende: while, south of Loch Broom, down to Fionn Bheinn (Ben Fin), and away to the south-west, the mica in predominating amount has again come back in glittering scales of yellowish muscovite, studded with garnets and interlaminated with quartz;—the veriest gneiss of all the range.

The line is a fairly straight one now, with no great amount of vertical undulation; but when it formed the sea-bottom, it may have lain in wrinkles: and at present we can only speculate as to how much of this local segregation of these dissimilar materials may have been due to substances of higher gravity settling first in the deeper pools;—and how much to slight differences or intensities of a local metamorphism, which produced different results from elements occasionally differing but little, if at all.

The marked dissimilarity of the rocks which immediately overlie the quartzite in Sutherland proves that, in attempting correlations in a country, it will not suffice to make an eight or ten mile section across a series of rocks;—a traverse of a hundred miles, keeping faithfully to the strike or along the junction, is also imperatively called for.

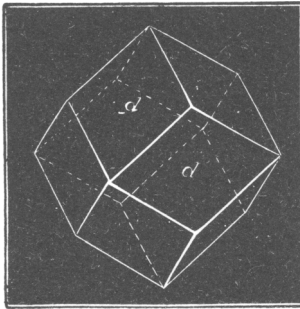
Although neither typical chlorite-slate, mica-slate, nor clay-slate, occurs among these rocks, the marked difference in their structure and composition, shews the wide range in lithological character and in mineral composition, which may occur in the members of one formation; and also testifies to the impropriety of any attempt to set aside a long-established name upon the merely-local features of one of its members. The proposal to dispense with the term "gneiss" as applied generally to the members of this formation, is therefore, on every ground of scientific nomenclature, to be deprecated. It was *to this very class of rocks* that the term was first applied in Scotland, and has ever been applied; we may indeed doubt if those who introduced it ever saw that "Hebridian gneiss" to which it is now proposed to restrict its use. Should the progress of discovery necessitate a distinctive term, such term must be applied to the rock which, in virtue of its dissimilarity to the recognised type, calls for an extended nomenclature; and the confusion which could not but have ensued from the adoption of any other principle in the present case (and which in point of fact has ensued) quite called for Nicol's remonstrance, that "it would take more arguments than had been brought forward, before he

could be induced to believe that Jameson and Maculloch, Boué, and Necker, did not know gneiss when they saw it." *

Minerals.

These occur not only in much greater numbers and variety, but are markedly different in what may be termed *type*, from such as I have above recorded as having been found in the hornblendic gneiss.

From the very varying basement layer of the upper gneiss, I procured minerals in but one spot. This was from the mica-slate. The locality was the foot of a line of cliff called Leiter Mussel; this is a south spur of Ben Hope.



At the north end of this cliff we (D. & H.) got garnets in rhombic dodecahedral crystals; these were sometimes formed of successive layers of garnet, with bands of grains of silica,—in fact glistening sand. These bands though composed of a mechanical debris, had been so under the control of the accession of each new layer of garnet, as to have been caught up or pushed before it, whilst the material of that layer was being drawn

to the common centre of the crystalline action.

* That no very marked petrological distinction can be drawn between the two classes of rocks, may be shown by quoting from the writer who most urgently insisted upon the change of name.

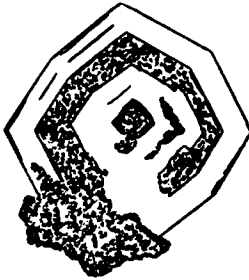
Sir R. Murchison in 1858, writes—"we ascertained that Farrid Head consists of the old gneiss." In 1859, he writes "that promontory was erroneously referred to the old gneiss in my former memoirs, on conclusions drawn from a hasty visit of my friend Mr. Peach, who brought me specimens from one part of the headland, which had a gneissose aspect."

One of two conclusions must be drawn from this—either, that the *haste* lay most in the writer's inferences,—or, that these specimens so strongly resembled the old gneiss, that the very geologist who was desirous of separating them, was himself unable to distinguish between them.

And yet, writing in 1861 we find Murchison again saying—"we are of opinion that no geologist can confound the fundamental gneiss with the so-called gneiss of the superior crystalline schists, which, instead of being a massive hornblendic and granitic rock, is a flag-like, micaceous, and quartzose deposit of very different character."

No strata of the upper-series are *more* "flag-like, micaceous, and quartzose" than those of Farrid Head; yet their "great dissimilarity" in character to those of the lower-rock would not appear to be so marked as to be *always* capable of ocular apprehension; and it is therefore strange that they should have formed the text for the above quoted specimen of scientific dogmatism.

The climax as regards the rocks of the Farrid is more curious still. We find in a foot note to the last paper by Murchison (Feb. 6th, 1861), that specimens of the rocks from *this promontory* were exhibited to the meeting "to show their dissimilarity to the old gneiss of Kean na bin, with which Prof. Nicol connects them." Many years ago Dr. Maculloch cynically told us that geologists had "to be taught even to see;"—does not the above entitle us to say, that we should be taught to be *slow to believe*? And what do the words "with which Prof. Nicol connects them" teach us,—saying that Murchison was himself the first to make the connection?



The crystal figured *seems* to have a crystalline nucleus of granular silica:—it can hardly be conceived that the centripetal action of crystallizing molecules could induce a powder, caught up in their midst, so to arrange itself as to assume a form not belonging to the system in which its own material usually crystallised. Probably therefore there is in the specimen a minute nucleus of garnet.

This garnet has a specific gravity of 4·127.

It yielded—

Silica	.. .. .	35·
Alumina..	.. .. .	21·539
Ferric Oxide..	.. .. .	2·822
Ferrous Oxide	.. .. .	26·537
Manganous Oxide	.. .. .	4·461
Lime	.. .. .	7·107
Magnesia	.. .. .	2·307
Water	.. .. .	·143
		99·916

(H).

The rock which contained these garnets was very peculiar. *Actinolitic hornblende* of a fine colour was present in lanceolate crystals; the matrix was a snow-white granular silica of extremely high lustre,—each grain sparkling, transparent, and appearing as if quite detached from those in contact with it.

Midway between this locality and the waterfall on the Allt na Callich, crystals of *hornblende* lie sprinkled like grains of corn, in a similar matrix. Both varieties form specimens of great beauty.

Actinolite-slate occurs at both localities, in small quantity.

Inferior specimens of *chlorite* with *magnetite* occur upon the south slopes of Ben Hope.

The discovery of mineral localities in the upper-gneiss of this county must be to a large extent fortuitous:—from its vast extent it would be impossible for a single explorer thoroughly to examine it.

Dr. Joass, observing a singularly elevated ridge in the neighbourhood of Collabol, searched it, with the result of finding lamellar *baryte*, coated with *chrysocolla*.

A little to the north-west of this, a very peculiar and beautiful hornblendic-rock occurs (D. and H.).

It appears to consist of nothing but a fine granular felspar of a cream colour, containing imbedded patches of light-green fibrous *hornblende*.

Small crystals of brilliant *epidote* occur in its cavities, and also, rarely, minute *sphenes*.

A well-marked hornblendic rock with a granular felspar, occurs also at the knoll called Cnoc na haire, some miles to the west;—also near Overscaig,—the whole of this district, indeed, being markedly hornblendic.

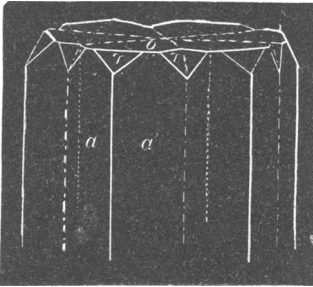
Achadhaphris.—This is the name of a farm which lies about a mile north of Loch Shin and a little east of Collibol. During the improvements carried out by His Grace the Duke of Sutherland, the ground was here much cut into; and during the ditching the rock was in one or two spots exposed.

It was found to be a hornblendic gneiss, with a north east dip.

The *hornblende* was somewhat foliaceous, and light in colour.

The small amount of the rock which was exposed yielded, in its more felspathic portions, the following minerals.

Sphene, (D. and H.) Ill-defined and small crystals of the short flat form which is common in Scotland, occur in the more felspathic portions of the rock; they are of a pale hair-brown colour.



Apatite (D. and H.) Occurs in small pale bluish-green crystals, sometimes in twinned forms as in the figure. It accompanies the sphene. Both of these minerals have here somewhat of a waxy lustre.

Minute fibres of *rutile* were associated with the apatite.

Lepidomelane (D., Jo., and H.)—This mineral, so rare in Scotland, occurs here in plates of two to three inches in length. The colour of these plates was from a yellowish-brown to a chocolate-brown. They were easily cleavable; but, as the mineral was brittle, only short flakes could be raised. It was slightly bi-axial, and had a muddy yellow-brown colour by transmitted light. The specific gravity is 2.971.

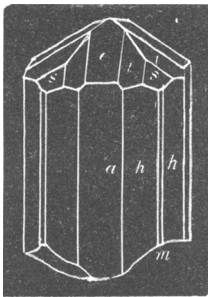
Its analysis yielded—

Silica	40·384
Alumina.. .. .	12·11
Ferric Oxide.. .. .	14·523
Ferrous Oxide	3·03
Manganous Oxide	3·146
Lime	1·033
Magnesia	13·
Potash	7·128
Soda	1·801
Water	3 567

99·722 (H).

Ilmenite in thin plates was associated with the lepidomelane (D. and H).

There was found here in making the clearances, a piece of white quartz studded with small but finely formed crystals of *rutile*. Some of these crystals were in the form of the annexed figure. This was the most perfectly crystallised rutile which the writer has seen from Scotland.



Clach an Eoin.—The tract of country which lies on each side of the river Naver, and indeed the whole whole way between it and the Borgie is of extreme roughness. The gneiss seems tumbled in all directions, and is removed not only from its normal dip, but presents characters of a higher metamorphism than it displays in most parts of the county.

The rock or craggy knoll called the Clach an Eoin exhibits on its glaciated front a peculiarity of structure which I have not seen described. In comparatively feeble development something of the same kind is to be seen in the gneiss of Boggierow quarry, near Portsoy,—at Strath Virick bridge near Arguish,—and at Innisbay, on the Dirrymore road.

At the first, and possibly also at the second of these localities, the structure may be regarded as a mere modification, or a badly developed instance of porphyritic arrangement in the felspathic portion of the stone.

At Boggierow the crystals of the felspar, if felspar they be, are devoid of all edges and angles, appearing rather as kernels or nodules, of some half-inch or so in size. Of these there is here no definite arrangement whatever,—they are promiscuously scattered throughout the mass.

As regards the size, and want of angularity of the felspathic portions of the Innisbae rock the above also holds: but there is here no promiscuous scattering,—no absence of arrangement: these felspathic kernels lie in regular layers which accord with the micaceous lamination of the rock,—following obediently that lamination where it has been crumpled. Something very close to this is given by Cotta, as his description of typical porphyritic gneiss:—"in the otherwise uniform schistose mass there occur at intervals, large egg-shaped crystals of orthoclase (sometimes amorphous), round which the foliated texture bends itself with a wavy sweep." This description approaches it, though it is really different from, what is to be seen at Clach-an-Eoin.

The study of the Boggierow rock leaves the impression that the felspathic portion had attempted to arrange itself as crystals, or had been crystals,—porphyritically disposed. Such a conclusion will hardly apply to the Innisbae rock,—the felspathic matter is certainly not porphyritically disposed when it is confined to a regular arrangement in layers; and such a conclusion certainly will not apply at all to what obtains at the northern locality. First, it will not apply in *size*;—the individual collections of felspathic matter, to which inches would apply at the other localities, are here of the dimensions of feet and yards. Second, it will not apply as to *internal structure*; a certain amount of rough cleavage which is to be obtained in the first cases, showed that each—all being much of a size—was to be regarded as an individual mass of which the components were *its molecules*; here, nothing like cleavage is to be got; the components are crystals, granules, plates, promiscuously agglutinated, and forming masses of greatly varying size. Thirdly, it cannot apply as to *shape*; there is here no residual trace of geometric form,—for the masses are lenticular.

The strike of the rock is N. by E. and S. by W.; it stands nearly vertical; its bedding is well shown by the parallel disposition of its layers of black mica; it is singularly free from all plication; between the bedding of its micaceous layers, however, there occur in marked abundance, though at quite irregular distances, parallel arrangements of the segregated felspar of the rock, disposed like the glands on a duct, or ganglia on a nerve,—the enlargements being of ever varying size, composed each of numberless crude crystals, and hence totally different from *Augen-gneiss*.

In one respect the comparison with ganglia on a nerve is not satisfactory—the felspathic bands are generally not continuous; but the juxtaposition of the two micaceous layers which lately sheathed what I have represented under the figure of ganglionic enlargements, leads, in straight course, to the next and not far separated lenticular mass.

There can be little room for doubt that this is a modified development of that segregatory process in virtue of which the felspathic material of gneissose rocks so frequently arranges itself in layers or belts. As these belts consist of a material more plastic when heated than the less fusible quartz and mica, they are, where plicated, thinned off to nothing at the more compressed flexures, only to re-appear in ampler development among the loosened or more drooping folds. But at Clach-an-Eoin we have no plications which compress or loosen,—*the portions of the rock where the felspar thins off, being actually the least compressed of the whole;—this is seen by the opening out of the micaceous layers in the immediate vicinity.*

Can it be that metamorphism—for it is a district of considerable, though not extreme, metamorphism—has rendered the more fusible material so plastic, that cohesion has here been tugging hard to cause it to assume actually a spherical form, and has been baffled only by gravitation, which flattened out the sphere into a lens-like shape, or rather retained what, without its action, would have been a sphere, in a lens-like shape.

But the description is as yet faulty: I have used the recognised geological term “lenticular” as the adjective altogether most applicable; but the relative proportions of these masses—which vary from the size of a goose’s egg to that of a grampus,—are a length about twice as great as their breadth. Since, however, they thinned away also somewhat as they merged into their connecting band, they presented an appearance so similar to that of an *eye*, that it appeared to my fellow workers, Dr. Joass and Mr. Dudgeon, that it would be most fitting that we should meanwhile designate what I have described, as an “oculitic structure.”

The black mica, which so clearly defines the rock-layers, is here *Haughtonite* (D. and H.)

Towards the north-east cliff of the hill, it is to be found in plates of some inches in size; these plates protrude edgeways from the quartz-veins of the rock,—are much weather-worn,—and have upon these weathered edges the colour and lustre of somewhat tarnished metallic lead. This weather-wearing affects only the edges of the crystals, which have smooth rounded depressions with an appearance as if portions had been eaten out by some insect. There is not the smallest appearance of internal alteration or even of loosening asunder of the plates, as in the case with the mineral from Cape Wrath. These plates are associated with *garnet, rutile, ilmenite, and chlorite* (D., Jo., and H.). All are imbedded in quartz.

The colour of the Haughtonite is clove-brown; red-brown by transmitted light. The plates are uniaxial, or very slightly biaxial. The specific gravity is 2·96.

It yielded

Silica	.. .. .	35·846
Alumina	.. .. .	21·539
Ferric Oxide	.. .. .	4·467
Ferrous Oxide	.. .. .	18·306
Manganous Oxide	.. .. .	·307
Lime	.. .. .	1·249
Magnesia	.. .. .	8·076
Potash	.. .. .	7·759
Soda	.. .. .	·794
Water	.. .. .	1·956

100·299 (H.)

The *garnets* here occurring are quite inferior in quality and form,—they are rhombic dodecahedra of a brown-red colour.

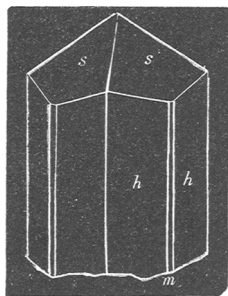
They yielded—

Silica	.. .. .	39·923
Alumina	.. .. .	19·808
Ferric Oxide	.. .. .	13·69
Ferrous Oxide	.. .. .	13·294
Manganous Oxide	.. .. .	1·
Lime	.. .. .	9·132
Magnesia	.. .. .	3·307

100·154 (H.)

When the nature of the matrix is considered, the quantity of lime is great. The *ilmenite* is in blue-black plates, and is rare; the *chlorite* is in small ill-defined rosettes of crystals.

These are all associated with the Haughtonite; on the north-east side of the hill.



The rutile occurs in single, isolated crystals, imbedded in a yellowish vein-quartz, upon the top of the Clach. The crystals are small but fairly well formed, as in the figure. Some are translucent and ruby red.

Rutile in crystals nearly two inches in length, but transversely fissured, with the matrix lodged in the interstices, occurs also in a yellow quartz, in the crags beneath a Pictish "brough," which is placed upon the south-east shoulder of the same hill. (D. and H.) The form is indistinct.

I have received through Dr. Joass portions of a rock or stone,—I believe a large boulder,—which was found in making a road at Ribbigill near Tongue.

This consists of a basis of fine-grained, scaly, and very soft chlorite, (apparently); in this there are disposed in a porphyritic manner, at distances of about an inch, crystals of lustrous white *talc*, of about the size of peas.

In my experience the rock is unique. I have some hesitation in calling the one mineral chlorite, on account of its extreme softness, and from its being weathered to the depth of an inch. This is a greater amount of change than I ever saw in chlorite: it bears some resemblance to scaly saponite; but the occurrence of talc in association with saponite is unknown; as is the occurrence of saponite in sedimentary rocks. From "till," a little south-east of Tongue, I have myself got ordinary unchanged chlorite, imbedded in white quartz.

The Primary Crystalline Limestones.

These are known in Sutherland in but two localities,—the north and the south shores of Loch Shin;—at Shinness, and at Arskaig.

At these localities they present the appearance which is so usual to this rock in its higher state of metamorphism,—a congeries of crystalline particles which have mutually nullified each other's efforts to assume a regular form, and so have produced only a granular mass,—the cleavages of the several granules lying in every direction.

The primary limestones of Scotland sometimes present themselves as extremely barren of minerals; at other localities they contain a few species, which may be said to pertain to such limestones in a very special manner; while again they occasionally supply so many mineral species as to present themselves as one of the richest matrices of all rock masses. It thus becomes of interest to examine into the circumstances, and to endeavour to attain to the causes of this diversity of fruitfulness in limestones.

The first fact which is noted after the enquiry has been sufficiently extended, is that the *nature of the rock* immediately in contact with the limestone seems to have little influence; and that regard has to be had, primarily, to the *physical circumstances in which the lime is placed*.

It will be observed, that if the limestone bed is of *trifling dimensions* it will afford no minerals,—whether it be disturbed or undisturbed, convoluted or not so.

Turning the attention to the conditions and characters of the lime rock itself, it will be found that in this case it is simply *limestone*, (generally

dolomitic),—a more or less impalpable paste, amorphous in its nature, structureless, and more or less coloured or muddy, evidently through mechanical contamination.

If we look next at the including rock, it will be found that it shows no changed structure,—no greater amount of metamorphism in the vicinity of the limestone, than throughout its general mass.

It will also be observed that not only does the limestone contain no minerals, but that the strata in contact with it also afford none other than those which go to form its general mass; and that under such circumstances the crystal-dimensions of such constituent minerals is not increased.

All this *also holds*, with equal force, under the circumstances of the lime-stratum being of considerable thickness, so long as it is untroubled or convoluted.

But it is not so if the stratum be, at one and the same time, large in mass, and either itself highly-contorted, or, in those cases where it is not sufficiently exposed for this to be determined, if it be seen to be lying among highly-contorted rocks. Then, the calcareous mass no longer is amorphous in its substance; it presents itself as a *granular limestone*, often as a true marble; that is, it is *calcite*, and is crystalline in structure, and in all its inherent properties.

Here the including rock in the immediate vicinity, is much more highly metamorphosed than it is throughout its general mass; the crystalline development of its constituent minerals being not only more distinct, but more ample.

While lastly, imbedded in the limestone, and to a smaller extent in the altered rock, but in both cases near their point of contact, there are found numerous minerals which *are such as can be formed by the union of the constituents of the inclosed limestone with the inclosing rock*.

These three circumstances, then, I believe to be invariably observable with regard to the "primary limestones,"—namely, that whenever they are much folded or crumpled,—thrown at a high angle,—or when the adjoining rocks exhibit rents and fissures,—there the granular structure will show itself in the largest development of individual particles;—there simple minerals will be found in immediate association in the greatest numbers and amount;—and there the limestone will be the purest *in its own substance*, as regards both colour and translucency.

This directly points to *combination having taken place between the constituents of the rock and of the limestone*; and, if the amount of such combination be at all in the ratio of the amount of folding and contortion, it may result that the whole amount of the calcareous

matter has been taken up in such combination,—and *the limestone stratum, as such, may actually disappear.*

Local interruptions in the continuity of a limestone stratum, while a continuation of a vivid grassy verdure vouches, in these, for the presence of a large amount of calcareous matter in the rock which yields the soil, are of frequent occurrence in the Highlands.

In the bed of limestone which courses down Strath Dee, a gradual increase of the amount of imbedded mineral, (here malacolite,) and diminution of residual calcite, may be traced as we follow the bed through the constantly augmented plications to which it is subjected as it passes eastward. An average sample of the limestone taken from the Glengairn quarry, leaves after treatment in acid, about 3 p.c. of insoluble mineral. The percentage of residue increases as the stratum passes eastward along the course of the Dee. In the stone from the quarries which are opened into it as it twists about at Muir and Midstrath, there is so little calcareous carbonate that a fragment retains its shape after treatment with acid; while Dr. Young tells me that the substance which was worked and burned as lime on his property of Durris, *does not effervesce at all*, when so treated.

The most striking feature, however, is the change effected upon the rocks which are in contact with the limestone. So marked is this feature that, under the circumstances detailed, these limestones may be said to *function* in the Highlands *in a manner somewhat similar to that of igneous rocks*;—I mean as regards the changes which they seem to induce.

Such a mode of functioning is most anomalous, at first sight, as regards a substance and a structure unquestionably of organic origin; it is only to be explained through a consideration of the *circumstances* which obtain, and cannot well be assigned to the *mere presence* of limestone in a rock which is undergoing ordinary metamorphism.

Ordinary metamorphic change is, in our almost total ignorance of the subject, usually assigned to a hydro-thermal action, which has taken place at great depths, i.e., under enormous pressure. Such a thermal change should affect a plicated, and a nonplicated included rock alike; and should certainly affect a thin bed of limestone more than a thick one. As the result of any change thus pressing from *without inwards*,—that is, from the gneiss to the limestone,—we should expect to find the thinner parts of the stratum of the latter wholly converted into large granular marble, and very fully pervaded with mineral species; while the thicker parts of the limestone should be much less altered in both respects; but this is the opposite of what

obtains; and so any explanation which requires that the agent of change should act from *without inwards*, does not suffice.

The whole facts of the case seem to point to an action taking place from *within outwards*. This view, at least, would seem to account for there being a greater change where the stratum is thickest;—the greater the mass, the greater must be the amount of action, if that action proceed from within.

But what action, physical or chemical, can be conceived to take place within, or emanate from a sedimented, amorphous, organic limestone, which could credit it with being at one and the same time the agent of its own metamorphosis into its crystalline allomorph,—of augmenting the metamorphosis of a rock in its immediate neighbourhood,—and of stimulating to the chemical union of the material of its own mass with the constituents of that rock?

Among the physical agencies which induce a change from the amorphous or colloidal to the structural or crystalloidal condition, we find *plication* and *heat*. Sir James Hall's experiments have shown that direct heat under pressure will change limestone into marble or calcite; and *plication*, in the very act of transforming a colloid into a crystalloid, does so at the cost, so to speak, of an elimination of heat from the substance so plicated. If we melt lead and pour it out on a flat stone, it assumes upon cooling the structureless, amorphous form, with rounded colloidal outline. If, after cooling, it is bent in the hand, it gives out heat, becomes crystalline in structure, gradually loses its pliability, and assumes the brittleness inseparable from the crystalloidal state. The same holds for iron, and for all metals capable of assuming the colloidal state; bend or beat them, they give out heat, becoming crystalline and brittle in so doing.

The heat here eliminated is doubtless partially the representative of arrested motion; but it is probably *chiefly* an outcome of the change from the colloidal to the crystalloidal condition; the agent of the elimination was the plication to which the substance was subjected, which plication was at the same time the immediate agent of the physical transformation.

I would venture to predict that it will come to be found that *the specific heat of substances in their colloidal state is always greater than that of their crystalloidal*.

I am not aware that any researches have been made specially to determine this point; or even that the attention of physicists has been directed to it; but the following table, which embodies all that I have been able to find, seems clearly to bear out such a view:—

COLLOID.		CRYSTALLOID.	
Water	1·	Ice	·72
Lamp Black	·26	Graphite	·201
Limestone and Chalk ..	·264	Diamond	·174
Chalcedony	·195	Calcite and Marble..	·201
Titanic Acid (artificial) ..	·172	Quartz	·179
Peroxide of Iron (artificial)	·176	Rutile	·163
		Hematite	·166

Should it prove to be the case that the amorphous form has a specific heat always exceeding that of the crystalline, a step probably will be gained in the explanation of metamorphism generally; it may at least be held that the high specific heat of limestone, and the much lower heat of calcite or granular marble, explains the local metamorphism which we are now considering; as the plication, crushing, and folding of the strata *expressed, or extricated as heat of active energy* the difference in the amount of the specific heats of carbonate of lime in its two states,—the excess which is special to it in the colloidal. This expressed heat left only a residue, so to speak, sufficient for granular limestone; while it became the active agent in stimulating the chemical affinities existing between the limestone and the silica, alumina, and alkalis, of the gneissose matrix. It thus led directly to the formation of minerals, while it at the same time expedited or perfected a more thorough metamorphosis,—i.e., the assumption of a more perfectly-developed crystalline structure, in the previously only partially metamorphosed rock.

The assumption of a definite crystalline structure,—a character or property directly attached to a definite chemical composition,—must of necessity extrude from the resultant calcite the phosphate of lime, and fluoride of calcium, which limestones contain uniformly distributed throughout their mass. *Apatite* and *Fluorspar* are accordingly among the crystallized minerals found imbedded in the saccharoid “primary” limestones.

Whether the extruded heat can actually *fuse* the residual calcite may possibly yet be ascertained by direct experiment; but it would seem to be almost a necessary deduction that no mineral could be formed by such an action possessed of, or requiring a specific heat greater than that of the original source of the expressed heat.

It must be borne in mind that chemical elements do not alone go to the formation of any substance;—a due amount of certain physical agencies is the special portion of each, lodging, as it were, in their pores as resting places. Of the chemical ingredients, one alone may suffice; of the physical agencies, among which heat, phosphorescence, and magnetism, may be said to be those most germane to minerals,—

heat is the only one which is never absent. Chemical affinity then can only *predispose* to the union of the constituents which go to form the substance, for something more is requisite before the formation can be accomplished,—before the substance can, so to speak, assume an independent existence,—namely, the supply of the heat special to it,—to the perfect putting together of the whole as a mineral species.

It has, however, to be admitted that we are unable positively to affirm that the expressed heat may not be so concentrated in the spots where the chemical action is operating, as to afford any specific heat required.

Two arguments against such a view may, however, be adduced.

The first.—That the heat extricated throughout the general mass, would not readily be localised, or carried specially to any point in so badly conducting a substance as granular limestone or marble; more probably would it accumulate within the limestone itself, even to the point of its fusion;—and indeed the occurrence of porphyritically disposed crystals of quartz, with rounded angles, throughout the general mass of some marbles, (e.g. Ledbeg, Sutherland,) would seem to indicate actual fusion.

The second.—That it has not yet been shown that there is the necessity for such concentration.

The high specific heat of the matrix is, in the present case at least, amply sufficient; no one of the minerals found in the above localities possessing so large an amount of heat as $\cdot 264$,—that of limestone.

That of the following is known:—

Fluor	·19
Apatite	·17
Tetrahedrite	·192
Actinolite	·204
Augite	·195
Diopside	·19
Pyrrhotite	·16
Molybdenite	·102

It is a somewhat significant fact that *limestone has a specific heat superior to that of any other rock mass*; we speak of mollusks and crustaceans as “cold blooded,”—though it is believed that they have a temperature somewhat higher than that of the medium in which they live;—but the calcareous matter which they have secreted from solution in that medium, for the defence of their soft parts, is deposited and arranged with an organic and non-crystalline structure, and consequently has had conferred upon it the high specific heat of the amorphous state; and so the long buried skeletons of these

organisms are abiding store-houses of heat, until called upon to yield up their surplus store, and thus become the active agents of future change.

I have here, as an indirect corroboration of certain of my views, to direct marked attention to the following observations on the circumstances which were conceived by the writers to be capable of accounting for the markedly crystalline texture and high metamorphism of the rock which occurs in Glen Logan in Rosshire.*

Mr. Hudleston speaks of "the complex dislocations of the region."

Nicol says that the rock "becomes serpentinous *where in contact with the limestone.*" Elsewhere he writes—"all along this line the rocks are broken by faults—some longitudinal, some transverse—with large fragments, which have slipped down into the yawning chasms that opened into the vast rock, rent asunder as it rose. But there is no reason to regard this as the result of a solitary convulsion. Rather as nature's analogy would teach, that the arch was often forced up and fractured,—often gave way, sank down and became welded anew by intense heat. For long ages the Titanic conflict may have gone on. Is it then wonderful that along this line the strata should be *crushed, contorted*, thrown into apparently discordant position. That masses of one age should be brought into contact with masses of another: that wedges of the higher limestone, or quartzite, should lie alongside or even lower down than the once deeper-seated sandstones or gneiss."

Professor Geikie writes—* * * "seem to us to prove it to be in reality a highly metamorphous band of felspathic grit,—*the superior degree of metamorphism being due to the existence of the limestone*, and possibly also to the larger amount of felspar in the original rock."

Also—"the metamorphism *which is often most intense in the presence of a limestone* is conspicuous here."

Mr. Hudleston writes that it "gives the idea of an old gneiss *partly invaded by extravasated matter.*"

Professor Bonney speaks of a rock "which exhibits a *very marked fragmental structure*, which he strongly suspected to be due to *crushing in situ*. That not only the rock itself, but the *limestone* in contact with it appeared to be crushed.

Here it will be remarked that all the observers have noticed,—first, a very unusual amount of crushing and fracturing,—second, an undue amount of a change rarely referred in great part to increase of temperature. This change has by each and all been assigned

* The italics throughout are the present writer's.

to the presence of limestone,—while one, apparently from his finding that the felspar of the rock contains lime, says that it gives the idea of being partly *invaded* by extravasated matter.

No one of these writers has, however, attempted to account either for this evolution of an excess of heat, or shown how the presence of limestone came to affect the rock,—or how the rock came to be affected by the excess of heat, in presence of the limestone.

According to the view of the writer, during this crushing and rending, the organic and colloidal limestone, if it became crystalline, must have given out much extra heat;—and in those localities where the greatest amount of this crushing turmoil was going on, the limestone might even come to play its usual part of acting as a flux,—rendering some portions of the rock so pasty, that they were forced into the gaping rents;—“invading” and altering the felspar of other portions; and being in some localities, itself so totally absorbed through combination, that occasionally,—as it is put by Murchison,—the absorbing rock “occupies the place of the limestone.”

If the above be a philosophic rendering, then, inasmuch as it has lately been seen to be necessary to discriminate between *injected* rocks, and *eruptive* rocks, so now will it be necessary to find a place, and furnish a name, for those which, in the presence of limestone, have been rendered pasty, or perchance semifluid, by crushing *in situ*.

I shall have to adduce, in future numbers, many localities where the more correctly termed “diallagic rocks” of Scotland, generally if not always associated with limestone,—show themselves to have been originally sedimentary deposits, which have been metamorphosed *in situ*, and that to such an extent that they were certainly softened in their own mass,—assuming *then* that structure which has led to their having been regarded as injected,—sometimes either involving fragments of other rocks, or apparently throwing out “veins.”

It was with feelings of no ordinary gratification that I have lately read a paper by Dana, published in the American Journal of Science, for September, 1880, upon “The geological relation of the limestone beds of West Chester Co., New York,”

It is now five years since, in an address, delivered to the Mineralogical Society, in Glasgow, I endeavoured to show how a rock might be rendered plastic if not even fused *in situ* by the heat eliminated during its folding and crushing. Without assigning any of the heat so evolved to precisely the same cause as I did, Professor Dana clearly shows that a certain class of rocks, of diallagic, hypersthenic, and dioritic type, have been so metamorphosed *in situ* through crushing and folding, that they have become fluent to the extent of *involving portions of other rocks* in their mass, and of having been forced into the fissures of these rocks.

So important are the views and illustrations of this eminent geologist, and so immediately applicable to the circumstances of many of the diallage and limestone localities in Scotland, that no apology is needed in quoting what follows.

“ The examples of what appear to be veins or dikes are also numerous. * * *

Some, if not all, of such veins must, therefore, be true veins or dikes; and are evidence as to the former fused or plastic condition of the material, and its injection into fissures. Veins formed in this way are not veins of infiltration or segregation; that is, they are not due to the filling of fissures by material supplied slowly in solution or vapour; for no difference in coarseness of texture or structure exists between the rock constituting them and that of the massive rock elsewhere; they are just such as have been made by simple injection. There are also peculiarities in the exterior of inclusions, and in the walls of veins or dikes, in some cases, which favour the idea of fusion. And in other cases, the limestone is impregnated with the hornblende or augitic material in irregular lines or bands. Still more positive evidence, if possible, of fusion are shown at the junction of the schists of Cruger's Point with the soda-granite, where the schist itself bears evidence of partial fusion, and exhibits other contact phenomena.

The proof of the crystallization of the rocks from a more or less perfect state of fusion or plasticity is thus complete. But admitting fusion or a plastic condition, the question still remains:—

Were these once-fused rocks fused approximately *in situ*; that is, where, or near where, they now lie; or were they erupted through fissures from great depths below? that is, using Dr. Hunt's terms, are they *indigenous*, or are they *exotic*?

If they were fused where approximately they now lie, that fusion must have come from accessions of heat, and such accessions may have resulted from the movement and friction connected with an upturning of the rocks; and it may have been one of the results, in that region, of metamorphic action at an epoch of general metamorphism, and if so, at the very time that these rocks became fused or plastic through the process, other rocks of the region, owing to less extreme metamorphic action, or to less fusibility, may have been left with their bedding unobliterated; just as much granite in New England and other countries received its crystalline condition in the same process, and at the same time with the associated schistose rocks,—the gneisses, mica schists, etc. * * *

As has often happened in the case of granitic rocks, and even granular limestone, the fused or plastic material, under the pressure attending the subterranean movement, would have entered and filled all fissures that might have been opened to it, and so have made veins or dikes having the sizes of the fissures, were they large or small, and possessing also a uniformity of grain like that of ordinary erupted rocks.

Again, whatever the process of ejection, fragments, large or small, of any rocks adjoining such fissures might have become included in the fusil or plastic material. In the writer's Manual of Geology (1880), veins of this kind are called *veins of plastic injection*, an abbreviation of the full statement that they were made by the injection of material rendered plastic or fused during a process of metamorphism. * *

The results of fusion of sedimentary beds under metamorphic action may have distinguishing peculiarities. *First*:—

The kinds of rocks so resulting are likely to vary greatly, at comparatively short intervals, because sedimentary beds often vary thus. They should not have that uniformity for scores or hundreds of square miles, which often characterizes ejections that have come up from the regions beneath the supercrust. Sediments, and therefore sedimentary deposits, are liable to frequent and sudden changes as to material, which igneous outflows cannot imitate. *Secondly*: the rocks are likely to have no columnar (basaltic) structure; because the fractures to be filled in such cases are fractures in rocks which are participating in the movement, and which, therefore, are heated rocks, and not cold. * * *

The facts with reference to inclusions, and all contact phenomena bear directly, as will appear, upon the question as to any stratigraphical relation in the Cortland rocks to the limestones; and they are, therefore, here taken from the vicinity of particular limestone areas. * * *

A natural inference from the series of facts presented in this section would be that the heat was a consequence in part, if not chiefly, of the movement and friction attending the flexing; and that consequently there was produced a more and more yielding condition in the material of the schist as the region of complete fusion was approached, and at the junction, perhaps, a fusing and obliteration of portions of some

layers of the schist; but are not these flexed portions of beds, fragments that were broken off and carried up by the fused or plastic material as it rose from the depths below? They lie so conformably to the flexures of the schist as to suggest a negative reply to this query. * * *

Since it is obviously impossible that the inclusions taken in and carried up by rock erupted through deep fissures should be beds of schist 100 to 200 feet long, and a series of such beds separated by the fused rock retaining together their parallel position, we have to admit that these indications of bedding are of *unobliterated* bedding. The rest of the upturned strata were fused or at least softened; these portions of beds were not fused, though flexed and variously displaced.

There is reason for the resistance to fusion in the mineral nature of the beds; for quartz, staurolite, fibrolite, magnetite, are infusible minerals; muscovite and biotite are but slightly fusible on thin edges; and orthoclase fuses with great difficulty, much greater than the other feldspars, oligoclase, labradorite and albite.

Thus the study of the phenomena of contact becomes in this region a study of "inclusions;" and the larger of the inclusions turn out to be beds of schist, conformable to the schist. We seem to be thus forced to the conclusion that the *soda-granite* and the included *diorite* were once parts of the same *sedimentary strata with the schist*, and that all, with the Cruger limestone, were once a continuous stratified formation; and that the plasticity given to the granite-making or diorite-making portions, because of the heat, occasioned the exceptional geological features of the region. * *

All the material is very pyrrhotitic. * * *

The impregnation of the limestone along the junctions with pyroxenic or hornblendic material, sometimes in minute crystals, looks as if it may have been in part at least a result of mixture attending original deposition. This view is also sustained by the occurrence in the limestone near the schist, 1000 yards from the point, of coarse spots of pyroxene with mica and chlorite rudely in layers, which must be due to the original deposition of impurity, and metamorphic action. * *

The plasticity occasioned in part of the latter, (augitic and hornblendic rock) during the progress of the metamorphism, accounts for all that looks like eruptive phenomena, even to the broken feldspar grains found in a slice of the pyroxenite of one of the so-called veins. There is nowhere evidence of injection into or through cold rocks. * *

And, among so extensive masses of rocks that became plastic or fused in the era of upturning, this abnormal position of included strata is not strange. * * *

This ledge, although made up mainly of massive norite and augite-norite, bears thus positive evidence of its having once had bedding throughout, and affords thereby a demonstration that its norite is of metamorphic origin, and that the associated beds comprised also the limestone of the region.

The whole facts appear to sustain fully the following conclusions:

(1.) These rocks, although they include *soda-granite*, *norite*, *augite-norite*, *diorite*, *hornblendite*, *pyroxenite*, and *chrysolitic* kinds, are *not* independent igneous rocks erupted from great deposits. However complete their former state of fusion or plasticity may have been they are *metamorphic* in origin. On the view reached, it follows that the limestones, schists, and other rocks of the Cortland region, originally constituted together one series of horizontal strata. They underwent an upturning through subterranean movements, and in the course of it, they became metamorphosed; part into mica schist and gneiss, part, by loss of bedding, into the massive rocks. The number of these rocks does not imply widely different ingredients in the original strata. For hornblendite and pyroxenite have the same chemical constitution; the chrysolitic rocks contain no ingredient not in them also, and are peculiar mainly in their less proportion of silica. Moreover, the diorite, norite, and augite-norite are like in containing the same bases in nearly the same proportions. The *soda-granite* differs in chemical constituents only through its mica, which indicates the presence of potash.

The title of this paper might, therefore, well have been:—

Soda-granite, norite, diorite, hornblendite, pyroxenite, and various chrysolitic rocks made through metamorphic agencies in one metamorphic process.

The geologist will nowhere on the continent find a more instructive spot for a day's walk than in the western portion of the Cortland region.

He may see enough to satisfy himself that, although there has been fusion and some eruption, it was *not* eruption from the earth's deeper recesses, like that which brought up trap (dolerite) through a series of great fissures, for a thousand miles along the eastern Atlantic border, from the Carolinas to Nova Scotia, all of it rock of one kind essentially; but eruption from less depths, not greater than the lower limits of a series of formations that were subjected together to foldings, fractures, and metamorphic change, and *mostly far short of this*.

While the Shinness locality by no means, according to my own observation, affords the best illustrations of the facts upon which the above speculation is founded, still it is one which aids in supplying direct evidence.

It is observable, as we approach the neighbourhood, that the ordinary muscovitic-schists and lepidomelane-gneiss of Achadhaphriz become more and more hornblendic; while a bed of hornblende rock overlies the lime itself. Hence it would appear as if some thinner beds of limestone, or at least more calcareous strata, had supplied the lime of the replacing hornblende.

It is next notable that the rock adjacent to the lime has suffered, a markedly higher metamorphism; for *determinate crystals*, and imbedded groups of crystals of *orthoclase*, *hornblende*, and *lepidomelane*, are to be obtained from it.

A kind of *welding* of the rock with the lime stratum, is next observable; and this is accomplished by the occurrence of a linking zone *which consists of those minerals which are formed (or could be formed) by the union of the two*. This zone is here the chief site of the mineral species, comparatively few occurring *in the mass* of the lime itself.

If such occurrence,—*i.e.*, central to the lime itself,—depends upon the separatory crystallization of the several chemical ingredients, and the consequent clarification of the calcareous bed, it is evident that a deposit of pure carbonate of lime could yield only *calcite* crystals.

A dolomite would probably yield crystals of *magnesite* and of *pearlspar* in addition thereto: a silicious limestone would, in addition, supply *Wollastonite** and *malacolite*,—according to the amount of silica present; while a fossiliferous limestone should likewise supply *apatite*, *fluorspar*, and, in the *first* stages of its metamorphism, *pyrite*.

An impure or argillaceous limestone would yield *garnet* or *idocrase*, or a *felspar*:—the latter would be less likely to occur in dolomitic limestone, argillaceous varieties of which would contain *magnesian* garnets.

*Bischof writes:—"The adherents of the plutonic theory regard granular limestone as sedimentary limestone that has been altered by volcanic action; and they would, therefore, suppose Wollastonite to have originated in the same way, more especially as it occurs in the masses erupted by Vesuvius. It is remarkable that Wollastonite occurs only in granular limestone; not in sedimentary limestone, where the conditions for its formation obtain equally." *i.e.*, they obtain equally according to *Neptunian* views.

Much more information may be expected to be derived from the minerals which occur in the limestone itself, than from the mere contact-products. If, however, the stratum be not a single thick bed, but, is subdivided by laminæ of what had been muddy silts, the amount of information is minimised.

We are in some localities forced to the conclusion that the marble has been *plastic, if not fluent*. At Glengairn in Aberdeenshire, and Allt Gonolan in Invernesshire, it passes round and cements fragments of inclosed rock, not at all after the manner of a breccia cemented by igneously-intruded calcareous matter.* In the latter case, the size of the rudely crystalline calcareous concretions, depends upon the size of the vein or fissure, from either side of which they grow, sometimes in successive bands or layers with varying size of granules. But the granular structure of the marble, at the above localities, passes into the cementing portions *unchanged in size and appearance*; and the plug is of uniform grain throughout.

Another fact which goes a certain length to vouch for much of the heat having emanated *from the limestone*, is the fact of the invariable occurrence of the *augitic* type of mineral within it.† The assumption of, or at least the fact of the occurrence of *hornblende* in the

* I shall afterwards adduce facts which almost incontestably show that many so-called "igneous rocks" in Scotland owed that plasticity which enabled them to be "injected" into fissures of moderate size, to an exalted metamorphism in situ; the requisite heat being due to crushing and folding. At present I confine myself to an *augmentation* of that heat, consequent upon the presence of lime.

† So great and so *invariable* is the occurrence of one or other form of *augite* in connection with the "primary limestone" throughout the whole of the Highlands of Scotland, that it was with no little wonder that the writer observed the following statement—in a critical review of a work by Messrs. King and Rowney, in which these authors are being taken severely to task for postulating points in dispute. "Augite and hypersthene are placed among mineral species 'common to ordinary metamorphics.' The authors are surely aware that at any rate normal augite cannot be called common in metamorphic rocks." While prepared to admit that the augite present here in the outer-zone of the contact-band, may, if it shews a uralitic structure, possibly result from a transmutation of the adjacent hornblende, yet there are many localities in which such augite is seen, where there is no hornblende in the neighbouring gneiss; while the mode of occurrence and the amount of the sahlite and malacolite in the limestone, is such as to entitle us to say that it becomes the mineral *typical* of this metamorphic rock;—while in some localities it *actually forms its mass*, and this it does to such an extent that the quantity of *augite* in one form or another, cannot, in the upper-gneiss of Scotland, be much smaller than that of the *hornblende*.

Very possibly the above writer will hold primary limestone to be not an "ordinary metamorphic"; and, as he seems to regard augite as being typical of rocks which have at least been *subjected* to a high heat, we should expect him to agree more or less with our views relating to this limestone; his adhesion to our views would bring satisfaction, if we did not observe that the microscope seems to be by him regarded as an *instrument of precision*, instead of being at present a mere adjunct—however valuable,—in lithology.

adjacent strata has been noticed. In what may be called the contact-zone this gives place to the augitic type of the mineral; though *there* an actynolitic, or perhaps it should be said a *zoisitic* form of hornblende occasionally occurs: but, as we pass from the outer sides of the zone *sahlite* makes its appearance, while the central parts of the limestone contain *malacolite* alone. Indeed, as has been noted, that mineral frequently occurs in such amount that but little lime remains.

The last fact to be noted is that there has been, in every case where the lime is highly granular, a *strong reducing action* of some kind. Flakes of *graphite* stud these beds, frequently throughout, (a small vein of it was found at Urquhart); and the *pyrite* of the little-altered limestone, is *invariably pyrrhotite in the marbles*.

I am not prepared in the present state of our knowledge to consider how the carbonic acid was reduced to graphite, or whether any residual organic carbon was crystallised into it. The occurrence of the lower sulphuret of iron (*pyrrhotite* is Fe_7S_8 ,—*pyrite* FeS_2) is not, in the presence of the formation of the graphite, so difficult of explanation. Both Berzelius and Rammelsberg found that Fe_7S_8 was the direct result of the action of heat upon FeS_2 . The occurrence of a spring strongly charged with sulphuretted hydrogen, about 200 yards north of the line, also aids in the explanation in this case; for that gas is the product of the action of even weak acids (? carbonic) on pyrite.

The facts, then, which are to be observed regarding the granular limestones are,—a higher degree of metamorphism, as evidenced by a more dominant exercise of the crystalline force in the adjacent strata;—the occurrence of a *contact-zone*, rich in such minerals as would result from the combination of the siliceous rock with the calcareous seam;—the segregation apart in that seam itself of its own specially constituent parts—and the occurrence therein of reduction products.

The circumstances which are favourable to a dominant exercise of the crystalline force, in the direction of forming crystals larger than the normal, have no power to limit it to the direction alone of inducing merely a state of more ample aggregation. Such dominant exercise must also have given rise to that which is self-evidently a preliminary to the formation of more amply developed crystallization,—namely the drawing together,—the local segregation of the material, through the accretion of which such crystals are built up.

From this it results, that there are drawn to the situation where the crystalline action is operating in full force, certain at least of those

substances which occur throughout the general mass of the siliceous rock in quantities so minute as to be there incapable of recognition, even with the aid of the microscope. These are now presented to us definitely crystallised from a calcareous flux; and convey all the precise information which a special crystalline form affords. This often more than compensates for the minuteness of their bulk.

Such substances are *sphene*, *zircon*, *Allanite*, and *molybdenite*.

The place of the occurrence of these is significant.

A few crystals, say of sphene, are found in small open cavities, some inches distant from the junction of the siliceous rock with the limestone;—a very few imbedded in the rock near these, but these are distorted through surface contact; but by much the largest number line the surface of the rock where it is in contact with the limestone, and are only seen when the latter is dissolved off by acid.

They are then found to have grown out of the rock surface; and those portions which had been imbedded in the limestone are *perfectly formed crystals*, the perfection of the faces being in no way detracted from by the effect of any crystalline effort on the part of the limestone.

How comes it that the crystals which have formed here are as perfect as those which have formed in the *vacuous* cavities;—and why did they form there at all? *Only because there was there as perfect freedom of motion for the molecules to arrange themselves, as there was in the cavities*,—with greater space also for that arrangement. A fluent medium,—a readily displaceable fluid—must have filled both spaces. Air filled the one; it will not be suggested that the limestone was an after injection, therefore the limestone which filled the other *must have been fluent at the time when the sphenes pushed its particles aside in order to assume their own individual form*.

Nay more, it was no mere hasty arrangement of molecules, in some one of the simplest forms of the mineral;—the forms here occurring are the most complex in the country,—several are twins with many faces. There was time, so to speak, for the deliberation of choice, and the exercise of the highest and most intricate whimsicalities of the force of crystallization.*

When we take into consideration the whole of the granular limestones of Scotland, *andesine*, *Biotite* and *sphene* are found to be characteristic of the contact-zone;—*malacolite*, *pyrrhotite*, and *apatite*

* I do not here, for want of sufficient data, enter into a consideration of the *modifications* produced by the presence of certain media,—calcite, however, does not generally induce complex modifications.

equally so of the limestone itself;—while *orthoclase* and *actynolite* appear in the neighbouring rocks.

The occurrence of minerals at this—one of the richest limestone localities in Scotland—was first noted by Dr. Joass. Through the courteous assistance of His Grace the Duke of Sutherland, Mr. Dudgeon and the writer were enabled to make a thorough examination of it, at the time when it was being worked. The following are the results.

There are two beds of limestone, each about seven feet in thickness; they are first seen upon the shore of the lake, on the west side of the promontory of Shinness; they extend for about 400 yards as limestone; and the calcareous compounds which they form by their union with the gneissic rock, continue for about an equal distance to the eastward, disclosing their presence in a series of green knolls.

The dip of the beds is to the E.N.E., at an angle of about 35°, and this dip is maintained by the overlying rock nearly to Lairg,—where syenite comes in,—and in a northward direction as far at least as to the road which passes to the Crask.

Both beds are similar; being large granular, with at times very little cohesion of the granules. The upper is the coarser in structure, the granules being of the size of peas. This bed is sometimes very strikingly diversified by red bands of a high colour and a parallel disposition.

In its general mass the limestone is very pure, the minerals occurring only towards its sides, and chiefly the upper side. The intermediate zone of rock is about a yard in thickness.

Dr. Thomas Anderson has given the following analyses of the limestone.

	TOP.	MIDDLE.	BOTTOM
Carbonate of Lime	84·11	93·70	89·95
Carbonate of Magnesia ..	7·45	3·49	4·93
Ferric Oxide and Alumina..	·76	·28	·46
Silica and Insoluble	7·42	2·52	4·77
	99·74	99·99	100·11

In the gneiss which is in contact with the limestone, only two minerals occur of purity and size of crystals fitted for analysis. These are a dark mica, and a pale brownish white *orthoclase*.

A qualitative analysis showed the mica to be *lepidomelane*. It was in plates about three-fourths of an inch in size.

The felspar was in interpenetrating crystals of nearly uniform size; its specific gravity is 2·56. As it occurred within twenty or thirty feet

of the limestone, it was analysed to ascertain if the quantity of lime was in excess of that normal to the mineral.

It yielded—

Silica	64·23
Alumina	18·682
Ferric Oxide	1·318
Lime	·69
Magnesia	·384
Potash	12·377
Soda	1·256
Water	·705

99·642 (H.)

It can hardly be said that there is here any marked increase in the normal amount of lime.

In the contact zone there was found the following large assemblage of minerals,—

<i>Biotite, common.</i>	<i>Apatite, rare.</i>
<i>Actinolite, rare.</i>	<i>Chlorite, rare.</i>
<i>Augite, (Funkite).</i>	<i>Asbestos, common.</i>
<i>Pyrite, rare.</i>	<i>Tremolite, rare.</i>
<i>Sahlite, common.</i>	<i>Steatite, rare.</i>
<i>Andesine, rare.</i>	<i>Talc, very rare.</i>
<i>Sphene, scarce.</i>	<i>Pyrrhotite, scarce.</i>
<i>Molybdenite, very rare.</i>	<i>Malacolite, common.</i>

These are arranged in the order of their occurrence from without inwards, in the rock.

A point of much interest here is the occurrence, so near to one another, of the three varieties of the one mineral,—the dark-green *Funkite*, the pale sap-green *sahlite*, and the milky *malacolite*. These in no way pass into one another,—they are perfectly different in appearance; occur invariably in different positions; and differ much in the size of their crystals.

Another point of note is the paragenetic occurrence of the *hornblende* type of mineral; this also presents itself in three varieties, which do not shade into one another,—*actinolite*, *asbestos*, *tremolite*; these also differ entirely in appearance. It must be here noted, however, that I have offered no proof, analytic or otherwise, that the asbestos and tremolite are not of the augitic type of mineral.

The first mineral noted above is *Biotite*. This frequently forms a solid crust between the gneissic rock and the contact zone; this crust seems to consist of little more than a dense mass of minute flakes of the mineral.

Rarely it occurs in large rich-brown flakes in the chlorite, and more frequently in smaller ones of a light greyish-brown colour. The smaller crystals are superimposed upon one another, so as to have a foliaceous appearance; this variety also coats crystals of sahlite.

As the peculiar greasy lustre of these pale crystals gave some hope of their being *phlogopite*,—a mica which I have not yet found in Scotland,—they were analysed, and yielded

Silica	39·769
Alumina.. .. .	16·676
Ferric Oxide.. .. .	·653
Ferrous Oxide	6·73
Manganous Oxide	·615
Lime	2·196
Magnesia	20·923
Potash	6·5
Soda	·476
Water	5·398

99·936 (H.)

being thus merely Biotite.

The specimens of *actinolite* were dark-green in colour, they were in interlacing imbedded crystals associated with *Funkite* and *Pyrite*. They were rare, and inferior as specimens. The *Funkite* was also in imbedded crystals of about an inch in length, by half that width; it was in four-sided crystals, but their terminations were obscured. Cubes of pyrite occurred along with these, and pyrrhotite in larger amount was also here associated. It was massive only.

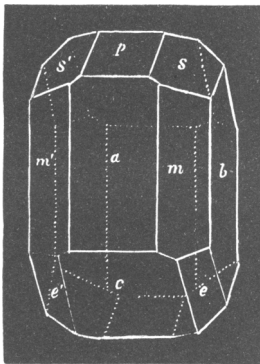


Fig. 1.

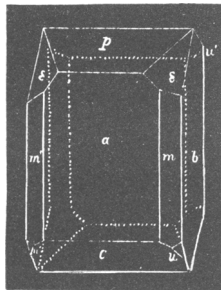


Fig. 2.

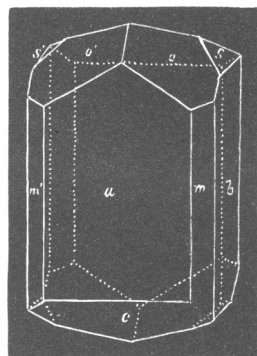
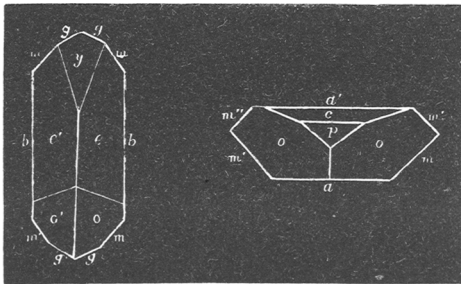
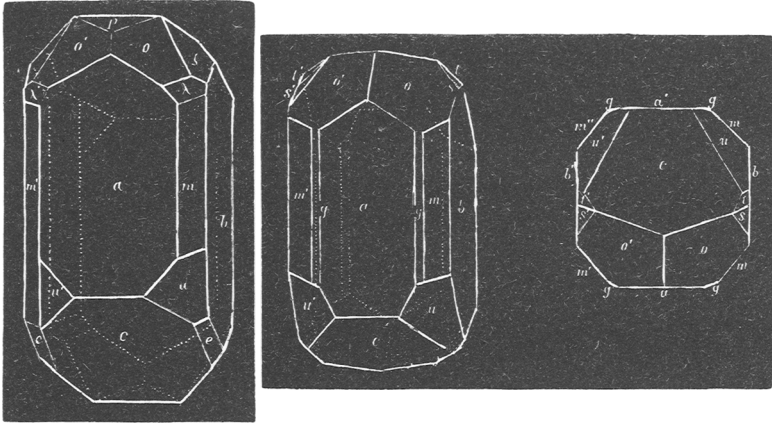


Fig. 3.

Sahlite occurs in great quantity generally in interlacing foliaceous crystals, but sometimes in flat crystals, imbedded partially in limestone; these are disposed one over the other, with half an inch of limestone

intervening: they are an inch in thickness by several inches in length and breadth. We were not so fortunate as to break up the masses of lime in such a way as to obtain the terminations of these large crystals; some, which were placed in acid in large mass, gave only rough terminations; but the surfaces of the large crystals were occasionally studded with small individuals, five forms of which are depicted. These crystals had a dull sap-green colour; but occasionally equally large crystals were of a fine grass-green.

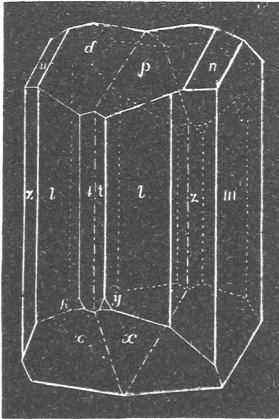
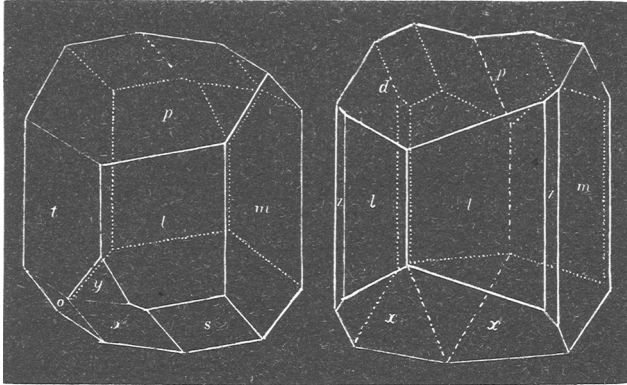


Occasionally the small crystals of sahlite have their faces so abnormally developed as to appear distorted, and to be with difficulty recognisable.

The summits of the two extreme forms of such are drawn in the same position.

Cavities of any notable size rarely occur in the massive lumps of the sahlite.

A very few of the larger of these contain a felspar, of which I had not enough for analysis. This, from a chemical determination of the felspar of the granular limestones in other parts of Scotland, where it invariably has proved to be *andesine*, I assign to that mineral.



I was able to draw three of the forms in which this felspar occurs—one simple crystal, and two twins; these forms would equally well accord with the mineral being *albite*, but, for the above reason, and another immediately to be stated, I prefer to consider it *andesine*.

The crystals have the colour and lustre of bleached wax, or cold suet; they are of the size of peas or small bullets; they show striation occasionally.

A point of very great interest connected with them is this;—a specimen of sahlite which had a cavity plugged with calcite, happened to have been placed in acid stronger than that which was usually employed for the removal of the lime carbonate. When the action was at an end, it was found that the cavity contained several of the felspar crystals, and all had their composite striation-structure disclosed through the *alternate layers* having been dissolved almost entirely away. A series of thin plates remained; these also had been slightly acted upon.

So much had the plates been dissolved away, that the crystals upon another specimen were tried gently with a knife, and touched with acid to see whether it was not possible (however improbable), that the alternate layers were calcite. This they were found not to be.

Here is a most valuable piece of information.

It shows firstly that the crystals could not be *albite*; for it is insoluble in *strong* acid, even when in powder. The acid used was about one of chlorhydric acid to four of water.

It shows in the second place, that sometimes striated crystals of felspar are made up of alternate plates of two homacomorphous felspars. In this case one was soluble in weak acid, while the other was not.

The question now presents itself. Supposing it to be *andesine* in composition, is that composition, and is the crystal-fabric, made up of alternate and reversed layers of *anorthite*, which is soluble in acid,—and of *albite*, which is not?

Unfortunately I have not enough of these crystals to decide this by the aid of chemistry. They differ in appearance from such of the limestone andesines as I have analysed;—first in their being regularly and perfectly crystallised, and secondly in their waxy translucency; those from other localities being milky and opaque. There are however trifling distinctions.*

The *Sphenes* of Shinness are certainly the finest in Britain, at least as regards their form. One specimen also was the largest crystal which I have seen from Scotland. This was a crystal of simple form, which we found exposed on the roadside. As this crystal seemed to be somewhat loose in its matrix of sahlite, it was measured, and found to be two inches in length, by one in width; it was of a pale-yellow colour. In "dressing" the specimen the crystals started in fragments from the stone. Its specific gravity was 3·617.

The fragments were analysed and yielded—

Silica	.. .. .	34·666
Titanic Acid	.. .. .	35·464
Alumina	.. .. .	2·897
Ferric Oxide	.. .. .	tr.
Manganous Oxide	.. .. .	·499
Lime	.. .. .	26·853
Magnesia	.. .. .	tr.

100·378 (H.)

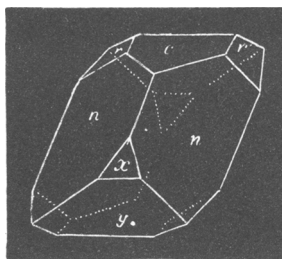


Fig. 1.

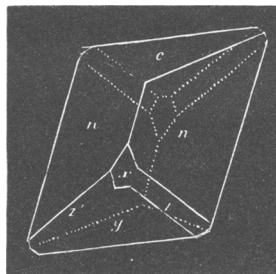


Fig. 2.

In general however, the sphenes are not half the size of peas. With the exception of the before-mentioned crystal, they are all of a dark hair-brown colour.

* I have since treated the andesine from Urquhart and that from Dalnein—both of which analysis has proved to be andesine, and both of which are striated—with acid [of one to four of water, and also with strong acid,] without observing any effect.

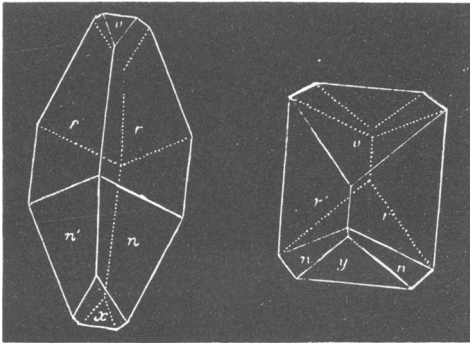


Fig. 4.

Fig. 3.

They are seldom of simpleform. Figures 1 and 2 show the simplest.

A difference of dominance in the faces *n* and *v* occasions the diversity of appearance shown in the figures 3 and 4, which are nearly the same form.

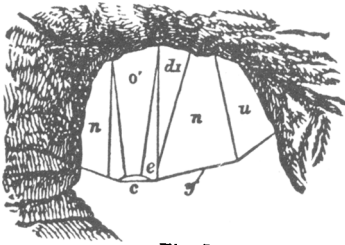


Fig. 5.

In the very complex form, figure 5, the crystals are so imbedded in the matrix that some of the faces have been somewhat conjecturally lettered.

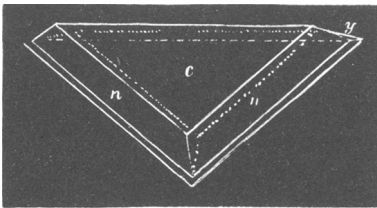


Fig. 1.

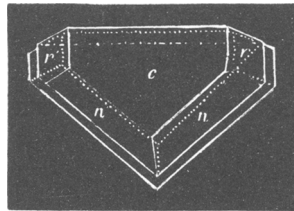


Fig. 2.

In the twin forms,—which are nearly as frequent as are the simple

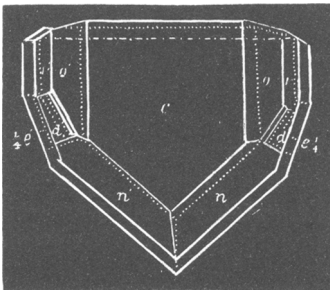


Fig. 3.

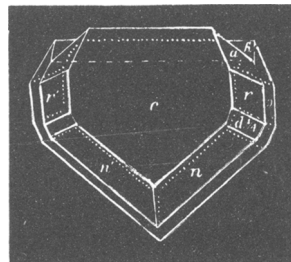


Fig. 4.

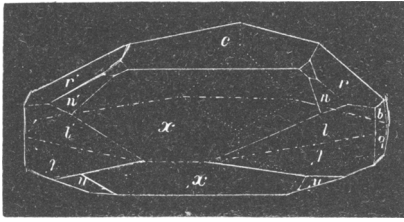


Fig. 5.

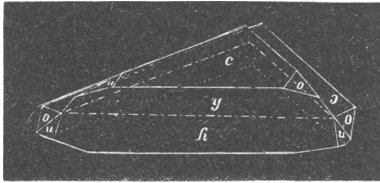


Fig. 6.

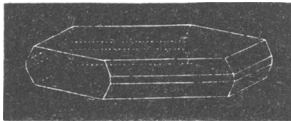
crystals,—the face which truncates the angles of *n c r*, and which is seen in three of the crystals, would appear to be new. It is somewhat too rounded for measurement. Figures 5 and 6 are placed in an inverted position, in order to show a larger number of faces.*

The dark-brown sphenes yielded to analysis :—

Silica	.. .. .	36.789
Titanic Acid	.. .. .	35.893
Alumina	.. .. .	2.208
Ferric Oxide	.. .. .	.284
Manganous Oxide	.. .. .	.299
Lime	.. .. .	25.403
		100.376 (II.)

The cavities which held these sometimes also contained crystals of *Biotite*

Molybdenite is very rarely associated with the sahlite. Sometimes in plates imbedded in it, sometimes in rosette crystallizations perched upon the surface of its crystals.



The annexed form was seen; this, if correctly drawn, would leave some doubt as to its being hexagonal. The crystal however was extremely minute.

The *Apatite* which occurs here is also imbedded in sahlite; it is in fissured lumps of a pale asparagus green colour.

The only specimens I have seen of *asbestos* were sent me by Dr. Joass, but they must at one time have been found in great quantity, for some of it performed the function of "packing" to the other minerals sent me by him.

It was in fibres of several inches in length of a greyish straw colour and a high lustre. It was hard, rigid, and rough, though in

* In figure 6 the faces marked *o* should be *d*, in the lower half.

other respects very similar to the valuable variety from Balta; it contained a little chlorite among its fibres.

It yielded—

Silica	56·864
Alumina.. .. .	·232
Ferric Oxide	·484
Ferrous Oxide	2·124
Manganous Oxide	·23
Lime	12·535
Magnesia	23·923
Potash	·439
Soda	·538
Water	2·525

99·866 (H.)

Dr. Joass also sent me long hatchet-shaped masses of closely-packed parallel fibres of a pale-green colour; these were somewhat amianthiform.

To Dr. Joass I am also indebted for a specimen of *tremolite*, which not only surpasses in beauty anything of the kind which I have seen from abroad, but which is one of the finest minerals ever found in Scotland. Nearly a foot in size in all directions, the mass is covered with parallel bundles of glancing fibres of the most delicate tenuity; these flash with a brilliant but chastened light, of more than silvery whiteness. No natural object devoid of colour could possibly be more beautiful. Its specific gravity is 2·964.

It yielded—

Silica	56·153
Alumina.. .. .	·857
Ferric Oxide.. .. .	1·617
Ferrous Oxide	·716
Manganous Oxide	·069
Lime	13·31
Magnesia	24·138
Potash	·441
Soda	·211
Water	2·5

100·012 (H.)

It is not only possible, but very probable, from the small amount of alumina which replaces silica in these last two minerals, that they are both *augitic* minerals; the nature of their matrix also bears out such a view.

For the next two minerals also,—*steatite and talc*,—I am indebted to Dr. Joass; all of these occurred in a quarry which was exhausted

before my confrere, Mr. Dudgeon, and myself examined the stratum; it is well for the records of Sutherland science, that so keenly observant an eye had been there before us.

This steatite is peculiar; it occurred in rounded nodules,—from the size of a marble to that of a golf ball,—one side of which lay directly in the calcite. It was massive, but had an obscure laminated structure; the colour of it was that of cream, blotched with pale blue. It was hard, cutting like slate pencil; from its rough surfaces there rarely protruded small crystals of *calc.*

This steatite is aluminous; it yielded—

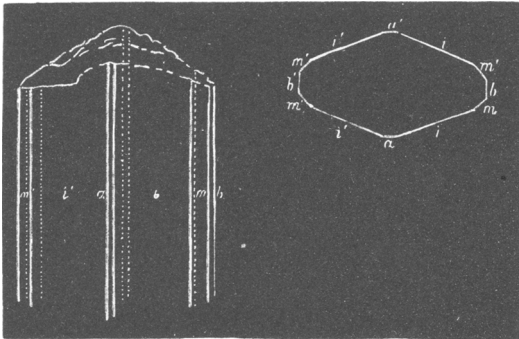
Silica	.. .. .	67·089
Alumina	.. .. .	1·586
Ferrous Oxide	.. .. .	1·822
Magnesia	.. .. .	23·297
Water	.. . . .	6·048
		99·837 (H.)

Its specific gravity is 2·74.

Pyrrhotite occurs at this locality in perhaps smaller quantity than at any other of the primary limestone localities in Scotland. It is here generally associated with the darker varieties of augite, but seldom appears in the limestone, and scarcely ever sprinkled throughout it, in the manner usual to the mineral.

Indeed the same may be said of the last mineral I have to notice, *viz. malacolite*. The freedom of the general mass of this limestone from imbedded minerals does not give countenance to its having been a highly fossiliferous stratum; its purity indeed, entitles us to doubt its having been at all fossiliferous.

As the contact-zone merges into the limestone, *malacolite* of a dull yellow colour appears.



locality in Scotland.

It shows rarely the untruncated form drawn. The variety of this mineral which is actually in contact with the limestone, or is imbedded in it, occurs not only in larger crystals, but in much larger quantity than at any other

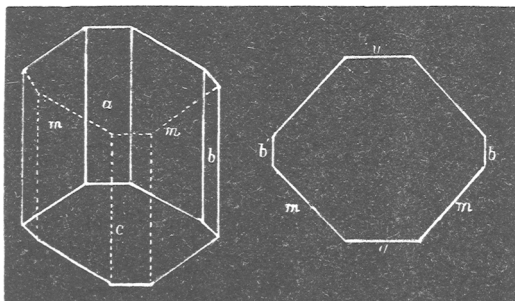
Though very seldom showing crystalline faces, being imbedded, it is here so pure in colour, so lustrous, and in such large masses, that this must be regarded as decidedly its best Scotch locality. Sometimes it occurs in distinct layers in the limestone.

Frequently it is found in widely radiating crystals; and single crystals a foot to sixteen inches in length, by an inch or two in breadth occur. These are frequently fissured transversely,—delicate amianthiform fibres of extreme tenuity and silky lustre, stretching across the gaps, sometimes a fourth of an inch in width, to connect the severed portions. These gaps are filled with transparent calcite.

The malacolite has a cleavage angle of $87^{\circ} 5'$, and a specific gravity of 3.149; it yielded—

Silica....	.. .. .	53.062
Alumina..	.. .. .	1.93
Ferric Oxide..	.. .. .	1.773
Ferrous Oxide	.. .. .	.47
Manganous Oxide..	.. .. .	.153
Lime ..	.. .. .	23.626
Magnesia	.. .. .	19.295
Water ..	.. .. .	1.546

100.116 (H.)



The only crystalline form I have seen is the simple one drawn.

The *c* cleavages of the malacolite and sahlite of Shinness, and indeed of the malacolite of Scotland generally is so eminent that the crystals, dur-

ing extraction from the rock, frequently fall asunder along it. This is not admitted to be a cleavage face by Brooke and Miller, being regarded as merely a line of opposition of a plurality of crystals.

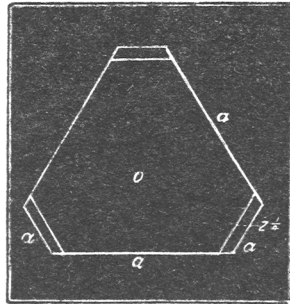
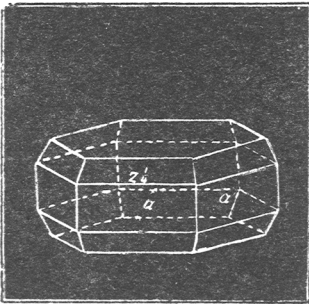
These *c* cleavages are here, and at several other localities in Scotland, evident to the sight by a parallel lineation of the mineral. In the more transparent of the Shinness specimens this lineation appears as narrow opaque white bands; in the sahlites generally, as in that of Tiree, as lines which are not only opaque, but which have a depth of colour which is invariably paler than that of the general mass of the crystal. This parallel lineation also constitutes the most characteristic microscopic feature of the stone; but the writer has one

specimen which with polarised light exhibits a singular oblique-angled and crossed tartan pattern.

Arkaig.—The same bed of limestone, thrown up by a fault, appears at this locality on the south shore of Loch Shin. It here lies between two cross faults.

It has been mostly wrought out, but is more feebly developed than at Shinness. *Malacolite*, *sahlite*, *actinolite*, and *pyrrhotite* were seen here. Doubtless if it were still wrought, other substances would be found.

The pyrrhotite was occasionally in well-defined small crystals.



These had sometimes a hemihedral habit,—the more largely-developed of the faces *a* being in that case striated.