The Geognosy and Mineralogy of Scotland.

By Professor Heddle.

SUTHERLAND.—Part V.

The "Igneous" Rocks Continued.

THE granite of the Ord forms one, and that probably the smallest of a number of masses which constitute the border-land between Caithness and Sutherland. The features of this granite vary considerably at different points. It will, however, be afterwards shown that the rock is possibly continuous from north to south,—that is, from Sandside Bay, on the Pentland Firth, to Navidale, near Helmsdale.

The question as to whether any part of this granite is igneous, in the sense of being eruptive, or indeed in any sense, is best deferred until a consideration of the same point as regards the syenite of Ben Loyal has been entered upon,—the evidence as regards this last mass being every way clearer, and the locality more accessible. I owe it to Mr. Mitchell, of Ribigill, that I have lately been enabled again to take up this point. Through his courtesy and scientific enthusiasm, I have, in company with Mr. John Gunn of Dale, thoroughly examined the hill and surrounding district, in circumstances of such exceptional comfort that the minutest points could be attended to in detail. Either now or on former occasions each individual aiguille has been ascended, and the section on its scalped front examined; while, with the exception of a mile of grassy slope, the hill itself has been walked round.

There is no hill in Scotland, not even Arthur's Seat or North Berwick Law, which conveys to the eye so decided an impression of its having burst through an overlying crust, and thrust its spire-like summit aloft while it was in a plastic condition. This perhaps should not be said of the hill itself, except when viewed from the north; but the isolated aiguilles which cluster round the central and more massive height, convey that impression much more emphatically than could any single cone even of steeper angles, (though it is doubtful if angles higher than those here seen could be compatible with stability).

Notwithstanding this extremely volcanic appearance, the hill seems to have been little visited; and a locality which should have been regarded as a fruitful field of information as to the operations of old igneous action, seems to have been reported on by Murchison and Cunningham alone.

The views of the former regarding it are precise, positive, and well-known; they are to be found scattered sparsely through the various papers he has published on the district, and may be said to be summarised and emphasised in the general section he gives of Sutherland, where the hill is figured protruding as an eruptive mass, which throws the ruptured rocks at high angles off from its eastern and western flanks.

The views entertained by Cunningham are, as is usual with that writer, enunciated with more caution; and there is this rare value to be attached to them, that, as he himself puts it,—"I have never made a statement on any other than my own individual examination."

The following condensation of Cunningham's observations is inserted, in order that some justice and some deference may be paid to one who commences his work by writing—"Love of theory, rather than love of examining, has so disseminated itself among geologists, that the greatest opprobrium which those ignorant of geology can cast upon it is found in their merely rehearsing a catalogue of the theoretical hallucinations which an inattention to anything like inductive philosophy has so prolifically generated"—who concludes it by writing,—"I have never been influenced by that baneful love of controversy which is far from rare in scientific discussions,"—and who throughout his essay has shown himself to be singularly free from both weaknesses, observing with a single eye to the recording of facts, and annotating in the true spirit of a *student* of nature.

Cunningham writes:—

"There are two districts in which syenite, a rock very generally associated with granite, and only differing from it by a mineralogical accident,* is most abundant—the mountain of Ben Laoghal and a tract of country near Lairg.

"The syenite of Laoghal consists of a light flesh-red felspar, grey quartz, and dark hornblende; sometimes the quartz almost disappears, the rock then becoming a binary compound of felspar and hornblende. On the large scale this syenite is disposed in a most distinctly tabular manner. From various parts of the summit the entire structure of the mountain may be traced with the utmost precision, and the several tabular concretions followed throughout its whole extent. In thickness these masses vary from a size recognisable in

* "The result of an examination of their connections is that the formation of both rocks is similar, and that they are to be considered merely as modifications of each other."

a hand specimen, to others of a magnitude so immense that they can only be examined in the district. The lateral planes of the tabular concretions are, in general, nearly parallel, and exhibit an almost polished surface

"I shall next proceed to detail the associations of the true crystalline stratified rocks with the granites and syenites—geognostical phenomena that can never be too strictly investigated, bearing, as they do, both on the chemical and mineralogical department of the science.

"It is found that the simplest mode in which the two series are connected, is that in which the granite forms *imbedded masses* in the gneiss. It may be stated that no gneiss (the components of which are large) can be discovered in which these components are not, in greater or less quantities, so arranged in some parts of the stratum as to be a granite in the strictest mineralogical sense.

"Another relation which must be attended to is the appearance which exists *at the plane of contact*. The result of an examination of many hundreds of these over Sutherland is, that no definite line of boundary is visible when the rock is unweathered; but on the contrary the minerals of both masses interlace each other intimately, so that it is impossible to discover where the one begins and the other ends.

"In some instances the gneiss exhibits an almost complete transition of one or more parts of a stratum into a nearly perfect granite; into a rock which indeed, in a mere hand specimen, is such. The only mark by which to distinguish on the large scale this gneiss from undoubted granite, is in there being usually a possibility of detecting in it a certain series of parallelly-disposed bands of micaceous scales.

"On entering upon the examination of the gneiss of Sutherland at a distance from granite, either in veins or in large bodies, the first appearance which attracts attention is the general dip of the strata to one point of the compass, or, if this is reversed, a sameness in their direction. Advancing to the vicinity of a granite group, before arriving at the main mass of the rock, a district is invariably found which is traversed so abundantly by granitic or syenitic veins, that it is often difficult to determine whether the granite, syenite, or gneiss, prevails most. The district so constituted, too, is not of limited extent, but occupies miles of country; the direction of the strata, however, will be found to be the same as that which was observable in quarters where there was neither granite nor syenite. The veins pass through the strata without causing disturbance, and the same strata meet the principal formations of granite without their positions being changed. If, when at a distance from the granite, they are inclined against it, when in contact with it they are the same; and, on the contrary, if, when far removed from it, they are so disposed that if they were extended downwards they would sink under the granite, so, when in actual junction, the same position is apparent. Frequently, when examining the more central parts of the granitic or syenitic nuclei, large enveloped masses of the neighbouring stratified rocks may be detected; the laminæ of all these, however, will be found to have the same direction and dip as the several laminæ which compose the great body of the Neptunian deposit. The position of the strata, however, as being not affected by the presence of granite (if these strata are examined all round the granitic mass), becomes still more conclusive and remarkable, as the very same appearances, in regard to mineral and positional character, are found to exist over every part of the stratified system, which is extended for miles round the granite."

The most prominent statement of fact here is, "the strata meet the principal formations of granite without their position being changed;—if when far removed from it they are so disposed that were they extended downwards they would sink under the granite, so, when in actual junction, the same position is apparent."

Perplexed by such absolute discordance as to facts, I commenced the examination of the district by making two traverses to determine what was the disposition of the rocks *when far removed* from the granite. Though Murchison and Cunningham seem here to be much in accord,—the former figuring an easterly, the latter a south-easterly dip,—still I conceived it well to make assurance trebly sure.

The first of these traverses, made in a previous year, was commenced at a height of 2,250 feet above the fork of the Allt-na-Cailleach on the south slopes of Ben Hope,—a spot passed over some years ago by Mr. Dudgeon and myself. Having thus connected the line with a previous traverse, I held across the moor as directly at right angles to the strike as the ground permitted. This line I found carried me past the north end of Loch-na-Meide, over the north shoulder of Cnoc-an-Daimh Mohr, and joined the Altnaharrow road near Loch Buidhe.

In our previous traverse we had found the mica schists of Ben Hope dipping E.S.E. In some cliffs on the S.E. shoulder of the main hill, I saw some indications of a shallow trough on that slope; while away to the S.S.W. there appeared to be a local anticline at the summit of Cnoc-na-Togaile. At every spot, however, that my foot passed over, the rock, at dips varying from 15° to 20°, fell to the S.E. and E.S.E.

For the greater part of the way to Loch-na-Meide, glaciation from the west rounded the numerous outcrops, and disclosed the gradual passage of the dark flaggy schist into more silicious and gneissic layers. The central portion of the ground is obscured by vegetation, but, in passing over the more southern, innumerable outcrops, like interminable waves of the sea, become wearisome to body and mind alike.

Continuing the section by a second traverse from Altnaharrow over Ben Cleith-bric (*Klibreck*), the beds—somewhat more gneissic—are found near Loch Naver still dipping the same way, but at an angle of about 25°. This rises, in the steep and rocky face of the hill, to nearly 50°; while its 3,000 feet of altitude, added to the twelve miles previously gone over, vouches for an enormous thickness of rock, laid down with scarce a wrinkle.

This continuously unwrinkled floor is in strong contrast with the section at Strath Oykell on the one hand, where, between Oykell Bridge and Rosehall, five synclines and four anticlines may be seen, and the northern section between Scullomie and Melvich, on the other, where, though the prevailing fall is to the east, great and tumultuous fracturing, with rocky knolls, is the chief feature.

The impression conveyed is altogether against the probability of the northern mass of syenite being metamorphic, unless something very different in the nature of the rocks, and in the circumstances in which they are placed, should there obtain.

The starting point of the second traverse was separated from that of the first by about half a mile; the line was from the south shore of Loch a Ghobha Dhuidh to Ribigill, being nearly at right angles to the first.

Except that the dip swings round somewhat more to the east, and that the angle of the dip is somewhat greater, there is in the western portion of this traverse nothing different from the first. At the Carn a Mhadaidh, however, there is a marked change. The eastern frontlet of this hillock has been torn off and hurled eastward,—possibly by ice;—and its shattered masses show a great hornblendic change in the nature of the rock. Eastward of this it is again mica gneiss; but still further eastward, where the cuttings of the new bridle-path lay the beds freshly bare, first hornblende-slate with garnets, succeeded by mica gneiss, and that by chlorite or ripidolite slate, are seen alternating. A very felspathic grit appears at Carn Fada, and this, above Ribigill, gives place to ordinary mica gneiss and hornblende-slate. The dip of the whole series is persistently towards Ben Loyal, but in this traverse it varies, ranging from 15° to 45°. At the rock-exposure which in this line is nearest to the east end of the north face of the hill,—namely a knoll directly N. of Canaisaite,—a gneissic flag with a black mica, dips S. by E. (mag.) at 40° to 45°.

North of Clach-an-Armuinn, and opposite the western end of the same face, there protrudes out of a morass a mass of *serpentine*, the original gneissic structure of which is admirably disclosed by parallel undulating layers of scaly talc. Two beds of this rock are seen dipping under Loyal at about 20°.

This second traverse has thus shown that there is this marked difference in the rocks in the more immediate neighbourhood of Loyal as contrasted with those further south and more distant from the hill, that there is considerable variation instead of marked sameness in the nature of the rocks themselves. It must also be said that they are, on the whole, somewhat more alkaline. The circumstances in which they are placed, however, seem, up to this point, to differ to an inappreciable extent.

The structure of the hill itself has now to be considered.

From the vicinity of Clach-an-Armuinn, indeed from many points to the north-west, it is clearly seen that the whole of the lower portion of Ben Loyal consists of gneissic rocks, which form a plateau protruding beyond the syenitic superstructure, to east, to north, and markedly to the west. This plateau is most evident along the north face, and the north-west angle. At the western foot of Sgor-a Chonais-aite the height of this plateau is about 880 feet above the sea, while it reaches to near 1,000 at Creag-an-Dithreibh,—the whole mass of which is gneiss. Under Creag-an-Speireig on the east of Ben Hiel the plateau is less well seen, and has fallen to a height of about 530 feet; while at Beinn Eudainn on the south, it protrudes from under the syenite at a height of about 650. Along the north face of the hill this projecting hill-foot presents a steep and craggy frontlet, for the most part birch clad. Everywhere the strata composing it dip into the hill, plunging under the syenite about S.S.E. (mag.), at slightly higher angles than the average of those of the rocks mentioned in the last section.

The beds on the south side of the hill issue from under the syenite with a dip towards the same point of the compass.

The syenite is disposed upon this gneissic plateau as a central dome with castellated summit, which throws out protruding spurs terminating in four sharp peaks. The hill thus, when viewed from the north, bears a resemblance to the knuckles of a clenched hand.

At the delta of a stream which has cut a gash in the face of the eastern peak,—Sgor-a-Chonais-aite,—flaggy micaceous gneiss of a pale green colour is seen dipping into the hill at an angle of 23°. In its greenish or yellowish white colour this rock bears some resemblance to the *sericite-schiefer* of Hellgarten and Nerothal. It is, however, devoid of its silky lustre, and is much more fissile. The beds of this gneiss are cut diagonally by veins of white oligoclase (?) and also by thin layers of a pale greenish yellow schist. Some little way above, veins of red syenite, with a distinctly laminated arrangement of its mica, cut the flags. These veins often insinuate themselves between the laminæ of the flags.

Veins also of coarse-grained granitic structure occur. These contain a highly lustrous felspar, which shows no knitted structure, but contains a chloritic substance, and *ilmenite*. A few feet above this a peculiar black hornblendic rock occurs. For about 70 ft. the section is now concealed by debris; then the micaceous green flags are again seen, but with an increase in the number of the granitic veins, which here ramify to a greater extent, but show everywhere a tendency, more or less marked, to follow the bedding of the flags. This is evidenced by the fact that when in ramifying they cut through the flag layers, they almost immediately bend to follow the lines of its bedding, and, sooner or later, their flexures again cut the layers and return to the parent stem. Where this feature is seen the flaggy rock is markedly less micaceous. There is at this point, indeed, but little of either hornblende or mica to be seen in either the granitic veins or in the general mass of bedded rock. The veins consist of little else than quartz and pink felspar, and the foliation of the rock itself is disclosed merely through a darker or lighter tint in the zonation.

Above this point the solid rock is concealed by an enormous talus of debris. When the syenite is itself reached at the foot of the cliff, its almost erect exposed surface presents at first sight an appearance very similar to ripple-marking. On examination this is found to be due to a laminated structure which perfectly accords in strike and apparently in dip with that of the underlying rock.

The syenite is disposed in enormous slabs many hundred feet in dimensions; these droop in huge but gentle curves from the summit or from overhanging bosses of the hill.

The main jointing of these slabs is at right angles to the structure which has been described (and which would be taken as the original bedding of the rock by those who hold it to be of metamorphic origin).

To the general dip of the rock being here about 20°, and to the jointing hence departing from the vertical to only a similar extent, and also to its being very open, is to be assigned the great precipitousness of the cliff, and the apparent feeble hold which these enormous slabs have of the face of the precipice.

It may be scaled diagonally along some grass slopes, and the rock where freshly exposed is seen occasionally to contain imbedded and often dislocated bands of laminated or chloritic rock. The direction of the lamination accords with the strike of the underlying rock. Fragmentary portions are also seen imbedded, though very rarely, and the softened or diffused character of the crystalline constituents which form the edges of these certainly conveys more the impression that this is a rock in the last stage of metamorphic change, than of its being one in which mere fragments have been caught up and impacted in an igneous outburst.

At the N.N.W. foot of this great slab-sheathed precipice, and at a height of about 790 feet, the same schistose gneiss is seen, but here the dip is considerably higher. Its features are the same as those assigned to it at the first locality, only perhaps there is somewhat more condensation in space as regards its assumption of a granitic structure. The last true gneissic bed is also somewhat more convoluted, and apparently more hornblendic. Syenite, perfect in its structure, succeeds directly to the hornblendic bed, and with a sharp and close fitting junction. The syenite itself occurs in well marked beds, of about 5 ft. in thickness. Weathering discloses in these a laminated structure, perfectly similar though hardly so minute as that seen in the gneissic beds. The strike and dip both of these laminæ and of the beds themselves are identical with that of the gneiss. The laminated structure is better disclosed as we continue to rise. These lower beds of syenite are succeeded by gneissic beds of about 80 ft. in thickness. They are seamed, nearly horizontally, by pale granitic belts.

Immediately above the gneissic beds a boss of syenite appears of a much more massive description than that seen below.

At first sight this boss seems to be formed of beds of about 10 ft. in thickness, which appear to roll over both to the N.N.W. and the N.N.E.; weathering again, however, discloses the same lamination noticed below, while a dip in the previously noted direction is still apparent; so that the division of the rock into the huge blocks which simulate beds with a roll over is, in all probability, the outcome of a jointing similar to that seen in basaltic columns, and results from the rending associated with the consolidation of a semi-fluid mass.

At a height of about 1,450 ft. on the north-west shoulder of the spur which runs north from The Castle, the face of the cliff shows beds of micaceous schist, gneiss, hornblendic and granitic beds,—all *overlying* the syenitic beds last noticed. Here the syenite both below and above these beds still shows the same foliation developed by exposure, and the dip is the same. Of the beds of a schistose nature it has to be expressly noted that they can hardly be said to exhibit a greater extent of those appearances which have been assigned to metamorphic action, than do similar beds occurring at a distance from the syenite.

Viewed from the north peak of Sgor-a-Chleirich the syenite of the whole hill top in all its peaks is seen to be divided into great flat nearly vertical slabs of ever-varying thickness. The rents which form these slabs pass from peak to peak, so that the shorn-off ends of the pseudo-beds of the one peak are repeated most perfectly both in thickness and in disposition by those of the opposite peak.

The impression conveyed is that the intervening valleys had been scooped by denudation subsequently to the period when the hill as a great solid mass had been jointed or disjointed into these enormous sheets of rock.

In the col which lies between Sgor-a-Chleirich and the central dome of the hill the syenite very distinctly shows the true bedding of the rock, which here dips 29° south by east (mag.); and, that the appearance of vertical bedding is merely the outcome of a highly developed system of jointing, is at this spot very evident.

Again, on the ridge which connects the central dome with The Castle, a number of cromlech-like blocks are seen which admirably display the same original bedding of the rock.

Creag an Dithreibh, which rises with some 700 ft. of ribbed cliffs out of the lake of the same name, and which has a flat summit a square mile in extent, is entirely composed of gneiss dipping under the hill, or, more precisely, under the detached Sgor Dhu. The Creag itself is merely a semi-detached portion of the basement plateau.

The gneissic beds, however, are found on the western side of Sgor Dhu above the summit level of the Creag, up to a total height of about 1,300 ft. They are in two thick series of beds, the higher of which is somewhat more quartzose than usual. The dip throughout is the same. The junction with the syenite is not here seen, there being 10 feet of intervening cover. The first syenite seen shows no bedding, its dominant jointing being almost vertical, and agreeing in its strike with that of the jointing of the rest of the hill. As we ascend the Sgor, the syenite is found to be distinctly bedded, and to have a fissile structure alternately thick and thin, and again conformable with the bedding of the gneiss.

These fissile beds appear from this point to extend over the western slopes of the two southern summits of the hill.

An excessively massive and lofty cliff overhangs Loch an t'Sionnaich from the west side of Sgor-a-Chleirich. A very massive bed at the N.W. foot of this lofty rock, shows a laminated structure, which structure has a N.W. by N. strike, with a dip of about 30° to the S.W. by S. At one spot a slab-jointing of the syenite of Sgor Dhu is seen to dip in the opposite direction. Loch an t'Sionnaich lies in a trough between these dips. This is the only fact which is in disaccord with all the others.

I have said that where the syenite is seen to overlie the gneiss, the contact was close; the surfaces also were even; and in no spot did I see any vein to issue from the syenite. At several spots imbedded "neres" were seen in the syenite; very seldom were the gneissic layers of these neres removed from a horizontal position, and in no one case had the neres sharp angles.

Such are the facts which I have to adduce bearing upon the question of the eruptive origin of this syenite.

It is to be observed, in the first place, that every single observation is opposed to Murchison's views. The strike continues unaffected by the presence of the syenite,—under this the rocks pass,—and the dips are not affected at any one spot where the gneiss is in contact with the syenite.

The successive interbedding, for so many hundred feet, with gneissic, hornblendic, and micaceous layers, almost as positively negatives the view that the syenite can have been poured over the rocks, as a great cake, from some central vent.

Cunningham, distracted only by Neptunism and Plutonism, writes:— "The period when the geologist may frame an untangible theory in regard to these ancient rocks, is not yet arrived; nor will it until they are more accurately studied in their mineralogical features, and examined without any relation to an existing belief. Plutonism, expressive as it often is of vague and loose research, is too implicitly relied on, and made in many instances to explain appearances which are inexplicable by it or perhaps by any known process. It is not my intention to add in regard to granite another theoretical crudity to the many already belonging to the imaginative department of geology. The fact, however, is apparent that granite is in its nature intimately connected with gneiss, and that perhaps it may be considered more as a modification of it than a distinct rock."

Metamorphism was not then even in the nursery of "known processes," and never did it seem to the writer to come so absolutely within the category of theoretical crudities as when he attempted to apply it to the explanation of the formation of this syenite, in the light of the circumstances which here obtain.

Can metamorphism suffice to explain continuous and perfect transmutation on one side of a knife-edge line,—a bedded unaltered rock lying in contact on the other side, and even sometimes in the midst of the rock held to be transmuted? and where lie, unaltered, the two thousand feet of highly alkaline or felspathic beds, the representatives of which in a granitic form are now reared aloft on a pedestal of near 1,000 feet in height? The dip of even the highest beds on Ben Hope would carry them down probably as low as the plateau of Ben Loyal; so that, if the syenite of its aiguilles represents any bedded rock, such rock must have been higher in the series than the flags of Ben Hope. The upper beds of Ben Klibreck occupy such a position, but these are far from being so felspathic as to be convertible into syenite.

Tried by the touchstone of such circumstances as these, it is impressed upon us how much as yet "metamorphism" is "expressive of vague and loose research,"—how often it is relied on "to explain appearances, perhaps inexplicable by any known process."

It is clearly our present duty to render our existing theories of rocks more unassailable ("untangible,"—Cunningham,) by a more and more accurate study of their mineralogical features;—and to have as little to do as possible with "the imaginative departments of geology." Assuredly if the changes assigned to metamorphism be not more sedulously studied both in the field and in the laboratory, it must be relegated to the category of what Robert Dick calls "fashionable speculative dreams." At present it is little better than the shibboleth of the superficialist.

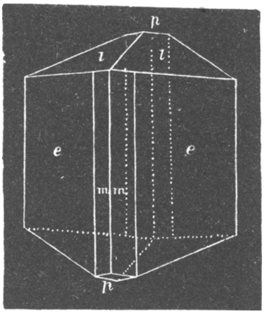
Minerals of the Gneiss.

The first mineral I have to notice as found during these recent traverses is *red avanturine*. This occurs possibly as an accidental transmutation or alteration of a very quartzose mica-schist, where the latter is passing over almost into a quartz rock. It is to be found near the shores of the Gorm Loch under the east shoulder of Ben Hope. The specimens are moderately fissile, and from the brilliant red tint of the imbedded mineral which gives the colour, and the high lustre of the mica which produces the spangling, they are very striking in appearance. To the microscope this imbedded mineral does not present the appearance of a mica, or any foliated structure;—its form being that of elongated masses like grains of rice. These grains have a fine amber or a ruby-red colour; they more resemble augite in form than any commonly occurring mineral, and are not to the smallest extent dichroic.

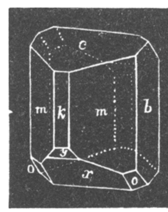
The eastern frontlet of Cairn-a-Mhadaidh, noticed above, presents an extraordinary scene of ruin and rock dislodgment. That portion which had apparently been the original summit has been rent from its attachment, and slid downwards, hurling vast masses before it, so that, for several hundred feet of altitude, there is a labyrinth of countless blocks which is rendered more involved from the comminuted rock giving sustenance to a grove of birch.

The rock is here commencing to be hornblendic, and is passing into a laminated arrangement of red felspar and matted actynolite. A few minutes' search showed occasional flat cavities in the layers, which contained *rock crystal*, *hornblende*, *sphene*, and *orthoclase*.

The rock crystal was in its usual form.



Well-crystallised *hornblende* is exceedingly rare in Scotland. I do not remember better than that here seen. The crystals are generally of the actinolitic type (see fig.), in radiating brushes which extrude their free terminations from their matrix of felspar. This, apparently solely *orthoclase*, is in the annexed form.

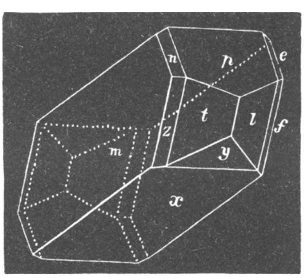


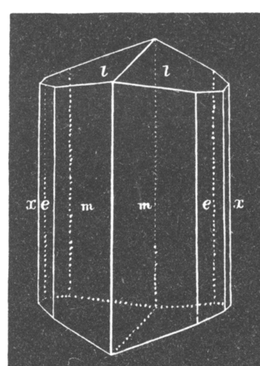
The *sphene* is in crystals of about the size of split peas, and is both pale yellow and dark brown. It is in the forms numbered 1 and 4 of the Shinness crystals.

The beds of hornblende-slate come in on the south-eastern flanks of Meallan-Liath; the imbedded *garnets*—much flawed—are in rhombic-dodecahedra.

Still further east are beds of foliaceous *ripidolite* (?), containing loosely imbedded *garnets* of the same form, and with edges sometimes truncated. These are smooth-faced, lustrous, and somewhat transparent.

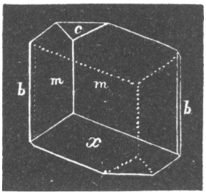
A quarry hole on the road above Ribigill shows hornblendic beds, cavities in which have much the same assortment of minerals



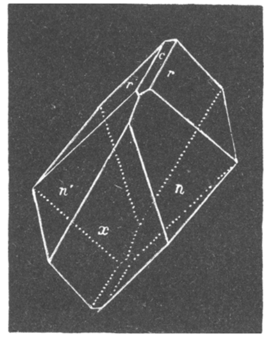


as those seen at Cairn-a-Mhadaidh, but contain also *albite* in the form *m*, *p*, *t*, *l*, *n*, *z*, *e*, *f*, *y*, *x*, more elongated along *m* than in the annexed figure.

The *hornblende* is in the form drawn.



The felspar as in the figure.



The hornblendic beds sometimes contain bands of lustrous pale green *byssolite*, which has a slightly waved but parallel arrangement of the fibres.

Sphenes occur in the form figured, and also with *c* truncating deeply; they are rare.

Minerals of the Syenite.

I have elsewhere alluded to the disadvantage at which the collector of minerals is placed, in comparison with gleaners in other departments of natural history;—how dependent he is upon the operations of force in its various forms to lay bare and dislodge the objects of his search. I spoke of the aid afforded to him by the breaching power of sea waves, or the elevating force of earthquake throes. The turmoil at Cairn-a-Mhadaidh suggests another,—the direct, continuous, and ultimately prevailing operation of gravity, where precipitous slopes admit of its acting as a rending power. Another agent,—the force of running waters,—the operations of a "waterspout," does not so readily suggest itself, yet to this, though here operating only once in a century, are we indebted for laying bare the chief treasures of the syenite of Ben Loyal, and for establishing to a great extent the direction of the ice flow in the district.*

In the description of the great boulder which lay upon the west slopes of Ben Bhreck, it was pointed out that in all probability it had been *ice carried* from the opposite cliffs of Ben Loyal;—an inference exceedingly repulsive to the views of those geologists who hold that the ice swept over the north of Scotland from the Baltic, the North Sea, and the South-east. The finding by Mr. Mitchell of the piece of amazonstone which he sent to Dr. Joass,* was a step in the determining this question, and in order to ascertain the circumstances of that find, the writer was induced with all haste to return to the locality.

A summer's shower of but two hours' duration, but of unprecedented violence, had burst with concentrated force upon the northern frontlet of Ben Loyal, (in fact it burst nowhere else). The deluge had, by the

* Foot note, page 178.

action of a water-wedge, torn slabs of rock from the great cliffs, and had cut great trenches in the talus at their foot; which talus had lain undisturbed so long that it was everywhere turf-covered and swathed in birch.

Here was a rare opportunity for the mineralogist.

Masses of rock which had hammered themselves against each other after plunging through the air for some hundred feet, and gashes out of which the torrent had tossed up the debris of former falls, to a depth of fifteen feet and for a length of half-a-mile.

I have described the section laid bare in more than one of these gashes; the minerals found were got almost entirely from that which scars the great cliff on its western fringes.

While desirous to find *amazonstone in situ*, and so definitely to connect the Ben Bhreck boulder with the hill, the writer was above all anxious to find the *thorite* in quantity sufficient to enable him to analyse it.

Three blocks only were found which contained veins with amazonstone. One appeared to be an old block disinterred,—a second was a fresh new-fallen mass,—the third was doubtful. Though only three blocks showed veins with *green* felspar, several others carried veins in which the felspar showed the same structure as does the amazonstone, but from which the green colour seemed to have been bleached.

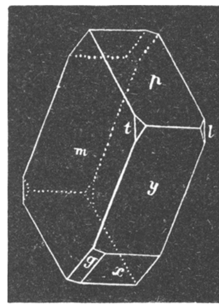
It has in this connection to be remembered that exposure to *light* exalts the colour of amazonstone; and that a mantle of peat *bleaches* almost all rocks, and that turf, to a certain extent, effects the same change. The cliffs of Ben Loyal "weather" purple; those portions from which the mantle of turf has lately been skinned off, are as white as paper.

Almost all of the blocks which had these exfiltration veins of bleached amazonstone carried *thorite*, but usually in particles too small to be broken up with advantage in collecting it. Next to the felspar and greasy looking quartz, the thorite is the most frequently occurring substance in the veins; *magnetite* is next in frequency. The two latter may be distinguished by the conchoidal fracture, pitchy lustre, and dark brown to clove colour of the one,—and the magnetism, the flat or the hackly fracture, and the blue-black colour of the other. The magnetite sometimes contains specks of the *thorite*, which when broken appears red-brown or yellow. Occasionally there are traces of crystallisation in the thorite, the surface of which is then dull, pitted, and light brown. On fracture the brilliant-lustre appears, so that the surface may be altered.

Such is the appearance of the specimens which contain particles of the thorite of the size of shot.

Occasionally these specimens contain *Babingtonite*, and the specimens of this mineral are much superior to those found in the boulder at Ben Bhreck. The imbedded crystals are one to two inches long; when broken they show a facile lustrous cleavage, which runs along the length of the crystal. They are bright green, but are unfitted for analysis on account of being pervaded by plates of brown mica. Such crystals are quite thin. Others, fortuitously broken transversely, show several faces; but the number of specimens obtained was not sufficient for ascertaining the position of these.

The forms of the *amazonstone* are those of the first type of the Ben Bhreck boulder. As the veins here found were never above three inches in width, the crystals are small, and they are almost always altogether imbedded. Small cavities sometimes contain crystals of form m, b, c, x, o; and these sometimes carry on their surfaces small crystals of albite of the form drawn.



One mass, which had fallen with such force as to throw the fragments of amazonstone out of the trench on to the sward, contained a jet black lustrous mineral, with a hackly fracture.

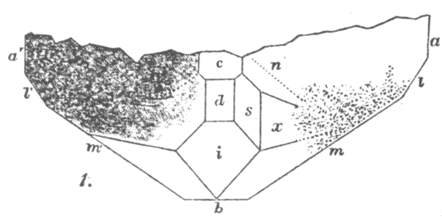
Being only partially soluble in chlor-hydric acid, it cannot be thorite. It is also harder, and of lower specific gravity.

This was disposed between the crystals of amazonstone; it showed portions of broken crystals of its own substance.

The patches of this mineral, though thin and much spread out, are two inches long and broad. Possibly the fragments obtained may suffice for analysis.

The other specimens contained comparatively little thorite, but one carries fine *topaz* in the four forms figured.

These topazes are of an entirely different cast from those many years



ago found in the Grampians, but are somewhat similar to those from the Urals. The blow has dislodged most of them from the stone, so that only their casts remain. The largest remaining is a broken crystal $1\frac{1}{2} \times \frac{5}{8}$ inch; the largest perfect crystal is $\frac{3}{4} \times \frac{3}{8}$. They are exceedingly brilliant, and of perfect polish; colourless to pale yellow. About one half of the length of some of the crystals is pervaded, apparently in rents, by *rubin-glimmer*, so as to give that termination a red purple tint.

For some time I was doubtful as to these crystals being topaz, and for the following reasons:—

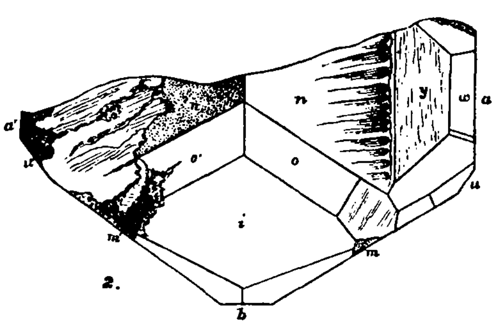
I could see no striation on any face,—I could see no trace of the dominant cleavage of topaz,—and, lastly, every one of the larger crystals shows the macropinacoid brilliantly developed. This is a face given neither by Descloiseaux, Kokscharov, or Miller, as occurring in topaz.

The imperfect traces of cleavage seen are prismatic, and are parallel to *l*, and to the brachypinacoid.

Upon applying force to the broken crystal, however, the summit cleavage appeared; and the application of the contact goniometer to those crystals which project sufficiently for its application, showed that much of the peculiar appearance was due to the prisms lying on their sides in such a position as to show the face *b* uppermost. It is largely due also, however, to the brachypinacoid being sometimes the most highly-developed face.

All the crystals have the prismatic faces brilliant and smooth, but the pyramidal faces are rough or uneven; still it would appear that in addition to *b* there are other new faces on these crystals.

The felspar alone has been protero-genetic to the topaz here; the crystals of the latter being disposed on the former. The quartz again is moulded over both. The paragenetic formation of this last mineral cannot thus have in any way impressed false faces on the topaz; indeed, these apparently new faces reflect a flash of light from a *level* though not a smooth surface.



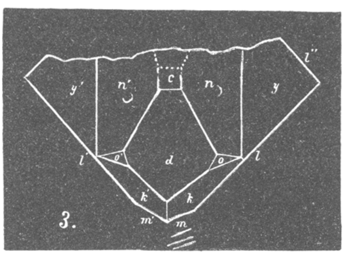
2.

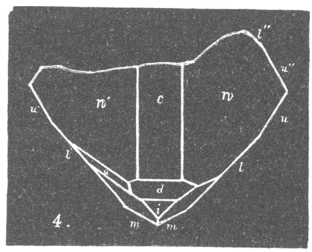
In the figures, I have delineated merely what can be seen of each crystal; as I have detached none from the rock, the lettering is conjectural as regards the summit planes; and from the distorted view which can alone be obtained the drawings are doubtless incorrect.

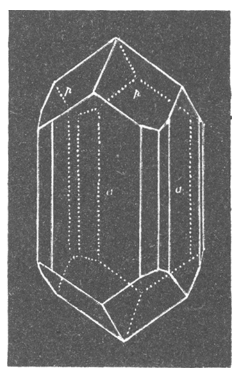
As regards the prismatic faces, the contact goniometer gave *a* on *b* 90°; *a* on *m* about 117° 30′; *a* on *u* about 147° 30′; and *u* on *u* about 115° 30′,—on two of the crystals.

The larger crystals are hemihedrally developed in their accuminating planes, but some minute crystals are less so.

The first two figures represent the terminations of two of the larger crystals; two of a cluster of small crystals are figured below.



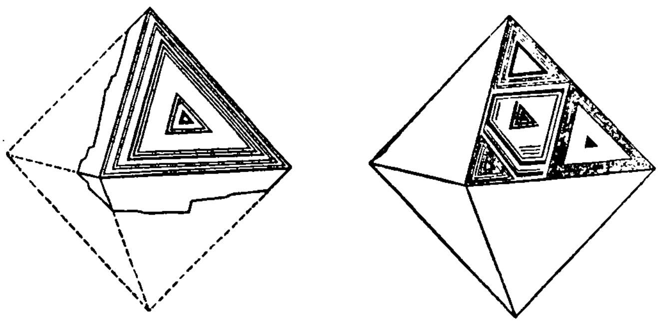




I am much perplexed by the crystals of thorite which are found here; the figure shows one of the crystals. This accords with the form of those from Ben Bhreck, but there are also two distinct *octahedra* half the size of peas. The form seems the *regular* octahedron. The fracture both of the pyramidal and of the octahedral crystals is conchoidal, the lustre pitchy, and the colour deep brown. In addition to their being non-magnetic, there is no risk of here mistaking magnetite for whatever mineral these octahedra may be, as the magnetite here is blue-black, with distinct cleavage and hackly fracture. But the internal structure of the crystals which occur in these two irreconcilable forms is no more like that of a pseudomorph in the one case than in the other.

Of course it is mere guesswork to say that the one may be *pyrochlore*. I have not enough for any test, and the crystals are much too minute for estimating the hardness on. The pyramidal mineral is soluble in chlorhydric acid, with separation of silica; and the orange-coloured solution gives a copious ruddy precipitate with ammonia.

The magnetite is in minute octahedra and rhombic dodecahedra. The crystals of the first form show the irregularities of surface shown in the following figures.



Rubin-glimmer here and there lines cavities; it also pervades a granular felspar which forms the roots of the larger crystals, so as to give it a certain amount of "sonnenstein" appearance. Galena in small specks is the only substance found here which did not occur in the more ample veins of the Ben Bhreck boulder.

The syenite of Sgor Dhu is of a redder tint, and is also more hornblendic than that of the rest of the hill. It contains *sphenes* in well-developed but simple crystals.

The beds of serpentine noted as found in the swamp at the N.W. foot of the hill are of much interest. Mr. Mitchell had noticed many blocks of a partly-weathered rock lying in the vicinity,—and only in the vicinity of Ribigill. He was so struck with its appearance that he had it cut into ornaments; but the peculiar appearance of the stone is in these much marred by partial decomposition.

This bed of serpentine is their source—and the easterly carry of the ice is again vouched for by these loose blocks.

In the beds themselves the decomposition has penetrated to less than half an inch; and the rock itself is seen to be a dark-green oily serpentine, very uniform in its general granular structure. But it is pervaded by scales of *talc*, which are dispersed *firstly* in continuous belts of varying closeness to one another, and *secondly* in isolated rosette crystallisations.

As the rock takes a high polish and is deep in colour, and as the talc is high in lustre and silvery white, unweathered blocks cannot but form a highly ornamental stone,—the glancing scales being sprinkled throughout it in all positions.

I know of no serpentine the appearance of which is more unusual, and its appearance under the microscope is unusual likewise.

It shows like a mass of smashed up olivine; there is no appearance of serpentinic change, the sharp-angled fragments polarising like olivine with a flat field of uniform colour, and lying in immediate contact with each other, with no intervening coating or layer of serpentine.

Still the rock weathers brown, like serpentine; and bruises with the blow of a hammer, without any splintering.

There are certain of the rocks noted above, the microscopical appearances of which call for some short notice.

The first of these is the hornblendic schist, carrying garnets, which occurs on the south-east shoulder of Meallan Liath.

The characteristic structure of this rock is—like that of many others —only disclosed by what may be called macroscopic sectioning, in contradistinction to rock-slicing for the microscope.

A slice, the size of an ordinary "hand specimen," is obtained by the use of the "diamond slitter." If the plate has cut flat and fair, all that is necessary is, after thorough scrubbing and drying, to cement the cut surface on to plate glass, and to cut off a slice of about one-sixteenth of an inch in thickness.

The second surface of the slice has now to be ground down on a glass plate with washed flour emery, until light will pass through.

Should the first section, however, not be flat, the process is very tedious. As emery splinters the edges even of imbedded crystals when rolling over the surface of a slab of rock in the process of grinding, it is necessary, in order to guard against this accident, to employ it in a state of extreme subdivision, and of perfect uniformity of grain. A much better article is to be obtained by repeatedly washing ordinary flour emery (separating the coarse, and setting apart the floating scum), than by using the "mirror flower" of the shops. The whole surface must be "brought up dead flat" (as in making a microscope slice), cemented by balsam on to plate glass, and the second surface ground down, if not from the very commencement with the fine emery, at least for such a length of time that all the pittings and roughnesses caused by the coarser emery are entirely smoothed out.

From the great consumption of time such sections are very costly; but by no other process are those crystal arrangements of rock structure which lie between the powers of recognition of the eye and of the microscope suitably and fairly disclosed.

Such slabs of rock are, when held between the eye and a bright light, found to be more beautiful, merely as transparencies, than jaspers, carnelians or moss-agates; while they at the same time often display the reign of law—dominating over the self-assertion and segregatory isolation of individual minerals.

The hornblende schist, when thus examined, presents a most singular appearance. The garnets which it contains are promiscuously scattered as regards crystal position, but may be said to be equidistant. The hornblende is in form like minute grains of rice. These grains sometimes, though rarely, infold the crystals of garnet in successive layers, so as to form a kind of sheath to each. Usually, however, they are grouped so that they project in clusters, their long diameters *standing erect from the angles of the garnets*, which are thus set round about with a series of plumose arrangements. Such granules as lie intermediate between garnet crystals, present the appearance of a current flowing between islands.

The impression conveyed is that, after the solidification of the garnets, a specific force of crystalline attraction and polar arrangement emanated from them, which not merely influenced but *determined* the position of the crude crystals of the hornblende, notwithstanding the dissimilarity of the two minerals in composition, and their discordance in crystalline form.

Two other rocks spoken of above are deserving of notice here, from the fact that the nature of both may be said, on a first impression, to be rendered more obscure; while the interest of the first is exalted by the fact that the microscope altogether fails in directly determining its nature. The one is the pale green or yellow schist occurring in thin layers; the other the hornblendic rock which overlies the former a little higher in the series, among the flags at the foot of Sgor-a Chonais-aite.

Sections of the yellow schist, cut transverse to the bedding, show a zoned structure which is for the most part made up of more or less continuous layers of quartz. These traverse a confused arrangement of imperfect crystals of a yellow mineral which is unaffected by the rotation of the polariser. Rude crystals of magnetite are sprinkled here and there, with blotches of a dull-white substance which is probably an altered felspar. Both the upper and lower surfaces—those, namely, which had been the contact surfaces of the bed,—contain flakes of hornblende. A parallel slice, cut medial to the bed, shows no hornblende, but exhibits strains; these pass through the yellow crystals as a line of deeper tint, and through successive portions of the quartz as zones of fluid cavities. The quartz-granules are united by a sutured structure. Rarely, minute well-formed crystals of the yellow mineral, which are apparently oblique, are imbedded in the quartz.

With the upper Nicol the yellow-green mineral gives a play of colours so much more brilliant than is to be expected from epidote, that the determination with the microscope cannot be said to be absolute or satisfactory, the information afforded being negative.

By comparing the slices, however, with the *epidotfels* from Amerbuch in the Odenwald, Hessen, an almost perfect identity of appearance is seen. The rock from Hessen has fibrous hornblende filling rifts, a little augite, and garnet instead of magnetite. The crystals of epidote, also, are larger, and the structure is not altogether so schistose. No other differences can be seen; so this may, with some measure of confidence, be set down as *an epidotic schist.*

The hornblendic rock has, in hand specimens, much of the appearance of a dark mica slate, with the mica scales running out along one axis after the manner of Haughtonite.

When sliced parallel to the bedding it has a harlequin-coat appearance; a uniformly disposed mélange of hornblendic structure, less felspar, and magnetite. The last is in quantity about one-third of either of the others; these occur in nearly equal amount. The hornblende is pale sea-green, and in rice-grain crystals, with feeble lineation. Revolution of the polariser produces hardly any effect.

A transverse slice, again, shows a zebra-like arrangement of the hornblende, which in this position shows normally dichroic.

This is thus a gneissic syenite, with a marked polarity in the arrangement of at least the hornblende. So dominant, indeed, is this polarity, that while the transverse slice, viewed as a transparency, is brown in colour, the parallel slice is pale blue-green; and in neither of the slices which I have have I seen a single crystal so placed as to show the lozenge cleavage.

The hornblende crystals thus lie with their long axes parallel to the bedding of the rock. The other direction—evidently equally definite—I unfortunately, not suspecting any such arrangement, failed on the spot to note.

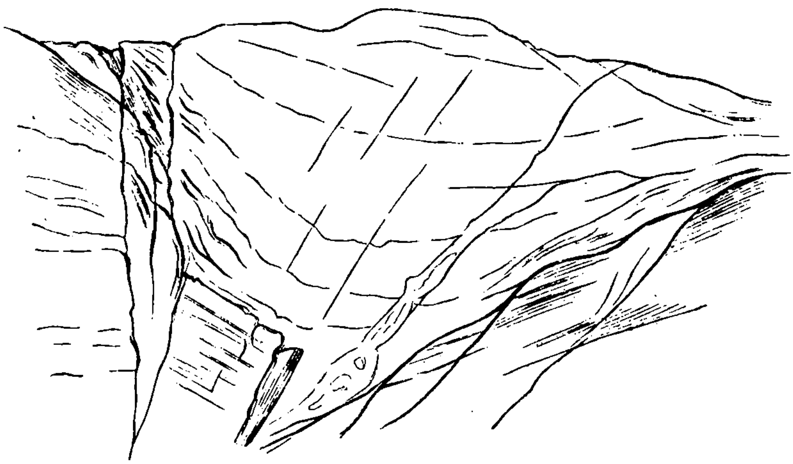
The Granitic Rocks in the East of Sutherland.

As the continuation of the section through Sutherland from Ben Hope to the Helmsdale district would, from the almost total absence of shelter eastward of Ben Klibreck, entail great hardship, the writer preferred to undertake a traverse further to the north; and that so near to the boundary of the county that any obscurity in inland districts might be removed by a detour to the shore exposure. Such a section is easily made by starting from Whitten Head, and availing oneself of all the conveniences associated with the line of road which stretches eastward across the country to Thurso.

I have, in the rude sketch of the Whitten Head (Plate xxxiv., Vol. iv.), shown the stepped fault, with the appearance of local western thrust of the eastern gneiss which is there seen. At the time of examining it I was of opinion that, if the fault there disclosed could be shown to extend in force southward, Nicol's contention as regards the structure of this part of the country might, with some slight modification, prove to be correct.

I accordingly, in company with Mr. Dudgeon, spent some time at Hope Lodge, in examining the surrounding ground, which we traversed to considerable distances all round. We endeavoured to keep the line, and trace the fault southward from the Bodach Derag in the direction of Hope Lodge. The latter, however, we failed to do for any great distance, partly from the obscurity of the ground, but chiefly from all marks of disturbance ceasing. We were satisfied that the fault died out before

Cnoc an-Uillt Tharsuinn was reached. Close examination of the fault itself satisfied us that there had been no over-slide of the gneiss. As will be noticed in the sketch, the fragments of quartzite are all pulled or have fallen downwards; while some at the bottom have a tilt to the east. There is also a total absence of all rolling up of the truncated end of the beds of the quartzite.



A second sketch of the fault, drawn at right angles to the first, is now given. The exposure here is along the strike. The sea has cut away the quartzite, forming a little bay; and it has, to a small extent, impinged upon the gneiss, laying bare its shorn-down face. The lines of bedding are full disclosed, and the manner in which the beds droop to the centre, with dislocated fragments of the quartzite pitching against them to the downthrow, is suggestive of anything but an over-slide.

Again, an examination of the ground in the vicinity of the Lodge led to the conclusion that the beds on the west side of Loch Hope and of the Hope River ascended by an unbroken sequence into the upper schists. No palpable break is to be seen either in the shore cliffs, or is in any way indicated in any traverse of the Moin, or even in the appearance of the hills which skirt it to the north or to the south.

These upper schists, where they first come in, are in a general sense micaceous for a long way to the south; indeed until Loch More is approached. There is, however, considerable variation in their structure, and probably also in the composition of the mica. In the north, this ingredient is dark green, plicated, and greasy in lustre; in the south, it is purplish-brown, flat foliated, and splendent. I have indeed very considerable doubt as to its nature in the northern rock, which was called "chloritic schist" by Murchison. I have made repeated but unsuccessful attempts to separate from the rock a quantity sufficient for analysis. It may be an intimate mixture of margarodite with a decomposition product of hornblende.

Underlying the mica-slate of Ben Hope, there are, on the west side of Loch Hope, beds of a loose-grained quartz rock, with high sparkling lustre; and something of the same kind is seen in the beds of Leiter-Mussel; besides this, none of the rocks on this horizon exhibit any of the appearances which to the unaided eye are considered typical of high metamorphic action.

As the Kyle of Tongue is approached, what little can be seen of the rocks shows them to be gneissic in structure; felspar being abundant, but mica deficient. At the Kyle, a rock which has been called mica-slate is seen on both of its shores. For the most part it is a laminated quartz rock,—a mica-slate without the mica,—hard, tough, flinty, durable,—clearly highly metamorphosed.

Eastward of this,—and eastward, be it noted, of the line of overlying outliers of the Old Red Conglomerate,—there is a long stretch of country (as far as Strathy) where the rock has much the same type,—that of a "gnarled gneiss."

The usual, and stratigraphically the prevailing, dip, is to the south-east; but there are numerous folds. These are altogether trifling in amplitude; but in the centre portions of the tract they suffice to crumple up the rocks into a surface of extreme ruggedness. The gradual appearance of hornblende, and the separation of the several constituents of the rock into segregatory veins, has also here conferred upon it appearances of much increased metamorphism.

In the immediate neighbourhood of Strathy, and on at least the east shores* of the promontory of that name, a pale tint has returned to the rocks, either from an actual increase in the relative amount of quartz and felspar, or from the hornblende being here in segregatory belts. Albite also is now largely present.

Eastward of this point, and on to Reay, the rock may be said to be again distinctive.

If the hornblende has not actually increased in quantity, it has, along with black mica, been diffused so much more uniformly throughout the rock that the tint is for the most part dark. The rock is minutely lineated, but the lineation is not segregatory; for each layer which developes the lineation contains (though in varying amounts) all of the

*I have not examined the west shore.

constituents of the rock. These occur in minute crystals, and have a granular arrangement.

The rock in fact is a granitic—or, more correctly a *syenitic* gneiss.

Occasionally, as near the Jibigall burn, it is even porphyritic, containing large crystals of orthoclase.

As we pass still further eastward, the granitic change increases, so that everywhere here,—and I believe everywhere to the south where it approaches or comes in actual contact with the present margin of the Old Red,—it has either actually passed into syenite or granite, or is a rock in which the gneissic structure and the gneissic bedding are more or less obscure.

In a map by Murchison, in addition to the large masses of granite laid down in the border-land, there are to be seen numerous sprinklings of small patches which are laid down all about the Strathy and Farr districts. These probably are to be held as representing small eruptive intrusions, seeing that the larger masses are held to be such. Not being able to discover any such masses at the point indicated, the writer concluded that they might represent a more condensed development of exfiltration granitic-veins; and the general appearance of the rock in the district between Strathy and Farr led to the expectation that such would be found.

This is exactly, however, what does not occur. With the exception of the east coast of Strathy Point, afterwards to be spoken of, the rock is one of fairly uniform structure; and what venation does occur is a *segregatory arrangement*, and not one of *granitic exudation*. The change in the nature of the rock is in fact one which comes in gradually, and which *occurs in masses;* while the evidence of the facts seen is *everywhere* against the view that these masses are eruptive. All the clearly exposed localities evidence that they are metamorphic.

The most westerly point at which the granitic rock is seen, is the shore line between Baligal and Port Skerry; the next at the Red Point, just within the confines of Caithness; the third in the neighbourhood of Sandside, specially at the Isald Burn,—whence it stretches as a more or less perfectly transmuted rock southward for many miles, passing under the Old Red rocks at every spot where the junction can be seen.

These are the three localities at which the question, *eruptive or metamorphic ?* has to be put to the rock itself and to its surroundings.

As this question has been directly entered upon by Sedgwick and

Murchison,* by Cunningham,† and indirectly by Geikie,‡ the evidence and opinion of these authorities must be considered.

Of the rock in the neighbourhood of Port Skerra, Sedgwick and Murchison (1835) write :—" Two masses of granite interrupt the regular range of the sandstone strata, which are in consequence tilted in opposite directions from these granitic nuclei."

Of that at the Red Point they write :—" A mass of granite, in rude prismatic forms, here intrudes upon the stratified rocks. On the western side of this junction the beds are in the utmost confusion, the limestone being not only highly inclined, but also crystalline and cellular. Close to the point of contact these same beds assume a brecciated structure, and even contain many fragments of the granite itself. It appeared to us that the disturbed and brecciated masses could not be brought into comparison with the old conglomerate of Port Skerry, but had been formed by the mechanical action of the granite, which must in that case have been protruded in this place, after the deposition of the part of the secondary system above described.

" Some masses of the conglomerate rest upon the tilted edges of the limestone, whilst others are of a wedge shape, and appear as if they had been mechanically driven in among the shattered edges of the higher beds of limestone and sandstone. The cement of the conglomerate is generally granitic ; it is, however, in some parts calcareous, and in other places it approaches to the character of sandstone :—one great block of sandstone, with the usual undulating surface, seemed to be entangled in the granite. At the eastern extremity of this disturbed portion of the cliff there is no conglomerate, and the stratified beds cannot be traced into immediate contact with the intruding granite ; neither do their dip and direction appear to have been much disturbed.

" This mass of well-characterised granite may be considered as the extreme spur of a ridge of that rock, which, in retiring from the coast, is first seen in rounded knolls on the north of Sandside House, whence it ranges to the south-east, and rises into a low chain called the Dorrery Hills, which are peninsulated amidst the plains of calcareous schist and sandstone of Caithness."

Again, Murchison,* writing in 1859, says :—" In travelling eastward (from Farr) intruding bosses of granite again prevail ; and some of these not only penetrate the crystalline strata but also throw off the overlapping Old Red Sandstone and Caithness Flags." " The bosses of granite on the shore near Port Skerry have evidently penetrated, when in a molten state, into the gneiss ; whilst both these rocks have afforded the fragments composing the lower breccia and conglomerate. In truth, all this part of the coast having been subjected to violent breaks and faults, the hard crystalline granite, porphyry, altered rocks and gneiss, have in such movements been necessarily protruded here and there through the softer sandstone and flagstone. But that all such crystalline rocks were previously solidified is proved by the fact that their materials forming the breccia and conglomerate here constitute the highly irregular base of the Old Red Sandstone. In proof of the very local character of the coarse breccia, the observer has only to move to Reay, and in the banks of the burn of Isauld to the sea shore he will find that there the fundamental granite has undergone no dislocation ; and that the conglomerate, or base of the Old Red lying on it, consists of pebbles which have evidently been rounded by the long-continued action of waves upon a shore."

In criticism of the observations of Sedgwick and Murchison on the appearances at the Red Point, Cunninghame, in 1839, writes† :—" Messrs. Sedgwick and Murchison appear to be of opinion that the secondary strata have been acted on by the granite.

* *Trans. Geol. Soc.* 2nd Ser. Vol. III.
† *Trans. High. Soc.* Vol. VII.
‡ *Trans. Roy. Soc. Edin.*, Vol. XXVIII.

* *Quar. Jour. Geol. Soc.* Vol. XV.
† *Trans. High. Soc.* Vol. VII.

I saw not one appearance which could justify this belief. The circumstances appeared to me to present only a well-marked instance of strata reposing on a rock, which had in nothing influenced their position after they had been deposited." "We have here an example of a rock which, besides being partly derived from the subjacent one, has been also quietly deposited in its hollows, and on the edges and planes of the strata."

Speaking of the same spot, Geikie* writes:—"Three quarters of a mile westward of Sandside Geo, a portion of the uneven platform of crystalline rocks rises up through the later deposits. Bosses of gnarled gneiss and dark mica-schist, traversed with pink granite veins and with an easterly dip at high angles, appear on the shore reefs, and rise up to the summit of the cliff. The singularly unequal surface presented by these ancient rocks when the Old Red Sandstone began to be laid down on them is well shown by this part of the coast. A pink granitic breccia with intercalated seams of green sandstone and flagstone occurs at the base of the overlying strata, filling up hollows of the gneiss and allowing projecting parts of that rock to be wrapped round by the succeeding sandstones. This breccia is so hard and crystalline as to be in part scarcely distinguishable from a jointed granite. Some calcareous bands are here, as usual, associated with the base of the flagstones. A few small faults have the effect of here and there bringing the sandstones and the gneiss together along a vertical junction line."

It has first to be observed, with regard to these quotations, that as regards the two westerly localities the rock termed granite by Sedgwick and Murchison is regarded as gneiss by the other observers; while their writings show that there was a perfect agreement among all as to the nature of the rock at the Isauld Burn,—the easterly locality.

Again, Murchison and Sedgwick contend that the granite at Port Skerry was eruptive *in situ*, and that it was connected with eruptive movement—was indeed possessed of inherent "mechanical action" at the Red Point.

I would say with regard to these two localities that, as the rock at both is separated by a cincture of flags and sandstones from the gneiss of the interior, we cannot at either trace *progressive* metamorphic change up to and into it; and that the difference in the name applied to the rock by the above authorities shows that it may be regarded as being intermediate in character. This, indeed, it appeared to me to be.

The fact of granite *bursting through gneiss* at Port Skerry is not noticed by either Cunningham or Geikie; neither could I find any spot at the locality which presented such an appearance. The rock appeared to me to be pretty uniform,—a red granite rock, with little quartz and less mica, but still one which evidenced a gneissic origin. But the coast line, where it is exposed, is so extensively cut up by sinuous and branching "geos,"† and the foothold along the verge is so precarious from slippery grass,—which mantles a steep deposit of "till" down to a crumbling edge overhanging rocky spikes rising from a seething ocean,—that it is very possible that

* *Trans. Roy. Soc. Edin.*, Vol. XXXIII.

† "Geo" is a local word in the Northern Counties for a small creek or rent in a rocky coast.

I overlooked the spot referred to. Again, neither Cunningham nor Geikie seem to have observed "the sandstone strata tilted in opposite directions;" nor could I myself find any spot where there was any such departure from the usual dip.

As to the second locality—the Red Point—Cunningham and Geikie are perfectly in accord, (except as regards the term by which they designate the rock). With these writers I entirely agree. I cannot conceive how beds of sandstone and limestone, brecciated by the upward thrust of previously solidified granite, and mingled with fragments of the same, could have a cement which, generally granitic, was still in some parts calcareous and in others of the nature of sandstone: and if, as Murchison puts it, "all the crystalline rocks were previously solidified,"—*i.e.* previously to their having been subjected to violent breaks and faults,—how could a great block of sandstone "be entangled *in the granite itself*"?

Murchison considers that the granite at the Red Point is connected with the knolls on the north side of Sandside House. This inference I conceive is quite borne out by the configuration of the ground. That the knolls north of Sandside are connected with the cluster, equally near, to the south of the road is perfectly evident. And that these are connected with the gneiss of the watershed about Loch Holliston on the west, and with the syenite of Isauld on the east, I think will be admitted by every one who examines the ground.

In passing eastward from the western watershed of the syenitic gneiss, it is seen that its bedding, its dip, and the lineation which vouches for its original laminated structure, are gradually lost. The rock which pierces the turf at Achavarsdal Lodge some would term syenite; others, granitic gneiss. A hand-specimen broken from any part of the rock is nothing but syenite. Standing some feet away, faint traces of paler felspathic banding disclose the prevailing dip and strike of the gneiss (as seen some miles to the west). Looking from this point southward to Creag Leathan, the bedding and the dip of the rock are clearly seen. Standing on the Creag, neither are to be made out; and one does not know what to call the rock, except *an intermediate*. Walking from Creag Leathan to Beinn nan Bad Mhor, and back over Beinn Ratha to Beinn Ruadh and the gneissic watershed, most of the ground laid down in the maps as granitic is passed over; and while many varieties of intermediate rock are seen, it is, as a whole, more clearly bedded and more clearly gneissic in structure than is the rock which forms the passage-beds in a direct line.

There being no encircling band of sandstones cutting off this syenite of Isauld from the gneiss,—as in the case of the two previously considered localities,—the question as to metamorphic transition should here be decided.

At the mouth of the Burn of Isauld the rock is altogether uniform in structure, in all respects and directions. Neither bedding nor any definiteness of arrangement of the component crystals can be seen. As noticed by Geikie, there is a large proportion of black mica; but there is a still larger proportion of black hornblende, while brown *sphene* is far from rare.

If it be a metamorphic rock, the metamorphism is here complete. There is not the smallest tilting of the overlying beds of the Old Red. The first bed indeed is a conglomerate, made up of smoothly rolled nodules of the syenite; and this bed passes under the flaggy beds with a dip identical with their own. Further inland, where some trace of bedding is seen in the syenite, it passes with an angle of about 15° under the same flaggy rock, which has a dip of about 3°. There is an overlap of each bed of an ascending series of the flags, mantling up upon each little knoll of the crystalline rock, which formed a shore-line to each succeeding bed, supplying to it a fringe of conglomeratic shingle. This conglomerate varies in character from well rounded *syenitic*, to nodular *granitic*, and angular *gneissic*, according to the nature of the local base.

It has been objected to the rendering advanced by Messrs. Murchison and Geikie of the sequence of the rocks of the north-west,—and the objection has been repeatedly brought forward, as if it were the sure ground of an unanswerable logic,—that it is exceedingly repulsive to geological science, if not opposed to all *à priori* reasoning, that a series of highly metamorphosed schists are made to overlie quartzites and limestones, which are feebly metamorphosed, if at all;—and, secondly, that the metamorphism of these upper schists themselves increases as we pass eastward, that is, ascend on the series.

This objection has sometimes been enforced in terms which seem to imply that the objector conceived that the very enunciating of such a view was the conveying of a slight to the intelligence of those who were asked to consider it. The first part of this objection falls to be considered afterwards; as to the second,—the impossibility, or improbability or irrationality of supposing it possible that the *upper members* of a series of rocks should be in the most advanced state of change,—it has simply to be replied, as regards the series of rocks which lie between Loch Hope and the Isauld burn in Caithness, that *it is the fact*. The lowest rocks have been declared to show little evidence of change; the highest is a syenite, as uniform in structure and as brilliantly crystalline in aspect as anywhere occurs.

Present circumstances hardly suffice to show how this has come to be the case. We may inquire whether past circumstances can throw any light. To do this we will retrace our steps as far as the east shore of the Kyle of Tongue. We are there on the western fringe of the tract which in its gnarled and hornblendic gneiss, wrinkled into a rough and abruptly undulating country, had assumed distinct features of the operation of alterative processes; and we are at the same time looking upon an extensive line of Conglomerate outliers, which vouch for all the low country east of them having had to sustain the burden in heat and pressure of a new formation drawn over it like a blanket.

These outliers are proximate to the western fringe of the blanket. There is here but little evidence of the blanket having been continuous along the north; there being there only one outlier, it may have been tattered at the edges and thin in the fringe. But when we pass to about Bighouse, where the rock commences to be syenitic, we have come to a part of the country where the gneiss is, along its northern shore-fringe, overlaid nearly continuously by the flags of the Old Red Sandstone.

Hugh Miller described Sutherland as a gneissic picture set in a frame of Old Red; and this shore-fringe is the north side of his frame.

But Hugh Miller seems not to have observed that the workman had left fragments of his frame sticking every here and there over the surface of his picture. Such fragments occur at Drum Holliston, to the east of Ben Ruadh, and south of Milton Moss;—deep holes in the floor of the old lake, out of which denudation has not scoured all the shingle and the silt laid down in them in Old Red times.

Had he drawn any inference from these *valley-outliers*, taken in conjunction with the *hill-outliers*,—the Griams and the range at Tongue,—and had he considered the nature of the materials of which each consists, he must have seen that the Old Red formed no mere frame;—that the outliers represent but the fragments of a formation which had once been continuous, and which had mantled at least all the lower portions of the intermediate land.

It was my fortune, along with Mr. Tait of Thurso, to light upon another outlier; and one which vouches in a striking manner for the thickness of the formation at that part of the country.

Upon the south-east side of Reinn Ratha, in the bend of the hill between its two highest summits, and at a height of 775 feet, we found several beds of white sandstone, circling round the hollow for a considerable distance. This sandstone is very similar to that seen at Isauld, Bighouse and elsewhere. I have not heard of such a rock occurring elsewhere in

Caithness, at anything like this height. A somewhat similar bed, but distinctly more argillaceous, occurs in the Dorrery Hills, at a height of about 650 feet; but as that bed dips to the north-north-west at an angle of about 4°, and as these hills are eight miles to the south-east, it must underlie the Beinn Ratha beds at a great depth.*

This section, then, goes to prove that *the syenite of the Reay district* is metamorphic, and not igneous; and that it was formed by a secondary metamorphorism of the hornblendic gneiss. This section also demonstrates the fact that the former circumstances in which the higher beds of the upper gneiss were placed were that they had been overlaid by a vast thickness of another formation; circumstances which supply pressure and heat, which are usually regarded as chief factors in metamorphic change.

Speaking of the basement beds of the overlying Old Red, Geikie writes:—"As on the southern margin of the Highlands, so here, the crystalline or metamorphic character of the older rocks was as distinct as now before the formation of the conglomerates. The metamorphism of the gneiss, quartz-rock, and other associated bands, and the extravasation of the multitudes of granite and quartzite-porphyry veins, had been completed long before any portion of the Caithness Old Red Sandstone began to be laid down."

Clearly the "metamorphic character" of the older rocks had been perfect, and the metamorphic change into gneiss and quartz rock had been completed *as such;* but many authorities hold that gneiss may undergo *a secondary metamorphism*, and be transmuted into granite and syenite. If so, all metamorphic change is not *completed* by the time that the rock has become gneiss. A secondary metamorphism may be yet before it; and it is this secondary metamorphism which is being now considered.

We are, in this consideration, at the very outset brought in face of an apparent difficulty. If the rock had not been metamorphosed into syenite *before it was overlaid by the strata of the Old Red*, how could conglomerate beds of syenitic-shingle have been formed? A ready answer is, the change *in both* may have been effected afterwards; as the agency which could alter the large mass would assuredly suffice to effect the same change upon the fragments. But, it may be replied,—not without cementation and reunion of the particles. A certain amount of this may be admitted; but a new or increased crystalline arrangement of the particles of a loose

* These Beinn Ratha beds, which are hanging on to the side of the hill like a fringe, prove that there was *here* no passage of ice from the E., S.E., or S.

fragment could hardly, in the circumstances of the case, go the length of a new crystalline protrusion from the surfaces of each fragment, so as to produce mutual interlocking, and the formation of a uniformly solid rock. Some such process,—some such protrusive interlocking,—or some such infolding on the part of the more tractable felspar, does, under greater pressures and at greater depths, result in the formation of crystalline grits, and effect the all-round re-agglutination seen in clastic rocks. Moreover, if Macculloch and Cunningham and Geikie's accounts of the basement conglomerates of the Burn of Ousdale and of the flanks of the Scarabins,—the deep depths of this formation—be read, it will be seen how great an amount of this reunion *has* been effected. All agree that it is not always possible to determine where the solid rock ends, and the once-fragmented rock begins. Geikie speaks of a felspathic sandstone near Badbea "which is so distinctly cleavable that it might readily be mistaken for a porphyry vein." Here the granulated felspar must not only have been re-agglutinated but recrystallised; and that as perfectly as the calcite in Fontainbleau sandstone. The question comes to be very much this,—Would or would not the amount of pressure and of heat, &c. which enabled the dislocated particles of a crushed rock to reassume the structure of an uncrushed rock and present a definite crystalline arrangement, suffice to enable previously crystallised particles to assume a new crystalline arrangement?

There is an observation which can be made while examining the syenitic conglomerate of Isauld, which bears upon the question. It is this; on account of a thin investing layer of mud (the condensed slime from the foam of waves), the nodules of this conglomerate have so feeble a grip of the matrix that they may be easily knocked out. If the layer of dirt be removed by a hard scrubbing brush, it will be seen that the hornblendic crystals which meet the surface are cut across, and the nodules, as a whole, are polished; and the lens discloses that it is a surface of *truncated crystals* which is polished.

But yet again has the other side to be stated;—sections of the nodule, and of the reagglutinated cement or paste show that the crystalline structure *is as intimate and as coherent* in the one as in the other; and the lines of fracture cannot in the latter be discerned.*

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* All that has been written above as to the mode of formation of the syenite of Reay is submitted by the writer as nothing more than a *consideration of the subject*,—a suggestion of a possible mode of formation. He is not to be considered as "maintaining it," or "believing it," or anything of the kind. The dogmatism of many geologic writers,—the dogmatism of all scientific theorists,—is to him an

Whether the presence of the overlying Old Red in any measure has brought about the secondary metamorphism or not, the facts remain that metamorphism may be traced in successive steps up to the present fringe of the newer rocks;—and that granitic and syenitic rocks occur along most if not every part of that fringe, for some distance back, that is, west thereof,—while it will be seen they are also exposed through denudation several miles to the east also.

If the syenites and granites of the Reay patch can be connected with the great mass of the same rock in the district of the Knockfin heights, and if that can be connected with the Ord, Loth, and Culgower mass, it is safe to argue that these also are metamorphic. Such connection might be traced, if denudation has at any intermediate spots exposed the lower rock to such an extent that it could be directly seen whether it was metamorphosed. It might also to a certain extent be indirectly traced if a local base of the series was exposed, and that was found to consist of a granitic conglomerate.

Geikie writes: *—"From Reay south-eastwards the granite and gneiss are fringed with sandy and pebbly strata, not, however, as a continuous mantle sloping away from them, but in successive beds, abutting against the eastern edge of the crystalline area, and dipping towards the north-north-west, or north-east."

This I read as impressing the fact of the overlap of the flaggy beds upon the crystalline strata; and not as intended to convey the meaning that the pebbly fringe is confined to the horizon which at the present stage of degradation happens to be the visible junction of the rocks.

Certainly if the dip of the overlying flags had been away from the crystalline rocks, the drag of its fragmented portions would have carried them further away from the shore-line where they were produced, and so have formed a more continuous mantle; and equally certainly must we expect to find that all elevated points of the very uneven bottom-rock will, if granitic, be surrounded and mantled with a granitic conglomerate.

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utter abomination. Did we, with regard to points which are *subjects for inference* and nothing more, less often read such expressions as "this is," and "this was," we might has been spared the following cruel lashing from one of the most earnest and most conscientious workers whom this country has known,—"I am not sure, not exactly sure, whether the deductions of scientific men are always such as to merit the approbation of Heaven. Of all geologic reasoning one soon gets tired. There is nothing on which the mind of the reader can lay hold, and rest. 'What is truth?' is an old question; but no man in his senses would seek for it in the books of geologists."

* Loc. cit.

We may not get down to the fixed rock at many points, but we may reach here and there its immediate envelope of conglomerate. The inference, however, is not an altogether safe one, for although conglomerates are *usually* shore or shallow water deposits, and also usually, as Giekie puts it, "notoriously local formations," yet their component blocks have frequently been swept considerable distances from the parent rock. A conglomerate of markedly distinctive character we may safely conclude does not lie far removed from its source;—witness those of Isauld, Red Point, and Port Skerry, the last of which Sedgwick and Murchison declared "could not be brought into comparison" with each other; and yet they are distant only three miles, and are possibly on the same horizon.

Having traced the syenite and syenitic gneiss southward to within about three miles of the railway at Beinn nan Bad Beg, and observed a spur of the more westerly range of the same rock to approach it somewhat nearer, I found the country to the south so swaddled up in continuous boggy moor that nothing was to be learnt. Mr. Tait, however, informed me that a crumbling granite was dug into for gravel, near Alltnabreck station, and showed me a quantity; while in passing along the railway cutting I observed decomposing granite, but certainly *in situ*, on both sides of the line between Sletill Hill and Cnoc nan Gall.

It is thus clear that the granite of Reay is continuous with that great expanse of it which stretches along the Knocklin hills southward to the quartzite of Cnoc nan Eireannaich.

A traverse was next made across the Dorrery Hills down to Dale, as Murchison states that these hills are granite; but having observed flaggy schists lying between them and the syenite of Beinn nan Bad, I had some doubts of the accuracy of the observation.

I found no trace or indication of the near presence of the older rock. The two hills show outcrops all round; these consist of thick beds of sandstones of a somewhat flinty description, with feeble layers of shivery flags. The beds dip to the north-north-west at a very low angle. They lie upon the other beds like two piles of oval "bannocks;" and I could see from their summits no beds with which I could connect them. They are the remains of upper beds seen nowhere else in this part of the county.

Having been informed by Mr. John Gunn that igneous rocks appeared at Dirlot, in the bed of the Thurso River, this locality was visited and proved in many respects a most interesting one. It is an illustration in little of Niagara, only that here the river has finished its work, while at Niagara it has not.

The river runs in a curve, and, in a general sense, from south-west to north-east. At the lower end of the curve a granitic rock, and at the upper, about a half-a-mile distant, a gneissic rock, have been faulted (?) up, bearing between them a shallow trough of some lower beds of the Old Red.

This triple structure, thrust aloft to a height of about 50 feet, had formed a dam to an old lake, a continuation of Loch More. This lake had been enclosed, and bottomed by water-dressed drift on all other sides than that of the rock dam.

Simultaneously the lake-waves urged by the south wind, and the river, mantling over the dam and running in a shallow channel, had engaged in sawing through the dam, operating from opposite sides.

From the south a sinuous off-set of the lake, and from the north a river-canon, were gradually formed, and unceasingly lengthened.

The stream clearly was working to greatest advantage, for it could always sweep away the gravel it formed, whilst the lake-waves often must have banked theirs up in front.

The river also, after cutting through the fissured and granular granite, had a much softer rock to operate upon than had the lake; hence, as will be seen, the river has accomplished about double the amount of work. At a certain stage of the double process, it had cut through the whole of the Old Red rocks, through even a basement conglomerate, before the lake had cut through the gneissic rock. Upon the remaining portion of this, both were now to operate.

The lake had been impeded, during part of its operations, by two unusually dense and hard belts of rock, the remnants of which thereafter stood in the lake as rocky islets; and it was ultimately and for long brought to a standstill in its work by the very last of the beds of gneiss.

This bed is tilted at a very high angle; it is laced through by veins of quartz; and it is backed by a thick post of a fine granular felsitic rock, which is possibly eruptive.

The lake could not attack this barrier, faced as it was by the wall of gneiss; but the stream, so soon as it had shovelled out of the trench the disintegrated conglomerate, attacked it; and this it did both by the mechanical force of its falling waters, and by sapping at it, in virtue of the solubility of the alkaline silicates of which the rock so largely consists.

The profound depth of the river at the foot of the truncated cliffs vouches for the protracted endurance of this barrier,—the removal of which left but the one belt of gneiss between the river and the lake.

An examination of the gneiss above, and a consideration of the rocky islets which now stand stranded in the turf, evidence the "gnarled" nature of this gneiss,—the inequality in thickness of its layers, and the variation in hardness and doubtless in solubility of its different parts. The islets vouch for and represent an original concretionary structure; and such a knotted concretionary structure is present in that one remaining belt which, it has been seen, had successfully resisted the sap of the waters of the lake. The concretionary portions of this belt were alone, however, destined to resist the friction of the running stream.

One of these bossy enlargements occupied the very centre of that part of this dam which faced the lake. Probably by the time that the stream had cut out the felspathic prop, the waters of the lake had curved round the harder part of the dam on either hand, so that that more enduring portion protruded southward at the centre, but was linked to both banks of the river by a dyke-like cincture.

Over these thin connecting bands the waters of the Thurso river were now falling in two cascades of equal altitude; ever deepening the gulf into which these waters fell; but also ever deepening the two notches in the dam, through which they were precipitating themselves.

It was probably at this stage that the Castle of Dirlot was built upon what was now a rocky islet.

The Castle is figured and described as standing in a lake;—it certainly stood surrounded by water, and infinitely better protected than if it had stood merely in the occasionally still waters which surround a lake islet.

Waters in front of it, waters to right of it, waters to left of it,—behind it at a depth of forty feet a boiling gulf, and at either shoulder the ceaseless sweep and plunge of those waters which had cut a river canon near half-a-mile in length:—there is not a fortress like it in the world, nor will there be until one of the rocks of Schaffhausen, or Goat Island, are fortified! But the water finished its work;—on either hand it gradually cut away the dam down to the lake bottom; and since, has cut it on one side some feet lower.

There was some attempt to form a draw-bridge, but the stronghold is now in ruins.

This is not only a most interesting spot for studying the operations of certain physical agencies, but it is the most picturesque nook in Caithness.

The section at Dirlot, commencing where the rock rises out of the clay bottom of the drained lake, is as follows.

The first seen rock is a fissile red felspathic gneiss with a north and south strike (mag.), and a dip of 75° to east. This is highly metamorphosed, and has numerous thin quartz veins at right-angles to the strike. A little eastward it contains a 4-foot bed of fine-grained pinkish granite, which has little quartz. As we pass south, though still showing a gneissic lineation, it is almost a granite; the dip here is 60°. Near the bridge, and between that and the Castle, there is the delineation of some folding in the rock, which has still a gneissic appearance, but a granitic structure.

At the Castle the dip suddenly rises to 80°, and the rock is distinctly a gneiss, but is considerably metamorphosed.

Its last thick beds contain quartz-bands, with crystallised *ripidolite*, and rosettes of either *talc* or *margarodite*. There is then a thick bed of fine granular and very felspathic rock; but I could not satisfy myself that this was intrusive, and the cause of the tilting. This bed may be 50 ft. thick.

Rough, angular, tumultuous conglomerate, about 40 ft. thick, succeeds. While formed of fragments of the underlying rocks, it seemed to me to contain proportionally much more red-felspar granite than these rocks could have afforded. The nodules are imbedded in an exceedingly rough and nodular condition, and could not have rolled long on a sea-shore. This conglomerate appears as a whole to be more metamorphosed than are the underlying rocks.

Over the conglomerate there is a thin bed of micaceous limestone, above which are ochre-coloured flags, dipping east-north-east at 25° for about 160 yards. A shallow trough succeeds; the dip at both sides of the basin being only about 7°. There are traces of vegetables in these beds.

Sixty yards below, still east of the trough, limestone is seen protruding out of the east bank of the river. The lowest visible portion of this mass, which is concretionary throughout, contains numerous imbedded fragments of granitic gneiss. Its upper portion is much rent; the rents being lined with crystallised calcite in the form *e. b.*

About 60 yards down the stream, granitic conglomerate occurs, best seen on the other side of the river; it has a very low dip to the west: then granitic gneiss with no evident bedding for 70 yards, when the same conglomerate again comes in with a reversed dip. A bed of micaceous limestone is now seen crossing the river diagonally, so that the dip is swinging round somewhat to the north of east. Over this there is a 15 ft. bed of flaggy grey limestone on the west side of the river, the dip of which apparently swings round still more to the north. This limestone is overlaid by boulder clay.

Red granitic gneiss passing into almost perfect granite has again come out from below the conglomerate on the east side of the river, and this continues down its eastern bank for some distance, when it in turn is covered by the boulder clay. It may thus be this granitic mass or spur which has swung round and thrown off the beds on the opposite side of the river.

The granite or granitic gneiss last noticed is so broken up, and altogether so unsatisfactory in appearance, that an opinion as to its nature can hardly be ventured on; its bedding is very indistinct, but it seemed to form an arch. Giving all due weight to the appearance of swing round in the newer rocks, I am still of opinion that at both ends of this section the rocks have been faulted up, though not to a great extent. The felsitic rock near the castle I admit may be igneous; still, if so, it has forced its way between the gneiss and the conglomerate without any clear marks of disturbance.

The manner in which the boulder clay at the south end of the section mantles up over the gneissic rock also prevents any decided opinion being offered as to a fault occurring there. However, as the rock is first seen on the opposite side of the river in much the same line, the existence of a fault is probable.

The whole mass has been by some writers termed granite, and it may be conceded that it is a fair example of gneiss having passed over into it; but there is nothing either in the appearance of the granitic rock, or of its surroundings, which connects it with the masses of the same rock in the west; it is here a mere local base. The occurrence and the appearance of this mass, with its beds dipping much in the same direction (though at increased angles) as do the beds of the same rock where last seen in the west, and its occurrence in the midst of the general flat of Caithness with no marks of disturbance anywhere around, strongly impressed me with the idea that a granitic or gneissic-floor stretched far into Caithness *at no great depth* below the flaggy rocks. Robert Dick evidently thought so; for, speaking of geological map makers, he writes, —"Oh bold men and daring! how gallantly have you set the truth aside! How inimitably you have run your Old Red in Caithness sheer up to the root of Morven, in defiance of every intervening obstacle. Outbursts of granite are nothing. Their iron-pointed crests (stubborn facts) standing up here and there are only trifles; yet they riddle in rotten holes your pretty pictures! Seriously, if any junction of the Old Red with the granitic rocks be as irregular and complicated as that in Caithness, it will be no easy task to delineate it correctly. It would require such an amount of time and patience, such a crossing and recrossing of the country, that few private individuals could venture on."*

It is to be remembered, moreover, that a granitic conglomerate has been observed far north on the east shore of Caithness; and this must be held as vouching for the near presence of granite.

The next portion of the country examined was the Morven, Braigh na h-Eaglaise, and Kildonan district.

The great pile of granitic conglomerate described as constituting the cone of Morven, leads to the expectation that there must be in the near neighbourhood at least the evidences of some pre-existent large mass of granite, throwing out perhaps a spur indicative of connection with Knockfin to the north-west.

* But, if the dauntless Dick,—the man who could walk sixty miles a day, or rather a night,—who had his home in the country,—would not undertake it, there could not be much likelihood that one of those "gentleman geologists" for whom he entertained so great a contempt could accomplish it in a short visit. It is all very well for Dick tauntingly to excite to the work by writing "Try it, gentlemen geologists! Try it! Away through the moors; and again through the moors," when of these moors he gives us the following as his experiences,—"In the name of all that is truly miserable nothing can be conceived more dreary than those wide stretching heaths: nor bird nor insect is there, even the hardy club-moss has acquired a yellow hue; all is lonely and melancholy. The whole breadth of the country lies before with mires and moors unutterable. To linger might be fatal should darkness overtake. 'On, on,' is the watchword! On and on through marsh and mire, ankle-deep, and deeper! Hop, step, and jump is holiday diversion compared to passing over these rude hummocks. One's frame trembles with the concussion. Try it on the hummocks! Try to pick your way by wading through the pools of water. Try to get round and between them. It is all the same. You sigh in hopeless agony. You get bemired to the knees, and long for a clear pool of water where you may have a satisfactory washing."

It might have been better service of Dick had he left some more precise jottings of his own observations on these outbursts of granite.

Several days were spent by Mr. John Gunn and myself in examining the district. Fired rock of a granitic nature was found only at two spots.

We found the fissile beds of sandstone which have so red or chocolate-coloured a cement, dipping under the Maiden Pap from the north; and, observing these to overlie an unusually rough conglomerate, which is best exposed in the north bank of the Berriedale Water under Con-na-Craige, Mr. Gunn examined that bank, and the Con itself.

He found the conglomerate to consist of very large blocks, which he described as being not so much rounded and rotten-looking as what occurs at Dirlot; and he found the Cnoc to consist of granite, disposed, as is indeed evident from a distance, in huge slabs.

The other spot at which we found granite is nearly directly north of Morven; here it occurs in the bed and banks of the Morven Burn. It is here in a state of extreme disintegration, and might almost be dug as gravel. It showed, however, an anticline, falling nearly east and west (mag.); and the bedding of the rotting rock was frequently more clearly delineated by layers of quartz.

I conceive that the conglomerate of the river bank may be possibly near the position of the basement conglomerate described by Geikie; and I fancied, from its appearance from the summit of Morven, that Ben Alisky, which lies due north of Con-na-Craige, might be granite. If so, these two hills, with possibly Ben Glass Choire, may form some of the granitic pinnacles to which Dick refers as piercing the pretty pictures of those geologists who bring the Old Red flags right up to Morven.

Should there be, or have been, a great mass of granite in this direction, the vast accumulation of conglomerate which forms this clustre of picturesque little hills may be accounted for. I cannot account for it otherwise, except by the supposition that neither the basement conglomerate nor the great cake of a similar structure, which overlies the red flags, has been derived from closely adjacent rocks.

The granitic nodules of the upper conglomerate do not much resemble any granite I know in the north. It is not like the granite of Loth; but as I conceived that that granite might change its features as it extended north, I walked over Sal Voich towards the granitic hill Braigh na h-Eaglaise. As I approached it, however, I saw no spot where the solid rock was exposed, and an examination of rolled masses swept from its foot did not support the view that the huge heaps, now hemmed in by Scarabin, Sal Voich, and the Small Mountain, had been carried from the very extensive stretch of the rock which passes southward from Braigh na h-Englaise to form the great mass of the Ord.

The bedded nature of the rock on Con-na-Craige points to a metamorphic origin; but whether this mass is, or is not, continuous with the orthoclastic and highly granitic rock described by Geikie as occurring a few miles removed,—namely, at the north-east shoulders of the Scarabins,—only detailed plotting can reveal. All that can be said at present is, that if it did not lie immediately to the north, there is little indication here of any such mass of granite as could have supplied the material of the great upper cake of conglomerate. This in Morven towers some 800 feet above the nearest and loftiest portion of those lower-rocks which must have formed the local shore line or lip of the basin in which the conglomerates were deposited.

A strong argument in favour of the almost total removal of the mass of granite which furnished the conglomerates of the little cluster of Caithness Alps, is *the markedly local character* of the conglomerates in this district. Geikie speaks emphatically on this point:—"We find them to indicate with considerable distinctness the character of the more ancient rock beneath them. Near the granite they are made up in great measure of granitic debris. Round the quartz rock they are largely composed of that material. The existence of the well-veined orthoclase-gneiss is indicated some distance before the underlying rock is actually seen, by the abundant fragments of beautifully fresh cleavable pink felspar in the conglomerates."

I shall have, in speaking of the conglomerates at some of the local shore lines in the north, to adduce further evidence of the same fact; but such evidence is not wanting even here.

The only two spots I could find where there was a visible junction between the conglomerates and the quartzite were—on the north slope of Sal Voich, and at the east foot of the Small Mountain. The conglomerate at the first consists of mica schist, granite, vein quartz, and quartzite, with a granitic paste. The rock in contact with the quartzite of the Small Mountain is a purple flaggy sandstone; this has angular fragments of quartzite, half the size of the head, imbedded in it in all positions, but lying chiefly on the tops of the slabs. While this evidence is not so strong as that of the former locality, seeing that quartzite is only one of several constituents, still as quartzite is not seen in the conglomerate of other districts, its presence here and absence in these vouches for no great amount of transfer of the other materials of this conglomerate.

That no granitic mass lay *at the immediate spot* where the clustre of conglomerate hills now stands, I think is evidenced by the arrangement of the quartzite of Scarabin and Kildonan.

This quartz rock had always, from what I had heard of it, been to me a puzzle.

Murchison figures it as dipping to the west: Geikie, as dipping to the east, under Morven; while Dr. Joass informed me that the dip was vertical. It was at least *hoped* at one time that it might prove to be the quartzite of the west, metamorphosed and brought up by the granite of the Ord;—the eastern lip of a basin which underlay all the rocks of central Sutherland. Geikie, however, makes it part of a regularly ascending series:—"Towards the southern corner of Caithness, the underlying crystalline rock is chiefly a rather fine grained pink granite. Further north this gives way to flaggy micaceous gneiss, dark greywacke, and quartz rock, which in turn, dipping gently towards north-west, are overlaid by the thick but lenticular band of white quartz rock of the Scarabin Hills. Higher still in the series comes a remarkably beautiful gneiss. Other bands of white quartz rock and dark schist occur further to the north." This leaves no question of its being but one of a series of beds, but it makes the dip *north-west.*

I found the quartzite to be disposed in two parallel ridges of hills. The southern and somewhat loftier range commences near the shore line and is nearly continuous to Sal Voich; west of this there is a considerable heath-covered depression, but it again appears in Creag Scalabsdale, and stretches through Creag nan Gearr and Cnoc Salislade on to Ben Duan.

The northern ridge comes out from under the western foot of Morven, and rises into the Small Mountain, whence it continues through Cnoc an Eireannaich (the Irishman) on to the westward.

Having walked along nearly the whole stretch of both of these ridges, I have to say that I am far from surprised at the discrepancy of statement with regard to the dip of the rock. There is much concealment from a sprinkling of loose fragments, and where the rock is fairly exposed, there is a jointed structure which dominates over the traces of bedding which the high metamorphism has alone left. This jointing in many places simulates bedding so perfectly as to engender doubt.

The rock is evidently highly metamorphosed; and is in many spots a breccia, in which the cement has united itself most intimately to the fragments which it agglutinates.

On the north-west foot of east Scarabin, and just above a rising ground called Shian, there are, at the height of 1000 feet, several beds of fragmentary quartzite. The fragments of this are cemented by a granular paste which is quite as much "vitrified" as are the fragments themselves.

The colour of this cement, however, is deep flesh-red, while the fragments are pure white. These beds dip south-east at an angle of 6°.

So very fragmentary is the appearance of the rock, that it was only the perfect union of the parts, and the finding of overlying purplish clay-grits of the sandstone dipping to the north-west, that satisfied me that this was not a breccia of the upper rock. I afterwards found that this brecciated structure was characteristic of this quartzite, though it is generally seen in what are apparently its lower beds.

In the col between the middle and west Scarabin, there are beds 8 feet in thickness, which dip at an angle of 76° to north by west. The rock is still very fragmentary. On the north side of west Scarabin, massive beds are seen with a very slight dip to the west; while at the foot of a low shoulder of the same hill, the dip is to the north-north-west at varying but generally low angles.

On the summit of Sal Voich (1322 feet) the dip is north-north-west at 42°; while at the height of 1270 feet on its north-east face, the dip is only 7°.

On the south-east slope of the Small Mountain (1585 feet) at a height of nearly 1500 feet, the dip is to east of south, at an angle of about 35°. The quartzite here is much more uniform in structure, more milk-white on the surface, and more saccharine when broken, than it is at any point before noticed. The strike-joints show a series of striæ, as if there had been motion. There can here be no question as to the dip, as the bedding is distinct.

These observations go in the main to show that the quartzite forms a trough of which the parallel ridges of hills are the lips; this trough has high dips at the outer edges, and lower towards the centre of the hollow. The conflict as to direction of dip is possibly to be explained by supposing that Murchison's observations were made on the Scarabins, while we know that Geikie's section is drawn through the eastern end of the northern ridge.

The bed of the burn, south of "The Irishman," consists of flaggy quartzite, with mica clearly visible. The rock near the Kildonan burn also shows layers of deposit; so the rock at its western limits probably passes into fissile gneiss.

The question has now to be asked,—What caused the exalted metamorphism,—a metamorphism at first sight apparently very much greater than that of the rock occurring in the west of the county to which the same name has been most unfortunately applied?

Let those who hold that the granite of the Ord is igneous find junctions.

What has again to be recorded here is, that the beds which are high in the series exhibit the highest metamorphism. Geikie chronicles still higher members of a "quartz-rock" nature, all abundantly traversed by veins of granite and quartz porphyry, or with ribbons and kernels of orthoclase.

Minerals.

It was noticed above that the gneiss of the district near Strathy was more veined than is usual. Many of these veins are to be seen near the mouth of the Halladale River, and along the east shore of the promontory. The veins themselves present a structure which is not usual. In one part pale blue vitreous quartz, in another a fine grained crystalline *mélange* of pink orthoclase with some quartz, and in another hornblende in laminated rice-grained crystals have segregated apart in bands of three or four inches in thickness. Those of orthoclase and of hornblende are geniculated, and appear to intersect the general mass, as veins within a vein.

When examined in section with the microscope the hornblende is found to be mixed with crystals of a milky-white striated felspar, probably albite. It is dark green, and highly lustrous in mass; but the section shows only pea green and blue green of pale tints, and is very feebly dichroic. Very seldom in a section which has been cut parallel to the sides of the vein are the crystals found to be sectioned transverse to their length,—the position of greatest dichroism.

It is thus seen that the long axes of the crystals lie *parallel to the sides* of the vein :—a fact which, taken along with their other features, shows that these, if originally veins of exudation of the material of the rock, have suffered a new arrangement of their constituents.

The gneiss here is highly *albitic*. Considerable masses of interpenetrating crystals, the sections of some indviduals of which show a striated surface of about two square inches, are occasionally found. Crystals of considerable size of form *m p x y t l n* occur. These are repeatedly twinned on the face *m*, and there is this peculiar feature to be observed in some of these twins—the relative thickness of the plates of the repeated twinning diminishes progressively from right to left of the twin, that is from *n* towards *e* (wanting), until it is so excessively minute, that the striation is only to be perceived by the microscope.

The general tenuity of the twin plates, and the pure white colour, are features of this albite.

Masses of it contain patches of a red granular felspar,—imbedded rosettes of *margarodite* (simulating talc),—massive crystalline *chlorite* pure in substance,—massive *pyrite*,—and *Haughtonite* of a deep brown colour.

The massive quartz rarely contains small imbedded nodules of *apatite*. These are transparent, vitreous, and of an asparagus colour. This apatite is totally soluble in nitric acid, showing no trace of cryptolite.

The granitic gneiss which protrudes at "The Red Point" contains a tortuous but nearly vertical band of very singular appearance. At the spot, both from its position and relations, and from its macroscopic aspect, I set it down as without question igneous. The appearance of a slice in the microscope, however, leads me to think that there may have been a rent in the granite, which has been filled up with a kind of grit. Still there is an aspect of very considerable alteration, if not of actual secondary crystallisation. The angularity of the fragmented portions—consisting of a striated felspar, Biotite, and quartz—is softened off. What seem to be crystals of either apatite or some acicular mineral, lie in interstices of the fragments, which these crystals sometimes have pushed aside and sometimes have apparently penetrated.

The mica slate, noticed by Geikie as seen here, is to me an unknown rock. As it contains no quartz, or almost none, it should not be termed mica-slate. A section shows a parallel arrangement of plates of rich brown mica, apparently *Biotite*, among which there are occasional rice-grain white crystals, seemingly a felspar.

The syenite of Reay has been mentioned as containing quartz, felspar, hornblende, mica, and sphene. The quartz, small in quantity, is vitreous; the felspar is white, bordered by red; the hornblende dark green; the mica, dark brown in colour, is apparently Biotite; the *sphenes* are hair-brown, and rarely well crystallised. The rock is one of very brilliant appearance.

It has been said that the rock of the neighbourhood is everywhere more or less syenitic. The perfected change generally appears in belts. One such—seen in the rock face on the north side of a great gash—which had probably been a former outlet of Loch Thormaid,—is singularly bordered by a belt of flesh-coloured felspar, fine in the crystal grain. This syenite contains well crystallised hair-brown *sphene*, in the forms $c\ n\ y$ and $c\ n\ y\ r$.

Near Loch Scye, to the north of the first geniculated bend of the stream which flows out of it, there protrudes from a covering of heather a small boss of a very singular and, I imagine, *unique* rock. It is only some 25 yards in length and breadth, and about 10 feet in height. It has to a small extent decomposed into a brown granular soil, and this, from the lime and alkalies which it contains, has induced the growth of grass, so that the spot is visible from a distance on account of the contrast it affords to the brown of the surrounding heather. This boss is on all sides surrounded by syenitic gneiss.

The rock has a most singular aspect. It does not weather on the surface to the smallest extent, nor is it acted on by vegetable growth; so that portions from which the turf is newly peeled, and portions which have been exposed for some years, are alike as fresh in appearance as is a new fractured surface.

That surface spangles and flashes in the sun just as would a quantity of silver or bright steel buttons sprinkled thickly on a dark green sward.

Examined macroscopically, the silver buttons are seen to be plates of *talc;* the continuity of these being broken up by a knitted lineation which produces a surface-structure similar to that of shagreen.

The dark green material consists of foliated crystals of augite.

The talc crystals lie so close-packed throughout the rock in every position, that broken masses are found to have the fracture of their surfaces determined in almost all directions by the cleavage of the plates of this mineral. Certain points, however, show the interrupted fracture of the augite; which, from the tenuity of the plates of talc, must be present in larger proportion than outward appearance would suggest. The unaided eye discerns no other ingredient; but the lens discloses rare crystals of pyrite, and apparently a minute quantity of magnetite. The plates of talc are from one to two inches in magnitude.

When examined in the microscope, cut parallel to the foliation of the talc, it is found that this mineral is not everywhere transparent, but is for the most part brown and clouded, to opaque. Apparently the flour emery employed in the grinding has been forced between the folia of the talc. As the portions which remain transparent give a pearly reflection somewhat better than do those which are brown, there can be no question that the true appearance of the latter has been interfered with in the darkened parts.

The talc polarises with pale grey tints, and in cross section with brilliant tints which are disposed in an arrangement similar to that of a riband. The augite has occasionally a thin envelope of serpentine, which very rarely penetrates its rents. Ill-defined olivine is totally changed into obscurely fibrous serpentine. This shows no olivine rents, and is occasionally blotched with nearly opaque granules. Much magnetite is present everywhere. I could find neither felspar nor quartz.

The following statement of the composition of the rock was sent me by Mr. Hugh Mill, as the average of three analyses which had been conducted by him in the Laboratory of the University of Edinburgh. The analyses did not vary much as regards any ingredient, except the alkalies. These in one analysis were as high as 4·85 per cent. :—

Silica	42·10
Alumina	3·38
Ferric Oxide	8·27
Ferrous Oxide	2·13
Manganese Oxide	·70
Lime	3·77
Magnesia	30·65
Soda and Potash...	1·90
Water...	7·73
	100·53

The magnetite explains the ferric oxide ; but as I could find no felspar I am unable to explain the presence of alkalies, and the water seems high for a mixture of such nature. To the eye the rock looks like a mixture, in equal amounts, of talc and augite. In its mode of occurrence it appears to be igneous.

Immediately to the north-east of Achavarasdal Lodge there is a very considerable deposit of iron ore; this has been previously referred to under the name of limonite. Having had an opportunity of thoroughly examining the locality and of analysing the ore, I find that it is *Göthite,* and that it occurs in the form of a bed, or more correctly of two beds.

Somewhere about 100 yards immediately to the west, the gneissic structure of the rock is faintly evidenced by a linear arrangement of the felspar; at the spot where the bed occurs it is a true syenite.

Three pits, at an extreme distance from one another of 300 yards, have been sunk upon the ore, to a trifling depth. So far as exposed, both rock and ore are in a state of complete smash, The rock is also considerably disintegrated, but not to such an extent as to account for the presence of so large a mass of iron as a mere result of the decay of the Biotite which the rock contains. Indeed, it cannot be said that the Biotite is altogether changed.

The strike of this bed of ore is north-east by north; which is very much that of the gneiss of the knolls lying in near proximity towards the south-west.

So far as the smashed condition of the ore entitles one to speak, it is not in the form of a vein. The dip of the sheet of ore, about 46°, is somewhat greater than that of the adjacent hill.

The lower portion of the bed is in the form of massive ore with much disseminated quartz. Over this there is a layer of powdery red and yellow ochre, the latter possibly *xanthosiderite*. A thick band of ore follows,—cavities in which are lined with mamillations of radiated ore. Certain of these cavities are lined by acicular crystallisations in downy tufts. These have considerable beauty from their velvet-like surface, and rich orange-brown colour.

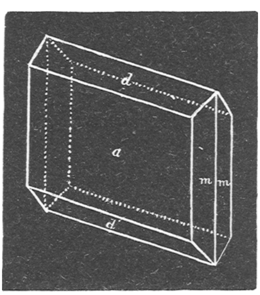
Pellucid *rock crystal* is beautifully capped and penetrated by feathery plumes of the Göthite.

An ochreous clay overlies the solid ore; and over this, with some feet of intervening rock, there is a thin vein of the same ore.

The analysis yielded—

Ferric Oxide	88·662	88·69
Alumina	·336	
Ferrous Oxide	·663	
Baryta	·11	
Lime		trace
Magnesia		·30
Sulphuric Acid	·06	
Soluble Silica	·67	·93
Insoluble Silica	1·112	1·83
Water	8·8	8·25
	100·353 (H.)	100·

The second analysis was handed to me as having been made by Dr. Thomas Anderson.



The only mineral I have found crystallised in the cavities is *baryte*. It is in minute crystals of the form figured. It also occurs in thick veins, with cockscomb crystallisations.

Occasionally the acicular tufts of velvet-like crystals above referred to are disposed on the reniform surface of the Göthite in so segregatory a manner as to suggest that they may be a different substance.

At Gleann Thorcaill, the head trench of the Sandside burn, about five miles to the south of this locality, and nearly in the strike of this bed, there is either a fault or a crushed syncline of the rock. It is here a quartzose fine grained granite, and it carries traces of pulverulent *psilomelane*.

Busby, in his "Minutes and Observations in the course of a Mineralogical Survey of Caithness," writes:—"The channel of the (stream flowing from) Loch of Clachningill (LochnanClach Geala) is composed of decomposed granite, chiefly white quartz. Found at rear of the above, the black oxide of manganese of considerable purity imbedded in decomposed red granite; it is an irregular vein." As this lake is less than a mile from Gleann Thorcaill this may be the same vein, or even the same spot may be referred to.

Busby also states that the red granite of the Ord contains "several large veins of the spar of lime, the crystallisation is thomboid bevellio," ? rhomboid bevelled; (*r v* or *r w* λ).