THE GRANITIC AND SCHISTOSE ROCKS OF NORTHERN DONEGAL. 221

24. *On the GRANITIC and SCHISTOSE ROCKS of NORTHERN DONEGAL.*

By C. CALLAWAY, Esq., D.Sc., F.G.S. (Read March 11, 1885.)

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In my paper * on "The Age of the Newer Gneissic Rocks of the Northern Highlands," I suggested that a study of the old rocks of Ireland would probably aid in connecting the Scottish types with those of South Britain; and, in the summer of 1884, I visited the north of Ireland to ascertain how far my suspicion was justified by the facts. As Professor Hull had announced the discovery of Laurentian gneiss in the same area, I included the relations between this group and the schists in my investigation. A continuance of stormy weather prevented the completion of my plans; but I obtained satisfactory proof of the nature and relations of the chief granitoid mass, and collected partial material for the study of the schistose rocks. As the result of a month's work, I came to the conclusion that the schistose rocks of Northern Donegal were separable into two groups, and that the so-called "Laurentian" was merely a mass of granite intrusive in the older of them.

The President (Professor Bonney), with his usual kindness, has examined fifty-five microscopic sections of Irish rocks, and he permits me to use at my discretion the rough notes which he has furnished. It is to be regretted that pressure of other work has prevented him from undertaking a more elaborate investigation.

* Quart. Journ. Geol. Soc. Aug. 1883, p. 355.

I. THE GRANITE.

1. STATE OF PREVIOUS OPINION.

Mr. R. H. Scott, F.R.S.*, claims a metamorphic origin for this rock.

Mr. E. H. Blake † takes the same view.

In a subsequent paper ‡ Mr. Scott offers a theory of the origin of the granite. He considers that all the rocks of the region were originally stratified, but that, by subsequent metamorphism, some of the beds were altered into granite, some into gneiss, and some into other kinds of rocks, without much altering the relative positions of the strata.

The Rev. Dr. Haughton, F.R.S.§, regarded the granites as "being stratified and not intrusive, and therefore varying considerably in different localities according to the beds from which they have been formed by the metamorphic action."

Professor Hull || accepts the metamorphic theory of the granite, but regards it as of "Laurentian" age; and the schists which follow it on the east and west are referred by him to the "Lower Silurian," the structure of the district being, in his view, on the type of the Highlands of the north-west of Scotland. This writer agrees with previous observers that the granite "contains beds of crystalline limestone," and that it is "foliated and bedded;" and he adds that "the upper beds which occur along the south-eastern margin are largely interstratified with hornblendic and micaceous schists."

2. THE GRANITE PROMONTORY.

The granite appears in several patches in Donegal. The chief area is a squarish mass sending off from its north-eastern corner an arm or promontory, about fourteen miles in length, and in breadth tapering from six miles to three. The arm strikes nearly north-east. Disappearing under the schist near Glen, the granite reappears in Dunaff Head, and again in Malin Head. These outlying patches are precisely on the north-easterly prolongation of the strike of the promontory. There is distinct foliation in the promontory; but I am not aware of any in the main mass or in the outlying patches to the north-east. This promontory will therefore receive our chief attention.

3. RELATIONS BETWEEN THE GRANITE AND THE ADJACENT SCHISTS.

The evidence for the sedimentary origin of the granite adduced by Prof. Hull, agreeing, as it did, with the observations of previous observers, left me in little doubt that I should find the old gneiss in

* Journ. Geol. Soc. Dubl. vol. ix. p. 285.

† *Ibid.* p. 295.

‡ Report Brit. Assoc. 1861.

§ Quoted in the 'Memoirs of the Geological Survey of Ireland' (105 and 114, p. 9).

|| Trans. Roy. Dubl. Soc. ser. 2, vol. i. (1882).

Donegal. The revelation made by the rocks themselves was both a surprise and a disappointment. I have visited Prof. Hull's most critical sections, and some districts not described by him.

Fig. 1.—Section in Barnesbeg Gap and on Lough Greenan.

Section in Barnesbeg Gap (fig. 1, north-west end).

It was in this wild ravine, near a wooden barrack erected for a body of soldiers appointed to protect a cottage opposite, that I first touched the granite. The rock surfaces on each side were well rounded by ice-action, and the colouring and weathering suggested some bits of Hebridean scenery in Scotland. The first blow of the hammer destroyed my preconceptions. The rock was grey in colour, uniform in texture, consisting of a well-crystallized, coarse-grained aggregate of quartz, black mica, and felspar, mostly orthoclase. There were no signs of bedding, and, but for a roughly linear arrangement of the mica, I should have declared I had before me as typical a granite as I had ever seen.

Towards the junction with the schists at the south-eastern end of the Gap, the granite grows lighter in colour and less coarse in grain. At the entrance of the gorge we reach the important part of the section. Masses of schist lie between masses of granite, and at a hasty glance the two appear to be interstratified. I first came upon a thin band of well-crystallized mica-schist, dipping at a moderate angle to the south-east, with granite on both sides of it. A little further on, I reached hornblende-schist, the hornblende (consisting of small black sparkling crystals) predominating over the quartz. This rock at first was rather puzzling. It had no regular dip, but rose vertically like a dyke, with irregular sides, as if it had thickened abruptly downwards. But this diorite-like mass was distinctly foliated, and I at first thought that I had before me a case of pressure-foliation in an igneous rock. The foliation, however, was not parallel to either of the margins of the mass or at right angles to the direction of the thrust which had contorted the region, but sloped at a medium angle to the south-east, in accordance with the prevailing dip of the schists outside the granite.

Grey orthoclase granite appeared on the other side of this schist, and fifty yards further on I came to a second mass of hornblende-schist, succeeded by several others separated from each other by granite, which sometimes penetrated the schists in veins. The granite between the fragments of schists was similar to the variety at the barrack, but was less coarse, and a linear arrangement of the mica was not apparent in it. The last rock seen in this traverse was a glistening mica-schist, which seemed to lie outside the granite.

From this examination it appeared to me perfectly clear that I was on the margin of a mass of intrusive granite. This rock, homogeneous in texture and composition, lay between irregular fragments of schist, which displayed a foliation-dip to the south-east. The mica-schist being very fissile, the granite had passed up foliation-planes; but the hornblende-schist is very tough and comparatively non-fissile, so that the planes of least resistance are probably joints. There was not the slightest indication of a melting-up of the schist, the lines of junction being quite sharp. But if a general fusion had taken place, some of the hornblende-schist must have undergone the process; for its foliation-planes end abruptly against the granite. We can hardly believe, however, that a rock which is nearly all hornblende could have been melted up into a highly acidic granite. The foliation in the granite I will discuss further on; and will simply remark here that, on the metamorphic hypothesis, it is singular for granite in mass to be foliated, while the narrow bands between the schist-fragments show no trace of foliation.

Section on Lough Greenan (fig. 1, south-east end, p. 223).

Leaving the Gap, I now struck to the north-east along the eastern slopes of the granite mass of Crockmore, and in one place collected beautiful hand-specimens showing the contact between granite and schist. I then attacked the scarp which overhangs the pass at the south end of Lough Greenan. The lowest rock seen was hornblende-schist, with a moderate S.S.E. dip, overlain by a lead-coloured, friable mica-schist. We next come, after a short interval, to a band of blue compact limestone, slightly micaceous, dipping E.S.E., passing under hornblende-schist, these strata forming the steep escarpment overlooking the south-eastern side of Lough Greenan, and being surmounted by the quartzites and associated strata which rise into the steep hills overhanging the eastern margin of Lough Salt.

Prof. Hull places an unconformity between the lead-coloured schist and the limestone, assigning the former, with the underlying hornblende-schist, to the Laurentian, and the limestone and associated rocks to the Lower Silurian. There is certainly a discordance, as is indicated by the dips in my section; but such local variations of strike occur too often in this and other disturbed regions to justify so important an inference. The strike in this district, a little further from the granite, is to the S.W., and therefore not agreeing with either of the strikes in the section, but coinciding

with the trend of the schist within the granite of Barnesbeg Gap. The lithological evidence is decidedly against the creation of two formations. The hornblende-schist of the so-called Laurentian is specifically the same as that above the limestone, and cannot be distinguished in hand-specimens from rocks on the other side of the granite, near Creeslough, which are placed by Prof. Hull in the Lower Silurian. The lead-coloured schist, too, may be matched over and over again in the supposed newer series on both sides of the granite promontory. It should also be observed that these schists, hornblendic and micaceous, are fine-grained and thin-bedded, thus differing widely from the massive gneisses of the Laurentian, whether in Scotland, the Malvern Hills, or the Wrekin. On the whole, I can see no reason of any serious weight for separating the schists in or near the granite from the ordinary schistose rocks of the region.

Fig. 2.—Section West of Croagh.

Section west of Croagh (fig. 2).

Coming to the western side of the granite promontory, we find a second junction between the granite and the schists on the main road west of Croagh Hill. The breadth of the granite, where it is crossed by the road through Barnesbeg Gap towards Creeslough, is about three miles. Approaching the western margin of the promontory from the east, we observe that the foliation in the granite becomes very marked. In one spot there is a clear dip to the S.E. at 80° . This rock is mainly composed of felspars, one of which is orthoclase, and black mica. The foliated structure is seen, not only in a linear arrangement of the mica, but also in a distinct striping of light and dark bands, corresponding in direction with the strike of the mica, the dark colouring being due to the abundance of that mineral.

A few yards beyond we come to the junction. The rock next to the granite is a thin-bedded, flaggy, grey schist, containing a whitish mineral, which Prof. Bonney is disposed to think hornblendic. I would suggest that the occurrence of this mineral may be due to the presence of granite in the vicinity of limestone, of which there are signs near at hand. A granitoid material is also seen to penetrate a rock which Prof. Bonney considers pyroxenic. I am inclined to regard this as a case of intrusion of granite in limestone, with subsequent chemical reactions. In Prof. Bonney's opinion, some of the

Fig. 3.—Section North of Dunlewy Church.

felspar has probably been converted into saussurite, a change which would, of course, support my suggestion; but he does not consider that the slide examined by him displays evidence of a junction. However, I leave my hint to be confirmed or refuted by further observation. Except in the immediate vicinity of the granite, the rocks are ordinary mica-schists, at first dipping away from the granite, and then bending up to the N.N.W., in accordance with the usual dip of the rocks west of the promontory. These schists are also contorted on a smaller scale, and penetrated by veins of quartz and a coarse granite. The section thus appears to furnish another example of the intrusion of the granite.

Section in the road north of Dunlewy (Protestant) Church (fig. 3).

This locality is also at the western margin of the granite, but ten miles further south. Commencing east of the road, where it begins to turn round to the north, we leave the granite, which is coarsely crystalline and unfoliated, and, on the other side of the road, come to mica-schist, containing a mineral which Prof. Bonney thinks may be allied to kyanite, and he agrees with me that this mineral may be the result of contact-alteration. This rock dips north-westerly, and is followed by quartzose schists highly contorted, and penetrated by a vein of fine-grained granitoid rock. Then follow in succession friable schists, a thin band of limestone, and lead-coloured mica-schists, repeated again and again by folding and fracture till

we come to the Errigal quartzite. The secondary contortion is at some points very great, and the numerous disturbances render the reading of the ground somewhat perplexing. The schists and limestones are penetrated by several quartz veins and a dyke of dolerite. Similar schists, especially the quartzose and lead-coloured varieties, occupy much of the ground as far west as the sea, and crystalline limestone also occurs near the coast. In fine, I can see no reason whatever for separating the schists east of Errigal from those to the west, and assigning the former to the Laurentian system. There may be a fault between the Dunlewy schists and the Errigal quartzite; but this does not afford sufficient ground for evolving a second formation out of a section which, from Dunlewy to the Atlantic, displays alternations of similar rocks.

The three sections thus described supply the main evidence which has been relied upon for proving that the granite has resulted from the metamorphism of sediments, that it is associated with certain schists and limestones, supposed to be of the same age, and separated by a fault on the west and an unconformity on the east, from similar schists and limestones which have been called "Silurian." The facts adduced by me appear to favour the hypothesis that the schists on both sides of the granite are of (approximately) the same epoch, and that the granite has been intruded as an igneous mass. Further evidence of the igneous origin of the granite is supplied by the descriptions which follow.

Ground round Bunbeg.

At Dunlewy (fig. 3) the western margin of the granite turns round and strikes to the west for several miles; but towards the coast the granite projects to the north in a second tongue, near the base of which Bunbeg is situated. The rock about this village is coarsely crystalline, and, so far as I could ascertain, destitute of foliation. Several masses of quartz-schist, some of, perhaps, an acre in area, others mere hand-specimens, are immersed in this granite, which also sends veins into the schist, and sometimes overlies it. Limestones also occur, and have undergone great alteration near the igneous rock. A very interesting combination of facts is seen in a low, flat-topped elevation, situated near the "e" of "Bunbeg" on the Ordnance Map. The western escarpment presents a face of bedded limestone, highly crystalline and very full of garnets, some seams being crowded with large, well-formed, brownish-red crystals, while others consist of garnet-rock. The bed at the base of the section, in presumed proximity to the granite, is a *mélange* of minerals, amongst which Prof. Bonney recognizes garnet, more than one member of the hornblende group, and perhaps staurolite. I have little doubt that these minerals are produced by the contact of the granite. Rock is covered between the limestone and the eastern end of the monticule. Here quartz-schist crops out in a low cliff, at the top of which a vein of granite is very clearly seen to penetrate and overlie the schist. As the limestone and schist both dip at a low easterly angle, there is probably a fault between them,

and this weak point may have permitted the intrusion of the granite. The schists of this locality have usually an easterly dip, and are frequently intensely contorted.

That this granite is intrusive is perfectly certain, and there is no doubt that it is continuous with the promontory of gneissic granite.

Granite of Dunaff Head and Malin Head.

South-east of Dunaff Head rock is well exposed on the flat bare shore. For some miles to the S.E. the region is occupied by quartzite; but north of Lenan Head granite comes in, appearing amidst the quartzite in irregular masses and sending out veins. On the same strike, to the N.E., granite is exposed on the south side of Malin Head, and is clearly intrusive in the quartzite of the district.

Prof. Bonney has examined microscopic sections of granite from all the localities described, except the last, and he is of opinion that they "exhibit traces of an original igneous structure, which appears to have been much modified at a later time."

4. THE FOLIATION IN THE GRANITE.

It seems to have been generally assumed that the presence of a gneissic structure in a rock is a certain proof of its metamorphic origin; but this opinion has never been justified by facts. There is no *à priori* reason why an intrusive igneous rock should not be foliated. Of late years we have acquired larger views of the effects produced by pressure. A lateral force which could thrust regional masses of Hebridean gneiss over newer rocks to the breadth of a mile, and squeeze a north-western into a north-eastern strike along a line of many miles in length, may well be capable of producing a foliated structure in a band of granite some three or four miles in width. Certain parts of the Donegal granite mass are incontestably intrusive in the schists. Which view, then, must we adopt: that the granite is igneous, with a gneissic structure subsequently superinduced; or that it was originally part of a mass of bedded sediments, some portions of which have been heated to the point of fusion? As the question is one of considerable theoretical interest, a careful review of the evidence is desirable.

Arguments for the Metamorphic Origin of the Granite.*

- (1) The Granite is "gneissose in character."

This fact I hold to be consistent with the igneous theory.

- (2) It occurs "in thin beds corresponding to the bedding of the stratified rocks of the district."

If this means that the strike of the foliated granite corresponds with the strike of the district, it is sufficient to say that this would also be the case on my hypothesis. But if these words imply that the granite is truly stratified, I reply that, in the typical section at Barnesbeg Gap, the granite lies between the masses of schist, not in beds, but with the irregularity of an intrusive rock.

- (3) In the granite oligoclase occurs associated with quartz. This

* R. H. Scott, Journ. Geol. Soc. Dubl. vol. ix.

would be "hardly possible," if the rock had been in a "state of simple fusion." But the granite has been in a state of fusion on either hypothesis, and yet the oligoclase in the presence of quartz has declined to pass into a more acidic felspar. Whether or not the granite was once stratified rock does not matter if fusion has actually been produced.

But the evidence which Mr. Scott most strongly urges is that—

(4) "Far within the limits of the granite" occur "isolated patches of metamorphic rock, not lying *on* the granite, but *in* it."

This fact is in perfect harmony with the igneous theory. Why should not fragments of rock sink down into a molten mass? Or why should not fused matter rise up round masses of schist? If the granite was squeezed up through rocks which were traversed by faults and joints, it would probably carry up some masses before it and become entangled amongst others. The former would be the first to be removed by denudation, so as to expose the subjacent granite, amidst which fragments of the stratified rocks would be preserved.

The Author's Objections to the Metamorphic Hypothesis.

(1) If the granite is simply a metamorphosed portion of a mass originally sedimentary, we should expect to find it graduating into the adjacent schists and limestones. But I have been unable to detect the least evidence of such a passage. The numerous junctions I have seen have been quite distinct, or there has been a slight welding together of the two rocks. Prof. Bonney has microscopically examined sections selected by me as showing the contact of granite with schist—one from Bunbeg, where the granite is unfoliated, and one from Barnesbeg Gap, in the foliated region—and he quite agrees with my interpretation. At Bunbeg pieces of schist no larger than a man's hand are immersed in granite, yet their margins are quite sharp. This surely would be an impossibility if these fragments were merely the unmelted remnants of a series which had undergone partial fusion. On the other hand, these appearances are not uncommon where igneous rocks have been intruded into stratified rocks. For example, on the same coast, near Horn Head, the diorite at one spot is crowded with fragments of contorted schist.

(2) A uniform mass of granite could not have been produced by the fusion of a varied series of strata, including quartzite, quartz-schist, micaceous and hornblendic schists, and limestones. There would surely be bands in the granite corresponding with the materials out of which they were formed. The chemist, too, would be curious to know how granite could be produced by the melting of quartzite, or limestone, or hornblende-schist. I admit variations in the granite, but these give no support to the metamorphic hypothesis. Thus, the granite of Barnesbeg Gap, associated with micaceous and hornblendic schists, is mainly composed of quartz and orthoclase; while in the granite of Dunaff Head, surrounded by quartzite, plagioclase predominates, and there is a fair amount of mica.

Possible Explanations of the Gneissic Structure.

There appear to be three possible causes of the foliation:—

(1) Flow-structure. The foliated granite may be regarded as a huge dyke. As the molten rock was being slowly forced up the great fissure in which it lies, its motion would be more rapid in the middle than at the sides. This might give rise to a vertical fluxion-structure, on which foliation was subsequently induced.

(2) Pressure during consolidation.

(3) Pressure after consolidation. This hypothesis may take two forms:—

(a) Cleavage with superinduced foliation. The gneissic structure is nearly vertical and as regular as cleavage. We know that rocks may be cleaved, and that cleaved rocks may become foliated. In this case there would be two periods of crystallization, the first when the granite consolidated, the second when there was a redeposition of minerals in accordance with cleavage-planes.

(b) Pressure-foliation. Prof. Bonney, from microscopical examination, informs me that the granites exhibit signs of great crushing, by which the original structure has been "much modified." I have already (p. 228) suggested that the foliation is probably due to lateral thrust; but I am not prepared, without a more elaborate study of the ground than I was able to give, to pronounce an opinion on the exact mode of operation. The evidence for the existence of the required pressure will be more satisfactorily estimated when the schists have been described.

II. THE SCHISTOSE ROCKS.

These may be separated into two groups:—

(1) *Lough-Foyle Series*.—Semicrystalline: consisting of quartzose grits; quartzite with distinct traces of fragmental structure; fine-grained schists, some of them black; shaly and slaty beds; crystalline limestone and compact dolomite. Usual dip north-westerly. Well exposed in that part of the Inishowen peninsula which lies west of Lough Foyle. The following extracts from Prof. Bonney's notes will be seen to be confirmatory of the above description:—"schistose rock;" "might even be a phyllite;" "fragmental structure still conspicuous;" "schistose slate;" "fragmental structure very marked."

(2) *Kilmacrenan Series*.—Crystalline: consisting of true quartzites, quartz-schists, mica-schists, hornblende-schists, schists with hydromagnesian silicates, and crystalline limestones. Dip south-easterly. Occupying a large part of the district or barony of Kilmacrenan, lying to the west of the village of that name. Prof. Bonney, in reference to these rocks, writes:—"I should quite agree to the idea of these, or the bulk of these, being old rocks. The majority, however, do not seem of the oldest type." Some of the most typical varieties are described by Prof. Bonney as "mica-schist," "idem, with garnets," "idem, with probably some chlorite or hornblende," "hornblende-schist," of "the Lizard" type, "idem, with garnet and

chlorite," "crystalline limestone, with garnet," "calcareous schist, with some quartz and mica."

Some account of the distribution and relations of the above groups will be given in the following paragraphs.

Section from Londonderry to Dunaff Head (fig. 5, p. 235).

This line passes from S.S.E. to N.N.W. across a band of about 20 miles in breadth, striking to the S.W. The Lough-Foyle series occupies the south-eastern side of the zone, and is 13 miles broad. The remainder of the breadth is covered by the upper part of the crystalline group.

Drumahoe Quarry (two miles E.S.E. of Derry).—The quarry-section is now partly obscured by débris, and rock is better seen in and near the river-bed, where a fine-grained limestone, 3 ft. thick, and some slaty bands, dip E.S.E. at 80°. Near the water-mill, a little lower down the stream, are fine-grained bluish-grey schist and altered quartzose grit, rather contorted, dipping at a low angle to the N.W. The schist is of the peculiar type so characteristic of the hypometamorphic rocks of Anglesey. At first sight it might be taken for shale or slate; but looking more closely we see the surfaces of the laminae glistening like the folia of a true mineralized schist. This view is confirmed by the microscope. Prof. Bonney considers the rock a schist of a late type, in which the fragmental structure is still conspicuous. I call special attention to this variety, because it predominates throughout the newer Archæan rocks of Ireland, wherever I have seen them.

Londonderry.—Near the east end of the Foyle Bridge there is a large quarry of normal hypometamorphic schist, dipping N.W. at 60°. On the west side of the river, in the Strand, the rock is a quartzose grit, separated into thin seams by folia of mica, and is highly suggestive of the "foliated grit" of Melin pant y Gwyda*, in Anglesey. About two miles north of the city, east of Summer House, there is a good exposure of similar schistose grit in a small quarry. The beds are puckered into gentle undulations, such as might be mistaken for ripple-marks. A mile and a quarter due west of this section, in some large quarries on the Buncrana Road, is an extensive exposure of rock which differs from the preceding only varietyally. The gritty materials, consisting of quartz and felspar, are very clearly fragmental. The schist is very fine-grained, often occurring as mere flakes in the grit, sometimes in regular seams. The dip of the rocks hitherto examined west of Londonderry is usually N.N.W.

Cashel Hill.—This elevation, four miles N.W. of the last locality, is the spur which terminates Scalp Mountain on the S.W. The rock is of grit, arranged in thin regular seams, and little of the schistose material is present. The bedding, a little contorted, dips N.N.W. at from 30° to 60°. This grit passes down through gritty beds with schistose interlaminae into intensely contorted satiny schist, in folia so thin that, but for the micaceous lustre, we should

* Quart. Journ. Geol. Soc. (May 1881), vol. xxxvii. pp. 222, 234.

call it shale. Some of it is black. Lower down the slope, in the quarry west of Burnfoot, we have grit and black schist closely interfoliated, the folds being reflexed to the S.E. Some of the grit is massive, and its contortion can sometimes only be determined by observing the behaviour of the associated schists.

Shore north of Fahan Station.—At Fahan we reach Lough Swilly, and our section keeps to the eastern margin of this picturesque arm of the sea up to Dunaff Head. Rock is well exposed on the shore, grits and black schist being still the prevailing types. Some of the latter is still more modern-looking than at Cashel Hill, and Prof. Bonney agrees in thinking it is not far removed from phyllite. The beds stand at very high angles to both N.W. and S.E., and are sometimes vertical. The evidence of lateral thrust is very pronounced. The strata are not only crumpled into numerous folds, but in some places are crushed into masses of angular fragments thrown together with their divisional planes lying at all angles. This pressure is not evenly distributed. For example, the grit in one place is normal, differing only from a Palæozoic grit in the mineralization, entire or partial, of the matrix; but at a little distance, where the crushing and contortion are more intense, the particles of grit are flattened, and strong folia of a silvery mineral (? talc) come in between them, so that the rock approaches a schist in structure. It is not difficult to understand that if the squeezing process were carried still further, the fragmental structure might be entirely obliterated, and a true schist be formed. This suggestive case is not unlike examples I have already described elsewhere*, where the thrust of the Caledonian gneiss in Sutherland has converted quartzite into quartz-schist. The overthrust in this locality is to the N.W., and the same fact is to be observed at Buncrana, about two miles further on.

I did not see any limestone in the section between Derry and Buncrana; but the Culdaff limestone is on the strike of the rocks east of Buncrana, and pieces of it, as well as of a similar variety at Illies, near Buncrana, have been kindly furnished me by Mr. R. J. Cruise, of the Irish Geological Survey. These limestones are dark bluish-grey in colour, and are intermediate in degree of crystallization between the Drumahoe limestone and the limestones of the crystalline schistose series.

Between Buncrana Bay and Ballynarry Bay.—We commence this part of our section at Ned's Point. Again we come upon the black schist. It is here associated with a hard quartzose grit and a quartzose micaceous schist. The dip for some distance is to the N.W. at 20°–30°. The same beds are repeated again and again in a succession of reversed faults of the structure represented in fig. 4, a bed of grit, underlain by a seam of the black schist or phyllite, resting unconformably upon a coarse schistose rock, dipping at a high angle in the same direction. Sometimes black schist is wanting, and the grit is in contact with the coarse schist. In one place a seam of the last-named rock is bent into a series of V-shaped folds,

* *Geol. Mag.* Dec. 3, vol. i. p. 221.

while a bed of grit in contact with it remains uncontorted. The grit-bands and coarser schists occupy the shore to Porthaw. Here the dip changes to S.E., with much contortion and frequent intrusion of quartz-veins.

Fig. 4.—*Thrust-plane*.
S.E. N.W.

At Hegarty's Rock the strata are largely of quartzose grit. Quartzite comes in for the first time. It differs from the quartzites of the crystalline series in presenting even to the naked eye evidence of fragmental structure in the occasional occurrence of angular grains of quartz. The strata of grit and quartzite dip at a low angle to the N.W., and each bed is sharply cleaved for a distance of several inches from the surface inwards. North of Hegarty's Rock, the succession is clear, the grit being overlain by the quartzite, and the quartzite by the fine and coarse schists, the whole undulating at a gentle angle to the N.W. The beds then lie in a low broad anticlinal arch; but the oblique foliation of some of the seams of schist points to the continued action of lateral thrust. Towards Ballynarry Bay the strata begin to rise to the N.W., and the outcrops terminate at the sands of the bay in a considerable thickness of quartzose beds and thin schistose bands, the whole dipping to the S.E.

This brings us to the north-western edge of the subcrystalline band. We have seen that at the eastern side fine-grained schists and schistose grits prevail. West of these we have more massive grits and black phyllites or schists; and further west similar types are again seen, associated with quartzites and quartzose schists. The state of alteration is tolerably uniform from east to west, the beds which exhibit the least crystallization being perhaps the black schists, occurring most conspicuously in about the centre of the traverse. The dip being usually to the N.W. and N.N.W., the thickness might seem to be considerable; but there appears to be frequent repetition by both folding and faulting, the folds at first being thrown over to the S.E., then to the N.W., and again to the S.E. This alternation of thrusts would be explained if we supposed each series of folds whose axes dipped in the same direction to occupy one slope of a large monocline. Though the thickness of strata may not be great, there is sufficient variation from east to west to show that the same beds are not repeated throughout the traverse. With my scanty knowledge of these rocks, I cannot say what is the true order of the strata; but I am disposed to think that the succession rises from west to east. The beds at the western margin of the subcrystalline band dip away from the metamorphic series, but I do not ascribe decisive weight to this evidence.

Between Ballynarry Bay and Dunree Head.—The bay is about half a mile wide, its south-eastern boundary being formed of the

rocks just described, while along the north-western side runs a wall of strata of the metamorphic group. The only rock which appears in the interval is a mass of coarse diorite, which projects from the sands about midway between the two schistose series. In this line of section, then, the two groups are separated by igneous rock, apparently an intrusive mass.

Continuing the section, we find the beds for the first half-mile lying anticlinally, and consisting of quartzites of the older type, quartz-schist, mica-schist, and subordinate bands of chloritic or talcose schist. We then come in succession to quartz-schist with garnets, talcose or chloritic schist, and a considerable thickness of quartzose schist. A mass of diorite next appears. Beyond this is a beautiful silvery schist, underlain by a black variety, much more strongly foliated than the black schist of the younger group. Then, for a considerable distance, the prevailing rock is green micaceous and talcose schist*. These rocks I followed to within a mile and a half of Dunree Head. The dip of most of the above schists is to the S.E., and there is frequent contortion. I was prevented from visiting the section beyond; but the rocks on the same strike to the N.E. and S.W. are quartz-schists.

From Dunree Head to Dunaff Head.—Dunree Head terminates the quartzite range over which the pass of Mamore is carried. It is composed of easterly-dipping quartzite, and the same rock forms the precipices which overhang Lough Swilly for nearly three miles to the north, and again appears in Lenan Head, north of which the granite soon comes in, and is continued to Dunaff Head. Mr. Cruise informed me that this fine headland is composed of granite and quartzite.

The superficial appearance presented to us by the traverse N.W. of Ballynarry Bay is that of a considerable thickness of quartzite, overlain by a great succession of quartzose, micaceous, and talcose or chloritic schists. This series is certainly quite distinct from the rocks between Buncrana and Derry. It nowhere presents under the pocket-lens, so far as I have seen, any traces of a clastic structure. The schists are well foliated. They do not, indeed, suggest the highly crystalline rocks of the Hebridean system, but they are on the other hand easily distinguished from the partially mineralized schists of the Lough-Foyle series.

It is also to be noted that, while the older rocks dip almost uniformly to the S.E., the dip of the Lough-Foyle group is north-westerly. That this is not a true synclinal structure is evident from the great dissimilarity between the rocks of the two sides of the apparent basin.

Section from Malin to Malin Head.

This traverse is substantially the same as that part of the last section which passes over the older series. Between the village of Malin and the quartzites of the west coast, a breadth of about three

* I do not commit myself to a definite opinion on the exact mineral nature of some of the schists of this region.

miles, we have the micaceous and talcose (or chloritic) schists. They are frequently folded, and in addition are intensely crumpled in numerous small contortions. The dips are alternately N.W. and S.E., but sometimes there is more north or south in them. These schists are frequently penetrated by intrusive diorite. Towards Lag, quartz-schist and quartzite come in, and quartzose rocks are found as far west as Malin Head.

The rocks of Malin Head are on the strike of the quartzites of Dunaff Bay, and are composed of quartzite and quartz-schist. They are bent into an anticline, well seen at Esky Bay. On the south side of the headland, I saw a mass of hornblende-schist, which had apparently been forced up amongst the quartzites by the intrusion of the granite. The extremity of the Head, which is the most northerly point of Ireland, is composed of flaggy quartz-schists, greatly contorted, plunging vertically down to the west.

Comparing the mica-schists of this traverse with the similar rocks in the last section, we find the alternating dips west of Malin represented on Lough Swilly by a tolerably uniform dip to the S.E. The great apparent thickness of strata on Lough Swilly may therefore be explained by repetition.

Section between the Granite of Croagh and the Diorite of Horn Head (Dunfanaghy). (Fig. 6, p. 235.)

The metamorphic rocks of Lough Swilly and Malin are only the upper portion of an extensive succession. If the quartzite of Dunree Head be followed on the strike to the S.W., it is seen to coincide with the quartzite ridge of Lough Salt, where it is underlain (p. 224) by schists and limestone. These are the lowest rocks east of the granite promontory.

West of the granite of Croagh, we pass through a succession of micaceous and hornblendic schists, underlain at Lough Natooney South by bedded crystalline limestone with seams of mica and some quartz, the dips being usually to the S.S.E. at 80°. There is a general resemblance between these rocks and those east of the granite, but the dip is much higher and is occasionally vertical.

At Creeslough there is an apparent thickness of several hundred feet of well-foliated mica-schist, dipping conformably with the preceding rocks. Omitting numerous masses of diorite, we find the following descending succession between Creeslough and the coast.

Stream east of Derryharriff.—Mica-schist of the lustre and colour of black lead.

South of the R. C. Chapel at Doocashel.—Similar schists, dipping S.S.E. at various angles, some low.

East of Chapel.—Quartzite with low S.S.E. dip.

Bridge south of Ballymore Church.—Quarry of coarsely crystalline massive limestone. Colour white; some bands blue; the former sometimes with folia of mica. Dip S.E. at 40°-50°.

Road north-west of Church.—Quartzite with low dip or horizontal; in places greatly contorted.

South of Faugher Upper.—Quartzite.

Faugher Upper.—Crystalline limestone like the beds south of Ballymore. Dip at a low angle to S.S.E., passing below the quartzite. This limestone is continued along the road to Dunfanaghy for about a mile.

Round Dunfanaghy.—Quartz-schist is almost the only bedded rock which appears below the limestone. It is well seen in the shore, west of the town; in quarries one mile to the S.S.W.; in Doorus Point; and in parts of Horn Head. Near Horn Head House, to the N.N.E., the schist in a hillock presents a fan-shaped arrangement. Elsewhere the schist dips at low angles, and is apparently conformable to the limestone.

The apparent descending succession in the metamorphic series is thus summarized:—

1. Micaceous schist of Lough Swilly.
2. Quartzite of Lough Swilly and Lough Salt.
3. Schists (hornblendic and micaceous) and limestones of Lough Greenan.
4. Similar rocks west of Croagh.
5. Mica-schist of Creeslough.
6. Lead-coloured schists south of Doocashel.
7. Quartzite of Doocashel.
8. Crystalline limestone south of Ballymore.
9. Quartzite N.W. of Ballymore.
10. Crystalline limestone of Faugher Upper.
11. Quartz-schists of Dunfanaghy.

We have seen (p. 236) that in Malin Head the granite occupies the core of an anticlinal fold, with vertical strata in the western limb, as if there had been a thrust from the east. In the last section, too, the strata on each side of the granite are similar, and the rocks on the west side are nearly vertical; but I cannot venture with my present information to say that the same structure exists in both cases, though the matter is one which it would not be difficult to determine.

*Section between the Granite north of Dunlewy Church and the
Granite at Bunbeg.*

This section is drawn across the same rocks as in the last traverse, at a distance of about 12 miles to the S.W. We are here near the broadened base of the granite promontory, and the continuation of the beds of schist west of Croagh is apparently cut out by it. The following is the probable succession:—

1. Dunlewy schists; possibly representing the Creeslough series.
2. Quartzite of Errigal; apparently on the strike of the quartzite at Doocashel.
3. Lead-coloured schists at Bunaninver Bridge.
4. Quartz-schist between Gweedore Hotel and the western granite, and crystalline limestone at Bunbeg, probably on the horizon of the rocks round Dunfanaghy.

It is interesting to note that the Dunlewy schists dip to the N.W., that is, in the opposite direction to their presumed equivalents near Creeslough. This fact illustrates the difficulty, in these disturbed regions, of determining the original position of the beds.

III. PROOF OF LATERAL THRUST.

From the preceding descriptions, it will be seen that there are two prevailing strikes in this region, one to the W.S.W., the other to the S.W., and that these strikes are found in both groups.

In fig. 5, the strike of the Lough-Foyle series is W.S.W., between Londonderry and Cashel Hill; but between Fahan and Ballynarry Bay it is S.W., and this is the strike of the older series right up to the granite, and in the granite itself.

West of Malin the older schists strike sometimes W.S.W. and sometimes S.W.; but in the quartzose series further west the strike is S.W.

In the Kilmacrenan section (fig. 6), the trend is almost uniformly to the W.S.W. from the granite to the west coast.

These observations are corroborated by an interesting section in Croaghmore, a mountain W.N.W. of Letterkenny. This elevation trends east and west, in agreement with the strike of the strata, which consist of strong mica-schists dipping steadily to the north, with perhaps a few degrees of west. Near the summit the schists form a low escarpment facing to the south, and these scarp-faces display intense contortions, with small folds reflexed to the east. These two systems of folding must have been produced by earth-thrusts acting in different directions and at different epochs.

The facts indicated do not suffice for a complete induction, but they are enough for my purpose. During one of the periods of contortion, the thrust came from the S.E. or the N.W., probably the former. This pressure was capable of producing the foliation in the granite and the south-west strike in the schists on its eastern side; for, as we have seen, it was violent enough to squeeze hard grits into schist-like rocks, to crush strata into masses of angular fragments with the divisional planes lying in all directions, to produce cleavage in coarse grits, to contort rocks into closely appressed folds, to throw over the folds, and sometimes to give rise to thrust-planes. It was probably during this important corrugation of the crust that the granite was squeezed up from below. At any rate, the lateral thrust easily accounts for the gneissic structure, which may have been in part acquired during the extravasation and completed after consolidation by a continuance of the pressure, or entirely produced after consolidation.

The production of regional foliation by pressure in the case of the Donegal granite may have an important bearing upon the origin of the crystalline schists.

The Rev. E. Hill, F.G.S., has called attention* to a gneissic structure in the granite of Guernsey and made a similar suggestion in reference to some gneisses.

SUMMARY OF RESULTS.

1. The granitic rock of northern Donegal, originally supposed to be the result of the metamorphism of sediments, and recently re-

* Quart. Journ. Geol. Soc. vol. xl. p. 419.

ferred to the Laurentian system, is a true igneous granite, as seen in its intrusion into the adjacent schists, in its inclusion of masses and fragments of other rocks, and in its metamorphic action on limestone in contact.

2. This granite is distinctly foliated, the gneissic structure being caused by lateral pressure (probably from the south-east), of which there is evidence in the marked cleavage and intense contortion of strata, in their occasional fractured and crushed condition, and in the frequent overthrow of folds and overthrust of faulted masses.

3. The granite is intrusive in a thick group of quartzites, quartzschists, hornblendic, micaceous, and talcose (?) schists, and crystalline limestones, called the *Kilmacrenan Series*. These rocks are truly crystalline, but usually thin-bedded and fine-grained.

4. The crystalline schists are bounded on the east by a semi-crystalline series, consisting of quartzose grits and itacolumites, quartzites, crystalline limestones, compact dolomites, phyllites, inter-laminations of grit and schistose matter, and finely foliated micaceous schists. These may be designated the *Lough-Boyle Series*.

DISCUSSION *.

Mr. RUTLEY remarked that there seemed to be no greater reason for surprise at the inclusion of large masses of schists &c. in intrusive granite than at the occurrence of small fragments, or "horses," in dykes. In connexion with the change of limestone into garnets, he inquired whether the limestone was siliceous or aluminous. He also objected to the use of the term "mineralized grit," and inquired what was to be understood by it. He doubted whether Dr. Sterry Hunt's correlations ought to be accepted in the present instance.

Mr. R. H. SCOTT had hardly expected his paper to be exhumed after the lapse of twenty-two years. He objected to the title of Dr. Callaway's paper; it should have been on part of the north-west of Donegal instead of on the whole county. The granite of Barnesmore was of a different type from that of the district described in this paper, which is similar to that of Argyllshire. When he had worked upon these granites microscopic examination of rocks was not so well understood as it now is; and he could not investigate the rock thoroughly. He had not assigned any particular age to the granite, and he had expressly alluded to intrusive veins, though he considered the rock to be metamorphic. There were similar beds north-west and south-east of the granite in the north, showing a possible anticlinal. He remarked that Dr. Callaway would find work to do in the south of the county and eastward in Tyrone. There are similar altered rocks throughout this region, passing on to fossiliferous beds. There are two

* Portions of this discussion relate to certain views, as to the correlation of the rocks described, which were put forward at the conclusion of the paper, but which were subsequently withdrawn by the author.

types of granite in the main granite district, one with two feldspars, the other white like an elvan, and containing sphene. This latter appears in the island of Arranmore. There is a totally different granite further south, near Barnesmore, and that does not exercise metamorphic action on the neighbouring rocks. In conclusion, he inquired, What relation did the beds in Wexford bear to the Silurian near Enniscorthy?

Mr. TEALL said that the two portions of the paper struck him very differently. The first portion evidently contained a very interesting record of carefully observed facts, the second portion dealt with the correlation of the schists of the district with those of other localities,—the only evidence for such correlation being a certain lithological resemblance. He was extremely sceptical about the possibility of determining the chronological relations of such rocks in this way, and believed that some of the characters relied upon were merely structural and mineralogical peculiarities, dependent upon the mechanical actions which determine regional metamorphism. The eruptive origin of certain foliated rocks had been clearly established by Darwin, Forbes, Kjerulf, Lehmann, and many other observers. The development of micaceous minerals in connexion with regional metamorphism was a common feature; and he especially referred to the gneissose flagstones and associated schists of the north-west of Scotland. The mica in these schists appeared to be developed at the expense of feldspar. In some cases "eyes" of feldspar remained, while in the more perfect schists these were almost if not entirely absent. A quartz-feldspar grit, such as the Torridon Sandstone, if subjected to regional metamorphism, might thus be readily converted into a mica-schist, and he was strongly inclined to think that some of the eastern schists had been made in this way. The Lough-Foyle and Kilmacrenan series of the author were evidently the result of regional metamorphism, and possibly many original groups had been involved in the action.

Mr. BLANFORD mentioned that some interesting evidence had recently been brought forward by Colonel McMahon, showing that certain Himalayan gneisses were intrusive. If the differences between the Lough-Foyle rocks and the Pebidian of St. David's were such that these two could not have been identified by mineral characters unless connecting links had occurred in Wicklow and Anglesey, was it not absurd to endeavour to identify either of them with beds in North America? The determination of the age of rocks in distant countries by mineral characters had formerly been applied to sedimentary beds, then to igneous; it had long been abandoned in the former, and was gradually being given up in the latter, and there was much reason for caution in applying the same key to ancient altered formations, the succession in which was often very obscure.

Mr. MARR considered that, in order for the correlation to be safe, the Pebidian must be traced across; but vulcanicity continued up to and throughout Cambrian times, so that Cambrian rocks, if altered, would be undistinguishable from the Pebidian.

The PRESIDENT said that he had been unable to examine the specimens in minute detail, but had carefully looked through them. Of the so-called granites, seven out of eight were certainly, and the remaining one probably, granites. They gave indication of considerable crushing since their first crystallization. Of other rocks there was good evidence of two series, one agreeing in general characters with Scotch schists, the other with the Pebidian of Wales. He doubted Mr. Teall's evidence of the production of all schists by crushing. As regards mineral character, he thought that the general condition and amount of alteration of rocks, rather than their actual mineral composition, should be employed for correlation.

The AUTHOR, in reply, suggested that the production of the garnets in the limestone might be due to a chemical action of water from the granite in contact. He regarded a grit as "mineralized" when distinct mineral folia had been produced between the grains. The omission of the word "Northern" before "Donegal" in the title of his paper was an oversight, which he would correct. He had not attempted to definitely correlate the Donegal rocks with any American system, but had merely pointed out certain lithological analogies. His identification of Pebidian rocks in Ireland had not been based only on lithological affinities, but he had specially insisted on their state of crystallization and upon the fact that in Wexford they occurred side by side with unaltered Cambrian and Ordovician sediments, separated from them by sharp lines. The difficulties suggested by some of his critics would, he thought, be removed if it were remembered that in some of the British localities the Pebidian rocks were mainly of volcanic origin. He had compared the Lough-Foyle series with the British Pebidian in the non-volcanic districts.