Chapter 20 The Girvan district — continued. Intrusive igneous rocks

The intrusive rocks associated with the Arenig volcanic series are admirably displayed in the region between Girvan and Ballantrae. They consist of ultra-basic, basic, and acid masses, including serpentine, olivine-enstatite rock (saxonite), hornblende-picrite, pyroxenite, gabbro, epidiorite, dolerite, and granite. But while the variety of these intrusive types is strikingly exemplified throughout the region, the relations which they respectively bear to each other in the field are in many places obscure. For over much of the area, owing partly to the more rapid decomposition of the serpentine and partly to the covering of superficial deposits, the lines of contact between that rock and the other igneous masses are not visible. Further, planes of schistosity have been locally developed in some of the intrusive rocks, whereby the serpentine has been rendered schistose, the gabbro' and hornblende-gabbro have been foliated, and the epidorite hay been converted into hornblende-schist. Lines of movement traceable for miles have in one or two instances destroyed the evidence of the original relationship of the serpentine to the adjacent rocks, the resulting flaser-struc-tures being apparent in the field, and confirmed by microscopic examination of the rocks. For these reasons it is difficult in many cases to determine the relations and sequence of the intrusive rock masses.<ref>A short summary of the results of the re-survey of these plutonic rocks is given by Sir A. Geilde. "The Ancient Volcanoes of Great Britain", vol. i., p. 200.</ref>

The detailed mapping of the region, however, leads to the belief that the more highly basic rocks, comprising serpentine, olivine-enstatite rock, hornblende-picrite, gabbro, and other compounds, which are the most abundant, were the earliest to be injected. They pierce the lavas, tuffs, and agglomerates, while on the shore the serpentine is in visible contact with the Middle Arenig black shales and radiolarian cherts. In some of the exposures, where the junction between the serpentine and the less basic rocks is laid bare, the latter do not show any evidence of having been intruded into the former; indeed, their relations, judging from certain exposures, are such as to suggest that some of the rock types may be different modifications of the same original basic magma. But while this relation is probable, it is nevertheless clear that the complex basic masses, together with the interbedded lavas and agglomerates, have been subsequently invaded by irregular dykes or veins of dolerite and gabbro, which present chilled margins at their lines of contact with the surrounding rocks.

Between Girvan and Ballantrae the intrusive rocks form two prominent belts, which run generally along the strike of the volcanic series, black shales and cherts. The northern one occupies three miles of the coast line between Pinbain Burn and Burnfoot, south of Lendalfoot, and extends inland by Lochton to Byne Hill; while the southern is traceable from the raised beach south of Bennane Head eastwards by the slopes of Knockdolian and Balhamie Hill to Millenderdale. Small isolated basic masses occur beyond these limits, as, for instance, on Knockormal Hill, at Ballantrae Castle, and other places.

On referring to the Geological Survey Map (Sheet 7) of the region, it will be seen that serpentine occupies by far the largest part of the area covered by the intrusive rocks. Though owing to the mantle of superficial deposits, the boundaries of the respective igneous masses shown on the map are in some instances conjectural, yet the more basic rocks usually form more or less lenticular bands or bosses in the midst of the serpentine areas, protruding at the surface as rocky knolls frequently bare of vegetation. We shall therefore begin with the description of the development of the serpentine in the two prominent belts just mentioned, proceeding thereafter to deal with the masses of gabbro, epidiorite, and other intrusive materials of a less basic kind.

Serpentine

Southern Area. — This belt, which extends for a distance of seven miles from Drummore shore south of Bennane Head to Millenderdale, with an average breadth of about a mile, is mainly occupied by serpentine, which generally occurs in the massive form, though at certain localities foliated varieties are likewise met with (Figure 110). One of the best places for studying the massive type of serpentine is on Balhamie Hill [NX 13585 86531], about a mile to the north of the village of Colmonell, where it is exposed on the southern slope and in streams that drain the declivity. The lithological and microscopic characters of this type, as developed on this hill, have been well described by Professor Bonney, who clearly recognised the igneous origin of the serpentine and its resemblance to the type of that rock seen to the north of

Cadgwith, Cornwall. He refers specially to an exposure in a pit near the roadside, about three-quarters of a mile from the village of Colmonell, and gives the following description of the rock.<ref>On the Serpentine and Associated Igneous Rocks of the Ayrshire Coast, Quart. Jour. Geol. Soc., vol. xxxiv., p. 770.</ref> The serpentine, "on old surfaces, assumes the same rugged grey-brown aspect as that at the Lizard; its fracture is sub-conchoidal. The ground mass is a deep black, weathering to a pale grey-green. It is full of crystals of glittering bronzite, just like those in the Cadgwith rock. A detailed description of the microscopic structure is needless, for what I have written of that will apply here almost word for word, the only difference being that, in the specimen examined, the conversion of the olivine into serpentine, stained and clothed with granules of black ferric oxide, exhibit a rude parallelism over part of the slide. The bronzite also in this rock is a little more altered than it is at Cadgwith; some grains contain numerous ferruginous microliths. There is in the slide a grain or two of a dark brown mineral, possibly picotite. I have not the slightest doubt that this is an altered olivine-enstatite rock".

In this quarry near Colmonell, Professor Bonney observed, an irregular vein of a greenish mineral, about four inches thick, which was analysed by Mr. Houghton, who thus reported on the specimen sent to him for examination.<ref>Quart. Jour. Geol. Soc., vol. xxxiv., p. 772.</ref> "This rock appears to coincide in all its properties, both chemical and physical, with the mineral chonicrite, which is stated by Dana to be found associated with serpentine in Elba. It differs in having less Si and more Fe".

The observations of Professor Bonney regarding the petrographical characters of the serpentine of Balhamie Hill have been confirmed during the recent revision by the Geological Survey. The glistening crystals of rhombic pyroxene, or its alteration product, bastite, set in a black or dark green matrix, form one of the characteristic features of the rock as developed on this hill. Two specimens collected during the recent revision from this locality are thus described by Mr. Teall. The first No. (S6428) displays in the hand specimen "crystals of bastite, giving a brilliant lustre from their cleavage surface, and often measuring more than a quarter of an inch across, which are set in a compact dark green matrix. Cleavage flakes of the bastite, detached with a knife, show the characteristic negative bisectrix in convergent polarised light. Under the microscope the large plates of bastite a re found to be irregular in form. They lie in a matrix traversed by anastomosing veins of dusty magnetite, and possessing the mesh structure of serpentine derived from olivine. The rock is a serpentine derived from a saxonite (harzburgite of Rosenbusch)". The second No. (S6429) shows, in the hand specimen, "small irregular patches of picotite (hardness greater than that of quartz) in a compact dark greenish matrix. Under the microscope it shows serpentine derived from olivine, together with irregular masses of picotite, which are only transparent in very thin sections, and then appear a deep rich ckesnut brown. The rock is a serpentine derived from Dunite".

On the moor to the north of Poundland Hill [NX 17326 87755], two miles northeast of Colmonell, massive picotite occurs in the serpentine. The best locality is about 300 yards north from the margin of the serpentine area, and near the source of the Poundland Burn [NX 17091 88490]?, where several veins have been observed. A specimen collected here No. (S6449) is described by Mr. Teall as "massive picotite (sp. gr. 3.68), containing a few irregular white patches, which apparently represent altered felspar. Under the microscope, the picotite is Chesnut brown in very thin section. The supposed felspars have been converted into a veins traversing the massive picotite".

The following analysis of the rhombic pyroxene, which forms such a conspicuous feature in the Ayrshire serpentine as developed on Balhamie Hill, Knockdaw Hill near Lendalfoot, and other places, has been made by Professor Heddle:<ref>Trans. Roy. Soc. Edin., vol. xxviii., p. 424.</ref>

SiO_2	37.776
Al_2O_3	2.123
Fe_2O_3	5.069
FeO	2.095
MnO	0.076
MgO	37.014
K_2O	
Na_2O	trace.
H_2O	16.07

In addition to the normal type of serpentine, examples of the type intermediate between the serpentines and true gabbros also occur in this region and are of considerable interest as lending support to the conjecture that some of these varieties of intrusive rocks may be modifications of the same basic magma. An excellent example of this intermediate type occurs on the northwest slope of the Breaker Hill, about the level of the 700-feet contour line, at the southern margin of the serpentine. The locality may be readily found, as it lies about a mile to the, north-west of the Daljarrock limestone quarry, at a point where a- branching vein of serpentine leaves the main mass (see Sheet 7). By following the stone fence from Daljarrock Wood in a north-west direction to the margin of the serpentine, the observer will find the spot without difficulty. A specimen No. (S6430) collected from this locality is described by Mr. Teall as "a dark, almost black rock, containing small irregular white patches, which are unevenly distributed through the specimen. This rock bears a close resemblance to varieties of serpentine which occur at the Lizard, and which are intermediate between true serpentines and gabbros. The white patches probably represent felspars. The microscopic examination shows that the constituents include olivine, augite, hornblende, biotite, serpentine, iron ores, and a turbid substance which probably represents felspar."

"Serpentine derived from olivine, with the unaltered mineral still preserved in the cores of the meshes, is an important constituent of the rock. The augite is nearly colourless, and occurs both in the form of large irregular plates and as granulitic aggregates. The hornblende is peculiar as regards its colour and pleochroism, a, colourless, β and γ, rich but not very deep brown, and with only slight differences. Biotite is not present in any considerable quantity. It occurs as aggregates of small scales, and possesses the same colour as the hornblende."

"This rock possesses decided affinities with the hornblende-picrite from Penarfywydd in Anglesea (see British Petrography, Plate vii., fig 5), described by Professor Bonney. It also resembles certain banded rocks which occur at the Lizard in intimate association with serpentine ("Some Coast Sections at the Lizard," Fox and Teall, Quart. Jour. Geol. Soc., vol. xlix. (1893), p. 200). The resemblance in this case is, however, limited to mineralogical composition; both rocks contain the colourless augite and the peculiar brown hornblende, together with serpentine, olivine, and turbid alteration products after felspar. The Lizard rock is a well banded schist, whereas the Ayrshire rock is massive, with, however, a marked variation in the amount of altered felspar present in the different portions of the specimen".

A rock of a similar intermediate type was observed on the slope of Balhamie Hill at a point about 200 yards west of Balhamie Burn, where it appears as a thin vein of dark massive material in serpentine. Under the microscope, this rock No. (S6432) "shows numerous large irregular individuals of olivine only partially serpentinised in a fine-grained matrix, composed of small irregular individuals of pale brown hornblende, and serpentinous and chloritic alteration products. There are also some turbid alteration products, which may indicate the presence of a small quantity of felspar". This rock has been named by Mr. Teall hornblende-picrite.

Regarding the relations of the serpentine of the southern belt to the bedded lavas, tuffs, and associated sediments, it is clear that the boundary-line between the two series of rocks in some cases is a fault or line of movement. Such seems to be the nature of the boundary along the north side of Knockdolian Hill, where the serpentine rises to a height of about 400 feet (Figure 107). Along the margin, and especially on the north-west part of the slope, the serpentine has been rendered schistose, fine flaser-structure being observable at certain places. Where this feature is developed the rock is traversed by calcareous veins, which in some instances have been burnt for economic purposes. Between Knockdolian and Garnaburn, north-east of Colmonell, the boundary of the serpentine is concealed by superficial deposits; but along the Prieston and Poundland Hills the junction is probably a faulted one. On the Breaker Hill a vein of schistose serpentine is traceable from the main mass into the bedded lavas.

In the river Stinchar, at the base of the south-eastern slope of Knockdolian Hill [NX 11642 84447], the serpentine is in contact with black shale, which, as already stated, is believed to be on the horizon of the Middle Arenig band at Bennane Head. The junction, which appears to be an intrusive one, is visible only when the river is low. Here also the volcanic agglomerate is indurated, probably by contact with the serpentine. Though the rock cannot be traced continuously from the river to the Leffin Knowes, north of Balknowlart, at the base of the south-west slope of Knockdohan, it probably occupies the hollow at Macherwhat.

In probable underground continuity with the mass on the south side of Knockdolian, the serpentine is again seen on the left side of the river near Salachan [NX 12442 84334]. On the south-east side of Salachan Hill it is exposed in various quarries at the roadside near Knockdhu Bridge [NX 13329 84540], associated with a mass of gabbro, which will be referred to in the sequel. At the edge of the wood, where there is a bend in the high road leading to Colmonell, schistose green serpentine is visible, and in a quarry at the roadside close to Knockdhu Bridge the rock has a red tint.

North-east of Ballantrae, between Balnowlart [NX 10652 83837] and Croseclays [NX 09910 84742], the boundary of the serpentine, as mapped, is conjectural, for the ground is largely covered with superficial deposits, but an excellent section of the schistose variety of the rock is displayed in the Drummore Burn [NX 09525 85496], to the south of Bennane Head. Reference has already been made to the fact that near the mouth of the Bennane Burn (Bennane Head), at the margin of the old sea-beach, the serpentine is intrusive in the radiolarian cherts. Along the northern margin of the area, from the shore south of Bennane Head eastwards in the direction of Boghead, the boundary is concealed, and between Boghead [NX 14302 87566] and Knockdaw Hill [NX 16302 88658] there seems to have been a certain amount of movement between the serpentine and the Arenig lavas lying to the north of it.

Northern Area. — The lithological characters of the serpentine in the northern tract resemble those met with in the southern belt. The rock at various points on the shore between Pinbain Burn [NX 13757 91424] and Burnfoot is associated with numerous bosses of gabbro and veins of dolerite. Its principal varieties, as exposed on this part of the coast, have been described by Professor Bonney. He states that "about Lendalfoot the serpentine has a rather conchoidal fracture, with a very compact dark olive-green ground mass, containing rather minute and not very lustrous bronzitic crystals and thin veins of chrysotale. On placing a slide beneath the microscope, we see that the structure made so familiar by the Lizard specimens (Quart. Jour. Geol. Soc., vol. xxxiii., p. 916) is at once evident, though in this specimen the black iron peroxide is less markedly aggregated in the neighbourhood of the strings of doubly refracting serpentine, and the distinction between 'strings' and doubly refracting 'mesh' is less conspicuous. Much of the iron is disseminated in extremely minute granules over the field, which, with crossed Nicols, shows fibrous serpentine extending towards the centre of the mesh, and sometimes occupying the whole. Where these strings are more clearly defined they exhibit a rough parallelism, and the fibrous structure is at right angles to them. The serpentine is irregularly banded with chrysotile. One vein shows unusually bright colours with crossed Nicols. There are two or three grains of a rich brown mineral, probably picotite. Here and there is a little of a fibrous, very strongly dichroic green mineral, changing from light green to almost black. Altered bronzite is present in rather small grains, and a clear yellowish mineral, with very minute belonites, about 0.001 inch in length, crossing nearly at right angles, so as to form a sort of prismatic reticulation".<ref>Quart. Jour. Geol. Soc., vol. xxxiv., p. 775. </ref>

On the shore to the south of Carleton Port [NX 12458 89422], red serpentine appears with crystals of bastite and veins of chrysotile; to the south of the fifth milestone from Ballantrae the dark green variety, is met with, and near Burnfoot beautiful red and green mottled serpentine is exposed on the shore.

The following is a description by Professor Bonney of the microscopic character of two varieties of the red serpentine from this district.<ref>Quart. Jour. Geol. Soc., vol. xxxiv., p. 776.</ref>

1. "Specimen from south of Burnfoot. In general structure this resembles the other, except that the meshes' are often partly or wholly occupied by an imperfectly translucent ferruginous mineral of burnt-sienna colour, doubtless akin to hematite and the colouring matter of the rock. There is some calcite in a crack traversing the slide, mixed possibly with a little minute dolomite; it also occurs associated with a microlitic ' dust' replacing some (? pyroxenic) mineral. Bronzite is present, though in small grains, and much altered.
2. "Specimen collected from rocks a little to the south of Carleton Port headland. This is a compact rock of an Indian-red colour, marbled or mottled with purplish or purplish-grey, in which are rather rounded grains or 'eyes' of a greenish mineral, apparently a decomposed bronzite. Under the microscope this rock is seen to be in general structure very similar to the last, but with the ' strings a little more definitely parallel; to these also the coarser part of the ferruginous constituent is rather more restricted, though an extremely minute dust is everywhere thinly disseminated in the serpentine. There is bronzite, much altered, and a minute grain or two of picotite (?)".

When the northern belt of intrusive rocks is traced inland from the shore, numerous exposures of serpentine, having a green tint and sub-conchoidal fracture, occur on the moor to the south-east of Pinbain Hill. The schistose variety is met with near Laigh Knockclauch [NX 17251 91921], in the valley of the Lendal Water. In a small stream, about 100 yards west of the ruins of Lochton Cottage [NX 17580 92858], near the margin of the serpentine, a dark-green massive rock, when examined under the microscope, is found to consist "mainly of an aggregate of irregular grains of a colourless monoclinic pyroxene. It contains also yellowish patches and veins of serpentine". This rock has been termed Pyroxenite by Mr. Teall (Pyroxenolite of Lacroix). At the extreme north-east limit of the serpentine, on the north-east slope of Byne Hill, the rock is dark-green and compact, containing a few small crystals of bastite. Under the microscope it shows "bastite, serpentine, and a few irregular grains of picotite".

With reference to the relations of the northern belt of serpentine, it seems clear that the south-east boundary, extending from Carleton Hill to Lochton, south of Byne Hill, has been a line of movement, as the rocks along the junction show marked flaser-structure. The flaser-epidote rocks at the margin of the serpentine on Carleton Hill and in the Lendal Water, near Lendalfoot, have been already referred to, and highly sheared rocks likewise occur along the boundary near Loch Lochton. In like manner, on the south-eastern slope of Byne Hill [NX 18283 94771], there is evidence at one place of deformation along the boundary between the serpentine and the mass of gabbro and dolerite to the north. On the shore near the mouth of Pinbain Burn, as already described (see (Figure 104)), the serpentine is intrusive in the Middle Arenig black shales, and pierces the Arenig lavas and agglomerates.

Gabbro, dolerite, epidiorite, diorite, granite.

A remarkable feature of the intrusive series is the abundance of irregular and lenticular masses of various types, chiefly basic, which occur within or at the margin of the serpentine areas, or as small isolated bosses piercing the Arenig lavas and agglomerates. Owing to their number, special reference will be generally restricted to those from which illustrative specimens have been taken for microscopic examination.

Beginning with the coarse gabbros and gabbro-pegmatites, we find in one of the small streams draining the south-east slope of Pinbain Hill [NX 15333 92018]?, in association with the serpentine, a highly altered coarse-grained gabbro-pegmatite, composed of individual crystals measuring an inch or more across. A specimen No. (S6440) shows under the microscope "that the felspar is entirely replaced by secondary substances, of which a brown isotropic material is the most common. It occurs in small grains, granular aggregates, and as irregular patches. More or less altered crystals of pyroxene also occur". A similar change is observable in a vein of coarse gabbro in serpentine at Lendalfoot [NX 13070 90053]. The vein is about three-quarters of an inch thick, and is mainly composed of a nearly white compact substance. Under the microscope No. (S6439), "the white substance cannot be definitely referred to any distinct mineral. It appears brown in thin section, is without action on polarised light, and may possibly be garnet. A brown substance is frequently found as an alteration of felspar in the Lizard gabbros, but this is doubly refractive". Another specimen taken from an exposure, a little north of Lendalfoot [NX 13178 90174] No. (S6441), shows under the microscope that the felspars are entirely replaced by ill-defined saussuritic substances, while the dillage is partly preserved and partly uralitised. These coarse gabbros with their giant crystals, and with no chilled margins, may be the pegmatites of the rock which gave rise to the serpentine.

Among the best examples of coarse gabbros are those found on the beach between Lendalfoot [NX 13127 90037] and the mouth of Pinbain Burn [NX 13758 91424], which have been described by Professor Bonney and Professor Heddle. On the sandy beach, about 450 yards south of the mouth of Pinbain Burn, a vein of coarse gabbro, that runs in a westerly direction, occurs in the serpentine and traverses an older gabbro composed mainly of diallage. The junction between the serpentine and the westerly vein of gabbro is visible. The former rock is seen adhering to the edge of the latter, and small inclusions of serpentine occurs in the gabbro. A specimen No. (S7806) taken from the northern edge of this vein, where the rock is fine-grained and schistose, shows under the microscope "that it has been subjected to a considerable amount of dynamic action and that the marginal portion was originally a fine-grained rock, similar to the bands of fine-grained granulitic gabbro near Millenderdale", to be referred to presently. The following description by Professor Bonney applies evidently to this locality south of Pinbain Burn, where he recognised gabbros of two ages:<ref>Quart. Jour. Geol. Soc., vol. xxxiv. (1878), p. 778.</ref>

"Rising conspicuously above the serpentine and the sand are two dykes of a hard whitish rock, spotted with brown. A short examination shows this to be a gabbro of plagioclase and diallage, in which, as at the Lizard, the former mineral has been converted into a kind of saussurite. It always forms the major part, and sometimes almost the whole of the rock. As it resists the weather better than the diallage, the rock has often a curious pock-marked" aspect. Close at hand is a most remarkable rock, best seen near the southern dyke of gabbro, though a little of it also occurs near the other. This rock consists almost wholly of coarsely crystallised sub-metallic diallage, the crystals being often two or three inches long. It breaks into serpentine in irregular branching veins, which die away in mere threads (remaining rather coarse to the last, like the gabbro at the Lizard); in places it has almost shattered the serpentine, and includes fragments of it. Its weathered surface, as might be expected, is extremely rough, the diallage crystals projecting. The thicker parts of the mass form little skerries. Here the rock may be four or five feet thick, but generally it is in veins not more than a foot across. Careful examination left not the slightest doubt on my mind that this is a true intrusive rock, and has not been formed by segregation or otherwise.

"I have examined microscopically each of the above rocks. In the former, the saussuritic mineral is partly translucent, but for the most part is rendered opaque by a fine earthy dust with a somewhat fibrous arrangement. With crossed Nicols the field is generally dark, but exhibits occasional specks and streaks of brighter colours and indistinct traces of aggregate polarisation. In one or two parts, however, some very characteristic plagioclase felspar still remains (very transparent and free from all enclosures, except some minute dark acicular microliths), thus indicating the origin of the saussuritic constituent.

"The other constituent of the rock exists in three forms — (a) Crystalline grains of diallage (and in one or two cases of normal augite) comparatively little altered; (b) wholly or partly replacing diallage, green-coloured, strongly dichroic, exhibiting occasionally very characteristic hornblende cleavage; (c) a transparent, nearly colourless, and non-dichroic, rather fibrous mineral, which sometimes is associated with either of the above, sometimes occurs alone. Part of this exhibits brilliant colours with crossed Nicols; part changes from a light bluish white to a blue-black like some fibrous serpentines; the former mineral is probably actinolite, the latter may be only a variety of serpentine. This rock thus appears to have been a coarsely crystalline gabbro, which, perhaps, contained a little olivine.

The second rock is practically a mass of diallage crystals. Some of these are very fairly preserved, others are traversed by cracks with dusty borders, showing incipient decomposition; while others are green-coloured and dichroic, indicating a change towards uralite. Others, again, are full of microliths, which are bright-coloured between crossed Nicole, while the main part of the crystal is dull or dark".

The following description of coarse gabbro by Professor Heddle applies to one of the localities on the shore north of Lendalfoot.<ref>Trans. Roy. Soc. Edin., vol. xxviii., p. 464.</ref>

"The specimens examined were from a low spit which protrudes far seawards about mid-tide level. This consists for the most part of the diallage in large platy and intermatted crystals; these lie embedded in a granular massive hydrated saussurite, the rock here being also of singularly simple constitution, with no accessories.

"The diallage here is an excellent type of this variety of augite, broad cleavage foliations and even crystal faces flash with a splendent lustre, but with a uniformity which is frequently broken by a singular reticulated or arborescent appearance, the interrupting duller structure having the ordinary non-lustrous appearance of the stone".

"The pseudo-metallic semi-nacreous flash, brought out in certain positions by reflected light, appears to arise from an internal reflection from flat fissures or broad cleavages. Rough crystals of half the size of the palm of the hand may here be obtained.

"The colour is olive green; the specific gravity is 3.251. 1.3 grammes yielded:

Silica	0.66	
From alumina	0.013	
	0.673 =	51.769
Alumina		2.1

Ferrous oxide	2.955
Manganous oxide	0.307
Lime	22.098
Magnesia	18.461
Potash	0.628
Soda	0.579
Water	1.085
	99.982

Insoluble silica, 3.863. Impurity unknown".

Within the serpentine area near Burnfoot [NX 10911 88333], and about a mile south of Lendalfoot, an interesting type of gabbro shows partial conversion into aluminous serpentine. Regarding a specimen of this type No. (S6442) Mr. Teall notes that "the whole mass has been converted into a soft translucent substance which can be cut with a knife. The darker and lighter portions of this substance probably mark the positions of the original felspar and diallage, but no trace of these minerals remains. Under the microscope the rock shows a more or less structureless mass of indistinct flecks and scales. I have no doubt that this is an aluminous serpentine (pseudophite) similar to that which has been described as occurring near Kynance at the Lizard, where it also arises as an alteration product from a coarse-grained gabbro". Another specimen of altered gabbro from the same place No. (S6443) shows "altered felspar, green and brownish-green hornblende, a little unaltered augite, surrounded by green hornblende, biotite (scarce), and iron-ores".

No less interesting is the evidence of the replacement of the pyroxene by hornblende in the gabbro masses. One example occurs on the south-east side of Salachan Hill [NX 13143 84537], in the valley of the Stinchar, about a mile to the south-west of Craigneil Castle, where uralitic gabbro is found in association with the serpentine, as already indicated (p. 471). Under the microscope, this coarse-grained granitoid rock No. (S6447) is found to be composed "of altered plagioclase and pyroxene, largely replaced by hornblende. The secondary hornblende has often been developed as minute pale green needles of actinolite, which do not lie with their axes parallel".

At the base of the south-east slope of Balhamie Hill, a quarry in a field near Deafstone Farm [NX 14097 86343], about 700 yards N.N.W. of Colmonell Parish Church, affords an excellent exposure of a peculiar type of gabbro-like rock, which occasionally occurs within the serpentine area. The serpentine is seen a little to the north of the quarry, but its relations to this rock are not visible. A typical specimen No. (S6450) was examined by Mr. Teall, on which he makes the following note: "The rock is composed of large and more or less irregular black and white patches. The black patches are formed of hornblende, and the white of felspar; both minerals occurring rather as aggregates than as individuals, although cleavage faces an inch across may sometimes be observed in the hornblende. Under the microscope are seen plagioclase in large plates, and more or less granular aggregates belonging to the andesine-oligoclase series, and brown compact hornblende also occurring in large irregular individuals and as aggregates. Apatite and iron-ores occur as accessories".

Proceeding now to the consideration of those phases of the gabbro which show "flaser" and "augen" structure, we may observe that these types are best seen in the basic masses in the southern belt of serpentine between Balhamie Hill and Millenderdale. Perhaps the finest examples of the foliated type in the Ballantrae region are to be found on the moor, about one third of a mile to the east of Millenderdale Farmhouse [NX 17670 90565]. Here the foliated igneous rocks form a series of rocky knolls or bosses, traceable at intervals over half a mile of ground, until they are covered unconformably on the north side by the Benan Conglomerate and associated strata. Where the foliation planes are best developed, at the south-east margin of these bosses, their general dip is towards the W.N.W. and N.W. at angles varying from 50°–55°. Special reference may be made to the section exposed on a rocky knoll, 600 yards east of Millenderdale [NX 17669 90555], on the north side of a stone-fence that runs due east from that farmhouse. Here bands of coarse gabbro alternate with fine-grained granulitic gabbro, both having a common foliation, the planes of which dip to the W.N.W. Both types are traversed by irregular veins or dykes of fine-grained igneous rock, which, though they cut the foliated masses, are not themselves, schistose. Specimens of these three varieties were here taken for microscopic examination which are thus described by Mr. Teall. The first No. (S7793) is a coarse-grained, foliated, saussuritic gabbro.

"Its principal constituents are brown hornblende, a pale or colourless pyroxene and plagioclase (altered). These three constituents occur either in large individuals or in the granulitic condition. The large pyroxenes are more or less inter-grown with brown hornblende, and frequently have on their margins a granulitic aggregate of hornblende and pyroxene. Iron ores are locally abundant in the thin section, and bear the same relation to the other constituents as they do in the rocks of Druim-na-Eidhne (Skye), that is, they are often allotriomorphic with respect to these constituents". The second specimen No. (S7791), exhibits a junction between the coarse and fine types of foliated gabbro. The coarse rock is a saussuritic gabbro in which the large pyroxenes are more or less replaced by brawn hornblende. The fine-grained rock is a granulitic aggregate of brown hornblende, malacolite and felspar (altered). These granulitic rocks appear to me to be comparable to the granulitic gabbros of Druim-na-Eidhne". Other two examples of the fine-grained types (S7792) and (S7794) resemble the fine-grained portion of (S7791); one of them being exceptionally rich in brown hornblende. Mr. Teall considers that these fine-grained rocks may be conveniently referred to as basic granulites. The remaining specimen No. (S7795) was taken from a dyke that cuts both gabbros and granulites. Under the microscope it shows "phenocrysts of turbid plagioclase (indeterminable), in a granulitic matrix of turbid felspar, unaltered malacolite and chlorite. The ground-mass of this rock is similar in structure to that of the granulites and the malacolite is of the same character. There is, however, no brown hornblende.

Again, on the north-west face of the Breaker Hill, about a mile S.S.E. of Millenderdale [NX 18030 89411], at the margin of the serpentine, another example of the foliated type is met with. When examined under the microscope, the section No. (S6444) shows that "some folia are composed most entirely of a colourless granular pyroxene; others of decomposition products after felspar. The rock is too much altered for precise determination, but it is probably a foliated phase of the gabbro".

The moor between Poundland and Knockdaw Hill, where the veins of massive picotite occur, near the source of the Poundland Burn [NX 17048 88476], presents a coarse-grained somewhat foliated rock of the gabbro type, which, when examined microscopically No. (S6448), shows "felspar mostly destroyed by alteration, pale-coloured pyroxene in large patches, and granulitic aggregates; biotite also in large plates, and granulitic aggregates and iron-ores".

The serpentine area between Poundland Moor and Balhamie Hill, includes a type of fine-grained banded rocks of granulitic structure, which have probably been subjected to dynamic metamorphism, and which contain an interesting assemblage of minerals. One example of this series forms a small boss protruding through the turf, close to the edge of a drained lochan [NX 17048 88476], at the southern margin of the serpentine area, about a mile north-east of Garnaburn Farmhouse. Microscopic examination shows that this banded granulitic rock (No. (S6494), (Plate 22)., figure 1) is "composed of malacolite, brown hornblende, and felspar. The specimen is traversed by a well-marked grey band, in which malacolite occurs to the exclusion of the serpentine, and in which iron-ore is fairly abundant". Another instance is met with on Balhamie Hill, at a point about half a mile due west of the cairn on the hill-top [NX 12551 86554], where the granulitic rock appears as an isolated knoll near a sheep-fold. A specimen taken from this exposure shows, under the microscope (No. (S6495), (Plate 20), fig. 2), that the rock is "essentially composed of granulitic felspar and brown hornblende, together with a small quantity of reddish-brown biotite. The grains are not uniformly scattered through the slide, but occur in aggregates. In some places the felspar aggregates appear to replace more or less idiomorphic felspars; in others the aggregates of both felspar and hornblende form streaks or folia. It is highly probable that the granulitic structure is wholly secondary". A third example forms a small boss in the midst of an alluvial flat a third of a mile E.N.E. of the cairn at Balhamie Hill-top [NX 13650 86711], and a third of a mile south-east of Lochhead. From a microscopic section No. (S6497) it appears that the rock is "too fine in grain for precise description, but apparently it is a foliated rock, composed essentially of small grains of brown hornblende and altered felspar. It is a rock similar to the one previously described No. (S6495), in which shearing has affected the entire mass".

In the northern belt of serpentine, on the north-west slope of Carleton Hill, near Lendalfoot [NX 12910 89397], a mass of epidiorite near the margin of the serpentine, is associated with a small development of hornblende-schist. A specimen of the epidiorite, when examined microscopically No. (S6502), displays "irregular patches of very pale green hornblende, and more or less altered felspars, which often show lath-shaped outlines penetrating the hornblende; the hornblende is probably secondary after augite; iron-ores are scarce". A section No. (S6503) of the hornblende-schist, which forms part of the same mass, shows that the rock is composed of "green hornblende and felspar, with iron-ores and chlorite as accessories". Another example (S7802) of fine-grained hornblende-schist with much epidote, occurs at the margin of the

northern belt of serpentine, in a burn about a quarter of a mile west of Laigh Knockclauch [NX 16937 91866]. A narrow lenticle of garnetiferous hornblende-schist is to be found within the serpentine area and about thirty yards from its margin on the hill slope, 600 yards north-west from Laigh Knockclauch, which has already been described in connection with the flaser-rocks along the southern margin of the serpentine area between Lendalfoot and Lochton (p. 458). The planes of schistosity in this lenticle are roughly parallel to the boundary of the serpentine, and towards its western limit it shows evidence of having been subjected to marked dynamic action.

In addition to these examples which show more or less trace of foliation probably due to dynamic action, some granulitic rocks, exposed in small isolated masses within the serpentine area, suggest the probability of their present structures being due to contact metamorphism. They are found on the Littleton Hill [NX 12531 86556], the western termination of Balhamie Hill, near the edge of the cultivated ground, and about half a mile north of Bougang Farmhouse. Three sections have been prepared from specimens taken from these bosses, viz.: Nos. (S5927), (S5928), and (S6496). The first (S5927), (Plate 20), fig. 1) shows "phenocrysts of basic plagioclase in a granular aggregate of brown hornblende and felspar, reddish-brown mica being also present". The second is composed of "a granulitic aggregate of brown hornblende and felspar, with minute specks of iron-ore". The third displays "a few phenocrysts of felspar in a ground-mass of brown hornblende and more or less lath-shaped felspar, with a few specks of iron-ore". The relations of these granulitic rocks to the serpentine are here also concealed from view. All that we certainly know is that the rocks lie within the serpentine area. Their origin is a matter of doubt. If they represent an altered phase of the porphyritic diabase-lavas, then the matrix must have been entirely recrystallised.

Reference may now be made to certain lenticular masses and veins of dolerite, which at various places present chilled margins along their lines of contact with the serpentine. Frequently they have a sinuous course, and are very irregular in their mode of occurrence, differing in this respect from the basalt dykes of Tertiary age. Professor Bonney has already called attention to the existence of rocks of this type near Lendalfoot hamlet [NX 13106 90065], suggesting that they are veins rather than dykes. He states that "in the thicker parts they resemble dolerites, mottled, dull, white and dark-grey (sometimes like a fine variety of the Corstorphine rock), and they appear to pass into thin veins (less than a foot thick) of a compact pinkish-grey rock with dull, green spots". He adds that the microscopic examination confirmed his view of the igneous character of these rocks, for "the coarser varieties consist mainly of felspar (or rather of what was once felspar, probably plagioclase, but is now an aggregate of earthy dust and bright-coloured irregular microliths) and well-preserved augite, of a serpentinous mineral, and of decomposed ilmenite. The finer variety is so completely decomposed as to show little of its original constitution"<ref>Quart. Jour. Geol. Soc., vol. xxxiv., p. MS.</ref>.

During the recent revision by the Geological Survey, three specimens were taken from one of these intrusive dykes on the shore 300 yards north from the hamlet of Lendalfoot [NX 13008 90037] opposite the Sailor's Monument (Plate 14); the first from the chilled margin in visible contact with the serpentine, the second a little further inwards, and the third from the centre of the mass. This intrusive mass, which runs roughly parallel to the shore, contains small inclusions of serpentine and the latter rock is likewise seen adhering to the walls of the dyke. The first No. (S6451) is a dense compact grey rock that shows a few phenocrysts of plagioclase in an extremely fine-grained matrix, the constituents of which cannot be satisfactorily determined, the second No. (S6452) is a medium-grained, dark, massive rock, which under the microscope shows "augite, lath-shaped plagioclase, and iron-ores, with chlorite and epidote as secondary accessories. Biotite occurs generally in association with the iron-ores as a primary accessory"; the third No. (S6453) is a moderately coarse-grained dark massive rock, "which has the same constituents as the preceding, with this exception, that biotite is not present as an accessory".

At Lendalfoot [NX 13138 90056] a porphyritic dolerite likewise occurs as intrusive veins in the serpentine. A slide of this type No. (S6454) displays "phenocrysts of basic plagioclase, often measuring more than a quarter of an inch across, set in a ground mass of augite, lath-shaped plagioclase, and iron-ores, with chlorite and epidote as secondary accessories". Similar porphyritic dolerite with chilled margins occur at the edge of the serpentine area, on the south-west side of Knockdaw Hill.

These intrusive dolerites are well developed in the neighbourhood of Garna Burn, about a mile north-east of the village of Colmonell, where they form rocky knolls protruding through the serpentine on the west side of the valley [NX 14119 87906]. The junctions with the serpentine are visible about half a mile up the stream from Garnaburn Farmhouse, at the

south-eastern limit of the alluvial flat below Boghead. A section cut from a knoll, about 200 yards south-east of Boghead Cottage [NX 14415 87414] No. (S5926), shows "a few large grains of olivine, traversed by veins of magnetite and presenting a turbid appearance, in consequence of the presence of minute specks, lath-shaped plagioclase, pale-brown augite, brown hornblende, and iron-ores". The rock has been named by Mr. Teall a porphyritic hornblende-olivine-dolerite. Similar intrusive junctions between the dolerites and serpentine occur on the east side of Garna Burn, on the moor, about three-quarters of a mile due north of the farmhouse of that name [NX 15547 87769].

Again, at the base of the northern stone of Knockdolian Hill, several lenticular masses of basic rock protrude through the serpentine; one of these, named on the six-inch map "Duniewick" [NX 11568 85177], has a chilled margin, with the serpentine, the latter adhering to it in patches. The strip of intrusive rock which forms Balnowlart Knowes [NX 10697 83787], about a mile and a half north-east of Ballantrae, and is bounded on the north by serpentine, on the south by volcanic agglomerate, is composed of dolerite, containing augite, plagioclase, and iron-ores, with chlorite as a secondary product. In like manner the rock at the Castle of Ballantrae [NX 08648 82418], which pierces the agglomerate of Mains Hill, is a dolerite No. (S6460) with traces of ophitic structure, and containing augite, altered plagioclase in broad lath-shaped sections, iron-ores, and chlorite. The rock at Ballantrae Harbour [NX 08048 83140], the relations of which are uncertain, is a dolerite which shows under the microscope No. (S6461) plagioclase, augite, and iron-ores, with chlorite and other decomposition products.

The mass of basic and acid intrusive rocks which extend from the Byne Hill [NX 18406 94923] to the Grey Hill [NX 16267 92631], present certain interesting petrographical features arising from the marked variation of the rock-types. This mass forms a narrow strip, bounded on the south-east by serpentine and on the north side partly by the Benan Conglomerate, partly by the Arenig lavas, and partly by serpentine. The main portion of the area is composed of gabbro, hornblende-gabbro, and dolerite; while the Byne Hill and Grey Hill display two small patches of quartz-diorite and granite, which to all appearance pass gradually into the more basic varieties. Where the basic rocks are in contact with the serpentine, they are more fine-grained than towards the centre of the mass. Some of the microscopic sections prepared from specimens taken from the margin on the east and south-east sides of Byne Hill show brecciation or cataclastic structures, due to movement between the basic rocks and the serpentine.

In order to show the variation in the rock types and the character of the rocks at the margin, specimens were collected from the east and south-east slopes of Byne Hill, which have been examined by Mr. Teall, who furnished notes on the respective specimens and microscopic sections. Several were taken from the margin of the basic mass, nearly due east of the cairn on the hill-top; the rest were collected from the south-east slope, along a line extending from the junction with the serpentine in a north-west direction towards the cairn on the hill-top.

The observations of Mr. Teall may thus be briefly summarised. On the east side of Byne Hill, the basic rock in contact with the serpentine No. (S6465) is compact, and shows under the microscope "a confused crypto — or micro-crystalline aggregate of indeterminable minerals. Here and there granular aggregates of pyroxene may be recognised, and small grains of iron-ore are scattered through the slide. The original character of this rock appears to have been destroyed both by alteration of the constituents and by movement." Another specimen No. (S7786) also from the margin of the basic mass in contact with serpentine is "a compact brownish rock, showing decided traces of a porphyritic structure when examined with a lens. Under the microscope, the phenocrysts are found to be either felspars or pseudomorphs after idiomorphic augite. The pseudomorphs after augite are formed either wholly or partially of brown hornblende similar to that which occurs in the rocks of Littleton Hill No. (S5927). The ground-mass is very fine in grain. Examined with a high power, it is seen to be an aggregate of brown hornblende nd felspar. It resembles the ground-mass of the rocks from Littleton Hill in composition but the structure is much finer".

Westwards from its margin, for a distance of about 70 yards, the basic rock varies from hornblende-olivine-gabbro No. (S6470), with "large ophitic individuals of nearly colourless augite, olivine, labradorite, with brown hornblende as an accessory constituent", to hornblende-gabbro. The latter rock No. (S6475) contains hornblende, both brown and uralitic, altered felspar, iron-ores, little or no pyroxene and a little biotite. At a point about 76 yards from the edge of the intrusive mass, the eruptive rock becomes richer in felspar. About 86 yards from the margin it merges into a quartz-biotite-diorite, and still nearer the top of Byne Hill into biotite-granite, with oligoclase, orthoclase, quartz and biotite.

Similar evidence is obtained from the southern slope of the Grey Hill, where a fringe of basic rocks (dolerite and gabbro) surrounds the core of granite.

Though the evidence in the field shows that the passage from the hornblende-gabbro to quartz-biotite-diorite and biotite granite is tolerably abrupt, yet no indication of a chilled margin or intrusive junction is observable. It is probable, however, that by a process of differentiation the biotite granite may be a slightly later product of the same magma that gave rise to the basic rocks.

On referring to the Geological Map (Sheet 7) it will be seen that the various plutonic rocks have been injected mainly along the bedding-planes of the volcanic series and overlying sediments. Fortunately there is definite evidence regarding the date of these intrusions, for they are clearly older than the formation of the Kirkland and Benan Conglomerates, which are mainly made up of their detritus and rest unconformably on the volcanic platform. It is interesting to observe that the evidence, though imperfect, points to the conclusion that the total thickness of conformable sediments under which the intrusive rocks were injected was not great, and yet the injections include coarsely crystalline rocks such as gabbro and granite.

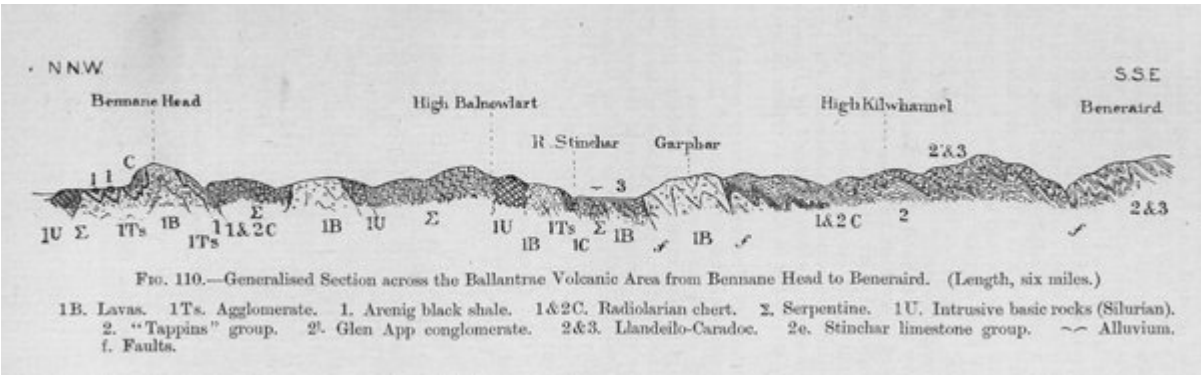


FIG. 110.—Generalised Section across the Ballantrae Volcanic Area from Bennane Head to Beneraird. (Length, six miles.)

1B. Lavas. 1Ts. Agglomerate. 1. Arenig black shale. 1&2C. Radiolarian chert. Σ. Serpentine. 1U. Intrusive basic rocks (Silurian). 2. "Tappins" group. 2e. Glen App conglomerate. 2&3. Llandeilo-Caradoc. 2e. Stinchar limestone group. ~~ Alluvium. f. Faults.

(Figure 110) Generalised Section across the Ballantrae Volcanic Area from Bennane Head to Beneraird. (Length, six miles.) 1B. Lavas. lTs. Agglomerate. 1. Arenig black shale. 1&2C. Radiolarian chert. Serpentine. 1U. Intrusive basic rocks (Silurian). 2. "Tapping" group. 2I. Glen App conglomerate. 2&3. Llandeilo-Caradoc. 2e. Stinchar limestone group. [symbol] Alluvium. f. Faults.

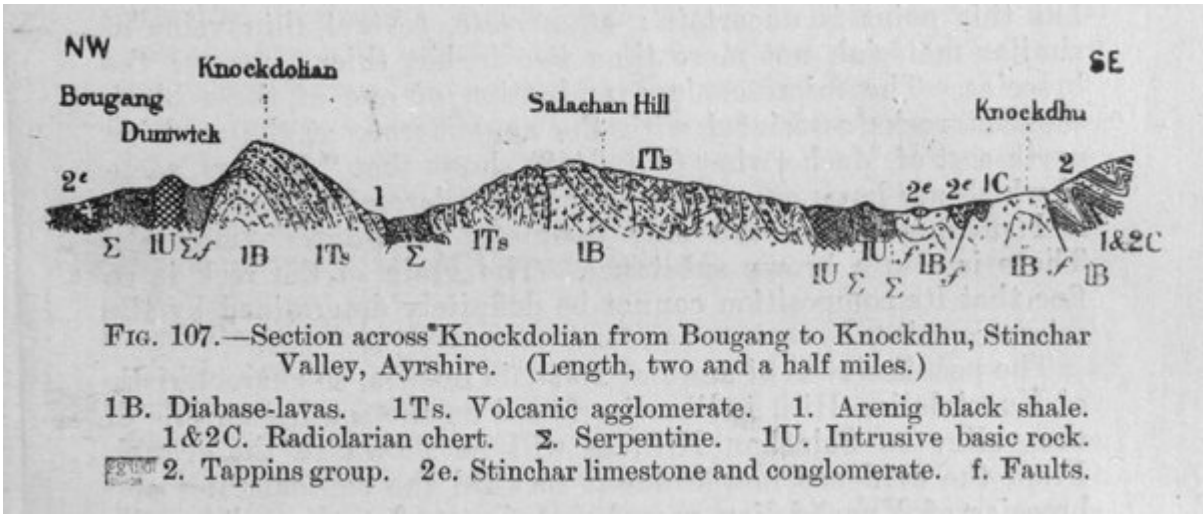


FIG. 107.—Section across Knockdolian from Bougang to Knockdhu, Stinchar Valley, Ayrshire. (Length, two and a half miles.)

1B. Diabase-lavas. 1Ts. Volcanic agglomerate. 1. Arenig black shale. 1&2C. Radiolarian chert. Σ. Serpentine. 1U. Intrusive basic rock. 2. Tappins group. 2e. Stinchar limestone and conglomerate. f. Faults.

(Figure 107) Section across Knockdolian from Bougang to Knockdhu, Stinchar Valley, Ayrshire. (Length, two and a half miles.) 1B. Diabase-lavas. 1T s. Volcanic agglomerate. 1. Arenig black shale. 1&2C. Radiolarian chert. 2. Serpentine. 1U. Intrusive basic rock. 2. Tappins group. 2e. Stinchar limestone and conglomerate. f. Faults.

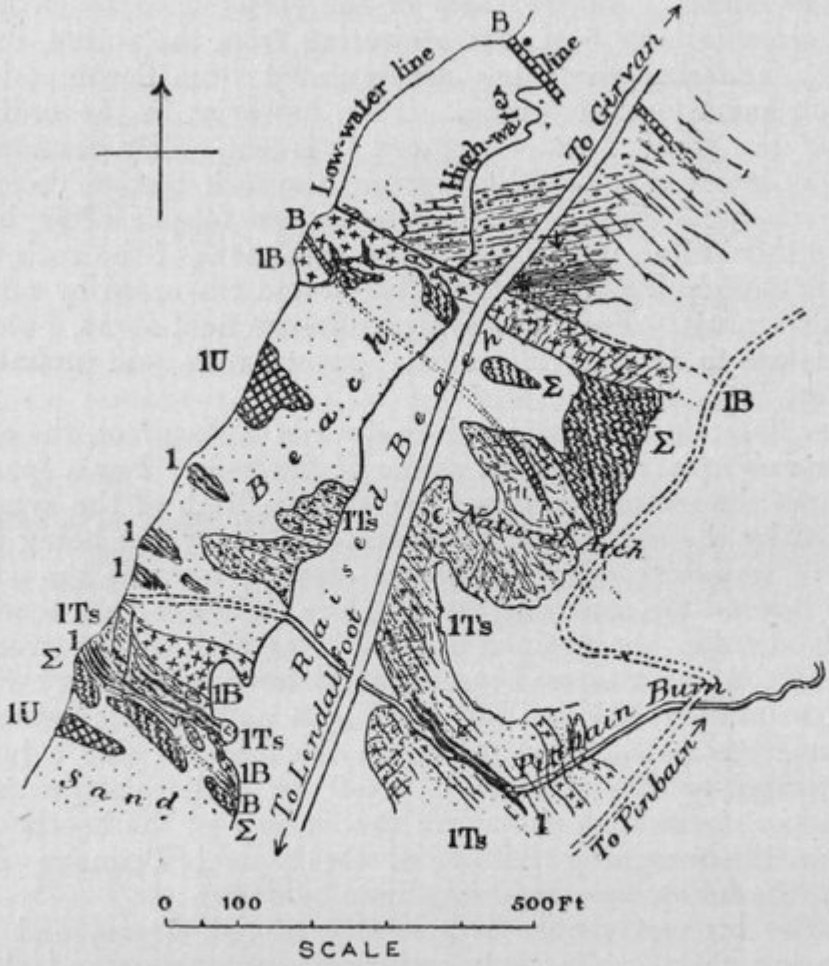
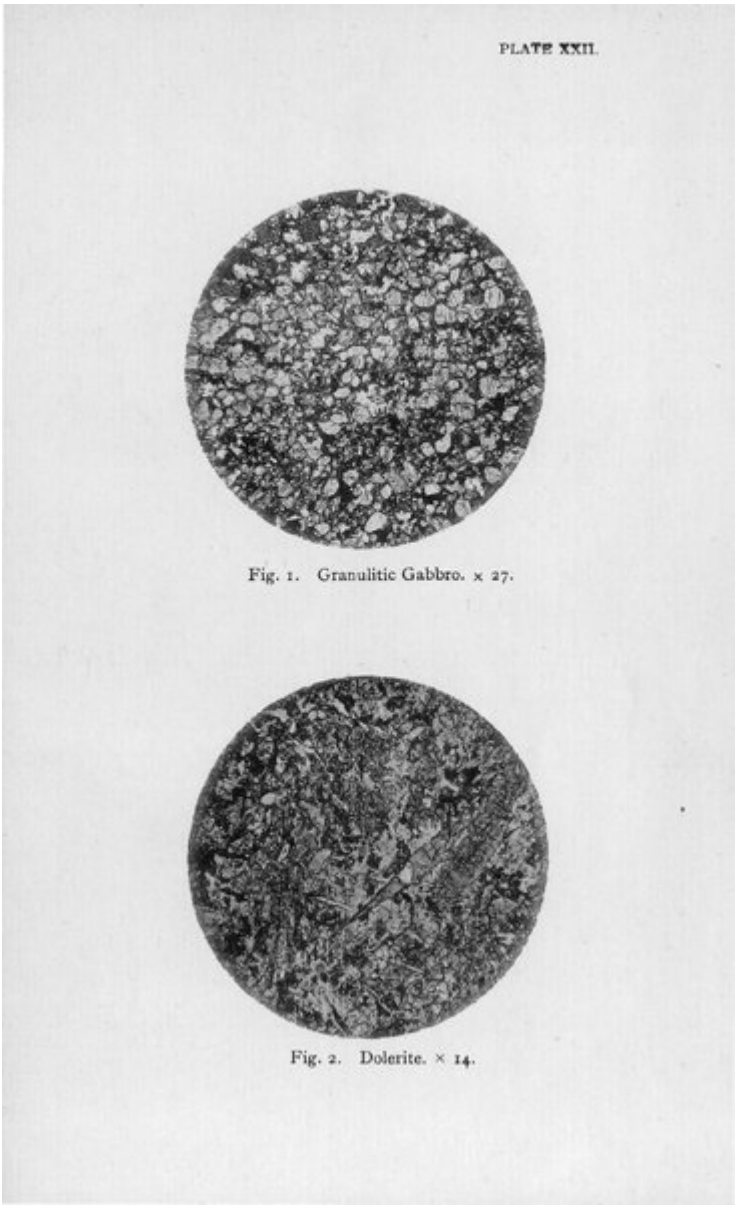


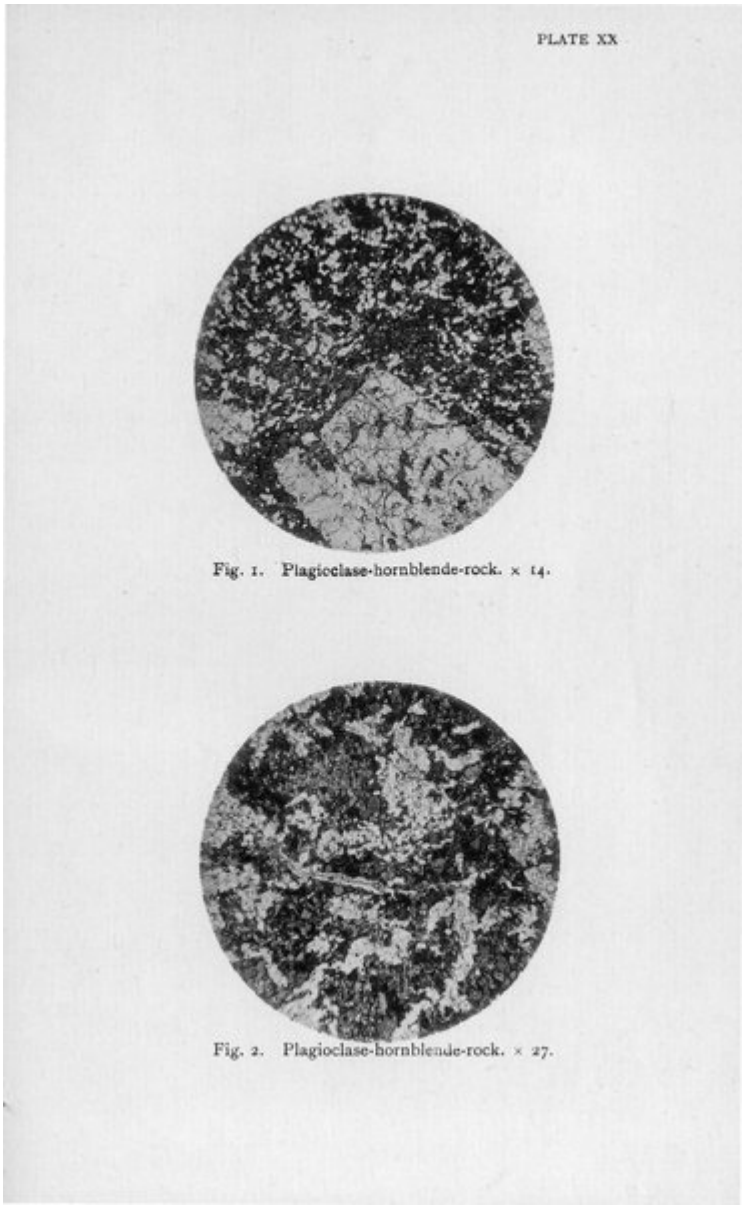
FIG. 104.—Plan of Strata on the Shore, Pinbain, one mile north of Lendalfoot, Ayrshire.

1. Arenig black shale. 1B. Diabase lava. 1Ts. Agglomerate. Σ. Serpentine. 1U. Intrusive basic rock (Silurian). B B. Dolerite dykes (Tertiary). f. Fault.

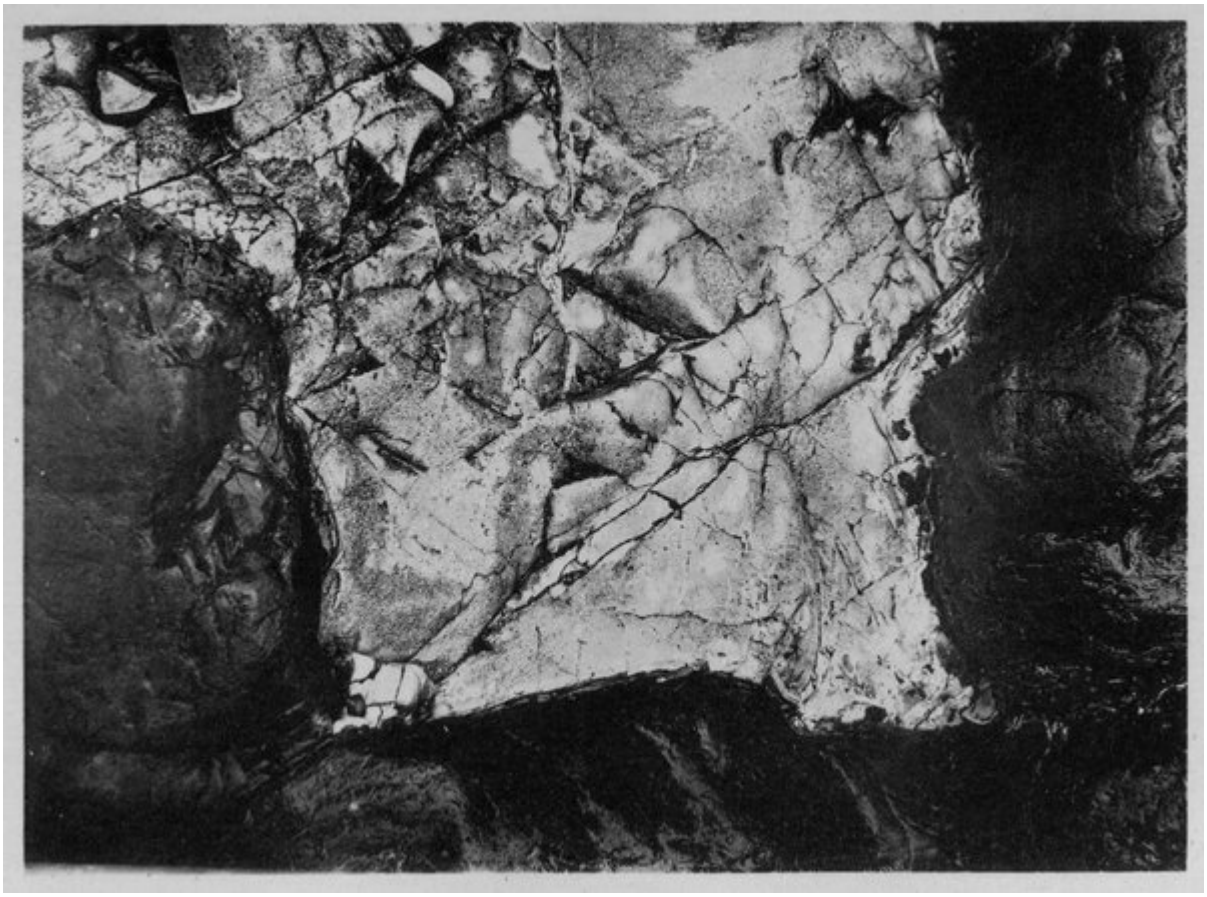
(Figure 104) Plan of Strata on the Shore, Pinbain, one mile north of Lendalfoot, Ayrshire. 1. Arenig black shale. 1B. Diabase lava. 1 Ts. Agglomerate. Σ. Serpentine. 1U. Intrusive basic rock (Silurian). B B. Dolerite dykes (Tertiary). f. Fault.



(Plate 22) 1. (S6494) Near old loch, Craig Hill. One mile N.B. of Garnaburn. Magnified 27 diameters. Banded granulitic rock composed of malacolite, felspar, brown hornblende, and iron ores. The greater portion of the figure represents a band of malacolite, felspar, and iron ore; at the top and slightly to the left is a small portion of a band formed of hornblende and felspar. This rock is the beer-bachite of Chelius. 2. (S6453). —Dolerite from centre of dyke, Lendalfoot. Magnified 14 diameters. The minerals represented are augite, more or less altered plagioclase, and magnetite. The augite shows a marked tendency to elongation in the direction of the vertical axis. Fig. 1. Granulitic Gabbro. x 27. Fig. 2. Dolerite. x 14.



(Plate 20) 1. (S5927) Littleton Hill, Colmonell. Mass surrounded by serpentine. Magnified 14 diameters. Portion of a large phenocryst of plagioclase containing inclusions of brown hornblende in a ground-mass of brown hornblende, granulitic plagioclase, and iron ore. 2. (S6495) From boss near sheepfold, half a mile due W. of Balhamie Hill. Magnified 27 diameters. The dark patches are aggregates of brown hornblende; the white patches are aggregates of granulitic felspar. It will be observed that some of the patches of granulitic felspar show decided traces of a lath-shaped form. It is probable that the original rock was a dolerite. Fig. 1. Plagioclase-hornblende-rock. x 4. Fig. 2. Plagioclase-hornblende-rock. x 27.



(Plate 14) Junction of Dolerite dyke (light coloured mass) with Serpentine (darker mass), stack on shore 300 yards north of Lendalfoot.