Chapter 4 Petrography of the igneous rocks in the Lower Silurian formations of the Southern Uplands

Lavas and tuffs of basic and intermediate composition occur in the neighbourhood of Ballantrae (Sheet 7) and in that of Sanquhar (Sheet 15). The petrographical description of the rocks is attended with considerable difficulty on account of the extensive alteration to which they have been subjected and the consequent unsatisfactory state of preservation of the specimens.

The rocks which undoubtedly occur as lavas in both localities are usually dark green, more rarely purple in colour. Two fairly well marked types may be recognised, but they are connected by more or less ill-defined transitional forms. The one type is a compact, dark green, non-porphyritic rock, often containing numerous small spherical amygdules, which usually measure about 2 or 3 mm. in diameter; the other is markedly porphyritic, containing large crystals of more or less altered plagioclase embedded in a dark green matrix.

These two types would be termed respectively diabase and diabase-porphyrite by German petrographers. Specimens of the latter type often bear a close resemblance to the well-known "porfido verde antiquo". (See (Plate 18)., figs. 1 and 2; (Plate 19)., fig. 2.)

Both types, as well as the intermediate varieties with scattered and often inconspicuous phenocrysts of felspar, were in the first instance probably composed of plagioclase, augite, iron-ores, and a variable quantity of imperfectly crystallised interstitial matter. Augite may now be detected in some specimens, but it has often entirely disappeared. Only one generation of this mineral appears to have been present in the majority of the true lavas; but the tuffs contain large idiomorphic crystals similar in form and size to those which may be picked up on the slopes of Stromboli, and also rock-fragments in which similar crystals occur as phenocrysts.

When two generations of plagioclase occur, the phenocrysts are more basic than the constituents of the ground-mass. The former occur as thin or thick tables and sometimes as crystalline groups. They are often completely decomposed, and sometimes possess a green colour in consequence of the presence of chlorite. The felspars of the ground-mass of the "diabase-porphyrites" and of the non-porphyritic "diabases" occur either as microlites, or in forms giving the ordinary lath-shaped sections. The microlitic forms are especially characteristic of the lavas with "pillow-structure", in which porphyritic crystals are com paratively rare; the lath-shaped sections are, on the other hand, more characteristic of the rocks containing conspicuous phenocrysts of felspar.

Chlorite and carbonates are present in great abundance. They occur scattered through the rocks, and also in veins and as the infilling material of many of the amygdaloids.

The lavas with "pillow-structure" are of special interest, because rocks of the same general character, and possessing this remarkable structure, have been found associated with radiolarian cherts of different ages and in such widely separated localities as the Southern Uplands of Scotland, Cornwall, Saxony, and California<ref>On Greenstones associated with Radiolarian Cherie. By J. J. H. Teall. Roy. Geo.. Soc., Cornwall. 1894. Page 3.</ref> A specimen from Gatelochside Burn, near New Cumnock, may be selected as a type of this class of lava. It was taken from the outer portion of the pillow-like masses, and is a greenish-grey, fine-grained rock containing small spherical vesicles, filled with calcite. Under the microscope the rock is seen to be composed of long slender microlites of felspar, chlorite, carbonates, and iron-ores. Granular augite was probably present, but, if so, it has entirely disappeared. There was doubtless also a small quantity of interstitial matter. The microlites of felspar are often carved, and sometimes arranged with their long axes more or less parallel to each other, in consequence of differential movements in the magma before final consolidation. Flow-structure is not, however, a character of the rock as a whole. Those microlites which lie in the immediate neighbourhood of an amygdule show a tendency to arrange themselves tangentially with respect to the wall of the original cavity. All the microlites give approximately straight extinction and possess a refractive index closely agreeing with that of hard balsam. They are, therefore, oligoclase.

An analysis of this rock is given below, together with that of the "spheroidal basalt" from Point Bonita, near San Francisco, described by Mr. Leslie Ransome.<ref>The Eruptive Rocks of Point Bonita. University of California. .Bull. Depart. Geol. Vol. 1., p. 106.</ref> It is interesting to note that the latter rock is also associated with radiolarian cherts.

	I.	II.
SiO_2	46.4	49.45
TiO_2	0.24	2.23
$A1_2O_3$	20.4	17.58
Fe_2O_3	6.9	{3.41
FeO		{3.41
CaO	7.7	7.20
MgO	3.5	4.05
Na,O	6.93	5.83
K_2O	0.54	1.57
CO_2	5.8	—
Loss on ignition (less CO_2),	1.1	Total lose, 4.34
	99.51	99.07

I. Amygdaloidal "diabase", Gatelochside Burn, near New Cumnock: Specimen taken from outer portion of one of the pillow-like masses.

II. Spheroidal basalt from exterior portion of a large spheroid, Point Bonita, California.

The rock from Point Bonita bears a very close resemblance to that from New Cumnock both as regards macroscopic and microscopic characters. Both rocks show the same "pillow-structure", both contain spherical amygdules of about the same size, in both the amygdules are more common in the outer portions than in the centres of the pillow-like masses, both are associated with radiolarian cherts, and both have the same mineralogical composition and microscopic structures. Under these circumstances it is interesting to note that they possess marked chemical affinities. The special feature is the high percentage of alkalies, 7.4 in both rocks, as compared with the low percentage of silica.

Other specimens of the pillow-lavas, both from the Ballantrae and Sanquhar areas, agree in general characters with the one selected as typical of the group. The principal differences arise from the occasional presence of micro-porphyritic felspars and the more pronounced development in some rocks of interstitial matter containing grains or rods of iron-ore and extremely minute felspar-mifxrolites. In some cases the amygdaloidal cavities have been wholly or partially, filled with this interstitial matter. In one case tuffaceous fragments were observed in a section prepared from a specimen taken from the interior of one of the "pillows". This points to the conclusion that the pillow-like masses, in rolling over, incorporated scoriaceous fragments which either fell upon the stream or were formed by the breaking up of portions of the stream itself.

The pillow-lavas above described present many points of resemblance to the variolitic diabases of Mont Genevre. In speaking of these rocks, Messrs. Cole and Gregory<ref>The Variolitic Rocks of Mont Genisvre. Quart. Jour. Geol. Soc. Vol. XLVI, (1890), p. 311).</ref>, say: "The most striking character of the compacter series is a tendency to spheroidal jointing. Sometimes, as among the crags forming the east side of the Chenaillet valley, south of Mt. La Plane, the spheroids appear piled regularly one above the other, forming walls, as it were, which are divided by conspicuous vertical joints; but the structure is more commonly irregular, the masses resembling pillows or soft cushions pressed upon and against one another, each cliff face thus exhibiting a number of swelling surfaces and curving lines of junction. Examined more closely, small vesicles are seen in these rude spheroids, especially toward the margins; and in some places, as on the east of Mt. La Plane, the whole rock becomes vesicular and slaggy. The surfaces of the masses are covered by a crust of variolite, from 1 to 7 or 8 centim. thick".

Variolitic rocks have not as yet been found in the Ballantrae and Sanquhar areas, but it is clear from this quotation that, the conditions which led to their formation at Mt. Genèvre have been closely approximated to in those regions. It is interesting to note that at Ballantrae, in Cornwall, and at Mt. Genèvre, diabasic lavas with pillow-structure occur in the

immediate neighbourhood of gabbro and serpentine, and that in all three localities some difficulty is experienced in determining the precise relations of the plutonic and volcanic rocks.

The rocks of the "diabase-porphyrite" type do not require detailed description. ((Plate 19), fig. 2.)

The large felspars, which are always so much altered as to make identification difficult or impossible, are sometimes embedded in a ground-mass similar to that of the rock above described, and sometimes in one which is more coarsely crystalline. In the latter case augite is often preserved, the felspars are lath-shaped, not microlitic, and the iron-ores are represented by plates of ilmenite.

The pyroclastic rocks which are associated with the lavas, both in the Ballantrae and Sanquhar areas, are composed of crystals, crystal-fragments, and lapilli derived partly from lava similar to those above described, and partly from rocks of a different character which have not been observed in the form of lavas.

The common type of lava does not contain phenocrysts of augite and hornblende, but the tuffs of Bail Hill, near Sanquhar, have been largely formed by the breaking up of a magma in which crystals of these minerals, often measuring more than 1-inch in diameter, had separated out.

These augitic and hornblendic tuffs are dark green, often almost black in colour, and it is frequently difficult to recognise their tuffaceous character in the hand specimen. The black crystals of augite sometimes project from the freshly-broken surface. Their angles are often quite sharp, and the forms observable are those of the clinopinacoid (010), orthopinacoid (100), prism (110) and the positive hemipyramid (11¯1). Under the microscope the sections of this mineral are yellow or yellowish-green, and a slight pleochroism may often be detected. Inclusions of magnetite are common.

The hornblende, which is sometimes found in association with the augite and sometimes by itself, occurs under similar conditions. The crystals are bounded by the clinopinacoids, the faces of the prism, and by the terminal faces which probably represent a hemipyramid and the basal plane. Under the microscope this mineral is brown or greenish-brown; but the colour is not so strong as in ordinary basaltic hornblende. Sometimes the outer portion of an individual is more deeply coloured than the interior, thus giving rise to a kind of zonal structure. Twinning of the common types may occasionally be seen both in augite and hornblende. Associated with these minerals we find also numerous crystals and crystal-fragments of altered plagioclase similar to that occurring in the lavas of the "diabase-porphyrite" type.

Amongst the rock-fragments which occur in the tufts are lavas of the "diabase" and "diabase-porphyrite" type, and also rocks containing phenocrysts of augite and hornblende in addition to those of, plagioclase felspar. The ground-mass of these latter rocks contains microlites of felspar, grains of iron-ore, and in some cases minute prisms of hornblende or grains of augite. It is often, however, too much altered for precise description. A careful study of the rock-fragments in the tuffs and agglomerates of Bail Hill makes it highly probable that augite-andesites (augite-porphyrites of many authors), hornblende-andesites, and augite-hornblende-andesites contributed to the formation of these rocks.

The only other locality in Great Britain where rocks like those of Bail Hill are known to occur is at Rhobell-Fawr, in North Wales. This locality has been described by the Geological Survey<ref>Mem. Geol. Survey of Great Britain. Vol. III. (2nd Edit.), p. 58.</ref> and by Professor Cole<ref>The Rocks of the Volcano of Rhobell-Fawr. Geol. Mag. 1893, p. 337.</ref>, and the petrographical descriptions of the latter author leave no doubt that the phenomena are substantially identical in both areas. Similar rocks occur near Predazzo, in the South Tyrol, where they have been described as tuffs of augite-porphyrite or porphyry.

Some interesting volcanic rocks of Bala age from Sheet 24 have recently been examined. Amongst these are soda-felsites or keratophyres and perlitic felsites. The soda-felsites occur in Wrae Quarry, near Broughton; at Hamilton Hill, 1¾ mile north-west of Peebles; and in Glencotho Quarry, Holms Water, near Broughton; perlitic felsites are found at Winkston Hill, 2 miles north of Peebles.

The rock of Hamilton Hill may be taken as a type of the soda-felsites. ((Plate 21), fig. 1.)

It is composed of small phenocrysts (3 or 4 mm.) of felspar in a compact dark greenish matrix. The phenocrysts usually give rectangular or rhombic sections, the former being three or four times longer in one direction than the other. They occur also occasionally in the form of crystalline groups. The determination of these phenocrysts is attended with considerable difficulty. They are certainly in all cases alkali-felspar, but they may be in part an acid plagioclase, and in part either orthoclase or more probably anorthoclase. The ground-mass is an aggregate of microlitic felspars, having ill-defined boundaries. Like the keratophyres and bostonites the rock is almost entirely composed of alkali-felspars. Ferro-magnesian minerals formed only a very small proportion of the original rock. They are represented now by extremely minute scales of chlorite which are associated with the microlitic felspars of the ground-mass.

The rock was analysed with the following result:

Silica	64.38
Alumina	16.98
Ferric Oxide	4.04
Carry forward	85.40
Brought forward	85.40
Lime	1.08
Magnesia	0.28
Soda	7.57
Potash	4.30
Loss on ignition	1.64
	100.27

All the other varieties of soda-felsite resemble the one above described in the character of the phenocrysts, but they differ somewhat in the structure of tne ground-mass. This is sometimes cryptocrystalline rather than microlitic, and not unfrequently it shows a spotted appearance under the microscope when viewed with ordinary light.

The perlitic felsites of Winketon Hill ((Plate 21), fig. 2) are compact, dark reddish, mottled rocks. Under crossed nicols, they are cryptocrystalline with frequent traces of very minute microliter. The perlitic structure is very perfectly developed. Small irregular patches of carbonate occur, apparently replacing portions of the original felsite, and the perlitic cracks traverse these patches. Ferrite is scattered through the rock, and occurs also in the perlitic cracks. It is probable that these perlitic rocks are soda-felsites, hut the point has not been definitely settled by analysis.

The petrological characters of the serpentines and gabbros of the Ayrshire coast have been well described by Professor Bonney<ref>On the Serpentine and Associated Igneous Rocks of the Ayrshire Coast. Quart. Jour. Geol. Soc. Vol. XXXIV. (1878), pp. 769–785.</ref>. These rocks hear the closest possible resemblance to the corresponding rocks of the Lizard district in Cornwall. The serpentine of Balhamie Hill, near Colmonell, is composed of glittering crystals of enstatite or bastite in a black compact matrix, and is substantially identical with the black serpentine of Cadgwith. As stated by Professor Bonney, it is an altered olivine-enstatite rock. The following analysis of this rock, made by Mr. Haughton, is quoted from Professor Bonney's paper:

Silica	38.29
Alumina	3.95
Ferric oxide	2.53
Ferrous oxide	4.04
Lime	0.57
Magnesia	35.55
Manganese oxide	tr.
Nickel oxide	0.15
Iron sulphide	tr.
Water	14.08
	99.16

The Survey Collection includes several specimens of serpentines derived from saxonites (olivine-enstatite rocks) in addition to those from Balhamie Hill. In all cases the microscopic structure is perfectly characteristic. Large individuals of enstatite or bastite he in a matrix of serpentine showing the well-known "mesh-structure". In addition to serpentines derived from saxonites there is one derived from dunite, in which picotite occurs as an important accessory, and others about the origin of which it is impossible to speak with confidence. There is no doubt, however, that all have been derived from igneous rocks belonging to the peridotite family. The chrome-spinelle (picotite) which is often present as an accessory constituent has occasionally segregated in masses of considerable size, and the collection includes a specimen measuring 2¼in. by 2in. by 1½ in., almost entirely composed of this mineral. Closely allied to the serpentine in composition is a peculiar rock from Lochton, near Girvan, mainly composed of irregular grains of a colourless monoclinic pyroxene, but which contains also irregular patches of a soft brown substance (? bastite). This rock may be termed a pyroxenite.

The gabbros vary considerably in composition and structure. The ferro-magnesian minerals include angite, diallage, uralitic or fibrous hornblende, and a compact brown hornblende which has many of the characters of an original constituent. In one or two specimens the compact brown hornblende appears to be the only ferro-magnesian mineral present, so that these rocks are diorites rather than gabbros; but as they are closely, linked on to the more normal gabbros by the occurrence of transitional forms, and as they resemble the gabbros in general appearance and in structure, it has not been thought desirable to separate them under a distinct name.

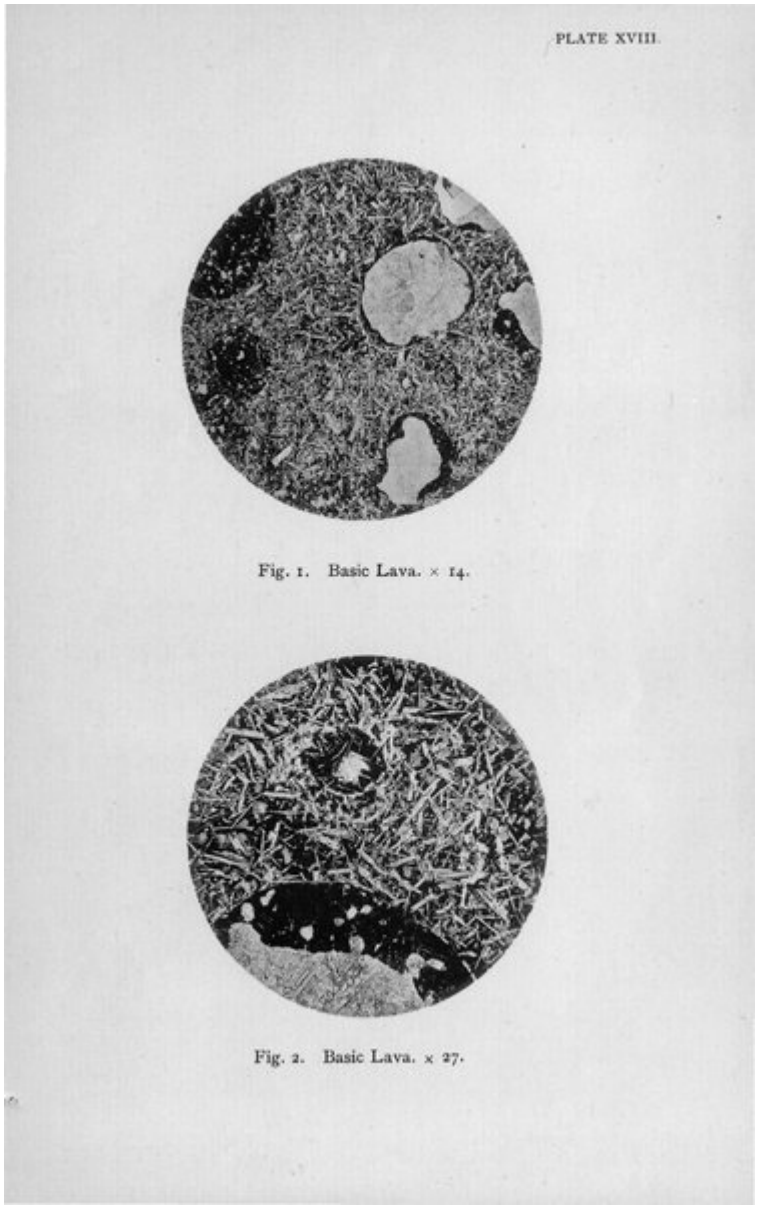
The felspars of the gabbros are rarely, present in their original condition. They are usually represented by white or cream-coloured, compact, hard, saussuritic aggregates which do not admit of any very precise description. It is now well known that many so-called saussurites are aggregates of zoisite or epidote and albite or some allied felspar, but this is not the case with the aggregates in question. Not unfrequently they are largely composed of a pale brown isotropic substance occurring in large irregular patches or in small grains. This substance resembles garnet in many of its characters, but as crystalline form is absent it is impossible to speak with confidence as to the identity of the mineral.

Another mineral which enters into the composition of these dense white aggregates, and which is certainly an alteration product after felspar, is colourless, strongly double-refractive, biaxial, and apparently positive. This mineral occurs in grains which mutually interfere with each other and never shows any definite form or cleavages from which its crystalline system can be inferred.

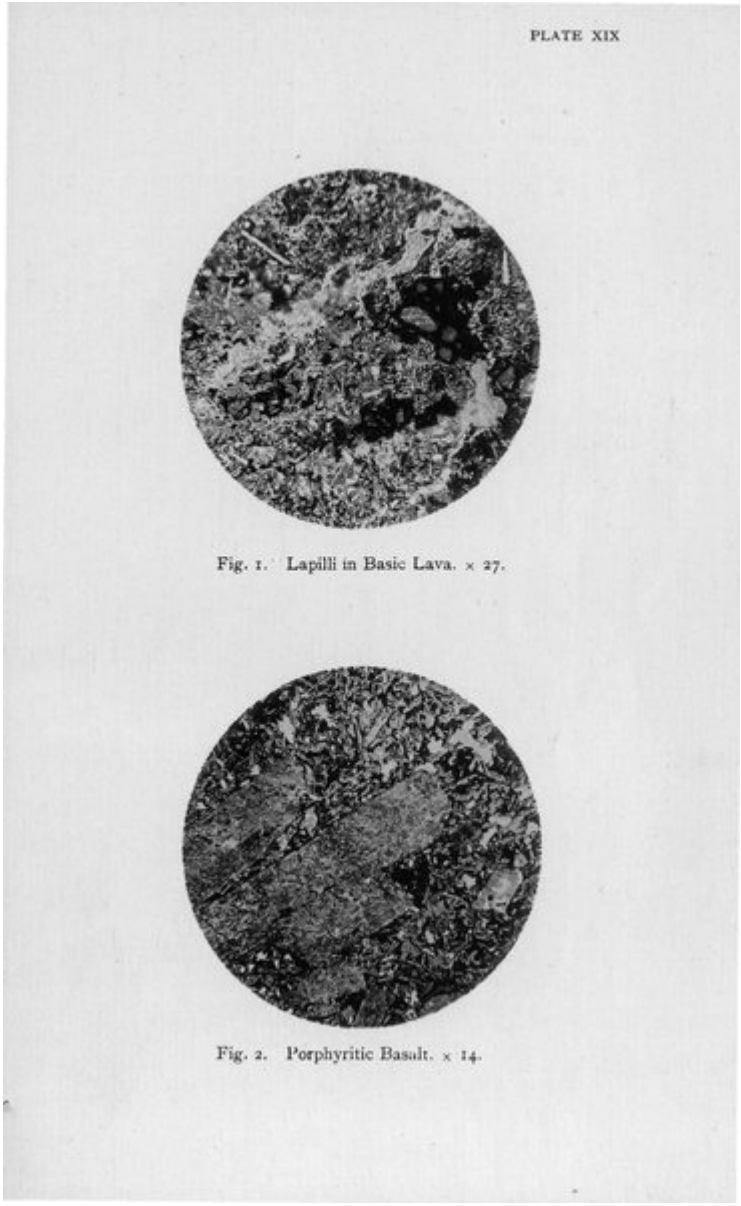
In specimens of gabbro from Burnfoot, one mile south of Lendalfoot, the felspar has been replaced by a soft aluminous serpentine (pseudophite) similar to that occurring in a gabbro-dyke traversing normal serpentine near Kynance, in Cornwall.

The hand specimens of the rocks vary considerably in structure. Some are very coarse and formed of black and white patches measuring an inch or more across, others are of medium grain; some are massive, others show a marked flaser-structure, and a few may be described as banded or even laminated. Under the microscope the massive varieties are granitic in structure, the banded varieties are granulitic, while the flaser-gabbros show a combination of granitic and granulitic structures. The foliation is evidently the result of interstitial movement either during or subsequent to consolidation, and the granulitic structure is a consequence of this movement.

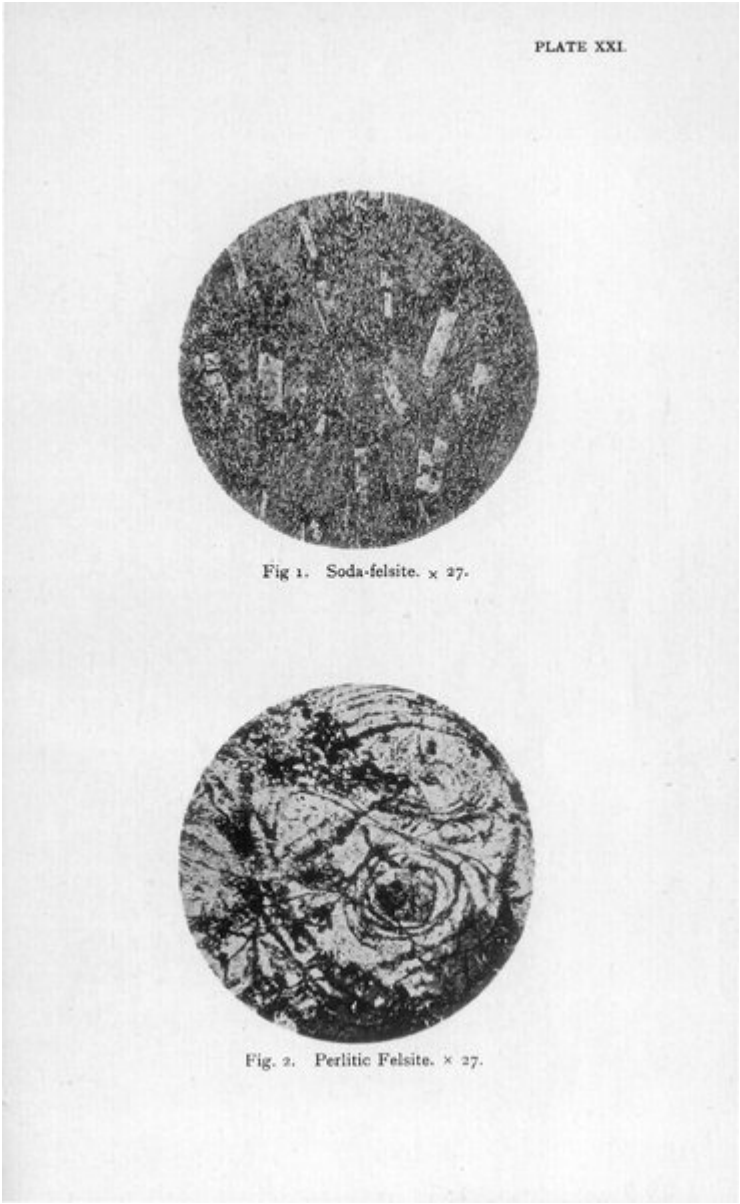
The other intrusive rocks of the district may be grouped as dolerites (ophitic) — (Plate 22), fig. 2, and (Plate 24)., fig. 1, — hornblende-dolerites, epidiorites (altered dolerites), diorites, quartz-diorites, and granitites. Hornblende-schists, which are so common at the Lizard, appear to be rare. The Survey Collection includes, however, specimens of this rock from the north face of Carleton Hill and from the hill-slope one-third of a mile south-west of Loch Lochton.



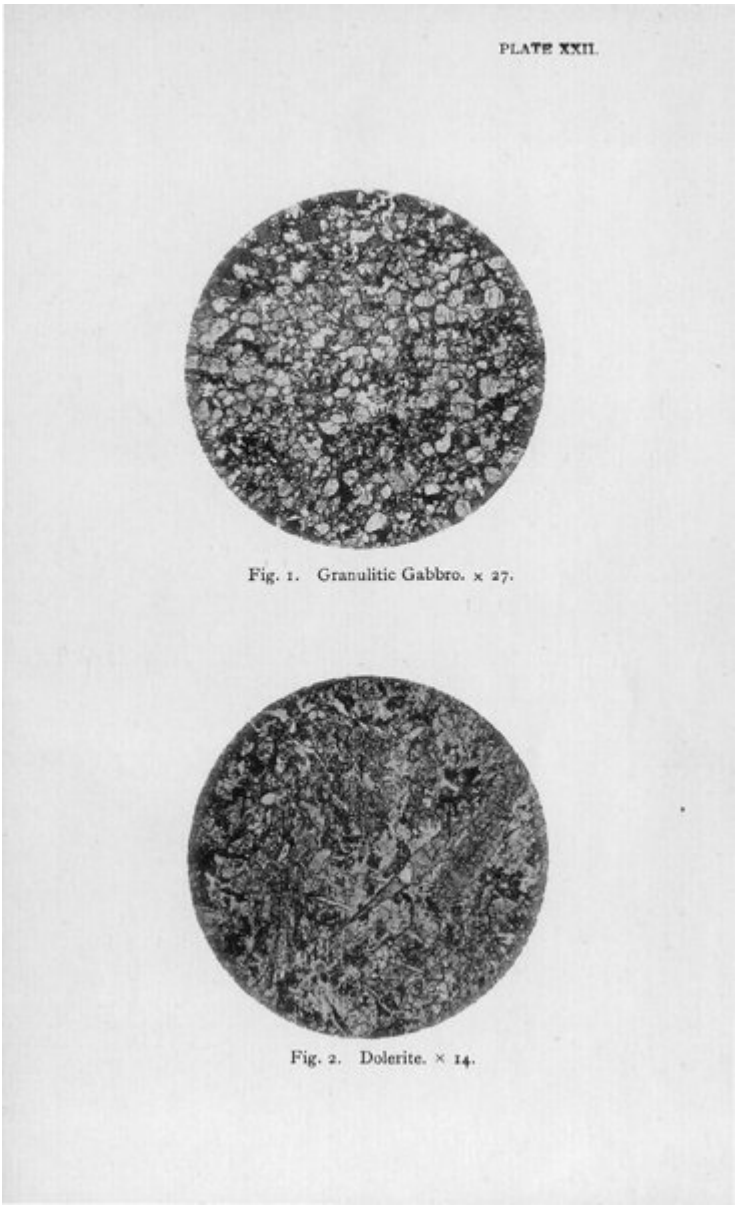
(Plate 18) 1. (S6415) Basic lava; slaggy margin of pillow-shaped mass. 350 yards N. of Port Vad, Ballantrae. Magnified 14 diameters. The large amygdaloid is mainly filled with calcite. A little interstitial matter may be seen round the margin. The irregular cavity below contains both calcite and interstitial matter. At the upper left-hand margin is seen a portion of a large amygdaloid entirely filled with interstitial matter. The main mass of the rock is formed of microlitic felspars, augite-granules, chlorite, magnetite, and interstitial matter. The microiltic felspars only can be clearly recognised in the figure. 2. (S6415) Another portion of the same slide. Magnified 27 diameters. Fig. 1. Basic Lava. x 14. Fig. 2. Basic Lava. x 27.



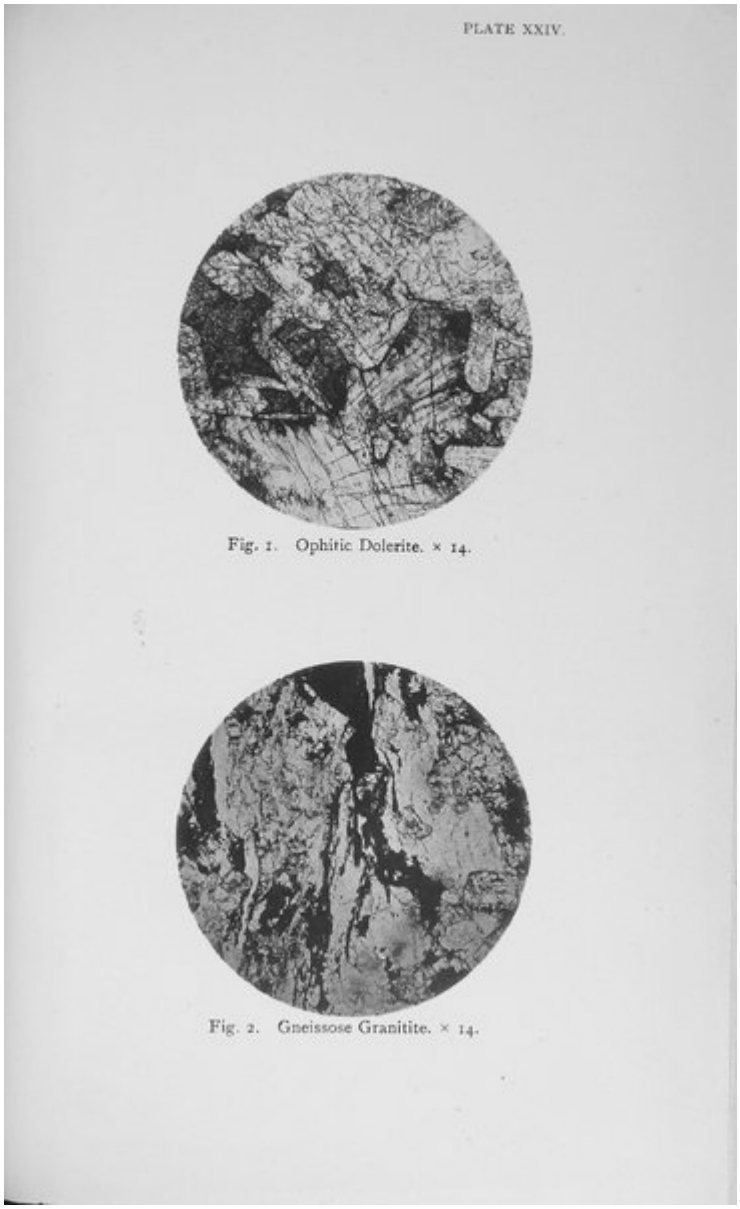
(Plate 19) 1. (S6416) Core of one of the pillow-shaped masses. Magnified 27 diameters. The portion of the slide represented in the figure contains vesicular lapilli; other portions of the same slide are similar to the main mass of the amygdaloidal rocks. 2. (S6419) Porphyritic lava. On shore 400 yards S. of fifth milestone from Girvan. Magnified 14 diameters. Large phenocrysts of basic plagioclase in a ground-mass of small felspars, chlorite, small augites, and a little interstitial matter. Fig. 1. Lapilli in Basic Lava. x 27. Fig. 2. Porphyritic Basalt. x 14.



(Plate 21) 1. (S7510) Crest of Hamilton Hill, Peeblesshire. Soda-felsite. Magnified 27 diameters. Small phenocrysts of alkali-felspar in a ground-mass mainly composed of microlitic felspars (specimen analysed). 2. (S7152) Winkston Hill. Two miles N. of Peebles. Perlitic felsite. Magnified 27 diameters. The perlitic cracks are stained with ferric oxide. In the lower part of the figure the dark space represents a portion of a mass of carbonate which appears to replace the felsite, and through which the perlitic cracks pass without interruption. Fig 1. Soda-felsite. x 27. Fig. 2. Perlitic Felsite. x 27.



(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 24) 1. (S6470). Another portion of the same slide.