

"THE GEOLOGY OF ST. KILDA"

by

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I. INTRODUCTION.

PHYSICAL FEATURES.

St. Kilda lies in Latitude $57^{\circ} 49'$ N., Longitude $8^{\circ} 34'$ W.

It is the largest of a group of four islands located some 50 miles west of Harris and about a hundred from the mainland of Scotland. The submarine bank of Rockall lies 180 miles almost due west. On the east the shallow trough between Harris and St. Kilda never exceeds a depth of 70 fathoms, while the 100-fathom line is situated about 30 miles to the west.

The main island of St. Kilda has an extreme length and breadth of $2\frac{1}{2}$ by $1\frac{3}{4}$ miles and an area of 1575 acres. The two principal inlets of the sea, Village Bay or Loch Hirta, and the Glen Bay open to the south-east and north-west respectively. The highly indented coast line is guarded by almost impregnable cliffs except in the Village Bay where there is a sandy beach a quarter of a mile long backed by a great storm-beach in which the rounded boulders sometimes exceed a diameter of two feet or more.

The island culminates in the beautiful cone of Conachair, 1396 feet above sea-level. Mullach Sgar (715 feet) is connected with/

* See topographic map at end.

with the hog-back ridge of Mullach Geal and Mullach Mòr (1172 feet) by Am Blaid, a broad col over 700 feet in height, which serves as the pass between the north and south bays. On the west coast Mullach Bi attains an elevation of 1146 feet and is the second summit of the island. It is connected by a narrow neck with the Cambir (693 feet), the most northerly point of St. Kilda.

The smoothness of the inland topography is very marked. The flowing contours of Mullach Sgar, Mullach Mòr, and Oiseval, and the almost perfect cone of Conachair, together with the horse-shoe shape of the Village Bay have given rise to an open grassy amphitheatre broken only on the south-east by the sea. Gleann Mòr to the north, bounded by the eastern slope of Mullach Bi and the western slopes of Mullach Geal and Mullach Mòr, is characterised by the same smoothness of outline. The valley has a wide U-shaped form. Inland rock-exposures are comparatively few and small and the treeless slopes are clad to their summits with peat and mountain grass. Six feet of peat were found on the summit of Conachair and an equal depth in many other parts of the island.

There are only two streams of any size on St. Kilda. Amhuinn Mhòr rises on the western slope of Conachair at an elevation of about 800 feet. From its source it falls over 400 feet in/

in a series of cascades and chutes and runs into the Village Bay through the storm-beach. The grade of Amhuinn a' Ghlinne Mhoir, which rises on the 500-foot contour, is more gentle, but the stream drops a hundred feet into the sea over triple falls on the roof of the cave Geo nan Ron. Both streams are rather less than three-quarters of a mile in length and quickly dry up in times of drought. They are quite inadequate to account for the present size of the valleys in which they run. Springs of excellent water occur in several parts of the island, and those within the village wall are freely used for all purposes.

The Dùn is separated from St. Kilda by a channel less than a hundred yards wide and acts as a great breakwater on the south-western side of the Village Bay. It is barely a mile long and about 400 yards broad. Its south-western coast is highly irregular. In places the sea has eroded deeply into the cliffs and is in the process of cutting up the island into a line of stacs. At several points only a hundred yards of rock remain between the bay and the open sea. Levenish (185 feet), two miles from the entrance to the bay, is a relic of the Dùn. Bìoda Mòr (576 feet), the highest point of the island, is precipitous on the west and on the east falls rapidly away in steep grassy slopes to the Village Bay.

Boreray lies four miles north-east of St. Kilda and

Soay a quarter of a mile to the north-west of the Cambir.

These two islands are little more than great stacs. They are girded by a wall of cliffs never less than three hundred feet high, and a landing on them can only be made with great difficulty and when the sea is quite calm. Of the two, Soay has the greater area — 244 acres as against 189 acres for Boreray. The highest point on Boreray is 1245 feet above sea-level, while the summit of Soay is exactly twenty feet lower. Both islands are about a mile long by half-a-mile broad. There is no level ground on either of them, nor are there any streams. Both, however, have permanent springs of good water.

The islands are surrounded by a large number of isolated rocks and stacs, no less than five of which exceed a height of two hundred feet. Stac an Armin (627 feet), lying a quarter of a mile north of Boreray, is the highest stac in Britain. Stac Lee, a mile to the south-west, is 544 feet in height.

A boating expedition round the islands reveals the incessant warfare of the sea against the land. The coastline is honey-combed by caves or 'geos',^{*} as the natives call them, some of/

* The term "geo" (Norse "gja", a creek) is used on the north and west coasts of Scotland to denote "a narrow tide-filled gully on a rocky coast" (I**, p. 69).

** Roman numerals refer to numbers in Bibliography, p. 131.

of which are very large and deep. Many are over a hundred feet in length, and a few pierce the cliffs for nearly three hundred feet, while the beautifully domed or arched roofs may be as much as eighty or a hundred feet high. In some it is possible to row right up to the farthest wall in several fathoms of water. A few terminate in small, rapidly-shelving 'mols' or beaches. These caves have frequently been eroded along the line of a gently inclined igneous dyke where it strikes sea-level. Complete natural arches or tunnels have been formed in a similar manner where a dyke or system of dykes crosses a narrow jutting point. Several blow-holes exist, a particularly fine example occurring near Am Biram on Stac an Armin. Ledges within a hundred feet of the sea are swept clean of debris and vegetation. All around, the great cliffs tower hundreds of feet above the observer. On the north coast of St. Kilda the granophyre of Conachair plunges thirteen hundred feet to the sea below. The dark gabbros have yielded along a diverse system of joints on a grand scale, giving rise to great castellated and bastion-like masses of rock separated by long sheets of dangerous scree and deep chasms from which the dyke rocks have weathered. The serrated northern ridges of Boreray, where spindle and spire are developed on an extraordinary scale, and the appalling cliffs on the north coast of Soay present scenes of the utmost desolation.

Cultivation is confined to the main island where a patch of ground 20 or 30 acres in extent is used to grow potatoes, oats, and hay. The remainder of the area is given over to sheep and cattle. There is an abundance of good peat, little of which, however, is used, the natives preferring to cut and dry sods of green turf.

2. HISTORY OF RESEARCH.

The first authoritative account of St. Kilda was written by Martin Martin (II), who visited the island in 1697 and published his memoir in 1698 under the title: "A Late Voyage to St. Kilda, the Remotest of all the Hebrides, or Western Isles of Scotland." Martin, among many other subjects, gives a good description of the topography of the group, including some notice of the rocks. In his description of Boreray he notes that: "There was an Earthquake here in the Year 1686, which lasted but a few Minutes; it was very amazing to the poor People, who never felt any such Commotion before, or since."

Macculloch (III), in his classical work on the Western Isles of Scotland, published in 1819, has given the first account of the geology of St. Kilda. His intimate knowledge of the rock types/

types of this wide field led him to compare the geology of St. Kilda with that of other Tertiary centres in Scotland. He classified the rocks as all belonging "to the trap family, using that term in its most extensive sense so as to include syenite." He gave a description of the "syenite" (granophyre) of Conachair and Oiseval, and on a sketch map of his own construction indicated the probable line of contact of this rock with the "dark trap rocks" (gabbro and dolerite) with a fair degree of accuracy. Concluding his remarks on the geology, he says: "It must be recollected that in both Mull and Rum there is distinct evidence of the transition of the trap and the syenite into each other, proving that they belong to a common deposit. There is probably the same community of origin in St. Kilda;" Though he noticed the passage of veins of "syenite" into the "dark trap rocks", he held that this was no argument for the posteriority of the "syenite", and considered that the veins might be concretionary.

In 1884, Mr. Alexander Ross of Inverness (IV) published an account of a visit to St. Kilda with some excellent notes on the geology of the island. Ross inclined to the belief that the granophyre was younger than the gabbros and dolerites, but left the question unsettled.

In 1889 Professor Meddle (V) wrote a short paper on the geology of St. Kilda. His visit to the island was very brief and he added nothing new to Ross's account.

It is to Sir Archibald Geikie (VI), who spent a short time on St. Kilda in 1895 and 1896, that we owe the best and most comprehensive record of the geological history of this outlying group of islands. He showed that the main island consists of "1st, a series of gabbros, dolerites, and basalts which have been intruded through and between each other as sills; 2nd, a mass of granophyre which invades those sills; and 3rd, abundant dykes and veins of basalt which occur both in the basic and acid masses." He discovered and described the contact between the granophyre and basic rocks on the northern cliffs of Mullach Mòr, and showed that the granophyre is intruded into, and is therefore younger than, the gabbros and dolerites. Sir Archibald Geikie pointed out that the gabbros and dolerites dip north-eastwards at angles varying from 15° to 60° on St. Kilda and Soay, but that the direction of dip in Boreray appeared to be reversed. Again, similarities with other Scottish Tertiary areas were noted. Dr. Harker gave descriptions of some eight or nine microsections, which may be found incorporated with Sir Archibald Geikie's final account of the geology of St. Kilda in his "Ancient Volcanoes of Britain."

The inaccessibility of the islands and lack of accommodation/

accommodation, the danger of the work, where practically all the rock exposures are situated among cliffs and crags, and the absence, until recently, of a topographical map, have undoubtedly retarded work on this interesting area.

The present thesis is the outcome of two visits to St. Kilda, the first for five months in 1927, when the writer assisted Mr. John Mathieson, F.R.S.E., F. R. S. G. S., in his topographical survey of the group, published by the Ordnance Survey in 1928; and the second for two months in the summer of 1928.

III. STRUCTURAL RELATIONS.

A. INTRODUCTORY.

The islands of the St. Kilda group are a mere relic of what must once have been a much more extensive complex of igneous rocks. They are composed of a series of gabbros and dolerites invaded by three later masses of granophyre. In addition there is a numerous assemblage of dyke rocks which can be divided roughly into two groups of pre- and post-granophyre age. The complete absence of sedimentary and volcanic rocks and the consequent lack of a base or summit to which reference might have been made, have rendered it almost impossible to interpret the form taken by the older intrusions.

Sir Archibald Geikie (VI., p. 407) stressed the sill or sheet-like relations of the gabbros and dolerites to one another/

* In the latest edition of the Encyclopaedia Britannica it is stated that besides volcanic rocks, St. Kilda "contains hills of sandstones in which the stratification is distinct." This is an error, and may be traceable to Sands' book 'Out of the World, or Life in St. Kilda', published in 1877, pages 30-31. Seton ('St. Kilda: Past and Present', 1878, pages 87-88) quotes Sands but continues: "Professor Geikie informs me that all the specimens of St. Kilda rocks submitted to him by Mr. Sands were of igneous formation."

another, and came to the conclusion that along the western coasts of St. Kilda, the Dún, and Soay the various intrusions were continuous and showed a dominant north-east dip varying in inclination from 15° to 60° . He seems to have inclined to the belief that the dip of the sheets in Boreray was reversed. The writer feels that Sir Archibald Geikie has been influenced by a prominent set of joint planes and the marked north-easterly hade of practically all the dykes cutting the gabbro and dolerite of St. Kilda, Soay, and the Dún. While the conclusions he reached are in part quite accurate they require to be somewhat modified. Differences in the surface weathering on the great sheet-like faces and cliffs of gabbro give the appearance of the presence of several different types of gabbros. Certainly from boating expeditions around the group such a conclusion might appear quite justifiable. Many practically continuous lines of section, run from sea-level to the crests and ridges facing seawards on Levenish, the Dún, the west coast of St. Kilda, and Soay, coupled with the study of a large collection of micro-sections have shown, however, that there is only one gabbro present, an olivine-bearing eucrite. While it is true that varietal forms of this gabbro and small sheets of granulitic and pegmatoid gabbro are crossed in such sections, and that they generally/

generally dip in a northerly or north-easterly direction, they are comparatively small and unimportant. One line of section was run from sea-level to near the summit of Mullach Bi, specimens of the gabbro being collected at intervals of from fifty to a hundred feet. In a vertical distance of over 1100 feet only one gabbro was crossed - the eucrite. Similar but much more interrupted lines of section on Boreray have revealed a similar state of affairs.

This eucrite, with its local variations, is the oldest rock on the St. Kilda group. A sheet-like exposure, 500 or 600 feet in width, of a more acid gabbro practically free from olivine occurs near sea-level on the rock shelves on the western slopes of the Glen Bay. Its contact with the eucrite has not been seen, but it is probably slightly younger than that rock. Then follow the intrusion of some thinner irregular sheets of coarse-grained olivine dolerites and still later of a series of ? sheet-like masses of fine-grained olivine- and olivine-free dolerites. The latest major intrusions are three masses of granophyre which are probably slightly separated from one another in time.

B. THE GABBROS.

a. The largest continuous exposure of gabbro extends from Ruaival through Claigeann Mòr and Mullach Bi to the Cambir. It is continued south-eastwards through the Dùn to Levenish^{*} and north-westwards into Soay, (Plate I., Figs. 1 and 2, Plate II., Figs. 1 and 2, and Plate III., Fig. 1.). At its present maximum development it rises unbroken from sea-level to the summit of Mullach Bi, a height of 1146 feet. It is a bluish or purplish blue eucrite composed essentially of augite, olivine, and a basic felspar. Decrease in the amount of pyroxene with a corresponding increase in the olivine give it sometimes a troctolitic aspect. Local variations in the amount of felspar present also somewhat alter its appearance.

Small lens-shaped or dyke-like bands of granulitic gabbro a foot or two wide are occasionally encountered in the cliff sections. They pass rather abruptly into the normal gabbro but are quite unchilled against it. One unusually large mass/

* Macculloch (III., p. 55) included Levenish in his "syenite" (granophyre) area. The writer spent several hours exploring this small stac, which was found to be composed of gabbro and a few small dolerite dykes. There is no granophyre on Levenish apart from a few veins cutting and "brecciating" one of the dolerite dykes.

large mass of granulitic gabbro occurs in the north-western cliffs of the Cambir (Plate III., Fig. 2.). Great difficulty was experienced in discovering its relations to the surrounding gabbro. First discovered at an elevation of about 600 feet, it was examined at lower levels in the cliffs where erosion along a series of moderately inclined dykes has produced long, narrow, but negotiable rock-ledges. It was found again at sea level in Geo Chaimbir. It is estimated to be about 300 feet thick and appears to dip south-eastwards at a high angle of between 70° and 90° . It is dark blue in colour, of fairly uniform fine grain, and quite unchilled against the surrounding gabbro, into which it sends a number of small irregular tongues. The possibility that this mass may represent a huge block of lava or tuff engulfed and metamorphosed by the gabbro has been carefully considered. Dr. Harker (VII., pages 27, 51-53, and 115-116) has described such phenomena among the gabbros of the Cuillin Hills of Skye, and they have also been noted by Geological Survey workers in Mull. The field and microscopic evidence do not seem to support the possibility of any such origin for the mass described above.

Sheet-like and irregular lens-shaped bodies of olivine-free pegmatoid gabbro are more common than the granulitic bands. They/

They are much larger in size and often attain thicknesses of from ten to fifteen feet, running through the normal gabbro for distances of over a hundred feet and tending to occur at definite horizons among the cliffs. They are fairly sharply demarcated from the gabbro. At several points below the summit of Mullach Bi in the neighbourhood of the Carn Mòr occur huge patches of extremely coarse gabbro in which giant, bladed crystals of augite, six or seven inches in length, are segregated in solid masses or intergrown ophitically with a small amount of felspar. One or two circular masses of prehnite were found embedded in the augite. Plate IV., Fig. 1 shows a ball of prehnite a foot in diameter. There is a fairly abrupt transition from the ordinary gabbro to the giant type described above, but as a rule a slight increase in the amount and size of the augite is noticeable towards the coarser areas, which may be regarded as segregations.

A faint mineral banding is commonly encountered in the gabbro but never on the scale described by Teall, Geikie, and Harker in the gabbros of the Cuillin Hills of Skye. A curious patchy texture was noticed on several occasions. Rounded or oval areas of gabbro richer in the ferromagnesian minerals are surrounded by comparatively leucocratic rock (Plate IV., Fig. 2). There is no change in the grain nor are there any unusual minerals/

minerals developed; we are probably dealing with another form of local segregation. The same figure shows, rather poorly, another feature commonly found in the gabbro. The rock is traversed in many places, notably on the eastern slopes of Mullach Bi, by very numerous bright green veins of actinolitic hornblende and epidote. They are commonly from $1/10$ th to $1/4$ th of an inch wide, occasionally branching and anastomosing, but generally running persistently for long distances through the gabbro, frequently along or parallel to the major joint planes, one series of veins crossing another in a very regular fashion. They project from the weathering gabbro giving it a curiously reticulate surface.

Before leaving the western area it may be noted that all the minor features, the granulitic and pegmatoid bands, the slight mineral banding, and the dominant joint planes show a northerly or north-easterly dip varying from 15° to 60° .

(b). The more acid, olivine-poor gabbro of the Glen Bay occurs as a sheet about 300 feet wide. Its contact with the eucrite is either hidden by a deep covering of soil and turf or inaccessible in the cliffs. Enough has been seen, however, to show that it has a north-westerly strike, and it is presumed to be younger than the surrounding gabbro. A broad/

broad sheet of granophyre has split it unequally into two portions, leaving only a few feet of gabbro on Leacan an t-Sluic Mhoir, the ledges on the eastern side of the bay. The main exposure is confined to the rock shelves immediately north-west of Geo Chruadalian. It was traced for short distances up the two streams which descend the eastern slopes of Mullach Bi and run into the sea near Geo Chruadalian. It is never encountered in Amhuinn a' Ghlinne Mhoir and it is impossible to say how far it may extend up the Glen. It is a coarser rock than the gabbro of the west coast, the component minerals being more obvious to the eye. It differs markedly from all the other gabbros of the group in its high content of iron, which is found in the form of lustrous crystals of magnetite. Several large masses of this mineral occur in the form of rounded segregations up to five feet in diameter. The behaviour of a magnetic compass close to such masses, and indeed anywhere within the gabbro, is very erratic. Crush phenomena are developed throughout this gabbro and will be dealt with in section V on page 50.

(c). A darker more basic gabbro than the last is exposed in Creagan Breac and Creagan Dubh on the south-eastern flanks of Mullach Geal and Mullach Mòr, and also among some isolated knolls on the western slopes of Mullach Mòr (Plate V., Fig. 1.).

It is somewhat coarser and darker in colour than the gabbro of the west coast but in other respects is quite similar. Crushing is found in all the exposures.

(d). A coarse-grained gabbro poorly exposed for about a hundred feet in the upper reaches of Amhuinn Mhor is characterised by the development of small brown plates of biotite and a good deal of green hornblende, both minerals replacing original pyroxene. It is in close proximity to the granophyre of Conachair, a fact which may have some bearing on the alteration of the pyroxene. In the bed of the river and where it has recently been covered by soil, the rock has developed spheroidal weathering on a big scale. Individual spheroids of perfect shape and up to three feet in diameter lie firmly embedded in the surrounding rock or are rotted to a friable, earthy mixture of decomposed crystals, conspicuous among which are abundant glistening flakes of brown mica. The relation of this gabbro to the gabbro of Creagan Breac is not clear. It may be a separate intrusion or a mere local modification of the other gabbro. It is cut by a fine-grained sheet of olivine dolerite and by offshoots from the granophyre and must belong to the earliest phase of intrusion.

(e). Only a cursory examination of the rocks of Boreray, Stac an Armin, and Stac Lee has been made, (Plate V., Figs. 2 and 3.). From a series of specimens fairly widely collected the gabbro composing Boreray and the two stacs appears to be on the whole rather coarser in grain than the eucrite of St. Kilda. Microscopic examination shows that most of it is rather basic in composition and that it is quite comparable with the eucrite of the main island. Apart from the dykes, no structural lines have been distinguished in this area. In the course of a traverse from a point near Sgarbhstac north-eastwards across the island to Sunadal only one type of gabbro, an olivine eucrite was observed. Rather more acid varieties have been found elsewhere on the island.

How the various isolated outcrops of the gabbros of St. Kilda and the adjacent islands are related to one another, whether they originally took the form of a number of separate bosses or whether they are remnants of a complex laccolite, comparable with that of the Cuillin Hills of Skye, is a question which the writer is quite unable to answer.

C. COARSE-GRAINED DOLERITES.

Two sheets of coarse-grained dolerite are found on the west coast of St. Kilda. They are probably only slightly younger than the eucrite into which they are intruded, for at one point or another they have been found cut by all the other intrusions. The first intersects the gabbro of the west coast in the cliffs above the rock An Torc. It is rather irregularly intruded and has been in part destroyed by the invasion of two hybrid granophyre sheets of much later date. It was encountered on the rock shelves around Geo Chile Brianan in the Village Bay. It dips north-eastwards. The second sheet is exposed below Claigneann Mòr at an elevation of about 600 feet. It is between fifty and sixty feet wide and dips south-westwards at an angle of about 50° . It is poorly exposed at the base of the Lovers' Stone, only the upper contact and some ten feet of the sheet being visible. Throughout its entire exposure it is intruded by a dyke and innumerable stringers of granophyre.

A coarse-grained markedly ophitic dolerite that becomes almost gabbroitic in texture, is exposed in the cliffs extending from Gob na h' Airde through the Glacan Mòr to a point immediately above Na Cleitan. The cliffs along this section are so dangerous/

dangerous that it was found impossible to explore them in any systematic way, and the form of the intrusion is not known. The rock is in most places highly crushed.

D. FINE-GRAINED DOLERITES.

The fine-grained dolerites are coloured pale green on the appended geological map. Four different types have been recognised, and, while their areal distribution is fairly accurately known, their relation to one another is completely obscured by the detached nature of the outcrops and the confusion arising from an intricate veining of granophyric material of later age. Moreover, hybridisation of the dolerites on Mullach Sgar by acid material of unknown age has rendered the disentangling of the structural relations of the various intrusions practically impossible. A dark, heavy, fine-grained olivine dolerite found at Lag Aitimir on the southern slope of Conachair and in contact with the gabbro of Creagan Breac and Creagan Dubh is exposed at sea-level and among the cliffs above Na Cleitan on the northern coast. The other three types, which resemble one another very closely in the field, are intruded into the gabbro of the west coast and are exposed near sea-level on the north-eastern shores of the Dùn, in the Dùn passage, and on the upper/

upper slopes of Na h' Eagan north-west of Ruaival. Taken together, the fine-grained dolerites make a very large body of rock, forming the entire hill of Mullach Sgar from sea-level to its summit. Their contact with the gabbro masses is very puzzling. Considering them as a unit, their plane of contact with the gabbro of the west coast, from the Dùn to Laimhrig nan Gall, dips south westwards, (Plate VI., Fig. 1.). Beyond Laimhrig nan Gall there is an abrupt change of dip. In a cave a hundred feet north west of this point, piercing the cliffs for over three hundred feet, it was found that the finer grained dolerites were now dipping northwards. In the Village Bay at Creagan Breac and Creagan Dubh they appear to dip under the gabbro in a north easterly direction. One type, mentioned above, appears again in the cliffs of the north coast at Na Cleitan. They do not appear in the Great Glen, where exposures, however, are small and practically worthless.

E. THE GRANOPHYRES.

The granophyres are confined to the main island of St. Kilda, and are found in three areas.

(a). The granophyre of Conachair and Oiseval.

This is by far the largest of the three intrusions, forming the whole of Conachair and Oiseval and accounting for about/

about a third of the area of St. Kilda, (Plate VI., Figs 2 and 3.). Its contact with the basic rocks at sea-level in the Village Bay is completely hidden but is fairly accurately indicated by the distribution of the boulders in the storm beach and bank of alluvium fronting the sea. The granophyre is not exposed in Amhuinn Mhòr, but from a study of the boulders exposed on the surface of the ground it is possible to follow the line of contact fairly closely until its first exposure is encountered among the crags of Glacan Conachair about 600 feet above sea-level. From this point it may be followed to a height of about eight hundred feet after which a deep covering of peat and turf completely hides it from view. It is exposed again on the north side of the col between Conachair and Oiseval at an elevation of about 1000 feet and descends rapidly to sea-level at Na Cleitan (See Plate VII., Figs. 1 and 2, and Plate VIII., Fig. 1.). A landing was made at Na Cleitan and from a series of specimens collected it was found that the granophyre is quite unchilled on its contact with the basic rock which at this point is a dark fine-grained olivine dolerite. It sends a fine network of dykes, veins, and stringers into the dolerite in all directions. The plane of contact for the first hundred feet above sea-level dips south-westwards at an angle of between 60° and 80° . For the next few hundred feet the angle decreases and after becoming almost/

almost horizontal the line slopes upwards to the col between Conachair and Mullach Mòr at an angle of about 40° , the plane of contact always dipping to the south-west. Towards the summit of the northern cliffs the granophyre was found in contact with a hybrid rock into which it sends abundant offshoots. A number of acid dykes on the northern slope of Mullach Mòr, four of which have been mapped, are probably offshoots from the granophyre. They carry abundant xenoliths of the basic rocks through which they run. In the crags of Glacan Conachair the granophyre is in contact with a strip of dark coloured hybrid rock which is certainly older than the granophyre, the latter not only sending abundant dykes, veins, and stringers into it but also picking up and corroding numerous fragments of it.

The granophyre everywhere underlies the older rocks. The line of contact (See Map) runs N.N.W. by S.S.E. But it is evident that in the Village Bay it must turn eastwards to avoid the gabbro of Levenish. Four and a half miles to the north the gabbro of Boreray and its stacs limits the possible extension of the granophyre in that direction. From such considerations it would appear likely that the granophyre may have formed a circular or oval mass not exceeding five miles in diameter.

The fine-grained dolerites of the Village Bay are everywhere/

everywhere intimately pierced by a complicated network of fine granophyre veins. Sometimes the veins can be traced to small dykes of granophyre cutting the dolerites, but more often they appear abruptly, branching and anastomosing in all manner of intricate patterns and dying out as suddenly as they appeared.

(b). The granophyre of the Glen Bay.

This granophyre is sheet-like in form and intrudes the olivine-poor gabbro of the Glen Bay. It is exposed on Leacan an Eitheir and the rock shelves of the west side of the bay and has been traced for a quarter of a mile up Amhuinn a' Ghlinne Mhoir. A small sheet of similar rock fifty feet west of the main outcrop is probably an offshoot. The western line of contact of the granophyre with the gabbro is remarkably straight. The actual plane of contact is poorly exposed but appears to dip south-westwards at an angle between 60° and 80° . The eastern contact exposed at the entrance to Geo nan Ron and in the waterfall above is approximately vertical. At its maximum the sheet is about 1000 feet broad. A feature noted in this granophyre and not found in any of the acid intrusions elsewhere is the presence of small lines of crush. These take the form of thin thread-like, quartzose veins up to 2 mm. in breadth. They are neither abundant nor very persistent, and their true nature was not realised in the field.

(c). The granophyre sheets of the West Coast.

Two sheets of pale coloured granophyre burst through the gabbro and dolerites of the west coast between Ruaival and Laimhrig nan Gall. They are admirably exposed on the steep rocky slope immediately above An Torc and are seen to be of very variable width, (Plate VIII., Fig. 2, and Plate IX.). Where they emerge from sea-level to the north they are only some ten or fifteen feet wide. Running roughly parallel to one another they increase in width as they ascend the rocky slope, the lower sheet attaining a maximum breadth of about thirty feet, the upper about sixty feet. They strike through the basic rocks in a north-westerly direction, dipping south-westwards at angles varying between 40° and 60° . On the higher parts of the slope, and particularly where they disappear under the grassy western slope of Ruaival, they break up into innumerable dykes, veins, and stringers, often losing their identity as individual sheets. The surrounding rocks have been shattered and veined in the most extraordinary fashion. A certain amount of actual transference of material has taken place, fragments of coarse gabbro lying embedded among the angular debris of fine-grained dolerites. There is thus formed an "intrusion-breccia", the angular or rounded fragments varying in size from large blocks over a foot in diameter/

diameter down to mere chips half an inch wide, (Plate XI., Figs. 1 and 2.). The remnant of a third sheet, or an offshoot from one of the intrusions already described, is exposed in a very inaccessible position below Ruaival (Plate X., Fig. 2.). These intrusions and innumerable offshoots can be traced through the Dun passage to the north-west corner of the Dun where they disappear under turf and soil at the cliff edge, appearing once more in the western cliffs of that island near An Fhaing. The coarser gabbro and dolerites have offered much greater resistance to the disruptive and penetrating magma. They are seldom as intricately veined as the finer-grained dolerites, and it is very striking to note in the field how the fine veining and brecciation practically die out at the contact of the finer-grained dolerite with the gabbro, only a few veins here and there succeeding in penetrating the coarser rock (Plate X., Fig. 1.).

The scene of confusion caused by the brecciation and veining of the country rock in the neighbourhood of the granophyre sheets can scarcely be described. The contrasting colours of the basic and acid rocks enable the observer to follow the brecciation and veining throughout the great inaccessible cliffs on both sides of Anhuinn Gleshgil and among the lower slopes of Leathaid a' Sgithoil Chaoil. A number of small granophyric dykes up to a foot in width cut the granophyre sheets in/

in various places. They are not notably chilled against the older acid rock and can be distinguished from it only with great difficulty. Between the granophyre of Conachair and the intrusions described above the whole of the country rock is intimately veined by innumerable acid stringers. It is quite impossible to say from which mass any particular set of veins are to be derived. Sir Archibald Geikie (VI., p. 412) considered that the granophyre sheets of the west coast were probably apophyses from the main body of granophyre on Conachair. There is, however, a possibility that the former are slightly older in age than the bigger mass. Several dykes of a type of dolerite never encountered in the granophyre of Conachair and Oiseval cut the acid sheets of the west coast. The value of this evidence, however, is doubtful and of rather a negative character.

F. HYBRID ROCKS.

A large exposure of hybrid rock occurs at the base of Mullach Sgar in the Village Bay along the indented shelves at sea-level, where the granophyre magma has broken unevenly through a medium- to fine-grained dolerite. Hybrid zones occur as uneven patches and streaks many feet wide and are distinguishable from the dolerite only by their slightly paler colour, the presence/

presence of a few small druses, and inconspicuous patches of less digested basic rock. In hand specimen the hybrid has a very deceptive doleritic appearance which is not seen in micro-sections of the rock. The characteristic net-veining of the fine-grained dolerites described in the last section is everywhere visible, both in the normal dolerite and in the hybrid. A number of rather coarse granophyre dykes cut the hybrid rock at the eastern extremity of the exposure. They are unusually rich in dark coloured minerals and small, rounded, almost completely digested inclusions of basic rock up to half an inch in diameter. Occasional blocks of the hybrid rock described above also occur in the granophyre dykes, which are quite unchilled on their contacts. The net-veining at this point is difficult to follow, individual veins fading into the surrounding hybrid, and it is conjectured from the facts observed in the field and from the study of microsections that hybridisation may have taken place in two stages, an earlier intrusion of granophyric magma followed very closely by a second intrusion of similar material. We do not seem to be dealing here with a case of impregnation of the fine-grained dolerite, but rather with later intrusion and veining of an already hybrid rock.

Several hundred feet above the hybrid zone just described the fine-grained dolerites exposed among the crags of Mullach Sgar/

Mullach Sgar around Clash na Bearnaich are again hybridised. They are finer in grain than the dolerite exposed at sea-level and very intricately veined, and their hybrid nature is not obvious in the field. They are separated from the hybrid at sea-level by a deep covering of scree and grass.

A coarse-grained hybrid rock is exposed in the crags of Glacan Conachair and again on the northern precipices of Mullach Mòr. Its hybrid nature is generally betrayed by its patchy, uneven, drusy crystallisation. In places it is almost gabbroitic in texture, in others more finely doleritic. It has been seen in places in contact with the granophyre of Conachair and Oiseval and it is intruded by granophyre veins which are almost certainly offshoots from the acid rock of these hills.

G. THE DYKE-ROCKS.

Many interesting features among the dykes of St. Kilda have been observed, but it is only possible here to note the more important and critical points. The following observations hold true for the dykes as a whole, irrespective of age and composition. On the appended map only a small fraction of the dykes examined have been represented, partly to avoid confusion, and frequently on account of the fact that many have been seen only/

only in cliff-section.

On the western coasts of the Dùn, St. Kilda, and Soay the predominant strike of the dykes is N.W. to N.N.W., while in the Glen Bay and along the northern cliffs of Mullach Mòr it is N.E. The change does not occur as abruptly as the map would indicate — a number of N.W. dykes were observed in dip section in the Glen Bay among the cliffs and sea-caves. (The strike of the dykes is of no use in any scheme of classification, as all types, basic and acid, have been found trending in both directions.). While the strike of the dykes on the western coast of Soay is predominantly N.W., those seen among the eastern and south-eastern cliffs appear to strike in a N.E. direction. On Boreray the predominant strike is N.E.

Vertical dykes are of rare occurrence; the vast majority "dip" at angles of from 30° to 60° , the north-westerly dykes dipping north-eastwards, the north-easterly to the south-east. A curious feature was noted among the late dolerite dykes which are so abundant in the sea-cliffs of Conachair and Oiseval. All the dykes exposed on Conachair and those north of Sgeirnan Sgarbh, a rock off the eastern cliffs of Oiseval, have a north-easterly strike and dip south-eastwards. In the Village Bay and among the south-eastern crags of Oiseval as far as Rudha an Uisge the same/

same series of dykes dip north-eastwards. (See Plate VII., Fig. 2). North of Rudha an Uisge the dip of three or four dykes exposed steadily decreases until a point is reached where they become horizontal. Farther north, towards Sgeirnan Sgarbh, the same dykes may be seen sloping up the cliff face, the dip being now reversed and inclined south-eastwards. (Plate XIV., Fig. 1.). One of the dykes described above is known to suddenly plunge below sea-level, resuming its original north-easterly dip, but two or three others can be traced for long distances still ascending the cliffs. The more rapid weathering of the dolerites has given rise to a series of broad ledges, and it is possible to follow two of the dykes described along the broken cliffs, the "synclinal" nature of the ledges reflecting the changing dip of the dykes.

Few of the dykes exceed a width of four feet. Notable exceptions are found among the late dolerites cutting the granophyre cliffs of Oiseval, where one 20-foot dyke splits into three roughly parallel dykes, 11, 7, and 2 feet wide respectively. The agency of the dyke rocks in producing sea-caves and tunnels has already been discussed in the Introduction. By far the largest tunnel in the islands is cut through the point Gob na h-Airde (Plate XIII., Fig. 2) where the sea has eroded along the strike/

strike of three dykes which converge at sea-level, forming an arched tunnel 80 feet high and 400 feet long.

Multiple dykes are of common occurrence; true composite dykes in the sense in which Messrs. Thomas and Bailey (VIII., p. 32) have used the term in Mull are comparatively rare. Without exception the acid members are central and of later age than the basic. The study of the internal contacts is complicated in many cases by the frequent but limited corrosion of many of the basic dykes by the central acid member and by the tendency for the latter to pick up small fragments of the basic rock. Nevertheless it is possible to say that slight chilling of the acid rock on the basic has taken place in most cases. A very interesting composite dyke cuts the granophyre sheets above An Torc. The outer member is a dark medium-grained basalt chilled against the surrounding rocks, the central member a green porphyritic pitchstone largely devitrified. A thin zone of modified rock an inch or two wide intervenes between the two types, and a few highly corroded and modified blebs of the basic rock are included by the acid. The total width of the dyke is about 8 feet. It is symmetrical, the pitchstone being 4 feet wide and bordered on each side by 2 feet of dolerite.

Some of the dykes traversing the various gabbros have been involved in the local crushing. Others of later age, and including all the acid types, traverse the crushed gabbros and are quite undisturbed.

IV. PETROGRAPHY OF THE GABBROS.(a). The EUCRITE of the WEST COAST of ST. KILDA.

Gabbro. This gabbro is a dark bluish or purplish blue rock of medium grain. Ophitic plates of augite, rounded crystals of olivine, and felspar can be distinguished in hand specimen. Magnetite is rather poorly developed. The rock is generally very fresh, with only a thin skin of secondary iron oxides. The more rapid weathering of the feldspars has left the ferromagnesian minerals projecting as sharp, hackly crystals giving a good grip to both hand and foot, a striking contrast with the smoother, treacherous surfaces frequently developed in the granophyres. Locally, the gabbro becomes quite coarse, individual augite crystals measuring nearly an inch in length being common. Occasionally a decrease in the amount of pyroxene, accompanied by an increase in the amount of olivine, gives the rock a troctolitic appearance. The rock is strongly jointed. One very prominent plane dips north-eastwards, and frequently there is an approach towards a rude tabular jointing.

The eucrite of this section is composed essentially of a very basic felspar (bytownite), olivine, and augite, with smaller amounts of hypersthene and magnetite. It is rather highly felspathic, and, though a micrometric analysis of the rock/

rock has not been made, it can be stated with a fair degree of accuracy that the felspar accounts for between 50% and 60% of the total bulk of the rock. As it covers over a third of the total area of the main island it will be described below in some detail, and subsequent comparison will be made between it and the other gabbros of the island group.

In thin section (Plate XV., Fig. 1.) the rock is seen to be remarkably fresh. Except for a small amount of magnetite, olivine is the first mineral to crystallise and occurs as idiomorphic, rounded, and corroded crystals of very variable dimensions. It is quite colourless and in a very fresh condition. Only occasionally is it replaced by fibrous green serpentine or a dark-coloured chlorite that exhibits a strong pleochroism from leek-green to brownish yellow. Though generally free from inclusions, a few crystals were found to be very rich in minute, opaque, rod-like bodies, imparting a faint dusted appearance to the olivine. These schiller inclusions, possibly of ilmenite (IX., page 385), are generally definitely oriented in two directions crossing one another at an angle of about 60° . Magnetite dust has separated out along cracks and on the margins of crystals, and rarely the olivine carries a small amount of dendritic magnetite peripherally. Reaction-borders are seldom developed and when present consist of a narrow/

narrow fringe of small granular crystals of colourless augite or short needles of actinolitic hornblende.

Monoclinic pyroxene is rather more abundant than olivine. It is a colourless to faintly brown or green tinted diopside. Diallage structure and basal striation are common, but twinning parallel to the orthopinacoid has not been encountered. Schiller inclusions are very common and sometimes occur in such abundance as to render the augite practically opaque. They are orientated along two directions intersecting at a high angle and the larger individuals exhibit rather a black or bronze lustre, an effect which is sometimes visible in hand specimens of the rock. The characteristics of these inclusions need not be enlarged upon here. Judd, Harker, and many other workers have described them in great detail in various monographs and Geological Survey Memoirs (X ., page 379 and VII., pages 108-109). It may be noted, however, that in this gabbro the inclusions are found developed in the pyroxene quite evenly throughout the entire rock mass. They do not necessarily increase in occurrence or abundance in the direction of the areas of crushing within the gabbro, while they totally disappear in the more highly disturbed, granulitised rock.

Hypersthene is present in sparing quantity. It is strongly pleochroic from pale green to pink and occurs as rather small/

small poorly-developed crystals closely associated with olivine.

The felspar is typically a very basic one, with a mean refractive index near 1.569, indicating bytownite. Faint zoning is a fairly constant feature and occasionally a crystal demonstrably passes outwards from a kernel of bytownite to more acid labradorite-bytownite, or, more rarely still, to basic labradorite. Carlsbad and albite twinning are common and are sometimes accompanied by a certain amount of fine pericline twinning. It has been noticed that the frequency of pericline twinning increases towards known areas of crush within the gabbro. Though some of this fine twinning is doubtless original, the presence of an unusual amount of it is always an indication of approach towards the crushed rock. Another phenomenon associated with the felspar of this and other gabbros of the St. Kilda group has been noted by observers in other gabbro districts and described at some length by Professor Sollas in his account of the gabbro of Barnavave, Carlingford, (XI., p. 483.). This is the frequent clouding of the felspar by an immense number of dusty and seemingly opaque inclusions of ultra-microscopic size. These inclusions have no definite arrangement within the host felspar, though they appear to avoid the margins of crystals, leaving an irregular, clear fringe towards the crystal edges and thus throwing individual felspars into strong relief with one another/

another in ordinary light. Again this phenomenon is associated with crushing of the gabbro masses. The subject will be discussed more fully when the crushed rocks are described.

Accessory minerals are very sparingly developed. Magnetite is found in poorly shaped crystals enclosed by felspar and augite or in the form of dendritic growths in the olivine and hypersthene. Apatite was seen in only two slices from a collection of over a hundred examined. A few crystals of brown hornblende and reddish brown biotite were encountered, but the original nature of the minerals is questionable, as the rock carrying them was in close proximity to a younger intrusion of granophyre.

Coming now to the order of crystallisation it is noted that olivine, though generally the first mineral to crystallise, sometimes completely encloses little laths of early formed felspar. It is frequently enclosed in poikilitic fashion by the augite (Plate XV., Fig. 3), or fringed in part by an irregular crystal of hypersthene. Hypersthene seldom occurs in the form of discrete crystals and is of earlier growth than the monoclinic pyroxene. The two are never intergrown and it is common to find olivine fringed by a hypersthene crystal on which the augite is moulded. Augite is so commonly moulded on lath-shaped felspar that the texture of the gabbro frequently becomes coarsely doleritic.

SPECIFIC GRAVITIES and ANALYSES.

Five determinations of the specific gravity of different specimens of the eucrite gave the values: 2.88, 2.91, 2.92, 2.93, and 2.95, averaging 2.92.

The chemical analysis of a specimen of eucrite from the western cliffs of Mullach Bi tabulated on the next page is compared with the analyses of: A, the eucrite of Allt Mor na h-Uamha, Rum; B, the eucrite of Ben Buie, Mull; and C, the allivalite of Rum.

In silica percentage, the eucrite of St . Kilda falls between the allivalite of Rum and the eucrites of Rum and Mull. The abnormally high alumina content of the St. Kilda rock may be accounted for in part by its rather highly felspathic nature. Total iron is rather low, but the values for magnesia, lime, and the alkalies compare very closely with the corresponding values for the Rum and Mull occurrences.

ANALYSES.

	1.	A.	B.	C.
SiO ₂	44.78	48.05	46.66	42.20
TiO ₂	0.11	0.49	0.47	0.09
Al ₂ O ₃	22.26	15.35	16.71	17.56
Cr ₂ O ₃	....	0.14	....	0.06
Fe ₂ O ₃	0.88	1.86	2.69	1.20
FeO	5.99	7.53	5.87	6.33
MnO	0.13	0.28	0.12	0.18
(Co,Ni)O	....	0.11	....	0.13
CuO	....	0.05	....	0.04
MgO	12.98	12.53	12.36	20.38
CaO	11.18	11.02	12.57	9.61
Na ₂ O	1.22	1.26	1.16	1.11
K ₂ O	0.23	0.19	0.27	0.11
Li ₂ O	....	....	nt.f.d.	....
H ₂ O + 105°	0.44	0.45	1.24	1.13
H ₂ O at 105°	0.08*	0.15	0.13	0.06
P ₂ O ₅	Trace	....	0.13	....
CO ₂	nt.f.d.	0.44	0.18	Trace
S	nt.f.d.	0.20	nt.f.d.	0.02
Totals	100.20	100.10	100.56	100.21
S.G.	2.91	2.95	2.97	2.96

* not added in total. Rockpowder dried at 105°C before analysing.

1. Eucrite, Mullach Bi, St. Kilda. Analyst, Dr. Naima Sahlbom.
- A. Eucrite, Allt Mòr na h'Uamha, Rum; quoted from A. Harker, Mem. Geol. Surv. Scot. "Geology of the Small Isles of Inverness-shire," 1908, p. 98. Analyst, W. Pollard.
- B. Eucrite, Major intrusion, About 500 yards south-east of summit of Ben Buie, Mull. H. H. Thomas and E. B. Bailey in Mem. Geol. Surv. Scot. "Tertiary and Post Tertiary Geology of Mull, Loch Aline, and Oban," 1924, p. 23. Analyst, F. R. Ennos.
- C. Allivalite, 70 yards south of summit of Allival, Rum. Quoted from A. Harker, Mem. Geol. Surv. Scot. "Geology of the Small Isles of Inverness-shire", 1908, p. 80. Analyst, W. Pollard.

Veining of gabbro.

Thin sections of the numerous green veins that traverse the gabbro so strikingly on the eastern slope of Mullach Bi, and found elsewhere, show them to be composed chiefly of tufted or longitudinally-arranged acicular crystals of actinolitic hornblende and a good deal of fibrous greenish-brown 'uralite', accompanied by epidote and some pale brown radiate zeolitic mineral. They send numerous fingering veinlets into the surrounding minerals. Augite is uralitised and chloritised and the felspar in places is slightly saussuritised. The effects produced by these veins are quite localised, often to the area of the slice examined, and are in no way to be connected with effects produced by later disturbances in the mass. They are regarded as pneumatolytic or juvenile in origin.

Granulitic bands.

The granulitic bands occurring within the eucrite are composed of the same minerals found in the latter rock, namely: olivine, augite, hypersthene, bytownite, and magnetite (Plate XV., Fig. 2.). The texture is granular, using that term in the sense that the minerals composing the rock are approximately equal in size and of small dimensions. Occasionally there is a slight tendency for the felspars to show a certain amount of flow structure, a feature which is sometimes encountered in the gabbro./

gabbro. In none of the slices of the smaller bands of granulitic gabbro of the western cliffs of Mullach Bi, nor in the slices of the great band of granulitic gabbro exposed in the cliffs of the Cambir, is there any sign of unusual minerals which might have been developed by the inclusion and metamorphism of a foreign rock. The schillerisation of the augite and the "dusted" nature of the feldspars, frequently encountered in the granulitic gabbro, are matched by identical occurrences in the normal, coarser-grained gabbro, and are not considered as evidence of the "baking" of foreign rock.

Pegmatoid gabbros.

The small bands and sheets of pegmatoid gabbro are composed of augite, feldspar, and magnetite. Olivine has not been observed. The feldspar is generally a more acid variety than that of the eucrite. Values for the mean refractive indices determined range from over 1.553 to under 1.563, indicating acid labradorite and labradorite. The feldspar is more frequently saussuritised and epidotised than in the normal gabbro, while the schillerised augite is widely replaced by fibrous brownish green 'uralite' and actinolitic hornblende. On rare occasions a little quartz was found in slices carrying acid labradorite feldspar. Magnetite/

Magnetite occurs as much larger crystals than in the gabbro. The texture of the pegmatoid gabbros is coarsely ophitic, individual crystals of augite attaining lengths of three or four inches and including small irregular crystals of felspar.

(b). The GABBRO of the GLEN BAY.

This gabbro is never quite free from the effects of crushing. Enough has been seen, however, to indicate its original characters. It is a coarse-grained gabbro composed essentially of augite, labradorite, and an unusually large amount of magnetite. The ophitic and poikilitic texture so characteristic of the eucrite of the west coast of St. Kilda is seldom observed in thin section. Frequently in the less crushed rock, however, a certain amount of flow-banding is indicated by the felspars, which tend to occur as rather large, lath-shaped crystals arranged roughly parallel to one another. The colourless or pale brown augite is rendered almost opaque by the inclusion of disseminated iron oxide and the development of strong basal striation. This 'salite' structure, combined with a certain amount of twinning on the orthopinacoid, gives rise in places to the characteristic 'herring-bone' appearance. A few rounded and irregular patches of chlorite and magnetite may replace original olivine, which is never found in a fresh condition in any/

any of the slices cut. The felspar present is labradorite. (Mean Refractive Index = approximately 1.5580). It is rather finely twinned both on the Albite and Pericline Laws. A good deal of both forms of twinning, however, is probably secondary and due to strain developed within the felspars. Magnetite is developed in large macroscopic crystals on which the later augites are frequently moulded. Apatite, often completely enclosed by magnetite, is rather abundant.

The specific gravity of this gabbro, by reason of its high content of iron oxide, is unusually high and averages 2.99, between the extremes 2.97 and 3.04.

The heavy, rounded segregations noticed earlier are seen in thin section to consist mainly of augite and magnetite, the latter between 30% and 40% of the total bulk. A few flakes of biotite, generally moulded on the magnetite, and occasional crystals of apatite and felspar also occur. The average specific gravity is 3.71.

(c). The GABBRO of MULLACH MÒR and MULLACH GEAL.

The gabbro exposed at Creagann Breac and Creagann Dubh and on the western slopes of Mullach Mòr and Mullach Geal is rather coarser in grain than the eucrite of the west coast. It consists mainly of augite, basic labradorite, and magnetite. Olivine is present in very small amount. The felspar is a basic labradorite (mean refractive index > 1.558 but < 1.563) showing rather fine Albite twinning. Augite occurs as large plates up to 1 cm. in length and is very commonly moulded on the felspar, which is often also carried in poikilitic fashion by the former mineral. It is fairly widely schillerised, and when clear is seen to be coloured a pale tint of brown or green. Uncrushed olivine has not been encountered. It is very sparing in amount, and from its distribution among the granulitised augite crystals was probably poikilitically enclosed by the latter mineral. Apatite was observed in a few slices.

(d). The GABBRO of AMHUINN MHOR.

The coarse-grained gabbro of Amhuinn Mhòr is quite free from olivine. It is composed of markedly ophitic pale green diopside, acid labradorite, and magnetite. The labradorite (mean refractive index rather under 1.558) is fairly strongly zoned and fringed by a more acid felspar, the refractive index of/

of which is always rather higher than that of the balsam in which the slide is mounted. Some corrosion of the more basic felspar has taken place, fine fingering threads of the acid fringe often piercing to the centres of the crystals. The large plates of ophitic augite are seldom fresh. Sometimes they are completely chloritised but much more commonly they are converted to a fine fibrous aggregate of green amphibole. Rarely this latter mineral is replaced peripherally by a small fringe of brown amphibole. At other times augite is completely replaced by a rich brown biotite, which can be seen developing along definite zones within the less altered crystals, or from the secondary chlorite. Large well developed crystals of apatite are common. It is worthy of note at this point that apatite always increases in abundance with increasing acidity in the gabbro. Dr. Harker has noted the same feature in the gabbros of Skye (VII., p. 113). A number of unusually coarse pegmatoid veins a few inches wide traverse the gabbro of Amhuinn Mhor at different levels, carrying large bladed crystals of augite up to three inches in length and completely pseudomorphed by silky green amphibole and brown biotite.

While the chloritisation and uralitisation of the augite are looked upon as of juvenile origin it would seem probable that the development of biotite, rare in the gabbros of/

of St. Kilda, is due to the proximity of the granophyre of Conachair. A number of small dykes and veins of the latter cut the gabbro in question, and the main mass of the acid rock cannot be more than 400 feet distant.

(e). The gabbros of Soay, Boreray, Stac an Armin, etc.

A detailed study of the outlying gabbros has not yet been made, but the following points may be noted.

The main mass of Soay is composed of a eucrite comparable with that of the west coast of St. Kilda. It is rather coarser in grain than the latter but carries the same mineral assemblage. Refractive index tests indicate that the felspar is bytownite or occasionally labradorite-bytownite. Though the effects of slight crushing have been noted in micro-sections, particularly towards the north-west corner of the island, the gabbros of Soay are, as a whole, relatively undisturbed. The "dusting" of the felspars seen in the gabbros of the main island is scarcely seen and often quite absent.

Stac an Armin, from base to summit, is composed of remarkably fresh olivine eucrite. A hundred feet above sea-level a finer grained band of gabbro of unknown width was encountered, characterised by a large development of hypersthene and only a sparing amount of olivine.

Boreray/

Boreray is composed mainly of a medium to coarse-grained olivine eucrite. Varieties in which the feldspar is labradorite-bytownite and labradorite also occur. Some of the slices cut show a good deal of albitisation, and occasionally some analcinitisation, of the basic feldspars, the alkaline minerals spreading through the feldspars as fine anastomosing threads and irregular patches. These changes are accompanied by a good deal of chloritisation and uralitisation of the pyroxenes and the serpentinisation of olivine. Strain is frequently visible in the feldspars and occasionally the rocks exhibit small lines of crush and granulitisation.

V. CRUSH PHENOMENA.

The crush phenomena observed in the gabbros may be divided into two types:

1. Crushing with the production of a mylonite, unaccompanied by re-crystallisation.
2. Crushing accompanied by granulitisation, implying the partial or complete disruption of individual crystals and re-crystallisation of the same minerals in granular form.

A. The gabbro of the Glen Bay.

The sheet-like intrusion of gabbro in the Glen Bay illustrates crushing of the first type only. In the field, the incipient stages are not visible to the eye except occasionally where some bending among the flow-banded feldspars is seen. Gradually, however, as the observer passes north-westwards over the exposure cataclastic phenomena become obvious in the form of a marked streaking of the rock and the breaking of individual crystals, until a point is reached where the original character of the gabbro is practically lost and it takes on almost a schistose appearance. A rough plane of schistosity striking north-westwards and dipping to the south-west at a high angle is developed, corresponding approximately with the strike and dip of/

of the contact plane of the granophyre to the east. Though never far from the granophyre, the most intense crushing is seldom developed along the line of contact of the two rocks. The most highly disturbed rock is of rather a pale greenish grey colour, slightly mottled in appearance and streaked by long, sinuous bands of smashed pyroxene and iron ore alternating with paler coloured, more felspathic bands.

In thin section the first signs of crushing are always visible among the feldspars which develop fine strain-twinning and shadow-extinction. The fine "dusting" so characteristic of the crushed gabbros elsewhere on the island, is here poorly developed. With increasing crush, faulting of the feldspars takes place — as many as half a dozen fault planes may cut a single feldspar, the displacement of the various fragments being visible under crossed nicols. Actual tearing apart and maceration of the feldspar follows, until crystals originally about 1 cm. in length are reduced to angular fragments $\frac{1}{50}$ mm. or less in size. Further abrasion has often worn the rough edges off many of the sharper fragments, rendering them sub-angular or even rounded in outline. Augite and magnetite have suffered the same disruption but have offered more resistance to the crushing forces. A certain amount of saussuritisation of the feldspar is accompanied by uralitisation/



uralitisation and rarer chloritisation of the augite, and the final product of crushing is a mylonite composed of small irregular grains of felspar, uralitised augite, and magnetite set in an almost opaque, streaked groundmass of iron oxide and dirty green uralite and chlorite (Plate XV., Fig. 5.). Small 'eyes' or 'augen' of less crushed rock are occasionally found, or individual crystals, quite fresh and almost intact, lying in the highly macerated groundmass. (Mörtelstruktur of Törnebohm).

While slight uralitisation of the pyroxene and some saussuritisation of the felspar are always present in the less disturbed rock, there can be no doubt that most of the alteration of both minerals is to be attributed to the act of crushing. Epidote is only occasionally developed. Prehnite has not been encountered in hand specimen or in microsections.

On the small exposure of the eastern contact of the granophyre sheet with this gabbro above Geo nan Ron both rocks are rather highly crushed along the line of contact. The granophyre has acidified the gabbro for a distance of an inch or two east of the contact and is itself slightly basified. There is no doubt concerning the relative age of the two intrusions. The granophyre is slightly finer in grain marginally and sends a few small tongue-like offshoots into the basic rock. Minute lines of crushing are developed sporadically throughout the main body/

body of the granophyre mass and the crushing of the acid rock on the eastern contact is rather intense. The disturbance of the acid rock, however, is slight compared with that seen in the basic, and from the study of microsections the crushing of the acid rock appears to have taken place after crystallisation had ceased. Thus it would seem that we have two episodes of crushing in this area. The gabbro has been crushed probably prior to the intrusion of the granophyre, the granophyre after cooling. The possibility that the intrusion of the granophyre sheet, splitting the gabbro into two very unequal portions, may have been the immediate cause of the crushing developed in the basic rock has been carefully considered, but the writer feels that if this had occurred it would have been reasonable to expect a good deal of admixture of the two rocks along their line of contact, unusual irregularity of the granophyre offshoots, and the filling of a large number of fissures within the gabbro by streaks and threads of granophyric material. Concomitant veining, so characteristic of the granophyres of Conachair and the west coast of the island, is practically wanting, however, and mingling of the two types of rock is confined to a zone an inch or two wide and is of a chemical rather than a mechanical nature.

B. The gabbro of Mullach Mòr and Mullach Geal.

Both types of crushing are present in this gabbro.

On Mullach Geal the crushing is of the second type, i.e., accompanied by granulitisation, implying re-crystallisation of the crushed minerals. On the western slopes of Mullach Mòr, however, the crushing is of the first type, the results of which are in every way comparable with those observed in the gabbro of the Glen Bay and do not call for particular attention, (See Plate XV., Figs. 4 and 6.). The same maceration and streaking of the constituent minerals has taken place, but, on account of the darker colour of the gabbro of this area, the effect is not so obvious to the eye. A highly irregular cleavage is found in the crushed rock, but the rough plane of schistosity developed in the Glen Bay occurrence is not repeated here.

In hand specimen the granulitised rock of Mullach Geal sometimes shows little sign of disturbance beyond an occasional fine, dull grey streaking. At other times, and especially in areas of intense granulitisation, the rock takes on a coarse mottling, the pyroxene losing its sharp outline and vitreous lustre and taking on a dull, almost lustreless appearance. Irregular patches of close-grained, highly granulitised rock several inches in diameter are surrounded by coarser, less crushed/

crushed rock. Epidote is found fairly commonly in the form of bright green clusters of prismatic crystals. Prehnite occurs sparingly.

It is not possible to trace any order or progression in the intensity of crushing. Indeed, from specimens collected from exposures in close proximity to one another, an extraordinary amount of variation is seen. In some slices the feldspars are strained, twisted, and broken, while the large plates of augite have suffered only slight granulitisation marginally and the magnetite remains practically intact. In others, in which the pyroxene is almost completely granulitised, the feldspars, though strained and fractured, retain their original shape.

The feldspars show all stages of crushing, from the development of fine strain-twinning and uneven extinction to twisting and actual shattering followed by recrystallisation in granular form. (Occasional lath-shaped crystals enclosed poikilolitically by undisturbed pyroxene are quite unstrained). They are clouded by innumerable rounded, almost ultra-microscopic inclusions - which have been referred to previously as causing "dusting" - quite unresolvable under a magnification of over 300 diameters. Most of these inclusions appear opaque, but a few of the larger show a definite black border and colourless centre as the tube of the microscope is gently raised or lowered, suggesting/

suggesting that they are probably fluid or gas cavities. They are quite absent from all the re-crystallised granules of felspar, and no new minerals appear to be developed by their destruction. The newly crystallised felspar is seldom twinned and appears to be of about the same refractive index as the original labradorite.

Schiller structures are only sparingly developed within the augite, and it is surprising to find that the cleavage traces never show any sign of bending and that strain-extinction is quite absent. On the other hand, granulitisation of the peripheral portions of the augites seems to take place fairly early. With increasing crush entire crystals are broken up and recrystallised in the form of clear, unschillerised granules, one large pyroxene giving rise to hundreds of the newly formed rounded crystals. Though many of the granules have moved away from the parent augite crystals and form a fine granular mosaic of pyroxene and felspar, the original coarsely ophitic structure of the gabbro is often still visible. (Plate XVI., Fig. 1.). Magnetite is granulitised in the same manner, and is seen migrating along irregular lines of solution in the strained felspars, along with granules of augite and newly formed felspar. Along such lines of solution the dusting of the larger felspars is quite/

quite cleared. The migration of solid trains of granulitised augite, or augite and feldspar, across the larger fractured crystals is common. Olivine has not been identified with certainty, but clusters of bright green completely serpentinitised granules probably represent that mineral in re-crystallised form.

A remarkable feature of this gabbro, and indeed of all the other granulitised rocks, is the freshness of the constituent minerals. Albitisation or analcinitisation of the feldspars and uralitisation or chloritisation of the pyroxene is never encountered.

C. The eucrite of the West Coast.

The interest of the crushing seen in the eucrite of the west coast of St. Kilda lies in the fact that it is possible to trace the phenomenon from its earliest appearance through all stages to the point where a completely granulitised rock is produced. Moreover, the areas of crushing within the eucrite would appear to be definitely connected in some way with the intrusion of the granophyre sheets and dykes extending from the Dun to the Lover's Stone.

The earliest stages of crushing are seldom identifiable in the field, but the method adopted in the collection of hand specimens/

specimens — the system of running long and nearly complete lines of traverse from sea-level to the summits of the crags above, with more particular sampling of the eucrite in the neighbourhood of granophyre intrusions — has shown that the intensity of crushing increases towards the acid masses and their numerous offshoots. It has to be noted, however, that the most highly disturbed rock has been found only once on the contact of the two types of rock. Offshoots of the granophyre sheets, in the form of thin dykelets up to two or three inches in width, cut across the crushed zones within the eucrite, picking up and largely digesting particles of it but never showing any cataclastic phenomena themselves.

From Bìoda Mòr on the Dùn south-eastwards in the direction of Gob an Duin and from the Lover's Stone north-westwards to Mullach Bi, the effects of crushing are confined to the "dusting" of the feldspars as seen in microsection, the dust obviously decreasing in amount in the directions indicated. In the neighbourhood of the Lover's Stone and among the crags of Claigeann Mòr, where a small sheet of granophyre some ten or fifteen feet wide and dipping south-westwards at angles varying between 10° and 20° cuts the eucrite, the latter shows slight crushing which is visible only in thin section. Fine anastomosing lines of crushed/

crushed, granulitised felspar, augite, and olivine traverse the larger strained, "dusted" crystals of felspar and pyroxenes showing peripheral granulitisation. Individual granules have flowed along irregular lines of solution within the strained felspars along which the "dusting" has been cleared. Occasional crystals of olivine and augite are represented by aggregates of minute rounded or sub-angular granules in mosaic form and retaining the original outlines of the respective minerals. At other times granulitisation may be seen commencing along the margins forming a pseudo-reaction-rim.

The most intense crushing of the eucrite was found at three fairly widely separated spots.

(1). In an isolated knoll 400 feet above Laimhrig nan Gall.

Though not encountered in the surrounding grassy slopes, the north-westerly continuation of the granophyre sheets of An Torc are in all probability close at hand.

(2). In a deep gully N.W. of and immediately below the summit of Ruaival. The lower granophyre sheet of An Torc is some ten or fifteen feet distant and sends one or two dykelets an inch or two in width into the highly crushed rock.

(3). At the N.W. corner of the Dun among the almost inaccessible cliffs facing the Dun passage the lower granophyre/

granophyre sheet cuts the highly crushed rock. Samples of the latter, which forms a zone several feet wide, were obtained, but the junction with the acid rock could not be reached.

In all cases the zone of most intense crushing appears to strike north-westwards and, except in the last instance cited, is seldom over a few inches wide. On weathered surfaces the typical rugosity of the normal eucrite is quite lost. The rock breaks with a conchoidal fracture and on a fresh surface has a highly streaked, grey, flinty aspect. Here and there a few un-crushed ferromagnesian stand out from the dull sub-vitreous to almost lustreless, cryptocrystalline groundmass. Where the crushing has crossed segregations of coarser augite-rich eucrite the colour of the "flinty" rock darkens considerably. The passage of this "flinty" rock, which forms only narrow irregular streaks a few inches wide, into the less disturbed rock is always rapid. Indeed, the effects of crushing, though visible under the microscope, can seldom in the field be traced outwards for more than a few feet, and are confined to a fine thread-like streaking which is very difficult to follow for more than a foot or two on either side of the "flinty" zone just described.

Microsections of the "flinty" rock (Plate XVI., Figs. 2 and 3) show it to be composed of a very fine-grained mosaic of rounded/

rounded, granular crystals of augite, olivine, and felspar, literally thousands of granules appearing in the field at any one time, their average diameter being about $\frac{1}{100}$ th. of a mm. Small wedges of less crushed rock or the strained and broken remains of individual crystals are strewn through the groundmass of finer material. The abrupt change from a highly crushed, partly granulitised condition of the rock to a "flinty" zone is sometimes seen in slices. Felspar crystals sometimes reach a surprisingly high degree of curvature before snapping to give off trains of innumerable granules which soon become mingled in an intimate mixture with granules of augite and olivine. Contact metamorphism that may be attributed to the granophyre sheets appears to have produced the amphibolisation of much of the granulitised pyroxene. It is impossible to distinguish granular olivine from granular augite with any certainty, but it seems likely that the former has also suffered amphibolisation. The hornblende is generally pale green in colour, but a pale cinnamon brown variety was occasionally detected. At other times a little pale reddish brown biotite replaces the pyroxene.

Granophyre veins cutting the "flinty" rock are always hybridised. The acid material has picked up small fragments and crystals of the eucrite, and microsections show a curious mixture of/

of broken, corroded crystals of pyroxene, corroded, "dusted" crystals of basic felspar surrounded by clear, more acid zones, irregular crystals of hypersthene, perhaps representing the re-crystallisation of material derived from the solution of the ferromagnesian of the eucrite, and a good deal of magnetite, all cemented by irregular growths of quartz and turbid alkali felspar chiefly in the form of micropegmatite. Occasionally elongate aggregates of the granulitised minerals of the flinty rock, sometimes amphibolitised, are included and may account for the presence of many of the granules of pale green augite which are included in the more acid plagioclase fringing the "dusted" crystals of bytownite.

None of the microsections of the contact of the eucrite with the main masses of the granophyre sheets show very intense crushing of the basic rock. Nevertheless, the following generalisations are possible. Strain-twinning and shadow-extinction, the "dusting" of the feldspars, granulitisation, and contact metamorphism of the eucrite increase towards the position of the granophyre sheets or their apophyses. While a satisfactory explanation of the phenomena observed cannot be given, it would seem that the eucrite has been crushed after crystallisation had ceased within the basic rock and prior to the intrusion of the granophyre, which has perhaps made use of the resultant lines of

of/

of weakness produced by crustal stresses set up by gas explosion or other agency preceding the actual intrusion of the acid magma to reach its present position, which is not necessarily the position of maximum crushing within the eucrite. The ability of the granophyre to shatter the rocks through which it has passed is certainly well demonstrated in this area, and it may be that a release of gas from the granophyre magma, preceding the intrusion of the acid rock, has caused the disturbance seen in the basic rock. It is only fair to state, however, that evidence of mineralisation consequent upon an escape of gas has not been found, unless some of the contact metamorphism of the basic rock observed is to be ascribed to such gaseous action.

VI. PETROGRAPHY OF THE COARSE-GRAINED DOLERITES.

In this section are placed the coarser-grained dolerites of the south-west coast and the northern cliffs of St. Kilda, the distribution of which has been described on page 20.

A. Olivine dolerite of the west coast.

The dolerite intruding the eucrite of the west coast in sheet form above the rock An Torc and among the crags of Claigeann Mòr is a fairly coarse-grained rock of dark green colour and markedly ophitic. It has an average specific gravity of 3.03. In the field it shows a slight tendency to spheroidal weathering, but on the whole is a remarkably fresh rock.

In thin section it is seen to be composed essentially of olivine, both monoclinic and orthorhombic pyroxene, and a basic plagioclase, along with magnetite and a little apatite as accessory minerals, but certain petrographical features, such as the production of biotite from chlorite in the olivine pseudomorphs and the amphibolisation of much of the pyroxene, are probably to be ascribed to contact metamorphism produced by the later granophyre sheets which intrude the dolerite described or occur in the immediate vicinity.

Olivine is rather sparing in amount. It carries numerous/

numerous, minute, rod-like inclusions that frequently show a zonal arrangement, and is sometimes surrounded by a small reaction rim of pale bluish-green fibrous amphibole. In places it is serpentinised, but is generally replaced by a pale greenish brown chlorite from which is derived a good deal of reddish brown biotite. The individual crystals are rather small, highly rounded or corroded, and are often wholly or partly surrounded by the monoclinic pyroxene.

By far the most abundant ferromagnesian is a pale brownish purple faintly pleochroic augite in the form of large ophitic plates. Schiller inclusions are distributed very irregularly throughout different crystals. It is frequently converted wholly or in part to greenish brown or cinnamon brown amphibole, the alteration appearing along the margins of the pyroxene and spreading along cleavage cracks eventually over the entire crystal. Occasionally this newly formed amphibole passes marginally into small irregular patches of a bluish green amphibole. Almost as commonly the pyroxene is replaced by a very pale green faintly pleochroic fibrous hornblende, and it has been noticed that when this or any of the other changes noted above are taking place the pyroxene in the neighbourhood of the new minerals is always bleached, losing its purplish tint, and becoming almost colourless.

The/

The orthorhombic pyroxene occurs as pale green faintly pleochroic crystals with a ragged columnar habit, occasionally moulded on olivine or closely associated with it. It is relatively small in amount and appears to be hypersthene. Alteration to the same pale green fibrous amphibole noted above in the case of the monoclinic pyroxene is common.

The felspar is lath-shaped and typically a basic variety, the mean refractive index being always rather over 1.5580, indicating a basic labradorite ($Ab_4 An_5$). It is twinned on both the Carlsbad and Albite Laws and is occasionally slightly zoned. It is generally highly "dusted" and quite frequently the longer lath-shaped crystals are slightly bent and show strain-extinction.

The iron ore is principally magnetite, on which is moulded some reddish-brown biotite, but a few crystals of skeletal ilmenite altering to leucoxene were observed. Apatite is very sparing in amount.

Sections showing the contact of the dolerite with the older eucrite are interesting and show a curious anomaly. The olivine and highly schillerised augite of the gabbro have suffered the same changes as were noted in the dolerite though in smaller degree. The felspar of the eucrite is highly "dusted" except along the immediate contact with the dolerite, which at this point is almost free from "dusting". For a distance of about/

about $\frac{1}{2}$ mm. from the contact the felspar of the gabbro is generally quite cleared of the "dust".

Acidification of the dolerite and hybridisation of the granophyre have taken place where dykes and veins of the latter cut the basic rock. The interaction of the acid magma with the dolerite is well seen among the crags of Claigeann Mòr and at the base of the Lover's Stone. The large ophitic plates of augite in the dolerite are often completely replaced by reddish brown biotite or brownish green hornblende or a bright yellowish green chloritic mineral. Olivine is completely chloritised. Where actual impregnation has occurred it is curious to note the presence of sphene and orthite, typical accessories of the acid rock, among patches of free quartz and acidified felspars in the dolerite. The basification of the granophyre has produced a hybrid rock resembling the hybrids of Mullach Sgar described on page

B. Dolerite of the north coast.

The dolerite exposed in the northern cliffs of St. Kilda from Gob na h-Airde to Glacan Mòr is rather coarse-grained and strongly ophitic and passes locally into a coarse, almost gabbroitic variety. It is composed of augite and basic labradorite (mean R.I. between 1.5580 and 1.5630) along with magnetite/

magnetite and a small amount of ilmenite.

In thin section the pyroxene is seen to be a pale brownish augite widely uralitised but occasionally replaced by a dirty green chlorite. The feldspar is seldom fresh. It is traversed by numerous fine veins of a more acid feldspar and occasionally by small fingering threads and irregular patches of analcite, the veins and threads passing from one feldspar crystal to another in a fine reticulate pattern. Albitisation is more common than analcitisation. In addition to the threads and veins of the alkaline minerals, numerous irregular veinlets of chlorite and uralite spread from the altered pyroxenes through the feldspars. Epidotisation of the feldspar is occasionally seen.

Crushing has occurred pretty widely throughout the intrusion, but the movement of the crushed material has been very slight. A few streaked lines along which broken fragments have travelled are occasionally seen. Granulitisation, implying recrystallisation, has not taken place. It is curious to note that not only are schiller inclusions uncommon in the pyroxene but that dusting of the feldspars, even where the rock is most highly crushed, is extremely rare.

VII. PETROGRAPHY OF THE FINE-GRAINED DOLERITES.

The petrography of this group of rocks is everywhere modified by the complicated net-veining proceeding from the later granophyres. None of the group show any very pronounced chilling against the gabbros or older coarse-grained dolerites and only rarely do they send offshoots into these rocks. The difficulty of separating the various intrusions has been commented upon on page 21. The following four types have been recognised.

A. Olivine dolerite of Lag Aitmir.

This dolerite is exposed in the Village Bay in Creagan Dubh, Creagan Breac, Amhuinn Mhòr, and Lag Aitmir, and again among the northern cliffs of Mullach Mòr at sea-level near Na Cleitan, in contact with the younger granophyre at the latter point, but intruded into the gabbros of the other localities mentioned. It is a heavy, dark bluish black rock of medium to fine grain and is practically unchilled on its contact with the coarse-grained gabbros. Small porphyritic feldspars up to 2 mm. in length occur evenly throughout the rock. It has an average specific gravity of 2.93.

In thin section this rock is seen to be an olivine dolerite, composed of olivine, augite, and a basic feldspar, with

a good deal of fine, evenly disseminated iron oxide.

The olivine is remarkably fresh, showing only a small development of green or yellowish brown serpentine and the separation of magnetite along irregular cleavage lines and cracks. It is generally rather highly corroded and is occasionally ophitically intergrown with felspar. One or two slices of the rock exposed on Lag Aitmir are abnormally rich in olivine and correspondingly poor in pyroxene, the olivine being very intimately intergrown with the lath-shaped felspars. A few large crystals of iron pyrites were found in association with this olivine-rich variety.

The pyroxene is a pale green- or brown-tinted augite intergrown ophitically with the felspar. A few crystals of faintly pleochroic hypersthene were observed in some slices.

The felspar is lath-shaped, the value for the refractive index (mean value between 1.563 and 1.569) indicating labradorite-bytownite. It is occasionally zoned, the marginal portion of crystals being always more acid than the centre.

Magnetite is abundant and occurs as small, evenly disseminated crystals principally in the ferro-magnesian minerals. Small flakes of reddish brown biotite are found intimately associated with olivine or moulded on magnetite. Occasionally they appear in part to replace a little of the augite.

The texture of the rock as a whole is doleritic,
but/

but where the augite becomes more granular in habit, it is almost basaltic.

The rock is never quite free from abnormal characters which increase in frequency and intensity towards the granophyre and in the neighbourhood of its many offshoots. The feldspars are seldom free from the fine "dusting" seen in the coarser gabbros and dolerites, and occasionally the normal grey polarisation colours are masked by a brown discolouration where the "dusting" becomes unusually abundant. Slight strain is sometimes indicated by the bending of twin lamellae and by shadow extinction. Olivine is serpentinised or replaced by rounded aggregates of green chlorite and brown biotite, while augite is replaced completely or in part by brownish green hornblende. Microsections of the dolerite cut by granophyre veins show a certain amount of acidification of the feldspars of the dolerite and corresponding basification of the feldspar of the veins. Olivine is always altered in the manner described above, but augite, though often altered to brownish green hornblende, generally re-crystallises, both in the dolerite bordering the veins and in the veins themselves, in the form of small, pale green, columnar, prismatic, or granular crystals of augite.

B. Dolerite of Amhuinn Gleshgil.

This dolerite is exposed in the ravine of Amhuinn Gleshgil east of Claigeann Mòr and among the crags surrounding the ravine. It is a fine-grained non-porphyrific rock of greenish grey colour, the chloritisation of the ferromagnesian minerals being obvious to the eye. The determination of the specific gravity of a representative specimen gave the value 2.89.

It is an olivine-free dolerite composed of augite and labradorite felspar. (Mean R. I. rather under 1.5580). The augite is a faintly pleochroic pale purplish brown variety, with a tendency to occur in elongated columnar crystals. It is markedly ophitic. It is often completely replaced by a green chlorite or marginally by bright green fibres of amphibole. The felspar is an acid labradorite, largely albitised. Amygdules of green fibrous chlorite, green epidote, and a pale green to colourless faintly pleochroic zeolitic mineral are a characteristic feature of this rock. Magnetite along with a little ilmenite altering to leucoxene and granular sphene are the only accessory minerals.

C. The dolerite of the eastern slopes of the Dun
and the rock-shelves east of Ruaival.

This rock is a fine-grained, non-porphyrific dolerite almost indistinguishable in the field from the last type. It has an average specific gravity of 2.86. The constituent minerals are augite, acid labradorite, and iron ores. The rock may originally have carried a little olivine.

The pyroxene is an almost colourless augite frequently showing slight bending of the cleavage lines. It is largely chloritised or replaced completely or fringed by a fibrous green amphibole. Rarely it has been observed flecked by reddish brown biotite which tends to lie along cleavage planes. The felspar is an acid labradorite with a mean R. I. rather under 1.5580. It is remarkably fresh. The accessory iron ores are magnetite and skeletal ilmenite along with a small amount of pyrites. Olivine may be represented by a number of rounded patches of chlorite and magnetite. It has not been encountered in a fresh condition.

Normally the rock does not carry any free quartz, but where granophyre veining occurs impregnation and acidification are visible, even in hand specimen, and quartz and greenish brown hornblende make their appearance. It is difficult to separate impregnation from partial fusion and hybridisation. Slices representing/

representing both conditions may be seen, the final product of acidification being a rock in which the augite is largely replaced by brownish green hornblende or a new crystallisation of pale green columnar augite. The doleritic texture is largely destroyed. The amount of free quartz present is very variable. It often encloses small idiomorphic crystals of newly formed brown amphibole. With the quartz is often associated a sparing quantity of well crystallised, slightly turbid orthoclase, the bulk of the felspar being an acid plagioclase of approximately the composition of oligoclase-andesine ($Ab_2 An_1$).

D. The dolerite of the rocky slopes above An Torc
and forming Na h-Eagan.

This rock is rather variable in hand specimen within narrow limits. It is always fine-grained, of a dark greenish colour, and sparingly porphyritic, carrying lath shaped and tabular crystals of felspar and small crystals of pyroxene up to 2 mm. in length scattered unevenly throughout the rock. The texture is sometimes doleritic, sometimes basaltic, and slices of the rock show several curious features. Free quartz, which cannot be detected in hand specimen, occurs in very variable amount, and the primary origin of most of it is doubtful. Net-veining proceeding from/

from the two granophyre sheets which intrude this dolerite is universal and consequent impregnation of the basic rock as a whole is probable. The average specific gravity is 2.84.

In thin section the doleritic type probably shows the greater amount of modification. It consists of augite, labradorite felspar, quartz, and a good deal of magnetite. The augite is in the form of ragged, slightly corroded sub-ophitic crystals. It is tinted pale green or brown and is largely chloritised and occasionally flecked with small crystals of pale brown biotite much of which appears to have been derived from the chlorite. The cleavage traces of the larger augite are frequently gently bent.

The tabular or lath-shaped felspar is a zoned labradorite passing outwards to acid labradorite. It frequently carries minute, acicular or prismatic crystals of an unknown colourless mineral. Large irregular interstitial patches of quartz, associated rarely with a little turbid untwinned felspar whose R. I. is well below that of quartz and which may be orthoclase, are scattered unevenly throughout the rock. The quartz often carries needles and prisms of the unknown mineral noted above as occurring in the felspar.

In the basaltic type of the same rock a certain amount of ophitic intergrowth between augite and felspar is seen, but the/

the augite tends rather to be granular in outline and non-ophitic. It is a curious feature of this type that the porphyritic augites, which tend to occur in clusters and are rather corroded in outline, are all brownish in tint, whereas the granular augites without exception are of a greenish tint. Moreover, the cleavage traces of the former are generally bent. With the porphyritic augites are associated porphyritic crystals of labradorite that frequently show slight bending and strain extinction. Interstitial quartz is sparingly present but increases very markedly in amount in slices of the dolerite cut by granophyre veins.

Impregnation of this dolerite by the granophyre magma has certainly taken place. The so-called porphyritic crystals of augite and felspar, however, may represent xenocrystic material derived by the dolerite during intrusion and prior to its acidification by the granophyre.

VIII. PETROGRAPHY OF THE GRANOPHYRES.1. The GRANOPHYRE of CONACHAIR and OISEVAL.

The granophyre of Conachair and Oiseval is a medium to fine-grained highly leucocratic rock of even texture. There is often a tendency, however, for the felspar to assume porphyritic dimensions. In colour it is generally some pale shade of cream or grey, but sometimes shows a pink or greenish tint, the colour at any particular point depending on the colour of the felspar present. On weathered surfaces it is stained brown or red by iron oxides or it may have a highly bleached appearance. A coarser, more granitoid variety of the rock is found and occasionally a finer-grained saccharoid type, the latter occurring as small, ill-defined lenses and sheets in the normal rock. The bulk of the rock, however, is a granophyre in the sense in which the term has been used to describe many of the finer-grained granitic intrusions of the British Tertiary province.

Graphic intergrowth of quartz and felspar on a small scale may be seen with a hand lens, the quartz standing out in relief from the duller felspar. Magnetite is the only other mineral visible and is always sparing in amount. The most characteristic feature of the rock is the great development of small druses/

druses. These seldom have a diameter exceeding a quarter of an inch, but as many as thirty or forty can be counted on a surface a yard square. The druse minerals, which often show perfect crystal terminations, consist of quartz, orthoclase, and magnetite, to which must be added green epidote, recorded by Macculloch and Sir Archibald Geikie. The writer has not encountered this epidote in hand specimen, and though a few crystals of this mineral were found during microscopic examination of the powdered rock, it must be comparatively rare. A few small druses in the granophyre of Mol Ghiasgar and Oiseval contain beautiful little clusters of bright green, fibrous actinolite.

Along the line of contact between the granophyre and earlier basic rocks, where the acid rock often carries rounded and corroded inclusions of gabbro and dolerite, the granophyre is visibly richer in the dark-coloured minerals. Magnetite and dark-green, almost black hornblende can be seen with the naked eye. The druses tend to increase in size at this point, particularly in the neighbourhood of the basic inclusions. This zone is narrow, seldom exceeding a foot in width.

Ribbon-like veins of pale green or grey aplite traverse the rock in many places. They are seldom over an inch wide. Occasionally they become sparingly porphyritic where a vein of normal, fine-grained aplite passes into a foot or so of more pegmatoid/

pegmatoid rock. A few show rather pronounced chilling against the granophyre, but none have pierced the late dolerite dykes that cut the granophyre.

Tabular and sheet-like jointing are developed on a grand scale (Plate XII.Figs. 1, 2, and 3). Irregular jointing is common, and occasionally a simulation of the false bedding of sedimentary rocks is encountered. In deeper sections there is a tendency for a curved jointing to appear.

Granophyre.

Examination of the granophyre in thin section shows that it is composed of over 95% of alkali felspar and quartz. In ordinary light the turbidity of the felspar contrasts strongly with the clearness of the quartz, with which it is intergrown in micrographic fashion in varying degrees of coarseness or fineness. Crystals of pure orthoclase felspar are not so common as those containing patchy intergrowths of plagioclase felspar in very variable amounts. The intergrowth is rather fine and is therefore referred to as microperthite. Crystals of orthoclase and microperthite showing good crystal outline and fringed or completely enclosed by micropegmatite are fairly common, the felspar of the micropegmatite being often in optical continuity with that of the nucleus, (Plate XVI.,Figs.5&6). One or two crystals/

crystals of felspar with a refractive index indicating acid oligo-
-clase, edged by orthoclase or microperthite, were observed in a
few microsections. Frequently the complete area of a slice is
occupied by felspar crystals everyone of which is intimately inter-
-grown with quartz in delicate micrographic fashion, (Plate XVII.,
Fig. 1.). Again, and particularly in the more granitoid form
of the rock, irregular and rounded crystals of quartz that often
exhibit no optical continuity with one another are enclosed in
larger crystals of felspar. In the saccharoid type of granophyre
referred to earlier the texture is seen in thin section to be
coarsely aplitic, and there seems to be a greater amount of the
plagioclase felspar present in the microperthite than is usual in
the normal rock. The granophyre is never chilled on its contact
with the surrounding rocks, nor is there ever any felsitic or
spherulitic structure developed.

Ferromagnesian minerals occur in very small amount and
consist of poorly developed crystals of green hornblende with an
occasional shred of brownish green biotite. Even assuming some
indeterminate, patchy aggregates of limonite, chlorite, and magne-
-tite present in many sections to represent original hornblende
the total bulk of the ferromagnesians cannot have exceeded 2% of
the whole rock. In ordinary light the hornblende is brownish
green/

green in colour, occasionally showing a faint tinge of bluish green suggestive of a small content of soda. Of some eighty slices of the rock examined only seven or eight contain hornblende crystals of appreciable size. From these, two slightly differing schemes of pleochroism were noticed:

X pale yellowish green Y olive green Z bright green

$Z > Y > X$

X pale greenish brown to pale green Y turbid olive green

Z sage green to bluish green

$Y > Z > X$.

The accessory minerals, given in order of frequency, are: magnetite (easily the most abundant), zircon, sphene, fluorite, and a brown mineral which is identified as the cerium epidote, orthite. The magnetite occurs as early crystallised octahedra and irregular grains enclosed in quartz, felspar and hornblende. The zircon, colourless in thin section, but showing a faint yellowish tint in the rock powder, often carries minute prismatic inclusions. The sphene is in the form of imperfect crystals and rounded grains. Fluorite occurs in small irregular crystals and is more abundant in slices containing hornblende in which it is sometimes included along with small grains of early-crystallised quartz. The mineral which has been termed orthite occurs as minute, rounded, prismatic, or acicular crystals with an intense cinnamon brown colour and high refractive index. Cleavage is poorly/

poorly developed. It is strongly pleochroic, appearing quite opaque in the direction of greatest absorption. The extinction is apparently straight. The intense colour and absorption have hindered the determination of other optical properties, but the same mineral has been encountered in many of the offshoots of the granophyre where it is found passing outwards into a fringe of optically-continuous green epidote, and there can be little doubt as to its identity.

The contact of the granophyre with the hybrid rock of Glacan Conachair and the northern slopes of Mullach Mòr is described in the section dealing with : "Hybridism and Contact Phenomena" on page 101.

Aplites

Mineralogically the aplites consist of quartz, orthoclase, microperthite, and a sparing amount of magnetite, with occasional patches of limonite and chlorite which probably represent original hornblende. A few flakes of brown biotite were observed.

Dr. Marker (VII, p. 409), described the aplites as follows: "The material of the veins is of a type intermediate between granophyre and microgranite (6622, 6623). The chief bulk is a finely granular aggregate of quartz and felspar, the latter very turbid:

but/

but in this aggregate are embedded numerous patches of micropegmatite, often of perfect and delicate structure. These areas of micropegmatite show some approach to a radiate or rudely spherulitic structure, and, in some cases, are clustered round a crystal of felspar or quartz. Some granules of magnetite and rare flakes of brown biotite are the only other constituents of the rock." This description has been amply confirmed by the writer, the only additional fact observed being the occasional occurrence of true spherulitic structure.

SPECIFIC GRAVITY and CHEMICAL ANALYSES.

The specific gravity of the granophyre is very constant throughout the entire mass. Determination of the values for five specimens gave: 2.587, 2.598, 2.603 and 2.615, averaging 2.602.

The chemical analysis of a specimen taken from the southern slope of Oiseval is tabulated on the next page along with the published analyses of the Beinn a' Ghraig Ring-Dyke of Mull, the biotite granite of the northern granite mass, Glen Rosa, Arran, and the biotite granite of the spur east of Finlieve, Rostrevor, Mourne Mountains.

The silica percentage of the St. Kilda rock is 1% higher than the corresponding values for the Mull and Irish occurrences/

occurrences quoted, and about the same amount short of the value for the granite of North Arran. Total alkali is quite comparable in all cases but the St. Kilda rock is not so rich in potash as that of Arran. Traces of fluorine were found in the analysis. A test was made for cerium but the result was unsatisfactory.

Dr. Harker has divided the major granitic intrusions of the British Tertiary Province into two sub-groups; 1st, those in which the silica percentage ranges from 75 to 77, and 2nd, those in which the silica percentage ranges from 70 to 72. The first group is characterised by the presence of biotite, the second by hornblende. Dr. Harker (VII., p. 153) placed the granophyre of St. Kilda in his first group. The present re-examination of the St. Kilda granophyre has modified this view of its classification. The silica percentage falls little short of the required 75% to place the rock in the more acid division, but the characteristic ferromagnesian is hornblende, not biotite, which is extremely rare. Moreover the St. Kilda rock is characterised by abundant micrographic intergrowth of quartz and felspar, a feature which Dr. Harker links with the less acid group.

	1.	A.	B.	C.	
SiO ₂	74.02	73.12	74.87	73.09	SiO ₂
TiO ₂	Traces	0.39	0.26	0.22	TiO ₂
Al ₂ O ₃	13.06	12.44	11.24	14.15	Al ₂ O ₃
Fe ₂ O ₃	0.33	2.09	0.34	0.70	Fe ₂ O ₃
FeO	2.08	1.65	1.22	1.03	FeO
MnO	nt. fd.	0.17	0.05	nt.f.d.	MnO
(Co Ni)O	nt. fd.	nt.f.d.	....	....	(Co Ni)O
ZnO	nt. fd.	....	....	....	ZnO
MgO	0.64	0.14	0.22	0.47	MgO
CaO	0.93	0.83	1.30	1.04	CaO
BaO	n.d	nt.f.d.	0.04	....	BaO
Na ₂ O	4.02	3.90	3.31	3.73	Na ₂ O
K ₂ O	4.23	4.67	5.68	4.21	K ₂ O
Li ₂ O	n.d.	nt.f.d.	nt.f.d.	....	Li ₂ O
H ₂ O * 105°	0.45	0.24	0.49	0.70	H ₂ O * 105°
H ₂ O at 105°	0.10	0.25	0.29	0.60	H ₂ O at 105°
P ₂ O ₅	nt.f.d.	0.09	0.09	0.09	P ₂ O ₅
CO ₂	nt.f.d.	0.05	0.49	nt.f.d.	CO ₂
FeS ₂	n.d.	nt.f.d.	0.33	....	FeS ₂
Cr ₂ O ₃	n.d.	....	0.02	....	Cr ₂ O ₃
Ce	nt.f.d.	....	....	....	Ce
S	Trace	....	....	....	S
F	Traces	....	nt.f.d.	....	F
Totals	99.91	100.08	100.24	100.06	
S. G.	2.60	2.57	....	....

1. Granophyre, boat-run, southern slope of Oiseval, St. Kilda.
Analyst, W. H. Herdsman.
- A. Granophyre, Beinn a' Ghraig Ring-Dyke, Mull.
Analyst, E. G. Radley in "The Tertiary and Post-Tertiary Geology of Mull, Loch Aline, and Oban", Mem. Geol. Surv. Scot., 1924, p. 20.
- B. Biotite-granite, northern granite mass, Glen Rosa, half a mile above confluence with Garbh Allt, Arran.
Analyst, B. E. Dixon in "The Geology of Arran", Mem. Geol. Surv. Scot., 1928, p. 155.
- C. Biotite Granite, J. E. Richey on "The Structural Relations of the Mourne Granites (Northern Ireland)", Q. J. G. S., Vol. LXXXIII., 1927, p. 660.
Analyst, W. H. Herdsman.

2. The GRANOPHYRE SHEET of the GLEN BAY.

The granophyre of the great sheet-like intrusion of the Glen Bay is a compact, finer-grained rock than the granophyre of Conachair and Oiseval. It is quite free from the small druses so characteristic of the other rock but shows the same system of tabular jointing. It is generally richer in the ferromagnesian minerals, which have a very irregular, patchy distribution throughout the sheet. The more leucocratic portions are pale cream or grey in colour, the mafic dark yellow to buff. Occasional small rounded clots of ferromagnesian minerals up to an inch in diameter suggest the incorporation and digestion of fragments of a basic rock. The sheet becomes a little finer in grain for a few inches toward its contact with the crushed gabbro but never becomes felsitic or spherulitic in texture. Marginal xenoliths, so typical of the granophyre-gabbro contact zone on the south-eastern slope of Conachair, are quite absent in this case. The large, irregular, dyke-like offshoot fifty feet west of the main sheet is more leucocratic than the parent rock and much finer in grain. It is aplitic on its contact with the crushed gabbro. A few greenish-grey aplites cut both sheets. They are rather unusually fine-grained and seldom over an inch wide.

Granophyre.

Thin sections of this granophyre show a good deal of variation. The more leucocratic varieties consist predominantly of quartz, orthoclase, and microperthite intergrown in graphic fashion. Micropegmatite is abundant in sections of the finer-grained offshoot but rare in the rock of the main mass. With increase in the amount of ferromagnesian there is a noticeable increase in the basicity of the feldspar. It is possible to pass gradually from slices containing only orthoclase and microperthitic feldspar to slices rich in zoned oligoclase and oligoclase-andesine. The clear plagioclase feldspar is always surrounded by a wide fringe of orthoclase or microperthite. It is twinned on the Carlsbad and Albite laws and contrasts strongly with the turbid alkali feldspar surrounding it.

Two ferromagnesian minerals are present -- a green, faintly pleochroic augite and a brownish green hornblende. The colour and pleochroism of the augite suggest that it is a soda-bearing variety. It occasionally shows a slight colour zoning, appearing somewhat bleached centrally and passing outwards to a darker margin of richer colour. Several undoubted xenocrysts of a colourless or green-tinted augite (diopside) were observed in some slices. The margins of such crystals are always corroded and their optical properties suggest that they have been derived from/

from an earlier crystallised gabbro or dolerite. Schiller structure, typical of the augite of the gabbros of the vicinity, was observed in one instance. Hornblende is much more plentiful than augite. Single slices tend to carry only one of these minerals at a time, and it was noted that when the two do occur together the amphibole is always much more abundant than the pyroxene. As in the case of the augite, colour and pleochroism suggest that we are dealing with a soda-bearing amphibole. Both the augite and hornblende tend to adopt a columnar or elongate shape, though either may occur as aggregates of small granular crystals. The elongate crystals have a very irregular, corroded outline and occasionally enclose granular quartz. Magnetite, which is rather abundant in the more basic rock, is clustered in well formed crystals around the ferromagnesian minerals.

The xenocrystic diopside is seen in all stages of alteration, from the point where a large colourless crystal is merely fringed by hornblende or green augite, to the condition where only a few spongy relics of the original mineral remain surrounded by newly constituted pyroxene or amphibole. The modified xenocryst figures on plate ^{xvi} VI., fig. 4, is typical of the alteration taking place. It is about 1.5 mm. in length and highly corroded, and the diopside is replaced centrally by a little pale green actinolitic hornblende. For three-quarters of/

of its circumference it is fringed by a narrow border of pale green pleochroic augite, the cleavage lines running uninterruptedly through the two varieties of augite. Magnetite dust is collected along the transition line, mainly in the diopside, and appears to have recrystallised in larger individuals in the outer zone.

It is difficult to judge how much of the ferromagnesian in the granophyre is original and how much is due to the incorporation and digestion of foreign material. The unevenness of colour seen in many of the augite and hornblende crystals may indicate the addition of unequal amounts of soda to what were originally crystals of diopside. Moreover, the irregular shape of many of the plagioclase crystals suggests that they may represent the final product of corrosion and acidification of a more basic felspar. There is no sign of dusting or clouding in the plagioclase, a feature so common in the gabbros and dolerites and encountered in felspar xenocrysts elsewhere. There is also an abnormal amount of magnetite present, particularly in association with the ferromagnesian minerals.

It is felt that a good deal of basification of the original granophyre magma has taken place throughout most of the mass. It is not possible, however, to locate the source of the foreign material, though it is probable that we are dealing with the/

the inclusion of already consolidated basic rock and not with crystals caught up from another magma. The result of the process has been to produce uneven hybridisation of portions of the sheet.

The accessory minerals — sphene, zircon, orthite, magnetite, and a few flakes of brown biotite — do not call for particular attention.

CRUSH PHENOMENA within the GRANOPHYRE.

Microscopic examination of the thread-like veins of fine-grained material traversing the granophyre of the Glen Bay shows them to be small lines of crush. These veinlets, up to 2 mm. in width, branch and anastomose within the area of a single slice. They consist of a fine aggregate of highly smashed, angular fragments of quartz and felspar. The larger relics lying within the finer smashed material give strain extinction under crossed nicols, and both the quartz and felspar in the near vicinity of the veins show a good deal of strain. The age and significance of this crushing has been discussed on page 53.

SPECIFIC GRAVITY and CHEMICAL ANALYSIS.

The specific gravity of this granophyre varies from 2.58 for the most leucocratic variety to 2.66 in the most basic.

The analysis tabulated on **the next page** was made from a specimen known to be practically free from xenocrystic material. It compares very closely with the analysis of the granophyre of Conachair and Oiseval. Silica is barely 1% lower than in the rock of Conachair and Oiseval. Total iron is 1% higher. MgO is slightly lower. The ratio between K_2O and Na_2O is almost identical.

ANALYSES.

	I.	II.
SiO ₂	73.30	74.02
TiO ₂	0.13	Traces
Al ₂ O ₃	12.23	13.06
Fe ₂ O ₃	1.73	0.33
FeO	1.59	2.08
MnO	0.08	0.00
Ni, Co, Zn	n.d.	nt.fd.
MgO	0.15	0.64
CaO	1.08	0.93
Na ₂ O	4.23	4.02
K ₂ O	4.95	4.23
H ₂ O * 105°	0.04	0.45
H ₂ O at 105°	0.15*	0.10
P ₂ O ₅	0.19	0.00
CO ₂	0.00	0.00
S	0.08	Trace
F	n.d.	Traces
	<hr/> 99.73	
- O. of S	0.02	
Total	<hr/> 99.76	<hr/> 99.91
S.G.	2.59	2.60

* Not added in total: rockpowder dried at 105° before analysing.

- I. Granophyre, Glen Bay, St. Kilda. Analyst, Dr. Naima, Sahlbom.
- II. Granophyre, Oiseval, St. Kilda. Analyst, W. H. Herdsman.

3. The GRANOPHYRE SHEETS of the WEST COAST.

In this division are placed the two granophyre sheets so well exposed in the cliffs of the west coast of St. Kilda immediately above the rock An Torc, along with their north-west and south-east extensions to the Lover's Stone and the Dun respectively. Both sheets have been basified by the incorporation of fragments of gabbro and dolerite. The relic of a third sheet occurring twenty or thirty feet nearer sea-level than the two sheets mentioned above may represent an offshoot from the lower of the two sheets.

The rock composing the two sheets in question is pale cream or grey in colour and generally of medium to fine grain. Small, porphyritic, lath-shaped and tabular crystals of felspar up to $\frac{1}{2}$ cm. in length are fairly common and are accompanied by sparing amounts of macroscopic hornblende and magnetite. Xenoliths of dolerite and gabbro are abundant and are seen in all stages of dissolution. While the larger xenoliths retain their original textural characters the smaller are usually represented only by rounded clots of more basic rock rich in the dark-coloured minerals. Obvious enrichment of the granophyre around individual inclusions is commonly observed, and diffusion of the derived basic material has taken place fairly uniformly. On a wider/

wider scale, however, there is a vague patchiness in the distribution of the ferromagnesian, which together with small local variations in texture and grain indicate a good deal of hybridisation.

The myriads of offshoots from the main sheets in the form of dykes, veins, and stringers repeat all the features observed in the parent rock; frequently they contain as high a percentage of the dark-coloured minerals as the latter. Even veins half an inch wide may carry elongate inclusions of foreign rock split and veined by finer veinlets of the acid material.

Small druses up to an inch in diameter are fairly common, particularly in the neighbourhood of xenoliths, and the druse minerals consist of quartz, felspar, magnetite, and occasionally fibrous or acicular, actinolitic hornblende.

Fine tabular jointing is strongly developed in both sheets.

The specific gravity of the granophyre varies between 2.60 for the most leucocratic specimen determined and 2.64 for the most mafic.

In thin section the granophyre of both sheets is seen to be a hybrid rock composed of plagioclase felspar ranging from acid andesine to oligoclase and albite-oligoclase, quartz, perthite/

perthite, and very variable amounts of brownish green hornblende, largely replacing xenocrystic diopside, and magnetite. The diopside has occasionally recrystallised in the form of pale green columnar crystals of augite which have later been slightly corroded and replaced in part by hornblende or brown biotite.

As a general rule slices of the finer grained specimens collected are poorer in plagioclase feldspar and the mafic minerals, being composed chiefly of orthoclase, microperthite, and quartz. In the coarser varieties the relative amounts of plagioclase and alkali feldspar vary somewhat. The plagioclase feldspar, on the whole, is probably more abundant in most of the slices examined. Graphic intergrowth of quartz and feldspar is everywhere common. Micropegmatite, on the other hand, is rare except in slices of the more basic varieties where it is of late crystallisation and confined to irregular, interstitial cavities. The plagioclase feldspar is remarkably fresh and clear. It is generally slightly porphyritic and frequently corroded and fringed by perthitic feldspar. Determination of the refractive index and extinction angles of the plagioclase feldspar indicate that we are dealing with feldspar ranging from acid andesine to albite-oligoclase. It is always highly zoned. Rare corroded crystals of "dusted" acid labradorite, probably xenocrysts from

a dolerite invaded by the acid sheets, were encountered in some of the Dun specimens. Occasionally irregular fractures in some of the oligoclase crystals are filled by small, irregular crystals of alkali feldspar and quartz. In other cases the alkali feldspar appears to have corroded and invaded the crystals of plagioclase which it fringes. (The last two observations are in no way to be connected with crushing, which is quite absent from the granophyre of this area.).

The typical ferromagnesian is a brownish green hornblende occasionally tinted bluish green. It is sometimes idiomorphic but is generally in the form of irregular crystals obviously replacing xenocrystic diopside. As in the granophyre of the Glen Bay, the original augite of the xenocryst is found as a kernel surrounded by a deep fringe of amphibole. The fine, dusted iron oxide of the augite is recrystallised in larger individuals in and around the new hornblende, which also frequently carries small granular crystals of quartz. Pale green, columnar or prismatic augite also replaces the foreign augite but is never as abundant as hornblende. This new augite in its turn is often slightly corroded and replaced by the brownish green hornblende normally found. A good deal of bright green chlorite and reddish brown biotite, probably pseudomorphing pyroxene, are present in some sections. Olivine, which has/

has not been encountered either fresh or pseudomorphed, may be represented by a few crystals of ? hypersthene now replaced by fibrous green and brown hornblende.

The usual accessory minerals zircon, sphene, magnetite, and orthite are present. The orthite is frequently surrounded by optically-continuous green epidote. In addition a little prehnite derived from the surrounding gabbro, was observed.

The few small granophyre dykes are identical in mineral and textural characters with the granophyre sheets which they cut.

Both granophyre sheets become slightly finer in grain on their contacts with the surrounding gabbro and dolerite. Microsections of the junctions show several interesting features. Acidification of the bytownite of the gabbro has taken place, along with a certain amount of clearing of the "dusting" so characteristic of the crushed rock. The highly schillerised augite is replaced by brownish green hornblende and pale reddish brown biotite. Irregular solution lines crossing the basic feldspar are filled in by alkali feldspar and quartz. On the granophyre side of the contact there is obvious basification, prominent crystals of augite floated from the gabbro undergoing corrosion and alteration to brownish green hornblende and pale green/

green augite free from all schiller structures.

The inclusions of basic rock within the granophyre sheets are seen in all stages of dissolution. The larger blocks over a foot in diameter are highly altered and acidified marginally but pass inwards to a core where only incipient modification is seen in the form of flakes of brown mica and fine rims of brownish hornblende developed in the pyroxene. The smaller xenoliths are much more highly altered and are generally represented in thin section only by a rounded aggregation of newly formed pyroxene and amphibole. In some cases they keep their original shape, and though the felspar appears altered only marginally, the pyroxene is completely replaced by hornblende and biotite. Olivine is sometimes replaced by rounded patches of chlorite and biotite, at other times by newly formed hypersthene.

IX. HYBRIDISM and CONTACT PHENOMENA.

A. Hybrids of Mullach Sgar.

The dolerite exposed at sea-level at the base of Mullach Sgar is of the type C described on page 78. Hybridisation has produced varieties grading in the field from partly acidified dolerite to a hybrid type characterised by the complete absence of ophitic texture and the development of a newly crystallised suite of minerals. Chloritisation and amphibolitisation of the ferromagnesian minerals give the rock of this area a pale, greenish grey colour, which, along with the abundant development of biotite from green chlorite and the presence of fairly numerous fine veins of bright green epidote, chiefly along joint planes, clearly distinguishes it from all other rock types on the island.

Irregular albitisation* of the labradorite feldspar, replacement of augite by green chlorite and fibrous brownish green hornblende, the edging of augite by compact greenish brown hornblende, and the appearance of sparing amounts of free quartz represent/

* The term 'albitisation' is here used to imply the addition of soda to produce a more acid feldspar than labradorite and not necessarily albite.

represent the earlier phases of hybridisation. The texture remains largely doleritic, but with the appearance of newly crystallised augite, which tends to form broad prisms or slightly columnar crystals, and the tendency for the feldspars to assume tabular shape, the original ophitic relation of the two minerals is lost. The most characteristic feature of the hybrid rock, where solution of the basic rock is most complete, is the presence of elongate columnar crystals of an almost colourless hypersthene exhibiting faint pleochroism from pale green to pink. Corroded labradorite feldspars are occasionally seen, surrounded by the newly formed feldspar which ranges in different slices from oligoclase-andesine ($Ab_2 An_1$) to albite-oligoclase ($Ab_6 An_1$), and often carries small granules of clear, pale green augite. The larger monoclinic pyroxenes are widely replaced by occasionally twinned, compact, greenish brown hornblende, which also occurs in the form of idiomorphic crystals. Both monoclinic and orthorhombic pyroxene are frequently chloritised or replaced by fibrous aggregates of brownish green amphibole. Brown biotite, derived mainly from chlorite, is abundant. Interstitial quartz occurs in very variable amount in irregular grains of diverse size and is sometimes intergrown in graphic fashion with a little turbid orthoclase.

Microsections/

Microsections of the granophyre dykes vary a good deal according to the amount of basic material included. The texture is rather coarse-grained and micrographic intergrowth of quartz and alkali felspar is rare. In some slices the felspar is an unusually clear, tabular orthoclase, accompanied by a little zoned oligoclase, in others the proportions of the two felspars is reversed, the plagioclase predominating. A finer crystallisation of lath-shaped oligoclase associated with clear granules and small prisms of pale green augite and hypersthene and abundant iron ore marks the position of resorbed inclusions, which are seen in hand specimen as small rounded clots rich in ferromagnesian minerals and iron ore. The main body of the rock carries sparing amounts of compact brown hornblende and biotite.

The accessory minerals of the dolerite-granophyre hybrid and the basified granophyre dykes are sphene, zircon, orthite, magnetite, pyrites, and apatite, the latter a rare mineral in the normal acid rocks of St. Kilda, but here quite abundant and probably almost completely derived from the basic rock.

The original dolerite of the upper slopes of Mullach Sgar around Clash na Bearnaich has not been identified with certainty. It is largely hybridised and the same mineral changes have occurred as described above for the hybrid at sea-level.

It/

It is finer in grain than the latter and is very intimately veined by granophyre stringers. Hypersthene is of rare occurrence in this rock, which is interesting on account of the unusual characters of both orthoclase and quartz. These minerals occur as large irregular crystals up to 2 mm. in size and enclose abundant grains and prisms of clear, pale green augite and magnetite. The plagioclase felspar is lath-shaped and is oligoclase-andesine ($Ab_2 An_1$). It shows a certain amount of flow structure and is occasionally completely enclosed in the larger patches of alkali felspar. The greater part of the original augite of the dolerite has re-crystallised in the form of clear grains or small prisms of pale green augite or is replaced by green chlorite or brownish green fibrous amphibole, or is edged or completely replaced by compact brown hornblende.

Many of the features of the hybrid rocks of Mull, described by Messrs. Thomas and Bailey (VIII. p. 351-354) are repeated in the hybrids described above. Messrs. Thomas and Bailey summarise the effects of hybridisation of the Mull rocks as follows: "The outstanding features, therefore, of these hybrid rocks of Mull are: the acidification of basic felspars in irregular fashion; the replacement of olivine by rhombic pyroxene; the fringing of augite, frequently re-crystallised, by pyrogenetic hornblende; the complete local assimilation of basic material/

material followed by the independent crystallisation of rhombic pyroxene; the basification of the acid magma with the production of pyrogenetic hornblende; and a general increase in the basicity of the early separating feldspars." Though hypersthene is abundant in the lower hybrid zone of Mullach Sgar, the replacement of olivine by that mineral has not been observed. Certain patches of chlorite and biotite observed elsewhere in the dolerite, however, are presumed to represent a sparing amount of olivine. It is interesting to note also that the basified granophyre dykes cutting the dolerite-granophyre hybrid have departed from the typical micrographic texture of the normal granophyres, the feldspar adopting a tabular form and the quartz being of later crystallisation and truly interstitial.

B. The hybrid of Glacan Conachair, etc.

The hybrid rock exposed in Glacan Conachair and among the northern cliffs of Mullach Mòr is very variable in hand specimen. At the former locality it is a dark coloured rock of uneven grain varying rapidly in the field from moderately coarse patches to areas of rather fine grain. Coarse and fine varieties were found at separate points on the northern slopes of Mullach Mòr, the coarser varieties being rather rich in pink coloured feldspar and carrying obvious crystals of clear quartz, occasionally/

occasionally in small druses. The terms gabbroitic and doleritic can scarcely be used to describe the texture of this hybrid as microsections show a strong tendency for the feldspars to be tabular and often euhedral in development while ophitic relations between the pyroxene and feldspar are practically absent. Micrographic intergrowth of quartz and feldspar is visible in the coarser varieties. Numerous offshoots from the granophyre of Conachair and Oiseval cut the hybrid at all localities, and in addition, among the crags of Glacan Conachair, the granophyre is seen to carry many rounded and corroded xenoliths of the hybrid for a distance of about a foot from the contact of the two rocks. No trace of xenolithic structure is to be seen either in hand specimen or in microsection, and, apart from the uneven crystallisation, the only proof of the hybrid nature of the rock is to be found in the variation and occasional corrosion of the feldspars and the presence of an unusually large amount of hypersthene, which is comparatively poorly developed in the normal rocks of St. Kilda.

Microsections show the presence of both monoclinic and orthorhombic pyroxene in about equal amounts. The monoclinic pyroxene is a pale green-tinted to colourless augite, rarely schillerised, and occasionally showing salite structure. It occurs/

occurs as irregular and generally rather elongate crystals and in a few instances encloses parallel intergrowths of orthorhombic pyroxene. The latter mineral occurs sometimes in the form of large sparingly ophitic plates, but generally as long, slightly corroded, columnar crystals, and it appears to be of slightly earlier crystallisation than the monoclinic pyroxene which is sometimes moulded upon it. It is a fairly strongly pleochroic hypersthene.

The felspar occurs as large or small, according to the grain of the rock, tabular, euhedral or subhedral crystals and is generally zoned, the centres of crystals always being more basic than the margins. It is twinned on the Carlsbad, Albite, and Pericline Laws. The core of a few of the felspar crystals consists of a highly irregular patch of labradorite grading almost insensibly into a broad outer fringe of andesine. Typically, the bulk of the felspar has a mean R. I. of about 1.553 indicating andesine. Some slices, however, are rich in a more acid felspar with a mean R. I. of about 1.548, indicating oligoclase-andesine. Turbid orthoclase and perthitic felspar vary in amount in different slices and occur as narrow fringes around many of the plagioclase felspars or intergrown micrographically with quartz forming irregular interstitial areas of varying texture. The plagioclase/

plagioclase felspar is irregularly dusted except in crystals lying in areas rich in alkali felspar and quartz, in the more acid peripheral portions, and along irregular lines of corrosion. Along the latter the acid fringe has on rare occasions pierced the more basic centre. Quartz occurs principally in the form of micropegmatite, but occasionally forms irregular interstitial grains.

Apatite is rather abundant, occurring as stout, well formed prisms. Magnetite is common as large irregular plates on which is moulded a little reddish brown biotite. A few crystals of zircon and sphene are the only other accessory minerals present.

The original nature of the basic rock has been obliterated so completely in all the microsections examined that it was, considering the andesitic nature of the felspar present, at first thought to be a diorite showing a very uneven crystallisation. Comparison with the other hybridised rocks of the island, however, show that it is probably to be regarded as a hybrid in which the fusion of the basic rock by the invading granophyre magma is practically complete. The mineral suite and the columnar nature of the pyroxenes is strongly suggestive of the hybrid exposed at sea-level at the base of Mullach Sgar.

Microsections/

Microsections of the contact of this hybrid with the granophyre show that some small amount of interchange between the two rocks has taken place. The granophyre has picked up, corroded, and fringed many of the zoned plagioclase feldspars of the hybrid with a wide margin of orthoclase or microperthite. On both sides of the line of contact, the augite, and occasionally the hypersthene, of the hybrid, and the xenocrystic augite of the granophyre are fringed or completely replaced by compact brownish green hornblende. At other times the monoclinic augite shows a richer green colour and very faint pleochroism, both in the hybrid and the granophyre, indicating probably the addition of a small amount of soda. This augite in its turn is frequently fringed by brownish olive-green hornblende. Biotite occurs as small flakes partly replacing some of the augite of the hybrid. The basification of the granophyre is confined to a zone a few inches wide, whereas the amphibolitisation of the pyroxene of the hybrid can be traced to points fifteen or twenty feet away from the plane of contact. This evidence of localised contact metamorphism seems to show definitely that the hybridisation of the basic rocks of this locality antedated the intrusion of the granophyre.

X. The PETROGRAPHY of the DYKE-ROCKS.

Examination of the dyke-rocks has not yet been completed but the following preliminary report has been prepared.

A. Introductory.

It was stated in an earlier section (Structural Relations, p. 10) that the dykes of St. Kilda could be divided into a pre- and a post-granophyre group. This statement, however, has to be considerably modified on account of a probable difference in age between the granophyre of Conachair and Oiseval and the granophyre sheets of the Glen Bay and the West Coast, a difference which depends upon the presence or absence of certain dyke types in the respective masses. The latest intrusions are a series of dolerite-basalt and porphyritic pitchstone and? devitrified pitchstone dykes which have been found cutting all the major basic and acid masses and, at one point or another, all the other dykes. These dykes have been tabulated as "post-granophyre" on the appended map. The majority of the remaining basic dykes have been found cutting the granophyre sheets of the Glen Bay and the West Coast, but are quite absent from the granophyre of Conachair and Oiseval. They are frequently cut by a series of granophyre dykes of a type that appears to be closely related/

related in mineral and textural characters with the granophyre of Conachair and Oiseval and which are regarded as being offshoots from that mass. A few basaltic dykes never found cutting any of the granophyre masses, and cut by offshoots from the latter are definitely of pre-granophyre age.

The writer cannot regard the absence of all but two dyke types from the granophyre of Conachair and Oiseval as accidental. The acid mass is intruded by a large number of the late dolerite dykes which branch freely and run very persistently through it. They have been seen crossing the line of contact between the granophyre and older basic rocks without decreasing in size or suffering any deflection in strike or dip. Unfortunately this contact line is very inaccessible for the major part of its exposure and the only approachable dyke crossing it was found to be one of the late dolerites just referred to. In no instance has a dyke cutting the older rocks been seen cut by the granophyre of Conachair and Oiseval. The fact that the only two types of dyke intruding the granophyre of this area are found at various points cutting, but never intruded by, all the other dyke rocks within the gabbros and granophyre sheets elsewhere would seem to add weight to the contention that the acid masses can be separated from one another in age, that the granophyre of Conachair and/

and Oiseval is younger than the acid intrusions of the Glen Bay and the West Coast, and that the majority of the basic dykes are older than the granophyre of Conachair and Oiseval but younger than the other acid masses.

B. Basaltic dykes, younger than all the granophyre intrusions

All the dykes of this division are fine-grained sparingly porphyritic rocks, of dark blue to black colour, and seldom over about two feet in width. The felspar phenocrysts are generally very fresh and clearly visible as glassy, lath-shaped crystals up to a quarter of an inch in length. In thin section they are seen to be composed of labradorite and a colourless to pale brown augite. The porphyritic feldspars, accompanied by a sparing amount of porphyritic augite, lie in a fine-grained groundmass of granular augite and laths of basic felspar. Magnetite is the only accessory mineral and occurs abundantly in the form of small crystals evenly disseminated throughout the groundmass. One or two porphyritic variolites were found, carrying lath-shaped phenocrysts of labradorite and granular augite in a groundmass composed of sheaf-like aggregates of felspar and magnetite dust.

C. Dolerites probably older than the granophyre of Conachair.

Type 1. Olivine dolerite.

This type is not common. It forms, however, an unusually large dyke 12 feet wide on Leacan an Eitheir in the Glen Bay. It is coarse-grained and composed essentially of olivine, augite, and labradorite felspar. The olivine occurs as rather small rounded crystals, generally enclosed by the pyroxene. It is never fresh, being completely replaced by a pale greenish brown chlorite or a fine aggregate of colourless carbonates and magnetite dust. The pyroxene is a pale, purplish tinted, faintly pleochroic augite in the form of large ophitic plates; it is frequently chloritised or replaced by fibrous brownish green amphibole. It is moulded upon or ophitically intergrown with the lath-shaped felspar which has a mean R. I. of 1.558 indicating labradorite.

Type 2. Dolerite.

This is probably, next to the late dolerite dykes of Conachair and Oiseval, one of the commonest types. It is of medium grain and rather a pale greenish grey colour, carrying sparing phenocrysts of basic felspar. In thin section the pyroxene is seen to be a pale brown to colourless augite in the form of broad columnar crystals. It is frequently chloritised, and/

and fine threads of chloritic material spread outwards from the altered pyroxene through the surrounding felspar. The felspar, which is labradorite, occurs as sparing tabular phenocrysts up to 3 or 4 mm. in size but mainly as smaller lath-shaped crystals in marked ophitic intergrowth with the augite. It is rather prone to albitisation, being often threaded by fine veinlets of more acid felspar. The accessory minerals are magnetite and a little skeletal ilmenite.

Type 3. Dolerite.

This is a fine-grained sub-ophitic dolerite of greenish grey colour carrying rare porphyritic crystals of felspar. In thin section the augite is seen to be colourless and in the form of sub-ophitic nearly equidimensional crystals. As in the type just described it is largely chloritised. The porphyritic felspar and the lath-shaped felspar of the main body of the rock are an acid labradorite with a mean R. I. rather under 1.558. Granular sphene, magnetite, and probably ilmenite are the accessory minerals. Sparing amounts of quartz occur as small irregular grains. It is never seen in micrographic intergrowth with felspar, and its primary nature is in doubt.

Type 4. Dolerite.

A few dykes of dolerite showing an unusual mode of crystallisation of the pyroxene were noted. In hand specimen/

specimen they are indistinguishable from dykes of the last type, having the same greenish grey colour and carrying sparing phenocrysts of felspar. A few crystals of porphyritic augite occur in some of the specimens collected. In thin slices the augite phenocrysts are pale green to colourless and partly altered to a pale brownish green chlorite. The striking feature of the rock is the great development of skeletal curved fibres of almost completely chloritised augite which spread out fanwise from a common centre or in arborescent fashion from a curving axis, the terminal portions of the fibres being frequently spurred. The porphyritic felspars have a mean refractive index of about 1.563 indicating labradorite-bytownite ($Ab_2 An_3$), but the fine lath-shaped crystals of the groundmass appear to be rather more acid and probably have the composition of normal labradorite ($Ab_1 An_1$). A few crystals of greenish yellow epidote and a sparing amount of magnetite are the only other minerals present.

D. Acid dykes cutting the basalts of section B and
the dolerites of section C.

1. Spherulitic granophyre.

One or two dykes of a cream-coloured spherulitic granophyre have been found. The spherulitic structure is on a small scale and the rounded individuals can be observed in hand specimen only under a hand lens. In thin section the/

the dykes are seen to be in a fairly fresh condition. A few small ragged patches of chlorite and limonite may replace some ferromagnesian mineral which has not been encountered in a fresh condition. The spherules, which seldom exceed a diameter of about 1 mm., are often of perfect radiate structure. Centrally they appear to consist exclusively of fine fibres of felspar, but marginally they pass into delicate micrographic intergrowth with quartz. They are surrounded by a fine granular aggregate of quartz and felspar, the latter very turbid and probably orthoclase.

2. Aegerine-augite felsite.

This interesting type occurs on the West Coast and in the Glen Bay cutting the granophyre sheets of both areas. It is always some pale tint of cream or grey in colour and carries small porphyritic, tabular crystals of felspar. An obscure flow banding parallel to the dyke walls is occasionally seen. Aegerine-augite occurs as small porphyritic crystals and in the form of numerous granules in the groundmass. It is bright emerald green in colour and strongly pleochroic and has a high extinction angle. The porphyritic felspars are remarkably clear and are albite-oligoclase ($Ab_6 An_1$) showing both Carlsbad and Albite twinning. The groundmass consists of a microcrystalline aggregate of quartz and felspar with abundant granules of aegerine-^{augite} and rounded grains of opaque iron ore, the two latter minerals showing/

showing good flow banding. The quartz is rather abundant and is either roughly intergrown with the felspar or encloses minute laths of that mineral in micropoikilitic fashion.

3. Non-spherulitic granophyres.

The dykes of this division are very abundant both as individual intrusions and as the central members of multiple dykes. They range in width from an exceptionally large intrusion some forty feet wide, exposed in the upper reaches of Amhuinn Mhor, to narrow but persistent dykelets less than a foot broad. The vast majority, however, are from three to four feet in width. They are generally pale cream or grey in colour, porphyritic, of medium to fine grain, and rather poor in the dark-coloured minerals. They carry frequent rounded and corroded xenoliths of the basic rocks through which they run. In thin section they closely resemble the main intrusions of granophyre and are considered to be probably offshoots from these larger masses. The porphyritic felspars are chiefly oligoclase showing twinning on the Carlsbad and Albite Laws along with a certain amount of zoning. They are generally fringed by orthoclase or microperthite which is rather more abundant than the plagioclase felspar and is frequently graphically intergrown with quartz. A number of rather coarser dykes consist of porphyritic oligoclase and alkali felspar showing almost perfect euhedral outlines/

outlines and embedded in interstitial areas of fine-textured micropegmatite. In one of these the ferromagnesian mineral is a beautifully euhedral, brown hornblende. Normally, however, the ferromagnesian mineral present is either pale brownish green hornblende or a pale green-tinted to colourless augite, both minerals tending to occur in the form of elongate or almost acicular crystals. The accessory minerals are zircon, sphene, orthite, generally surrounded by optically-continuous green epidote, and magnetite.

E. Dykes of post-granophyre age.

1. Pitchstone and its devitrified representatives.

Above the rock An Torc, among the cliffs on which are exposed the granophyre sheets of the west coast and cutting all the rocks of that area, occurs a porphyritic pitchstone as the central member of a composite dyke. It is about four feet wide and is bordered on each side by two feet of dolerite of the type described in the following section. It strikes north-eastwards for the greater part of its exposure but on the upper reaches of the rocky slope it bends abruptly, striking almost due north for a short distance, and eventually dies out in a butt-ended fashion without appearing again. The upper portion is a dark olive green porphyritic pitchstone with prominent phenocrysts of tabular feldspar and rounded quartz crystals. The lower exposures pass gradually/

gradually into a completely devitrified rock of pale buff colour, the porphyritic crystals lying in an aphanitic groundmass.

Microscopic examination of the pitchstone shows it to consist of corroded tabular crystals of oligoclase and microperthite, highly rounded and corroded phenocrysts of quartz, and irregular, occasionally embayed, crystals of a pale green, non-pleochroic augite. Two highly corroded crystals of olivine (? fayalite) were observed in one section. The glass is pale brown in colour and crowded with acicular and plumose crystallites, the larger of which show a distinct green colour and probably represent pyroxene. A broad zone of devitrification, in which spherulitic structure is visible, frequently surrounds the crystals of felspar and quartz (Plate XVIII., Fig. 6.). At other times the crystallites may be seen flowing round the larger crystals or growing perpendicularly to their faces. All stages from the glassy down to the completely devitrified rock can be traced. The latter appears to be very prone to weathering, as seen by the growing turbidity of the felspars and the replacement of the pyroxene by chlorite and limonite. Occasional true spherulitic structure is encountered in the groundmass, which consists of an irregular, patchy, microcrystalline aggregate of quartz and turbid felspar. The texture is finely granular in places, micrographic in others. Olivine, fresh or pseudomorphed, has not been observed in/

in the devitrified rock. Perlitic fissures are quite absent, both in the pitchstone and the devitrified rock.

A number of widely separated dykes showing exactly the same mineral and textural characters as the devitrified rock described above were found, and may all represent the final result of devitrification of a glassy rock. No chemical analyses have been made, but the devitrified members, considering the amount of quartz present in the groundmass, can probably be classified as quartz-porphyrines.

2. Dolerite.

The dykes of this division, the youngest of all the intrusions of St. Kilda, are widely and evenly distributed throughout the whole island group. In the field they possess certain well marked characters which serve to distinguish them from all the earlier dolerite dykes. They are usually prismatically jointed and occasionally show an irregular hexagonal jointing. On chilled contacts a fine platy structure parallel to the dyke-walls is generally developed. The majority of the dykes examined weather rather deeply, with the formation of a thick, rich brown, ferruginous skin. They frequently show spheroidal weathering, individual spheroids in the larger, coarser dykes attaining diameters of over a foot. Texturally, they range from coarse-grained ophitic dolerites to finer-grained basalts with a granular/

granular development of the pyroxene which is occasionally sub-ophitic. Both types carry sparing phenocrysts of honey-coloured, glassy felspar, which, in the coarser dykes, occur up to an inch in length. Vesicular structure is common, the vesicles ranging in diameter from $\frac{1}{40}$ th of an inch up to over $\frac{1}{2}$ an inch. They are composed of a dark green chloritic mineral which in some instances undergoes a strong colour change, showing on freshly broken surfaces a pale apple-green colour which darkens in an hour or two to the dark green colour generally encountered.

In thin section the rock is seen to consist of purplish, rather strongly pleochroic augite (titaniferous augite), labradorite felspar, magnetite, ilmenite, and occasionally a few small crystals of apatite. Green and brownish green chlorite occurs abundantly as interstitial matter or occasionally replacing some of the pyroxene, which, however, is generally in a very fresh condition. The felspar is a normal labradorite ($Ab_1 An_1$), occasionally faintly zoned. Some of the porphyritic crystals, however, are more basic, having a mean R. I. of about 1.563 indicating labradorite-bytownite. The texture in different dykes varies widely from a coarse, ophitic dolerite type (Plate XVIII., Fig. 1.), through a finer grained ophitic dolerite (Plate XVIII., Fig. 2.), to fine-grained sub-ophitic or non-ophitic basalt in which the pyroxene is typically granular in form (Plate XVIII., Figs. 3 and 4.).

Pale greenish brown glass occurs rarely in the vesicles of some of the finer grained types or in the form of irregular streaks and patches. Fresh olivine has not been encountered in any of the slices examined but may be represented by a few rounded pseudomorphs of green serpentine. The pyroxene is rarely porphyritic. Magnetite and skeletal ilmenite are fairly abundant accessories and are accompanied by a little apatite. One or two of the finer grained basaltic dykes carry corroded crystals of quartz surrounded by a broad reaction zone of granular monoclinic pyroxene (Plate XVIII., Fig. 5.).

XI. GLACIATION.

In the entire absence of rock-striae, roches moutonnées, moraines, or other glacial phenomena, it is not possible to give any account of the glaciation of St. Kilda. The smooth rounded nature of the inland topography, however, is suggestive of moulding by ice, but whether the ice was of local or foreign origin it is impossible to say.

Professor Heddle (V) suggested the presence of a 100-foot raised beach in the Village Bay, but the writer has been unable to verify this. The extensive grass-covered scree and hill-wash on the steep south-eastern slopes of the Dun and the south-western slopes of Mullach Sgar have been swept away by the sea during storms up to heights of seventy and a hundred feet above sea-level, leaving only a platform of rapidly shelving rock. Professor Heddle probably referred to the ten- or twenty-foot banks of scree and soil left perched at various heights above sea-level. The examination of the material composing the bank of scree cut by Amhuinn Ruaival showed it to be composed of elongate, sub-angular and slightly rounded boulders that frequently exhibit marked "imbricate" structure, the individual boulders dipping lengthwise downhill at angles corresponding/

corresponding roughly with the present surface of the hill.

A number of highly rounded, unstriated boulders of gneiss were encountered in the storm-beach and around the cottages in the Village Bay at a height of about a hundred feet above sea-level. None were observed outside the village wall. The custom among the natives of carrying the more shapely and brighter boulders of the storm-beach to decorate the path in front of their cottages renders it difficult to use their present position anywhere above the storm-beach as a point of diagnostic value. * A careful search among the boulders of the ten-foot alluvial bank facing seawards, from which the boulders of the storm-beach have been derived, has not brought to light any rocks foreign to the island. Ross (IV.), who also observed the boulders of gneiss, remarks upon the danger of considering them ice-carried and suggests that they may have once formed ship-ballast. The examination of a sample of soil taken from a point 60 feet above sea-level in front of the Factor's house showed the presence of a number of grains of pink garnet in addition to an assemblage of minerals characteristic of the gneiss boulders. Garnets have not been found among any of the rocks/

* Rounded boulders from the storm-beach were also found buried in what looks like the relic of a circular rampart of peat on the very summit of Conachair.

rocks of the St. Kilda group. Their occurrence in the soil would seem to strengthen the view that the boulders of gneiss have been carried from the Long Island or the mainland of Scotland by some natural agency, probably ice.

Professor James Geikie (XII., pages 82-83) calculated that the Outer Hebrides, during the period of maximum glaciation, were covered by land ice to a height of 1,600 feet, and that the gradient of the ice sheet between the mainland of Scotland at Torridon to Cleisham in Harris, a distance of 56 miles, was 35 feet per mile or 1 in 150. It has been calculated that if this gradient were maintained uniformly from a height of 1,600 feet on Cleisham in the direction of St. Kilda the ice sheet would have died out some ten or fifteen miles east of St. Kilda. Thus it would appear that St. Kilda may have altogether escaped glaciation by the mainland ice sheet. The boulders of gneiss and foreign minerals in the soil examined may have been derived from icebergs floated into and stranded in the Village Bay. Though the gathering ground for snow and ice on St. Kilda is small, there must, during glacial times, have been a certain amount of local glaciation, and it is suggested that the hollow between Conachair and Oiseval (Plate VI., Fig. 3), now filled by scree and hill-wash, may represent a small lateral valley deepened/

deepened by "nivation" (XIII., page 18-19).

It is interesting in this connection to note that *Saxifraga oppositifolia* descends to the 300-foot contour line and that *Silene acaulis* is found at about the same level. Mr. W. B. Turrill, M.Sc., F.L.S., quoted by Mr. John Gladstone in a short botanical article in the Royal Scottish Geographical Magazine, Vol. XLIV., No. 2, 1928, is of the opinion that "the flora of St. Kilda is much as it was in late Pliocene times, that it survived the ice age in situ, and that it is actually a detached piece of West Scottish vegetation."

XII. SUMMARY AND CONCLUSIONS.

St. Kilda, with its attendant islets and stacs, is the relic of what must once have been a much more extensive igneous complex. No trace of effusive or sedimentary rocks, nor of possible metamorphosed inclusions of such rocks, has been found. Though stratigraphical evidence is wanting, it is possible on lithological grounds to classify the complex as Tertiary in age, the rock suite showing strong affinities with the deeper-seated igneous rocks of other areas within the Brito-Icelandic Tertiary province.

The oldest rocks are a series of olivine-bearing and olivine-free gabbros, by far the most abundant type being an olivine eucrite carrying a small amount of hypersthene. On account of the detached nature of the outcrops, the paucity of inland exposures, and the physical difficulties encountered among the cliff sections, it has not been possible to determine the relations of one gabbro to another. Moreover, the absence of a base or summit to the complex prevents the determination of the form taken by the individual intrusions.

The gabbros have been intruded, first by rather coarse-grained olivine- and olivine-free dolerites in sheet-like form, and/

and later by a series of finer-grained dolerites, one of which, exposed in the Village Bay and on the northern cliffs of the main island, is a basic olivine dolerite. The contact of the finer-grained dolerites with one another and with the older gabbros is of a puzzling nature, but they are regarded as forming a sheet-like complex. On their contact with the gabbros to the north of St. Kilda they appear to dip north-eastwards. On the western coast they dip south-westwards for the greater part of their exposure, but at Laimhrig nan Gall, where they disappear under the eucrite of the W. Coast, they are seen dipping northwards.

The basic rocks are intruded by three masses of granophyre. The largest, and probably the youngest, of these intrusions is a hornblende-bearing granophyre carrying about 74% of silica and forming the northern third of the main island. Its contact plane dips south-westwards at an average angle of probably about 60° . The two remaining intrusions are sheet-like in form and are exposed in the Glen Bay to the north and among the south-western cliffs of the Dùn and the principal island. They dip south-westwards at ~~moderate~~^{high} angles and have been slightly basified as the result of incorporation of basic rock. The intrusion of the south-western coast is in the form of two irregular sheets/

sheets running parallel to one another and separated only by some twenty or thirty feet. Their contacts with the basic rocks, which they have brecciated for a wide area, are very irregular. The finer-grained dolerites have been pierced by a complicated system of net-veining proceeding from the granophyre intrusions and hybrid rocks have been produced at several points as the result of interaction between the granophyre magma and the surrounding basic rocks.

Crushing has been observed within the gabbros at many points, and two types of crushing have been noted: 1st, crushing with the production of mylonitic rock without re-crystallisation of the crushed minerals, and 2nd, crushing with the production of a granulitised rock in which re-crystallisation has taken place. The cataclastic phenomena appear to have originated prior to the actual intrusion of the various granophyres, and it is thought that earth-disturbances, perhaps the result of gas explosions preceding the intrusion of the acid rocks, have produced lines of weakness along which the granophyres have subsequently been intruded. The granophyre of the Glen Bay intrusion appears to have been slightly crushed after consolidation.

The majority of the dykes on the main island, the Dùn, and/

and Soay strike N.W. - S.E., but on the east coast of Soay, on Boreray, and among the northern cliffs of the main island they trend N.E. - S.W. Great difficulty has been experienced in determining the respective ages of the different dykes, but a series of dolerite-basalt and porphyritic pitchstone dykes (or their devitrified representatives) are definitely of post-granophyre age and have been found cutting all the other dyke types.

The rounded nature of the inland topography suggests glacial action but in the absence of rock-striae, roches moutonnées, moraines, or other glacial phenomena it is not possible to give any account of the glaciation of St. Kilda. Boulders of gneiss discovered below the 100-foot contour line in the Village Bay and the presence of garnets in the soil within the village wall probably point to ice transport of material derived perhaps from Harris or Uist to the east. No trace of a raised beach has been found among the islands.

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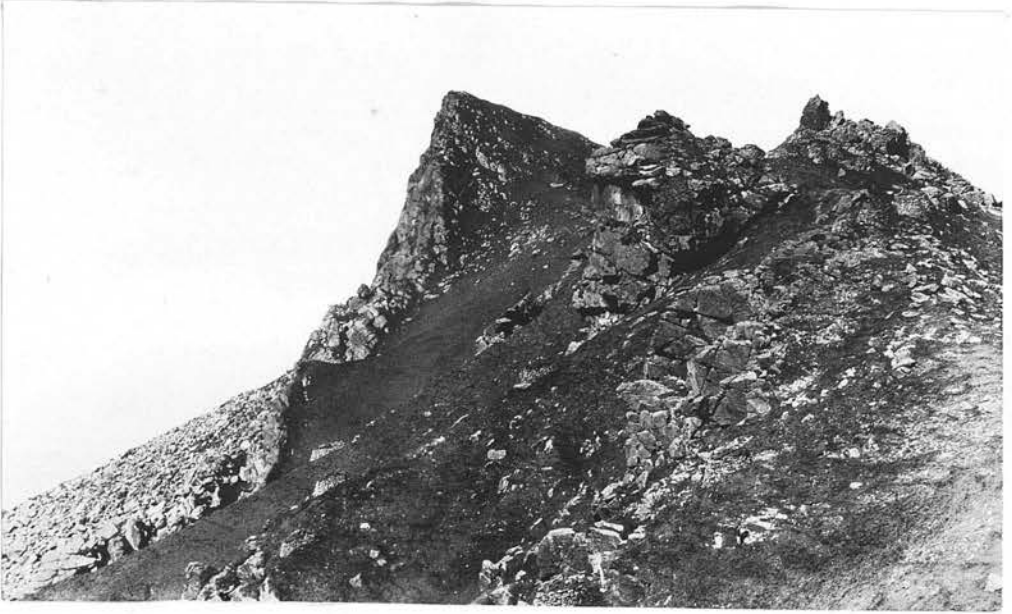
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EXPLANATION OF PLATES.

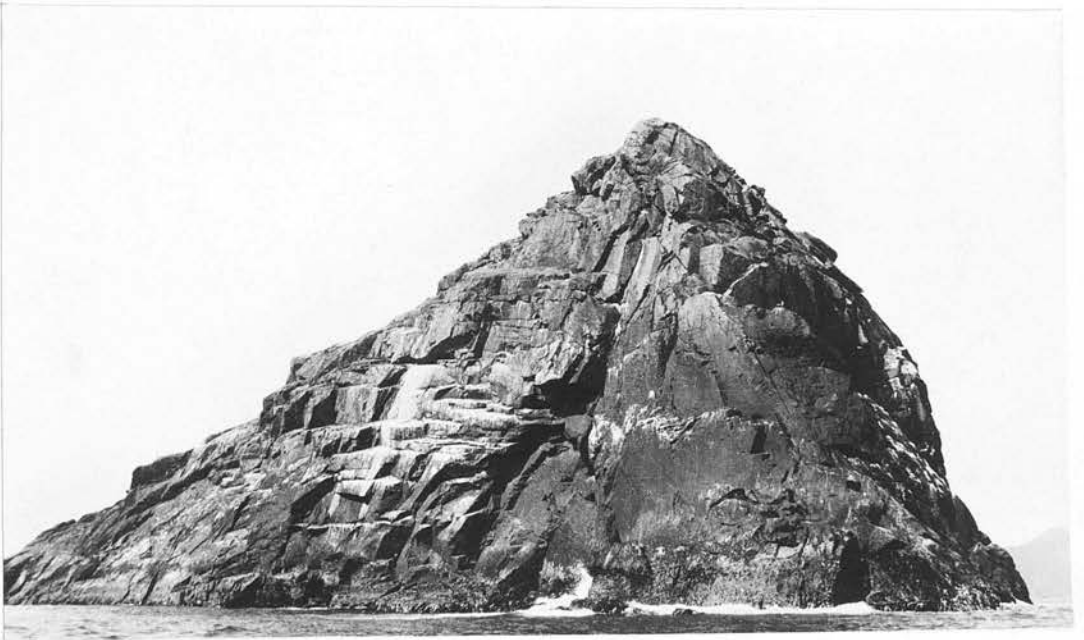
PLATE I.

Fig. 1. Summit of Mullach Bi (1146 feet), looking north-westwards from the Lover's Stone, west coast of St. Kilda; in the middle distance, Claigeann an Tigh Faire; Carn Mor on extreme left. Eucrite of W. Coast.

Fig. 2. Levenish (180 feet), 2 miles east of Village Bay. Rough tabular jointing developed in gabbro. Eucrite of W. Coast.



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PLATE . II.

Fig. 1. Claigeann Mòr (926 feet) from the Carn Mòr,
looking south-eastwards; west coast of
St. Kilda. Eucrite of W. Coast.

Fig. 2. Sea-cliffs below Claigeann Mòr, looking
south-eastwards. Note the notches and
hollows indicating the position of N.W.
dykes with marked north-easterly hade.

PLATE II.



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PLATE III.

Fig. 1. The Dun from the north side of the Village Bay. Line of contact of granophyre and basic rocks runs through middle of bay from right to left.

Fig. 2. From left to right: Soay, Stac Biorach (236 feet), Soay Stac (200 feet), Boreray, five miles north-east, Stac Dona (47 feet) and the Cambir. The granulitic gabbro described on page 14 dips south-eastwards among the cliffs of the Cambir above Stac Dona. Eucrite of W. Coast.



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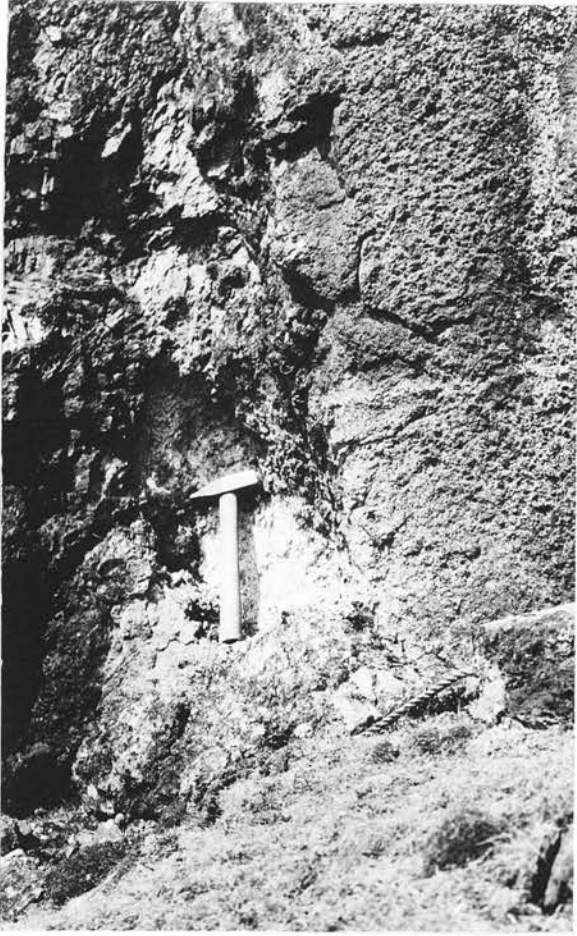
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PLATE IV.

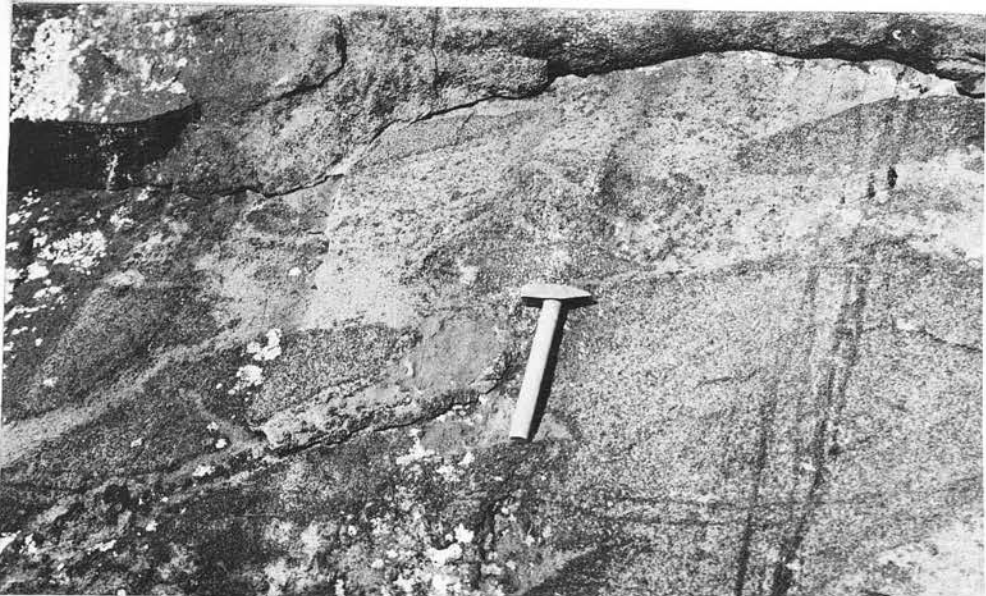
Fig. 1. Mass of prehnite (covered by hammer) in augite-rich segregation. Note bladed crystals of pyroxene at middle left; gabbro (eucrite) 500 feet below summit of Mullach Bi, west coast of St. Kilda.

Fig. 2. Rounded and oval segregations in gabbro as described on page 15; also veining described on page 16. Eucrite of W. Coast.

PLATE IV.



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PLATE V.

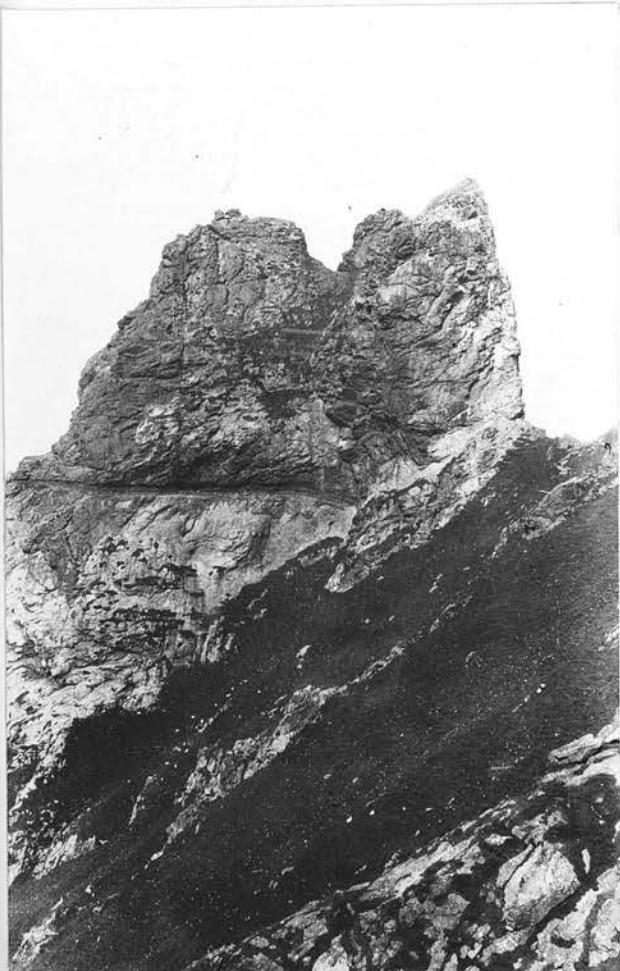
Fig. 1. From left to right: Mullach Mòr, Conachair (in distance) and Mullach Geal, from the Lover's Stone looking north-eastwards. The crushed gabbro referred to on page 17 occurs in isolated knolls near the summit of the Mullach Geal - Mullach Mòr ridge.

Fig. 2. Clesgor (781 feet), Boreray, from the east; composed of eucrite gabbro; dolerite dyke "dipping" towards observer at a low angle.

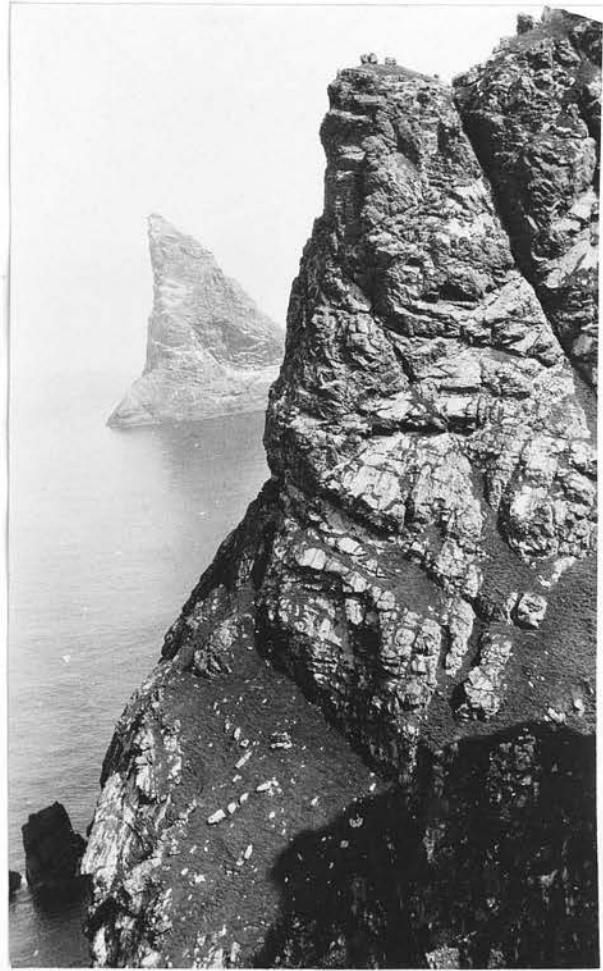
Fig. 3. Western cliffs of Boreray and Stac an Armin (627 feet).



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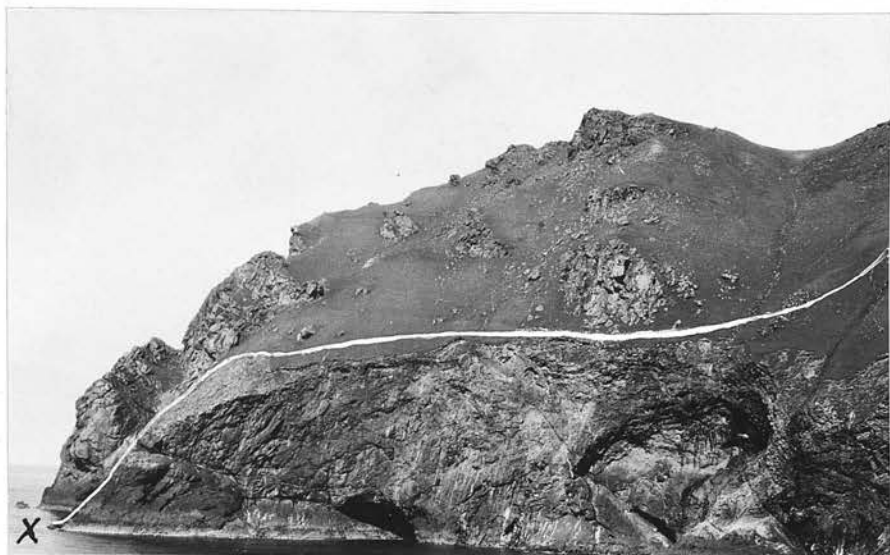
PLATE VI.

Fig. 1. Claigeann Mòr from near An Tòrc, looking north-west. White line indicates contact of fine-grained dolerites with eucrite of W. Coast described on pages 21 and 22. The point marked X is Laimhrig nan Gall. Fine-grained dolerites below white line.

Fig. 2. Conachair from Am Blaid, looking north-east. The white line indicates the contact of the granophyre with the older rocks, the granophyre being to the right of white line.

Fig. 3. Oiseval and the village from Am Blaid. Figs. 2 and 3 are panoramic, with Oiseval lying east of Conachair. Granophyre.

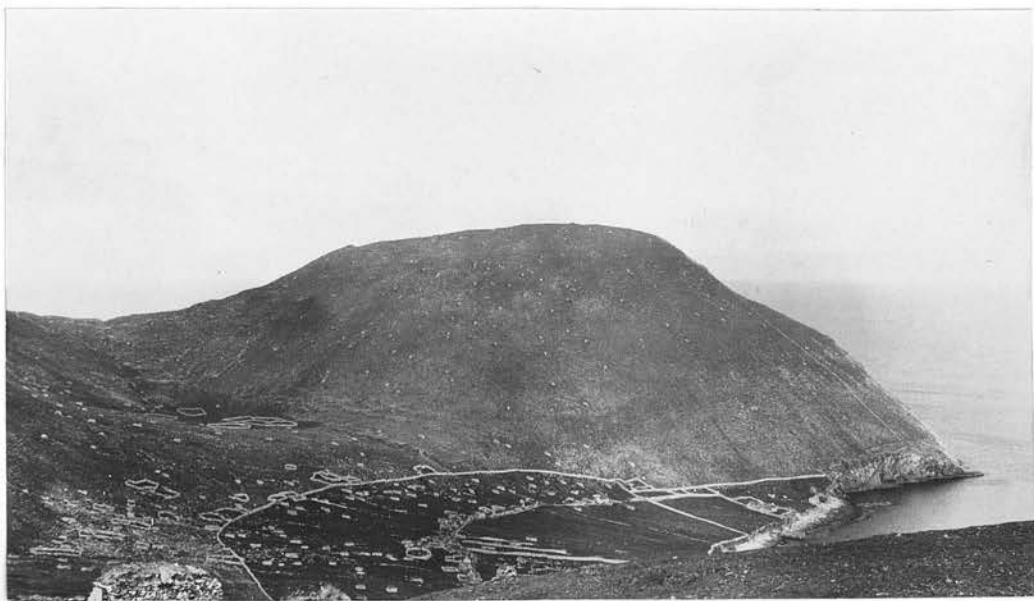
PLATE VI.



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PLATE VII.

Fig. 1. The northern cliffs of Mullach Mor from the northern face of Conachair; granophyre below white line, crushed dolerite sheets, hybrid rocks, etc. above. Observer facing north-west.

Fig. 2. Left to right: Col between Mullach Mor and Conachair, Conachair, and Oiseval, from near Gob an Duin, the south-eastern point of the Dun, looking north. Granophyre to right of white line.



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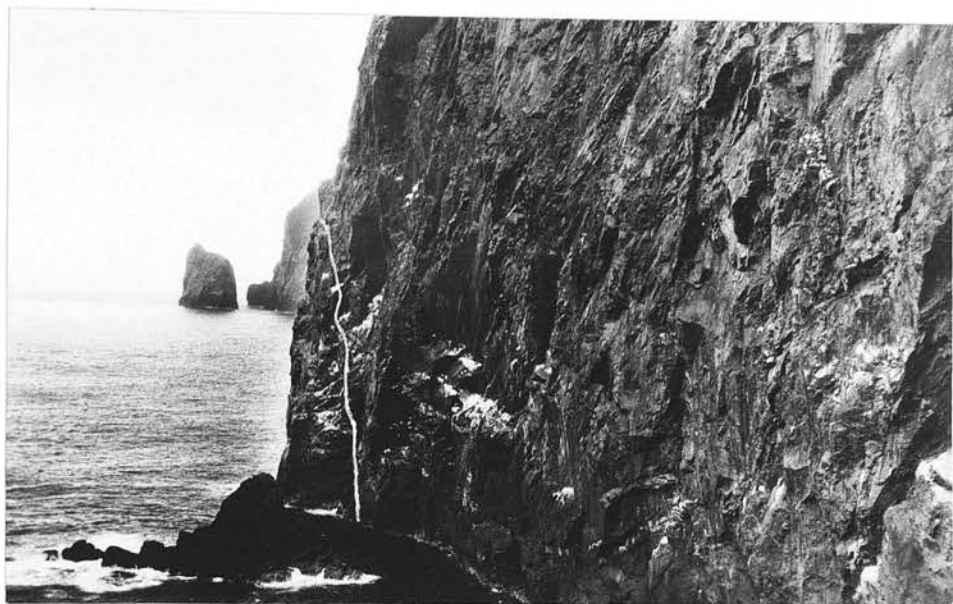
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PLATE VIII.

Fig. 1. The northern cliffs of Mullach Mòr. The rock in the foreground is Na Cleitan. Cliff in foreground approximately 300 feet high. Granophyre to left of white line, fine-grained olivine dolerite to the right. In the distance are seen the cliffs of Conachair and Mina Stac (212 feet); from rock-spit above Geo an t-Samh, looking due east.

Fig. 2. Bìoda Mòr (576 feet), summit of Dùn, in distance, a little right of centre; Ruaival (444 feet), to right of Bìoda Mòr; in middle distance the rock An Torc; W. Coast of St. Kilda; looking south-eastwards from near Laimhrig nan Gall. Note the two acid sheets (granophyre) above An Torc, dipping seawards, i.e. south-eastwards. In left foreground, on Ruaival, and the Dùn, the eucrite of the W. Coast.

PLATE VIII.



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PLATE IX.

From above An Torc looking north-westwards to Laimhrig nan Gall. In foreground the two granophyre sheets, showing irregularity of their contacts with the fine-grained dolerites and intricate veining of the dolerites on top right. Attenuated continuations of the two sheets occur in the cliffs to the north-west.



PLATE X.

Fig. 1. Contact of the fine-grained, olivine-free dolerite with eucrite of W. Coast, near Ruaival. The acid veining in the dolerite practically ceases along the contact with the coarser rock.

Fig. 2. Remnant of an acid sheet (granophyre) or an offshoot from one of the main sheets figured on plate IX. Below Ruaival.



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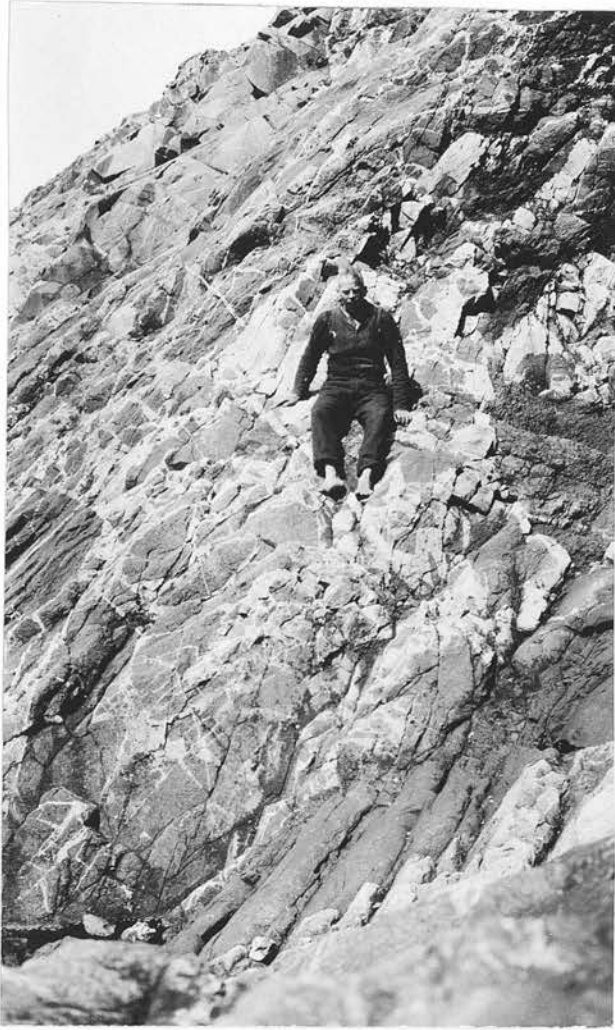
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PLATE XI.

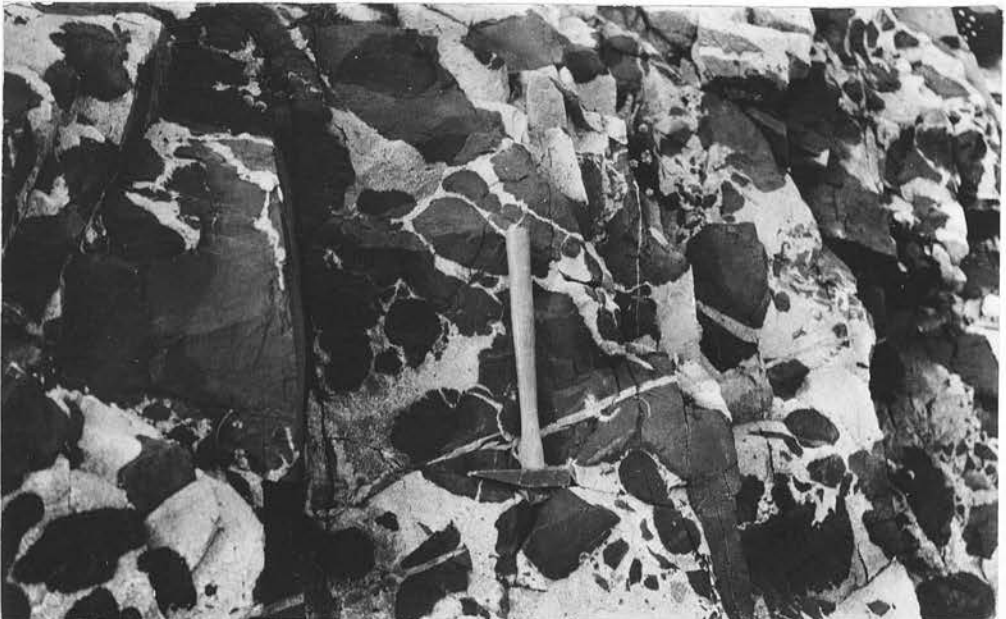
Fig. 1. Veining of "country" rock between the two granophyre sheets above An Torc.

Fig. 2. Brecciation and veining of fragments, upper granophyre sheet, above An Torc.

PLATE XI.



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PLATE XII.

Fig. 1. Sheet-like jointing in granophyre, southern cliffs of Oiseval. Looking eastwards to the Point of Coll.

Fig. 2. Irregular jointing in the granophyre, eastern cliffs of Oiseval.

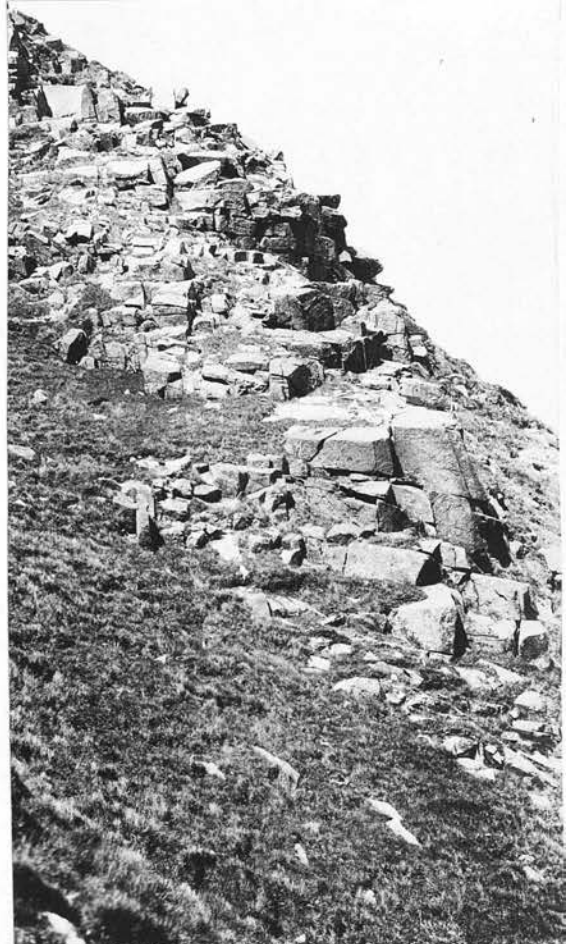
Fig. 3. Tabular jointing in granophyre, Glacan Conachair.



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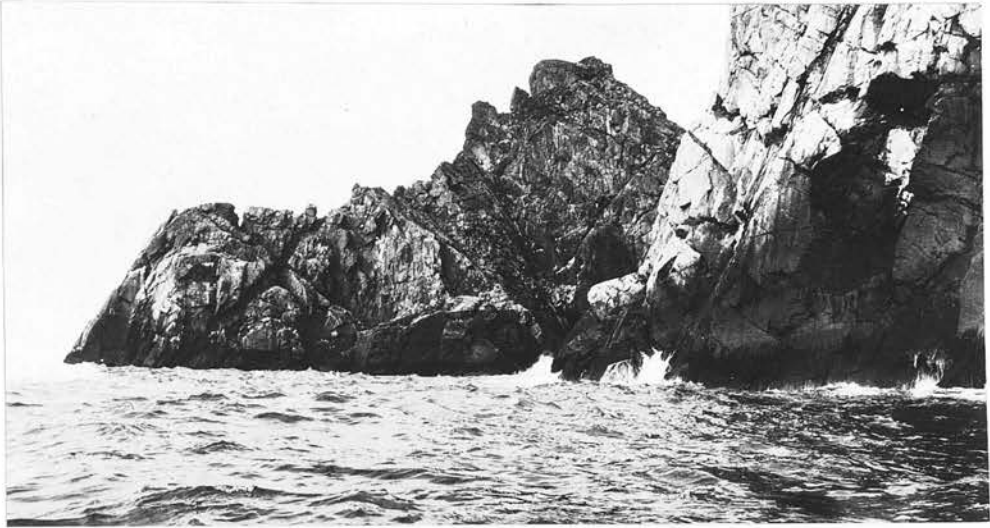
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PLATE XIII.

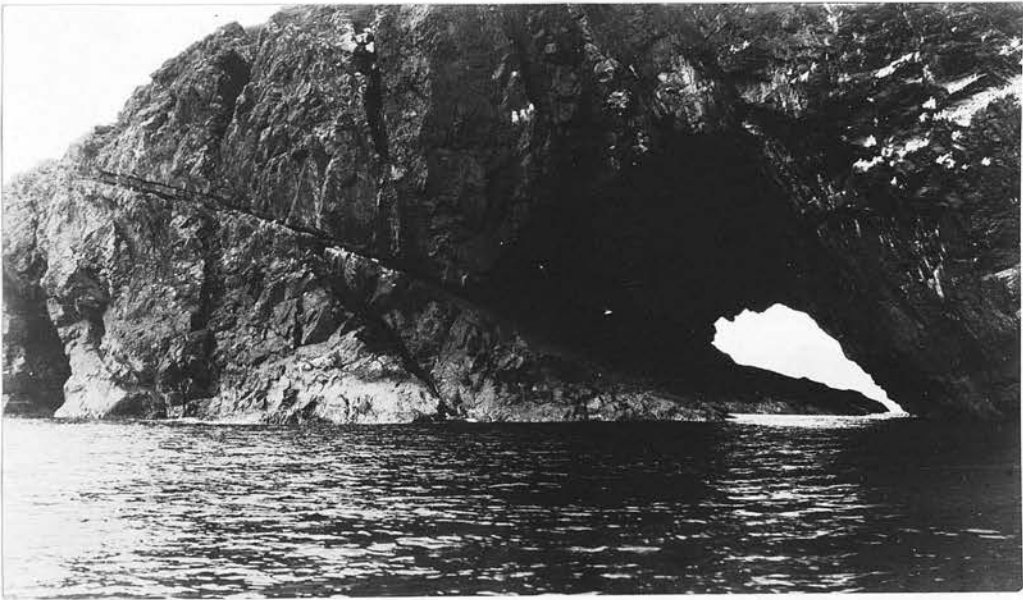
Fig. 1. Giunachsgor (408 feet), southern coast of the Dun, from the sea near Gob an Duin.

Eucrite, W. Coast. Note intersecting dolerite dykes on point, both of which strike almost due east and west; the narrower dipping coastwise, i.e. northwards, cuts the broader.

Fig. 2. Natural arch under Gob na h-Airde; Boreray visible 5 miles distant. Formed by marine erosion along three dykes where they converge at sea-level. The arch or tunnel is 80 feet high and almost 400 feet long.



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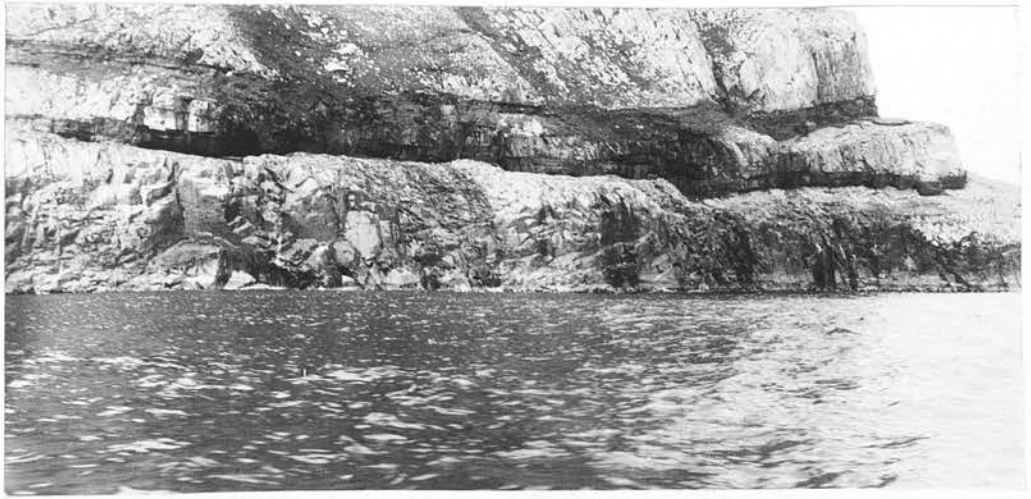
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PLATE XIV.

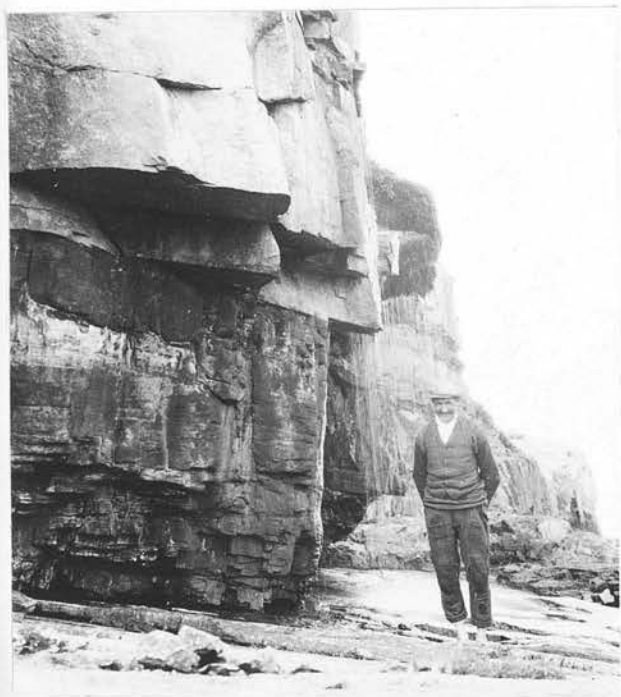
Fig. 1. Late dolerite dykes cutting the granophyre of the eastern cliffs of Oiseval between Rudha n'Uisge and Sgeirnan Sgarbh. On the right, the two dykes dip south-eastwards at angles of about 12° , in the centre of the photograph they are in places horizontal and sheet-like, and to the left they dip north-eastwards at angles of about 12° .

Fig. 2. The lower of the above dykes near Rudha n'Uisge, about 7 feet in width.

Fig. 3. The upper of the above dykes near Sgeirnan Sgarbh, about 11 feet in width. Spheroidal weathering and calcite veining well seen.



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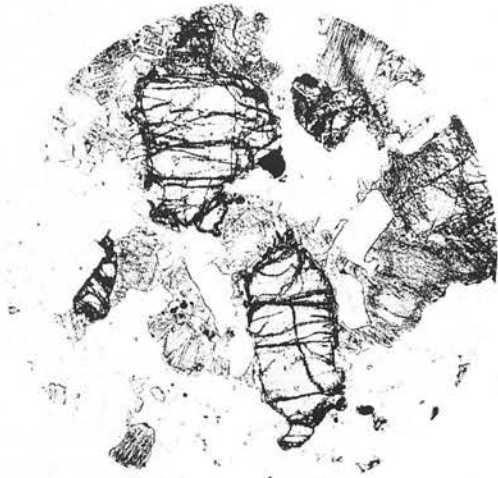
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PLATE XV.

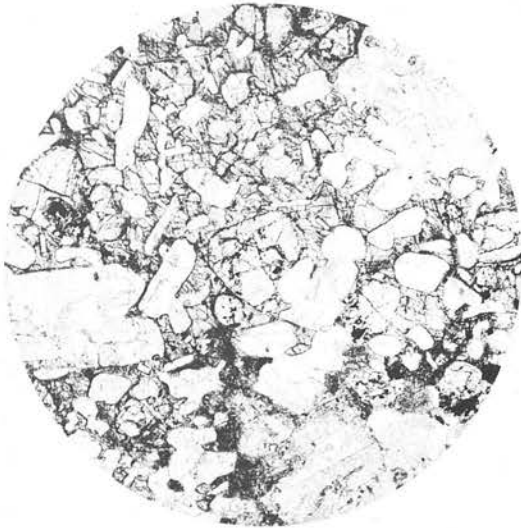
- Fig. 1. Eucrite, Mullach Bi, W. Coast of St. Kilda, showing corroded olivine serpentinitised along cleavage lines and cracks which also carry a good deal of magnetite; diopside moulded on bytownite feldspar and partly enclosing the olivine. "Dusting" of feldspars and schillerisation of the ferromagnesian minerals not well seen. Ord. light X 20.
- Fig. 2. Granulitic gabbro, Stac an Armin. Composed of augite, olivine (completely serpentinitised), bytownite, and magnetite. Ord. light X 20.
- Fig. 3. Large plate of diopside carrying olivine and bytownite poikilitically. Cliffs of Mullach Bi, eucrite of W. Coast. Ord. light X 20.
- Fig. 4. Crushed gabbro, western slope of Mullach Mor. Angular fragments of augite, magnetite and labradorite feldspar lying in a highly crushed base of the same minerals. Ord. light X 20.
- Fig. 5. Crushed gabbro, western rock shelves of Glen Bay. Angular fragments of augite, labradorite feldspar, and magnetite in a streaked groundmass of highly macerated augite, feldspar, and magnetite. The dark faulted band is composed mainly of streaked magnetite and dull green chloritic material. Ord. light X 20.
- Fig. 6. Crushed gabbro, western slope of Mullach Mor, showing streaked lines of flow in the crushed minerals, the angular fragments of feldspar and pyroxene lying roughly parallel to one another in the direction of movement. Ord. light X 20.



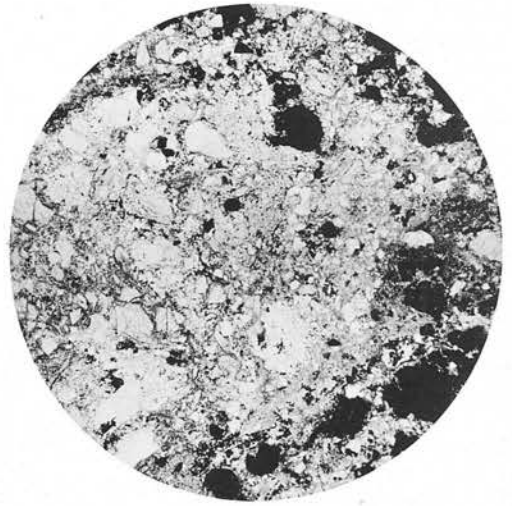
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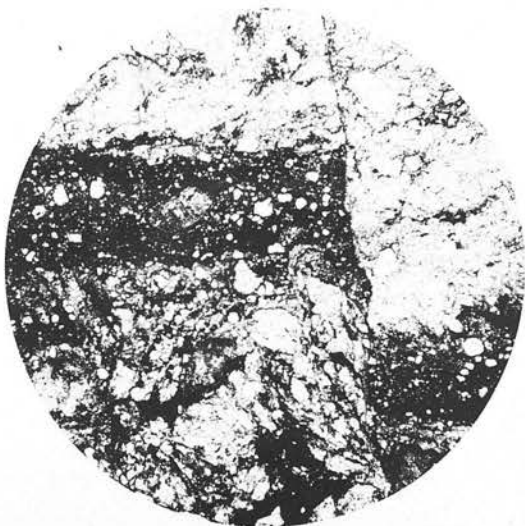
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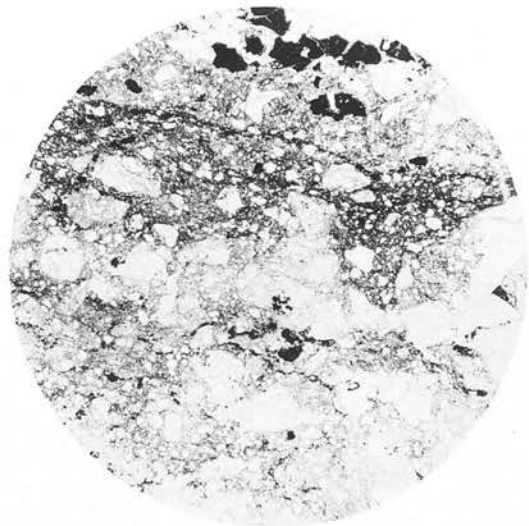
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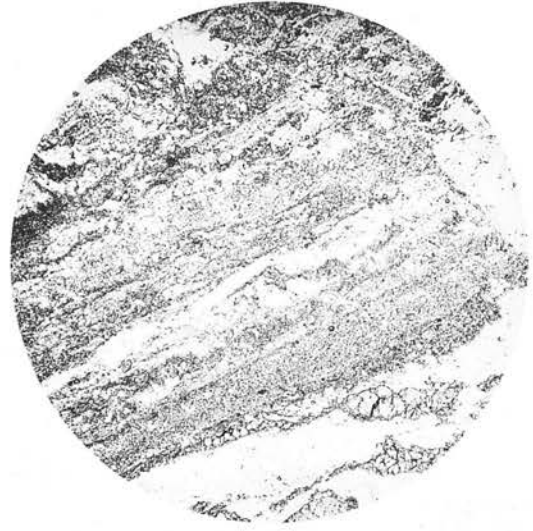
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PLATE XVI.

- Fig. 1. Crushed gabbro, Mullach Geal. The augite is almost completely granulitised, many of the granules lying along clear "solution" lines within the strained feldspars. Some of the feldspar also is granulitised. The ophitic relations of pyroxene and feldspar are still visible. Ord. light x 20.
- Fig. 2. "Flinty" rock, crushed eucrite of W. Coast near An Torc. Note flow arrangement of pyroxene and olivine granules and colourless bands consisting of granulitised feldspar. At bottom right the uncrushed remains of a crystal of olivine. Ord. light x 20.
- Fig. 3. "Flinty" rock, crushed eucrite of W. Coast near Claigeann Mór. Strained, faulted feldspar in a granular groundmass of augite, olivine, and feldspar. Ord. light x 20.
- Fig. 4. Corroded xenocryst in granophyre of Glen Bay. The main body of the xenocryst consists of diopsidic augite. Centrally it is altered to pale green actinolitic hornblende, while marginally it is replaced by a narrow fringe of pale green pleochroic augite. Ord. light x 16.
- Figs. 5 and 6. Granophyre, Oiseval. The minerals present are: turbid orthoclase (two large euhedral crystals, one showing Carlsbad twinning) microperthite, quartz, and a few crystals of magnetite. XM. x 25.



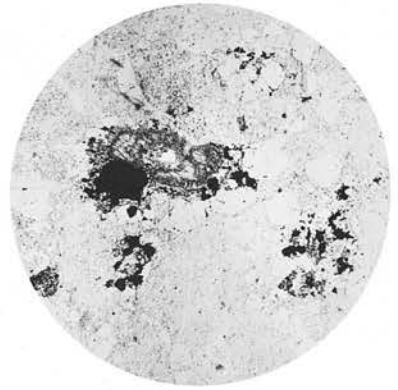
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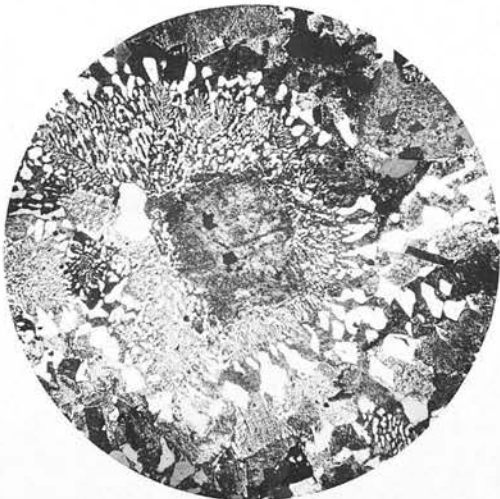
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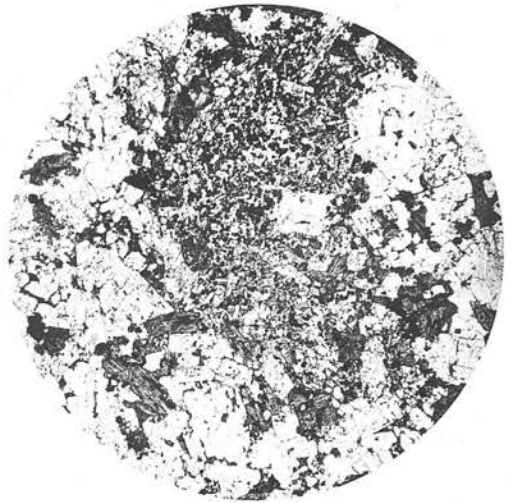
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PLATE XVII.

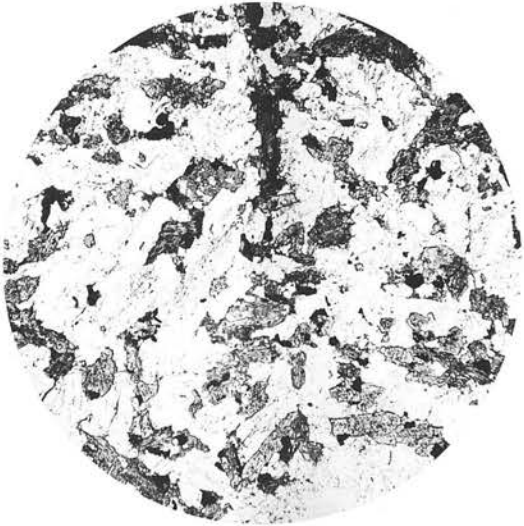
- Fig. 1. Granophyre, Conachair. Showing micrographic intergrowth of turbid orthoclase and quartz
XN. x 25.
- Fig. 2. Corroded inclusion of a basaltic dyke in granophyre dyke cutting the hybrid rock of Mullach Sgar at sea-level. The felspar of the inclusion has been largely acidified and the granular augite chloritised.
Ord. light x 20.
- Fig. 3. Hybrid rock, Mullach Sgar, at sea-level, consisting of elongate, newly crystallised monoclinic pyroxene and columnar hypersthene. A prominent crystal of the latter mineral, completely chloritised and appearing almost opaque, is seen in the top centre. The felspar is oligoclase-andesine in tabular and lath-shaped crystals. Ord. light x 20.
- Fig. 4. Dissolution of a xenolith of a fine-grained dolerite dyke in a granophyre dyke, W. Coast. The ophitic structure of the xenolith is seen at the top centre. Between the xenolith and the granophyre below occurs a mixed zone of acidified felspar and clear, recrystallised granular augite.
Ord. light x 20.
- Fig. 5. To show groundmass of ? devitrified pitchstone, W. Coast near An Torc. Consists of a patchy aggregate of quartz and fine fibres and laths of felspar. Porphyritic quartz and oligoclase occur elsewhere in the same slice.
XN. x 25.
- Fig. 6. Granophyre dyke, W. Coast. One or two zoned crystals of oligoclase may be seen, but the bulk of the rock consists of turbid orthoclase and microperthite and quartz in rough intergrowth. The ferromagnesian, which does not show clearly, is in the form of ragged crystals of pale green augite. Magnetite is sparing in amount.
XN. x 25.



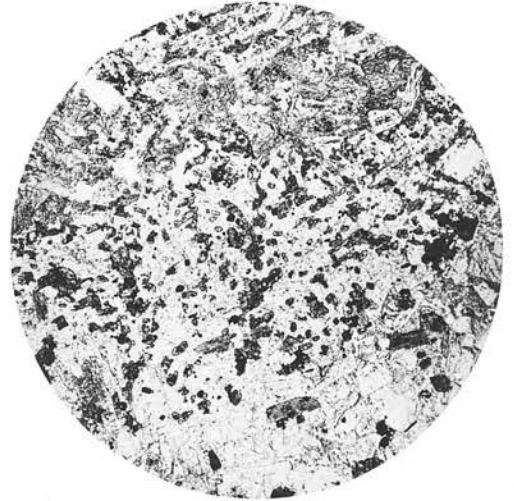
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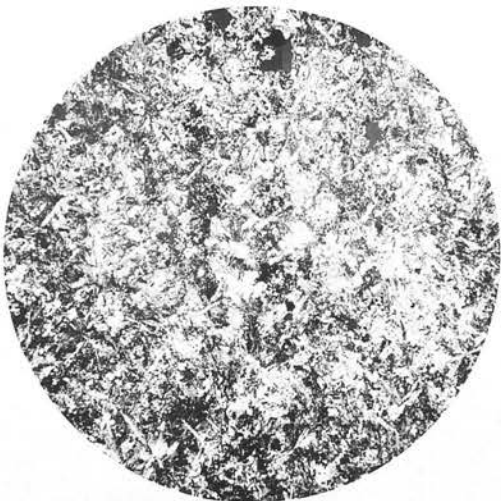
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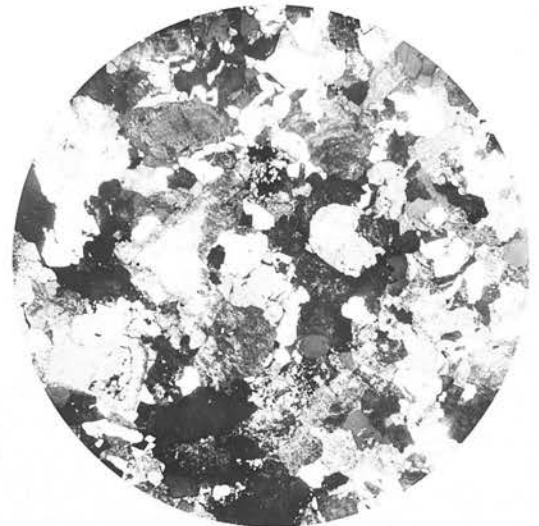
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PLATE XVIII.

(Figs. 1-5 of the post-granophyre dolerite-basalt group).
See pp. 120-122.

- Fig. 1. Coarse-grained dolerite dyke cutting granophyre of eastern cliffs of Oiseval. Consists of ophitic, purple titaniferous augite and labradorite feldspar, with magnetite and interstitial chlorite.
Ord. light x 20.
- Fig. 2. Medium-grained dolerite dyke cutting eucrite of W. Coast. Mineral assemblage as above. The black interstitial areas are composed of green chlorite which appears opaque in the photomicrograph. Ord. light x 20.
- Figs. 3 and 4. Porphyritic, sub-ophitic, basaltic dykes, eastern cliffs of Oiseval, the porphyritic feldspar being labradorite-bytownite. Ord. light x 20.
- Fig. 5. Porphyritic basalt, W. Coast. Note four corroded quartz grains surrounded by wide zones of granular monoclinic pyroxene. On the right, two glass-filled vesicles carrying microlitic feldspar and pierced by the lath-shaped feldspars of the groundmass. Ord. light x 20.
- Fig. 6. Porphyritic pitchstone, W. Coast above An Torc. The large porphyritic crystal on the right is finely twinned oligoclase. On the left, corroded phenocryst of quartz. The groundmass consists of partly devitrified brown glass. Ord. light x 20.



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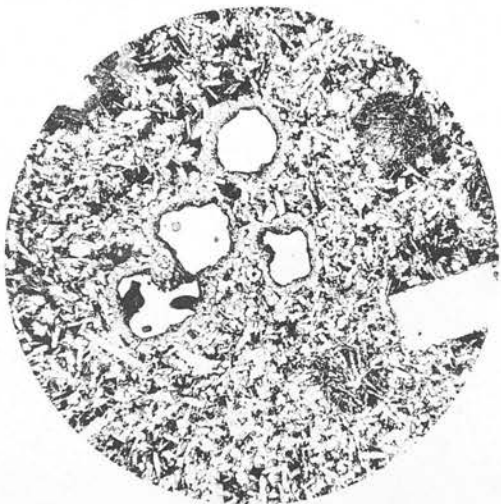
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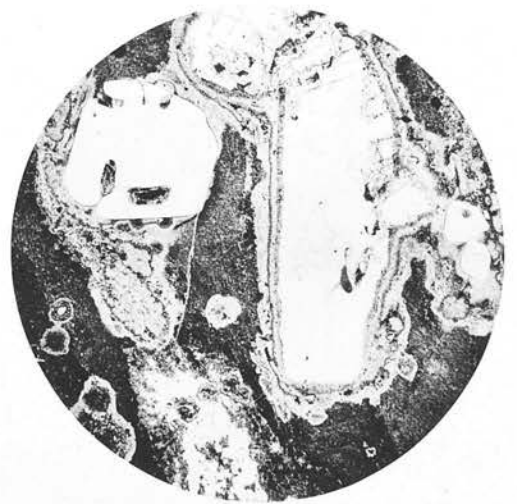
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