No. XXI.—THE IGNEOUS ROCKS OF BUTE. By WILLIAM R. SMELLIE, M.A., B.Sc., Hunterian Museum, Glasgow University.

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THE geological claims of Bute seem always to have been overshadowed by the near presence of Arran, with its superior size and variety of formations. MacCulloch, in his "Geology of the Western Islands" (1819, p. 445), devotes some space to emphasising the importance of Bute geologically, and then dismisses the island in twenty-nine pages. Bryce, in his "Geology of Arran and the other Clyde Islands" (1872), reproaches MacCulloch for his injustice, and then generously allows Bute three pages more, or thirty-two pages, as against 315 pages devoted to Arran. The object of the work recorded in the present paper has been to continue and amplify the work recorded in the Geological Survey Memoir (1903) as far as it relates to the igneous rocks of Bute. The igneous rocks in the area have been mapped and studied with the aid of numerous thin sections under the microscope. The lavas of Calciferous Sandstone age will be described in the light of recent classification, certain occurrences of rocks hitherto unknown in the district will be recorded, while in some cases evidence will be advanced which may necessitate change in the interpretation of rocks already described.

DISTRIBUTION OF THE IGNEOUS ROCKS.

The Island of Bute is divided into approximately equal halves by the Highland Boundary Fault which crosses the island from Rothesay Bay to Scalpsie Bay. The northern half is composed of Highland schists, grits, and phyllites, and the igneous rocks are confined to a few dykes and the Scalpsie epidiorite sill. The dykes running east and west are thick and persistent, and are granophyric quartz-dolerites of Permo-Carboniferous age, while those with a north and south trend are Kainozoic dolerites. The southern half of the island is occu-

pied for the most part by rocks of Upper Old Red Sandstone age, chiefly conglomerate and sandstone with some cornstone. Many dykes intersect those rocks, Kainozoic dykes being specially numerous. The sediments dip south-west, but are so repeated by faults that, with the exception of small outliers of lava at Ascog, Ambrisbeg, and Ardscaipsie, Old Red Sandstone occupies all the country between the Boundary Fault and the raised beach which crosses the island at Kingarth. South of this (see map) igneous rocks occupy the bulk of the ground, giving long, regular escarpments of bare lava, sill escarpments, and isolated vents, and producing a barren, rugged country, only relieved by the flats of the raised beaches. Except for the Suidhe vent, above Kilchattan, the country seldom rises above the 400 feet contour, but under hazy atmospheric conditions the small abrupt hills and ridges can look quite massive, and this may account for a singular over-estimation of heights given by MacCulloch (1819, p. 446). He gives the height of the Garroch Head district as 600 to 800 feet, while for the raised beach, crossing the island at Kingarth, which no more than breaks the 50-feet contour, he estimates a height of 300 feet.

Among the igneous rocks of Bute are found representatives of four periods of igneous activity—

	ROCKS.	AGE.
I.	Epidiorite Intrusion of Scalpsie.	Arenig?
II.	Basaltic and Trachytic Lavas, Ash, and Agglomerate: Minor Intrusives, one of which contains fragments of Plutonic Rocks.	Calciferous Sandstone.
III.	East and west dykes of Quartz-Dolerite. Large sill of Olivine-Dolerite, and doubtfully several small dykes and sills of the same rock.	Permo-Carboniferous.
IV.	Composite sill of five sheets, and numerous dykes and inclined sheets of Dolerite.	Kainozoic.

EPIDIORITE AND SERPENTINE OF SCALPSIE BAY.

Although previously described separately (Gunn, 1903, p. 22) these two rocks are here taken together as both field evidence and thin section indicate that they form parts of one and the same intrusion. It occurs on the west side of Scalpsie Bay, and forms a low but well-marked ridge, which runs from a short distance north of the Dun to the cliff of the raised beach, fully a quarter of a mile to the south. Here the outcrop is interrupted by raised beach material, but continuations of the lines across to the present beach pick up the rock again there. It is exposed about high-water mark, and is got rather irregularly owing to the mantle of large boulders which strew the beach and mar the exposure. It is from this part that serpentine has been described, and while serpentine certainly occurs, it by no means constitutes the whole of the mass on the beach, for another specimen from hard by may be devoid of serpentine. This exposure is undoubtedly only the more altered southern end of the epidiorite, which rock has been intruded as a sill at least 100 feet thick at the Dun, which forms its highest point. It dips west into the grits and quartzites which form its northern and western boundaries, but no sharp junction is got, as the ridge of epidiorite is separated from the overlying grits by a small turf-clad depression or a boulder-strewn hollow. On the east side it is bounded by raised beach material, while to the south, intervening between the sill and the sea, occur bars of red and white sandstones with interbedded clays. These are probably of Lower Carboniferous age, and are much disturbed, great variations in dip both in amount and direction being got within a few yards. The boundary fault runs between the sandstones and the southern end of the sill, but the actual fault line, occurring as it does well below high-water mark, is obscured in a tantalising fashion.

Petrography.—In the hand specimen the epidiorite is a dark-coloured thoroughly foliated rock, varying greatly in texture from a fine-grained amphibolite, with black shining hornblende needles to a coarse variety showing large plates of hornblende and a less well-marked parallelism of constituent minerals. The various grades can be got in one small block of the rock,

and do not appear to occur in any particular relation to positions in the sill. Veins of felspar, ranging up to 1 or 2 inches in thickness, are frequently met with traversing the mass, and when the vein has not been completely filled, felspars showing crystal faces are got projecting into the vugg. Veins of quartz and calcite also occur, and at a point about 100 yards south of the Dun a pocket of calcite about a foot in diameter was observed.

Thin sections were cut from specimens of the epidiorite taken from the northern extremity, the Dun, and several positions to the south. Slices from the centre of the mass show the least altered rock. It is a coarse aggregate of pale green hornblende, felspar, and quartz. The hornblende is drawn out and ragged, and is frequently replaced by chlorite. The felspar is partly cloudy, probably due to minute grains of epidote, separating out, and partly clear secondary albite. The albite and quartz are clear and granular, and sometimes occur mainly in the veinlets. Epidote and zoisite, though always present, vary greatly in amount, and the epidote frequently becomes one of the chief constituents of the rock. It occurs as strings and aggregates of elongated pale green grains with appreciable pleochroism and high single and double refraction. The zoisite grains are less numerous, and in some slides absent. It occurs as colourless grains, with very typical steel-blue interference colours. In the "serpentine" exposure on the shore more highly altered rock is got. One section shows little original hornblende, epidote, the main constituent, with a few wisps of chlorite drawn out in the centre of epidote aggregates, while quartz and felspar are very irregular in amount (Pl. XXXVI., Fig. 6). Some fields show almost pure epidote rock while others show the rock passing locally into epidosite, an epidote quartz rock. There is great variety in this shore exposure, and it is unfortunate that only occasional projections of the rock *in situ* appearing through beach material are available. Another specimen from this locality is very pale green in colour, and in thin section proves to be completely composed of high polarising fibrous talc, while a third, dark and foliated, and not unlike the amphibolite in appearance, proves to be almost entirely colourless serpentine

without a trace of the parent mineral or hint of its nature. The serpentine is in sheaves and bundles of fibres giving extinction brushes; a little stringy magnetite is present, and a few grains of epidote and zoisite survive. In the talc no trace even of the epidote remains. Between cross nicols the section of the talc shows a few areas of low colour, presumably serpentine interleaved with the highly polarising talc fibres, but in the serpentine rock no talc is observed in the thin section, although the rock scratches easily with the finger nail, and gives a sp. gr. of 2.8.

The large felspar veins are of perfectly clear albite, but in the small veinlets of albite seen in the slices of the epidiorite numerous small prisms of secondary hornblende occur. Where these veins cross hornblende crystals the secondary outgrowths of hornblende are often in optical continuity with the large broken crystal. The albite has been derived from the soda-bearing silicate in the original lime-soda felspar, when the lime-bearing silicate separated out to form the zoisite and epidote. The formation of epidote, zoisite, and chlorite in epidiorites is common, but the formation of serpentine from an amphibole rock is rather unusual, though occasionally recorded. (Emerson, 1898, p. 115.)

The age of the intrusion is uncertain. The thin section under the microscope gives no clue, as it is found to differ in no essential from other Highland epidiorites, such as those in the Strachur district. From field relations it seems that it was intruded probably as a dolerite in pre-Boundary Fault times, and metamorphosed to epidiorite by the same movements that metamorphosed the grits into which it is intruded. The further dynamic metamorphism suffered by its southern extremity is to be ascribed to the movements forming the Boundary Fault, which movements appear to have continued into Carboniferous times. Arenig has been tentatively put forward as the age of the intrusion (Gunn, 1903, p. 22), and this does not seem improbable.

CARBONIFEROUS IGNEOUS ACTIVITY.

The rocks of Lower Carboniferous age form the bulk of the igneous material in Bute, and consist of basaltic and trachytic

lavas, necks of agglomerate, beds of tuff and minor intrusives, while evidence of the existence of a plutonic phase is found in a suite of basic and ultrabasic rocks occurring as xenoliths in one of the minor intrusions.

Field Relations.—The lavas overly the sediments of Old Red Sandstone and Calciferous Sandstone age, and dip to the south-west at angles of about 20° to 30° . In direction and amount the dip is approximately the same as that of the

Diagrammatic section of north face of Barr Point, showing sill of Markle Basalt cutting across the bedding planes of Sandstone.

underlying sedimentary rocks, so that in any one section across the junction an unconformity is not apparent. [As will be seen later, the evidence of the section at the south end of Lubas Bay is inadmissible for purposes of demonstrating an unconformity (Gunn, 1903, p. 55), as the rock in question is a sill and not a lava. (See text figure.)] However, the unconformity can be proved by the different horizons in the sedimentaries at which the lavas are found to commence in different parts of the field, showing that the lavas have transgressed over the thin Calciferous Sandstone Series into the Old Red Sandstone. The unconformable nature of the junction can be further shown by a comparison of the sediments immediately beneath the lavas at two points only 300 or 400 yards

apart. At Creag a Mhara the sediments end with about 40 feet of reddish sandstone, in places baked and columnar by invasion, while just across the Hawk's Nib fault, towards Run-nan-Eun, the topmost sedimentaries consist of 20 to 30 feet of greenish-white sandstone, followed by 2 feet of clay, then 2 feet of white sandstone, and, finally, in contact with the lava, 3 feet of clay.

The lavas strike north-west in long ridges, which are frequently columnar, and strike faults throwing down to the north-east break the peninsula south of Kilchattan into several blocks separated by long, straight valleys. These features were observed and neatly described by Boué (1820, p. 257) in his "*Essai Geologique sur l'Ecosse.*" Three of the faults have sufficient displacement to bring up the sediments at the base of the lavas on the upthrow side, thus multiplying opportunities for comparing the sequence of the early lavas in different parts of the field. The various blocks of lava, marked off by the faults, will be described separately and referred to under the names of prominent topographical features occurring in them or bounding them; the points of emergence of faults on the shore will be found useful in referring to the map. Following the shore from Kilchattan south, the first lavas met with are those of Creag a Mhara. Creag a Mhara is a large vent piercing the Calciferous Sandstones, which are seen on the shore around its base. It forms the tall cliff of the raised beach, on the bare side of which the large boulders of the coarse agglomerate can be seen from a distance, while from its summit the lavas which it emitted stretch inland, in a north-westerly direction, nearly to the Kilchattan waterworks. These Creag a Mhara lavas form only a narrow strip, for at Hawk's Nib, a short distance further on, the first strike fault emerges on the shore, Hawk's Nib being a prominent undercut cliff of red sandstone on the upthrow side of the fault.

Continuing south over sandstones and cornstones, which are much invaded by igneous rock, the lavas are soon encountered a second time, and are associated with a neck of agglomerate very similar to Creag a Mhara. This Run-nan-Eun block of lavas is much larger than the last, and extends to the Suidhe

Hill, the large vent above Kilchattan, with its associated lavas. On Run-nan-Eun there are about a dozen flows, averaging about 30 feet thick, and the flows are frequently separated by beds of ash, which are sandy and occasionally attain a thickness of 4 feet. Where the lavas abut on the sea the differential action along the strike of the flows on the soft ash beds or scoriaceous junctions has resulted in numerous miniature bays and promontories, producing a very rugged coastline (see Pl. XXXV.). Inland the flows rise in terraces one above another till the long dip-slope of the topmost flow descends into Glen Callum, where the strike fault forming that valley abruptly terminates the series.

Across the valley lavas are seen again, rising terrace upon terrace to a height of 400 feet, but these are the beginning of the series again, for, on the shore of Glen Callum Bay the first lava is got resting on sandstone (Pl. XXXV.). Seen from the top of Run-nan-Eun the lava terraces stretching along the north-west side of Glen Callum are very imposing, and it may have been their regular superposition that caused MacCulloch (1819, p. 465) to state that "among the numerous instances of apparent stratification in trap which have occurred in the course of this survey, the present (Bute) is infinitely the most regular and perfect." This Glen Callum block of lavas consists of about twenty flows, and stretches to the strike fault which emerges on the shore at Port Uisg, and again brings up the sediments on its upthrow side. This is the largest of the lava blocks, but some of its extra extent may be accounted for by a partial repetition due to a possible fault running out at Port Leithne. The shore topography of this area is similar to that of Run-nan-Eun, but here the similarity ends, for the main feature inland is the dominating escarpment of the composite sill truncating the low-lying lavas and then sweeping round parallel to them. The olivine-dolerite sill cutting across the Run-nan-Eun lavas leaves no outstanding feature. Further variety is added to the Glen Callum block by the low elevation of the ground around Loch-na-Leighe, which must have been an arm of the sea at the time of the raised beach, with the composite sill escarpment acting as a protecting reef.

South-west of the Port Uisg fault, and overlying the sand-

Photo. by J. W. Roach, Esq.

Panorama of South Bute, taken from Run-nan-eun Point.

stones, stretch the Port Uisg—Dunagoil lavas, bounded to the north-west by the Dunagoil dip fault. Before these lavas have opportunity to accumulate into a block like the last they are bounded by the sea coast, which runs parallel to the strike of the flows. This gives a less serrated coastline, although at one point, at the boathouse of South Garrochty, the sea has breached one lava flow and then cut along the strike at the junction with the next, thus forming a small natural harbour with breakwater. There are about half a dozen different flows of lava in this block, and agglomerate and tuff are well developed. The north face of Dunagoil Fort shows the rocks well. The lavas are seen resting on the sandstone and dipping south-west. One of the flows is beautifully columnar, and the topmost flow, which reaches the sea, is pillowy, the pillows being best seen along the shore. A fairly thick ash bed outcrops beneath the lava, giving an undercut cliff on the north, and the fretting of the same ash bed where it meets the raised beach has produced one of the caves in which the prehistoric kitchen-midden material has been found. There are only about half a dozen lavas in this block, chiefly of markle type, but the development of agglomerate and tuff exceeds that in any other part of the area.

ASCOG, AMBRISBEG, AND ARDSICALPSIE.

These small outliers of lava, though insignificant compared to the lavas of the south end of Bute, have been the subject of more frequent reference, owing to the seams of coal got in association with those of Ascog and Ambrisbeg. The Ascog lavas form a small plateau stretching from Loch Ascog to the sea. They overly Calcareous Sandstone sediments exposed on their northern margins, and are faulted to the south against the Old Red Sandstone. The lavas composing the mass are chiefly mugearites, markle, and jedburgh basalts, with beds of tuff near the base. The flows seem to have been small and impersistent, and long, regular terraces are absent. The coal seam occurs near the base of the series intercalated between a very coarse and much-weathered markle basalt above and a bed of very crumbling rock, probably tuff, below. The section has been described in detail by Bryce

(1872, p. 318). The lavas of Ambrisbeg lie between the south end of Loch Fad and the north-east side of Loch Quien; they are bounded to the north-west by the Boundary Fault, while to the south-east their escarpments shade into the raised beach. They overly red sandstone, which is seen on the east side of Loch Quien dipping west at a high angle. The lavas here are also notable for the absence of persistent terraces, the flows being apparently of small extent. Mugearites, markle, and jedburgh basalts are present, but the most noteworthy point about the lava types is the number of markle-dunsapie basalts that occur, and this area certainly contains a higher proportion of dunsapie and transition types than any other part of the field. Coal is reported to have occurred among the lavas here, as at Ascog, and the remains of an old adit can be seen near Ambrisbeg Farm, but no other evidence of the coal remains. The Memoir (Gunn, 1903, p. 146) reports that "some 200 or 300 tons of coal were said to have been got out many years ago," the coal being a "kind of anthracite," in a seam "from 1 foot to 16 or 20 inches thick." On the other hand, MacCulloch (1819, p. 472) reports the coal in the sandstone, but indicates that there was no access to the spot, as it had been filled up after an unsuccessful pursuit. Judging from the unsuccessful attempts to work the much thicker seam at Ascog, and considering the poor quality of the coal, it seems highly probable that MacCulloch is right.

At Ardscaipsie Point occurs a patch of Carboniferous Basalts that are probably lavas. They can only be reached at low tide, are very badly weathered, and their relations can be only indifferently made out. They are separated from the Boundary Fault by the strip of calciferous sandstone and conglomerate which runs along the north-west shore of Scalpsie Bay, and they are intersected by a north and south Kainozoic dyke of ophitic dolerite, olivine free. Thin sections of two specimens prove to be markle basalt and mugearite, but they are so decomposed that little can be made out of them.

SEQUENCE OF THE LAVAS.

In the lavas of the Campsie Fells a definite sequence is found to hold throughout the area (Bailey, 1911, p. 99). In

South Bute the area is small, exposures are both good and plentiful, and the arrangement of the lavas, owing to frequent repetition by faults, is open to study at many points; under such favourable circumstances it was hoped at first that a very definite sequence might be made out and found to hold throughout the area. However, comparing several series of lavas, working from the base lava upwards, and employing localities separated by distances measured only in hundreds of yards, it was found that no uniformity in the order of the flows existed, nor was it possible to determine any general sequence among mugearites, markle, and jedburgh basalts. Any attempt to formulate a general rule of succession among these was immediately frustrated by the host of exceptions, and the conclusion reached was similar to that arrived at by Tyrrell (1912, p. 255) for the Kilpatrick Hills, namely, that "no divisions of general application can be profitably made." Lavas of mugearite, markle, and jedburgh type occur throughout the area, and a definite horizon cannot be ascribed to any one type more than another. However, it is noticeable in the lavas between Glen Callum and Port Uisg that it is near the top of the series that the extreme acid and basic types are got. No other lava block contains so many flows as this, and so none can be used to prove or disprove this in other parts of the field; but, judging from this one case where lavas of higher horizon are present, these seem to show an increasing divergence from the initial type. Throughout south Bute mugearite, markle, and jedburgh types occur at all horizons, but more acid types, bostonites, and more basic types, dunsapie and craiglockhart basalts occur chiefly near the top of the sequence. Thus it might be said, in a broad and general way, that the sequence is one beginning with intermediate lavas, mugearites, markle, and jedburgh basalts and passing into types, on the one hand more basic and on the other more acid than the original types. The development of the divergent types is very meagre, and at the top of the succession they do not occur to the exclusion of the intermediate types, and, in fact, do not even preponderate over them. This lack of a definite general sequence and the lack of agreement between the particular sequence in any two parts of the field finds at least a partial

explanation in the vents. The largest vents in Bute, such as the Suidhe, Creag a Mhara, or Dunagoil, are pigmy structures compared, say, to Dungoyn, so that while extensive flows are natural in the Campsie Fells, in Bute the numerous (fifteen or twenty) small vents within a small area would give rise to lavas of very limited extension, the flows dying out rapidly or interdigitating with the flows of neighbouring vents. In those circumstances unless each and every vent were ejecting similar material at the same time to form uniform sheets over the area, it is hard to see how a sequence in one part of the field could be got to correspond with that in another part, even when the localities are chosen close together.

PYROCLASTIC ROCKS.

These consist of agglomerate and tuff. The agglomerate, with the exception of a bed along the shore between Uamh Capuill and Uamh Phadaich, is confined to the necks, while the tuff occurs in beds ranging up to 6 feet in thickness, and in places these alternate with the early lava flows with fair regularity. One of these red ash beds from the shore north of Run-nan-eun Point was sliced, and found to be very sandy; in fact, it might be termed an ashy sandstone or sandy ash with equal truth. This points to some of the early lavas having been extruded under water. The dark green ash on the shore north of Port Leithne is very well exposed, and occurs in finely stratified beds out diagonally across by the olivine-dolerite sill. The necks with agglomerate vary in size from those like Suidhe and Creag a Mhara to small pipes only a few yards in diameter. The composition of the agglomerate in the necks becomes very significant when considered in relation to the neighbouring lava flows, and as the necks have been small and the flows from each limited both in number and extent it is possible in many cases to allocate the flows to the parent neck. The Suidhe vent is almost entirely occupied by an intrusive plug, so the method is inapplicable in that case, but Creag a Mhara, though invaded at the base, is mainly agglomerate composed of blocks of lava similar to the associated flows. The material ranges from fine ash and small angular

fragments up to boulders 6 or 8 feet across. Fragments of sedimentary rocks, sandstone, conglomerate, and pebbles of quartzite occur, but they are not common. The material in the neck just south of Hawk's Nib is much the same, but on its north-east face patches can be found containing baked cornstone, sandstone, and conglomerate boulders to the exclusion of igneous rock. Among the smaller necks cases occur which seem to indicate that one neck may only produce one type of lava; for example, associated with the flows of bostonite there is a small neck entirely composed of bostonite fragments, while the analcited basalt occurring about 300 yards north-east of Port Leithne has also possessed a private neck. The cases cited deal with types not easily confused—"kenspeckle" rocks—so it is probable that the principle applies to other cases less easy to prove. The existence of this close relation between the necks of agglomerate and flows of lava raises a point in connection with the dunsapie basalts of the south end—no neck has been found containing agglomerate with boulders of dunsapie basalt, and it is considered highly probable that they are mainly intrusive. There is nothing in their field relations to demand an extrusive origin, and what evidence there is inclines the other way. They do not show vesicular margins; they are sometimes hummocky, and lack the regularity of a lava, as at Port na Caillich, and, when presenting a good escarpment, it may be out of harmony with the neighbouring lava escarpments, as at St. Blane's Church. On the west side of the island the necks most worthy of note are the two at Dunagoil, one at the head of the bay, and one at the farm. The neck on Dunagoil Bay pierces the sedimentary rocks, and stands as an isolated hill rising from them and out of contact with the lavas. It is the only neck on the island so situated. The agglomerate forming it contains a high proportion of ash and fine material, but large boulders are also common, and an intrusion of markle basalt occupies the southern part of its base. Both necks are remarkably rich in agates and chalcedony, and in the neck at the farm fine flesh-pink botryoidal chalcedony can be got lining cavities. The neck on the bay is shot full of veins of chalcedony and jasper, while small milky pebbles can be picked out of the amygdales and made

to exhibit their agate banding by treating with sugar solution and charring with sulphuric acid. Jasper veins similar to those in the neck are continued in the sedimentary rocks on the shore across the fault, and though somewhat irrelevant it is interesting to note that the conglomerate there contains numerous worn pebbles of jasper, yellow and red, also pebbles of white and red unaltered sandstone, dark green cherts, a porphyritic lava very decomposed, and coarse red pegmatite, in addition to the usual suit of Highland rocks found in Old Red Sandstone conglomerates of the district.

MINOR INTRUSIVES.

The minor intrusive phase of Carboniferous igneous activity is well represented in the south end of the island, sills, dykes, and plugs being numerous. Of the sills the most important are a group of three on the west side of the island, north of Dunagoil. One occupies the north side of Dunagoil Bay, from the head of the bay to Barr Point, another occupies an exactly similar situation with regard to Lubas Bay, while a third, running north-west between Lubas and Largizean for over half a mile, forms a tall escarpment, which continues till it meets the sandstone cliff of the raised beach east of Lubas Port. These three occurrences have been formerly grouped with the lavas, and in the section at the south end of Lubas Bay the 20° dip of the sandstone, compared with the 10° dip of the "trap," together with the absence of intervening cornstone, is cited as evidence of the unconformity existing at the base of the lavas (Gunn, 1903, p. 55). However, the only evidence in support of these being lavas is that their escarpments strike in the same general direction as the lavas, and as that direction is mainly dependent on the directions of faulting and tilting, a fairly regular sill would naturally be affected in a similar way. What positive field evidence there is points to the masses in question being sills, and there is a section at Barr Point (see text figure) which proves the case incontestably for that particular mass. Here the base of the sill rests on the Old Red Sandstone, passes along the bedding, and then abruptly cuts across the stratification to a higher

horizon before continuing again along the bedding. Further, no vesicular margins are got in these rocks, no ash nor agglomerate is present in association, and single, and not stepped, escarpments are the rule, so that, if lava, each area would require to be one flow, and the depth and extension would be exceptional for the district. Where the junction of these markle sills with the sandstone is exposed at Barr Point and Fort Dunstrone, the lower part of the igneous rock is found to have assumed a form very common in sills of considerable thickness. A margin, 6 inches to 1 foot thick, and very compact, has separated off from the main body of the sill. This probably represents the depth of rock initially chilled during the intrusion, and it is usually divided off from the mass of the sill by a continuous joint. On the shore at Fort Dunstrone this marginal layer is greatly altered at its contact with the sandstone. While the mass of the sill is of very coarse blue markle dolerite, with large glassy labradorite phenocrysts, the margin is a pale buff rock studded with opaque white felspar phenocrysts. It effervesces strongly with acid, and, under the microscope, although little difference is noticeable in ordinary light, between cross-nicols, minerals and structure are entirely obscured by calcite. The fresh unaltered rock of the sills is composed of very large labradorite phenocrysts set in a groundmass, in which felspar laths greatly predominate over magnetite. A little green serpentine, occurring mainly interstitially, is present, but no fresh olivine is found. The rock is charged with long needles of apatite to a degree not observed in any of the lavas, and this, coupled with the comparative scarcity of femic minerals, form the only distinguishing mineralogical characteristics (Pl. XXXVIII., Fig. 4).

Along the coast south of Barr Point a number of negative dykes occur in this rock. These are irregular shrinkage cracks, 1 to 4 inches wide, which have been filled with sand and fine material washed in from the surface of the sill. Some of them would pass muster as small dykes of fine-grained, compact igneous rock, but a thin section reveals their elastic nature, the rock being mainly quartz grains in a cement of the fine material washed off the igneous rock or ground off the walls by subsequent movements.

Numerous small sills, 2 or 3 feet thick, occur in the sediments at the base of the lavas at Port Uisg, Creag a Mhara, and south of Hawk's Nib. At Creag a Mhara one sill just above high-water mark is a fresh markle, with spheroidal and columnar jointing, but usually the sills are soft, dull red, ashy-looking rocks in a very decomposed state. In thin section they are so much decomposed, and replaced by calcite, that little can be made out of them. They are altered olivine basalts composed of plagioclase, serpentine, and magnetite, and they are usually non-porphyrific.

Plugs.—Intrusive plugs filling the necks are not common, but the large vent of Suidhe Chatain is almost entirely occupied by an intrusion. It is a fairly fresh olivine basalt, tending to the markle type, and forms a steep conical hill, rising to 517 feet, the highest point in this part of the island. The rock is poorly exposed, and only in two places has a little agglomerate been observed, so it would appear that the plug occupies practically the whole site of the vent. Creag a Mhara is mainly agglomerate, and has been intruded in a complicated manner round its base. The south seaward face, below high-water mark, is occupied by a concentrically jointed intrusion of craiglockhart basalt, in which the olivine phenocrysts have been replaced by hæmatite, which shows bright red in the hand specimen (Pl. XXXVIII., Fig. 5).

Dykes—The dykes of Carboniferous age are numerous in the sediments at the base of the lavas, and also in the Old Red Sandstone further north. It is only occasionally that one of those dykes is observed to cut the lavas. They vary in trend and thickness, but, generally speaking, may be described as impersistent dykes, 6 or 8 feet wide, and with a tendency to run in a north-easterly direction, practically parallel to the dykes of Kainozoic age.

A good series of these dykes is got on the shore at Kerrytonlia, north of Kilchattan, and in Stravannan Bay, on the opposite side of the island. The dykes are never so fresh as the lavas, and the type of rock mentioned in connection with the sills as altered olivine basalt is a common type. Other types resembling the different lavas occur, such as dykes of mugearite and markle basalt. An easily accessible dyke of the

former type occurs on the shore south of Kilchattan Pier, while another cuts a neck of agglomerate next the composite sill on the shore south of Uamh Capuill. This dyke encloses a mass of agglomerate in its centre, and is veined with quartz and calcite, crystals of quartz almost bipyramidal being obtainable. At the north end of Stravannan Bay and at Kerrytonlia Point composite dykes are found. These are about 8 feet wide, and the one at Stravannan Bay contains three types of rock. The centre of the dyke is of coarse markle, 2 to 4 feet, the phenocrysts large and closely packed. On each side of this central core occurs a rock somewhat similar, but distinguished by a marked decrease in the number of the phenocrysts. The outside sheets, intervening between this and the country rock, are very fine grained, and at first glance seem non-porphyrific. Closer inspection reveals the presence of a fair number of phenocrysts, thin clear plates of felspar quite inconspicuous against the background of the groundmass, which in other cases throws up the white opaque rectangles of weathered labradorite. In places the junctions of the three different types of rock are so sharp that separate intrusions—probably from the same magma at short intervals—must be postulated to account for the multiple character of the dyke. A markle magma intrudes a thin 2-foot dyke into the sandstones, while the intra-telluric generation of felspars is weak in number and size of individuals. A little later a second intrusion with larger and more numerous phenocrysts is inserted along the central plain of weakness of the first, to be split in its turn by the third and last invasion, when the felspar phenocrysts have reached their maximum development. The Kerrytonlia shore shows the greatest variety of Carboniferous dykes in a short distance. They vary from coarse markle, through types with sparse or sporadic pink phenocrysts of felspar, to fine grained, greatly weathered olivine-basalts, and their north-east trend is very constant. The shore south of Hawk's Nib is an area intensely complicated by numerous dykes and irregular intrusions of this altered olivine-basalt, which bake and alter the sedimentary rocks till junctions become hard to determine. The intrusions here are very amygdaloidal with the amygdales filled with quartz and calcite.

INTRUSION CARRYING FRAGMENTS OF PLUTONIC ROCKS.

This intrusion occurs on the shore at a point about 400 yards south of Hawk's Nib, and it contains a most remarkable series of rocks. The credit of its discovery belongs to Miss A. T. Neilson, of this Society. It pierces the sandstones, cornstones, and clays of Calciferous Sandstone age at a point a short distance north of where they are overlain by the Runnan-Eun lavas. The whole mass is no more than about 20 yards by 30 yards in extent, and most of it lies between tide marks. It is intruded into the sediments at a high angle, dipping to the south, and on the land side, a bar of sandstone divides it from another small area of the same rock, which is seen to disappear under the scree from the lava cliffs bounding the raised beach, so that the limits of this second part are uncertain. In spite of its very limited dimensions the mass on the shore has proved a veritable museum of basic and ultra-basic rocks, all of them new to the district, and many of them thoroughly plutonic in habit. It is probable that here at last occurs tangible evidence of uncovered masses of Carboniferous plutonic rocks, and the number and diversity of the samples present in this small area are phenomenal. The occurrence is either an intrusion carrying xenoliths or a neck subsequently invaded, but the former seems the more likely. The intruded rock is a much altered, amygdaloidal olivine-basalt of a type very similar to the dykes and irregular intrusions of early Carboniferous age, which are abundant a few yards to the north. The southern half of the intrusion, which is also the upper half, is practically free from xenoliths, but as the northern and lower half is approached xenoliths become so numerous and closely packed that the enclosing olivine-basalt is seldom in evidence.

It is not intended, in the present paper, to give a full account of the petrography of the rocks present in this occurrence, but it will be sufficient for general descriptive purposes to state the rock types already found. The xenoliths average about 4 to 6 inches in diameter, and a number of these have been found to be practically single mineral rocks, such as anorthosite, a labradorite rock (Pl. XXXVIII., Fig. 1); dunite, a fresh

olivine rock (Pl. XXXVIII., Fig. 2); serpentine, a pale grey rock composed entirely of colourless serpentine; and pyroxenite, under which term are included augite rock, diallage rock, and hypersthene rock. Numerous rocks which are combinations of two or more of the different minerals named above have been found. For example, gabbro xenoliths are numerous, though the weathered condition of most of these contrasts strongly with the fresh state of the labradorite, pyroxene, and olivine in the single mineral rocks. Olivine-pyroxenite (Pl. XXXVII., Fig. 1), fresh and very tough, is one of the most common rocks present. To avoid a long list of rock names, olivine-pyroxenite can be understood here in its widest sense, as different pyroxenes occur, and the relative amounts vary. Types are got linking up pyroxenite, by a gradual increase in olivine, to pure olivine rock. In addition to the above formidable list of plutonic rocks, small blocks of various basalts are also found, including types, such as Hillhouse and Dalmeny, which have not been observed among any of the lava flows on the island. So far no fragment of any of the sedimentary rocks pierced by the intrusion have been found in it, although the pale grey serpentine looks exactly like a baked cornstone, and maintains the deception by effervescing strongly with acid. Large, fresh pieces of augite showing no good crystal faces are common, and these measure 1 inch or 2 inches across. These were noticed to be very similar to some augite specimens in the Hunterian Museum, which were collected by Dr. John Young from the Black Rock, Fairlie, and described by him in a short paper (1894, p. 13), so, acting on the possibility of the Black Rock holding further treasures, a short visit was paid to it. It resembles the Bute occurrence in some respects, and has yielded a fairly coarse biotite-pyroxenite not got in Bute so far.

The large number of different rock types occurring in an intrusion of such limited size seems difficult to explain, especially when one considers the distances that usually have to be covered to collect a variety of rocks in the field; but, when it is recognised that the rocks present are all basic and ultrabasic rocks, the problem of their presence in such variety

becomes more easy. In a complex of plutonic rocks the acid rocks occupy large tracts of country, but basic and ultra-basic types may occur within a very small area. Though the plutonic complex of Loch Garabal occupies most of the country between the heads of Loch Lomond and Loch Fyne, the ultra-basic rocks occupy only a small proportion of the whole. Some of these rocks bear a strong resemblance to the Bute specimens, and thin sections of wehrlite (Wyllie and Scott, 1913, p. 502) from the two localities are indistinguishable. In describing the ultra-basic plutonic rocks of Skye Harker writes (1904, p. 422), "The most striking feature is extreme complexity of structure. The rock types represented range from troctolite, through picrite, to dunite, and even to seams of pure picotite; and these have been intruded in part simultaneously, so that they alternate in bands, in part successively, so that a later rock veins an earlier, or is crowded with débris from it." With different types of rock occurring in this manner, it is clear how even a small intrusion or neck might be found to contain a large variety of rocks after having been thrust through such an area. Thus the obvious inference to be drawn from the occurrence of this suite of ultra-basic plutonic rocks in Bute is that a mass of Carboniferous plutonic rocks lies buried at no great depth under the Firth of Clyde and adjacent land; and, as the phase of minor intrusives follows the plutonic phase in a cycle of igneous activity, this particular minor intrusion in Bute must have traversed part of the ultra-basic plutonic area before reaching its present position.

PETROGRAPHY.

Trachytes or Bostonites.—At least three flows of this lava occur, and an associated neck of bostonite agglomerate. Similar rocks are present in Cumbræ and other parts of the Clyde area, but occur as minor intrusives, whereas in Bute bostonite is found only among the lavas. The flow of widest extent stretches from North Garrochty to the sea at Port Luchdach, and two slices from this flow have already been described in the Memoir of the Geological Survey (Seymour, 1903, p. 176). The other flows occur, one overlying the

olivine-dolerite sill at Port Leithne and the other at Uamh Capuill, where part of the flow has been partially enclosed by the composite sill. In the hand-specimen the rock varies from a reddish colour to a light grey with occasional pink felspar phenocrysts showing in the banded groundmass. The beach pebbles of this rock develop a very smooth surface, which exhibits to advantage the dark flow lines and red phenocrysts, and gives the rock a handsome appearance not apparent in the rough. Hand-specimens taken from the flow east of Loch-na-Leigh have all the appearance of agglomerate, but this is due to irregular staining with hæmatite, as thin sections show felspars passing from one pseudo-rock-fragment to another of lighter tint. The rock is composed of a felt of orthoclase and albite laths with small cubes of magnetite, enclosing phenocrysts of albite and orthoclase few in number but large individually and tending to group. Interstitial quartz is present in varying proportions, the bostonite from Port Leithne containing considerably more than either of the others. Scattered through the ground-mass of the Port Luchdach bostonite occur minute grains of a pale green mineral, probably soda pyroxene. All examples are holocrystalline, and show well the parallel orientation of the felspar laths.

Mugearites.—In Bute typical mugearites are not abundant, but basaltic mugearites and transition types approaching microlitic jedburgh basalts are common; porphyritic types, passing into markle basalts, are also of frequent occurrence. The presence of transition types makes the field diagnoses of mugearites somewhat unreliable, and the pale weathering tints and platy structure have not been found trustworthy criteria. In fact, without a thin section it is not easy to distinguish mugearites from jedburgh basalts. The best development of mugearites occurs in the Creag a Mhara lavas. In thin section they are found to be composed essentially of straight-extinguishing felspar laths with cubes and irregular patches of magnetite set in a groundmass of weathered felspar and pale-green decomposition products. Olivine is never present in a fresh state, but is represented by occasional areas of serpentine of irregular outline. Needles of accessory apatite are fairly numerous in some slides. The mugearites are seldom

fresh, and usually yield unsatisfactory slices, but the specimen figured (Pl. XXXVI., Fig. 1) is an exceptionally fresh rock.

Markle Basalts.—These are more numerous than any other type of lava in the area, and among the minor intrusives they likewise bulk most largely. They vary unaccountably from fresh, blue, compact basalts with glassy phenocrysts of labradorite to dull grey, weathered types with white opaque feldspars. Vesicular and amygdaloidal varieties are common, and the weathering of the margins between two such flows often simulates an intervening bed of tuff. In thin section the markles are seen to consist of large plagioclase phenocrysts, often labradorite, with occasional serpentinised olivines set in a groundmass which varies from holocrystalline to glassy and microlitic. In a slaggy lava from Run-nan-Eun the groundmass consists of microphenocrysts of feldspar and several sizes of microlites, many with bifid terminations set in a continuous dark glass, while in another Run-nan-Eun markle the groundmass consists of a holocrystalline aggregate of feldspar laths, magnetite cubes, and euhedral grains of augite. The appearance of sporadic augite among the phenocrysts produces types linking the markles with dunsapie basalts, but though such are common among the Ambrisbeg lavas, they are scarce in the south end of the island. The markle basalts, more than other types, have undergone the process of albitisation (Bailey and Grabham, 1909), and among them every stage leading to complete albitisation can be observed. Few have escaped entirely, others show only cores and isolated patches of albite in the labradorite phenocrysts, while others have had the phenocrysts entirely replaced and even the groundmass attacked. In the slaggy markle referred to above, the feldspar phenocrysts are large and abundant, a few are simply twinned and extinguish straight (presumably orthoclase), while all the others have been completely replaced by albite.

Jedburgh Basalts.—These are almost as numerous as the markles and, like them, occur at all horizons. Their greatest development occurs among the Glen Callum lavas, low down in the series. Both ophitic and microlitic types of jedburgh basalt are represented, but the typical ophitic jedburgh is scarce. It contains micro-phenocrysts of labradorite and ser-

pentinised olivine in a groundmass of magnetite grains and felspar laths in ophitic relations with augite. In patches a pale brown glass occurs in place of the augite, filling the interspaces and enclosing the felspar and magnetite. The micro-litic varieties of jedburgh basalt differ from the foregoing in having the augite present as subhedral grains instead of micro-ophitic plates. This type is by far the more common and passes imperceptibly into basaltic mugearite.

Dunsapie Basalts.—The basalts of dunsapie type are usually very fresh, dark blue rocks, with only a very thin skin of buff-coloured, weathered material. The black augite phenocrysts against this buff background enable this type to be easily identified in the field. In thin section the rock has a fine appearance (Pl. XXXVIII., Fig. 6), especially when the olivine phenocrysts have been replaced by red-brown pleochroic iddingsite. There are two generations of all the phenocrysts. The felspar is fresh labradorite, sometimes perfectly clear and at others packed with inclusions of magnetite cubes and augite laths. The augite phenocrysts are not so numerous as the others, nor do they present such regular boundaries, being frequently misshapen and eaten into by the groundmass. They are of a pale purple variety, but sometimes the purple hue is confined to the margins, while the central portions of the crystals are almost colourless. There are two generations of magnetite, one comparable in size with the micro-phenocrysts of the other minerals, while the other occurs in the groundmass which is a holocrystalline, granular aggregate of felspar, augite, and magnetite. In the dunsapie of Port na Caillich the olivine phenocrysts are entirely replaced by rich brown iddingsite, but in the dunsapie from the Cauldron the olivine is fresh, except for thin, serpentine linings to cracks.

Craiglockhart Basalts.—In the hand-specimen all the basalts of this type except the intrusion at Creag a Mhara are soft and weathered, resembling dull red tuffs rather than lavas. Of the lavas, the flow overlying the ash beds at Port Leithne is the least altered. It contains both micro- and macro-phenocrysts of augite and olivine; the augite is fresh and faintly purple, and the phenocrysts tend to gather in clusters; the

olivine is never fresh, but is replaced variously by hæmatite, iddingsite, and serpentine. The groundmass is made up of laths of plagioclase, small augites with sub-ophitic tendency, and cubes of magnetite set in a pale green isotropic base, probably a chloritic decomposition product.

Analcitised Basalt.—This rock is represented by a neck of agglomerate and associated lava occurring on the shore next the olivine-dolerite sill, 300 yards north-east of Port Leitline. In the hand specimen it resembles a markle with a compact, cherty-looking groundmass; in colour it is dark green in patches, and it has a general greasy or waxy appearance. It contains two generations of labradorite phenocrysts, some clear, others full of inclusions, and all more or less albitised. There are also large phenocrysts of augite, and the unaltered parts of these show them to be a pale colourless variety. The groundmass is composed of laths of felspar, cubes of magnetite, and indeterminate brown grains, either glass or decomposition products of augite grains. In addition to the albitisation of the felspar phenocrysts, the rock has been greatly analcitised. The augite phenocrysts have suffered most heavily from the analcitisisation; some of them are completely replaced, while the least altered among them can show no more than a marginal fringe enclosing a few islands of unchanged augite, all the rest having gone to analcite. The analcite pseudomorphs (Pl. XXXVI., Fig. 2) are frequently rendered dark and opaque by hosts of inclusions of ægirine-augite prisms, but these usually occur round the margins and along definite lines into the interior, thus marking off areas of water-clear analcite. From the dark lines small prisms of ægirine-augite protrude into the clear analcite, and with the high power can be individualised from the mass. Analcite has also replaced many of the small feldspars of the groundmass, and veinlets of analcite penetrate the rock, breaking across felspar phenocrysts, and displacing the halves in a way that shows the analcitisisation to be subsequent to the consolidation of the rock. The small analcite veins have the same opaque margins and clear interiors, into which the inclusions project. In addition to these small included prisms of ægirine-augite, that mineral is also formed

by direct alteration of the augite phenocrysts. Where the phenocryst is crossed by a vein of analcite it is found to pass insensibly into the green variety, and that portion of the crystal is distinguished from the unaltered augite by its intense pleochroism, lower extinction angle, and lower double refraction. At other times augite is replaced by the formation of little green prisms of *ægirine*-augite regularly arranged in parallel rows, the direction of the rows being apparently determined by the cleavage in the original augite crystal. The rock seems to have been a macro-porphyrific basalt with phenocrysts of augite and plagioclase. This is Type III. of the seven possible types indicated by Mr. Tyrrell (1912, p. 231), and it is a type that awaits a name. However, it is not considered advisable to name the type from this Bute occurrence, as its development is so limited and the rock is so heavily analcited. The alteration of phenocrysts is sometimes so complete that there is a possibility of olivine having figured as a phenocryst originally, in which case the rock would merely be an analcited dunsapie basalt. If olivine phenocrysts were ever present the analcite must have attacked them preferentially, and removed all trace of them. However, it is certain that no proved dunsapie on the island has been observed to show similar phenomena of analcitisation, and this fact rather strengthens the probability of the rock being a new type.

PETROLOGY.

A study of the morphology of the Bute lavas makes it clear that Bute must have formed the northern limit of the Clyde Plateau. The necks are numerous and small, flows are thin and limited in extent, and it is highly improbable that the main mass of lavas of the south end of the island were ever continuous with the small outliers to the north. No necks pierce the intervening miles of Old Red Sandstone, and none of the necks or flows in the lava areas suggest power to link up the different districts; so that the conclusion is come to that those outliers are not merely outliers of denudation, but outliers from the Carboniferous vulcanicity lying off the north-western margin

of the plateau. The phase of minor intrusives is well represented by dykes, sills, and plugs of essentially the same rock types as occur among the lavas, and among the reputed lavas it is not impossible that unproved sills occur, the basalts of dunsapie type being specially suspect in this connection. One notable minor intrusion carrying a suite of basic and ultra-basic plutonic rocks indicates the presence and proximity of rocks of the abyssal phase of Carboniferous igneous activity, and gives the first definite evidence of the types of rock constituting the plutonic complex.

ANALYSES AND NORMS

	I. *	II. †	III. *	IV. *
Si O ₂	50·24	61·19	66·60	51·45
Ti O ₂	3·09	1·83	·55	·93
Al ₂ O ₃	15·01	14·20	12·95	15·54
Fe ₂ O ₃	8·94	8·08	7·25	4·87
Fe O	6·46	2·49	·83	6·06
Mg O	3·16	·50	·76	5·91
Ca O	5·61	1·74	1·41	8·69
Na ₂ O	3·47	6·64	6·14	2·82
K ₂ O	1·91	1·80	3·10	1·94
P ₂ O ₅	—	·08	—	—
H ₂ O	{ (+) 1·77 { (—) 1·05	1·58	(+) ·46 (—) ·49	(+) 1·19 (—) 2·14
	100·71	100·13	100·54	101·54
S { Quartz, - -	8·16	12·60	17·16	2·10
Orthoclase, - -	11·12	10·57	18·35	11·12
Albite, - -	28·82	56·07	48·73	23·58
Anorthite, - -	20·02	3·61	—	24·19
Diopside, - -	6·05	3·23	4·10	16·03
Wollastonite, -	—	·23	·70	—
Acmite, - -	—	—	2·77	—
F { Hypersthene, -	5·10	—	—	12·20
Magnetite, - -	11·60	2·78	2·55	7·19
Ilmenite, - -	5·93	3·50	1·66	1·67
Hæmatite, - -	·96	6·24	4·48	—
Apatite, - -	—	·34	—	—
S/F Ratio, - -	2·29	5·08	5·18	1·64

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	ROCK.	LOCALITY.	MAGMATIC SYMBOL.
I.	Mugearite.	Second Lava Flow, near "R" in Reservoir, Creag a Mhara Lavas.	II., 5, 3, 4. <i>Andose.</i>
II.	Bostonite.	Lava enclosed by Composite Sill, Cave, Uamh Capuill.	II., 4, 1, 4. <i>Pantellerose.</i>
III.	Bostonite.	Lava, Loch na Leighe.	II., 4, 1, 4. <i>Pantellerose.</i>
IV.	Xenolithic Quartz-Dolerite.	Kainozoic Composite Sill, Glen Callum Bay.	III., 5, 4, 3. <i>Auvergnose.</i>

The lavas and minor intrusives constitute a series which ranges from bostonites, at the acid end, to craiglockhart basalts, at the basic end, and those two end types are linked up by intermediate rocks giving practically a continuous series. The mugearites, markle, and jedburgh basalts are intimately connected by numerous insensible gradations, and markle basalts pass imperceptibly into dunsapie types by the appearance and increase of augite phenocrysts. The most pronounced gaps in the series occur next the two end members; no intermediate types have been found to connect dunsapie with craiglockhart, and the same applies to mugearite and bostonite. A type of mugearite composed chiefly of oligoclase laths and magnetite (Pl. XXXVI., Fig. 1) approaches most nearly to the bostonites, and resembles them strongly in thin section. However, an analysis of a rock of this type (for which I am indebted to Mr. J. V. Harrison) shows that chemically there is still a considerable gap between this rock and the bostonites, especially in the silica, lime and the alkalies. The variation among the bostonites themselves is evident from thin sections, analyses, and norms. This consists chiefly of variation in free quartz and albite present, but how much of this is an original difference, and how much is due to silicification and albitisation it is impossible to say. An interesting point is brought out by

the norm of III., the bostonite from Loch na Leighe; the norm shows 2.77 per cent. of acmite, while II. contains none, and the thin section of III. shows in the groundmass numerous small green prisms of soda pyroxene, which are absent in II., so that in the case of those two bostonites the norms are comparatively modal.

Among the markle basalts, jedburgh basalts, and mugearites the field association is so intimate, and thin sections show every shade of gradation, linking up the three types, that it seems possible to connect the three immediately with the same magma without postulating separate magma reservoirs, and to ascribe the differences to physical differences of crystallisation and extrusion. In the thin sections of these rocks for every one that falls naturally and easily into a type there are several that are only named after weighing up the characteristics of the three types, and hesitating as to which has the greatest claim to the name. In this connection the composite markle dyke of Stravannan Bay is of peculiar interest. Going on the justifiable assumption that the three intrusions into this dyke were from the same magma, and represent progressive stages of intra-telluric crystallisation, then the first intrusion giving the marginal sheets of the dyke only required to be a little earlier to be classed as a basaltic mugearite or a microlite jedburgh basalt, and increase in size and proportion of feldspar phenocrysts gives the transition into typical markle basalt.

Albitisation and Analcitisation.—Among the Bute basalts examples of all stages of albitisation are common, and the process has gone on in the manner described by Bailey and Grabham (1909, p. 250). The more basic plagioclase feldspars of the more acid lavas have been attacked, while the feldspars of the more basic types, such as dunsapie basalts, have been untouched. Mr. Tyrrell (1912, p. 243), in remarking on albitisation, notes the field association of that phenomenon with the presence of zeolites, and suggests a connection between the two; but in Bute, except for a little stilbite in the necks, zeolites are absent, and jasper, agate, and calcite are the most common occupants of cavities. Analcitisation is an analogous process to the albitisation, and in the analcited basalt described the two processes have gone on side by side. The

analcite replaces the felspar in patches, and breaks across the twinning in thin ribbons, like a diagram of step faulting. While albitisation attacks by preference the more basic felspars of the affected rock, analcitisation singles out the ferromagnesian phenocrysts in preference to the felspars. The felspars can only show small patches and ribbons of analcite replacement working along cracks and solution planes, but many of the other phenocrysts have been completely removed and replaced by analcite (Pl. XXXVI., Fig. 2). While the lime of the original lime-soda felspar has often been completely removed by albitisation, it is interesting to note that the ferromagnesian silicates removed by the analcite have had soda added to the molecule, and have been redeposited as numerous minute prisms of aegirine-augite clouding the analcite pseudomorphs. In all probability the process of analcitisation like that of albitisation occurred after the solidification of the rock, and during the cooling. At this time a very appreciable percentage of soda must have been added to the rock by the soda-rich solutions performing the analcitisation and albitisation.

Minerals in the Lavas.—In addition to the minerals already mentioned as common in the lavas, there is an occurrence of garnet, lining vesicles in a mugearite, which is noteworthy on account of its rarity. The mugearite occurs on the shore of Run-nan-Eun abutting against the north side of the large olivine-dolerite sill. It is very vesicular, with the vesicles drawn out into ellipsoids in the direction of the flow. Many of the vesicles are filled or lined with delessite, but others occur lined with a topaz-coloured layer of garnet crystals in rhombic do-decahedra. In colour the garnets are a greenish yellow, and are presumably grossularite or andradite, or, what is more probable, an isomorphous mixture of those two molecules. Garnets in eruptive rocks were recorded by Cross (1885); these were spessartite, occurring in lithophyses in rhyolite, and were considered to be of primary origin and produced by sublimation. In the Bute occurrence the garnets can be added to the albite and analcite as pneumatolytic minerals formed during the cooling of the lava. In the same lava, pipes and irregular dyke-like masses of pale pink

rock like trachyte occur, but these prove to be only altered portions of the mugearite flow they occur in, and the alteration may be due to the same pneumatolytic agents. In these Run-nan-Eun lavas finely-coloured agates, with centres of crystalline quartz, occur, and banded jaspers up to 1 foot in diameter are fairly common. Jasper also occurs in veins and in irregular masses with ill-defined borders shading into the enclosing lava. On the suggestion of Professor Gregory that these might be formed by metasomatic replacement, a section of one was cut, and among the jasper small areas of the original lava were got, showing where the replacement had been incomplete.

PERMO-CARBONIFEROUS ROCKS.

The igneous rocks of this period consist of —

- (1) Thick east and west dykes of granophyric quartz-dolerite.
- (2) A small drumlin-shaped intrusion of quartz-dolerite east of Lubas.
- (3) A large olivine-dolerite sill crossing the south-east corner of the island, a small olivine dolerite intrusion on the shore north of Uamh Pharaich, and a few dykes and small sills. One of the small sills of olivine-dolerite contains veins of tachylite.

The East and West Dykes.—Two of these cross the island as thick, persistent dykes, one stretching between the south end of Ettrick Bay and the centre of Rothesay Bay, and the second running parallel about 1 mile to the south. As might be expected with this rather universal rock, it is found to differ in no essential from other examples already fully described (Tyrrell, 1909). However, at Bogany Point an east and west dyke, which may be part of the second dyke referred to above, is worthy of note on account of the way it is cut by a Kainozoic dyke. The north and south dyke cuts right across the quartz-dolerite, giving chilled margins which can be followed as wavy, irregular lines from one side of the older dyke to the other. In spite of the large numbers of dykes at different directions it is seldom that a

crossing is got unequivocally exposed as this one is. It is just at this point that the mineral spring occurs, and the right angle enclosed by the crossing dykes may have determined its point of emergence.

Fully half a mile east of Lubas Bay there is a small grass-covered intrusion of quartz-dolerite forming a low, round-backed ridge which runs east and west for about 400 yards before shading into the country on either side. In the hand-specimen the rock resembles a dark blue basalt, but the thin section shows it to be a quartz-dolerite of unusual type. It is a fairly coarse-textured aggregate of quartz, plagioclase, chlorite, magnetite, and apatite. The large decomposed chloritic areas show no structure to indicate the original mineral unless the indefinite way in which they enclose the feldspars at times can be regarded as indicating ophitic structure of an original pyroxene. The feldspar is an andesine-labradorite, fairly fresh, and it is the most abundant constituent. Quartz occurs next in order of abundance, and it does not occur chiefly in micropegmatite as in the east and west dykes, but in fairly large plates, filling interspaces and enclosing the other minerals like quartz in granite. Magnetite is plentiful in idiomorphic cubes, and apatite needles are so numerous, especially in the quartz, that they must form an appreciable proportion of the rock. In some of the interspaces among the feldspars micropegmatite is got in place of quartz, and occurs both in rod-like and triangular intergrowths. This rock is related to the quartz-dolerite of the east and west dykes, but differs in the large excess of free quartz, while its occurrence in the field contrasts strongly with the persistent nature of the large east and west dykes running unbroken for miles across country.

OLIVINE-DOLERITE SILL.

This large Permo-Carboniferous sill stretches practically across the south end of the island in a south-easterly direction. It rises from the sea about a quarter of a mile north of Runnan-Eun Point, and, dipping at first in the same direction as the lavas, but at a slightly higher angle, it rises obliquely up the lava cliff, its boundaries being apparent from a distance

by its distinctive soft brown weathering. Crossing the lavas of Run-nan-Eun, and making no prominent topographical feature, it descends to Glen Callum, where it is broken and displaced by the fault. Rising on the south-west side of the glen, it has thickened much beyond its original 20 or 30 feet, and forms a steep cliff with perched blocks. The peculiar rich-brown soil of its weathering, from which weathered spheroids protrude, renders its outcrop visible from Run-nan-Eun Point, a distance of nearly half a mile (Pl. XXXV.). After rising to a height of 485 feet in Torr Mor, it turns south and is abruptly truncated by the later Kainozoic composite sill. It is not observed again till it is got lying at a low angle and occupying all the ground between the composite sill and the shore at Port Leithne. It may have a continuous outcrop between this and Torr Mor, but with the exception of a slight hollow south of its crossing with the composite sill there is no evidence of it. On the shore north-east of Port Uisg it dips down under the ash beds, crossing them obliquely in a flat inclined plane, whose upper surface shows the chilled margin excellently. The innumerable joints intersecting the surface and marking off the ends of the miniature columns of the chilled rock give it a strong resemblance to a tessellated pavement. South of Barr Buidhe the boundary of the sill is indefinite and unsatisfactory to trace, but across the Port Uisg fault the olivine-dolerite stands out as a hard part, and forms quite a well-marked feature on the shore and raised beach. The rock composing this sill weathers more easily and deeply than any other igneous rock in the district. In places it can be crumbled with the hand, and in such a place, on the shore at Run-nan-Eun, the increased richness of the grass bordering the path where it crosses the sill testifies both to rapid weathering and richness of soil produced. As may be inferred, getting through the weathered zone to procure the fresh blue rock within involves operations approaching the borderline between geology and quarrying. The jointing divides the rock into large cuboidal blocks, and when horizontal joints are numerous very typical mural jointing is produced.

In thin section the fresh rock is a coarse ophitic olivine-dolerite composed of titaniferous magnetite, slightly serpen-

tinised olivine, and pale purple augite in ophitic relations to the labradorite. In spite of the considerable area occupied by this sill the rock is monotonously uniform, and the only variation found, in addition to chilled margins, is a type of lighter colour and coarser texture, which occurs in veins and tongues 1 or 2 inches across. These weather out as hard parts, and fragments can be easily picked out from the weathered dolerite. In thin section it is seen to be a very fresh rock (Pl. XXXVI., Fig. 4), just a coarser replica of the ordinary dolerite, and it shows the ophitic structure to perfection. The olivine is fresh, and seems to have crystallised about the same time as the augite, as it also poecilitically encloses the felspar. Filling the little triangular spaces enclosed by sets of three felspars, clear analcite occasionally occurs, so that this final product of consolidation of the dolerite magma has affinities with the orininites (Tyrrell, 1913, p. 307).

In addition to the large sill there are several smaller intrusions of the olivine-dolerite, which seem to be Permo-Carboniferous in age rather than Kainozoic. In thin section there is nothing to distinguish the olivine-dolerites of the two periods, but in the field the weathering of the large sill contrasts strongly with the olivine-dolerite dykes of undoubted Kainozoic age. In the Kainozoic dykes the weathering is only skin deep, and thin splinters from a weathered surface usually reveal fresh blue-black dolerite on the new fracture. When some dykes behave in this way and others weather deeply, like the dolerite of the sill, the most feasible explanation is that these latter are also Permo-Carboniferous in age. Such a dyke occurs on the shore 100 yards north of the olivine-dolerite sill at Run-nan-Eun, and running south, penetrates the sill, passes under the lava scree of the raised beach cliff, and emerges on the shore east of Run-nan-Eun Point. It is conveniently situated for comparison with the large sill.

Fifty yards north of this dyke a small impersistent sill of similar rock, 2 or 3 feet thick, pierces the lavas. It is a finer-grained olivine-dolerite, and is noteworthy on account of veins of tachylite, which penetrate it and are continued into the overlying lava (Pl. XXXVII., Fig. 2). The veins are about half an inch thick, and make equally sharp junctions with the

dolerite sill and the enclosing lava, so that they have been injected after the sill has solidified and cooled. This mode of occurrence as rapidly-cooled veins of residual magma penetrating both sill and country rock is peculiar, for in the tachylytes studied by Professors Judd and Cole (1883) the only mode of occurrence found in the West of Scotland was as rapidly-cooled selvages to basaltic dykes. The rock is a dense black glass with conchoidal fracture, opaque even in thinnest splinters, and yielding a powder which is strongly magnetic. In thin section the rock is found to be porphyritic with fresh acicular labradorite feldspars, occasionally in groups, but usually as single crystals sparingly sprinkled in a black opaque glass. A second generation of small bifid microlites is present. A few regularly bounded yellow areas pseudomorphs after augite or olivine are the only other crystals present. The glass is black and opaque even at the edges of the slide, but under favourable circumstances, say, where a feldspar occurs partially beneath the surface of the slide, and so covered only by an exceedingly thin film of the glass, the dense black is found to give way to reddish brown. In this are seen some scarcely resolvable spherulites, small areas lighter in colour and circular in outline. When closely packed their interference produces polygonal shapes like honeycomb. In reflected light the dark opaque mass of the glass is seen to contain numerous lighter-coloured patches of hazy, indefinite outline, reminding one of the groups of feathery microlites in Arran pitchstones. These may be due to the decomposition of feathery growths of titaniferous magnetite.

KAINOZOIC IGNEOUS ROCKS.

These consist of a composite sill and numerous dykes and inclined sheets of dolerite. The composite sill has been described in detail (Smellie, 1913), and will only be mentioned here. It is composed of five sheets, a thick central core of hypersthene-dolerite flanked by two sheets of quartz-oligoclase-porphry, each of which has a thin sheet of dolerite interposed between itself and the country rock. The dolerite has been intruded first, and carries xenocrysts of quartz and oligoclase

picked up from the quartz-porphyry magma prior to intrusion. The quartz-porphyry, intruded along two planes of weakness in the dolerite, carries xenoliths of that rock picked up during intrusion. At one point, about 400 yards north-west of Roinn Clumhach, the acid magma has pushed out beyond the protecting dolerite, and the consequent rapid cooling has produced a pitchstone-porphyry. The sill rises from the sea at Roinn Clumhach, runs north-west nearly to Torr Mor, where it turns abruptly and crosses the island to re-enter the sea at Uamh Capuill.

The dolerite dykes of Kainozoic age are very numerous, and are distributed over the whole island. They are usually about 8 or 10 feet thick, but range down to 1 or 2 feet, while in the north end of Bute dykes of 30 or 40 feet in width occur. One such occurring between Port-Bannatyne and Ettrick Bay is quarried for road metal. Another thick dyke is quarried at Crossbeg, south of Loch Fad, and it is noteworthy as a locality for good crystals of dog-tooth spar, which occurs in veins and pockets between the dyke and the conglomerate into which it is intruded. The Kainozoic dykes trend north and south, or north-north-east, but very occasionally dykes are met with which do not follow either of those directions. At the south-west end of Loch Fad a dyke of ophitic olivine-free dolerite occurs, and it runs east and west. No instance of crossing between those dykes has been observed, so that nothing can be inferred as to the relative ages of the two sets. In the hand specimen they are even-grained, blue-black dolerites, the grain varying with the thickness of the dyke and the distance from the margin. Under the microscope they are seen to be of two kinds, olivine-dolerite and olivine-free dolerite. The olivine dolerites are composed of labradorite felspar, augite, olivine, and magnetite, and the texture varies from coarse ophitic types through rocks, with augite partly sub-ophitic partly granular to types completely granulitic in Judd's sense. The olivine, usually in clear, fresh grains or misshapen plates, may be equal in amount to the pale brown augite, but a decrease in the amount of olivine gives a gradual transition into the olivine-free type. Some of the rocks in which olivine is scarce or absent show no other difference from the olivine-

bearing rocks, but usually the olivine-free dolerites have a distinctive texture, two grades being got in the one rock. The thin section shows an intimate mixture of a coarse and fine texture, the coarse with large feldspars and cubes of magnetite ophitically enclosed by plates of augite; intermingled with this occur patches in which the feldspar is in fine microlites, and the magnetite in very small cubes or drawn out into dark lines, and these are set in a groundmass of brown material, at first mistaken for augite plates, but found to be almost isotropic, and charged with another generation of microlites, seen only with the high power (Pl. XXXVIII., Fig. 3). This type has been got in both north and south dykes, and dykes with north-north-east trend. In addition to the dolerite dykes, which are more or less vertical, there is a number of inclined sheets or sills. These tend to occur where the course of the dyke is parallel or nearly so to the strike of the sandstones, in which circumstances the sheet tends to accommodate itself to the bedding planes of the sedimentary rock rather than rise vertically. In such cases the baking of the overlying bed of sandstone causes it to weather up as a hard part overhanging the space from which the sill has weathered. Apart from field occurrence, these inclined sheets do not differ from the dolerite of the dykes. A good example of a Kainozoic dolerite sill occurs on the shore about 200 yards south of Hawk's Nib. It dips south-west, and passing up from the sandstones and corallines on the shore, cuts through the base of the large neck of agglomerate on the raised beach, and continues in a north-westerly direction into the lavas.

Tachylyte.—Running off the north-west corner of the map a north and south dyke is shown on the shore. Where the northern end of this dyke meets the sand of Stravannan Bay the width of the dyke has decreased to 2 or 3 feet. In the last 10 feet of the dyke, just before it loses itself in the beach sand, veins of tachylyte are got coming up the central plane of weakness, common in dykes of this thickness. The veins are numerous and irregular, varying from an eighth to a half inch thick of black glass, as perfect as obsidian. In places these perfectly glassy bands are merely selvages to small dykelets of tachylyte 1 or 2 inches thick, the central portions of

which are porphyritic and dull black instead of shiny. In thin section the tachylyte is seen to be an opaque black glass, like the tachylyte already described from Run-nan-Eun, but it differs in the phenocrysts and in their distribution. The shiny black selvages are free from phenocrysts, but towards the interior of the tachylyte dykelet well-formed crystals of felspar, augite, and, very occasionally, olivine are got, set in a plentiful base of dark glass, which sometimes becomes less opaque round the phenocrysts, and shows its colour to be reddish brown. The large parent dyke is an ophitic dolerite carrying a few serpentinised olivines; and, presuming the tachylyte represents a stage in the attainment of that structure, it abundantly bears out Fenner's contention (1910) that ophitic structure represents an eutectic of the minerals involved. The augite and felspar have crystallised at the same time, and these minerals occur continually in pairs and groups surrounded by the glass. The stage at which magnetite crystals form has barely been reached ere the tachylyte solidified, unless a few feathery growths and the opacity of the glass are to be attributed to the separation of magnetite dust. In the glass, by reflected light, regular shapes much darker than their surroundings can be made out. They are shaped like felspar laths, and in some cases are seen to be continuations or completions of light, transparent felspars. In the Run-nan-Eun tachylyte felspar is practically the only mineral crystallised out (Pl. XXXVII., Fig. 2), so there has evidently been an excess of felspar over that required for the eutectic ratio.

Faults.—The faults have already been mentioned in other connections, and it only remains to state their age. As can be seen from the map, they break and displace all rocks older than Kainozoic, but the Kainozoic dykes and composite sill cross them unmoved. Thus the faulting is probably early Kainozoic in age. The faults are easily proved and located on the shore at their southern ends, but inland they probably die out, and towards their north-western ends their position and existence become matters of doubt.

I have to express my indebtedness to many friends, members of this Society, who frequently gave me their company during week-ends in the field. For the photographs forming the

panorama shown in Plate XXXV. I have to thank Mr. J. W. Reoch, and for assistance with the photomicrographs I am indebted to Mr. J. V. Harrison and Mr. D. I. Russell. Before closing I would like to bear testimony to the excellence of the mapping of the rocks in the area (1-inch sheet, No. 21) shown in the Geological Survey Sheet 21. What differences have appeared in the present work are differences of interpretation or differences of addition, or differences of choice in doubtful boundaries, but having put the map of the area to the test during the field work connected with this paper, I finished with a well-founded respect for the mapping of Mr. Gunn. In conclusion, I have to express my own and the Society's thanks to the Carnegie Trust for generously providing a grant for the illustrations connected with this paper.

REFERENCES.

- Bailey, E. B.
1911. In The Geology of the Glasgow District. *Mem. Geol. Surv., Scotland*.
- Bailey, E. B. and Grabham, G. W.
1909. The Albitisation of Basic Plagioclase Felspars. *Geol. Mag.* [V.], vol. vi., pp. 250-9.
- Boué, A.
1820. *Essai Géologique sur l'Ecosse*.
- Bryce, J.
1872. The Geology of Arran and Other Clyde Islands, 4th ed., pp. 316-48.
- Cross, W.
1885. On the Occurrence of Topaz and Garnet in Lithophyses in Rhyolite. *Amer. Journ. Sci.* [III.]. Vol. xxxi., pp. 432-8.
- Emerson, B. K.
1898. The Chester Amphibolite and Serpentine. In *Mon. U.S. Surv.* Vol. xxix., p. 115.
- Fenner, C. N.
1910. The Crystallisation of a Basaltic Magma from the Standpoint of Physical Chemistry. *Amer. Journ. Sci.* [IV.]. Vol. xxix., pp. 217-34.
- Gunn, W.
1903. In The Geology of North Arran, South Bute, &c. *Mem. Geol. Surv., Scotland*.

Harker, A.

1904. The Tertiary Igneous Rocks of Skye. *Mem. Geol. Surv., Scotland.*

Judd, J. W., and Cole, G. A. J.

1883. On the Basalt-Glass (Tachylite) of the Western Isles of Scotland. *Q.J.G.S.* Vol. xxxix., p. 444-65.

MacCulloch, J.

1819. The Geology of the Western Islands of Scotland. Vol. ii., Bute, pp. 445-74.

Seymour, H. J.

1903. In The Geology of North Arran, South Bute, &c. *Mem. Geol. Surv., Scotland.*

Smellie, W. R.

1913. The Tertiary Composite Sill of South Bute. *Trans. Geol. Soc. Glasgow.* Vol. xv., Part II., pp. 121-39.

Tyrrell, G. W.

1909. The Geology and Petrology of the Intrusions of the Kilsyth-Croy District. *Geol. Mag.* [V.]. Vol. vi., pp. 299-309, 359-66.

1912. The Petrology of the Kilpatrick Hills. *Trans. Geol. Soc., Glasgow.* Vol. xiv., Part III., pp. 219-57.

1913. The Petrology of Arran. *Geol. Mag.* [V.]. Vol. x., pp. 305-9.

Wyllie, B. K. N., and Scott, A.

1913. The Plutonic Rocks of Garabal Hill. *Geol. Mag.* [V.]. Vol. x., pp. 499-508, 536-45.

Young, J.

1894. On the Occurrence of Pyroxene or Augite in large crystals in two localities in Western Scotland. *Trans. Geol. Soc., Glasgow.* Vol. x., pp. 13-15.

EXPLANATION OF PLATES.

PLATE XXXVIII.

FIG. 1.—Anorthosite, labradorite rock, xenolith in intrusion carrying plutonic rocks. From the shore, 400 yards south of Hawk's Nib, South Bute, x 10. x nicols.

FIG. 2.—Dunite, olivine rock. From the same locality as Fig. 1, x 20.

FIG. 3.—Markle Basalt. From composite dyke, shore, north side of Stravannan Bay, x 20.

FIG. 4.—Coarse Markle Basalt showing albitised labradorite phenocryst. From large sill a quarter of a mile west of Largizean Farm, x 20.

Photomicrographs of Rocks from Bute.

FIG. 1.

FIG. 2.

Photomicrographs of Rocks from Bute.

Photomicrographs of Rocks from Bute.

MAP OF SOUTH BUTE SHOWING THE DISTRIBUTION OF THE IGNEOUS ROCKS.

FIG. 5.—Craiglockhart Basalt, showing phenocrysts of augite (basal section) and olivine, the latter partially replaced by hæmatite. From intrusion into south seaward face of Creag a Mhara vent, $\times 20$.

FIG. 6.—Dunsapie Basalt, showing augite phenocryst embayed by groundmass, phenocrysts of fresh labradorite, and red-brown pleochroic iddingsite (dark mass), a pseudomorph after an olivine phenocryst. From Port na Caillich, $\times 25$.

PLATE XXXVI.

FIG. 1.—Mugearite. From east side of road, Covin Hill, $\times 25$.

FIG. 2.—Analctised Basalt, showing phenocryst completely replaced by analcite in which are numerous small prisms (dark patches) of *ægirine-augite*. From the shore, 300 yards north-east of Port Leithne, $\times 25$.

FIG. 3.—Ophitic Dolerite, showing two grades of texture. From north and south Kainozoic Dyke, Dunagoil Bay, $\times 20$.

FIG. 4.—Coarse ophitic olivine-dolerite. From coarse vein in Permo-Carboniferous sill, shore, Port Leithne, $\times 10$.

FIG. 5.—Epidiorite; clear areas are quartz and felspar, hornblende, chlorite and magnetite are other constituents. From top of ridge, 100 yards south of the Dun, Scalpsie, $\times 20$.

FIG. 6.—Epidiorite showing epidote bulking largely as a constituent. From the shore, north side of Scalpsie Bay, $\times 20$.

PLATE XXXVII.

FIG. 1.—Olivine-pyroxenite; the large clear crystal of olivine, with dark veins of serpentine, exhibits cleavage. This rock of coarse plutonic habit is from the same locality as the anorthosite and dunite shown in Plate B, Figs. 1 and 2. $\times 40$.

FIG. 2.—Junction of vein of porphyritic tachylite and mugearite. The tachylite occurs in a small olivine-dolerite sill, 150 yards north of the large olivine-dolerite sill, shore, Run-nan-Eun and the vein of tachylite also penetrates the mugearite lava. Note the minute xenoliths of mugearite in the tachylite, $\times 40$.