002Chapter 2 Summary of geology; history of investigation

THE following table gives a complete list of the various formations, exclusive of Pleistocene and Recent deposits, which are to be found within the island of Arran. They are arranged in order from the youngest to the oldest. The igneous rocks, both intrusive and extrusive, are included in the formations of the geological period, within which their eruption is believed to have fallen. The symbols by which the various formations are indicated upon the colour-printed geological map of Arran are also appended.

CAINOZOIC	
Basalt and olivine-dolerite dykes of tholeiitic and crinanitic composition.	B
Pitchstone dykes and sills	F■
Quartz-porphyry and quartz-felsite	F
Quartz-porphyry—hypersthene-dolerite composite sills (Bennan,Drumadoon, etc.)	F"
Augite-diorite and granite of Tighvein	B+G■
Ring structure of central area: Granite, granophyre, and felsite intrusions	G, G■, G■
Ring structure of central area: Gabbro and diorite intrusions	U+D
Ring structure of central area: Rhyolitic agglomerate, with included masses of felsite and rhyolite	Ni
Ring structure of central area: Basaltic agglomerate, with blocks and masses of Cainozoic basalt lavas.	Ni
Ring structure of central area: Breccia and conglomerate, chiefly of Old Red Sandstone material	Ni
Granite of northern boss	G
Dolerite-granophyre and basalt-felsite composite sills and dykes	B
Dolerite, quartz-dolerite, and craignurite sills and dykes . .	B
Crinanite sills and large early crinanite and olivine-dolerite dykes (Dippin, Kingscross, Monamore Glen, Clauchland Hills, etc.)	B
MESOZOIC	
Cretaceous: Limestone with siliceous concretions, occurring in volcanic vent	h
Lias: Dark shale with many fossils, occurring in volcanic vent	g
Rhaetic: Black shale with ironstone and limestone, occurring in volcanic vent	fg
Rhaetic: Pale-coloured mudstones, do.	
New Red Sandstone: Upper Division (Trias)	f■
New Red Sandstone: Lower Division (Permian)	f
Palaeozoic (Upper)	
Carboniferous: Coal Measures with contemporaneous lava	d^5
Carboniferous: Carboniferous Limestone Series: Upper Limestone group	
Carboniferous: Carboniferous Limestone Series: Edge-coal group	d^2
Carboniferous: Carboniferous Limestone Series: Lower Limestone group	

Carboniferous: Calciferous Sandstones with intercalated volcanics series, and intrusive rocks	d^1
Old Red Sandstone: Upper Red Sandstones and conglomerates with volcanic series	c^3
Old Red Sandstone: Lower Red Sandstones, mudstones, and conglomerates with volcanic series, and intrusive rocks	C^1
PALAEOZOIC (LOWER)	
Ordovician (?) Cherts, grits, and dark schists associated with a greenstone, spihte, epidionte series	b
PRE-PALEOZOIC	
Dalradian: Mica-schist	[Gothic 'S' symbol]
Dalradian: Limestone	λ
Dalradian: Slate	[Gothic 'l' symbol]
Dalradian: Gritty schists or schistose grits	[Gothic 'z' symbol]

Summary of the geology

The oldest rocks in Arran are the mica-schists, phyllites, slates, and schistose grits, which are believed to belong to the Dalradian. Series. These rocks form an incomplete ring round the granite in the northern parts of Arran where they occupy high ground generally; for though the formation is found on the seacoast from Dougrie to Newton the land rises rapidly from the sea-level. The outcrop is interrupted from near Glen Sannox to the White Water on the eastern side of the granite, a distance of about 3 miles. The schists often occupy a kind of plateau rising to over 1000 feet in the district reaching from Glenshant Hill to Whitefarland (the 1000-foot platform). In the north-east of Arran the formation attains a height of 1453 feet above the sea. Crags and minor features are common in the formation, both on the coast and inland, some of which are in a great measure due to joints or faults.

Next in order of age are the presumably Arenig rocks which occupy a restricted outcrop in North Glen Sannox. These consist mainly of spilitic lavas, now in the condition of greenstone or epidiorite, with subordinate slates and schistose grits. The outcrop is bounded on both sides by gritty schists which are assigned to the Dalradian.

Separated from the metamorphic rocks by a fault, the Lower Old Red Sandstone of the northern half of Arran occupies in the main a curved strip, marked by steep dips, stretching from Corloch on the east side of Arran to Dougrie on the west coast. The conglomerates of this division form prominent hills in North and South Glen Sannox, but the highest point of this band is An Tunna (1184 feet), north of the String Road. There is also a detached portion of this sub-formation to the east and south of the smaller granite area at the heads of Glen (Gleann) Dubh, Benlister Glen, and Clauchan Glen. It rises to 1346 feet in Cnoc na Croise.

The greater part of the Central Ring area must be underlain by Lower Old Red Sandstone, since blocks and masses of the conglomerates and sandstones of this formation make up a very large proportion of the breccias here produced by Cainozoic volcanic action.

Rocks assigned to the Upper Old Red Sandstone occupy the shore between the Fallen Rocks (near Corloch) and Corrie, and they form a narrow band to the east and south of the Lower Old Red Sandstone and apparently conformable to that division. On the north side of North Glen Sannox the conglomerates of this division form a marked set of features with a northerly dip, and here they may be unconforrnable to the lower division. They also occur in a narrow semicircular strip to the south of the Central Ring area, about the heads of the Benlister and Clauchan Glens.

Volcanic rocks of Lower Old Red age are found only on the west side of Arran in a narrow inconspicuous band, and those of Upper Old Red age occupy a much-faulted strip on the east side of the island between the mouth of North Glen Sannox Burn and Corloch.

A conspicuous intrusion of salite-diabase occurring in the Lower Old Red Sandstone on the south side of Glen Rosa may doubtfully be referred to igneous activity of Lower Old Red Sandstone age.

Both Lower and Upper Carboniferous rocks occur in North Arran, from the Cock to the Fallen Rocks, where they occupy a narrow band dipping steeply northward, and bounded on the west by a fault. To the east and south-east of the northern granite there are to be found five areas of Carboniferous rocks, the outcrops of which are arranged in echelon roughly following the boundary of the granite, and are caused by its circumferential and radial faulting. Several other narrow strips of Carboniferous rocks are found on the south-east and south of the Central Ring area, where they are bounded by faults radial to the ring.

Basalt lavas and tuffs of Lower Carboniferous age occur in several of these areas, notably near Corrie, and in the outcrops at the head of Benlister Glen. At the head of the southern branch of the Sliddery Water is an area of Carboniferous rocks consisting chiefly of tuffs and lavas, but containing also shales and sandstones with fossils which show that the whole series is mainly of the age of the Lower Coal Measures.

Disregarding for the moment the extraordinarily abundant Cainozoic igneous rocks, it may be said that the remaining parts of Arran are underlain by formations belonging to the New Red Sandstone. In the Memoir on Sheet 21,<ref>Geology of North Arran, etc., (Explanation of Sheet 21), *Mem. Geol. Surv.,* 1903, p. 67.</ref> and on the geological maps, these rocks are assigned entirely to the Triassic; but Prof. J. W. Gregory has recently recognized four divisions (*see* p. 76), the two lowermost of which are referred to the Permian, and the two uppermost to the Triassic. The Corrie freestone, a round-grained red sandstone of olian origin, occupies an area of little more than half a square mile at the Cock of Arran; but its main outcrop is in the coastal strip between Corrie Hotel and Brodick Bay. The succeeding, or partly contemporaneous, Brodick Breccia also appears to be a desert accumulation, as some of the pebbles are wind-facetted. It occurs mainly on the south side of Brodick Bay, and in the region of the Glen Cloy Water and its tributaries. Fine cliff sections (Creag nam Fitheach) occur on the south side of Glen Dubh. About Lamlash and Whiting Bay occur coarse red and white sandstones with occasional conglomerates, which are doubtfully assigned to the Upper Permian.

The upper series consists of various sandstones, often calcareous and micaceous, with red shales, earthy limestones, and marls which are indistinguishable from typical English Keuper marls. This series is clearly of aqueous origin, and was probably laid down under lagoon conditions. It occupies most of the south and south-west of Arran, and good sections are to be seen at Auchenhew, Levencorroch, and Sliddery.

A band of volcanic conglomerate and breccia, chiefly of basaltic composition, has been found within the Brodick Breccia in the Glen Dubh Water. This may represent a volcanic episode of Permian times, or may be due to the erosion of an area of Carboniferous basalts.

The Triassic, Rhaetic, Lias, and Cretaceous formations are represented by fragments and masses which have been preserved by their incorporation within the Central Ring structure of Arran.

In Cainozoic times Arran became one of the principal igneous centres in the west of Scotland. The basaltic lavas which were doubtless produced here, parallel with those of Skye, Mull, and Antrim, have long been swept away by erosion, with the exception of one or two remnants preserved within the Central Ring. The main feature of Cainozoic igneous activity in Arran is the production of ring structures similar to those of Mull and Skye. The finest of these occurs in the very centre of Arran, about the hills of Ard Bheinn, A' Chruach, and Beinn Bhreac, to the south of the String Road. The map shows the interrupted annular disposition of the various component rocks, and more recent mapping has confirmed the ring shape (Plate 4). Three kinds of conglomerate and agglomerate are represented within the ring, which, arranged in order of abundance, are: broken masses of sedimentary rocks, chiefly Old Red Sandstone, rhyolitic agglomerate, and basaltic agglomerate. Early intrusions of gabbro and diorite take part in the structure, but the greater part of the area is taken up by a massive intrusion of granite or granophyre. The explosive activity of this centre seems to have been due to the intrusion of acid magmas, just as in the similar ring structures of Mull and Skye.

The greatest mass of Cainozoic igneous rock, however, is the northern granite boss, the erosion of which has produced the striking mountains of northern Arran. This granite has a roughly circular outcrop with a diameter of about 7 miles. It may be interpreted as a very deep-seated section of a ring structure, the upper fragmental parts of which have been eroded away. The intrusion of this granite was attended by interesting tectonic phenomena in the surrounding rocks.

Arran is riddled with innumerable minor intrusions, plugs, sills, and dykes in great profusion, which cause all the greater elevations and most marked features in the southern half of the island. The intrusions consist of both basic and acid members, of which the former are in general the earlier, although the igneous episode seems to have been closed by the intrusion of multitudes of basalt dykes, forming a swarm running north-west to south-east or north-north-west to south-south-east, roughly parallel to the Mull Swarm. The great crinanite (olivine-analcite-dolerite) sills of Dippin, Kingscross, Monamore, and Clauchland, in the south-east quadrant of the island, seem to be among the earliest intrusions of the Cainozoic igneous episode in Arran. Composite sills, consisting of dolerite and granophyre, or basalt and felsite, occur abundantly, and are associated with the intermediate rocks called craignurite in Mull. The acid rocks include quartz-porphyries (Bennan, Drumadoon, Dun Dubh, etc.), some of which are associated in composite sills with hypersthene-basalt, felsites, and the pitch-stones for which Arran is famous. Holy Island has recently been found to consist of an extremely uniform mass, 800 feet thick, of riebeckite-orthophyre or trachyte.

The present topographic features of Arran were all developed after the cessation of Cainozoic volcanic activity. The most important event of this period was the cutting of the 1000-foot rock platform (1000 to 1200 feet) over the island, the remains of which are especially well preserved around the northern granite mass (Frontispiece). The date of this feature is believed to be Pliocene. During the Glacial Period the Arran mountains nourished a local ice centre, from which ice streams pressed to the south, distributing numerous large granite erratics over the southern half of the island, but barely holding their own on the east and west against the great ice streams filling the Firth of Clyde and Kilbrannan Sound.

Since the Glacial Period an intermittent uplift has produced a series of raised beaches fringing the coasts. These occur roughly at 10 feet, 25 feet, and 100 feet above sea-level, with a variable series of beaches at intermediate levels. W.G., G.W.T.

History of investigation

The history of investigation of Arran geology opens with a few references to geological matters in Thomas Pennant's *Tour to the Hebrides* (1774). Only a general description of the island is given in this work, but the reference to the Drumadoon quartz-porphyry sill as 'a long range of columnar rocks (not basaltic) of hard grey whinstone, resting on an horizontal stratum of red stone; at the extremity one of the columns is insulated, forming a fine obelisk' (vol. i. p. 182), betokens acute observation of geological features. Pennant also noticed the occurrence of pitchstone at Dun Fionn (p. 185), and the former working of coal at the Cock of Arran.

But the most memorable early references to the geology of Arran are contained in the *Theory of the Earth* (1795), by the immortal James Hutton, the Father, as we may call him, of Igneous Geology. The third volume of the *Theory of the Earth,* not published till 1899 under the editorship of Sir A. Geikie, contains the first complete account of Arran geology that was ever written, if not published. One is only able to marvel at the astounding modernity of this description, which was probably written prior to 1795. As Sir A. Geikie says: 'This striking essay is a masterpiece of acute observation and luminous generalisation.' In it Arran is divided into five main geological regions: the northern granite; its investment of *schistus;* the secondary and tertiary strata comprising much of the rest of the island; the porphyries, and the whinstones, which break through these formations. The descriptions of these divisions are full of original observations and inferences. Modern petrography is represented by a reference to the quartz-felspar-porphyry of Brown Head: 'this ground [groundmass] is maculated with the crystalline or transparent quartz and the felt-spath. I would therefore term it a granite-porphyry, as containing almost the same materials as granite, only in a porphyry form' (p. 212). The general ground of the porphyries is *petuntze* or porcelaine-stone, and is an intimate mixture of the felt-spath and siliceous substance (p. 213). What appears to be a reference to xenocrystic minerals in basalts and dolerites occurs in the following passage: 'The whinstone in this island is sometimes maculated with felt-spath, and that peculiar quartz which is characteristic of the Arran granite' (p. 216).

Hutton clearly distinguished sills from transgressive intrusions, and descants on the extraordinary number of dykes in Arran, mentioning particularly the long dyke of Glen Rosa. He noticed that the dykes occasionally intersected the horizontal beds (*i.e.* sills) of whinstone, and therefore represented the latest phase of eruption. Sir A. Geikie comments on the modernity of this observation. In describing the pitchstones Hutton noted the crystallites they contain, and observed the close relation between pitchstone and felsite. The germ of the idea of composite dykes is contained in his allusions to the Tormore pitchstones, and their association with *petuntze* or felsite and whinstone (p. 254). He described the Kildonan Castle sill as a 'bed of whinstone… of a peculiar nature, much approaching to petuntze' (p. 259), which is a perfect description of the intermediate characters of the craignuritic type of which this sill is composed.

With regard to structural geology Hutton's genius was fully exhibited in his recognition of the Lochranza unconformity (*Theory of the Earth*, vol.i., 1795, p. 429). The passage is worth quoting: 'Here the schistus and the sandstone strata both rise inclined at an angle of about 45°; but these primary and secondary strata were inclined in almost opposite directions; and thus they met together like the two sides of a *lambda,* or the rigging of a house, being a little in disorder at the angle of their junction. From this situation of those two different masses of strata, it is evidently impossible that either of them could be formed originally in that position; therefore, I could not here learn in what state the schistus strata had been in when those of the sandstone, etc., had been superinduced'. In vol. iii. (pp. 235–6) the further observations are made that the secondary strata are a ' composition of sandstone and limestone [cornstone],' and that they 'overlap the ends of the alpine schistus', and are therefore the superincumbent body. Hutton also noticed the increasing dip of the strata as they approach the schistus in Glen Rosa (p. 218), and stated that the apparent stratification of the Goatfell granite was 'occasioned by the regular contraction or basaltic cracking of the mass in cooling' (p. 228).

R. Jameson, in his *Mineralogy of the Scottish Isles* (1800), gives a geological description of Arran which was published separately two years earlier. His account, which, of course, is thoroughly Wernerian in its point of view, is circumstantial, but contains hardly anything new, either as to facts or ideas. He gives a full description of the composite dykes of Tormore, accompanied by a very good plan of the shore (pp. 102–5).

In his *Illustrations of the Huttonian Theory* (1802), Playfair, the interpreter of Hutton, merely reinforces the arguments of his master in regard to the lessons of Arran geology.

The next investigator, the Rev. J. Headrick, in his *View of the Mineralogy, Agriculture, Manufactures, and Fisheries of the Island of Arran* (1807), while always Wernerian, and occasionally venting gentle sarcasm on the Plutonist ideas of Hutton and others, nevertheless contributed a large body of original information on the geology of Arran. He noticed that the inclinations of the granite slabs on Goatfell approximated to that of the slope on which they occurred. On p. 273 he says: 'The further the schistus was removed from the granite, the more its strata were inclined towards it; but near the junction, they were absolutely perpendicular, or, by strange contortions, bent backwards, as if afraid to face the granite,' which seems to be a foreshadowing of modern tectonic views.

In 1819 John Macculloch published a full account of Arran and its geology in his well-known *Description of the Western Isles of Scotland* (*vol.* ii. pp. 311–439). He realized that the stratification of the granite was only apparent, and guardedly asserted that the granite passed laterally into the surrqunding schists (pp. 345–6), basing that opinion on a confusion between the pseudo-stratification of the granite and the foliation of the schists. He also pointed out the petrological similarities between the granites of Arran, Skye, and St. Kilda. Macculloch seems to have been the first to subdivide the schists into micaceous schist, which forms the adjoining districts of Cantyre and Cowal [and]… the argillaceous schist which follows that rock in the order of superposition ' (p. 359), and to connect the Arran schists with those of the adjacent districts in the Clyde region. In one passage Macculloch employed a method used by later geologists to determine the relative ages of the schistose rocks when he pointed out that one of the varieties of chlorite-schist in Glen Chalmadale contained 'distinct imbedded fragments of common blue clay slate' (p. 363). Comparing the regular disposition of the schists in Bute and in adjacent parts of the mainland with their confused arrangement in Arran, he implied that the granite was the cause of the irregularities in Arran (p. 365).

In describing the Secondary strata of Arran, Macculloch wrote clearly of the Old Red Sandstone, the Carboniferous, and the New Red Sandstone, although not under those names. He noticed that where these strata approach the granite, 'they are in a certain degree adapted to its general outline; being elevated at angles, often of considerable inclination, and incurvated to suit the forms of that rock, or those of the primary strata which are interposed' (p. 385). He goes on to point out that: 'If the phenomena of the junction of the granite and schist are allowed to prove the elevation of the latter, it may follow that the same cause has elevated the Secondary strata, and that the granite is posterior to them, as it is to the schist ' (p. 386), which appears to be the first statement of the post-Secondary age of the Arran granite. In further support of this view he adduces the fact that no Arran granite fragments occur in the neighbouring conglomerates (p. 388). Macculloch's account of the Cainozoic igneous rocks of Arran, while very full, does not present any great novelty. He gives a good description of the Drumadoon quartz-porphyry sill, with its lower layer of nonporphyritic [basaltic] rock.

In the following year, 1820, appeared Ami Boue's famous *Essai géologique sur l'Ecosse,* which contains a number of interesting references to the geology of Arran. Perhaps the most interesting is his description of Holy Island, the rock of which he calls a phonolite, and compares with those types from the Auvergne region with which he was so familiar.

Modern modes of investigation of the Secondary rocks of Arran began with the paper by Sedgwick and Murchison in 1828 (published 1835), in which the younger series of red rocks in the island were correctly referred to the New Red Sandstone. In 1829 a notable German work on the geology of Arran was published by K. von Oeynhausen and H. von Dechen. John Paterson's *Prize Essay in the Transactions of the Highland and Agricultural Society of Scotland* (1837) is chiefly valuable for its copious references to agricultural matters in Arran.

In 1840 the Royal Society of Edinburgh published L. A. Necker de Saussure's remarkable memoir on the dykes of a part of Arran, the first detailed treatment of the Arran Swarm. Necker estimated that there were at least 1500 exposed and unexposed dykes in Arran. He gives an elaborate tabular statement of 149 dykes exposed in the northern and east central parts of the island, classifying his observations under the headings of locality, nature, state (weathering, etc.), direction, thickness, hade, rocks traversed, and remarks. Further reference is made to his results in Chapter 15., in which the Arran Dyke Swarm is more fully discussed. Necker also first described and named a new granite area (the so-called Ploverfield granite) in the Central Ring Complex bordering the String Road, which had, however, been observed by Ramsay in 1837.

In the same year (Sir) A. C. Ramsay published his geological map of the island, which was followed in 1841 by his memoir, *The Geology of the Island of Arran from Original Survey.* This was the first complete geological map, and the first published memoir devoted entirely to the geology of the island. The memoir is packed with new facts and descriptions, but is not prolific in new ideas or interpretations. Ramsay was apparently the first to put forward the notion that the apparent stratification of the granite was due to cooling propagated from the overlying schists, and conformed to their structures: and he also thought that the granite had been thrust up bodily in solid form. Both these ideas were later developed in detail by John Smith. Ramsay also gives a very good description of the mylonite band between the granite and the Old Red Sandstone in the White Water, although he had no idea of its true nature, and believed it to be an attenuated representative of the encircling schists. At this date, moreover, Ramsay had not grasped the intrusive character of the trap and porphyry sills, since he always spoke of them as having 'overflowed' the strata.

James Bryce was the investigator of Arran next in succession to Ramsay, if we exclude the Rev. David Landsborough, who, in 1847 and 1852, published a popular account of some excursions in the island and a poem. In 1855 Bryce published some geological notes on Arran, which may be regarded as the first edition of his book, and announced the discovery of a new granite area at Craigdhu or Derenenach. His book, *The Geology of Clydesdale and Arran,* published in 1859, with further editions in 1865 and 1872, long remained the standard work on the geology of the island. Of it may be said, as of Ramsay's work, that it added numerous new facts and observations, but little of new ideas or interpretations. In one respect, indeed, it regressed, as Bryce always refused to regard the predominant red sandstones of Arran as anything but Carboniferous, and poured scorn on the idea of their New Red Sandstone age. Bryce noticed the 'abrupt changes of dip' in the schists north of Glen Catacol, but speaks of the structure as an anticlinal, although the most prominent structural feature on that shore is a decided syncline. He was the first geologist definitely to recognize and describe the traces of glaciation in Arran. He noted many striae, roches moutonnées, and erratics, and pointed out the morainic characters of accumulations in Glen Iorsa, Glen Catacol, and Glen Rosa. In 1864 the Rev. R. Boog Watson published a full account of shell-beds which he had discovered in the boulder-clay of the south of Arran. In the following year Bryce pointed out that the shells occurred at a definite horizon between stiff boulder-clay due to land ice, and more sandy drifts which he ascribed to the reworking of the boulder-clay by local glaciers and rivers after a marine submergence that had given rise to the shell-bed.

Meantime, in 1858, H. Sorby had published his epoch-making paper on the microscopic structures of crystals, including therein an account of the Arran pitchstones, which therefore figured in the very dawn of microscopic petrography. In 1863 and 1867 F. Zirkel described the microscopic features of the Arran pitchstones in well-known early works. He was followed in 1872 by S. Allport, who contributed two papers on the pitchstones to the *Geological Magazine.* Two years later, in his famous paper on the microscopic structure and composition of the British Carboniferous dolerites, Allport described the Clauchland sill as a dolerite with 'a clear amorphous glass in the interstices of the constituents', a material which has since been identified as the mineral analcite. He also described the dolerites of The Ross, and the Dippin sill, as well as the traps' of Kildonan Castle, Auchenhew, and Levencorroch.

In 1866 E. A. Wiinsch discovered stumps of fossil trees embedded in 'trappean ash' at Laggan Bay, which belong to the Calciferous Sandstone Series. In 1874 Wunsch and Thomson made the momentous find of derived Carboniferous fossils in the breccias near the Cock of Arran, a discovery which established, once for all, the New Red Sandstone age of the breccias, red sandstones, and associated marls, which occupy the greater part of Arran. In the seventies of the nineteenth century the visits of foreign geologists to Arran were renewed, and important memoirs were published by F. Zirkel (1871) and A. von Lasaulx (1878). Prof. von Lasaulx (*see* Wiinsch's summary of his views in *Trans. Geol. Soc. Glasgow*, vol. vi., part ii., 1882, pp. 165–181) regarded the granite as having been intruded prior to the ' Silurian ' slates, and as having been forced up with them by great lateral mountain-making movements. In this he was doubtless misled by the erroneous views of the older writers, especially Bryce, as to the age of the granite and of the New Red Sandstone. Wunsch himself, however, controverts his view by showing that the Arran granite is actually later than the Old Red Sandstone, with which it comes into contact near Corrie.

The petrological study of Arran rocks was resumed in 1883 by Professors Judd and Cole in their memoir on the basalt glass (tachylyte) of the Western Isles of Scotland, in which examples from Lamlash (analysed by Delesse in 1858), and from the Castle grounds at Brodick, were described. In his *British Petrography* (1888), Sir J. J. H. Teall made numerous references to Arran rocks, and figured beautiful examples of pitchstone and spherulitic felsite from the island. In 1893 appeared Prof. J. W. Judd's memorable paper on composite dykes in Arran, the full recog- nition and description of these remarkable phenomena forming a notable advance in igneous geology. Sir A. Geikie also made numerous references to the Cainozoic igneous geology of Arran in his works on the *Ancient Volcanoes of Great Britain* (1892, 1897). G. S. Corstorphine in 1895 published a memoir (in German) on the igneous rocks of southern Arran, in which he fully described the Dippin, Auchenhew, and Levencorroch sills, a number of pitchstones, and the composite, hybrid mass of Berman Head. He noted the occurrence of analcite in the Dippin rock, and compared the latter with the teschenite of Moravia.

In 1896 appeared Mr. John Smith's paper entitled, 'A New View of the Arran Granite Mountains'. Undoubtedly the germ of Smith's idea was contained in earlier work by Ramsay and Bryce, but his paper is notable as the first application of the study of directional features, such as jointing, slabby partings, and dyke-fissures, to the elucidation of the history of the granite intrusion. Smith believed that the undulations of the slabby jointing of the granite reflected the anticlines and synclines of the overlying schists, against which the granite was cooled and moulded; and that the granite was finally pushed up in a quasi-solid condition along with its cover. These views are stated in more detail and criticized in Chapter 13 (p. 160).

The work of the Geological Survey in Arran began as far back as 1872, when Sir A. Geikie mapped a small portion of the northeastern coast. The main survey, however, was not undertaken until twenty years later, when Mr. W. Gunn started mapping from the south end, gradually carrying his lines northward until he had completed the six-inch survey in 1901. His work resulted in the detailed One-inch Geological Maps, Sheets 13 and 21 (Scotland), embracing respectively the southern third of Arran with Ailsa Craig and a tiny corner of Ayrshire, and the northern two-thirds of the island, with parts of Bute, the Cumbraes, the Ayrshire coast, and Kintyre. In 1910 a special geological map of Arran in one sheet was published. A Memoir on Sheet 21 was published in 1903, and a Memoir on Sheet 13 had been partly written by Mr. Gunn when death cut short his labours.

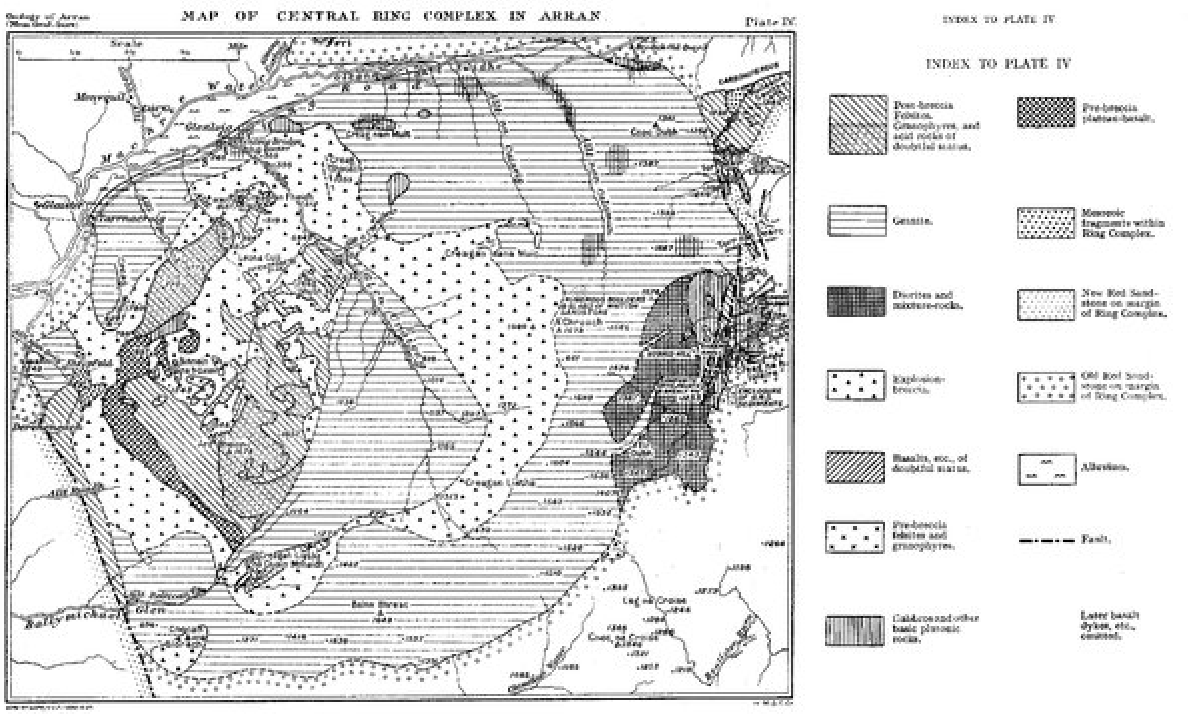
It is impossible to praise Gunn's mapping too highly, as anyone who has had access to his six-inch MS. maps, or has studied the one-inch map of 1910, can testify. The great majority of his geological boundaries stand to-day in no need of alteration; only interpretations need revision. His field-work was carried on under the supervision of the late Dr. B. N. Peach, and no doubt the solid, painstaking, detailed work of Gunn was often reinforced and illuminated by the inspired intuitions of Peach.

Undoubtedly the greatest result of Gunn's work was the recognition, in association with Peach, of the central 'volcanic vent', with its enclosed fragments of fossiliferous Mesozoic rocks (*see* Chapters 10 and 14), which proved the former extension of Rhaetic, Jurassic, and Cretaceous rocks across Arran, and rendered certain the identification of the red and green sandstones, and 'Keuper type' marls of the south end as Triassic, since the Rhaetic fragments are associated with similar rocks in the 'vent'. Recent work has brought to light another small Lias fragment on Windmill Hill (p. 105), and, more important, masses of plateau lavas, similar to those of Mull and Skye, have been found. Renewed study of the central volcanic vent ' in the light of the ring complexes of Lorne, Mull, Ardnamurchan, and Skye, have shown that it, too, is a ring structure, not indeed so perfect as some of those enumerated, but with as long, complicated, and instructive a geological history.

Other results of Gunn's survey were the discovery of strata of Coal Measure age; the identification of black slates, cherts, grits, and pillow lavas probably of Arenig age, in North Sannox; and the discovery of five other sets of volcanic rocks in addition to that of the Arenig, and the formerly known one of the Lower Carboniferous. Two of these episodes belong to the Old Red Sandstone; two are Carboniferous; whilst the remaining one is represented in the Tertiary volcanic vent mentioned above.

Subsequent work has taken the form of more or less detailed study of the petrology and stratigraphy of Arran. Dr. A. Scott has begun the physico-chemical study of the pitchstones, which promises results of great value to petrogenic theory. Dr. F. Mort and Prof. J. W. Gregory have gone a long way towards elucidating the physiographic history of the island subsequent to the Cainozoic igneous episode. Prof. J. W. Gregory in 1915 set the stratigraphy of the New Red Sandstone rocks on a sure footing. The relegation of the basal red desert sandstones of this formation to the Permian has been confirmed by the discovery of an horizon in the Brodick Breccias, rich in pebbles of basalt similar to the Permian basalts of the Ayrshire mainland. The study of igneous tectonics was enriched in 1926 by Mr. E. B. Bailey's comparison of the Arran granite with the great Vredefort dome of South Africa (pp. 159, 163).

In spite of all that has been done in Arran by a splendid galaxy of famous British and foreign geologists, an immense amount of work still remains to be accomplished in elucidating the stratigraphy, petrology, tectonics, and glaciology of the island. G.W.T.



(Plate 4) Map of Central Ring Complex in Arran.