The Tertiary Igneous Geology of Scotland in Relation to Iceland and Greenland.

By

G. W. TYRRELL, University of Glasgow

(Lectures to the Geological Society of Denmark, Oct. 1947)

Abstract.

The succession of the Tertiary igneous rocks in Greenland and Iceland is parallel to that in the Scoto-Irish region except for minor variations, the rock types in the three regions are petrographically identical, and the facts point to the geological and petrological unity of the great Thulean igneous region.

Introduction.

In a striking and graphic phrase Iceland has been called the safety-valve of Scotland, meaning presumably that if volcanism had not continued in Iceland to the present day, Scotland might now have been the theatre of modern volcanic outbreaks like that of Hekla in 1947. As, however, the igneous events in the West of Scotland and the north-east of Ireland (hereinafter called the Scoto-Irish region) are confined to the Tertiary period, comparisons and correlations should be made only with the corresponding events in the Tertiary history of Iceland and Greenland, and modern volcanism ought to be left out of account.

The Scoto-Irish Tertiary igneous region is perhaps the most minutely mapped and closely investigated igneous field in the world (see Lit. Nos. 1—15). Its investigation, mainly by the officers of the Geological Survey of Scotland, has given the geological world new concepts of igneous intrusion in the form of ring-dikes and cone-sheets, composite sills and dikes, dome-shaped plutonic masses and the correlated igneous tectonics, which have now been recognised and described from several other parts of the world.

My own acquaintance with these igneous fields, and my researches

therein, have enabled me to recognise similar features in the Tertiary basement of Iceland from actual traverses, and in the Faröes and Greenland from study of the literature. It has seemed to me that a comparison and correlation of Tertiary igneous events and products in the Scoto-Irish region with those in Iceland and Greenland would be an appropriate subject for lectures to Danish geologists, and would be useful on both sides of the North Sea for future research in, and the better elucidation of, the great Brito-Arctic or Thulean igneous region.

The Scoto-Irish Tertiary igneous region, large as it is, is only the south-eastern margin of that vast area of Tertiary and Recent volcanicity which is known as the Brito-Arctic, North Atlantic, or Thulean region (Fig. 1). This region comprises, besides the Scoto-Irish fields, the Faröes, Iceland, Jan Mayen, and both East and West Greenland. These now separated areas possess geological unity in that they are largely composed of thick piles of basaltic lavas with occasional sedimentary intercalations, intersected by plutonic masses of gabbro and granite, and accompanied by extensive dike-swarms. The Wyville-Thompson submarine ridge which connects the Hebrides with Greenland through Iceland, is probably covered with basalt as has been shown by gravity surveys, and by the evidence of dredgings from the Rockall[1]) and Porcupine[2]) Banks which are situated on it. If this is so, the total area of the Thulean basaltic floods may have been of the order of a million square miles, of which the presently-exposed remnants, even including the basaltic regions of East and West Greenland, probably cover less than 100,000 sq. miles.

The eruptions took place on land surfaces as is shown by the occurrence of soils, leaf-beds and coal seams intercalated with the lavas. Hence, according to the orthodox view, an enormous land occupied the North Atlantic region, and the North Atlantic Ocean was formed by the fragmentation and subsidence of the greater part of this continent. If, however, the theory of continental drift is accepted, — and there is some evidence that Greenland is actually moving westward at the present day, and that its separation from

---

[1]) G. W. TYRRELL, "The Geology and Petrography of Rockall", *Geol. Mag.*, 61, 1924, 19—25.

[2]) G. A. J. COLE and T. C. CROOK, "On Rock-specimens dredged from the floor of the Atlantic off the Coast of Ireland, and their bearing on Submarine Geology", *Mem. Geol. Surv. Ireland*, 1910, 36 pp.

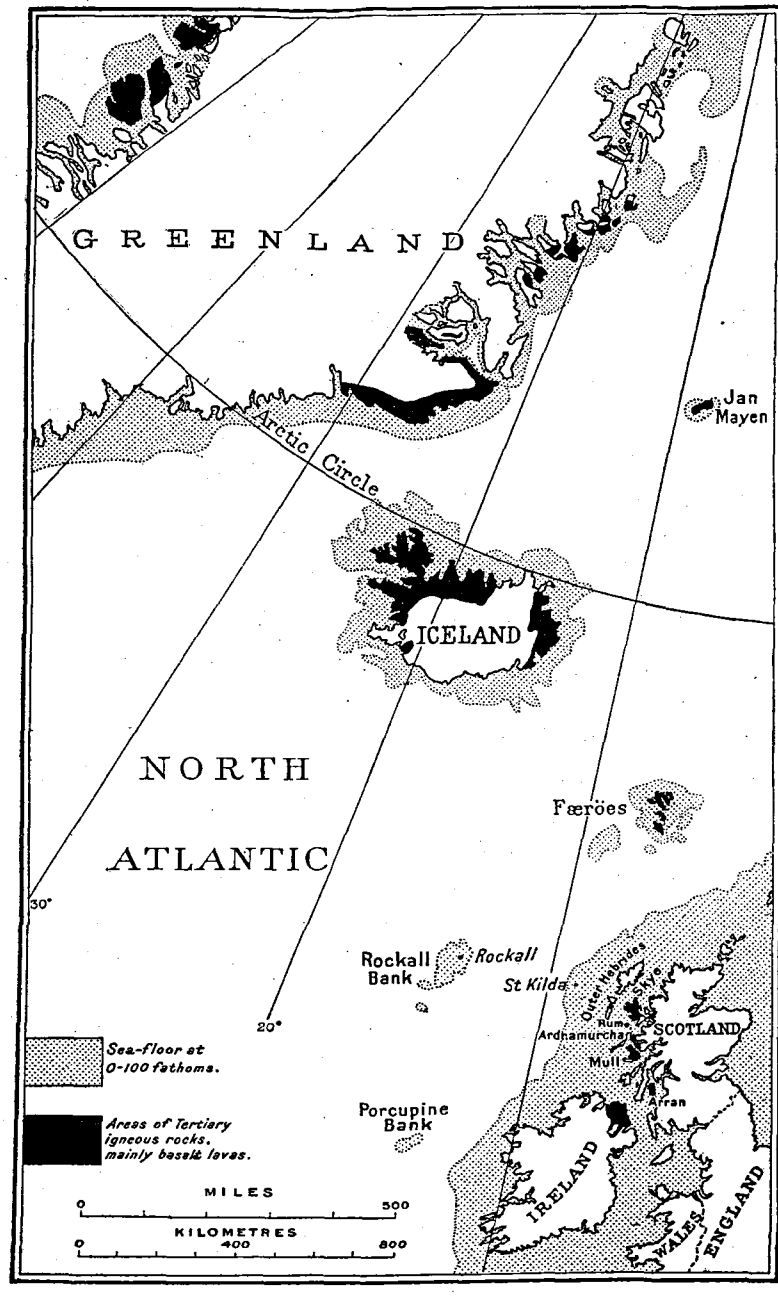
GREENLAND
Arctic Circle
Jan Mayen
ICELAND
NORTH
ATLANTIC
Færöes
30°
20°
Rockall Bank
Rockall
St Kilda
Outer Hebrides
Skye
Ardnamurchan
SCOTLAND
Mull
Arran
Porcupine Bank
IRELAND
WALES
ENGLAND
Sea-floor at 0-100 fathoms.
Areas of Tertiary igneous rocks, mainly basalt lavas.
MILES
0
500
KILOMETRES
0
400
800

Fig. 1.

North-western Europe took place as recently as the Glacial Period[1]) — the mode of formation of the North Atlantic Ocean becomes easier of explanation, and the improbably enormous area of the Thulean basalt floods is greatly reduced.

General Features of Tertiary Igneous Activity in the Scoto-Irish Region.

The Scoto-Irish igneous centres of Tertiary age are distributed along a broad belt of country running north to south from Skye, through Rhum, Ardnamurchan, Mull, Arran, to Antrim, Slieve Gullion and the Mourne Mountains (Co. Down) (Fig. 2). This tract coincides with a sunken trough of Mesozoic deposition, and probably marks a zone of crustal weakness which may continue up to the Färoes. Another, more western zone, is indicated by the Porcupine Bank, 200 miles west of Galway, and by Rockall and the Rockall Bank, 80 miles west of St. Kilda (Fig. 1). Subjacently, these zones may be occupied by Daly's "magmatic wedges", — elongated reservoirs along which the local centres above mentioned may represent the uppermost projections.

The plutonic centres of Skye, Rhum, Ardnamurchan and Mull break through a basement consisting of Pre-Cambrian gneisses and schists, associated with Torridonian and Cambrian sediments, upon the eroded surfaces of which rest flat-lying, normally unfolded sediments ranging in age from the Old Red Sandstone to the Cretaceous. Mesozoic rocks make up the bulk of this pile of sediments, occupying an elongated sunken area extending from Skye to Antrim. These sediments are folded and upturned only in areas adjacent to the plutonic centres. In Arran the Dalradian (Cambrian) and Ordovician are in contact with the Northern Granite; and in North-eastern Ireland Ordovician and Silurian sediments are met with in contact with the Tertiary plutonic complexes. The Slieve Gullion complex breaks through the Newry Granite which belongs to the Caledonian orogeny and is probably of Devonian age. In fact, according to Miss D. L. REYNOLDS, the granophyre and felsite ring dike of Slieve Gullion is due to the transformation of the Newry

[1]) G. W. TYRRELL, New Longitude Determinations in Greenland and Jan Mayen in Relation to Continental Drift. *Geogr. Review* July, 1935, 504—5.

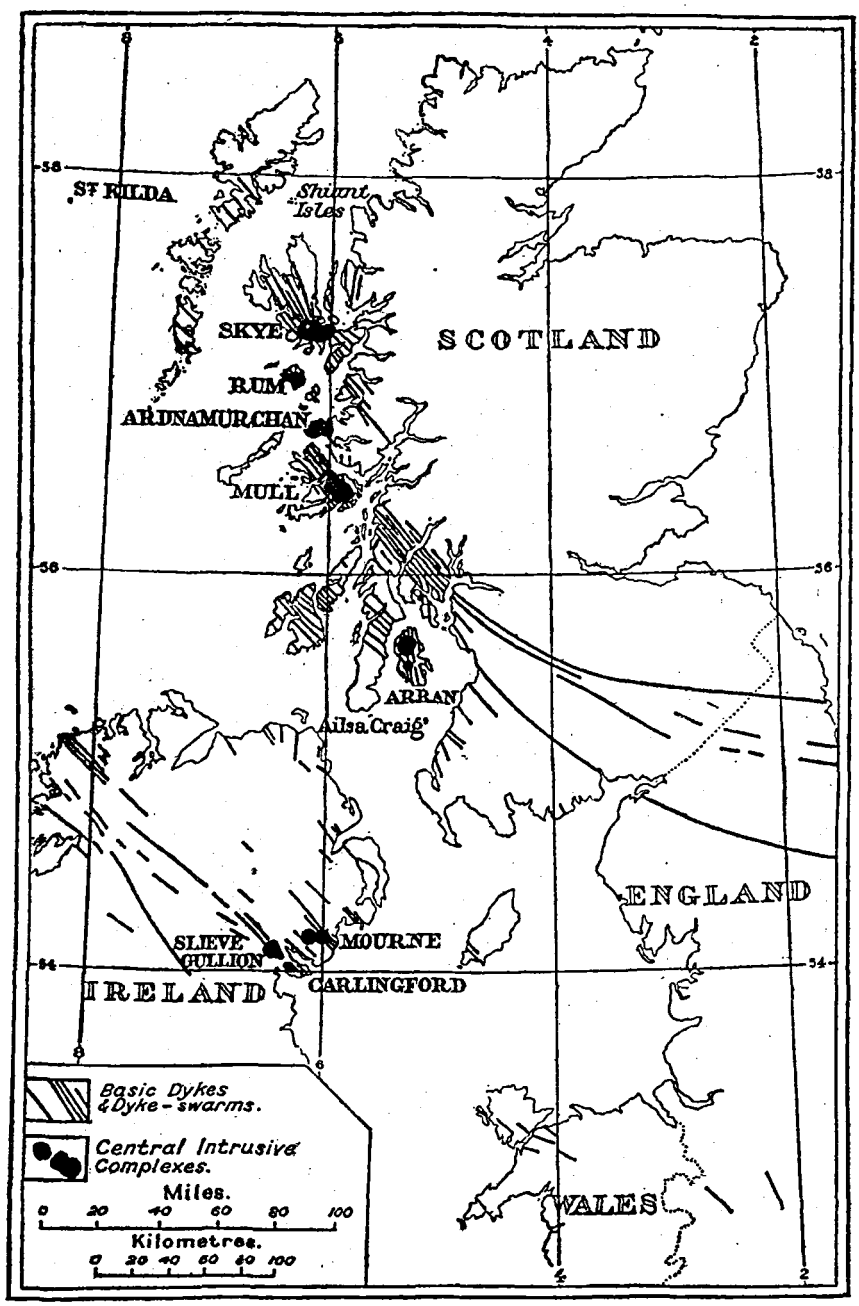
ST KILDA
Shiant Isles
SKYE
SCOTLAND
RUM
ARDNAMURCHAN
MULL
ARRAN
Ailsa Craig
ENGLAND
SLIEVE GULLION
MOURNE
CARLINGFORD
IRELAND
WALES
Basic Dykes & Dyke-swarms.
Central Intrusive Complexes.
Miles.
0 20 40 60 80 100
Kilometres.
0 20 40 60 80 100

Fig. 2.

Granite[1]). In addition, several of the plutonic centres cut through the great piles of Tertiary basalt lavas.

The Tertiary igneous centres thus cut indiscriminately across not only all formations from Pre-Cambrian to Cretaceous, but also every kind of geological structure. They are, however, localised at or near the intersections of major faults and thrusts with the N. to S. zone of weakness in which they are situated. Thus, the centres of Skye, Rhum and Ardnamurchan occur close to the Moine Thrust where, in its N. N. E. — S. S. W. course, it nearly coincides with the N. — S. zone of weakness. Mull is astride the Great Glen Fault, and Arran the Highland Boundary Fault. The Irish centres are located where the continuation in Ireland of the closely-folded Lower Palaeozoic rocks of the Southern Uplands of Scotland and their major faults, intersect the N. — S. zone of weakness.

In regard to age, the earliest basalt lavas rest on the Chalk (Antrim), and are hence post-Mesozoic. Leaf-beds (Mull) and other fossil evidence indicate an early Tertiary (Eocene) age for the igneous activity.

General Sequence of Tertiary Igneous Events in the Scoto-Irish Region.

With local variations at individual centres the general sequence of events seems to have been: 1. Regional activity; 2. Local centres; 3. Renewed regional activity, according to the scheme set out in the following table (see pag. 419).

The Tertiary igneous activity began with the eruption of a vast pile of basaltic lavas which still have a thickness of more than 6000 ft. in Mull. In the islands and promontories of western Scotland — Skye, the Small Isles (Rhum, Eigg, Canna, Sanday, Muck), Ardnamurchan, Mull and Morvern, these lavas cover 774 sq. miles, Skye (425 sq. miles) and Mull (280 sq. miles) accounting for almost the whole area. In Arran the basalt lavas are preserved only as remnants of a "screen" within the Central Ring Complex. The largest tract of Tertiary basalts is that which occupies the greater part of Antrim (1480 sq. miles.)

---

[1]) D. L. REYNOLDS, "The transformation of Caledonian granodiorite to Tertiary granophyre on Slieve Gullion, Co. Armagh, Northern Ireland". *Internat. Geol. Cong. XVIII th. Session, Great Britain, 1948.* Volume of Titles and Abstracts, p. 15.

3. REGIONAL	*Dike-swarms* mainly of basaltic composition. Usual sequence of types.		3. Occasional felsites, pitchstones, etc. 2. Tholeiites, etc. 1. Crinanites and Olivine-basalts.
2. LOCAL	*Central Volcanoes* (Ring-complexes)	Superficial eruptions	Mainly lavas of tholeiitic composition; *occasional trachytes and rhyolites.*
		Sub-surface	Ring-dikes and Cone-sheets; Sills and Dikes, often composite and xenolithic. Composition: dolerite and granophyre; tholeiite and quartz-porphyry, felsite and pitchstone.
		Roots.	Gabbro, granite, and mixture-rocks. Ultrabasic types.
1. REGIONAL	*Flood Basalts*	Surface Activity	Fissure eruptions fed from dikes; shield volcanoes of Hawaiian type. Great basaltic lava floods, mainly of the crinanitic olivine-basaltic affiliation, but *some (locally abundant) lavas of the* tholeiitic affiliation. Subordinate rhyolites, trachytes, etc.
		Sub-surface Activity	Sills and dikes of teschenite and crinanite; differentiates, picrite and peridotite.

The lavas are believed to have been erupted quietly and intermittently from fissure or rift systems, building up flattish shield volcanoes on the Hawaiian and Icelandic model at the intersections and weak points within the fissure network. Ash beds are very scarce, but beds of red clay or bole a few feet in thickness are intercalated between individual flows and these are interpreted as ancient soils. Other sediments, including impure coals, leaf-beds, sandstones and conglomerates, are also found; and these, with the old soils, testify to the long intervals of time which must sometimes have elapsed between successive flows. In fact, the eruptions are typical of those which the writer has called "flood-basalts" in preference to the equivocal and sometimes incorrect term "plateau-basalt"[1]).

The flows are often thin, less than 50 ft. in thickness, although a few may be 100 ft. or more. Usually flood-basalts arising from

[1]) G. W. TYRRELL, "Flood Basalts and Fissure Eruption", *Bull. Volc.* (Naples), Ser. II, tom. 1, 1937, 89—111.

fissure eruptions are very thin and widespread because they consist of extremely hot and mobile olivine-basalt magma; but if they are ponded in depressions, graben and calderas, they may, of course, attain much greater thicknesses. Petrographically, the majority of the lavas of the lowermost "Plateau Group" are olivine-basalts. Some may be enriched in olivine thus approaching oceanite; many contain a little mesostasial analcite or other zeolites, and thus show affinities to crinanites and teschenites.

The eruption of the higher series of plateau lavas (Central Group of Mull)[1]) constitutes the first event of the second or Local episode in the Tertiary volcanic history, and are closely associated with the development of calderas, ring-dikes, cone-sheets and the plutonic intrusions. They will be dealt with in more detail later.

The Mesozoic rocks which underlie the Tertiary lavas in Skye, and the New Red Sandstone in Arran, are penetrated by thick sills of olivine-dolerite, crinanite (analcite-olivine-dolerite) and teschenite (analcite-rich dolerite with or without olivine). These intrusions are also found farther to the north in the Shiant Isles and the isles of the North Minch[2]), and at Portrush and Fair Head in North-eastern Ireland. The sills often show the effects of gravity differentiation by the subsidence of olivine crystals and, to a lesser extent, of titanaugite-iron-ore aggregates, leading to the formation of layers of picrite and, in extreme cases, of peridotite, below the median plane of the sill[3]). Chemically, these teschenites and crinanites show a strong resemblance to the olivine-basalt lavas of the early regional episode, and there can be little doubt but that they represent contemporaneous intrusions from the same magmatic source as supplied the lavas. In Arran there is definite evidence that the over-saturated tholeiitic magmas which supplied the main mass of the second or Local episode were later than the great teschenite sills[4]).

The second or Local episode of Tertiary igneous activity gave

---

[1]) For concise details, see J. E. RICHEY, Lit. 6.

[2]) F. WALKER, "The Geology of the Shiant Isles". *Quart. Journ. Geol. Soc.*, LXXXVI, 1930, 355—98. "The Dolerite Isles of the North Minch", *Trans. Roy. Soc. Edin.*, LVI, 1931, 754—66.

[3]) F. WALKER, "Differentiation in the Sills of Northern Trotternish (Skye). *Trans. Roy. Soc. Edin.*, LVII, 1932, 241—57.

[4]) Lit. 4, p. 117.

rise to Central volcanoes or Ring Complexes which were constituted by *surface* eruptions from centres where calderas were developed, by *subjacent* intrusions, — ring-dikes, cone-sheets, sills and dikes —, and by plutonic intrusions which may be considered as the *roots* of the volcanic edifice. The episode probably began at all centres with the eruption of lavas of tholeiitic affiliation (non-porphyritic and porphyritic central type basalts). This was certainly the case in Mull (Lit. 6, p. 56), and calderas were established within which the frequent presence of standing water caused the formation of pillow-lavas of variolitic basalt. A thick series of rhyolites, trachytes and andesites occurs locally on the northern flank of the Cuillin Mountains of Skye (Lit. 6, p. 45) underlain and overlain by the "Plateau Basalts". In the writer's opinion these rocks are to be associated with the tholeiitic lavas of the Local episode than with the early Regional olivine-basalts. Intrusions of the same chemical composition also form an important part of the subjacent and deep-seated manifestations of this period of igneous activity.

Ring-dikes and cone-sheets tend to occur where the basement is composed of greatly-disturbed, faulted and folded rocks, difficult of penetration except by the mechanisms exemplified by ring-dikes, cone-sheets and the plutonic wedges from which they presumably spring. On the other hand where the basement consists of flat-lying sedimentary series, easy of penetration along the bedding planes and joints, the same magmas are injected as sills and dikes. This contrast in intrusion mechanics is neatly exemplified by Arran. The northern half of the island consists mainly of a great granite boss intruded into Dalradian schists practically on the line of the Highland Boundary Fault trending N.E. to S.W. In fact the course of the fault is actually diverted southward by the intrusion and forced to curve round its southern edge. During the forceful upward movement of the wedge-shaped mass of the Northern Granite the adjacent beds of the Dalradian, Old Red Sandstone, Carboniferous and Permian (Corrie Sandstone), in that order, have been upturned and even inverted in some places. A later and smaller structure, the Central Ring Complex, has been injected into these upturned rocks in the centre of the island a mile or two south of the Northern Granite, and has similarly upturned the sediments around its periphery. But in the southern third of the island the same magmas (quartz-dolerite, tholeiite, granophyre, quartz-porphyry, quartz-

felsite, pitchstone, etc.) have been intruded as sills, often composite, into the flat-lying sedimentary rocks which constitute that part of the island.

The plutonic masses which constitute the roots of the ring structures, and which make up some of the larger rings, are gabbros, granites and granophyres. In some centres (Skye, Rhum, Ardnamurchan) bytownite-gabbros (eucrites) and ultrabasic rocks such as allivalite, picrite and peridotite, produced by an accumulative type of differentiation, are found. In the smaller rings, cone-sheets, and the larger sills (e. g. of South Arran), the same magmas solidify as quartz-dolerite, craignurite, granophyre and quartz-porphyry. In the smaller sills and dikes tholeiites, craignuritic felsites, quartz-felsites and pitchstones, are prevalent. The phenomena of composite sills and dikes are often exemplified by these intrusions. The composite intrusions consist of basic magma which is chilled against the country rock, and of acid magma injected along the centre of the basic mass or along certain planes of weakness near its contacts, with hybridization phenomena along the interior contacts.

The third phase of Tertiary igneous activity in the Scoto-Irish region was marked by a return to regional conditions. Great swarms of dikes were injected mainly along N.W. and N.N.W. rift systems. That each swarm is concentrated where it intersects one of the local centres constitutes a link with the preceding Local phase. Furthermore, some dikes deviate southward from the Skye Swarm to Mull, and from the Mull Swarm to Arran, suggesting that all three centres were functioning at about the same time. Skye, Mull, Arran and the Co. Down centres in North-eastern Ireland each has its dike-swarm. Dike-swarms are believed to be due to the development of regional tension; and they have been localised by fracturing across the weak spots in the crust exemplified, in this case, by the local centres of eruption belonging to the second phase of activity. In Sir E. B. BAILEY's graphic phrase the fractures are localised by the central volcanic foci just as tears occur most readily across perforations in a sheet of paper.

The dikes are extraordinarily abundant especially in the neighbourhood of the volcanic centres of the second or Local phase. To illustrate their abundance the following table is adduced from Dr. J. E. RICHEY's general memoir (Lit. 6, 2nd. Ed. p. 98). The table also gives details of average thickness, and the amount of crustal

stretching occasioned by the intrusion of the dikes. The average thickness of the dikes in Arran is exactly double of that in Mull. Similarly the crustal stretching in Arran is nearly twice as much as in Mull. As regards direction a diagram in the Arran Memoir (Lit. 4, p. 243) shows that the most favoured direction in Arran is N.N.W., followed closely by N.W. and N.

The Skye and Arran Swarms are much less extensive than those of Mull and North-east Ireland, or, to put it in another way, they

Locality	Breadth of swarm examined	Number of dikes	Total aggregate thickness of dikes	Average individual thickness of dikes	Amount of crustal stretch due to dike intrusion
SE. coast of Mull	12.5 miles	375	2504 ft.	5.8 ft.	1 in 26.4
Arran	14.8 miles	525	6050 ft.	11.5 ft.	1 in 14.4

are much more localised around their respective centres. The Skye Swarm extends from the Outer Hebrides across the Cuillin Mountains to Loch Linnhe. The Arran Swarm is believed to be mixed, and related to at least two centres. North-west dikes, mostly olivine-dolerite and crinanite, cross Islay and Jura, and extend to the south-east across Kintyre, probably ending up in Arran. This part of the swarm is considered to be related to an unknown plutonic centre situated beneath the sea N.W. of Islay. The fact that the ophitic olivine-dolerite of the rock known as Dubh Artach, in the sea a few miles west of Colonsay, which Dr. F. WALKER[1]) regards as of Tertiary age from its petrological affinities, is in the direct line of the Islay-Colonsay Swarm, may be regarded as confirmatory evidence for this view. That part of the Arran Swarm on which the above table is based and which appears to be in direct connection with the plutonic centres of the island, conforms to a somewhat more northerly direction, mainly NNW.—SSE., than the Islay — Colonsay Swarm. It extends S.S.E. across Ailsa Craig and dies out on the Ayrshire coast south of Ballantrae.

[1]) F. WALKER, "The Geology of Skerryvore, Dubh Artach, and Sule Skerry" *Geol. Mag.*, LXVIII, 1931, pp. 318—20.

On the other hand the Mull Swarm extends to the south-east across Argyllshire, Renfrewshire and north Ayrshire, in greatly diminishing numbers. The survivors, however, gain in thickness, length and continuity and, bending round to a more easterly direction, join up with the Cleveland, Acklington, Kielderhead and other dikes in Northumberland, Durham, and the North Riding of Yorkshire. If these are indeed the continuations of the Mull Swarm (Fig. 2), and if dikes in South Uist and Barra to the north-west of Mull are attributed to the Mull Swarm, then the total length of the Mull Swarm is about 300 miles. Similarly, the dike-swarms of northern Ireland, the more southerly of which appear to be connected with the Slieve Gullion and Mourne Mountains centres, are much longer than those of Arran and Skye, and appear to die out in Anglesey and Carnarvonshire on the north coast of Wales.

The dikes of the swarms of the final regional episode are overwhelmingly basic in composition and, in fact, consist of crinanites, olivine-basalts and tholeiitic basalts. A few acid dikes — felsite and pitchstone — which occur in association with the plutonic centres, may perhaps be reckoned to the swarms. Where intersections of basic dikes occur, the later dike is almost always of tholeiitic type, the earlier crinanitic. Thus there seems to be a recurrence in this episode of the magmas which supplied the early olivine-basalt and crinanite-type lavas with the subjacent sills of teschenite, and the later quartz-dolerite or tholeiite sills of the Local episode, respectively.

While the majority of the Tertiary dikes were injected as swarms in a final Regional phase of activity, a number of dikes were certainly connected with the earlier episodes. Very thick, multiple and composite dikes, which may contain both the crinanitic and tholeiitic types of basalt, have recently been investigated in the south of Arran by Dr. H. J. W. BROWN[1]) These almost certainly represent the feeders, not only of sills, but also of the basaltic lavas which once covered Arran. In Skye, Mull and Arran, many dikes can be shown to be earlier than the plutonic masses. There can be no doubt but that dikes were injected in connection with each of the two earlier phases of igneous activity and with their sub-phases.

The above-described sequence of igneous events holds very gener-

[1]) Work not yet published.

ally over the Scoto-Irish Tertiary igneous region, but there are local variations. Two of the most important are: (1) the occurrence of a suite of basalts of tholeiitic or "Non-porphyritic Central" type (Staffa suite) in south-western Mull at the base of the Plateau Group, i.e. below the main suite of olivine-basalts and crinanite-type basalts; (2) the occurrence of a great sill, 800—1,000 ft. thick, of riebeckite-orthophyre, in the Holy Island, Lamlash, Arran, which appears to cut across dikes of the regional swarm and, so far as is known, is not penetrated by a single basic dike.

Correlation and Comparisons with Greenland and Iceland.

From the investigations of BACKLUND, NOE-NYGAARD, WAGER and many others in Greenland; of PJETURSS, NOE-NYGAARD, T. EINARSSON, and HAWKES in Iceland; and from the still mainly unpublished results of the 1924 Iceland expedition of TYRRELL and PEACOCK, the general sequence of Tertiary igneous events in these regions seems to be parallel to that of the Scoto-Irish region, i.e.

3. Dike-swarms.
2. Local centres (mainly gabbro and granite)
1. Basaltic lava floods.

But much more work is needed before this statement can be fully substantiated.

West Greenland. In the Svartenhuk Peninsula A. NOE-NYGAARD[1]) has determined the succession of the plateau basalts as follows: —

	Anorthoclase-trachyte (small domes)	
	Andesitic basalt	
	Olivine-free basalt	
Plateau Ser. (subaerial)	Porphyritic plagioclase-basalt with subordinate olivine	Post-Lower Eocene
	Olivine-basalt	
	Picrite-basalt [= oceanite]	
Submarine	Basaltic breccia and tuff	Lower Eocene
	Basaltic ash beds	Danian

[1]) "On the Geology and Petrography of the West Greenland Basalt Province. Part III, The Plateau-basalts of Svartenhuk Peninsula", *Medd. om Grønland*, Bd. 137, Nr. 3, 1942, 78 pp.

"Some Petrogenetic Aspects of the Northern Basalt Plateaux" *Medd. Dansk Geol. For.*, Bd. 11, H. 1. 1946, pp. 55—7.

The whole succession is stated to be about 10 km. in thickness. The submarine basaltic breccias and tuffs may perhaps be correlated with the palagonitic breccias and tuffs at the base of the Tertiary basalts in northern Skye[1]). This is, of course, the sequence one would expect on the assumption that olivine-basalt was the initial magma derived from the primitive basalt shell below the earth's crust. According to NOE-NYGAARD (*op. cit. supra*, 1946, p. 56) the earlier magma was of mildly Atlantic type, giving place to magma of calc-alkaline type as it became contaminated with sialic material. The only point on which the author would differ from NOE-NYGAARD is that he would regard the anorthoclase-trachyte as a differentiate from a new surge of primary olivine-basalt magma, of which the Qaersut (= Kaersut) ultrabasic sills of the Nugssuak Peninsula to the south of Svartenhuk (NOE-NYGAARD, *op. cit. supra*, 1946, p. 56), showing a sequence from peridotite, through gabbro, to syenite, may be the intrusive representative. Dikes are abundant in the Svartenhuk area especially in the lower part of the plateau sequence, and they are rightly regarded as the feeders of the lava flows.

A thin section of a basic rock from the Qaersut sill which I owe to the kindness of Dr. H. I. DREVER, shows that it is rich in analcite, and thus distinctly analogous to the teschenitic rocks of the great sills of Trotternish, Skye (p. 420). It is possible, therefore, that the Qaersut sills which also show ultrabasic differentiates, are the equivalents in West Greenland of the teschenite-picrite-peridotite sills of Skye and Arran, which are regarded as the intrusive representatives of the primitive olivine-basalt lavas, themselves often analcite-bearing. It is noteworthy that NOE-NYGAARD himself points out the similarity between the chemical composition of the ultrabasic magma of Qaersut, and that of the ultrabasic lavas of Svartenhuk (*op. cit. supra*, 1942, pp. 64—6).

The Local episode of central volcanism and intrusion is perhaps represented in West Greenland by the doleritic intrusions of the Nugssuak Peninsula[2]). These are described as quartz-dolerite and olivine-bearing quartz-dolerite. In their mineralogy and chemistry

---

[1]) *Geol. Surv. Gt. Britain, Summ. Progr. for 1935 (1936)*, pp. 81—4; *ibid.*, 1936 (1937), pp. 77—9; *ibid.*, 1937 (1938), pp. 73—4.

[2]) S. MUNCK, "On the Geology and Petrography of the West Greenland Basalt Province, Part V. — Two Major Doleritic Intrusions of the Nugssuak Peninsula." *Medd. om Grønland*, Bd. 137, Nr. 5, 1945, 61 pp.

these sills strongly resemble the sills of the central intrusion period in Mull and Arran. Miss MUNCK is probably correct in associating the sills with the plateau basalts; but their chemistry allies them with the later olivine-free basalts and andesitic basalts rather than with the earlier olivine-rich basalts and picrite-basalts (p. 421).

In Ubekendt Island DREVER and GAME[1]) have described a very thick series of basalt lavas, with more than 5,000 ft. of olivine-rich basalts and picrite-basalts comprised as a Lower Lava Group, and nearly 4,000 ft. of an Upper Lava Group which includes porphyritic plagioclase-tholeiite, rhyolite, biotite-trachyte, trachybasalt, monchiquitic basalt, and a few beds of volcanic breccia. In this upper series picrite-basalts do not occur, and olivine-rich basalts only occur at the very base of the succession. At one place (4 km. S.E. of the Erqua neck) is a series of rhyolites and acid pitchstones, with monchiquitic or calcitised lava, flow-breccias and tuffs. Between the Lower and Upper series of lavas is a thick section so covered up by glacial deposits that it may never be fully explored, but there is reason to believe that the olivine-rich Lower Lavas extend upwards at least another 5,000 ft. The feature of this succession, therefore, is the enormous thickness of olivine-rich lavas at the base, which finds no parallel in the Scoto-Irish region.

DREVER and GAME (*op. cit. supra*, p. 30) divide the Tertiary igneous episode in Ubekendt I. into an early period of Picritic Flood Basalts which they compare with the opening phase of activity in the Scoto-Irish fields, followed by a period of Central Eruption characterised by localised emission of over-saturated "Central-type" basalts associated with a great diversity of eruptive products (Upper Lava Group). This period saw the opening of volcanic vents one of which (Erqua) is large, and comparable with the Central Ring Complex of Arran. These vents are mainly occupied by an acid explosion breccia and exhibit the connection between explosive brecciation and acid igneous intrusions which is so characteristic of the Local phase in the Scottish fields.

A massive irregular sheet of gabbro, which is structurally overlain by a large mass of granite, occurs on the south coast of the island. The top and bottom of the gabbro is intricately intersected

---

[1]) H. I. DREVER and P. E. GAME, "The Geology of Ubekendt Island, West Greenland. Part I. A Preliminary Review." *Medd. om Grønland*, Bd. 134, No. 8, 1949, 35 pp.

by granitic veins, — another feature characteristic of the Scoto-Irish region. The relationship between gabbro and granite is likened by the authors to that obtaining in the Ardnamurchan ring intrusions.

DREVER and GAME state specifically that ". . . there appears to have been in West Greenland no late regional dyke swarm . . ." (*op. cit. supra*, p. 19); but they describe three groups of dikes, one clearly associated with the Lower Lava Group, another cutting the Upper Lava Group and the Erqua volcanic neck, while a third is associated with the major intrusions of the south coast. These dikes are dealt with under the rather unfortunate heading of "The Dyke Swarm". It is clear, however, both from NOE-NYGAARD's account of Svartenhuk, and DREVER and GAME's account of Ubekendt I., that nothing comparable with the prolific late Regional dike-swarms of the Scoto-Irish region has yet been discovered in West Greenland.

DREVER and GAME sum up the general sequence of events in terms of petrographic types as follows (*op. cit. supra*, p. 31): —

1. Olivine-rich basalt and picrite-basalt.
2. Tholeiite.
3. Gabbro.
4. Pyroxene-fayalite-porphyry.
   Granite, granophyre, microgranite and felsite.
5. Basic-acid composite dikes, and "craignuritic" types.
6. Augite-lamprophyre, monchiquite, nepheline-basalt.

Of these No. 1 must be relegated to the first (Regional) episode in the Scoto-Irish region. All the others must be assigned to the second (Local) episode. No. 6, however, seems to be unrepresented in the Scoto-Irish field.

East Greenland. Two main regions of Tertiary igneous rocks are recognised by geologists who have worked in this field, a convenient dividing line being provided by the great Scoresby Sound between a northern and southern portion. For the southern part we may obtain data from recently published works by L. R. WAGER[1]).

---

[1]) L. R. WAGER, Geological Investigations in East Greenland. Part I. — General Geology from Angmagsalik to Kap Dalton. *Medd. om Grønland*, Bd. 105, Nr. 2, 1934, 46 pp.

L. R. WAGER, *ibid.* Part II — Geology of Kap Dalton. *ibid.* Bd. 105 Nr. 3, 1935, 32 pp.

According to WAGER (1934, p. 28) the Tertiary igneous phenomena of East Greenland fall into three phases: 1. the volcanic phase, of mainly basaltic lavas with a few sills and minor explosive activity giving rise to tuffs; 2, a phase of plutonic injection; and 3, a phase of dike injection. It will be seen that this corresponds closely with the order of events in the Scoto-Irish field.

The main rock groups in the southern part of the region from Angmagsalik to Kap Dalton are, in order of age (WAGER, 1947, p.8);

1. A basement complex of metamorphic rocks (Pre-Cambrian).
2. Kangerdlugssuak Sedimentary Series, Senonian to lowest Eocene in age; about 600 ft. thick; rests on the basement complex.
3. Plateau Basalt Series, resting either on the sedimentary series or directly on the basement complex.
4. Tertiary igneous intrusions.
5. Kap Dalton Sedimentary Series, resting on a thick series of basalts. Probably of Lower Eocene age.

The Plateau Basalt Series forms a widespreading stratigraphical unit. It includes a thick mass of basalts with some interbedded tuff which is mainly found at the base of the series resting sometimes on the basement complex, sometimes on the Kangerdlugssuak sediments. This thick tuff horizon is believed to represent a definite period of explosive igneous activity, and provides a good basis for the correlation of the various sections. The probable maximum thickness of the lava pile is 7½ km., but the series rapidly thins between the coast and the inland mountains in a distance of only 100 km. It is probable, therefore, that the lavas do not persist much farther west, and certainly do not join up with the West Greenland basaltic series under the ice cap. Their age is well established. The eruptions began in the late Senonian, or just post-Senonian; but the highest basalts, as shown by evidence at Kap Dalton, belong to about Middle Eocene times.

The lavas are comparatively thin and thus conform to the widespreading "flood" type of basalt. WAGER (1934, p. 30) states that on Kap Vedel 46 flows occurred in a cliff about 2,000 ft. in height. Hence the average thickness is about 40 ft. but flows of 50 ft. to

L. R. WAGER and W. A. DEER, *ibid.* Part III — The Petrology of the Skaergaard Intrusion, Kangerdlugssuak. *ibid.* Bd. 105, Nr. 4, 1939, 352 pp.

L. R. WAGER, *ibid.* Part IV — The Stratigraphy and Tectonics of Knud Rasmussens Land and the Kangerdlugssuak Region. *ibid.* Bd. 134, Nr. 5, 1947, 64 pp.

100 ft. are occasionally observed. The tops of the flows are scoriaceous and pass up into definite "red earth" partings with plant impressions which prove that the basalts were poured out on a land surface.

So far not much is known about the lithological sequence of the lavas or their petrographical characters. The first kilometre or so of basalts above the main tuff horizon are mostly non-porphyritic types, and the upper part of the series below the Kap Dalton sediments is also non-porphyritic. Below this horizon, however, there is more than a kilometre of basalts in which porphyritic feldspars are abundant. These are perhaps roughly equivalent to porphyritic horizons which occur inland. Hence, as a first approximation to the recognition of a sequence, there seems to be a lower and an upper non-porphyritic series, with an intervening series of porphyritic basalts.

WAGER (1934, p. 32) gives three analyses of basalts from this region. One of them is a non-porphyritic tholeiitic basalt which is fully described in WAGER's 1935 memoir (p. 14). It was collected about 100 ft. below the base of the Kap Dalton sediments, and other basalts in the neighbourhood are very similar. WAGER compares them with the Staffa type of Mull (Mull Memoir, Lit. 3, p. 93). The other two analysed basalts come from the region south of Kap Dalton, and are regarded by WAGER as intermediate in composition between the Non-Porphyritic Central Basalts and the Plateau Basalts of the Scoto-Irish region. The first analysis mentioned above is slightly over-saturated with silica, about 4.5 per cent of quartz appearing in the norm, which confirms its relegation to the tholeiitic type. The other two basalts are also very slightly over-saturated with silica having less than one per cent of normative quartz, although both of them contain some olivine.

Two other analyses, respectively of variolitic basalt and olivine-basalt, and both lavas, are given by WAGER and DEER (1939, p. 16). These rocks contain respectively 10.7 and 11.7 per cent of normative olivine. They are extensively decomposed and are somewhat richer in soda than the corresponding fresh types. Both these features are probably due to the action of late magmatic soda-rich solutions as well as to ordinary weathering, producing some albitisation of the feldspars.

For the region north of Scoresby Sound the main sources of recent

information are papers by BACKLUND and MALMQVIST[1]), TYRRELL[2]), and KROKSTRØM[3]). In this northern area the Tertiary igneous rocks are not so widely distributed as in the south, but sills are found penetrating the older sediments more than 100 km. from the outer coast. Little is known of the chronological sequence and petrographical characters of the rocks. The lavas are mainly basaltic; zeolitic amygdaloidal types are common. The analysis of a coarse dolerite from a sill in Clavering I. (BACKLUND and MALMQVIST, 1932, p. 24) is of tholeiitic character and closely resembles that of the basalt from Kap Dalton (p. 430). A plagioclase-porphyrite from the chilled base of a lava flow in Liverpool Land (KROKSTRØM, 1944, p. 28) is chemically very similar to the Clavering I. dolerite. On the other hand a plagioclase-basalt from Kap Franklin (BACKLUND and MALMQVIST, 1932, p. 32) is an olivine-basalt with about 13 per cent of normative olivine and 0.5 per cent of normative nepheline. It closely resembles the olivine-basalt type of the Scoto-Irish region, as also does the basalt of a dike from Röde I. (KROKSTRØM, 1944, p. 42).

The olivine-trachybasalt of Loch Fine (Fyne?) in Hold-With-Hope, described by BACKLUND and MALMQVIST (1932, p. 36), and the ankaramite of Ladder Berg in Muskox Fjord (TYRRELL, 1932, p. 524) stand in a more alkaline category than the above. The first-named contains 18 per cent of normative olivine, and the amount of alkalis, especially potash, is greater than is usual in Greenland basalts. The ankaramite of Ladder Berg comes from a sill, and is rich in pyroxene, much less so in olivine. It is also relatively rich in alkalis. Rocks of these types seem to be uncommon in the Scoto-Irish fields. A trachybasalt similar to the above has been described by the author from Mackenzie Bay in Hold-with-Hope (TYRRELL, 1932, p. 523).

A fresh, finegrained olivine-essexite or essexite-dolerite, in which the groundmass is saturated with analcite (Walrus I. south of Sabine I.) was obtained by J. M. WORDIE from an undoubted sill

---

[1]) H. G. BACKLUND and D. MALMQVIST, Zur Geologie und Petrographie der Nordostgrönländischen Basaltformation, Teil. I. Die basische Reihe. *Medd. om Grønland*, Bd. 87, Nr. 5, 1934, 61 pp.

[2]) G. W. TYRRELL, The petrography of some Kainozoic igneous rocks and of the Cape Parry Alkaline Complex, East Greenland. *Geol. Mag.* LXIX, 1932, 320—7.

[3]) T. KROKSTRØM, Petrological Studies on some Basaltic Rocks from East Greenland. *Medd. om Grønland*, Bd. 103, Nr. 6, 1944, 73 pp.

(TYRRELL, 1932, p. 525). This may be the analogue in East Greenland of the crinanite and teschenite sills of Skye and Arran, which unquestionably represent the intrusive equivalents of the olivine-basalt lavas of the early (Regional) igneous episode. The latter, in Scotland, often contain interstitial analcite and small flakes of biotite.

The second or Local phase of Tertiary igneous activity in East Greenland is represented apparently by lavas, sills, dikes and plutonic intrusions which, with the possible exception of the lavas, definitely post-date the early plateau- or flood-basalt episode. A large number of plutonic intrusions cut and metamorphose the basalts along the coastal strip of which Kangerdlugssuak is the centre. The northernmost is the Lilloise Complex, 150 km. east of Kangerdlugssuak, which consists of syenites and nepheline-syenites. Then there is an apparent gap in the series in Knud Rasmussens Land, but it is resumed north of Scoresby Sound in the region about Kap Parry. Returning to the coastal region of which Kangerdlugssuak is the centre is the great Skaergaard Complex, made famous by the detailed investigation by WAGER and DEER (1939), consisting of gabbros and ferro-gabbros. Another gabbro mass is that of Kap. E. Holm, consisting of olivine-gabbros and eucrites with patches of bytownite-rock, which recalls the plutonic complexes of Rhum and Skye. Basic intrusions also occur at Nualik and Kialinek farther to the south-west.

Some of these basic intrusions are cut by the Kangerdlugssuak dike-swarm, but the syenite and nepheline-syenite masses which also occur in this region are definitely later than the dike-swarm, for one of them (Kap Deichmann) is intrusive into the Kap E. Holm gabbro complex and, with the alkali-granite of Kialinek, is not penetrated by the dike-swarm. It is thought that the other syenite masses, although they do not come into contact with the dike-swarm, are probably later than it. These late plutonic intrusions appear to mark the end of the Tertiary igneous episode, except for a small independent dike-swarm trending N.N.W. which cuts the Kangerdlugssuak Syenite (WAGER, 1947, p. 48).

WAGER distinguishes two groups of sills (1947, p. 41): 1. Thick sheets or thin laccoliths of gabbro found in the zone of flexure referred to below, which cut the basalt lavas and tuffs but pre-date the coastal dike-swarm; and 2. Columnar dolerite sills which occur abundantly in the sediments and tuffs on the southern and south-

eastern flanks of the inland dome. Some of these are earlier than some of the dikes of the coastal swarm.

KROKSTRØM also mentions a series of olivine-dolerite sills in the Fleming Fjord district of Jameson Land (1944, p. 5). As KROKSTRØM describes an obscure mesostasis of alkali-feldspar and quartz in micrographic intergrowth, it is possible that these rocks fall at the basic end of the tholeiite group, the olivine-tholeiites of Largs or Corrie type, in which olivine may co-exist with a mesostasis over-saturated with silica. The "plagioclase-porphyrite" described by KROKSTRØM (1944, p. 2), which occurs as a sill in Fame Ö. (Liverpool Land), is a rock of the same kind but with a much larger concentration of plagioclase feldspar. It is apparently equivalent to the porphyritic tholeiites or Porphyritic Central type of the Scoto-Irish region.

At the acid end of the series there are rhyolites occurring as dikes and small laccolithic bodies in the Kap Franklin district in Franz Josef Fjord[1]). These rocks are potash-rich in relation to soda, much more so than the corresponding rocks in the Scoto-Irish region, and it is doubtful whether they should be regarded as the equivalents in East Greenland of the granophyres, rhyolites, felsites, quartz-porphyries and pitchstones of the Scoto-Irish region. BACKLUND and MALMQVIST (1935, p. 20) regard the Kap Franklin rhyolites as earlier than the plagioclase-basalts of that locality, but they nevertheless belong to the Tertiary. If this is correct these early rhyolites represent a phase which is not present in the Scoto-Irish fields, unless the Tardree rhyolite and obsidian occurrence of Antrim, which appears to belong to the interval between the Lower and Upper Basalt Series of that district, is its equivalent.

It is fairly clear that, in the above-mentioned gabbro masses and in the tholeiitic sills, we have the equivalents in East Greenland of the rocks which occur in connection with the second or Local phase of Tertiary igneous activity in the Scoto-Irish region. There is an apparent absence of the acid rocks which are prominent in the Scoto-Irish fields, unless BACKLUND and MALMQVIST are mistaken in relegating the Kap Franklin rhyolites to a very early phase. Perhaps future research will reveal the acid eruptives belonging to the Local phase in East Greenland also.

[1]) H. G. BACKLUND and D. MALMQVIST. Zur Geologie und Petrographie der Nordostgrönländischen Basaltformation. II. Die sauren Ergussgesteine von Kap Franklin. *Medd. om Grønland*, Bd. 95, Nr. 3, 1935, 84 pp.

The numerous syenite masses of East Greenland clearly represent the main final episode of Tertiary igneous activity, later even than the dike-swarm described below. Nothing like them is found in the Scoto-Irish region unless it is the riebeckite-orthophyre sill of the Holy Isle, Arran (800—1,000 ft. thick) which is almost undoubtedly later than the Arran Dike-swarm (Lit. 4, p. 222).

The third or Regional phase of Tertiary igneous activity which is represented in the Scoto-Irish region by several dike-swarms, is marked in East Greenland by the magnificent Kangerdlugssuak Dike-swarm discovered and described by WAGER[1]). This assemblage conforms to the general direction of the coastline running north-east from K. Wandel to Kangerdlugssuak. At this locality it changes direction in conformity with the coastline to E.N.E. or nearly E. up to Nansen Fjord. Between the last-named and K. Grivel there are only a few sporadic dikes, but between K. Grivel and K. Dalton, the dike-swarm reappears, curving again to the N.E., but is only comparatively thinly represented. From K. Wandel to Nansen Fjord, a distance of 350 km., the dike-swarm is dense, averaging 100 dikes to the mile; but the north-eastern extension up to K. Dalton is thin, averaging 10—20 dikes per mile. The total known length of this dike-swarm, from K. Wandel to K. Dalton, is thus about 600 km. This compares well with the probable length of the Mull Swarm which is about 500 km. (p. 424).

The Kangerdlugssuak Dike-swarm follows, and is genetically connected with, a remarkable monoclinal flexure which affects the "Plateau Basalt" Series and presumably a certain thickness of the metamorphic complex beneath them. Here is a feature which is paralleled only by the Lebombo flexure and dike-swarm of South-eastern Africa[2]), and which resembles nothing in the Scoto-Irish region. A minor late dike-swarm trending N.N.W. cuts the Kangerdlugssuak Syenite intrusion. There are some thick dikes of basalt trending in the same direction on the eastern side of Outer Kangerdlugssuak, and a small dike-swarm in a nearly northerly direction

---

[1]) WAGER, 1934, pp. 41—4.

L. R. WAGER and W. A. DEER, "A Dyke Swarm and Crustal Flexure in East Greenland", *Geol. Mag.* LXXV, 1938, 39—46.

WAGER, 1947, pp. 30—8.

[2]) A. L. DU TOIT. "The Volcanic Belt of the Lebombo — A Region of Tension", *Trans. Roy. Soc. S. Afr.*, XVIII, 1929, 189—217; also "A Dyke Swarm in East Greenland (letter)", *Geol. Mag.*, LXXV, 1938, p. 189.

in Kraemers Ö on the same side of the fjord (WAGER, 1947, 42—3).

Iceland. The basement of the Tertiary basaltic plateau of Iceland is nowhere exposed, notwithstanding K. KEILHACK's hasty generalisation so well refuted by L. HAWKES[1]). Its upper limit is likewise uncertain owing to dubieties concerning the amount of erosion which separates it from the succeeding "Palagonite Formation", and about the real existence of the Palagonite Formation itself. According to T. EINARSSON[2]) this formation, which appears to cover the Tertiary basaltic foundation of Iceland and fills fault hollows in it, does not exist as such. He adduces field evidence in favour of the view that palagonite-tuffs and associated fragmental rocks are an integral part of the Tertiary basement on at least two horizons, one interbedded with the main body of basalts, and the other heaped up on the top of the plateau. Whatever view is accepted the upper limits of the Tertiary basalt pile remains uncertain.

Little or nothing is known about the petrographical succession of the Tertiary basalt lavas of Iceland. That information requires detailed investigation of the thickest and stratigraphically longest sections that can be found. So far as the present author knows no such investigation has yet been made. From petrographical studies in the literature and from the still unpublished work of the author and Dr. M. A. PEACOCK, it can be said that all the main types that make up the Tertiary basalt piles in the Scoto-Irish region are to be found in Iceland.

In regard to the second (Local) phase of Tertiary igneous activity Iceland presents many examples which clearly rise through and intersect the basalt lavas. Large and small masses of gabbro and dolerite, of granite, felsite and rhyolite, are of frequent occurrence.

Gabbro and granite intrusions very similar in petrographical characters and structural relations to those of the Scoto-Irish region, occur in several localities. The only gabbro actually seen by PEACOCK and the present writer, that of Miðhyrna in Snaefellsnes, is associated with granite and granophyre, and we collected specimens of hybrid and mixture rocks which show that this intrusion is essentially similar in its composition to the gabbro-granophyre ring complexes of the Scoto-Irish region. There are several other masses

[1]) L. HAWKES, "Icelandic Tectonics — Graben or Horst?", *Geol. Mag.*, LXXVIII, 1941, 305—8.

[2]) "Origin of the Basic Tuffs of Iceland" *Acta Natur. Islandica*, I, No. 1, 1945, 1—75.

of gabbro and granite in the West of Iceland. Rhyolite domes (or laccoliths) occur in Snaefellsnes, and at Skarðsheiði, Moelifell, Baula, etc.; granite at Froðakotsmúli (Snaefellsnes); and another gabbro in the Reykjadalur (Dala). Whether these masses possess the ring structure or domical form of the Scoto-Irish examples must await further investigation, for ring-dikes, cone-sheets, etc. depend on detailed mapping for their recognition.

Several composite masses of gabbro, granite and granophyre, and rhyolite domes, which have been described by L. HAWKES and his collaborators from south-eastern Iceland, have many resemblances to the products of the Local phase in the Scoto-Irish region. They have been described as stocks and laccoliths[1]). Dr. F. W. ANDERSON's notes and collections from a plutonic mass exposed in the Ketillaugarfjall and Miðalfell in the same region show that this intrusion consists of a central granophyre surrounded by a broad ring of gabbro, the latter being the earlier of the two[2]). This mass thus closely resembles some of the ring intrusions of the Scoto-Irish fields.

Furthermore, Dr. PEACOCK and the author encountered associations of rhyolite and felsite with craignuritic and basaltic rocks, together with hybrid types, as intrusions on the northern coast of Snaefellsnes (e. g. Setberg, Grundarfjörður), which vividly recalled to us the composite basalt-felsite and dolerite-granophyre intrusions of the Scoto-Irish fields.

In western Iceland there are many large rhyolite masses which appear to cut the basalt lavas, but which may, like those of south-eastern Iceland described by L. HAWKES[3]), have given rise to actual surface flows. In the Central Ring Complex of Arran there are late rhyolitic intrusions which appear to have produced surface flows (Lit. 4, p. 187).

As regards cone-sheets Dr. PEACOCK and the present writer encountered similar or analogous features at several localities in

---

[1]) H. K. CARGILL, L. HAWKES, and J. A. LEDEBOER, "The Major Intrusions of South-eastern Iceland". *Quart. Journ. Geol. Soc.*, LXXXIV, 1928, 505—39.
L. HAWKES & H. K. HAWKES. "The Sandfell laccolith, or Dome of Elevation. *Quart. Journ. Geol. Soc.* LXXXIX, 1933, 379—400.

[2]) F. W. ANDERSON, "Geological observations in Southeastern and Central Iceland. *Trans. Roy. Soc. Edin.*, LXI, Pt. III, 1949, p. 781—2.
G. W. TYRRELL, "Petrography of Igneous Rocks from the Vatnajökull, Iceland, collected by Mr. F. W. ANDERSON". *ibid.* pp. 769—7.

[3]) "The Sandfell Laccolith" *op. cit. supra.*

south-western Iceland. These are irregular complexes of ramifying sills, dikes and veins, of a hard, compact, over-saturated basalt or tholeiite which, in the field, we called "flinty basalt" in reference to its hardness. These complexes cut the basalt lavas and closely resemble the main types of rock found in the cone-sheets of Skye, Ardnamurchan and Mull. Occasionally they pass into thick, irregular sill-like masses of doleritic habit, which may carry a little olivine. On the other hand the thinner dikes and veins may be tachylytic.

The two best examples are found: (1) On the southern front of the Esja plateau from Brautarholt to the Svinaskarð Pass; and (2) in the region about the Brattabrekka Pass in the hinterland of Dala and Mýra Sýslas. Further, Sir GEORGE STEUART MACKENZIE[1]) described what appears to be a member of a similar complex invading the Tertiary basalts of the Akrafjall on the northern side of the Hvalfjord; and PEACOCK and the author found an intrusive sheet of tholeiitic basalt cutting the Tertiary lavas higher up the Hvalfjord at Saurbaer. There is also an occurrence of "flinty basalt" intrusions in the island of Viðey near Reykjavik[2]). There is some evidence that these complexes reach up in the succession and cut the palagonite-tuffs and the Glacial and associated sediments of the Pre-Glacial and Interglacial Series (Hvalfjord and Viðey); but if T. EINARSSON's views on the "Palagonite Formation" (p. 435) are correct, this may not have the chronological significance that it would seem to possess. Furthermore we do not yet know whether all these complexes are of the same age.

Dike-swarms are known in Iceland but, on the whole, there is a great paucity of dikes in the Tertiary basaltic basement of Iceland. THORODDSEN's map of the north-western peninsulas shows 62 dikes. In the southern half of the area the dikes trend N.E.—S.W., but in the northern part they mostly run N.N.W.—S.S.E.. THORODDSEN says that a few of the dikes are older than the Surtarbrand; but by far the greater number cut through all the Tertiary basalts up to the highest summits, but are older than the "Palagonite Formation" and the intrusions of glaciated dolerite and, in large part, older than the late-Miocene faulting.

Dr. PEACOCK and the present writer encountered one good example of a dike swarm. It occurs on both sides of the Alptarfjord and extends thence eastward along the south coast of the Hvammsfjord

[1]) *Travels in Iceland.* 1811, p. 377.

[2]) M. A. PEACOCK, "The Geology of Viðey, S. W. ICELAND: A Record of Igneous Action in Glacial Times", *Trans. Roy. Soc. Edin.*, LIV, Pt. II, 1926, 441—65.

as far as Snoksdal. The majority of the dikes trend N.E.—S.W., but a few run E.—W. (Cf. southern part of the north-western peninsulas, p. 437). The average width of the dikes is 4—5 ft. with a maximum observed thickness of 20 ft. Dr. HAWKES (1928, p. 505) mentions a dense dike-swarm trending N.E.—S.W. to N.N.E.—S.S.W. in south-eastern Iceland, which cuts the plutonic masses of that region.

It is fairly clear that these dike-swarms represent the latest phase of the Tertiary igneous succession in Iceland, and correspond to the third (Regional) phase of dike-swarms in the Scoto-Irish region. It seems probable that dike-swarms are just as numerous in Iceland as in the Scoto-Irish fields, but the fact that the basement rocks of Iceland are completely concealed beneath the blanket of Tertiary flood basalts makes the recognition of dike-swarms difficult.

We may therefore regard the conclusion as fairly well established that, so far as present-day research goes, the succession of the Tertiary igneous rocks in Greenland and Iceland is parallel to that in the Scoto-Irish region except for certain minor variations. The writer would urge on Icelandic and Danish geologists the valuable results that would accrue from detailed studies of structure and petrology, especially in Snaefellsnes. In regard to petrography, the identity of the rock-types in the three main North Atlantic regions of Tertiary igneous activity is clearly established, and the facts point to the geological and petrological unity of the great Thulean region.

Acknowledgment. Figures 1 and 2, from J. E. RICHEY. *British Regional Geology Scotland:* The Tertiary Volcanic Districts (2nd. Ed. Revised), 1948, figs. 17 and 2 respectively, are reproduced by permission of the Director, H. M. Geological Survey, and of the Controller of H. M. Stationery Office.

Literature. The following is a selected bibliography of the most important works on the Tertiary igneous geology of the Scoto-Irish region since HARKER's classic memoir on Skye (1904).

1. A. HARKER. The Tertiary Igneous Rocks of Skye. *Mem. Geol. Surv.* 1904, 481 pp.
2. A. HARKER. The Geology of the Small Isles of Inverness-shire. *Mem. Geol. Surv. Scotland,* 1908, 210 pp.
3. E. B. BAILEY *et alia.* The Tertiary and Post-Tertiary Geology of Mull, Loch Aline, and Oban. *Mem. Geol. Surv. Scotland,* 1924, 445 pp.

4. G. W. TYRRELL. The Geology of Arran. *Mem. Geol. Surv. Scotland,* 1928, 292 pp.
5. J. E. RICHEY, H. H. THOMAS *et alia.* The Geology of Ardnamurchan, North-west Mull, and Coll. 1930, 393 pp.
6. J. E. RICHEY. British Regional Geology Scotland: The Tertiary Volcanic Districts. *Geol. Surv.* 1935, 115 pp. 2nd. Revised Ed. 1948, 105 pp.
7. C. F. DAVIDSON. The Tertiary Geology of Raasay, Inner Hebrides, *Trans. Roy. Soc. Edin.,* LVIII, 1939, 375—407.
8. A. M. COCKBURN. The Geology of St. Kilda, *ibid.* 511—47.
9. S. I. TOMKEIEFF. The Tertiary Lavas of Rhum. *Geol. Mag.,* LXXIX, 1942, 1—13.
10. E. B. BAILEY. Tertiary Igneous Tectonics of Rhum (Inner Hebrides), *Quart. Journ. Geol. Soc.,* C, 1944, 165—91.
11. J. E. RICHEY. The Structural Relations of the Mourne Granites. *ibid.* LXXXIII, 1928, 653—88.
12. J. E. RICHEY. The Tertiary Ring Complex of Slieve Gullion (Ireland), with Petrological Notes by H. H. THOMAS, *ibid.* LXXXVIII, 1932, 776—849.
13. S. I. TOMKEIEFF. The Basalt Lavas of the Giant's Causeway District of Northern Ireland. *Bull. Volc.* Sér. II, VI, 1940, 89—143.
14. J. E. RICHEY. Tertiary Ring Structures in Britain. *Trans. Geol. Soc. Glasgow,* XIX, 1932, 42—140.
15. J. E. RICHEY. Some Features of Tertiary Volcanicity in Scotland and Ireland. *Bull. Volc.,* Sér. II, I, 1937, 14—34.

Resumé.

De tertiære eruptivers geologi i Skotland i forhold til Island og Grønland.

Formålet med denne afhandling, hvis indhold blev givet i et foredrag i Dansk Geologisk Forening 13. oktober 1947, er at sammenligne de tertiære eruptivers geologiske og petrografiske forhold i det skotsk-irske område med forholdene i Grønland og Island.

Det skotsk-irske område er trods sin betydelige størrelse kun den sydøstlige rand af et udstrakt område med tertiær eruptiv virksomhed, det brito-arktiske, eller som det også kaldes det nordatlantiske eller Thule-området (fig. 1 side 415). De skotsk-irske forekomster grupperer sig om de vulkanske centre på Skye, Rhum, Ardnamurchan, Mull og Arran i Vestskotland og Antrim, Slieve Gullion og Mourne mountains i Nordøstirland (fig. 2 side 417). Disse centre ligger langs en nord-syd-gående svaghedszone, som falder sammen med et mesozoisk sedimentationsområde. De vigtigste eruptivcentre skærer uden forskel gennem alle formationer fra Prækambrium til Kridt og går gennem alle de arter af geologiske strukturer, der forekommer i egnen. De bevarede vulkanske strukturer ligger på eller nærved skæringspunkterne mellem den nord-syd-gående svaghedszone og større forkastninger og overskydninger. Stratigrafiske og paleontologiske forhold tyder på, at den eruptive virksomhed er eocæn.

Tabellen side 419 viser den almindelige lagfølge i de tertiære eruptiver

i det skotsk-irske område. Vulkanismen begynder med en regional fase med plateaubasalter (med crinanitisk-olivinbasaltisk tilknytning) dannede ved spalteeruptioner og udstrømmende af gangsystemer (dikes) med retning hovedsagelig fra NNV til SSØ og NV til SØ og de ledsages af gange (sills og dikes) af teschenit eller crinanit med pikrit og peridotit som differentiationsprodukter. Disse gange repræsenterer den regionale fases hypabyssiske virksomhed. Herpå følger en lokal fase med centralvulkaner, der leverede basaltiske lavaer af tholeiitisk type og hvis gangdannelser repræsenteres af ring-dike- og cone-sheet-komplekser. De hypabyssiske typer er kvarts-dolerit, granofyr og kvartsporfyr, tholeiit, felsit og begsten, de plutoniske bjergarter især gabbro og granit. I denne fase opstod også mange hybride bjergarter. Den tredie og sidste fase var igen regional med store gangsværme, væsentlig af basaltisk sammensætning, skærende igennem de tidligere eruptiver og underlaget.

Den eruptive lagfølge og petrografi, som den viser sig i det skotsk-irske område, er blevet sammenlignet med forholdene i de meget mindre kendte egne i Vestgrønland, Østgrønland og Island. Så vidt vides forløber den almindelige udvikling af de tertiære vulkanske begivenheder i disse egne parallelt med udviklingen i det skotsk-irske område, hvilket afhandlingen giver mange eksempler på. Der er naturligvis mange mindre variationer, hvad der iøvrigt også er i Vestskotland og Nordøstirland. Således er der øjensynlig ingen repræsentanter for Østgrønlands store alkaligranitiske og alkalisyenitiske plutoniske komplekser i Skotland-Irland, ej heller noget, der kan sammenlignes med den bemærkelsesværdige monokline fleksur, der ledsager Kangerdlugssuaqgangsværmen.

Samme lagfølge som i Skotland-Irland synes også at findes i Island, hvor der også er forekomster af gabbro- og granit-masser med blandingsbjergarter, små dike-sværme og sandsynligvis ring-dike- og cone-sheet-fænomener, men det næsten allestedsnærværende dække af plateaubasalt vanskeliggør studiet af disse geologiske fænomener. Fremtidige undersøgelser især i Snæfellsnes-området vil sandsynligvis kaste lys over disse forhold.

Hvad petrografien angår er hovedbjergarterne i de fire hovedområder indenfor det nordatlantiske område temmelig godt kendte og alle kendsgerninger tyder på, at det store tertiære eruptivområde såvel i geologisk som i bjergartsmæssig henseende udgør en enhed.

Færdig fra trykkeriet den 23. januar 1950.