Geochronology and Continental Drift-The North Atlantic

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Phil. Trans. R. Soc. Lond. A 1965 **258**, 180-191
doi: 10.1098/rsta.1965.0031

XV. Geochronology and continental drift—the North Atlantic

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A geometrical fit of the land masses of northern Europe, Canada and Greenland has been constructed by Dr A. G. Smith using the method devised by Sir Edward Bullard and Mr J. E. Everett. The method involves taking points of latitude and longitude on the 500 fm. line at intervals of about 30 miles along the two coasts to be fitted. Young features such as oceanic islands are ignored.

By a method of successive approximation, the computer 'homes in' on to the centre of rotation which gives the minimum root mean square misfit between the rotated coastlines; the misfit being measured as the discrepancy of longitude relative to the centre of rotation.

In this manner the 500 fm. line along the east coast of Greenland has been fitted to that of northwestern Europe to form one unit. This unit, that is, the 500 fm. line of the west coast of Greenland and the Channel approaches have been fitted on to the 500 fm. line of Canada.

Maps of this fit drawn as a conical projection with two standard parallels of latitude will be presented and will show the geochronological patterns across the reconstructed land masses.

1. Introduction

Evidence that continental drift has taken place can be drawn from palaeomagnetic measurements, geological comparisons and from the geometrical fit of the continents. An investigation of the radiometric ages of metamorphic and granitic rocks, and their geographical distribution on a reconstructed landmass could provide further evidence for drift.

Such a study has been made on the basis of available geochronological information and is presented on a reconstruction of the North Atlantic made by Bullard, Everett & Smith (this Symposium).

2. Geometrical reconstruction of the North Atlantic

The actual method employed was precisely the same as that described previously by Sir Edward Bullard, and yields the position of the centre of rotation, the angle of rotation and the magnitude of misfit. With the 500 fm. line along the continental margins taken as reference, the east coast of Greenland was fitted on to the west coast of Europe. In compiling the data, the Faeroes–Iceland rise, the whole of Iceland and Jan Mayen were ignored on the assumption that they are much younger in age than the drifting. The Rockall bank was fitted by eye and the reasons for its inclusion as part of the original landmass are discussed later. Data obtained from the Greenland–Europe fit is given in table 1.

North America was then similarly fitted on to the combined Greenland–Europe block, though the Davis Strait rise and Mizen Head re-entrant have been neglected. Points on the American continental margin were taken as far as the Flemish Cap but do not include it. The results of this reconstruction are shown in table 1.

The position of Spain in any such reconstruction presents difficulties. In view of the deep water close in shore off the north coast of Spain, and the presence of Tertiary sediments inland to the east of the Bay of Biscay it could be argued that Biscay was closed prior to the onset of the episode of continental drift that resulted in the opening of the Atlantic Ocean. If the Bay of Biscay is closed by eye and the fit made of North America on to a combined Greenland–Europe landmass incorporating the Flemish Cap and the coast of Portugal very similar results are obtained (table 1). In view of the fact that such a fit would involve distortion in the Pyrennean region, Spain has been left in its present position for the purpose of this study.

In many of the areas where bathymetric data has been ignored (Davis Strait Rise, junction of Iceland Ridge with Greenland and Europe, Jan Mayen) there is reasonable geological or geochronological evidence to believe that the incompatible features are largely post drift in age. The Mizen Head re-entrant, the Flemish Cap and the Bay of Biscay, like Rockall, lie in the zone of greatest geometrical displacement where maximum fragmentation might be expected to occur.

TABLE 1. FITTING DATA, 500 FM. LINE, NORTH ATLANTIC

fit	rotation centre		angle	misfit r.m.s. (deg)	misfit r.m.s. (%)
	latitude	longitude			
Greenland–Europe	73·03	−96·5	22·02	0·74	3·35
North America–(Greenland–Europe)	88·44	−27·72	38·09	0·97	2·54
North America–(Greenland–Europe) Biscay of Bay closed and incorporating west coast of Portugal and Flemish cap	88·50	−27·72	37·95	0·94	2·48

3. GEOCHRONOLOGY OF OCEANS AND CONTINENTS

From the point of view of geochronology, the land areas bordering the North Atlantic are among those most thoroughly investigated, though there still exist large regions in which data are extremely scanty or entirely absent. Nevertheless, it is beyond question that the continental landmasses have been in existence at least in part for more than 2500 My and since the time of their initial formation have undergone frequent reconstitution and addition.

The Atlantic Ocean, on the other hand, has had a comparatively short existence in its present state, if the evidence of the few radiometric age measurements made can be accepted. In contrast to the wide variety of rock types encountered on continents, the floor of the Atlantic consists mainly of basalt and similar basic materials which have so far not yielded ages greater than Tertiary. Oceanic islands and volcanoes related to the Mid-Atlantic Ridge have proved to be extremely young indeed, often with ages of less than 1 My.

If continental drift has taken place and if the Atlantic Ocean is a comparatively young feature, it should be possible not only to produce an acceptable geometrical reconstruction, but to show the geochronological patterns which were produced as a result of periods of metamorphism and mountain building taking place intermittently over some thousands of millions of years. If the landmasses in question had always been apart in a manner similar to their present situations, it is unlikely that a complete set of geochronological patterns could be built up, though it would be possible for there to be by chance an apparent relationship in time between certain events. Should there have been a composite landmass which underwent recent fracture it should be possible to construct a map showing the general geochronological–geographical relations of events in both continents and such relationships would be shown not to be influenced by recent fracture when plotted on a reconstruction of the original landmass.

4. Ages and age zones

The age measurements used in this investigation have been collected from the published works of many workers and combined with published and unpublished results from the Cambridge laboratory. In most instances, results from the potassium–argon and rubidium–strontium methods have been used because they give the age of the last geological event which affected the rocks and resulted in parent–daughter product redistribution. Some figures yielded by the uranium–lead method have been incorporated where there was no alternative.

Ideally, to produce the simplest picture it would be best to apply the same method to the same mineral type throughout the whole of the investigation because this would eliminate discrepancies produced by slight variation in the response of both minerals and the individual radioactive elements to geological events. Owing to the limited amount of data available, this has not been possible; in consequence virtually all the results revealed by a search of the literature have been included.

Results yielded by different methods and by the same method applied to different minerals can provide useful information if interpreted carefully. As already mentioned, both the potassium–argon and rubidium–strontium methods when applied to certain separated minerals tend to produce apparent ages closely related to the date of the last metamorphic event that affected the rocks. In general, argon loss from rocks takes place more easily than rubidium–strontium homogenization, and consequently the potassium–argon method when applied to micas, for instance, would prove the more sensitive of the two in this respect. Concordant potassium–argon and rubidium–strontium ages on the same mineral would establish the age of the last recrystallization with added certainty. Discordant potassium–argon measurements obtained from biotite and pyroxene extracted from the same rock would provide evidence of successive metamorphisms and could place a minimum age on the older event. Partial overprinting of older ages by younger ones as a result of incomplete recrystallization are occasionally encountered and have also been used in this work.

In order to show the geographical distribution of apparent radiometric ages on the North Atlantic reconstruction, it is necessary first to select suitable time spans as a basis for classification. For the purpose of this study, Precambrian time has been divided into three: (*a*) 2250 to 2750 My, (*b*) 1520 to 1890 My, (*c*) 800 to 1120 My. These selections were made in order that the outstanding work carried out by the Canadian Geological Survey upon rocks from the Canadian Shield and related areas could be readily included. A further three divisions for phanerozoic time suggest themselves: (*d*) 380 to 440 My, (*e*) 340 to 370 My, (*f*) 260 to 300 My. Age patterns have been based upon this sixfold division (figure 1).

The distribution of rocks having apparent radiometric ages falling within each of the above ranges will be briefly described and the results from a few selected areas where data is of special interest will be considered in more detail.

(*a*) 2250 to 2750 My

By far the best delineated area lying within this range is situated along the south and east margins of Hudson Bay, Canada. A second area encompassing part of the Labrador coast, much of Greenland and a very small region of northwest Scotland has been constructed on the scanty evidence of seven age measurements. Armstrong (1963) has proved the existence of these old rocks in western Greenland by a measurement made upon a biotite sample from the Godthaab complex which yielded an age of 2710 ± 130 My by the potassium–argon method. Leech, Lowdon, Stockwell & Wanless (1963) report figures of 2250, 2390 and 2430 My from the coast of Labrador. Haller & Kulp (1962) have determined ages of 2300 ± 50 and 2290 My for rocks from the basement in the innermost Scoresby Sund region of Greenland. Measurements made by Giletti, Moorbath & Lambert (1961) upon feldspars, using the rubidium–strontium method demonstrate the existence of rocks at least 2520 ± 50 My old in the Scourie area of Scotland. Biotite samples from the same area give somewhat lower values in response to later geological events.

Wetherill, Kuovo, Tilton & Gast (1962) have established the existence of rocks 2700 My in age in the gneissic pre-Karelian basement of Finland by applying the lead method to zircons.

It is not suggested that these three very old areas are the only ones which exist. In fact at least one more occurs in Canada and occupies an area roughly to the north of the Great Slave Lake.

(*b*) 1520 to 1890 My

Leech *et al.* (1963) clearly show that a considerable tract of country surrounding the older 2250 to 2750 My old zone in Canada is occupied by metamorphic rocks, the apparent ages of which largely fall into the span 1520 to 1890 My. Rocks of this classification have been shown to exist in Baffin Island and in the land to the northwest of Wager Bay. Evidence for their continuation into Greenland is provided by Armstrong (1963) who reports a potassium–argon age of 1650 ± 80 My for a sample of biotite from a granodiorite gneiss collected at the northeast end of Søndre Strømfjord, west Greenland. The biotite was fresh and showed no signs of chloritization, and consequently there is no reason to consider this result spurious. It is so far not clear how much of the west Greenland coast is occupied by rocks of this classification.

The Julianehaab granite of southwestern Greenland falls within this age range and has been shown by Moorbath, Webster & Morgan (1960) to give concordant potassium–argon and rubidium–strontium ages of around 1597 My. Other results produced by Moorbath *et al.* indicate that the Gardar intrusives of the same region are significantly younger (1100 to 1200 My). It is likely, therefore, that this region was originally occupied by rocks whose ages lay in the range 1520 to 1890 My and was later subjected to a period of renewed intrusion. On this evidence, the zone 1520 to 1890 My has been shown in figure 1 overprinted by the younger cycle.

The existence of older rocks within a younger belt demonstrates that the production of the younger zone was not entirely brought about by the addition of new material, but was formed to a great extent by the reworking of pre-existing rocks.

Good evidence for the presence of the age zone of 1520 to 1890 My in Scotland is provided by the work of Giletti *et al.* (1961) who give the results of seven analyses on four micas from South Harris together with a muscovite from Loch Maree, feldspar from a pegmatite at Badcall Bay and a biotite from biotite-gneiss, Rhiconich Bridge, Sutherland.

Rocks of similar age occur in western Finland and bound the western margins of the older 2250 to 2750 My area (Wetherill *et al.* 1962). Rankama reports lead ages of similar magnitude from the Stockholm district, and upon this evidence much of the land which surrounds the Gulf of Bothnia and makes up the northern coast of the Baltic has been assigned to the 1520 to 1890 My division.

(*c*) 800 to 1120 My

This belt is well defined in Canada immediately to the north of the St Lawrence River and on the evidence of the ages of the Garder intrusives can be traced into southern Greenland. Measurements on biotite from Loch Diabaig made in the Cambridge laboratory by the potassium–argon method have given an age of 1120 ± 42 My. Other evidence for the presence of the zone are considered in the more detailed description of western Scotland given later. Kulp & Neumann (1961) report a number of potassium–argon ages from micas collected from southern Norway which fall within this range.

(*d*) 380 to 440 My

By far the most well defined zone of all is made up by rocks which fall into this age range.

The Canadian Geological Survey have amply shown the existence of this belt in the region south of the St Lawrence River extending into New Brunswick. Faul, Stern, Thomas & Elmore (1963) provide evidence of its presence in Northern Maine. One measurement from western Newfoundland suggests its continuation through the island but the absence of similar results to the north leave its exact path uncertain. Figures corresponding to the older 800 to 1120 My old belt have been produced by the Canadian Geological Survey from the north and could suggest weak overprinting of the older metamorphism by the younger 380 to 440 My old event. In view of the fact that the rocks lie to the south of the Caledonian front, they have been assigned to the younger system.

Results from the British Isles are too numerous to mention in any detail. Results produced in the Cambridge laboratory on micas from western and northern Ireland all fall within the range. Events in Scotland, the Lake District, Anglesey and Charnwood Forest can without doubt be considered as related in time. Isolated figures from Brittany suggest that the zone extended further to the south at a time preceding the onset of the succeeding events.

Measurements by Haller & Kulp (1962) made on rocks from east Greenland demonstrate the extension of the system northwards, and a geochronological survey of Spitzbergen made in collaboration with Mr W. B. Harland of the Department of Geology, Cambridge, establishes its existence in high latitudes.

The Shetland Islands fall well within this belt. Many measurements made upon samples of biotite show that the rocks in this area were recrystallized some 415 My ago and

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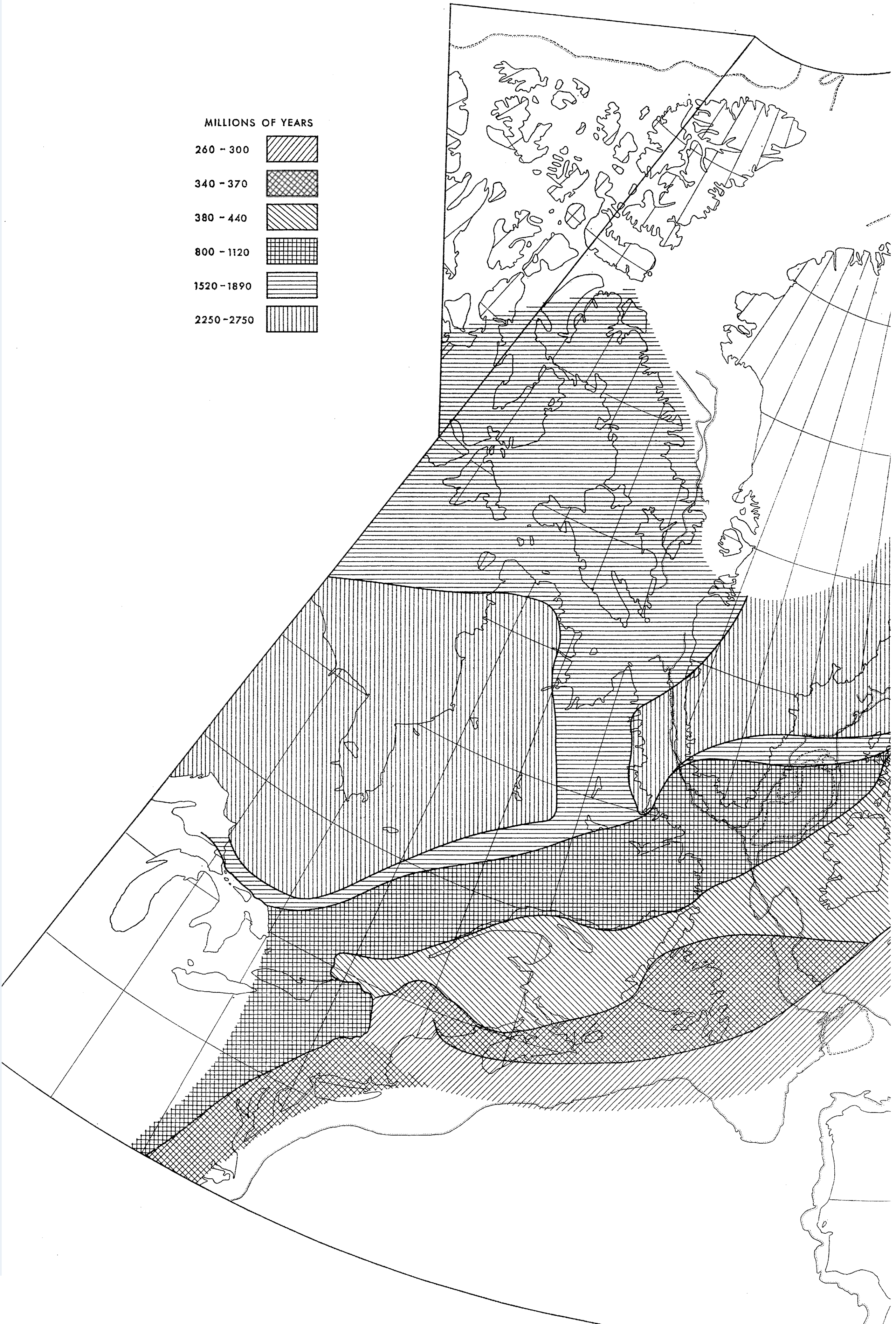
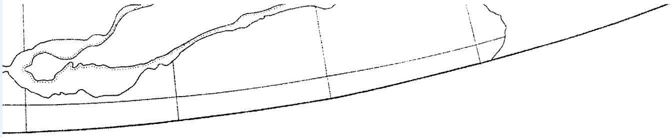


PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

Figure 1. General distribution of age zones in the North Atlantic before drift. The solid
For clarity individual age measu



ines marking the edges of zones do not imply that margins are accurately delineated.
rements are not shown.

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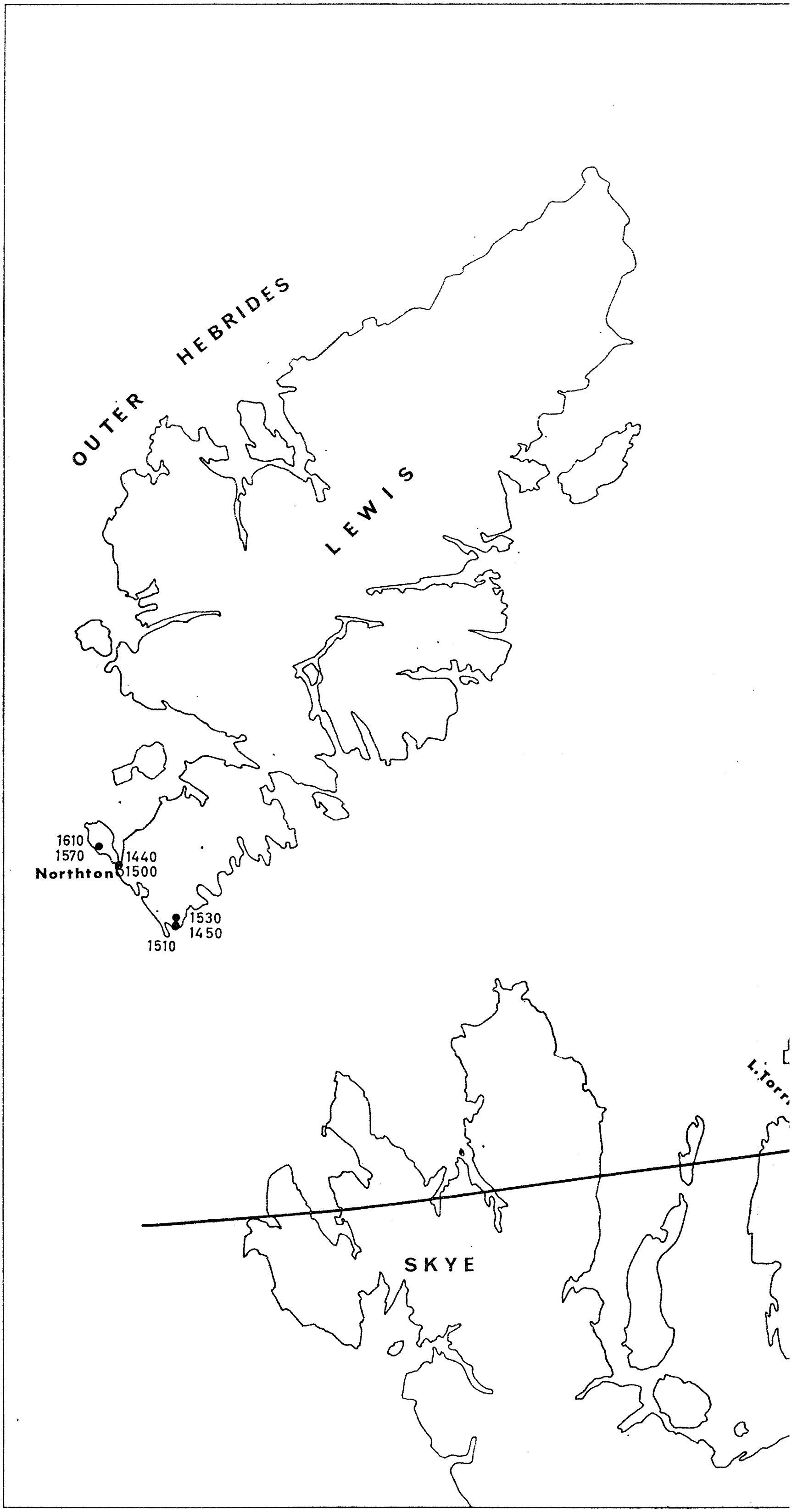

FIGURE

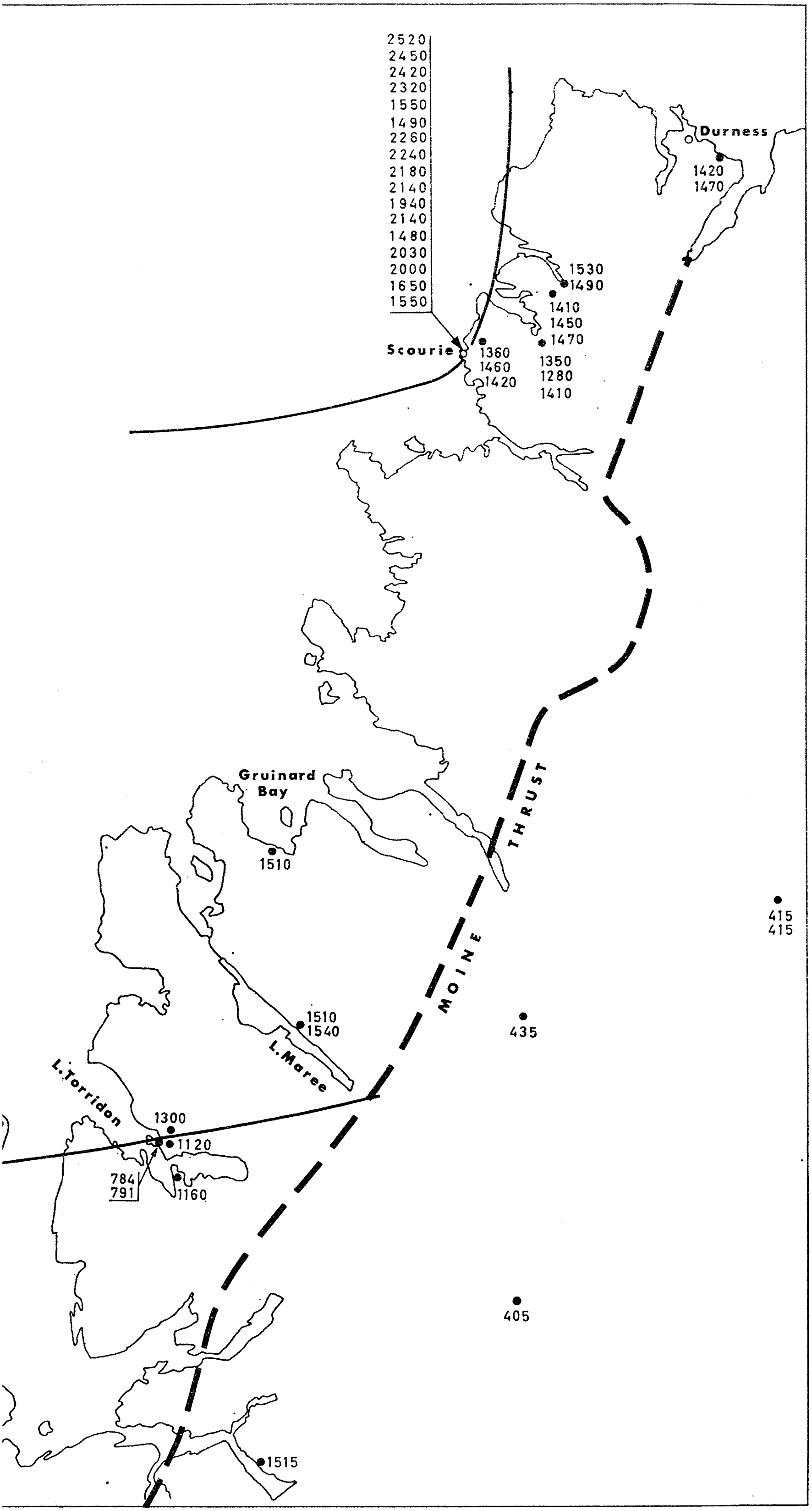
2520
2450
2420
2320
1550
1490
2260
2240
2180
2140
1940
2140
1480
2030
2000
1650
1550
Durness
1420
1470
1530
1490
1410
1450
1470
Scourie
1360
1460
1420
1350
1280
1410
Gruinard Bay
1510
THRUST
MOINE
415
415
1510
1540
L.Maree
435
L.Torridon
1300
1120
784
791
1160
405
1515

FIGURE 2

intruded by granites some 20 My later. This trend is common throughout the zone. Certain muscovites from the Shetlands, and hornblendes from Scotland and Spitzbergen have given significantly older ages which can be interpreted as evidence of the presence of metamorphic rocks in these areas prior to the onset of the last recrystallization.

Kulp & Neumann (1961) report figures which show the zone in Norway and have been used in the present work to estimate its eastern margin.

(*e*) 340 to 370 My

Rocks falling into this category occur along the eastern seaboard of the United States and northwards from New York (Long, Cobb & Kulp 1959). A sample of biotite collected from Tarrytown, N.Y. lying well within the belt gave an age of 440 My, and again demonstrates that pre-existing rocks have been re-worked to form the new belts. Faul *et al.* (1963) provide evidence to suggest that the zone extends through the northern Appalachians. Scanty information could be considered to suggest its presence in Nova Scotia and it seems certain from the seven dates of Leech *et al.* (1963) that an event occurred in Newfoundland at this time.

There is very little evidence of the 340 to 370 My zone in the British Isles, though dates of this type have been produced from rocks collected in the Lizard area of Cornwall. This interesting relationship is considered later.

Similar ages from the continent of Europe are so far lacking, and it seems likely that the zone may have been completely obliterated by overprinting by the later 260 to 300 My pattern.

(*f*) 260 to 300 My

Faul *et al.* (1963) have discovered evidence for a metamorphic event of Permian age in the northern Appalachians and have suggested a possible northern limit to its extension. A similar age has been found in southern Nova Scotia but detailed study of the event in that part of the world is so far lacking.

The many measurements made by several workers on the granites of Devon, Cornwall and the Scilly Isles have been reviewed by Miller & Mohr (1964) and demonstrate with certainty the existence of the belt in southwestern England.

Graindor & Wasserburg (1962) show its extension into the southern part of the Armorican massif from where it passes through the Massif Central (Depois, Sanselme & Vialette 1963), Vosges and Schwarzwald (Faul & Jäger 1963). Similar ages have been obtained from potash feldspar collected from Mont Orfana near Lake Maggiore (Jäger & Faul 1959) and like ages are found, by rubidium–strontium methods, preserved in rocks that have been involved in the Alpine folding further to the east (Jäger 1962).

5. Special areas in the British Isles

In certain parts of the North Atlantic reconstruction shown in figure 1 the age measurements are of special interest and throw light upon the relations of adjacent zones. Those areas of special interest where the radiometric data are sufficiently abundant to enable conclusions to be drawn will be discussed.

(*a*) *The Lizard area*

In the Lizard area of Cornwall, the sequence of events established upon geological grounds may be summarized as follows. Oldest: (1) regional metamorphism of (*a*) Old Lizard Head Series, (*b*) Landewednack hornblende schists, accompanied by the intrusion of the Lizard peridotite; (2) localized intrusion of gabbro; (3) intrusion of a basic dyke swarm and related sills, intruded in a stress field operating at approximately right angles to that which accompanied metamorphism; (4) minor intrusions of Kennack granite and injection gneiss; (5) thrusting of the Lizard block over the palaeozoic sequence to the north.

Ages given in table 2 do not appear to be in agreement with the geologically established sequence.

TABLE 2. RESULTS FROM THE LIZARD AREA

(After Miller & Green 1961 *a*, *b*)

material	K_2O (%)	[vol. radiogenic A^{40} (mm^3 n.t.p.)] / [weight of sample (g)]	atm. contam. (%)	apparent age ± error (My)
96388 muscovite (coarse), Old Lizard Head Series, Pen Olver	9·03	0·1206	2·7	357 ± 14
96388 muscovite (fine) as above	9·01	0·117	1·6	352 ± 14
96391 muscovite (fine), Old Lizard Head Series, near Lifeboat Station, Polperro	9·11	0·130	8·4	359 ± 14
96391 muscovite (coarse), as above	9·17	0·121	2·0	355 ± 14
96395 hornblende from amphibole at Predannack Head	0·211	0·00377	27·2	357 ± 20
96396 hornblende from Landewednack hornblende schist at Pencra Head	0·375	0·00611	16·5	371 ± 20
96394 hornblende from hornblende granulite at Pol Cornick	0·242	0·00465	3·2	492 ± 26
96392 biotite, Kennack gneiss, Kennack sands	6·97	0·1188	14·1	397 ± 14
96393 biotite, Kennack gneiss, Polgwidden	5·98	0·0874	3·8	384 ± 14

$\lambda_e = 0{\cdot}584 \times 10^{-10}\ \text{y}^{-1}$. $\lambda_\beta = 4{\cdot}72 \times 10^{-10}\ \text{y}^{-1}$.

In thin section, it is clear that the biotite–hornblende gneiss of Kennack has suffered little, if any, retrograde effects; therefore it is considered that the age of 391 My is near to the true one. Measurements on muscovites from the regional metamorphics of the Old Lizard Head Series gave younger figures averaging at 356 My. It could be argued that Hercynian movements in the area had partially 'overprinted' the muscovites in the regional metamorphics and had not affected the Kennack gneiss owing to its more massive nature. Such a hypothesis cannot be true, as pyroxenes from the metamorphics gave results concordant with those of the micas. If the rocks had been subjected to a weak secondary event, the pyroxenes would have given significantly greater values.

It is concluded that the area was influenced by the 380 to 440 My metamorphism which resulted in the production of regional metamorphics and the Kennack gneiss. Later, the 340 to 370 My event caused recrystallization of the hornblende–mica schists. It is not suggested that the area had a metamorphic history earlier than 440 My ago, for sample 96394 (table 2) of hornblende from hornblende granulite at Pol Cornick gave a potassium-argon age of 492 ± 26 My.

It is surprising that these rocks have escaped recrystallization during the 340 to 370 My event, but it would appear that the intensity in the area was low, for granitic rocks from nearby Normandy have escaped recrystallization and retained ages of greater than 580 My (Kaplan & Leutwein 1963).

(*b*) *The Rockall Bank*

In figure 1 it is seen that the Rockall Bank fits into the gap left between the continental margins of southeastern Greenland and northwestern Ireland. In view of the fact that Iceland and Jan Mayen were neglected in making the fit, the retention of Rockall needs some justification.

The aegirine granite of Rockall forms a small island standing some 70 ft. above sea level and is only about 100 ft. in diameter. Sabine (1960) has recently described the geology of the island and given an account of the history of research. The island stands on a submarine bank trending SSW–NNE about 96 km long and 48 km wide situated some 65 to 100 fm. below the surface and falls away to depths of 1000 fm. or more.

Though dredgings on the bank have produced quantities of basalt it is thought that continental type rocks may lie below. Radiometric measurements made on samples of basalt from the Mid-Atlantic Ridge and other parts of the Atlantic Ocean, have yielded young ages. Furthermore, those few measurements which have been made so far indicate that exposed oceanic islands tend to be younger than similar rocks from sea-mounts, and it is suggested that a typical basaltic oceanic island, being isostatically unstable, would have a life of about 20 My after which it would become a sea-mount.

Other non-basaltic islands in an oceanic environment are the Seychelles group of the Indian Ocean which have many continental affinities and are Precambrian in age (Miller & Mudie 1961; Baker & Miller 1963).

Age measurements were made on samples of pyroxene and altered feldspar from a small sample of the aegirine granite of Rockall and are given in table 3, along with results of potassium–argon age measurements made on samples from St Kilda's, which is the nearest landmass to Rockall (304 km away), Ardnamurchan and the Loch Fyne region of west Scotland. Table 4 shows results from Arran (Miller & Harland 1963) and table 5 those from Lundy Island (Miller & Fitch 1962) as comparison.

From all these figures it is clear that a period of granitic intrusion took place in the British Tertiary Igneous Province some 50 to 60 My ago, and upon the similarity between the age yielded by material from Rockall and elsewhere it is concluded that the island was a constituent part of the British Province and related to the European continent.

(*c*) *The northwest Highlands of Scotland*

Extensive rubidium–strontium measurements have been made upon rocks from the northwest Highlands of Scotland by Giletti *et al.* (1961), and are included in figure 2 together with a number of potassium–argon determinations made in the Cambridge laboratory.

In general, the oldest rocks occur in the Scourie area. There is a general decrease in apparent age southwards. Though some ages fall into the range 1520 to 1890 My, especially in the Outer Hebrides, many fall between the ranges 1520 to 1890 and 800 to 1120 My. Whether this is due to partial overprinting of the 1520 to 1890 My zone by later events cannot be ascertained from this study alone.

TABLE 3. AGES OF SOME TERTIARY INTRUSIVES FROM SCOTLAND, ST KILDA'S AND ROCKALL

material	K_2O (%)	atm. contam. (%)	[vol. radiogenic A^{40} (mm^3 n.t.p.)] / [weight of sample (g)]	age ± error (My)
quartz monzonite, centre 3, Ardnamurchan (biotite)	7·85	12·5	0·0144	55 ± 6
dolerite plug, Loch Fyne (sanidine + quartz)	5·15	6·8	0·01108	64 ± 3
	5·15	19·4	0·01021	59 ± 3
acid dyke, Boreray (T.R.)	2·26	64·4	0·00241	32 ± 7
granophyre of Conachair, St Kilda (T.R.)	4·58	50·5	0·00852	56 ± 1
granophyre of Conachair, St Kilda (T.R.)	4·13	56·3	0·00785	57 ± 3
granophyre of Glen Bay, St Kilda (T.R.)	3·87	72·0	0·00735	57 ± 3
	3·87	71·1	0·00774	60 ± 3
	3·87	67·5	0·00720	56 ± 6
granophyre sheet, An Torc, St Kilda (T.R.)	2·01	56·1	0·00375	56 ± 6
olivine basalt, Mullagh Sgar, St Kilda (T.R.)	0·85	56·5	0·00162	57 ± 2
olivine dolerite, Gob na h'Airde, St Kilda (T.R.)	0·40	83·7	0·00084	62 ± 2
type 2 dyke, Glen Bay, St Kilda (T.R.)	3·75	52·3	0·00813	64 ± 4
type 2 dyke, Glen Bay, St Kilda (T.R.)	0·54	89·9	0·00070	39 ± 28
rockallite, quartz + feldspar	6·34	45·2	0·01035	49 ± 3*
rockallite, pyroxene	0·67	53·2	0·00142	60 ± 10

$\lambda_e = 0{\cdot}584 \times 10^{-10}\ y^{-1}$. $\lambda_\beta = 4{\cdot}72 \times 10^{-10}\ y^{-1}$.

* Sample kaolinized.

TABLE 4. AGES OF TERTIARY INTRUSIVE ROCKS IN ARRAN

(Miller & Harland 1963)

material	K_2O (%)	atm. contam. (%)	[vol. radiogenic ^{40}A (mm^3 n.t.p.)] / [weight of sample (g)]	age ± error (My)
northern (outer) granite, Arran				
Coich na h'oighe, Sannox HA 765				
feldspar and quartz	5·12	10·4	0·01126	65 ± 6
biotite	6·18	10·2	0·01267	61 ± 6
coarse granite east of An Tunna, north Glen Sannox HA 850				
feldspar and quartz	5·15	15·1	0·009589	55 ± 5
feldspar and quartz	5·11	26·1	0·009607	56 ± 5
Porphyritic granite vein east of An Tunna, north Glen Sannox HA 849				
feldspar and quartz	5·15	1·2	0·009940	57 ± 6
central complex granite, Arran				
Dereneneach Quarry, HA 781				
feldspar and quartz east of Tarrnacraig, HA 916	4·59	18·1	0·009731	63 ± 6
feldspar and quartz	4·46	29·9	0·008965	60 ± 6
feldspar and quartz	4·30	21·7	0·009030	62 ± 6
quartz porphyry composite sills				
Bennan Sill HA 294				
feldspar and quartz	5·30	11·9	0·01086	61 ± 6
feldspar and quartz	5·39	33·2	0·01105	61 ± 6

$\lambda_e = 0{\cdot}584 \times 10^{-10}\ y^{-1}$. $\lambda_\beta = 4{\cdot}72 \times 10^{-10}\ y^{-1}$.

Table 5. Results of potassium–argon measurements on granite from Lundy

(Miller & Fitch 1962)

material	K_2O (%)	atm. argon contam. (%)	[vol. radiogenic A^{40} (mm^3 n.t.p.)] / [weight of sample (g)]	age ± error (My)
biotite	8·87	20·4	0·01490	50 ± 3
feldspar + quartz	4·30	31·4	0·00796	55 ± 3

$\lambda_\beta = 4{\cdot}72 \times 10^{-10}\ \mathrm{y}^{-1}$. $\lambda_e = 0{\cdot}584 \times 10^{-10}\ \mathrm{y}^{-1}$.

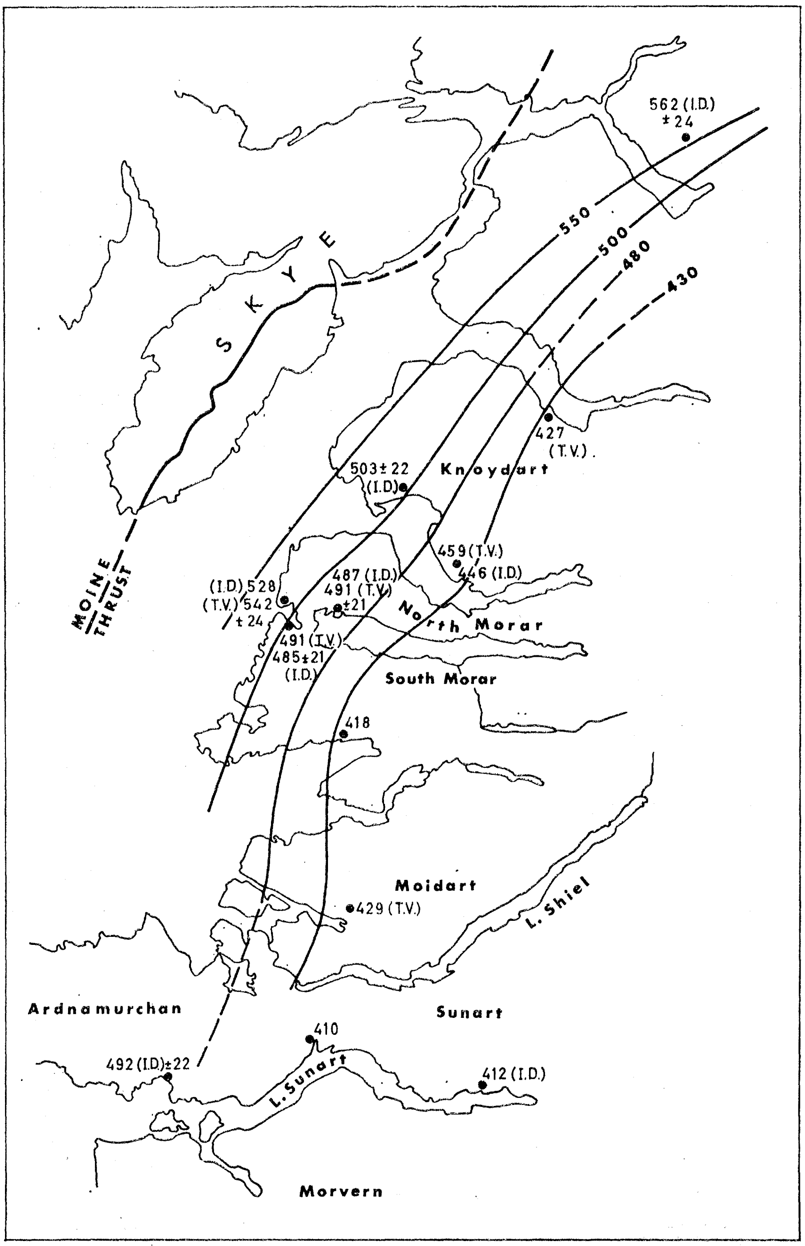

Figure 3

South of Loch Torridon, ages in general fall within the 800 to 1120 My zone. It is of interest to note that a pyroxene from the Glen Elg inlier, shown at the bottom of figure 2 yielded an age of 1515 to 104 My by potassium–argon analysis (Miller, Barber & Kempton 1963). The pyroxene was extracted from an eclogite collected from the northeast shore of Loch Duich, Ross-shire, which lies within the Caledonian front. Not only had the rock survived the 800 to 1120 My 'event' but also the powerful Caledonian movements that affected the area. This result is of particular interest as it indicates that the 1520 to 1890 My zone once extended into the areas now occupied by radiometrically younger material.

More evidence for the existence of the 800 to 1120 My belt can be drawn from the areas of Knoydart and Morar farther to the south (figure 3) (after Miller & Brown 1965). Apparent potassium–argon ages from micas consistently rise towards the Moine thrust, and probably represent the local remains of the 800 to 1120 My zone that escaped overprinting by the younger 380 to 440 My recrystallization. A complete transition cannot of course be traced owing to the presence of the Moine thrust and Tertiary volcanic centres which lie to the west.

From these results when considered as part of the geochronological reconstruction of the North Atlantic, it would appear that northwestern Scotland has been affected by three tectonic events in Precambrian times.

6. Conclusions

From this preliminary study it would appear that it is possible in a general way, to show that rocks having similar apparent radiometric ages can be traced over wide areas. The production of each new belt involves the reworking of older crystalline rocks, not just the addition and crystallization of new material. Geochronological and structural boundaries only coincide when metamorphic rocks of the two age groups present occur in contact. Consequently the western boundary of the Caledonian front in Scotland is marked by coincident structural and geochronological breaks.

It is not considered that the geochronological patterns shown in figure 1 are proved and accurately delineated. This is the preliminary investigation in a large programme of research in both the North and South Atlantic areas in which comparison is to be made between the geochronology and structures of the continental fragments involved.

The author thanks Sir Edward Bullard, F.R.S., for his interest and encouragement in this undertaking, Miss D. Bate for her assistance in preparing the diagrams, and the Royal Society of London for financial support.

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APPENDIX. THE STRUCTURAL UNITY OF THE RECONSTRUCTED NORTH ATLANTIC CONTINENT

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The map of chelozones (figure 4), which accompanies this short note, is a first attempt to show that when the pre-Tertiary North Atlantic continent is reconstructed in the manner

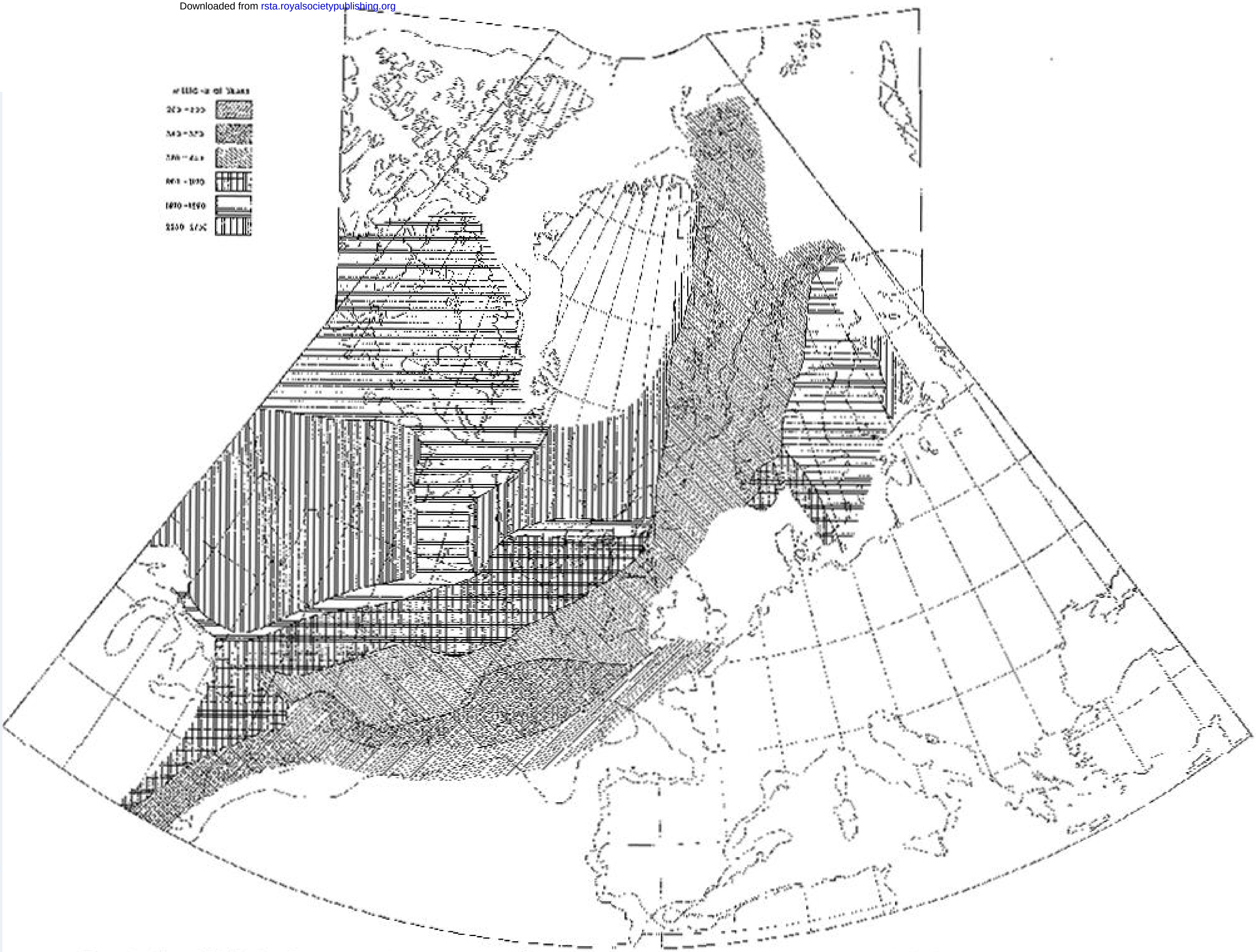

FIGURE 1. General distribution of age zones in the North Atlantic before drift. The solid lines marking the edges of zones do not imply that margins are accurately delineated. For clarity individual age measurements are not shown.

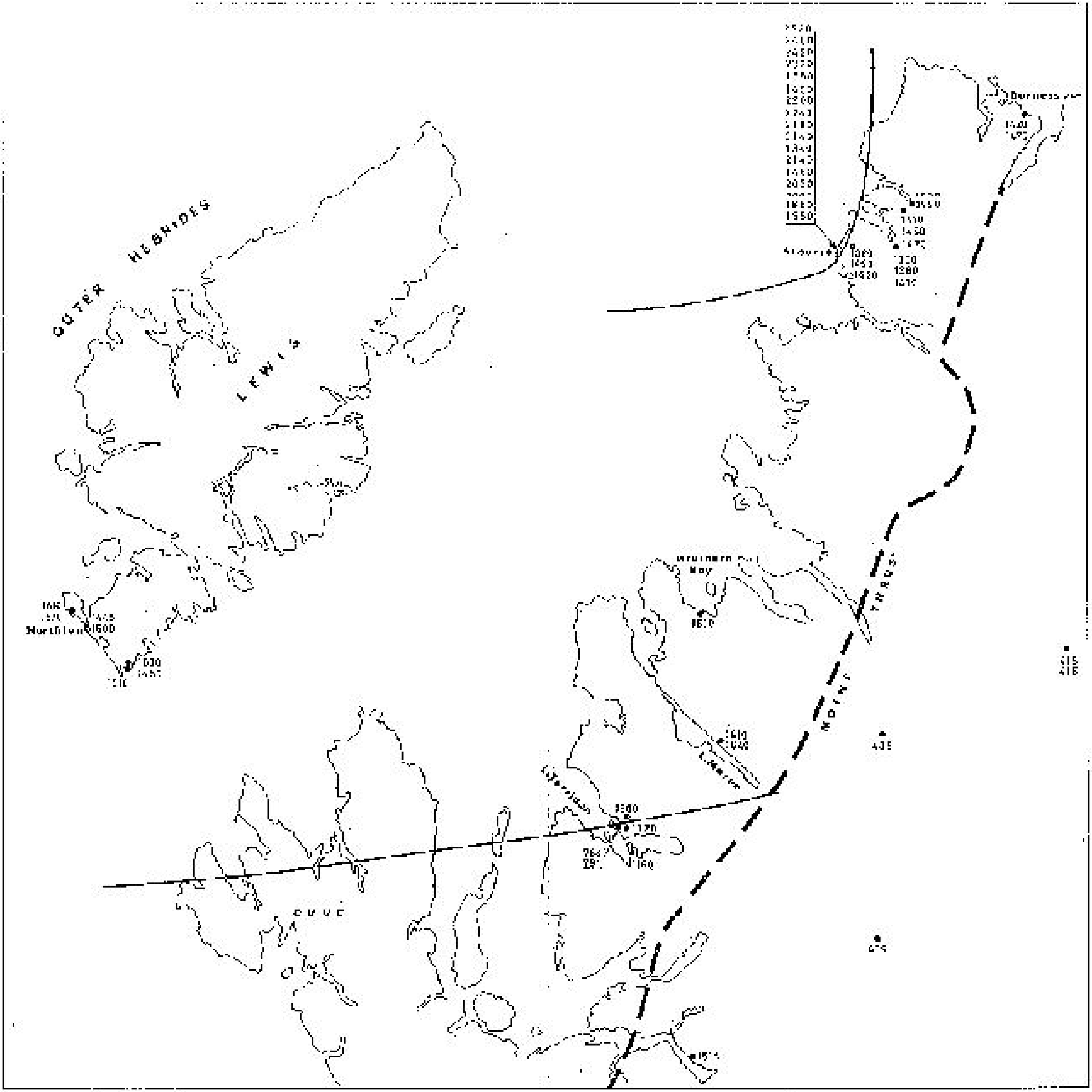
OUTER HEBRIDES
LEWIS
Northton
1600
1630
Durness
Stoer
1550
2050
2200
1450
1280
Gruinard Bay
L. Maree
Applecross
SKYE
1160
MOINE THRUST
435
415
416

FIGURE 2