THE STRUCTURAL AND METAMORPHIC HISTORY

of the

LOCHAILORT (MOIDART) AREA

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1. INTRODUCTION

A. GEOGRAPHICAL POSITION AND PHYSIOGRAPHY

Moidart is situated in west Inverness-shire, lying to the west of the town of Fort William, with the regions of Ardnamurchan and Sunart to the south, and the region of Morar to the north. It is a rugged, mountainous area with steep-sided hills rising to heights of over 2,000' and many parts, particularly in south Moidart, are not easily accessible. It is bounded to the south and south-east by Loch Shiel, and to the north by Loch Ailort and Loch Eilt. No roads or tracks penetrate the region and the small population is concentrated in villages situated around the mountainous area.

The area mapped covers some 20 sq. miles of north Moidart, and is covered by the O.S. six inch sheets Inverness-shire 135 S.E., 136 N.W., N.E., S.W., S.E., and 149 N.W. (fig. 1). The northern boundary is determined by the sea loch, Loch Ailort, in the west and the fresh water Loch Eilt in the east; the southern boundary is defined by Glen Ulgarry, some two miles north of Loch Shiel; the western boundary by the Irine burn which flows north and enters Loch Ailort near the hamlet of Roshven; the eastern boundary by Allt a Choire Bhuidh which flows north

LOCATION OF AREA STUDIED

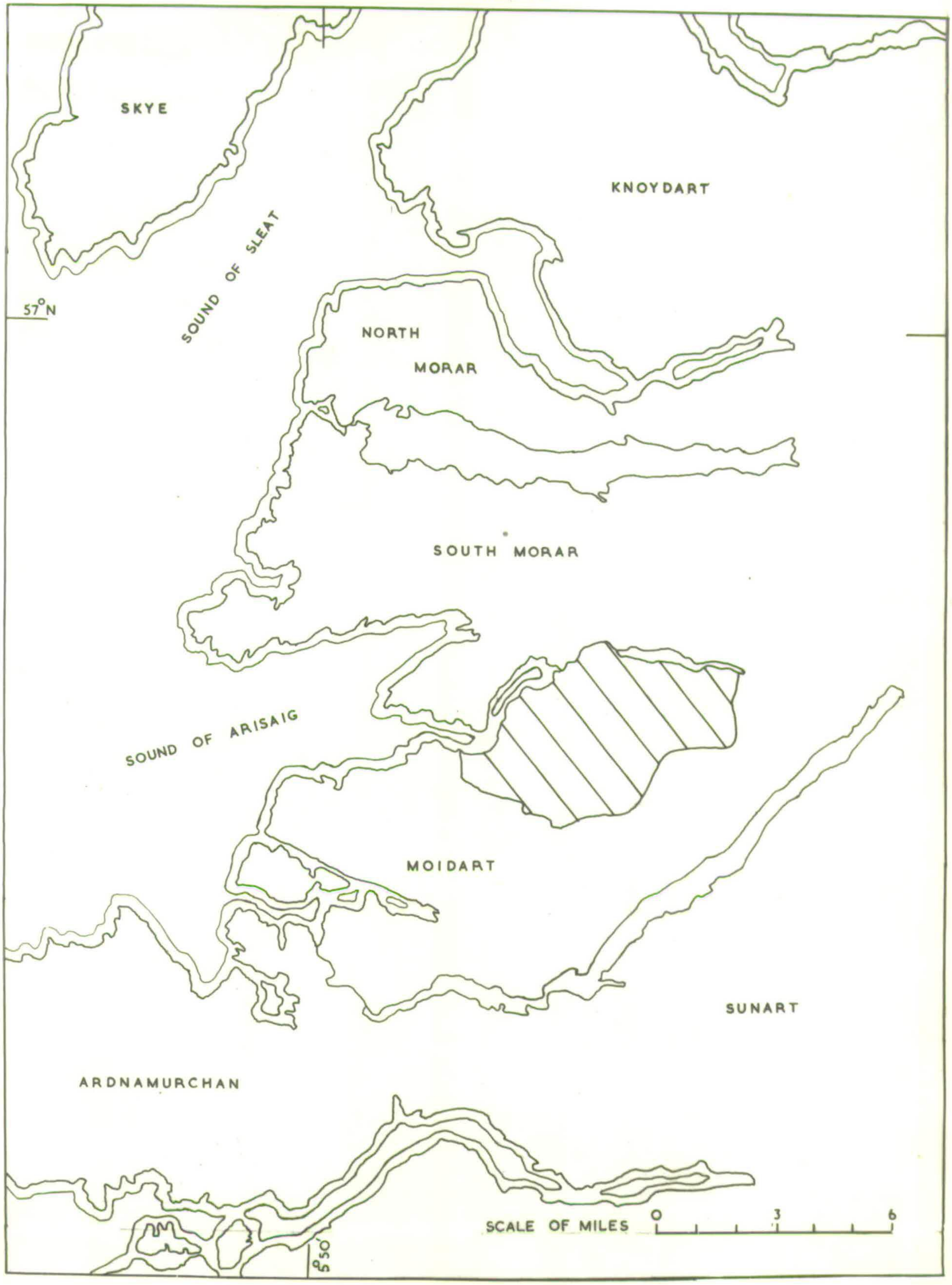


FIG. 1

into the eastern end of Loch Eilt. On the northern boundary of the area lies the small village of Lochailort, served by daily trains from Glasgow, and connected to the towns of Fort William and Mallaig by the Fort William-Mallaig road, the celebrated "Road to the Isles". The principal occupations of the inhabitants is agricultural, the tourist industry tending to be concentrated at the coastal villages of Morar and Arisaig, on the west coast of Morar.

Topographically the dominant feature of the area mapped is a ridge trending in an E. - W. direction and having an average height of about 2,000'. Locally, at Rois-Bheinn, Sgurr na Ba Glaise and Druim Fiaclach the ridge attains heights of over 2,800'. Between this ridge and the northern boundary lie the mountains of An Stac, Beinn Coire nan Gall and Diollaid Bheag, separated by N. - S. trending valleys. The general relief of the area is rugged, the ground rising steeply from sea level to over 2,000'. The hills show a large amount of exposed rock, while the intervening broad, grass covered valleys contain only a small amount of rock exposure.

The east-west trending ridge forms the main watershed of the area and divides the ground mapped into two parts, a northern area which forms the larger part and includes the mountains mentioned above, and a southern area which consists of the steep, south-facing slope of the ridge. To the north of the ridge the drainage flows into the sea loch, Loch Ailort, or into Loch Eilt, which is connected to the sea by the westward flowing River Ailort. South of the ridge and in the western part of the area mapped, the drainage flows southwestwards into the sea loch of Loch Moidart, while to the east the streams flow south, into the fresh water Loch Shiel.

The recent glaciation has had a considerable effect upon the topography, and many features characteristic of mountain glaciation are represented. Glenaladale and Glen Ulgarry are good examples of U-shaped valleys, and other features, such as corries, hanging valleys, rudimentary Horns can be seen. Glacial striae are not common, some have been found at Seann Chruach, north of An Stac and they indicate that the ice movement in that area was in an E. - W. direction. Poor examples of roches moutonnee in the same area, and at Beinn Bheag, immediately south of Lochailort, suggest the direction of the movement was from the east to the west.

Glacial moraine covers all the valley bottoms, and greatly reduces the amount of rock exposed. Good examples of morainic hummocks can be seen in Coir'a' Bhuiridh and in the valley east of Diollaid Bheag.

Post-glacial deposits consist in the main of river alluvium, which is deposited where the swift flowing streams enter the little disturbed waters of the lochs. The river Ailort has formed a large delta at the head of Loch Ailort and smaller deltas have been formed by the streams entering Loch Eilt. Allt a Choire Bhuidhe has formed an extensive delta into Loch Eilt, the loch being almost divided into two. No extensive post-glacial deposits are found in the valleys themselves. An exception to this is in Glen Ulgarry, where the river follows a meandering course through the river alluvium in the valley bottom.

Uplift of the land mass in post-glaciation times is indicated by the raised beach seen at Alisary, on the Loch Ailort shore some four miles S.W. of Lochailort village.

This movement has also affected the drainage, for all the major streams in the northern part of the area mapped either contain waterfalls, or in some part of their course pass through minor vertical-sided gorges.

The area, although rugged, contains no vertical rock faces and no part of the ground is inaccessible. The vegetation of the area is coarse grass, providing excellent feeding for the sheep and numerous deer. Trees and heather covered areas are confined to the low ground immediately south of Loch Ailort and Loch Eilt.

B. HISTORY OF RESEARCH

Although the N.W. Highlands have attracted the attention of geologists for a considerable period of time, very little work has been carried out in Moidart, and detailed information of the geology of the region is not available. The only previous geological work in Moidart was by H.M. Geological Survey, the work being part of the primary survey of the area covered by the 1" maps, Sheet 52 (Sunart) and Sheet 61 (Arisaig and Mallaig). These maps and their related memoirs have yet to be published and the annual Summaries of Progress of the Geological

Survey pt. 1,1930-31, 1933-35, provide the only available accounts of the work. The results of this primary survey have been incorporated into the Ordnance Survey "Ten Mile" map. This map shows that Moidart is made up of psammitic and pelitic rocks of Moine age, which are part of an extensive outcrop of Moine rocks that extends from Morvern in the south to Knoydart in the north.

The work of the Geological Survey in Ardnamurchan (E.B. Bailey, 1921, 22) showed the Moine Schists to consist of alternating belts of psammitic, semi-pelitic and pelitic rocks striking approximately N.-S. (E.B. Bailey, 1921). In east Ardnamurchan the psammitic and pelitic belts were traced northwards to Moidart (Bailey, 1922). In W. Ardnamurchan Bailey reports that the rocks are in a low state of metamorphism (Bailey, 1922), the psammitic rocks being well bedded white felspathic grits with pebbly bands. Eastwards, near Ben Hiant in Ardnamurchan, the rocks are more highly metamorphosed, the pelitic schists being garnetiferous and the psammitic rocks containing "pink felspar and obvious biotite" (Bailey, 1921, p. 89).

In 1930, continuation of the work by the Geological Survey in the area extending from Ardnamurchan to Sunart, showed further psammitic, semi-pelitic and pelitic belts which were traced northwards into Moidart, on to the area covered by Sheet 61 (J.E. Richey, 1930, 1933-35). The semi-pelitic and pelitic rocks show great variation in thickness, which was attributed to "infolding" of the pelitic rocks within the psammitic belts (Richey, 1930, p. 63).

In Ardnamurchan the dominant strike of the rocks was found to be in a N-S direction, but in Moidart, between Glen Moidart and Lochailort, the dominant strike changed to a N.E. - S.W. or N.N.E. - S.S.W. direction (Richey, 1934).

As the Survey mapping progressed eastwards into Sunart and E. Moidart it was found that the Moine rocks were injected with granitic and pegmatitic material (Richey, 1930). Richey states that "The injection begins in force east of a line drawn from Salen on Loch Sunart to Kinlochmoidart, and eastwards increases noticeably in intensity. It is especially obvious in a pelitic, or a semi-pelitic host" (Richey, 1930, p.63). Variation in rock type, from schists with pegmatite veins to lit-par-lit injection gneisses and permeation gneisses are present. Sillimanite is locally abundant, often associated with muscovite-rich rocks. Tourmaline and beryl occur in the pegmatites and adjacent gneisses. The rocks are of a much coarser grain than the uninjected rocks to the west in Ardnamurchan, and Richey states the typical rock of the injection zone is a garnet - muscovite - biotite - gneiss, the felspar of the gneiss being oligoclase, although locally potash felspar is abundant. (Richey, 1930).

To the east of Glen Moidart the rocks of the injection complex are involved in "a zone of complicated folding" (Richey, 1934, p. 65), which was traced from Ben Resipol, south of Loch Shiel, northwards to Loch Eilt (Sheet 61). Richey states that "The complicated zone of folding......between Ben Resipol and Beinn Gaire (Sheet 52), continues northwards to Loch Eilt in a well marked fold which closes to the south. A belt of garnetiferous pelitic schist forms an outer member of this fold.

The belt can be traced from the shores of Loch Eilt, immediately to the west of Sgurr na Paite southwestwards along Beinn Coire nan Gall to Druim Fiaclach. With a change of strike the belt continues in a south easterly direction along the ridge of Druim Fiaclach as far as Beinn Mhic Cedidh. Here it turns north east again and with minor complications continues back to the head of Loch Eilt. Within this arcuate outcrop and conforming with it in strike come a mixed pelitic and psammitic assemblage with a central belt of psammatic schist" (Richey 1935, pp. 79-80).

The injection complex of Moidart and Sunart is continuous with a zone of injection present further north in the Loch Duich - Loch Hourn area (Phemister 1948). Phemister (1948) reports that the results of the Geological Survey mapping show that the injection complex has a total length of at least 60 miles, extending from the Sound of Mull in the south to Loch Duich in the north and varies in width from 10-16 miles. H.H. Read (1931) described the Loch Choire injection complex in Sutherlandshire, and Phemister (1948) states that the rocks of the injection complex in Moidart are almost identical with those described by Read.

Phemister points out the "the parent body of the injecting magma" is not exposed in Moidart or Sunart (Phemister 1948, p. 31). In the injection complex of Sunart the Strontian granite is exposed, but although the intensity of injection in the rocks adjacent to the granite is intense, A.G. MacGregor & W.Q. Kennedy (1931) showed that the granite was of later date than the injection episode. The granite (a tonalite, granodiorite, biotite-granite mass) was found to be transgressive to the injected country rock, and banding within the gneisses can be traced to the granite contact but not in the granite itself.

W.T. Harry (1954) studied the gneisses of the injection complex in W. Ardgour, an area immediately to the south east of Moidart. In W. Ardgour the psammitic rocks are fold into a N.E. - S.W. trending anticline, in the core of which there is exposed a belt of pelitic rock. Harry reports that in this pelitic rock there is present a belt of composite gneisses. Adjacent to the junction of the pelitic rocks and overlying psammitic rocks, an oligoclase-biotite-quartz gneiss is found, and at structurally deeper levels of the anticline the gneisses are of granitic composition, containing quartz, microcline, oligoclase and biotite.

Harry states that these two gneisses were formed syntectonically, the granite-gneiss by a SiO_2 - K_2O front of metasomatism, which was preceded by the Na-Ca-Mg front of felspathisation that formed the oligolase-biotite-quartz-gneiss. No considerable time gap occurred between the formation of the two gneisses, the structures and textures of both gneisses show the effects of the same earth movements, and they are regarded as "products of an 'earlier' and 'later' phase of the same metasomatic episode" (Harry, 1954, p. 304). Minor structures found in the gneisses can be related to the major anticline of the area and Harry suggests that the formation of the gneisses accompanied this folding episode, although taking place towards the end of the movement. Thin sections show evidence of para - crystalline deformation, and small fractures in the rock are now healed by quartz-felspar material continuous with the quartz-felspar material in the surrounding gneiss.

Harry believes the injecting material affected rocks which had been previously metamorphosed and deformed. This is shown by the fact that the hornblende schists, (regarded by Harry as pre-metamorphism intrusions) found as pods and lenses in the Moine Schists, had been metamorphosed and disrupted before the intrusion of the granitising fluid.

The work of H.M. Geological Survey on the primary survey of the area covered by Sheet 61 was extended northwards from Moidart to Morar (J.E. Richey 1935-1938). The geology of Morat has been intensively studied and it will be useful to describe the results of the work in this area in some detail, so that comparison can be made with the conclusions obtained by the writer in Moidart.

The first detailed account of the geology of Morar is given by J.E. Richey and W.Q. Kennedy (1939), their work being part of the primary survey of Morar carried out by the Geological Survey. Richey and Kennedy found that the Moine Schists in west Morar contain abundant, well preserved sedimentary structures which consistently young to the west, and enable a stratigraphical succession to be established. The sedimentary structures are sufficiently abundant for Richey and Kennedy to state that reduplication of the rocks by folding does not take place.

The succession of Richey and Kennedy, which divides the Moine Schists of Morar into three main lithological groups, is given in table 1.

The thicknesses given to the three groups by Richey and Kennedy are applicable only to the particular localities mentioned. There is considerable variation in thickness of the two lower groups and this is said by Richey and Kennedy to be the result of "tectonic sliding of the strata during folding" (Richey & Kennedy 1939, p.28). Interbanding of the lithological groups along their junctions show that the sequence is a continuous one.

Certain features which would be useful in applying this succession to other regions were pointed out :-

a) The restriction of calc-silicate bands to the base of the Upper Psammitic Group and to the Upper Striped Schists and the Garnetiferous Pelitic Schists of the Striped and Pelitic Group.

b) Magnetite-zoisite seams are present in the Upper Striped Schists.

TABLE I

Upper Psammitic Group. (Upwards of about 12,000' near Arisaig).	b. Massive and well bedded pink siliceous felspathic granulitic schists, often finely pebbly with pebbles up to 1" in diam., and with frequent semi-pelitic beds. a. Well bedded greyish or white quartzose and felspathic granulitic schists, with frequent semi-pelitic beds. False bedding abundant and slump folding frequent.
Striped and Pelitic Group. (About 3,500' near Mallaig).	c. Upper Striped Schists. Banded series of finely laminated Psammitic, semi-pelitic and pelitic schists with thin layers and lenticles of pale garnetiferous calc-silicate rock centring psammitic ribs, and occasional thin dark fine grained magnetite-zoisite seams. b. Garnetiferous Pelitic Schists. Sometimes divisible into: 1. Garnetiferous pelitic schists. 11. striped schists with calc-silicate layers. 111. garnetiferous pelitic schists. a. Lower Striped Schists. Mainly laminated Schists as in c., but with psammitic laminae more developed, and with ribs of coarse psammitic schists. Calc-silicate bands absent.
Lower Psammitic Group. (About 3,500' near Mallaig).	c. Thinly bedded granulitic schists without false bedding (absent in N. Morar and Knoydart). b. Pink or grey felspathic granulitic schists often finely pebbly with pebbles up to 1" in diam., and with frequent semi-pelitic beds. False-bedding frequent, and slump folding occasionally seen. a. Thinly bedded granulitic Schists without false bedding (absent in S. Morar).

c) Coarse textured psammitic ribs are characteristic of the Lower Striped Schists.

d) The Upper Psammitic Group is much thicker than the Lower.

The succession in Morar was considered by Richey and Kennedy to have a regional significance, and the similarity of the succession to those established in Central and North Ross-shire (Peach and others 1912, 1913; Peach and Horne 1930) was emphasised. It was stated that "it is not improbable that the Morar stratigraphical sequence will be found to hold through-:out the Northern Highlands as a whole" (Richey and Kennedy 1939 p.37).

In their structural interpretation of Morar Richey and Kennedy divide the metamorphic rocks into two series, the Moine Series and the Sub-Moine Series, exposed in a N.-S. trending anticline which plunges northwards in Knoydart and southwards towards the Sound of Arisaig. In the "core" of the anticline and surrounded by an "envelope" of Moine rock lie the Sub-Moine Series, a complex assemblage of highly folded psammitic and pelitic rocks in which are interbanded hornblendic orthogneisses.

The Sub-Moine and Moine Series were said to show dist-:inctive tectonic, lithological and metamorphic features which enable them to be separated in the field and in the thin section. These distinguishing features are tabulated below.

Sub-Moine Series	Moine Series
The psammitic rocks show a cataclastic structure of the quartz mosaic, felspar is not abundant.	The psammitic rocks are felspathic with an even grained granoblastic texture.
They are commonly 'spotted' with patches of red haematite and have a high content of a pleochroic epidote.	The red haematite patches are absent, and a non-pleochroic epidote is locally abundant.
The micas in both the pelitic and psammitic rocks are orientated oblique to the bedding.	The micas of the psammitic and pelitic rocks are aligned parallel to the foliation, which defines the bedding.
Calc-silicate bands are absent.	Calc-silicate bands are present in some horizons of the Moine succession.
The rocks have suffered large scale recumbent folding.	Recumbent folding absent.
The rocks show evidence of retrogressive metamorphism.	The effects of the retrogressive metamorphism are absent.

Richey and Kennedy conclude that the Sub-Moine Series represents an older formation which had been folded and highly metamorphosed prior to the deposition of the Moine Series, and the junction between the two Series is an unconformity. The retrogressive metamorphism seen in the Sub-Moine Series is thought to be due to the effect of the later regional metamorphism of the Moine Series upon already highly metamorphosed Sub-Moine rock.

Richey and Kennedy's structural interpretation of Morar was questioned by A.G. MacGregor (1948), who stated that the features used by Richey and Kennedy to distinguish the rocks of the Sub-Moine Series were present in the rocks of the Moine Series, and features regarded as characteristic of the Moine Series could be found in the Sub-Moine Series. MacGregor however, pointed out that his evidence was not derived from the interior of the Sub-Moine core but only from the restricted area of the Moine and Sub-Moine boundary in the S.E. of Morar. MacGregor suggested that it would be "prudent to keep in view the possibility that all the metamorphic Sub-Moine sediments constituted a lower part of the Moine Series associated with hornblendic orthongneisses" (A.G. MacGregor 1948 pp. 274-275).

A re-examination of the structural evidence of Morar by W.Q. Kennedy (1955) modified the conclusions reached in the earlier paper (Richey & Kennedy 1939). The modified structural interpretation Kennedy considered to be applicable to the Loch Hourn-Glenelg area to the north of Morar, and Kennedy attempted to correlate the structure of Morar with that established west of the Moine Thrust Plane in the Sleat of Skye (Peach & others 1907; Bailey 1939).

In this later work Kennedy stated that the psammitic and pelitic rocks of the core of the Morar anticline, previously described as the Sub-Moine Series, were instead tectonic reduplications of the lower part of the Moine succession established in the "envelope" rocks of Morar. The junction between the rocks of the 'core' and the 'envelope' is not unconformity as suggested in the earlier paper, but a "plane of tectonic discordance", (Kennedy, 1955 p. 363).

The rocks of the 'core' identified as the Lower Striped and Lower Psammitic Groups of the Morar succession with tectonically incorporated hornblendic (Lewisian) gneisses, are folded into a series of broken recumbent folds which are consistently overturned to the west. The axial planes of these folds now have a variable dip, since they were refolded during the formation of the Morar anticline.

The rocks of the "envelope" of Morar show a stratigraphical succession and "occupy the flanks of the anticline and dip in normal succession at high angles to the east and west" (Kennedy 1955 p. 361). The Lower Psammitic Group of the Morar succession forms a completely closed outcrop around the rocks of the core, and Kennedy reports that at different localities the Lower Psammitic Group rests on different lithological units of the "core".

Kennedy states that the equivalent stratigraphical units of the "core" and "envelope" connect "to the west around the front of a broken recumbent anticline, or thrust" (Kennedy 1955 p. 366). The position of this thrust is difficult to place in the field, since any mechanical disturbance caused by the movement along this plane has been obliterated by the regional metamorphism which post-dated the movement. Kennedy states "It is probable nevertheless, that the discordance coincides very nearly with the original stratigraphical base of the Moine succession" (Kennedy 1955 p. 361).

The correlation of the psammitic and pelitic rocks of the core with those of the envelope, and the identification of the boundary between them as a thrust plane, led Kennedy to believe that the interpretation of Morar provides important evidence regarding the structure of that part of the Moine nappe which overlies that Moine Thrust Plane in Skye.

Kennedy's structural interpretation of Morar is that the rocks of the 'core' represent the Moine nappe, that is, the thrusted mass of rock that has been moved westwards along the Moine Thrust Plane, and consists of highly folded Moine rock with tectonically incorporated basement (Lewisian) gneisses. This is overlain by Moine rocks (the 'envelope' of the Morar anticline) showing a stratigraphical succession which has been thrust westwards over the rocks of the 'core' (the Moine Nappe) to form an Upper Moine, or Morar Nappe. Kennedy states that the Morar Nappe is of an earlier age than the Moine Nappe, the movement taking place before the regional metamorphism of the whole area.

If this structural interpretation of the Morar anticline is correct then it should be applicable to adjacent regions. Kennedy attempts to apply his structural interpretation of Morar to the Loch Hourn-Glenelg region further north. Kennedy, basing his conclusions on the mapping of the Loch Hourn-Glenelg area by C.T. Clough (Peach & Horne 1910), states that the major structure of the Loch Hourn area is the Loch Hourn anticline, which plunges southwards to Knoydart, and "opens northwards towards Loch Hourn and the great Lewisian inlier of Glenelg" (Kennedy 1954 p. 369). The Loch Hourn anticline Kennedy believes to consist of an "envelope of normal Moine Schists, which it shares in common with the Morar anticline to the south, and a complex core of Moine-like psammitic and pelitic schists of deformational facies, highly folded at deeper structural levels in Glenelg with basement gneisses of the Lewisian complex" (Kennedy 1955 p. 369).

Kennedy concludes that "The Morar and Loch Hourn anticlines are strictly homologous in that they share an envelope in common, occupy analogous structural positions along the strike and consist of similar rock types. Any structural interpretations must, therefore, be applicable to both folds" (Kennedy 1955, p. 369).

Kennedy attempts to correlate the structural history of the Morar-Glenelg region with that established to the west in the Sleat of Skye by C.T. Clough (Peach & others 1907) and E.B. Bailey (1939). From the work of Clough and Bailey, Kennedy concludes that the structural history of the Sleat of Skye shows two main phases of movement -

a) An earlier phase of recumbent folding of the Lewisian basement and the overlying Torridonian and Cambrian sediments.

b) A later phase of clean cut thrusting, (formation of Kishorn and Moine thrusts).

Kennedy believes that this structural history is similar to that he establishes in the Morar-Glenelg region, and he suggests the structural correlation as shown in Table II.

TABLE II

Tectonic Movements in the N.W. Caledonides	
Non-metamorphic (Skye) Sector	Moine crystalline Zone (Morar and Glenelg)
Earlier phase of movement	Earlier phase of movement
Recumbent folding of Lewisian, Torridonian and Cambrian rocks	Pre-crystalline folding of the (non-metamorphic) Moine sediments. Formation of Morar anticline and development of Morar Nappe
Main Orogeny in the North Western Caledonides	
Time Interval	Regional injection and regional metamorphism of Moine Series.
Post folding phase of transgressive clear-cut thrusting. Development of Kishorn thrusts and nappes.	Post crystalline thrusting of Moine Series. Development of Moine (and Tarskavaig - Balmacara) thrusts and nappes.
Post-orogenic movement in the N.W. Caledonides.	

Kennedy's conclusions on the structural history of Morar and adjacent regions aroused much interest (see discussion following Kennedy 1955). J. Sutton was not convinced by the evidence put forward for the Lewisian age of the hornblendic gneisses in Morar, or for the stratigraphical correlation between the Moine rocks of the 'core' and 'envelope', both factors essential to Kennedy's interpretation. R.M. Shackleton pointed out that the complex folding in the core may be intense disharmonic deformation, formed in the less competent beds underlying the massive Lower Psammitic Group, an extremely competent layer some 3,500' thick. G. Wilson suggested that the boundary between the 'core' and the 'envelope' may not be tectonic, but a "metamorphic transition from the envelope to the core rocks" (Kennedy 1955 p. 386).

It is interesting to note that Richey and Kennedy (1939) concluded that the rocks of the core and envelope had undergone different metamorphic histories, the core rocks showing evidence of retrograde metamorphism not seen in the rocks of the envelope. Kennedy (1955), however, concluded that there was "no metamorphic break at the base of the envelope, nor elsewhere within the structure"

(Kennedy 1955 p. 364) and considered that throughout Morar the rocks were in the garnet zone of metamorphism.

Kennedy (1949) studied the metamorphic history of the Moine rocks of W. Inverness-shire and N.W. Argyll (the area covered by the Geol.Survey Sheet 52 and Sheet 61), and separated the rocks into zones of progressive regional metamorphism, each zone being characterised by a distinctive mineral assemblage found in the calc-silicate granulites. The calc-silicate granulites occur as thin impersistent bands in the Moine succession and are rarely more that 2" wide. In the succession established in Morar (Richey & Kennedy 1939), the calc-silicate bands were found to be restricted to the Upper Psammitic Group and the Striped and Pelitic Group, but Kennedy points out that since these stratigraphical divisions comprise the major part of the Moine Schists in W. Inverness-shire and N.W. Argyll, the calc-silicate bands in the area have a wide distribution.

Kennedy states that the Moine Schists of W. Inverness-shire and N.W. Argyll "show a marked progressive increase in metamorphism when traced from the coastal districts eastwards towards the interior of the country" (Kennedy 1949 p.43). The mineralogical composition of the calc-silicate bands varies with this progressive easterly increase of metamorphism. Kennedy regards the calc-silicate bands as belonging to an iso-chemical series and the differences in mineralogical composition are due "directly to differences in metamorphic environment" (Kennedy 1949 p.49). Kennedy showed that the calc-silicate bands could be placed into four groups, or facies, each characterised by one of the following mineral assemblages -

GROUP I - garnet - zoisite - acid plagioclase - biotite
GROUP II - garnet - zoisite - acid plagioclase - hornblende
GROUP III - garnet - anorthite (bytownite) - horneblende
GROUP IV - garnet - anorthite (bytownite) - pyroxene.

Using these four groups of mineral assemblages, successive metamorphic zones can be established "each of which covers the pressure-temperature limits of one of the four mineral facies" (Kennedy 1949 p.50). From west to east Kennedy recognizes the following metamorphic zones in W.Inverness-shire and N.W. Argyll.

1) Zoisite - (calcite) - biotite zone
2) Zoisite zone
3) Anorthite - hornblende zone
4) Anorthite - pyroxene zone.

The boundaries of these metamorphic zones are distinct, the transition from one metamorphic zone to another taking place within a very short distance.

Kennedy states "In general the zonal boundaries conform with the regional strike of the rocks, but the metamorphic zones themselves are not symmetrically disposed with respect to major folds, such as the Morar anticline" (Kennedy 1949 p.52). Kennedy also points out "it is significant that the isograd which marks the zoisite-anorthite transition coincides almost exactly with the observed western limits of regional injection" (Kennedy 1949 p.52). The metamorphic zones are arranged parallel to the western limit of the zone of injection present in the area Kennedy studied, and Kennedy believes that the easterly increase in grade of metamorphism is due "to the thermal influence of regional injection" (Kennedy 1949 p.55). Within the zone of injection sillimanite is present in the pelitic rocks, and Kennedy finds that the sillimanite isograd of the pelitic rocks nearly conforms with the pyroxene isograd of the calc-silicate bands. Kennedy establishes a metamorphic correlation of the pelitic schists and calc-silicate bands, which he illustrates with the following diagram :-

Metamorphic Condition of Moine Schists	Uninjected		Injected	
Mineralogical Reaction in Calc-sil. Granulites	Zoisite → Anorthite Biotite→Hornblende		Horneblende→Pyrozene	
Zones based on Calc-silicate granulites	Zoisite-(Calcite-) Biotite	Zoisite Zone	Anorthite - Hornblende Zone	Anorthite Pyroxene Zone

The results of the work by R.St.J.Lambert (1958, 1959) in Morar support the suggestion put forward by G. Wilson (Kennedy 1955, in discussion) that the boundary between the rocks of the 'core' and 'envelope' of the Morar anticline is not tectonic but a metamorphic boundary.

Lambert (1958) concluded that the Moine Schists of Morar have been affected by a period of progressive metamorphism, followed by a period of retrogressive metamorphism which affected only the rocks of the 'core' (Kennedy's Moine Nappe). The boundary between the 'core' and 'envelope' of the Morar anticline is the outer limit of the affect of this retrogrssive metamorphism. Lambert does not accept Kennedy's interpretation that the 'core rocks are tectonic reduplications of the stratigraphical sequence of the 'envelope' and concludes that the Moine sedimentary succession in Morar consists of five lithological groups. The stratigraphical successions established by Kennedy and Lambert are compared in table III.

In the field Lambert regards the core-envelope boundary not as a mappable line, but as a zone of transition of variable width in which there is a gradual onset of the features used to distinguish the rocks of the core from those of the envelope. The passage from the 'envelope' to the 'core' rocks is marked by:-

1) Degree of macro-and micro contortion of foliation
2) Abundance and style of folding of quartz veins
3) Appearance of Haematite 'flecks' in the 'core' rocks.

A petrographic study of the psammitic and pelitic rocks of the 'envelope' of the Morar anticline indicates a progressive increase in the grade of metamorphism from west to east Morar. The psammitic rocks in west Morar contain albite felspar and iron-rich epidote, but to the east, near Arisaig House the felspar present in the rocks

TABLE III

KENNEDY 1955		LAMBERT 1958	
Upper Psammitic Group	Moine (envelope)	Upper Psammitic Group	Moine (envelope)
Striped and Pelitic Group		Upper Pelitic Group	
Lower Psammitic Group		Lower Psammitic Group	metamorphic boundary
Thrust			
Pelitic Group Lower Psammitic Group	Moine (core)	Lower Pelitic Group Central Psammitic Group	Moine (core)
Unconformity and Thrusts		Thrusts	
Orthogneisses	Lewisian	Orthogneisses and rare Paragneisses	Lewisian
		Thrusts	

is oligolcase (An_{25}) and the epidote is an iron-poor form. A similar mineral assemblage is found in the psammitic rocks in east Morar and Lambert reports "The metamorphic grade continues to rise eastwards." (Lambert 1958 p.187). The texture of the envelope psammitic rocks, when quartz is abundant, is tessellate, the quartz grains being of even size, regular shape and having smooth boundaries.

The rocks of the core do not show the evidence of this easterly increase in metamorphism. At the core-envelope boundary Lambert found that the main mineralogical changes that took place were,

1) Quartz texture gradually becomes sutured and inequigranular
2) Haematite appears as intergrowths.
3) The plagioclase becomes more albitic.
4) The epidote is the Fe-rich form.
5) Garnet, although rare in the core, is altered to a biotite-muscovite-epidote assemblage.

The mineralogical evidence indicates that the metamorphic state of the 'core' rocks corresponds with the low grade 'envelope' schists on the west coast of Morar.

Despite a detailed chemical and mineralogical study which illustrates the changes mentioned above, Lambert concludes it is "not possible to come to any firm conclusion about the detailed nature of the metamorphism responsible for the state of the core schists" (Lambert 1959 p. 583).

The core-envelope boundary is considered as the outer limit of a large scale retrogressive activity, and its formation due to "low diffusion rates and possibly also low reaction rates in the envelope in which the only widespread change is the chloritisation of garnet" (Lambert 1959, p.583).

Lambert attempts a correlation between the structural and metamorphic histories of the 'core' and 'envelope' of the Morar anticline, and tentatively proposes the following sequence of events:-

1. Initial folding, causing partial folding of the Morar dome.
2. Rise in temperature under high pressure conditions to produce the Biotite, Garnet zones of metamorphism.
3. After an unknown time interval localised folding took place with the recurrent development of the Morar

anticline so as to attain its present form. At the same time isotherms were concentric with the dome, the Biotite isograd assumed isothermal, lying outside the 'core' boundary. The core was thus in the Biotite zone, but retrogressive metamorphism was confined to the rocks of the "core".

C. SCOPE OF STUDY, AND OUTLINE OF RESULTS

The purpose of the present work has been to determine the structural history of the Moine rocks of the area by a detailed analysis of the large scale and small scale structural elements. In addition the petrography of the metamorphic rocks has been described and by study of the relationship between movement and mineral growth an attempt has been made to determine the relationship in time between metamorphism, migmatisation, and folding. The area mapped lies in, or near to, the "envelope" rocks of the eastern limb of the Morar anticline and tentative correlations with the structure and stratigraphy established in Morar by Richey and Kennedy (1939), and Kennedy (1955) have been proposed.

The study of the major and minor structures indicates that the area has suffered at least four periods of folding and the minor and major folds associated with each fold movement differ in style and orientation. The folds of the four fold periods have been described as :

1. isoclinal folds.
2. tight asymmetric folds with a N.N.E.-S.S.W. axial plane trend.
3. open asymmetric folds with a N.N.E.-S.S.W. axial plane trend.
4. open asymmetric folds having a N.W. - S.E. axial plane trend.

Over most of the area the rocks have been strongly migmatised, and the pelitic rocks have been transformed into oligoclase - biotite - gneisses and locally, granite gneiss. The migmatisation preceded and accompanied the second period of folding. During migmatisation the rocks were at sillimanite grade of metamorphism, but to the west of the area of migmatisation, the rocks were at garnet metamorphic grade. The petrographical evidence shows that the rocks have recrystallised several times during their movement history, the final recrystallisation taking place when movement had ceased.

II. GENERAL STRATIGRAPHY AND PETROGRAPHY OF THE METAMORPHIC ROCKS

A. INTRODUCTION

The metasedimentary rocks of the area are schists and gneisses of Moine age, and consist of psammitic, semi-pelitic, striped and banded and pelitic rocks with subordinate calc-silicate ribs. Within the Moine rocks igneous intrusions of different ages occur, and numerous dykes and sills have been mapped.

Throughout the area the Moine rocks have a vertical, or nearly vertical, disposition and as a result of folding show marked changes in trend. As will be discussed later, the rocks have been tightly folded and the original sedimentary succession has not been established. Sedimentary structures are rare and have only been found in the western part of the area.

The area lies at the western boundary of the zone of regional injection mapped in Moidart by the Geological Survey (J.E. Richey 1930). The results of the work carried out by the Geological Survey show that the injection complex extends from Sunart in the south, through Moidart and Morar, to Knoydart in the north (J.Phemister 1948). In Moidart the western boundary of the zone of migmatisation was considered to have a general N.N.E. - S.S.W. trend, extending from Lochailort in the north to Kinlochmoidart in the south.

Except in the western part of the area, all the rocks mapped show some effect of migmatisation, and to the east of the valley of Allt a Bhuiridh the Moine rocks are gneisses in appearance, and contain cross-cutting and concordant pegmatite sheets and lenses.

B. DISTRIBUTION OF ROCK TYPES

Psammitic, striped and banded, and pelitic rocks have been traced for several miles (map 1). These rocks are variable in width and sometimes the striped and banded and the pelitic rocks thin and disappear when traced along the strike. The stratigraphical thicknesses of the rocks are not known, for the structural evidence indicates that owing to tight folding and flowage of the rocks the original stratigraphical thicknesses have been repeated.

1. The Psammitic Rocks. The psammitic rocks are the most common rock type and are found in all parts of the area. The psammitic bands are commonly much thicker than the striped and banded and pelitic rocks and usually do not show rapid variation in thickness. The maximum development of psammitic rocks occurs to the west of Rois-Bheinn and An Stac, where a band of psammitic rock, at least 1½ miles

wide, extends from the western slopes of Rois-Bheinn and An Stac to the western boundary of the area mapped. These psammitic rocks show no obvious affects of migmatisation and it is in these rocks that the only examples of current bedding have been found. The opposed direction of younging of these structures indicates that the rock has been tightly folded and the true stratigraphical thickness has been repeated. Thin calc-silicate bands are found in these psammitic rocks but they are uncommon.

Psammitic rocks form a broad band, approximately half a mile wide, that can be traced from the northern boundary of the area, west of Arienskill, southwards to the eastern slopes of Rois-Bheinn. (Map 1). Like the psammitic rocks to the west, these rocks show no obvious affects of the regional injection, although on the north-eastern slopes of Rois-Bheinn discordant pegmatite veins, 10-15' thick, are found. Calc-silicate bands occur in these psammitic rocks.

East of the valley of Allt a Bhuiridh the psammitic rocks become more gneissic in appearance and the banding of the quartz-felspar and micaceous layers become distinct and more clearly defined. Quartz-felspar folia, usually aligned parallel to the foliation, are common, and cross-cutting quartz-felspar veins are also present. No sedimentary structures have been found in these psammitic rocks.

As a result of folding the psammitic rocks of Druim Comhnardaig, Druim Fiaclach and Diollaid Bheag trend in a general N.W. - S.E. direction, and in the latter place they show marked variations in thickness. To the south of Diollaid Bheag summit, psammitic bands have been traced westwards into Coire nan Gall, where they thin rapidly and disappear at Creag Dhearg. All the psammitic rocks in this area have been found to contain thin calc-silicate bands.

With increase in mica content along the bedding planes, the psammitic rocks grade into striped and banded rocks, and in some parts of the area the junction between these psammitic and striped and banded rocks is gradational over distances of 10 - 20 yards.

2. The Striped and Banded Rocks and the Pelitic Rocks.

The striped and banded and pelitic rocks are less common than the psammitic rocks and usually show greater variation in thickness.

The striped and banded rocks consist of thin bands of psammitic material (1-6" thick) that alternate with thin pelitic bands (1-3" thick). These striped and banded rocks occur in the central and eastern parts of the area, and they are well developed on Sgurr na Ba Glaise, to the north of Diollaid Bheag, on Sgurr na Paite and to the south of Garbh Leachd (Map 1). The striped and banded rocks have gradational junctions, and by increase in the proportion of either the thin psammitic or pelitic bands they grade into psammitic or pelitic rocks. The exact boundaries of the striped and banded rocks are therefore often difficult to map, and in some areas, particularly on Sgurr na Ba Glaise, the junctions of the striped and banded rocks are only arbitrary.

Calc-silicate ribs are quite common in the striped and banded rocks. They are always found in the thin psammitic bands and can be readily recognized by their distinctive weathered surface.

Pelitic rocks occur throughout the area and can usually be traced as continuous bands which vary considerably in thickness. All the pelitic rocks are coarsly banded gneisses, even in the west of the area, where the psammitic rocks show little affect of the "regional injection", the pelitic rocks have been strongly migmatised.

The pelitic rocks show great variation in thickness and sometimes they thin and disappear when traced along the direction of strike e.g., the pelitic band east of Arieniskill thins and dies out when traced in a S.S.W. direction into the valley of Allt a Bhuiridh.

A thick band of pelitic rock has been traced from the northern boundary of the area, east of Lochailort, in a S.S.W. direction to the southern slopes of Rois-Bheinn (Map 1). This pelitic band varies considerably in thickness, on An Stac it is approximately one mile wide, while at Glenshian it is only 500 yds. wide. Thin persistent psammitic bands 2-4' thick occur in this pelitic rock. One such psammitic band, approx. 70 yds. wide, has been traced from the southern slopes of Rois-Bheinn northwards to the northern face of An Stac, where it thins and dies out. (Map 1).

Pelitic horizons have been mapped on Sgurr na Ba Glaise and have been traced northwards through the valley of Allt a Bhuiridh to the southern slopes of Loch Eilt. (Map 1). In the valley of Allt a Bhuiridh the rocks are poorly exposed and the rock boundaries cannot be accurately mapped.

A strongly migmatised pelitic rock has been traced from Creag Dhearg in a S.S.W. direction to Druim Fiaclach, where it changes in trend to a N.E.-S.W. direction. On the Druim Fialcach ridge a psammitic band, some 150 yds. wide is present within the pelitic rock, which continues in a S.E. direction as two pelitic bands, each approximately 200 yds. wide. Three N.W.-S.E. trending pelitic bands have been mapped on Diollaid Bheag, and the structural evidence indicates that they are the same pelitic horizon that has been repeated by folding. By tracing the outcrop of these pelitic rocks the closures of the folds that cause the repeated sequence of rocks on Diollaid Bheag can be indentified. In this way the fold closures at Garbh Leachd and Druim Fiaclach have been recognized.

3. <u>Calc-Silicate Rocks.</u> The calc-silicate rocks are thin impersistent bands, 1-4" thick, which occur in the pelitic, striped and banded and psammitic rocks. Except in the psammitic rocks immediately to the south of Loch Eilt, they have been found in all the rocks of the area.

The calc-silicate bands are not common and have a sporadic distribution. In the pelitic rocks they are usually present as elongated, lens-shaped bodies aligned parallel to the foliation, and they may be tightly folded. The calc-silicate bands in the pelitic rocks are commonly found within thin, impersistent psammitic bands. In the psammitic rocks the calc-silicate bands are more persistent and can usually be traced for several yards in the direction of strike.

4. Hornblende Schist Bodies. The hornblende schist bodies occur as lens-shaped masses or angular blocks within the pelitic rocks (fig.2). Only two examples of hornblende schist bodies have been found in the striped and banded rocks and they have never been found in the psammitic rocks. They are present in the pelitic rocks in all parts of the area but they are not common. They usually occur as lens-shaped masses, approximately 1-4' wide which are elongated parallel to the foliation, and they are often highly folded. Angular, irregular blocks of variable size are also found. The hornblende schist bodies always have sharp junctions with the surrounding pelitic rocks and their schistosity remains parallel to the foliation. Only rarely are they seen to be traver-

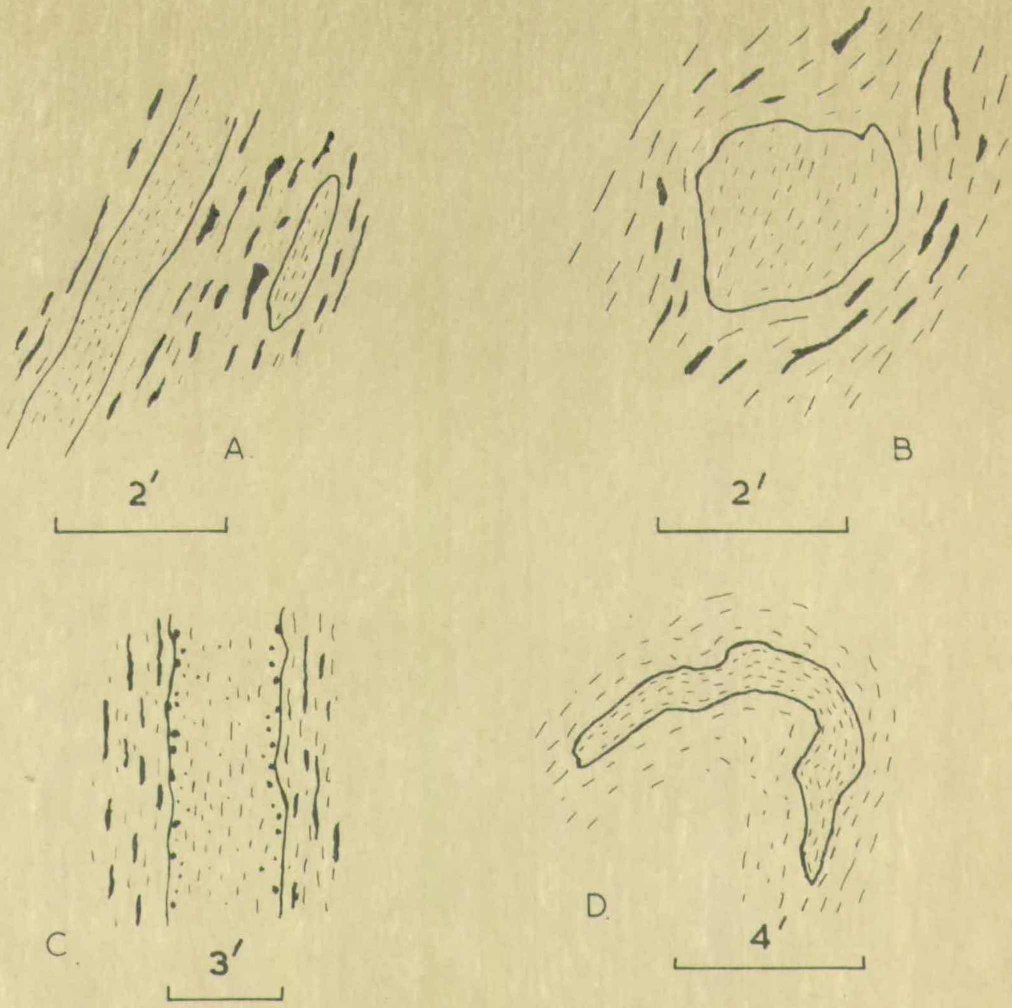


Fig. 2 Hornblende schist bodies in the pelitic gneisses

A. lens and sill-like bodies.

B. angular block which deflects the foliation.

C sill-like body with large garnets at contact to pelitic gneis

D refolded by third minor fold.

sed by thin quartz-felspar veins.

C. STRATIGRAPHICAL SUCCESSION

J.E. Richey and W.Q. Kennedy found that the Moine rocks of west Morar contain abundant, well preserved sedimentary structures which enable a stratigraphical succession to be established. The succession given by Richey and Kennedy divides the Moine rocks of west Morar into three main lithological units. (see pp.12-14).

3. Upper Psammitic Group

2. Striped and Pelitic Group

1. Lower Psammitic Group

In S. Morar, Richey and Kennedy traced the succession eastwards to the head of Loch nan Uamh (op.cit. 1939).

The psammitic rocks of the Ardnish penninsular, which are continuous with those to the west of Rois-Bheinn and An Stac, were correlated with the Upper Psammitic Group of Morar and in Moidart the Upper Psammitic Group could be traced from the head of Loch Ailort westwards for 4½ miles to east of Glenuig. (J.E. Richey 1938). The pelitic rocks of An Stac, immediately east of these psammitic rocks, were not correlated with the stratigraphical succession in Morar.

In the area mapped sedimentary structures are not common and are only found in the psammitic rocks west of Rois-Bheinn and An Stac that have been correlated with the Upper Psammitic Group of Morar. Examples of current bedding have been found some 300 yds. west of the junction with the pelitic rocks of An Stac (Grid.Ref.752802). These sedimentary structures young towards the pelitic rocks and, unless the rocks between the junctions to the pelitic rocks and the outcrop containing the sedimentary structures have been folded, indicate that the pelitic rocks are stratigraphically younger than the psammitic rocks and thus cannot be correlated with the Striped and Pelitic Group of the Morar succession.

The evidence of the sedimentary structures indicate that the stratigraphical succession of the Moine rocks in Morar and Moidart consists of four main lithological groups, the pelitic rocks of An Stac and Rois-Bheinn forming the youngest stratigraphical horizen of the succession. The following stratigraphical succession for the western part of the area may therefore be suggested :-

4. Rois-Bheinn Pelitic Group
3. Upper Psammitic Group
2. Striped and Pelitic Group
1. Lower Psammitic Group

The other examples of current bedding that have been found in the psammitic rocks west of An Stac young in the opposite direction and indicate that the rocks have been tightly folded (Map 1).

Sedimentary structures have not been found in the psammitic rocks east of An Stac and their age relationship with the Rois-Bheinn Pelitic Group cannot be established. Thin calc-silicate ribs however, have been found in these psammitic rocks, and Richey and Kennedy (1939) state that the presence of these ribs is indicative of the Upper Psammitic Group. This evidence may suggest that the psammitic rocks east of An Stac are stratigraphically older than the Rois-Bheinn Pelitic Group and can be correlated with the psammitic rocks in the western part of the area. It is interesting to note that all the psammitic rock bands east of An Stac and Rois-Bheinn contain calc-silicate ribs.

As will be discussed later, the structural evidence indicates that all the rocks of the area have been isoclinically folded, but the axial plane traces of the major isoclinal folds have not been recognized. It is probable that as a result of the isoclinal folding, the sedimentary succession has been repeated, but because of the lack of good stratigraphical marker horizons, it has not been possible to determine the position of the major isoclinal folds. The true sedimentary succession and original stratigraphical thicknesses cannot be established.

D. LITHOLOGY AND PETROGRAPHY OF THE METAMORPHIC ROCKS

All the Moine rocks have a banded appearance, due to the alternation of quartz-felspar and micaceous layers. The banded aspect of the rocks has been emphasized by migmatisation, for all the pelitic rocks are coarsely banded gneisses, and in areas that have suffered strong migmatisation the compositional banding of the psammitic rocks has become coarser and more clearly defined.

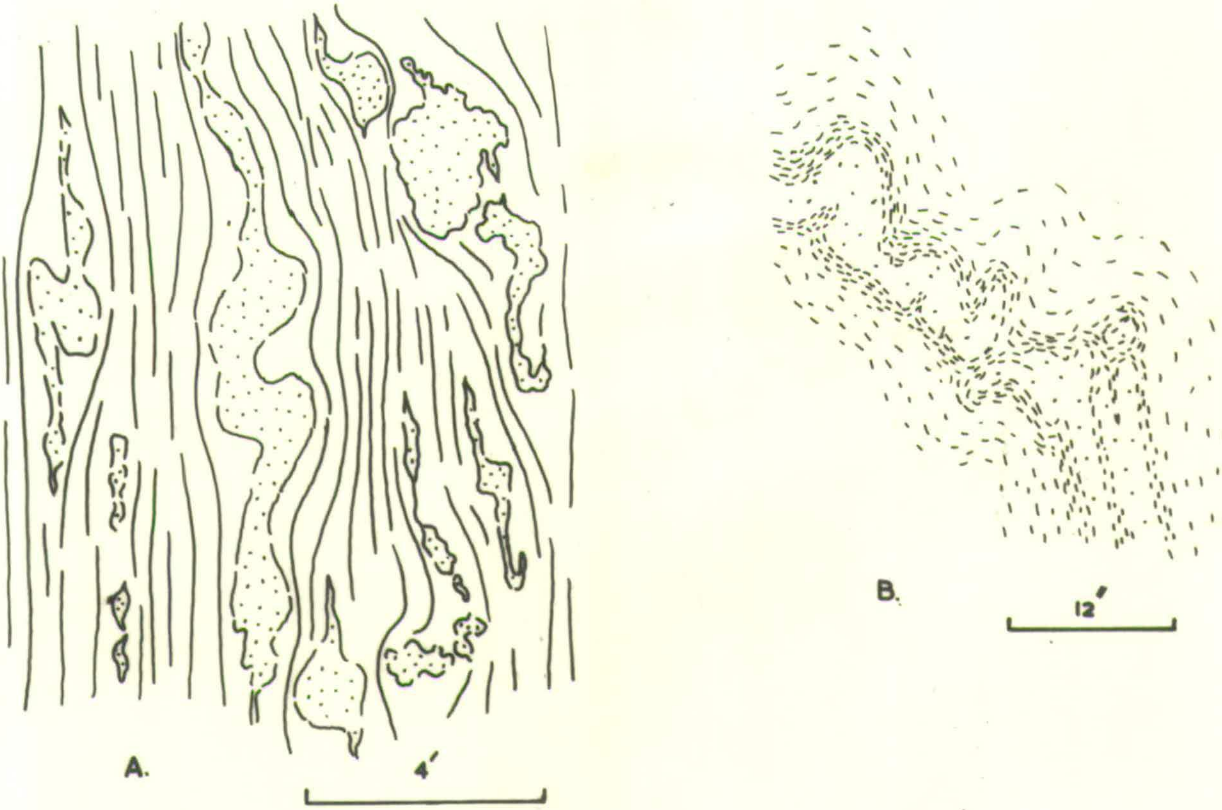
1. The Psammitic Rocks. The psammitic rocks are massive, sometimes flaggy, well banded medium-fine grained quartzo-felspathic rocks containing variable, but minor, amounts of mica. The banded appearance of the rocks is the result of variation in the amount of biotite in adjacent layers. On a fresh surface these psammitic rocks have a pale brown, grey, or blue colour, and the colour of the rock is an indication of the amount of biotite present.

Biotite is only a subordinate constituent in the pale brown rocks but is more common in the grey or blue coloured rocks, where occasional micaceous partings are found. Where the psammitic rocks have undergone strong migmatisation they are more coarsely banded and gneissic in appearance, and the junctions between the quartz-felspar and micaceous layers become more distinct. Quartz-felspar folia and lenses, aligned parallel to the foliation, are common (fig.3).

In the hand specimen quartz, felspar, biotite, muscovite can usually be readily recognized, and occasional pale pink macroscopic garnets are present.

In thin sections the psammitic rocks are seen to consist of a granoblastic aggregate of quartz and felspar, with subordinate mica and accessory epidote, garnet, sphene, apatite, zircon and iron ore. The quartz and felspars are approximately of equal size with rounded, smooth and distinct margins. The micas are dimensionally orientated and tend to be concentrated into thin impersistent layers. (plate VI).

<u>Quartz</u> is present as xenoblastic equidimensional crystals 0.5 - 1.0 m.m. in diameter. Sometimes the quartz exhibits a



A. Quartz - felspar folia in the psammitic rocks of Druim Comhnardaig.

B. Quartz-felspar folia, with biotite selvedges, in the pelitic rocks south of Glenshian.

FIG. 3.

rough dimensional orientation, the crystals being elongated parallel to the foliation. Undulose extinction is uncommon and generally evidence of strain in the quartz crystals is absent.

Plagioclase occurs as xenoblastic equidimensional crystals 0.5 - 1.2 m.m in size. It is equally abundant with quartz. Twinning on the albite law is common and determination of the symmetrical extinction angle indicates a basic oligolcase - acid andesine composition (An_{27} - An_{32}). The twin lamellae are narrow and sometimes disappear by the narrowing of one set of lamellae. The plagioclase is altered to secondary white mica and sometimes the degree of alteration is intense and the felspar crystals are cloudy in appearance, but in other sections alteration is restricted to the crystal edges and along the cleavage directions.

Orthoclase is the only potash felspar present, occuring as rounded equidimensional crystals 0.5 - 1.3 m.m. in size. Alteration of the orthoclase is much less intense than that of the plagioclase and often the orthoclase is clear and unaltered. The alteration product is sericite.

Myrmekite has been found in the psammitic rocks of Sgurr

Ba Glaise, Druim Fiaclach and Diollaid Bheag. It occurs as lobes and irregular shaped areas based on the plagioclase, with which it is in optical continuity, and projects into the potash felspar. The quartz tubules are usually arranged normal to the myrmekite - potash felspar boundary and are optically continuous.

Biotite is present in all thin sections and shows a strong dimensional orientation. The amount of biotite present is very variable, in some sections it is rare and present as small tubular crystals up to 0.3 m.m. in size, while in other sections it is common and occurs in thin impersistent layers. Biotites are generally of small size, from 0.1 - 0.5 m.m in length, with straight crystal boundaries, and bent crystals have not been seen. The biotites are strongly pleochroic in a dark chocolate brown colour, (X - pale yellow brown, Y.Z. - dark chocolate brown), but in the psammitic rocks from Creag Dhearg, Druim Fiaclach and Sgurr na Ba Glaise the biotite is pleochroic in a 'foxy' reddish-brown colour (X - pale yellow brown, Y.Z - reddish brown). "Foxy" brown biotites are present in the thin sections which also contain myrmekite. Zircon in-

:clusions are common, with well developed pleochroic haloes. Biotite nearly always shows alteration to pale green chlorite, which is usually developed along the cleavage traces or at the crystal edges of the biotites. In some sections the chloritisation has been complete. Sphene is often closely associated with the chlorite, occurring as hypidioblastic crystals 0.1 - 0.2 m.m. in size.

Muscovite is less common than biotite, with which it is closely associated to form mica-rich layers. Muscovite is often present along the cleavage traces of the biotites. Muscovite varies from 0.1 - 0.5 m.m. in size but in the psammitic rocks west of Creag Dhearg, on Druim Comhnardaig, Diollaid Bheag and Sgurr na Paite large porphyroblastic muscovites, 5.0 m.m. in diameter, are found. These porphyro:blasts have a random orientation and are found aligned at any angle to the foliation (plate XI).

Accessory minerals of the psammitic rocks are epidote, occasionally with orthite cores, sphene, apatite, pink garnet, zircon and iron ore. Garnets are uncommon, but in thin section they are spongy, hypidioblastic crystals up to 3.0 m.m. in size.

In thin section the coarsely crystalline quartzfelspar lenses that are common in the strongly migmatised rocks are seen to consist of quartz and plagioclase felspar. The quartz only occasionally shows slight undulose extinction and exhibits an intricate, sutured boundary with the felspar. Quartz 'blebs' are present in the felspar. The felspar has been identified as basic oligoclase (An 25-28) by determina:tion of the symmetrical extinction angle of the albite twin lamellae. The plagioclase crystals may show intense sericitisation, but the degree of alteration varies, and the sericitisation may be restricted to the crystal edges.

2. The Striped and Banded and the Pelitic Rocks

The striped and banded rocks are made up of alternating bands of thin psammitic and pelitic material. The psammitic bands tend to be thicker (1-6" thick) than the pelitic layers (1-3" thick) which weather away to form depressions between the psammitic bands and give the rocks a ribbed appearance. The striped and banded rocks have junctions that are gradational with the psammitic and pelitic rocks over dis:tances of 10-20 yards. The petrography of the striped and banded rocks is similar to that given for the psammitic and pelitic rocks. The thin psammitic bands are mineralogically similar to the psammitic rocks, as are the thin pelitic bands to the pelitic rocks.

Throughout the area the pelitic rocks are coarsely banded gneisses, and in the field and thin section the pelitic gneisses have been divided into two types :

a) Oligoclase - Biotite - Gneiss

b) Granite Gneiss.

a) Oligoclase - Biotite - Gneiss is the most common type of injection gneiss in the area and is a coarsely banded rock in which the quartz-felspar material is concentrated into folia that alternate with highly micaceous layers. (plate XII). The quartz-felspar folia, which are often coarsely crystalline, vary in thickness and locally show swellings and constrictions to form lens-shaped structures, elongated parallel to the foliation (plate V). These lens-shaped structures often show mica-rich selvedges (fig.3 Quartz-felspar veins and lenses, often coarsely crystalline, may occur within the oligoclase-biotite-gneiss and are nearly always elongated parallel to the foliation.

There is great local variation (i.e. on the scale of a single outcrop) in the amount of quartz-felspar material in the oligoclase-biotite-gneiss. The quartz-felspar folia may be sufficiently abundant to form the bulk of the rock and the micaceous layers become thin and subordinate, or the quartz-felspar folia may be widely separated and the micaceous layers predominate. No regional variation in the degree of migmatisation can be detected in the area.

The gneissic banding of the oligoclase - biotite - gneiss is often highly folded (plate V), and in many parts of the area, particularly on Druim Fiaclach, An Stac and Rois Bheinn, the micas have been folded into small-scale folds to form a mica crinkle. (fig. 4.).

In the hand specimen the oligoclase-biotite-gneiss is a hard rock, not easily splitting, in which quartz, felspar, biotite, muscovite and pink garnets can be readily identified. Idioblastic black tourmaline crystals are also very common, the tourmaline generally lying in the foliation plane, but having no dimensional orientation. Tourmaline crystals that lie oblique to the foliation have also been seen. Silli:manite is locally abundant, and has been found on An Stac, Creag Dhearg and Garbh Leachd and is very abundant in the pelitic rocks of Sgurr na Ba Glaise. On the weathered surface of the pelitic rocks the sillimanite stands out as separated "knots", approximately ¼" long, although larger examples up to 2" in length have been seen.

In thin section the oligoclase - biotite - gneiss is seen to consist of quartz, felspar, abundant biotite,

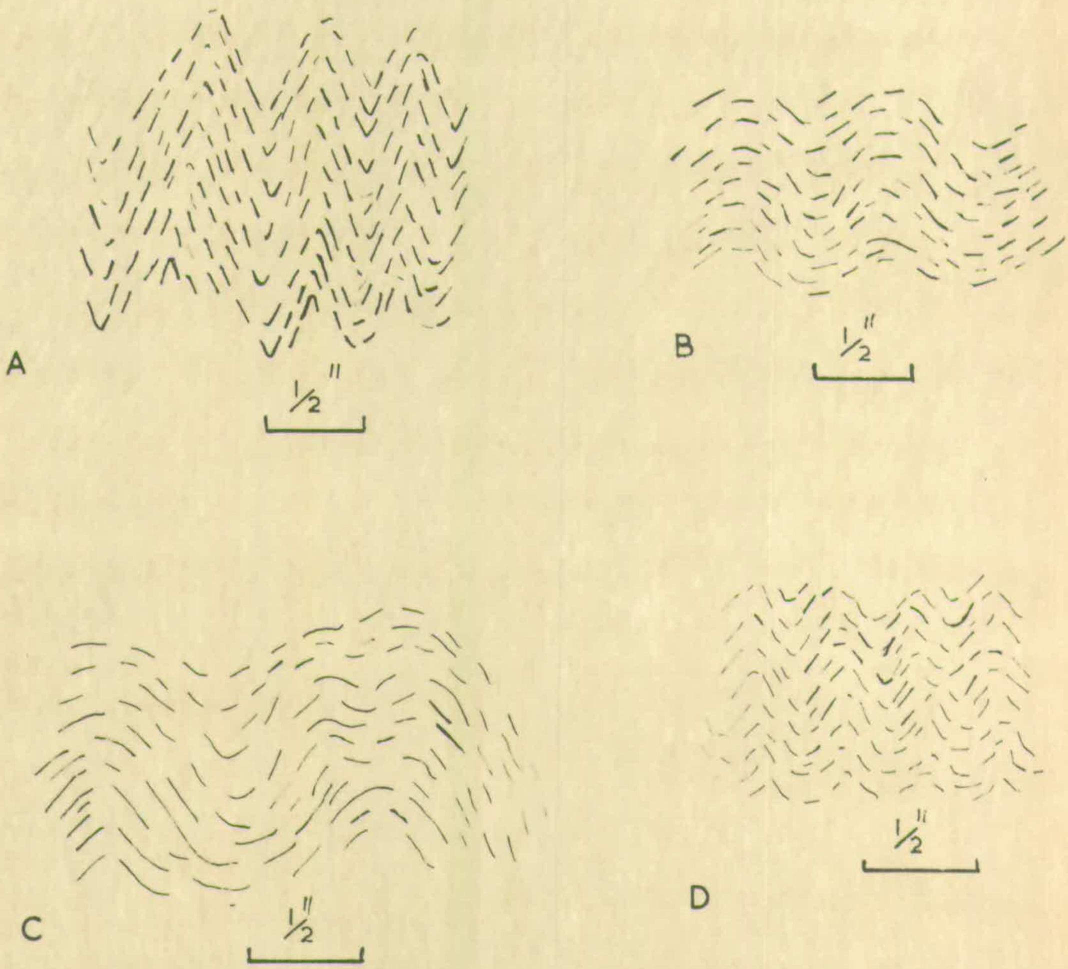


FIG. 4. Profiles of Mica Crinkling

A. second mica crinkle

B, D. third mica crinkle

C. fourth mica crinkle

muscovite and garnet, with accessory sphene, apatite and iron ore (Plate VII).

Quartz is always present as equidimensional xenoblastic crystals up to 1.0 m.m. in diam. The crystals have smooth distinct margins and exhibit rounded, lobed junctions with the felspars. The quartz sometimes shows undulose ex:tinction, but in many sections the quartz is clear and un:strained.

Plagioclase is the only felspar present and occurs as equidimensional crystals up to 1.5 m.m. in size. Twinning on the albite law is common, the twin lamellae generally being narrow, and determination of the extinction angle indicates a basic oligoclase composition (An_{27}-An_{32}). Quartz 'blebbing' is common in the plagioclase crystals. In all sections the plagioclase shows alteration to sericite, the alteration may be confined to the crystal edges and along the cleavage traces, but occasionally the sericitisation is intense and the plagioclase crystals have a cloudy appearance.

Biotite is very common and occurs as tabular crystals up to 1.5 m.m. in length. The crystals are dimensionally orientated and are concentrated into discrete layers. The biotites have straight margins, and bent crystals have not been seen. They are strongly pleochroic in a 'foxy' reddish-brown colour. (X - pale straw yellow, X,Z - reddish brown). The biotites are commonly altered to pale green chlorite, which is developed on the crystal edges or along the cleavage traces. Idioblastic apatite and irregular shaped masses of iron ore are present as inclusions, zircon is also present, with well developed pleochoric haloes.

The biotite crystals are often orientated into small scale folds ½ - ¾" wide. The biotites are not bent, and the small folds are formed by crystals which have straight crystal edges but different orientations.

Muscovite is less common than biotite, with which it is associated to form mica-rich bands. The muscovites have a maximum length of approximately 1.5 m.m. but a wide variation in crystal size within a single section is common. The muscovite crystals are often intergrown with the biotites and may be developed along the cleavage traces of the biotite crystals. Worm-like inclusion of iron ore are common in the muscovites, aligned parallel to the cleavage traces.

Garnet is present in most sections as hypidioblastic equidimensional crystals from 1.0 - 2.0 m.m. in diam. Most garnets contain inclusions of quartz, felspar, biotite and in some sections the crystals are spongy in appearance and have corroded, embayed margins. The foliation, as defined by the mica-rich layers, is deflected round the garnets, but the micas have not been bent (plate VII).

Sillimanite is locally a common constituent of the oligoclase - biotite - gneiss. (plate VII). Sillimanite may occur as small patches of needle-like crystals present as inclusions in the felspars and muscovites, or it may be present as a felted mass of crystals which wrap round the quartz and felspar. The sillimanite - muscovite knots common in the oligoclase - biotite - gneisses of Rois-Bheinn and Sgurr na Ba Glaise, consist of muscovite crystals, up to 1.0 m.m. in size, showing no dimensional orientation. Within these crystals thick felt-like masses of sillimanite occur (plate XI). Occasional rounded garnets, up to 1.5 m.m. in size, are present and are sometimes surrounded by a felted mass of sillimanite approximately 0.5 m.m. thick. Sillimanite "bushels" often penetrate into the garnets.

Tourmaline is quite common in the oligoclase-biotite-gneiss but has rarely been seen in thin section. In the hand specimen the tourmaline is black in colour and varies from ¼" - 1" in length. Larger tourmaline crystals are often present in the quartz-felspar lenses found in the gneisses where they may be 1" wide and over 2" long.

Staurolite has only been found in one section, from the oligoclase-biotite-gneiss of Rois-Bheinn. It occurs as hyp-idioblastic crystals o.3-o.5 m.m. in size and is included in an aggregate of muscovite crystals.

Graphite has been found only in two exposures of oligoclase-biotite-gneiss. A pod of graphite 9" long and with a maximum width of 3 - 4" is present in the pelitic gneiss on the north face of An Stac. The junction of the graphite pod, which is elongated parallel to the foliation of the rock, is sharp, and the graphite is rimmed by a thin layer of brown coloured quartz. Graphite has also been identified in the oligoclase-biotite-gneiss on the south facing slope of Sgurr na Ba Glaise, where it occurs as thin, separated lenses about 1" long and less than ¼" wide.

The quartz-felspar sheats and lenses present in the oligoclase-biotite-gneiss are petrographically similar to the quartz-felspar folia of the gneiss. They consist of coarsely crystalline quartz and felspar which vary from 1.0 - 3.0 m.m. in size. The quartz crystals exhibit smooth, rounded boundaries with the felspars. The felspar crystals are basic oligoclase in composition (An_{27} - An_{30}) and are often strongly altered to sericite. Quartz 'blebs' are common in the felspar crystals.

b) The Granite Gneiss is only of local occurence, it is found within the oligoclase-biotite-gneiss on Creag Dhearg, on the north face of Druim Fiaclach, and on Garbh Leachd. (Map 1). The granite gneiss is always present within the oligoclase-biotite-gneiss and the junction between the two gneisses in gradational over 6-10', the rocks passing gradually into each other both along and across the strike. Patches of oligoclase-biotite-gneiss, which vary in shape and size, are found within the granite gneiss.

A belt of granite gneiss, some 100 yds. wide, has been traced from Creag Dhearg to the northern slopes of Druim Fiaclach. (Map 1). Irregularly shaped patches of granite gneiss also occur in the oligoclase-biotite-gneiss of Garbh

Leachd, and the structural evidence indicates that these granite gneiss patches are found within the same oligoclase-biotite-gneiss as the granite gneiss of Druim Fiaclach and Creag Dhearg.

The granite gneiss is a coarsely crystalline, well banded gneiss in which the quartz-felspar material forms the bulk of the rock. The quartz-felspar layers usually maintain a more constant thickness than the quartz-felspar folia of the oligoclase-biotite-gneiss (plate XII), and individual layers can be traced through distances of several feet (i.e. within a single outcrop). The intervening micaceous layers are thin, but persistent, and all the granite gneiss mapped shows a well developed foliation, parallel to the foliation of the adjacent oligoclase-biotite-gneiss.

The quartz felspar layers may pass into quartz-felspar lenses or pods, which may be up to 6" in length and about 3" wide, and elongated parallel to the foliation. In thin section the granite gneiss is made up of abundant quartz and felspar, with biotite, muscovite, garnet and accessory minerals apatite, sphene and iron ore. (plate VII)

Quartz ranges in size from 0.2 - 1.0 m.m. and occurs as equidimensional crystals that have rounded, smooth boundaries. That quartz crystals may exhibit undulose extinction. Sometimes the quartz is concentrated into lens-shaped areas, made up of several crystals, which are elongated parallel to the foliation. Quartz blebs are common in the felspar crystals.

Plagioclase is present as equidimensional crystals up to 2.0 m.m. in size. Albite twinning is common and determination of the extinction angle indicates a basic oligoclase composition (An_{25-28}). In some sections the plagioclase shows only slight sericitisation, the alteration being confined to the crystal edges, but in other sections the sericitisation is intense. Clear rims to the plagioclase crystals, less than 0.1 m.m. thick are sometimes present. It is not possible to determine the composition of the felspar of the clear rims accurately but it has R.I.s that are lower than the main crystal.

Potash felspar is common and occurs as rounded, equidimensional crystals which vary from 0.5 - 1.5 m.m. in size. Microcline is common, in which the microcline "grating" may be well developed. Untwinned potash felspar is also present and may occur with the microcline.

The potash felspars show only slight alteration to secondary mica.

Perthite is common, and is usually vein perthite.

Antiperthite is common, the oligoclase crystals containing small irregular areas of unaltered potash felspar that are optically continuous.

Myrmekite is common, as lobe shaped areas situated on the plagioclase with which it is in optical continuity. The myrmekite protrudes into the potash felspar and the quartz tubules of the myrmekite are arranged perpendicular to the myrmekite - potash felspar boundary.

Biotite is present in mica-rich layers and is dimension:ally orientated. The crystals range in size from 0.3 - 0.6 m.m. It is strongly pleochroic in a green-brown colour (X - pale brown, Y, Z - greenish chocolate brown). Zircon is present as inclusions, with well developed pleochroic haloes, and inclusions of small idioblastic crystals of apatite are found. The biotite crystals show slight alteration to pale green chlorite, which is developed along the cleavage traces or crystal boundaries of the biotites.

Muscovite is rare in the granite gneiss. It is associated with the biotites, and crystals up to 1.0 m.m. in size are found.

Garnet is uncommon and occurs as small, irregularly shaped crystals up to 0.5 m.m. in size. The garnets are spongy in appearance, and contain abundant inclusions of quartz and felspar.

The accessory minerals are not abundant. Apatite is present as idioblastic crystals 0.1 - 0.2 m.m. in size which usually occur as inclusions in the biotite crystals. Irregular masses of iron ore, approximately 0.1 m.m. in size are found in the biotite rich layers. Sphene is occasionally present.

Numerous pegmatite veins occur throughout most of the area and are mineralogically similar to the granite gneiss. The pegmatite veins may be either concordant or discordant in habit with well defined, sharp margins. Pegmatite veins are found throughout the area, and they tend to be more common in the psammitic rocks. The largest development of pegmatite is found on Sgurr na Paite, where a thick mass of pegmatite, some 300' wide, trends in a general N.E. - S.W. direction, parallel to the trend of the foliation in that area. Usually the pegmatite veins are approximately

3 - 10' wide and they thin and disappear when traced along their length. Pegmatites are particularly common on Diollaid Bheag, to the north of Creag Dhearg, and on the north eastern slopes of Rois-Bheinn.

The pegmatites consist of large potash felspar and plagioclase crystals ½ - 3" in size, anhedral quartz, biotite, and muscovite crystals ½ - 2" in diameter. Muscovite crystals up to 6" in length have been found. Occasional pink garnets are present.

The potash felspar is commonly orthoclase and the plagioclase is oligoclase in composition ($An_{25} - An_{28}$). All the felspars show sericitisation, which may be intense, and secondary micas up to 0.1 m.m. in length are present.

The micas of the pegmatites are not dimensionally oriented, and muscovite tends to be more common than biotite.

3. The Calc-Silicate Rocks

The thin calc-silicate bands are uncommon, but they occur in the psammitic, striped and banded and pelitic rocks throughout nearly the whole of the area (cf. Richey and Kennedy, 1939). In the pelitic rocks they are easily recognizable as thin impersistent bands with sharp, distinct junctions. In the psammitic rocks the calc-silicate bands have a distinctive weathered surface, having prominent margins and less resistant weathered-away interiors.

On a fresh surface the calc-silicate bands are pale coloured medium to fine-grained rocks containing numerous small pink garnets and with a streaky appearance due to the parallelism of the dark minerals. The mineralogical composition of the calc-silicate bands is variable, in thin section they are seen to consist of quartz, felspar and garnet, with variable amounts of zoisite, hornblende and clinopyroxene. The common accessory minerals are apatite, iron ore and occasional biotite and muscovite (plates IX,X).

The quartz and felspar crystals form a granoblastic texture with smooth rounded margins, in which the dark minerals and zoisite and garnet have a ubiquitous distri:bution.

Quartz is usually the most abundant constituent and occurs as xenoblastic equidimensional crystals 0.1 - 1.2 m.m. in size. Quartz-rich bands, elongated parallel to the foliation, are sometimes present. The quartz may exhibit undulose extinction. Quartz "blebs" occur within the felspar crystals.

Plagioclase is the only felspar present in the calc-:silicates, and occurs as rounded crystals 0.3 - 0.9 m.m. in size. Twinning on the albite law is common. The composition of the plagioclase varies, in most sections it is basic labradorite (An_{63} - An_{70}), but the calc-silicate bands on the southern shore of Loch Ailort, in the N.W. part of the area mapped, contain plagioclase of acid andesine composition (An_{33}). In all sections the plagioclase shows sericitisation, the degree of alteration often being intense, and secondary micas up to 0.1 m.m. in length have been formed.

Zoisite is common in many sections, occurring as equi-:dimensional crystals up to 0.5 m.m. in size. In all sections the zoisite shows anamalous deep blue inter-:ference colours. Zoisite often shows an intricate relationship with the plagioclase, and thin veinlets of zoisite are seen to penetrate the felspar crystals (plate X). In extreme cases the plagioclase crystals become fragmental, surrounded and penetrated by zoisite.

The boundaries between the zoisite and plagioclase always remain sharp and distinct.

Hornblende is present in most sections, occurring as irregularly shaped crystals 0.2 - 0.6 m.m. in size. The crystals are strongly pleochroic in green (X - very pale green, Y - pale yellow green, Z - olive green). Quartz, zoisite commonly occur as inclusions in the hornblende. The hornblende crystals show alteration topale green chlorite, the alteration is sometimes intense and only small irregularly shaped shreds of hornblende remain, surrounded by a rim of chlorite.

Garnet is present in all sections as spongy crystals up to 4.0 m.m. in size. The inclusions may become so numerous that the garnet is reduced to isolated fragments and the original crystal shape is lost.

Clinopyroxene ($2v = 57 - 60^{\circ}$; $-c \wedge Z = 48^{\circ}$) is present in some sections as colourless crystals 0.1 - 0.3 m.m. in size. The pyroxene is often closely associated with the hornblende and may be present within, or at the edges of, hornblende crystals. In many sections the clinopyroxene shows alteration to a fibrous actinolitic hornblende which is faintly pleochroic in a green colour

(X - pale green, Y, Z - dark green).

Biotite is rare, and it only occurs in the calc-silicate bands that contain acid plagioclase and zoisite. The biotite crystals vary in length from 0.1 - 0.5 m.m. and are strongly pleochroic in a greenish brown colour (X - pale yellow brown, Y, Z - greenish-brown). The biotite crystals show alteration to pale green chlorite, and some:times complete chlorisation of the biotite has taken place.

The accessory minerals include ubiquitous idioblastic sphene, apatite, and small irregularly shaped masses of iron ore.

Metamorphic Zones based on the Mineral assemblages in the calc-silicate rocks

W. Q. Kennedy (1949) divided the Moine rocks of West Inverness-shire and Argyllshire into zones of progress:ive regional metamorphism, each zone being characterised by distinctive mineral assemblages within the calc-silicate rocks (see pp24-27). Kennedy showed that the calc-silicates could be placed into four sub-groups that contained the following mineral assemblages :

I. garnet - zoisite - acid plagioclase - biotite

II. garnet - zoisite - acid plagioclase - hornblende

III. garnet - anorthite (bytownite) - hornblende

IV. garnet - anorthite (bytownite) - pyroxene.

Using these mineral assemblages Kennedy recognized four metamorphic zones in W. Inverness-shire and Argyllshire and he established a metamorphic correlation between the calc-silicate rocks and the pelitic rocks :-

Zones based on Calc-silicate Rocks	Zoisite Biotite Zone	Zoisite Zone	Anorthite Hornblende Zone	Anorthite Pyroxene Zone
Equivalent Zones in normal Pelitic Schists	Garnet Zone		Kyanite Zone	Sillimanit Zone

In the area mapped only three of Kennedy's sub-groups have been recognised.

a. garnet-zoisite-acid plagioclase-hornblende (Sub-Group
b. garnet-anorthite (bytownite)-hornblende (Sub-Group I
c. garnet-anorthite (bytownite)-pyroxene (Sub-Group I

Acid plagioclase (An_{33}) occurs only in the calc-:silicate bands found in the psammitic rocks west of An Stac, where it occurs with garnet, biotite, zoisite and hornblende (Plate IX). The hornblende is closely associ-:ated with the biotite crystals. This mineral assemblage suggests that these rocks lie within the Zoisite metamorphic zone of the calc-silicate rocks.

Elsewhere in the area the plagioclase in the calc-:silicate bands is labradorite - bytownite in composition (An_{70}). The transition from acid plagioclase to basic plagioclase appears to take place abruptly, for the calc-:siliate bands of An Stac and Rois-Bheinn contain basic labradorite. This evidence supports the observation made by Kennedy that there is no gradual and progressive increase in the anorthite content of the felspars but rather there is an abrupt change from acid to basic plagioclase (Kennedy 1949 p. 48).

Zoisite is common in the calc-silicate rocks that contain basic plagioclase, and is found in the calc-:silicate rocks in which hornblende or pyroxene may be abundant. This evidence suggests that zoisite persists to a higher grade of metamorphism than Kennedy indicated. (fig. 6).

All the calc-silicate rocks examined contain horn-:blende, and throughout most of the area the calc-silicate rocks have a garnet - hornblende - basic plagioclase - zoisite mineral assemblage. With the exception of zoisite these calc-silicates have the mineral assemblage of Kennedy's Sub-Group III (the anorthite - hornblende zone).

Clinopyroxene is present in the calc-silicate rocks of Sgurr na Ba Glaise, Druim Fiaclach, Diollaid Bheag and Garbh Leachd. Locally it is abundant (e.g. Sgurr na Ba Glaise) and may show alteration to an actinolitic hornblende. The minerals that occur with the clino-:pyroxene are basic plagioclase (labradorite An_{70}), hornblende, which may be abundant, garnet and zoisite. The garnet - lime plagioclase - clinopyroxene mineral assemblage is identical to that of Kennedy's sub-group IV (the anorthite - pyroxene zone).

The mineral assemblages of the calc-silicate rocks suggest an increase in grade of metamorphism in a general W. - E. direction. The mineralogical composition of the calc-silicate bands present in the unmigmatised psammitic rocks west of An Stac and Rois-Bheinn suggest that they belong to the Zoisite metamorphic zone, while the calc-:silicates that occur within the zone of migmatisation fall into either the anorthite - hornblende or anorthite - pyroxene zones of metamorphism (fig. 5). The western limit of the anorthite - hornblende metamporphic zone

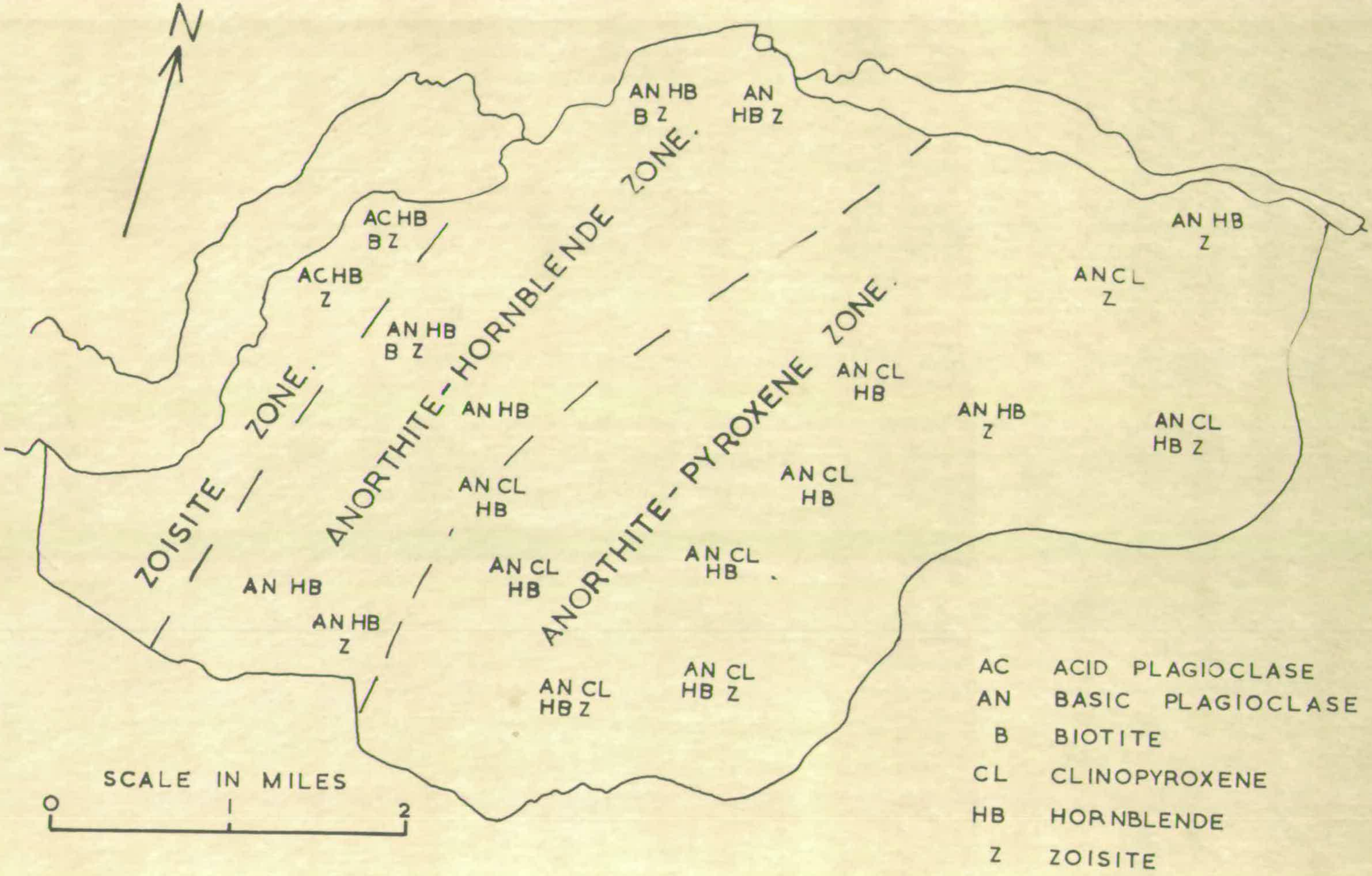


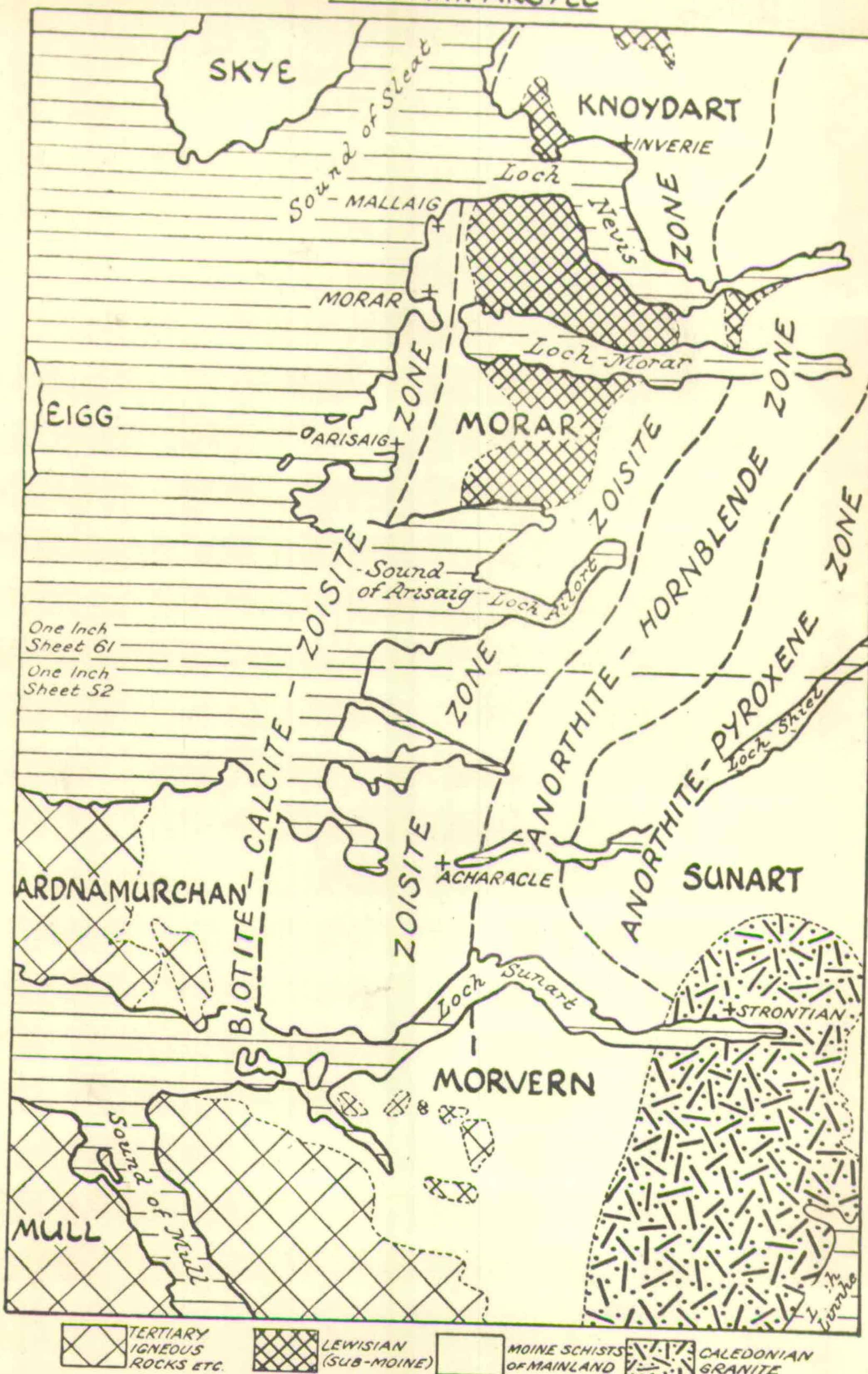
FIG. 5. METAMORPHIC ZONES BASED ON THE MINERAL ASSEMBLAGES OF THE CALC-SILICATE ROCKS

appears to conform approximately with the western limit of migmatisation. The presence of a garnet - anorthite (bytownite) - pyroxene mineral assemblage in the calc-:silicate rocks of Sgurr na Ba Glaise indicates that the western limit of the anorthite - pyroxene metamorphic zone, in that area at least, lies but a short distance to the east of the western boundary of migmatisation. In Moidart the anorthite-pyroxene zone of metamorphism appears to extend further west than suggested by Kennedy (Fig. 6).

The evidence indicates that at the western bounday of migmatisation there is a rapid increase in metamorphic grade from the zoisite zone to the anorthite-pyroxene zone.

In the pelitic rocks of the area, sillimanite is of widespread occurrence, it being found in all the oligoclase-:biotite-gneiss horizons (fig. 7). It is suggested that the sillimanite isograd is parallel to the western boundary of the migmatisation. Sillimanite has a much wider distribution than the anorthite-pyroxene metamorphic zone of the calc-silicate rocks, and there does not appear to be a strict correlation between the sillimanite metamorphic zone of the pelitic rocks and the anorthite-pyroxene

MAP OF METAMORPHIC ZONES IN WESTERN INVERNESS-SHIRE AND N.W. ARGYLL



from W. Q. KENNEDY 1949

FIG. 6

metamorphic zone of the calc-silicate bands (cf. figs. 5, 7).

From the evidence presented above, it is concluded that the metamorphic zones based on the mineral assemblages of the calc-silicate rocks indicate that within the area of migmatisation the metamorphic grade never falls below the anorthite-hornblende zone, regarded by Kennedy as equivalent to the Kyanite zone of the pelitic rocks. The anorthite-pyroxene zone, equivalent to the sillimanite zone of the pelitic rocks, covers a much wider area of Moidart than Kennedy suggested, and extends almost to the western boundary of migmatisation.

In most of the calc-silicate rocks examined, there is evidence of retrograde metamorphism, in that the hornblendes, and sometimes the garnets, show alteration to pale green chlorite, and the clinopyroxene is altering to an actinolitic hornblende. As will be described later, the calc-silicate rocks have undergone recrystall-:isation after the formation of the mineral assemblages described above, and during this later period of re-:crystallisation some retrogressive activity may have taken place. The age relationship between the development

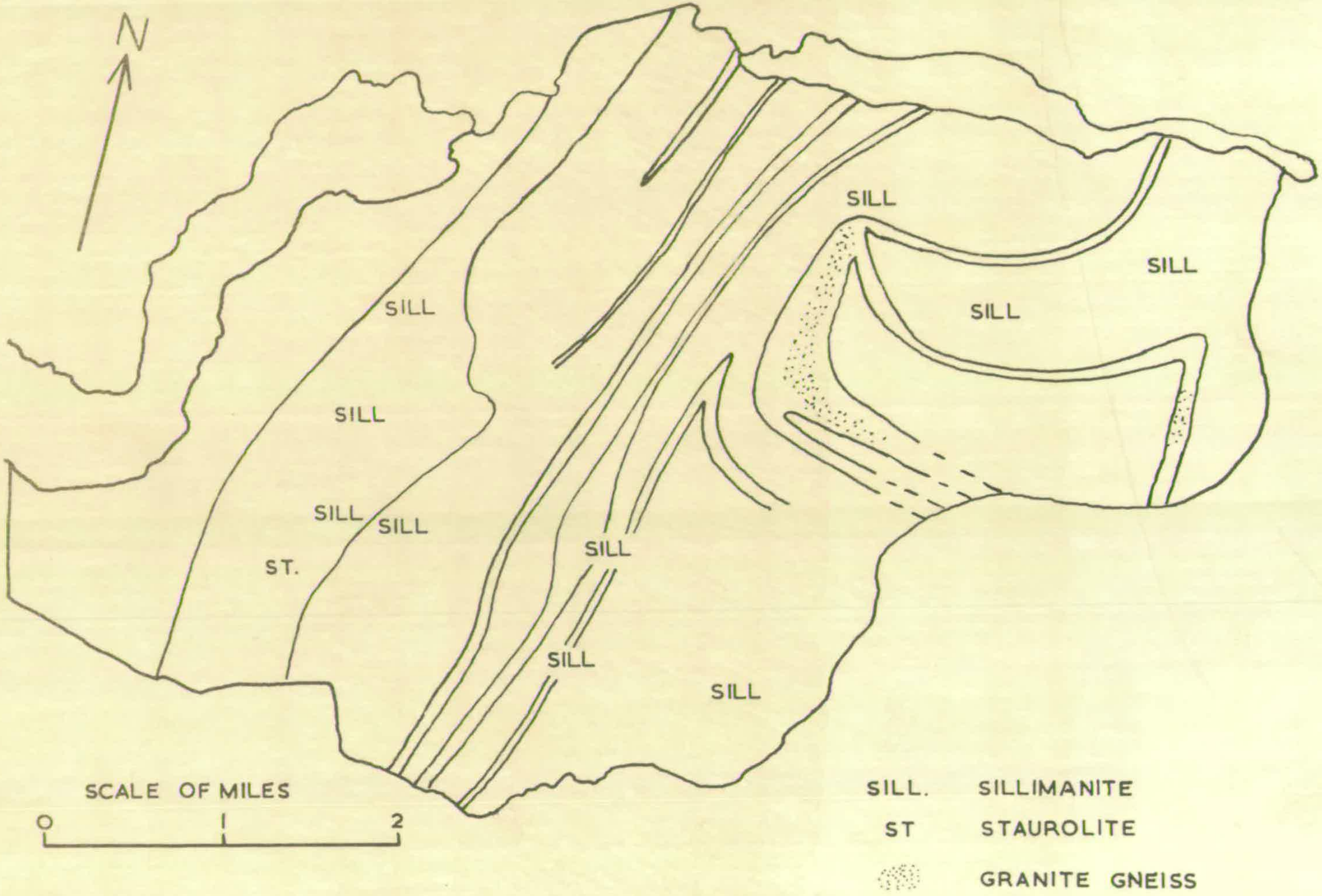


FIG 7. THE LOCATION AND DISTRIBUTION OF SILLIMANITE AND THE GRANITE GNEISS

of the mineral assemblages of the calc-silicate rocks and the periods of folding is discussed in Section IV.

4. HORNBLENDE SCHIST MASSES

Hornblende Schists, which usually occur as small lenses lying to and often folded with, the foliation and as irregularly shaped masses (some 2' - 3' in diameter) are common in the pelitic rocks, and have a wide distribu:tion. The largest hornblende schist body found is some 10' wide and 15' in length, but the hornblende schist usually occurs in smaller masses which vary in shape. (fig. 2).

Hornblende schist blocks are common both in the oligoclase-biotite-gneiss and granite gneiss and have sharp, distinct junctions. Only rarely have thin discor:dant quartz-oligoclase felspar veins been seen to cut across the hornblende schists.

In the hand specimen the hornblende schist is a black coloured rock in which the dimensionally oriented hornblende crystals are readily recognizable. Many of the hornblende schist bodies are highly garnetiferous, the garnet occurring as large, rounded pink crystals up to ¼" in diameter. In some hornblende schists garnet is absent. Within the hornblende schist bodies the garnets may vary in size, a good example of this is found in a hornblende schist lens present in the pelitic rocks east of Glenshian, where at the junction of the hornblende schist with the oligoclase-biotite-gneiss the garnets are ½ - 1" in diam., but towards the centre of the body the size of the garnets decreases until they are about the size of a pin-head. (fig. 2).

In thin section the hornblende schists are medium to coarsely crystalline rocks that consist of abundant common hornblende, with poikiloblastic felspar, quartz and accessory minerals sphene, apatite, garnet, iron ore and biotite. (plate VIII).

Hornblende is present as hypidioblastic crystals which vary in length from 0.8 - 1.7 m.m. The crystals are dimensionally oriented and are strongly pleochroic in green (X - yellow green Y, Z - dark green). The hornblendes contain numerous inclusions of quartz, sphene and iron ore. They exhibit smooth margins with the quartz and felspar, and bent or broken crystals have not been seen.

Plagioclase occurs as large, poikiloblastic crystals, containing inclusions of hornblende and quartz. The felspar crystals may be up to 2.0 m.m. in size. Twinning on the albite law is seen and determination of the symmetrical extinction angle of the twin lamellae indicates a basic labradorite composition (An_{63} - An_{66}). Quartz is common in the plagioclase crystals and in many cases is almost myrmekite-like in appearance. All the plagioclases show strong sericitisation and secondary micas up to 0.1 m.m. in length are present.

Quartz is common and occurs as equidimensional crystals up to 1.5 m.m. in size, although a great variation in crystal size is seen within the same section. Quartz occurs as interstitial material between the hornblende crystals and is also present in lens-shaped areas, made up of several crystals, which are elongated parallel to the schistosity. Undulose extinction is exhibited by the larger quartz crystals.

Garnet is present as irregularly shaped crystals containing numerous inclusions of quartz, sphene, iron ore, and occasional felspars. The garnets have rounded, embayed margins and are occasionally separated into isolated fragments.

Biotite is not common and it is absent in some sections. The crystals may be up to 0.5 m.m. in length and are strongly pleochroic in a 'foxy', reddish-brown colour. (x - straw yellow, Y, Z - reddish-brown).

Sphene is the most common accessory mineral, occurring as ubiquitous idioblastic crystals which are less than 0.1 m.m. in size. Sphene commonly occurs as inclusions within the hornblendes and garnets. Idioblastic apatite crystals are uncommon, while iron ore occurs as irregularly shaped masses, often present as inclusions within the hornblende and garnet crystals.

The hornblende schist bodies are thought to be derived from basic igneous rocks that were intruded as sills and dykes before the regional metamorphism and injection took place. During the subsequent metamorphism and folding these igneous sheets of igneous rock were disrupted and broken into isolated blocks and lenses and folded with the adjacent country rocks. In thin section no relic igneous features have been seen in the hornblende schists. J.E. Richey (quoted in W.T. Harry 1953), states that these "pre-granitisation basic intrusions" do not occur in the unmigmatised rocks to the west of the zone of regional injection." (W.T. Harry 1953 p.291). In the area mapped the hornblende schists are confined almost entirely to the pelitic gneisses, only two small hornblende schist bodies have been found in the striped and banded rocks and they have never been found in the psammitic rocks.

E. CONCLUSION

The lithology and petrography of the Moine rocks of the area mapped has been greatly modified by migmatisation. In the central and eastern parts of the area both the psammitic and pelitic rocks are migmatised, but tothe west of the valley of Allt a Bhuiridh only the pelitic rocks show evidence of migmatisation. Sillimanite is present in all the pelitic rocks mapped and it is evident that the grade of metamorphism in the rocks east of An Stac and Rois-Bheinn never falls below the sillimanite zone.

From the same area, the metamorphic zones based on the mineral assemblages present in the calc-silicate rocks suggest that the rocks lie within either the anorthite-hornblende or anorthite-pyroxene zones of metamorphism.

The migmatisation has been very selective in host rock, and the pelitic rocks have been intensely altered while the psammitic rocks and hornblende schist bodies have been only slightly modified.

Affect of Migmatisation upon the Hornblende Schist Bodies.

The hornblende schist bodies appear to have been affected only slightly by the migmatisation, and through:out the area they are garnet - hornblende - labradorite rocks. The affects of the migmatisation may be the intense sericitisation of the felspars, and the local occurrence of brown biotite. Thin quartz - oligoclase felspar veins, less than ½" thick are only rarely seen to traverse the hornblende schist bodies.

Affect of Migmatisation upon the Psammitic Rocks.

Throughout the area the psammitic rocks have completely recrystallised and have a granoblastic texture, the quartz and felspar crystals having rounded, smooth boundaries. The psammitic rocks in the valley of Allt a Bhuiridh and to the west of An Stac and Rois-Bheinn have suffered very little from migmatisation and the only affect appears to be that of complete recrystallisation.

East of the valley of Allt a Bhuiridh the migmat:isation is more intense and the psammitic rocks are generally coarser in grain size and more gneissic in appearance, the quartz-felspar and micaceous layers becoming distinct and more clearly defined. Myrmekite is locally abundant and the biotite crystals become pleochroic in a reddish-brown colour. Quartz-oligoclase felspar lenses and pods, aligned parallel to the foliation are locally common, many of these bodies having biotite-rich margins. Discordant and concordant pegmatite veins, with steep, almost vertical junctions are found in the psammitic gneisses.

Affect of Migmatisation upon the Striped and Banded rocks.

The striped and banded rocks occur to the south and east of the valley of Allt a Bhuiridh, in areas where both the pelitic and psammitic rocks have suffered migmatisation.

The thin psammitic bands of the striped and banded rocks have responded to migmatisation in the same way as the psammitic rocks. They are coarsely crystalline and have completely recrystallised with a granoblastic texture of the quartz and felspar. Myrmekite is locally abundant, and the biotites of the striped and banded rocks of Druim Comhnardaig and Doillaid Bheag are pleochroic in a red-brown colour. The pelitic layers become gneissic in appearance, with thin quartz-oligoclase felspar lenses alternating with micaceous layers, and petrographically are similar to the oligoclase-biotite-gneiss. The quartz-felspar folia never become sufficient-:ly abundant to form the dominant constituent and the pelitic bands are always very micaceous. Potash felspar is rare, and only very locally (e.g. on Sgurr na Ba Glaisse) is myrmekite present. Granite gneiss has not been seen within the striped and banded rocks.

Affect of Migmatisation upon Pelitic Rocks.

The pelitic rocks have been intensely affected by migmatisation and throughout the area the pelitic rocks are coarsely banded gneisses. The migmatite derivatives of the pelitic rocks have been divided into two types, the oligoclase - biotite - gneiss and the granite gneiss. The mineralogical differences between the two gneisses may be briefly summarised :

The granite-gneiss contains abundant potash felspar, only small amounts of biotite, pleochroic in a chocolate brown colour, and muscovite and garnet are subordinate constituents. Sillimanite is absent.

The oligoclase-biotite-gneiss contains no potash felspar, abundant oligoclase-andesine plagioclase, biotite, pleochroic in a reddish brown colour, muscovite and garnet. Sillimanite is locally common and tourmaline is ubiquitous. The oligoclase-biotite-gneiss is of widespread distribution while the granite gneiss occurs only locally, as a narrow band which can be traced from Creag Dhearg to the northern slop of Druim Fiaclach, and as irregular patches to the south of Garbh Leachd. The closest spatial relationship exists between the two gneisses, the granite gneiss occurs within the oligoclase biotite gneiss and contains 'inclusions' of oligoclase-biotite-gneiss. The contact between the two gneisses is gradational over several feet. Pegmatite veins, mineralogically similar to the granite gneiss, cut across, or are concordant with, the oligoclase biotite gneiss.

Previous work (H.H. Read 1931, Y.C. Cheng 1943, W.T. Harry 1953) in areas of migmatised rocks in the N.W. Highlands has shown that the process of migmatisation consisted of essentially an early phase of metasomatism in which the affect of sodic-rich material predominates and a later phase of metasomatism during which potassic-bearing fluids become active.

H.H. Read (1931) studied the injection complexes at Loch Choire and Strath Halladale in Central Sutherland. Within the Loch Choire complex Read recognised a Zone of Veins, at garnet-staurolite grade of metamorphism, and a Zone of Injection at sillimanite grade. Within the Zone of Injection rocks in which the host material is dominant alternate with rocks rich in granite material. Read considered that the injection took place under conditions of high temperature and stress and the injected material represents a volatile-rich sodic phase i.e. quartz and oligoclase, from a grano-dioritic magma. Potassic fluids became active at a late stage and to a lesser degree than the sodic material. Read considered that metamorphic differentiation in situs had not occurred, since the evidence indicated that some influx of material had taken place.

Yu Chi Cheng (1943) studied an area of the N. Sutherland injection complex. Cheng concluded that the migmatised rocks resulted from metasomatic changes brought about by the percolation of alkaline solutions. Pelitic rocks suffered soda metasomatism, the semi-pelitic rocks potash metasomatism and in the channels along which the passage of the alkali fluid took place pegmatitic and granitic bodies were formed. Cheng considered that some of the potassic metasomatic material was released by reactions taking place in the rock and was not derived from an outside source.

W. T. Harry (1953) studied the migmatised rocks of the W. Ardgour, Inverness-shire, and concluded than an "earlier" and "later" phase of the same metasomatic episode led to the formation of the oligoclase-biotite-gneiss and granite gneiss. The granite gneiss was formed syntectonically by a period of silica-potash metasomatism which was preceded by an "earlier" phase of Na, Ca, Mg. matasomatism in which the oligoclase-biotite-gneiss was formed. Harry concluded that both gneisses were formed by metamorphic differentiation in situ.

In the area mapped it is suggested that the rocks suffered an initial period of soda metasomatism in which the pelitic rocks were transformed into oligoclase-biotite gneisses, and a subsequent phase of potash metasomatism during which the granite gneiss was formed. The quartz-felspar folia of the oligoclase-biotite gneisses, and also those of the psammitic rocks, frequently show biotite-rich margins which may suggest that some degree of metamorphic segregation has taken place, the quartz-felspar material being segregated into folia and the biotites concentrated into biotite selvedges at the margins (fig. 3).

It is suggested that during the period of potash metasomatism the granite gneiss developed from the oligoclase-biotite-gneiss. The potash felspars appear to be developing at the expense of the plagioclase while the biotites are less common and the garnets become small and almost relic features. The close field relationship of the two gneisses also suggests that the granite gneiss has developed from the oligoclase-biotite-gneiss, by the action of potassic bearing fluids.

Both the oligoclase-biotite-gneiss and granite gneiss have been folded, and they both contain minor structural elements of the same age, so that it is probable that there was no considerable time gap between the formation of the two gneisses.

The numerous pegmatite veins and sheets that occur throughout the area appear to be a late stage effect during which volatile-rich potassic bearing fluids were active. Pegmatite veins have not been seen folded, and strongly discordant pegmatites cut across the minor structures of the third fold movement. The large porphy-:blastic muscovites that are locally common in the psammitic rocks, and the randomly oriented muscovite crystals of the muscovite-sillimanite "knots" may also be the result of the same late-stage alkaline fluids. The random orientation of the muscovite porphyroblasts indicate that they formed when movement had ceased.

The age relationship between the period of migmatisation and the fold movements is discussed later.

III. STRUCTURAL GEOLOGY

A. INTRODUCTION

The results of recent work carried out in the Highlands confirm an important concept of structural analysis that a close relationship, both in style and orientation, exists between the minor and major structures of the same movement episode. D.B.McIntyre (1951) working in an area which he showed to be homo-axial, states "the axial plunge of the small folds coincides with that of the structures on every inter-:mediate scale up to the dimensions of the whole area" (Q.J.G.S.1951 p.4.). Clifford et/al (1957) state that "the linear structures . . . . . are, with few exceptions, parallel to the axes of the folds to which they are related, and are developed parallel to the intersections of pre-existing foliation surfaces with axial plane foliation" (Geol.Mag.1957 p.1.). Clifford et/al conclude that "there is a constant relationship between the small and large scale structures, though this relationship is often obscured by the complexity of the folding". (Geol. Mag.1957 p.23).

The large scale structural pattern of an area is reflected in the minor structures, and a detailed analysis of these will provide evidence of the style and orientation of the major structures with which they are related.

Where more than one period of folding has taken place, minor structures associated with each of the fold movements will be preserved, and they can be distingu-:ished by their differing styles and orientation, which in turn reflect the differing style and orientation of the major structures. No single feature is character-:istic of the minor structures of a particular fold movement, the style of the minor folds may vary, as may their orientation, but by consideration of all the features, the minor structures of one generation can be separated from those of other generations and can be related to the major structures of the same movement period.

Where more than one period of folding has taken place, study of the minor structures will show the age relationship of the fold movements. Minor structures of one movement period that are refolded by those of another must be older in age and this relationship reflects the structure on the major scale.

The structural study of the area mapped involved the mapping of the various lithological units and the measurement of all the minor structural elements available in each outcrop. The mapping was carried out on the scale of 6" - 1 ml. and the accuracy of the mapping was aided by the use of aerial photographs. The area has been sub-divided into 18 sub-areas, each approximately 1 - 2 square miles in extent, and the structural data obtained from each sub-area have been plotted on two stereographic nets (lower hemisphere projection). On one stereographic net is plotted the poles to the foliation planes, and these poles have been contoured. On the same stereographic net are plotted the axes of the minor folds and linear structures. Using the variation in the orientation of the foliation planes, the orientation of the axes of the major folds can be determined and the stereographic net shows the relationship between the orientation of the axes of the minor and major structures in each sub-area. The poles to the axial planes of the minor folds and to the axial plane cleavages have been plotted on the other stereographic net and left uncontoured. (Fig.26).

By preparing such diagrams the variation in orientation of the major and minor structures, and the relationship between structures of different ages can be studied for each sub-area. The diagrams also enable the orientation of the structures to be traced from one locality to another.

B. RESULTS IN OUTLINE

Nearly the whole of the area mapped is made up of vertical, or nearly vertical, rocks, the foliation only rarely having a dip of less than 70^{o}. The changes in the orientation of the foliation planes are used to determine the axial traces of the major folds, and because the foliation planes are nearly vertical, the axial plunges of the major folds are also nearly vertical. All the major folds close sideways, and the map (Map II) can be regarded as a tectonic section, formed by the intersection of the major folds with present land surface, through the structure of the area.

Analysis of the distribution of the rock types and minor structures indicate that the area has been affected by four movement periods, and the folds formed during each movement differ in style and in areal distribution.

<u>The first fold movement</u> that can be recognized is one of isoclinal folding, the axial planes of which are aligned parallel to the foliation. In many localities a lineation is found, parallel to the axes of the isoclinal folds, formed by the dimensional orientation of the quartz-felspar material of the rock to form a minute corrugation of the foliation surfaces. No major closures associated with this period of isoclinal folding have been recognised. The age relationship of the isoclinal folds with the later fold movements is indicated by the fact that the isoclinal minor structures are refolded by other minor folds, and they are never found to refold other minor structures.

A second set of structures, the minor folds of which refold the isoclinal structures, and which are themselves refolded by other folds, occur throughout the area. They are the minor structures of the <u>Second Fold Movement</u> and they can be related to major structures that have been mapped in the area. The second minor folds are tight, asymmetric folds, the axial planes of which trend at an oblique angle to the foliation (plate II). An axial plane cleavage may develop with these folds, formed by a mineral alignment parallel to their axial planes. The linear structures that formed during this fold movement are of different types:

a) Quartz-felspar rodding, formed by the folding of quartz-felspar migmatitic foliae that originated before the fold movement.

b) Mineral elongation of the quartz-felspar material in the rock to form a minute corrugation of the foliation surface. This linear structure is identical to the linear structure formed during the first fold movement.

c) A mica crinkling; this linear structure is not common, and only occurs on the southern face of Rois-Bheinn.

d) Lineation formed by the intersection of the axial plane cleavage with the foliation plane. This linear structure is only rarely seen.

The major folds of the second movement period are long-limbed almost isoclinal folds which, in areas where no major third folds are found, have N.N.E.-S.S.W. axial plane trends. The axial traces of the second major folds at Rois-Bheinn and Creag Dhearg have N.N.E.-S.S.W. trends, but the other second major folds mapped have been folded during the third movement period. Thus the second major fold at Druim Comhnardaig has an axial plane trending in a N.W.-S.E. direction, and the axial plane of the second major fold at Garbh Leachd trends in a N.E.-S.W. direction.

The structures of both the first and second periods of folding have been refolded during the <u>Third Fold Move-:ment.</u> The minor folds of the third movement period are open, asymmetric folds that have an axial plane trend markedly different to the axial plane trends of the minor folds of the earlier movements. No axial plane cleavage has been seen with the third folds and the only linear structure that formed with this folding is a mica crinkling. The third minor structures can be related to a major structure - the Diollaid Bheag antiform, a broad open fold some two miles wide that trends in a N.N.E. - S.S.W. direction.

The axial planes of minor folds do not strictly reflect the orientation of this major antiform, but "fan" about its axial plane trend. The axial planes of the minor folds vary in trend from 40^{o}W. of S. to 20^{o}E. of S. about the axial plane trend (10^{o}W. of S.) of the major fold.

A much smaller "major" fold, approximately a quarter mile wide, occurs on the north face of An Stac. This structure is a broad open antiform that trends in a N.E. - S.W. direction, which is the trend of the minor structures of the third movement in this area.

Minor structures of the third fold movement are most common in the area affected by the Diollaid Bheag antiform, where they are found in all rock types, but to the eastern and western margins of the area mapped they become less common and are present only in the more pelitic rocks.

Major and minor folds of the Fourth Fold Movement have a N.W. - S.E. axial plane trend and they are only found in the southern part of the area, on Rois-Bheinn and to the west of Sgurr na Ba Glaise. The minor folds of this movement period are open asymmetric structures with an axial plane trend usually nearly at right angles to the foliation (fig. 15). The associated linear structure is a mica crinkling. The broad open fold found on the N.E. slope of Rois-Bheinn was formed during this episode.

A fifth set of structures occur which have only a local distribution. They occur only in the psammitic rocks west of An Stac and Rois-Bheinn and they are open asymmetric folds, trending in a N.N.E. - S.S.W. direction with a consistently low plunge. In many exposures they are monoclines (fig.15), with a well developed mica crinkle. These folds are seen to refold structures of the first and second fold movements, but their age relationship with the third and fourth periods of folding is not known. The style, and consistently low plunge of the folds suggest they are not related to the third and fourth movement episodes.

C. THE STRUCTUAL ELEMENTS

The structural elements that were mapped can be divided into two main groups.

1) Planar Structures

2) Axial Structures

1. Planar Structures.

Foliation Planes. Of the several megascopic S-planes that are present in the rocks, the most prominent is the foliation plane, which is defined by alternating layers of different composition. Throughout the area the foliation plane coincides with the original bedding plane. This relationship is obvious in the psammitic rocks west of An Stac, in which sedimentary structures are found and indicate that the foliation plane is the bedding plane. In the rocks of the remainder of the area no sedimentary structures are found, but the foliation always remains parallel to the rock boundaries, and in rocks consisting of alternating thin bands of pelitic and psammitic material, the foliation in the bands remains parallel to their lithological junctions. Throughout the area the foliation is nearly vertical, and only in Glen Ulgarry and to the south of Druim Comhnardaig are dips of less than 50° found.

Axial Planes and Cleavage of Minor Folds. The axial planes of the minor folds are important planar structures and their orientation was measured whenever possible. Over most of the area the axial planes of the minor folds, like the foliation planes, have a nearly vertical dip. The minor folds of the first and second fold movements develop an axial plane cleavage, which is parallel to the axial plane of the folds. This axial plane cleavage is defined by a mineral orientation, in the pelitic rocks the micas have their basal planes aligned parallel to the axial plane, in the psammitic rocks the axial plane cleavage is shown by an incipient dimensional orientation of the quartz-felspar material. In some areas quartz veins have been introduced along the axial plane cleavage of these folds and in the central and eastern parts of the area quartz-oligoclase felspar folia occur along the axial plane cleavage of the second minor folds (fig.12). No axial plane cleavage has developed with the folds of the third and fourth movements.

Minor folds of each fold movement show differing axial plane trends and this is an important feature for distinguishing the folds of differing age. The differences in axial plane orientation of the folds of the first and second fold movements is only very slight, while the axial plane trends of the folds of the second, third and fourth fold movements differ markedly from each other (fig.26).

These several sets of planar structures differ from each other in age and orientation. The first planar structure, or S-plane, to be formed in the rock was the original bedding plane, this can be termed S_1. During the first fold movement a second planar structure S_2, the axial plane cleavage of the isoclinal folds, was developed. The axial plane of the isoclinal folds is always parallel to the foliation (or bedding plane) S_1. The only exception to this is at the isoclinal fold closures, where S_2 is inclined at a high angle to S_1, the angle of inclination varying as S_1 is traced round the fold closure. Both S_1 and S_2 are folded by the second fold movement, and the axial plane cleavage of the second fold forms the third planar structure to be developed in the rocks, S_3.

2. Axial Structures

Linear structures are well developed throughout the area and are present in all rock types. These linear structures can be divided into the following groups:-

Minor Fold Axes. The plunge and trend of the axes of the numerous folds were measured.

Mineral Elongation. A lineation is formed from the dimensional elongation of the quartz-felspar material of the rock. It is particularly well developed in the psammitic rocks and appears as a minute corrugation on the foliation surface. Such a lineation has been formed during the first and second fold movements.

Rodding. Rodding is widespread in the area and is found in all rock types. It is a common linear structure of the first and second fold movements. The origin of rod-:ding has been explained by G. Wilson (1953) as the result of folding of quartz veins that originated either before, or in the early stages of, the fold movements. Shearing movement in, or near to, the plane of foliation disrupts the veins first into folds, and then into isolated, lenti-:cular rods. Examples can be seen which show every grada-

:tion from a folded vein to lens shaped rods lying in the general plane of the foliation (Plate I). The rodding that formed during the first fold movement consists of re-crystallised quartz, but those associated with the second period of folding are made up of quartz, or quartz and felspar, and sometimes quartz, felspar and mica. The mineralogical composition of the rodding lineation will be discussed during the description of the fold movements.

Mica Crinkle. This linear structure is formed by the re-orientation of the micas of the pelitic rock (S_2) into a corrugation which forms a prominent lineation (Fig. 4). Mica crinkling is the common linear structure of the third and fourth fold movements. Locally it is present as a linear structure of the second period of folding and has a style distinct from the mica crinkling formed during the other fold movements. It is a tight, sharp crested crinkle, whereas that formed during the third and fourth fold movements has a more open, rounded appearance.

Boudinage. Boudinage structure is not common, but is locally well developed in rocks which consist of alterna-:ting bands of psammitic and pelitic material. The boudinage is "barrel shaped" and probably forms when the more competent psammitic bands have responded to extension by plastic deformation, with the development of a zone of thinning, or "necking". (N.Rast, 1956). The less competent pelitic layers tend to "flow" and become accommodated in the attenuated portion of the competent bands at the point of "necking". At this region quartz segregations tend to concentrate. Boudin:age is well developed on Diollaid Bheag, where their axes of elongation appear to be parallel to the axis of the major fold of the third movement period.

Major Fold Axes. The axial plunges of the major folds have been determined by plotting, on a stereographic net, the change in orientation of the foliation planes at the fold crests. The poles to the foliation planes fall on a great circle, the axis of which is parallel to the axes of the major fold.

D. STRUCTURAL HISTORY.

The account of the structural history of the area will be given in two sections. The first section will consist of a detailed description of the structures of each movement period; this will be followed by the second section in which the style of the folding periods and the affect of refolding earlier structures by later movements will be discussed.

1. The First-Fold Movement.

The first recognizable event in the structural history of the area is a period of isoclinal folding, but the structural elements associated with this fold movement are not abundant and a detailed account of the orientation of the first folds cannot be given.

No major isoclinal fold closures can be definitely identified in the area. Various lithological units are seen to thin and die out when traced along the strike, but it is not possible to show that this is the result of plunging isoclinal fold axes. It is assumed that major isoclinal folds were developed, and the affect of these was to reduplicate the original sedimentary succession.

The minor structures of the first fold movement occur in all rock types and their wide distribution indicates that the movement affected the whole area. The minor folds are true isoclines with both limbs parallel to each other and to the axial plane of the fold (fig.8).

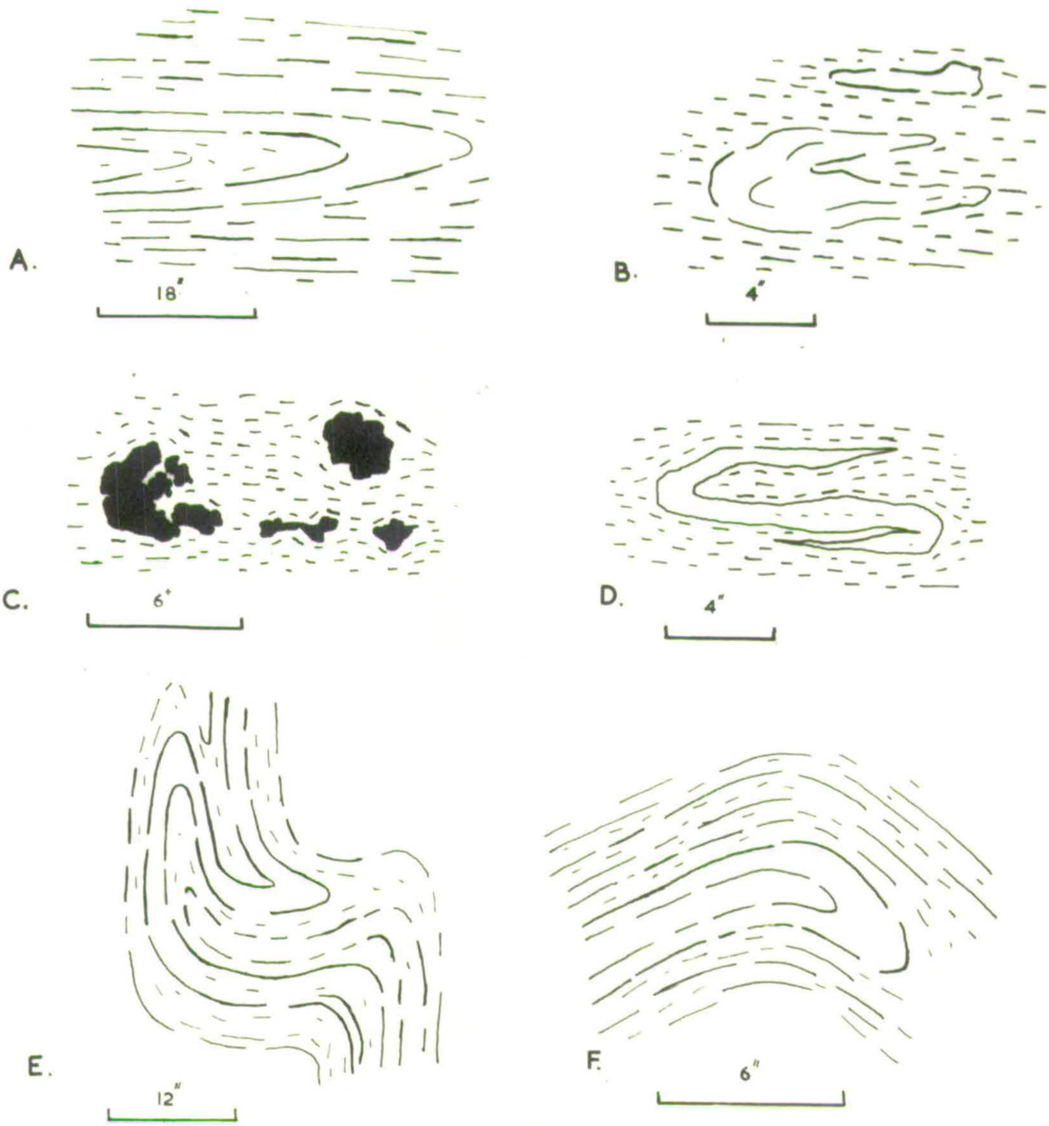


Fig. 8. Profiles of minor structures of the Ist. fold movement.

A. isoclinal fold in psammitic rock

B, D. isoclinal folds in pelitic rock ('tectonic inclusions')

C. quartz rodding in pelitic rock

E. isoclinal fold folded by a 2nd. fold, south of Seann Chruach

F. isoclinal fold folded by a 3rd fold 200 yds. S. of Glenshian.

An axial plane cleavage, defined by a dimensional orientation of the quartz-felspar crystals in the psammitic members, is developed at the fold closures. The axial planes of the folds (S_2) are always aligned parallel to the foliation (or bedding) S_1, the only exception to this is at the isoclinal fold closures, where S_1 is seen inclined to S_2, the angle of inclination varying as S_1 is traced round the fold.

A prominent lineation, which developed during this fold movement, is formed by the dimensional elong:ation of the quartz and felspar crystals of the rock, and is seen on the foliation surfaces as a minute corru:gation. An identical lineation formed during the second fold movement, and unless the lineation can be related the first or second folds it clearly cannot be definitely dated.

Quartz rodding is locally a prominent first linear structure and is found in both psammitic and pelitic rocks (Plate I). The rods are made up entirely of re-crystallised quartz and are regarded as having originated by the method suggested by G. Wilson (1953).

Although the minor structures of the first fold movement occur throughout the area, they are not abundant, and it is probable that during the strong deformation of the second and third movements, many first minor structures were obliterated. First minor structures are commonly found in the psammitic rocks which, being relatively competent, were able to preserve the first fold structures, while the incompetent pelitic rocks responded more readily to subsequent movement and the isoclinal structures were destroyed.

In the pelitic rocks, where the micas have become oriented parallel to S_2, thin psammitic and calc-silicate bands preserve relics of the isoclinal folds. During folding these psammitic and calc-silicate bands become discontinuous and are isolated into separate fragments. These fragments often preserve the isoclinal closure. (Fig. 8; Plate I). In some cases the fold closure becomes obscure and the psammitic or calc-silicate fragment becomes shredded into rod-like structures.

N. Rast (1956) proposed the term "tectonic inclusion" for such relic folds. Their mode of origin is very similar to that of rodding, from which they differ by being formed from the country rock. G. Wilson

(1953) distinguished between rodding and mullion structure by defining mullions as being formed from the normal country rock, while quartz rodding is developed from quartz that has been introduced into, or segregated in, the rock. The term mullion could be applied to these relic fold structures. Wilson divides the mullion structures which he describes into three groups, bedding - or fold - mullions, cleavage mullions, and irregular mullions, and it is suggested that these relic fold structures are a type of fold-mullion that was not described by Wilson.

In the psammitic rocks the isoclinal folds are often preserved within a single bed. (fig. 8). In many exposures the fold is only seen by a change in orientation of the compositional banding, and the meg-:ascopic parting planes (the foliation) do not pass round the fold closure. In such cases the axis of the fold cannot be measured, although the orientation of the axial plane is the same as that of the foliation. Such "shadow structures" are often seen refolded by later folds.

The plunge of the isoclinal folds is very variable, although the majority of the fold axes measured have plunges of more than 60°. The direction of plunge is also variable, and isoclinal folds in adjacent exposures may plunge in opposite directions. Near Arieniskill isoclinal folds are found which plunge at approximately 40° to the N.E., but some 50 yds to the south of this outcrop isoclinal folds plunge at 50 - 55° to the S.W. (Sub-area 1 fig. 26).

This irregularity of plunge of the isoclines may be an inherent feature of the isoclinal folding, or it may be the result of refolding the isoclines by later movements. It is difficult to conceive that the original plunge of the isoclinal folds, the first fold movement of the area, should show such irregular variation, and it appears more probable that later folding, the style of which was complex, is the principal cause of the irregular variation in plunge. As will be described later it is evident that the refolding by the second and third movement periods was partly Similar and partly Concentric in style, and the resulting complicated pattern of the isoclines may have formed as a result of this complex later folding.

An important consequence of isoclinal folding is to give a repeated stratigraphical succession. The original succession can only be determined if the position of the axial planes of the major isoclinal folds is known, and sedimentary structures are preserved to give the direction of younging. As has been previously described, the only sedimentary structures found in the area are some twelve examples of current bedding that occur in the psammitic rocks west of An Stac and Rois Bheinn. Of these eight occur within the same horizon of the psammitic rocks, and young to the east, suggesting that the Rois-Bheinn pelitic group is stratigraphically younger (pp41-43). The other examples of current bedding are found further west, along the Loch Ailort shore, and they young in the opposite direction. The relative positions of these sedimentary structures indicate that the rocks in this part of the area have been tightly folded. Because the structural evidence indicates that the area has been isoclinally folded, it is concluded that the stratigraphical succession has been repeated, but the amount of data available is insufficient to determine the location of the major isoclinal folds, orthe direction of younging in the rocks, so that the true stratigraphical succession cannot

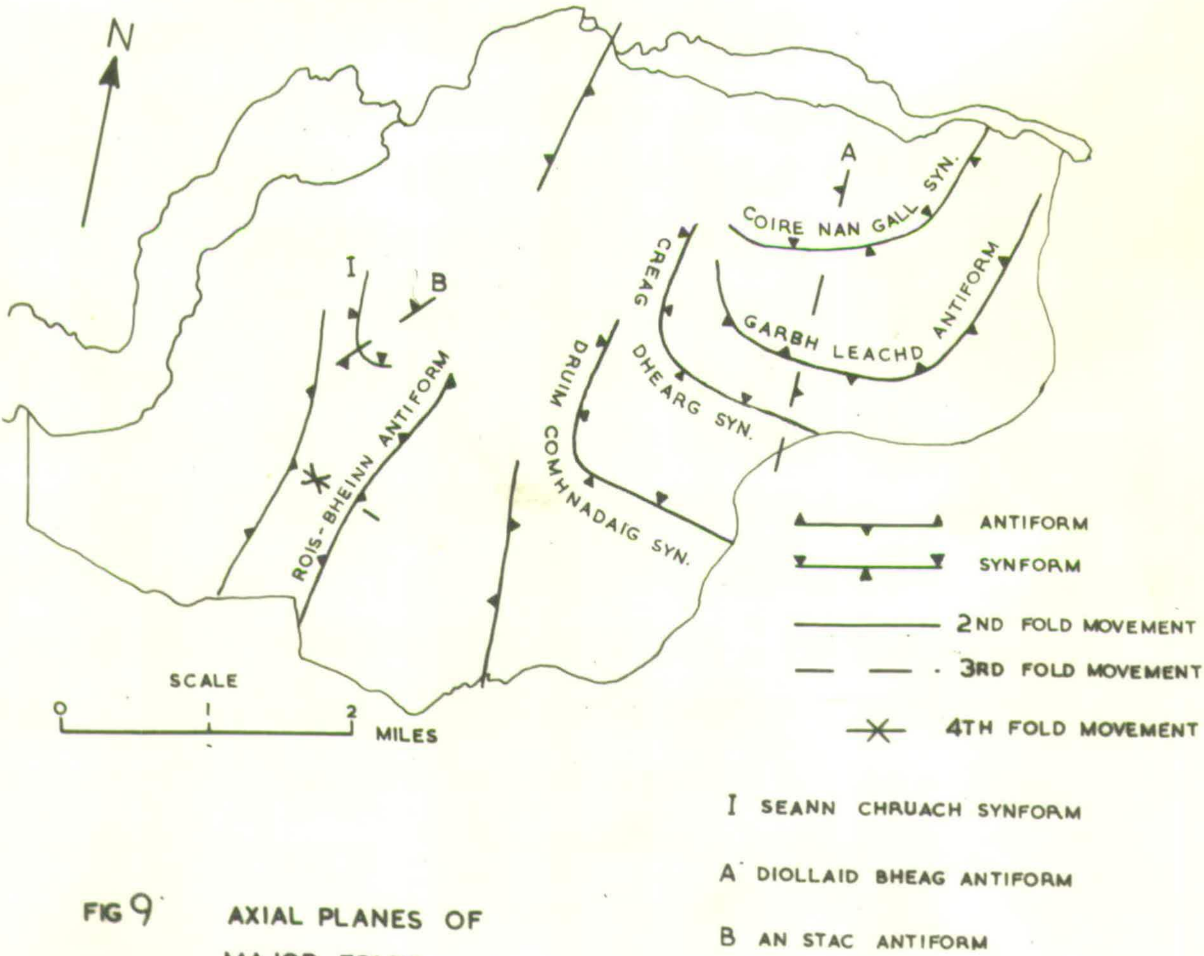


FIG 9 AXIAL PLANES OF MAJOR FOLDS.

be established.

2. The Second Fold Movement

The second event in the tectonic history of the area is the folding of the rocks into long limbed almost isoclinal folds that, in areas where no major third folds are present, have N.N.E. - S.S.W. axial plane trends (fig. 9). Several major folds of this movement period have been mapped, and the length of the fold limb is such that the corresponding antiform and synform can be as much as three miles apart.

Major folds occur at Rois-Bheinn, Creag Dhearg, Druim Comhnardaig and Garbh Leachd (Map 11), and their axial trends have been determined from the change in orientation of the foliation planes. (Fig. 26). The style of the folds is such that although the fold limb may be up to two miles in length, change in the orientat-:ion of the foliation planes takes place only at the fold closure, and along the axial plane trace no change in trend of the foliation is seen. The axial planes of other folds, the closures of which are not present in the area mapped, can be traced by using the movement sense of their associated minor folds. (fig. 9). The major folds of the second fold movement are superposed upon isoclinally folded rocks and the minor folds of the first isoclinal movement can be traced round these second major folds.

Throughout the area the axial planes of the major folds remain nearly vertical. The folds at Rois-Bheinn and Creag Dhearg have axial plunges greater than 80° to the S.S.W., but the other major folds have been folded by the third fold movement, and their orientation is different. Thus the Druimm Comhnardaig closure plunges at more than 80° to the S.E. and the closure at Garbh Leachd plunges at more than 80° to the N.E.

Second Minor Folds

Minor folds of the second movement period are common and are well preserved in the psammitic and the striped and banded rocks. They are less common in the pelitic rocks where, like the minor folds of the first fold movement, they tend to be preserved only by the thin psammitic and calc-silicate ribs. Second minor folds are tight, asymmetric folds, the axial planes of which are inclined oblique to the foliation by a small angle (10-15° - see plate II). The style of the folds in the psammitic rocks may vary along the axial plane trace. A fold begins as a small flexure of the foliation plane, but the style of the fold changes so that at the actual fold crest, the fold is almost isoclinal. (fig.10). In exposures where the complete fold is not seen, it can be very difficult to differentiate these second minor folds from true iso-:clinal folds of the first fold movement.

The thickness of the refolded lithological units can be very variable, being much thicker at the fold closure than on the fold limbs, where they show a marked attenuation. With increasing tightness of folding the difference in the thickness of a litholog-:ical unit on the fold closure and on the limb becomes greater.

In some outcrops rapidly repeated folding is seen, the rock being folded into a series of tight, almost isoclinal folds having parallel axial plane trends. (fig.11). Such exposures illustrate that rapid re-:duplication of the lithology can take place as a result of the second-fold movement. Often it is difficult to distinguish these folds from the first isoclinal folds, but although tight folds, their limbs are not parallel.

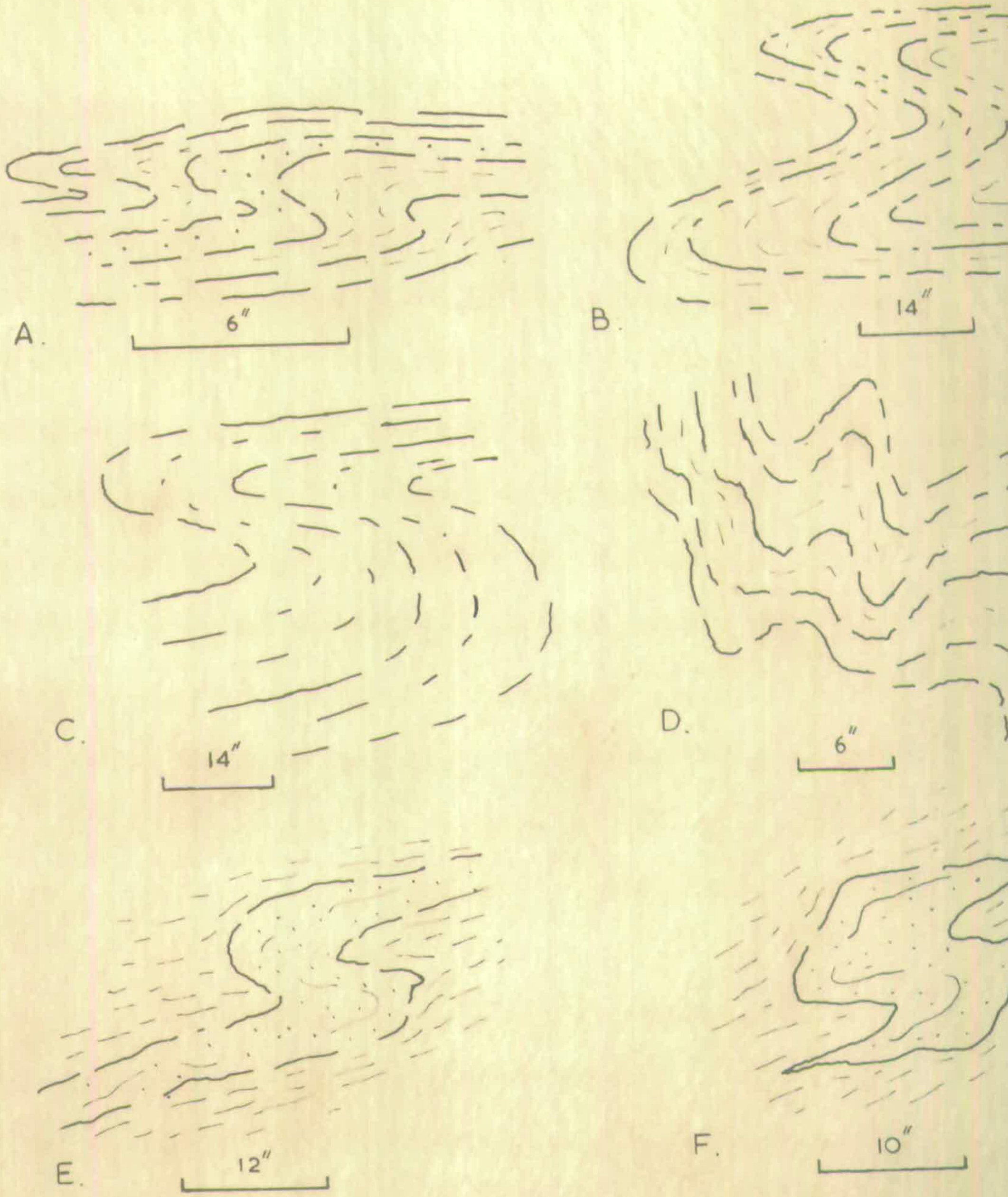


Fig. 10. Profiles of minor 2nd folds

A, B, C, D. - in psammitic rocks.

E, F. - in pelitic rocks

In some such exposures these folds are seen to refold isoclinal folds. Although the axial planes of the folds remain parallel, it is found that the plunge of their axes may vary, and adjacent folds may have different axial plunges.

In other exposures the foliation becomes highly distorted and diffuse, and very irregular, disharmonic folds are formed (fig. 11). The rock appears to have had a mobility similar to that of a viscous fluid at the time of deformation, and flow folds, with very variable axial and axial plane orientations, were formed. Occasionally on the psammitic bands that define these folds a well preserved lineation is seen.

The folds in the psammitic rocks may show an axial plane cleavage, aligned parallel to the axial plane of the fold. In the very psammitic rocks, where the mica content is small, this axial plane cleavage is not obvious. It is only seen as an incipient banding effect present at the fold closure, and is formed by the dimensional orientation of the quartz-felspar crystals of the rock. In rocks having a higher mica content, as in the striped and banded rocks, the axial plane cleavage is defined by the micas having their basal (001) planes oriented parallel to the axial plane of the fold.

Second minor folds found in the pelitic rocks are most commonly preserved by the thin psammitic and calc-silicate bands. (fig. 10; plate II). These folded psammitic and calc-silicate bands also show tectonic thickening and thinning when traced round the fold, being much thicker at the fold crest than on the limbs. Within the cores of these folds the micas of the pelitic rocks become aligned parallel to the axial plane of the fold (S_3). Only locally are second minor folds preserved in the pelitic rocks, where the micas have not become oriented parallel to S_3, but are folded by the second folds. Such folds are common on Rois-Bheinn, where mica crinkling is the associated linear structure.

Movement sense of the minor folds is an important feature used in determining the position and style of the major folds. By plotting the 'S' and 'Z' style of the minor folds the axial plane position of the major fold can be traced. It has been found that some minor folds show the 'wrong' movement sense. This may be due to the fact that minor folds of all dimensions may be formed, and

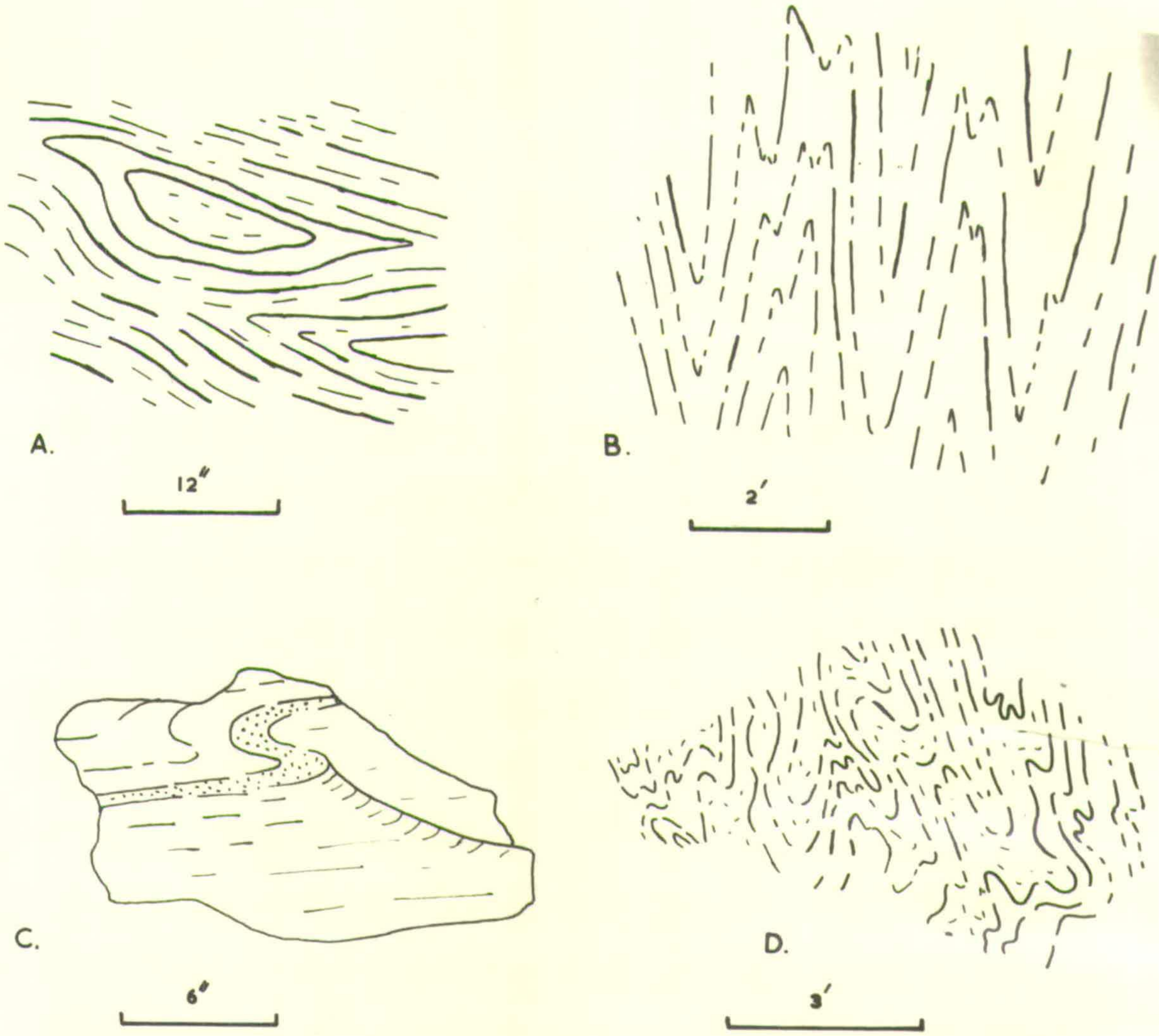


FIG. 11.

A. second fold with opposed directions of plunge to form 'canoe shaped' fold.

B. rapidly repeated second folds

C. second folds showing variable plunge

D. irregularly shaped, disharmonic second folds

folds having the opposite movement sense to the majority of minor folds of the same age are related to a large 'minor' fold, and not to the major fold. Plate II shows second minor folds in the same outcrop that have opposite movement sense.

Second Linear Structures.

The common linear structure seen with the second minor folds is formed by a mineral elongation of the quartz-felspar crystals of the rocks, and it gives the foliation surface of the fold a corrugated appearance. As has been mentioned previously, a similar linear structure formed during the first fold movement. Near Arieniskill there are exposures which contain isoclinal folds and second minor folds, and with each there is an identical lineation, parallel to the axes of the folds.

The mineralogical composition of the second rodding structures varies, but in most of the area the rods are made up of quartz and plagioclase (An_{28}), or of quartz, plagioclase and mica. On Sgurr na Ba Glaise second quartz-felspar-mica rods are present and contain silli:manite, and at Creag Dhearg and Garbh Leachd some rods contain garnet. To the west, in the psammitic rocks west of An Stac, rodding of the second fold movement is made up of quartz only. In this region it is not possible to distinguish between the second rods and the quartz rods of the first fold movement.

The veins from which the second rodding structure was formed were of variable composition, consisting of quartz-plagioclase-mica material over most of the area, but only of quartz in the west. In the psammitic rocks west of An Stac some second minor folds show quartz veins introduced along their axial plane cleavage.

Mica crinkling of the second fold movement is only found on the south face of Rois-Bheinn where the micas (which define S_2) of the pelitic rocks have become oriented to form a mica crinkle, the axial plane trend of which is similar to that of the axial planes (S_3) of the second minor folds. The style of the mica crinkle is very different from that formed during the third and fourth fold movements, it being a tight, sharp crested crinkle (fig. 4).

Orientation of the Second Axial Structures.

The plunge of the axial structures of the second-:fold movement is very variable. The diagrams showing the structural data of each sub-area illustrate this variation in axial plunge (fig. 26). Not only do adjacent folds in the same outcrop show different axial plunges, but the plunge of an individual fold can change very rapidly. One such fold is present south of Glenshian, and shows a rapid change in plunge from horizontal to 70° S.S.W. (plate III). In the same area second minor folds, as well as having very variable plunges, also show variation in direction of plunge, some plunging to the S.S.W., others to the N.N.E.

Individual folds have been mapped that plunge in opposite directions to form "canoe-shaped" folds (fig.11). A good example of this type of fold is seen south of Sgurr na Paite, where a fold plunges 28° to the N.E. and 52° to the S.W.

The variation in amount of plunge of the second minor folds only occurs in the psammitic and striped and banded rocks. In the pelitic rocks these folds do not show a marked variation in plunge but nearly always have very steep plunges. In the psammitic rocks west of An Stac second folds show a variation in plunge from $0-50^{\circ}$ (sub-area 18, fig.26)., and in the psammitic rocks east of An Stac the plunge of the second folds is equally variable. (Sub-area I, fig. 26). In the pelitic rocks of An Stac however, the plunge of these structures is almost vertical, and no fold with a plunge of less than 60° has been seen.

The cause of the variation in amount and direction of plunge of the second linear structures is discussed later in the section.

Orientation of Second Axial Planes.

The axial planes of the second minor folds remain nearly vertical throughout the whole area, but considerable variation in the axial plane trend occurs and is the result of the refolding of the second minor folds during later fold movements. (fig. 9).

Second Major Folds.

Rois-Bheinn Antiform.

This closure is found in the psammitic rocks east of An Stac and Rois-Bheinn. Plotting the foliation planes measured near the closure upon a stereographic net indicates that the fold is an antiform with a N.N.E. - S.S.W. axial plane trend and plunging at 80° to the S.S.W. (sub-area 13 fig. 26). The psammitic rocks, in which the trace of the antiform is found, continue southwards and reference to the Geological Survey "10 mile map" indicates that they close on Sgurr Domhuill Bheag, south of the area mapped. Because of the lack of exposure the axial plane of the antiform cannot be traced northwards through the valley of Allt a Bhuiridh, but at Arieniskill, on the northern boundary of the area, a pelitic band is present which, from the evidence of the movement sense of the second minor folds, contains the axial plane of an antiform plunging to the S.S.W. (Map II). This antiform is regarded as the equivalent of the Rois-Bheinn antiform. Because of the southward plunge of the fold the pelitic band thins and disappears when traced southwards.

The amount and direction of plunge of the minor structures of the Rois-Bheinn antiform is very variable (sub-area 13, fig. 26), and when plotted on a stereographic net they lie along a partial vertical great circle, in which lies the axis of the major fold. The significance of the great circle pattern of the second axial structures is discussed later.

Creag Dhearg Synform.

Creag Dhearg Synform

The closure of this synform occurs in the pelitic rocks at Creag Dhearg and it has a steep axial plunge of more than 80° to the S.S.W., with an axial plane trending N.N.E. - S.S.W. (Map. II). This major fold has been folded during the third-fold movement and on Druim Fiaclach, the axial plane of the synform trends in a N.W. - S.E. direction. The minor structures associated with the synform are refolded also and on the Druim Fiaclach ridge they plunge steeply to the south-east. Figure 17 shows the orientation of the minor structures associated with this synform and it illustrates the marked change in trend of these structures due to folding about the third major fold.

Because of the south easterly plunge of the synform the psammitic rocks present in the axial plane of the fold on the Druim Fiaclach ridge thin and disappear north westwards near the summit of Druim Fiaclach, and on Creag Dhearg the synform is found only in the pelitic rocks (Map II).

In the axial plane trace of the Creag Dhearg synform the rocks have undergone strong migmatisation, and the foliation trend of the psammitic rocks on the Druim

Fiaclach ridge becomes very irregular. This distortion of the foliation does not appear to be due to refolding about an axis, but is the result of plastic flow during the period of migmatisation. The orientation of the first-fold structures becomes very variable, and the second folds show marked changes in shape (fig.12), but despite the strong distortion the general trend of the second minor structures is maintained.

Garbh Leachd Antiform.

The closure of this antiform is found to the east of Garbh Leachd, in the valley of Allt a Choire Bhuidhe, and it is the complementary antiform to the Creag Dhearg synform, the pelitic horizon on the northern slope of the Druim Fiaclach ridge forming the common limb between the two folds. Plotting the orientations of the foliation planes indicates that at Garbh Leachd the antiform plunges at more than 80° to the N.E. and has a N.E. - S.W. axial plane trend. The direction of plunge of this fold is almost opposite to that of the Creag Dhearg synform and this marked difference in axial trend is the result of the folding of these structures about the third major fold.

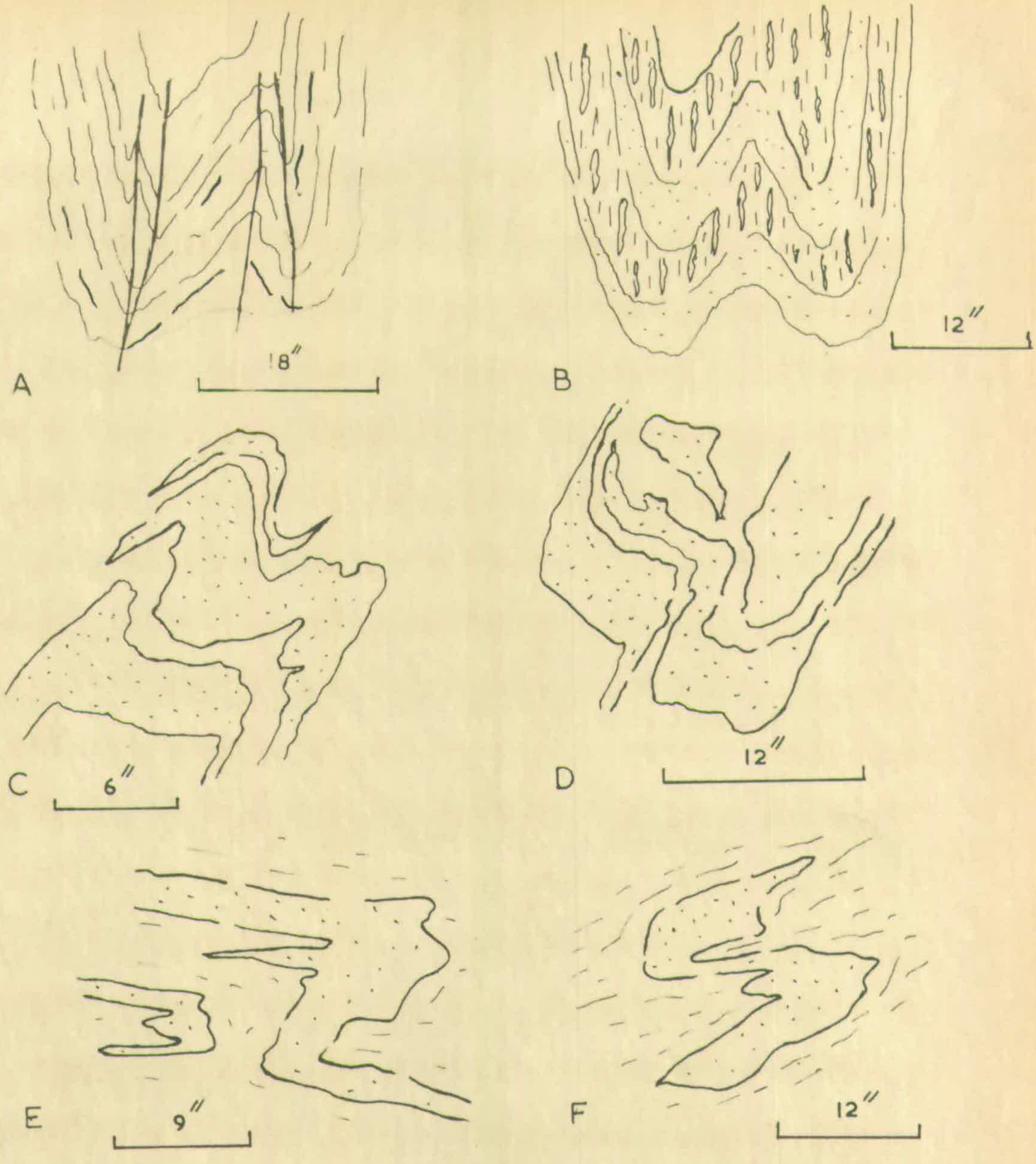


Fig.12. Profiles of 2nd. folds.

A quartz veining within axial plane of fold 1ml. west of Seann Chruach

B quartz felspar folia in axial plane cleavage. 200yds. south of Diollaid Bheag summit.

C.D. style of folds from strongly migmatised rocks on
E.F. Druim Fiaclach ridge

By using the movement sense of the minor folds the curved axial plane of the Garbh Leachd antiform can be traced round the third major antiform. The trend of the axial plane changes from a N.E. - S.W. direction at Garbh Leachd, to a N.W. - S.E. direction east of Creag Dhearg (fig. 9). Due to the refolding by the later fold movement the axial planes of the minor folds on both limbs of the antiform now dip in the same direction. The axial plunge of the minor structures, like the second minor structures of other major folds, show a marked variation in amount and direction of plunge. (Sub-area 7, fig. 26).

Druim Comhnardaig Synform.

This synform occurs in the psammitic rocks of Druim Comhnardaig and has an axial plunge of more than 80^{o} to the S.E. with a N.W. - S.E. axial plane trend. Like the other second major folds that have been folded by the third major folds, both limbs of the synform show the same orientation, dipping steeply to the S.S.W. Second minor folds are not common on Druim Comhnardaig, but those that do occur plunge steeply to the S.E. or S.S.E. (sub-area 16, fig.26).

West of Druim Comhnardaig, and east of Sgurr na Ba Glaise the axial plane trend of the synform appears to change from a N.W. - S.E. direction to a N.N.E. - S.S.W. direction on the eastern slope of the valley of Allt a Bhuiridh. This area is poorly exposed and definite evidence for this change in axial plane trend is not available. Striped and banded rocks have been traced from the core of the Druim Comhnardaig synform northwards to the south western slopes of Druim Fiaclach where they thin and die out (Map I). It is suggested that this closure is equivalent to the Druim Comhnardaig synform. The axial plane of the major fold has been folded by the third-fold movement from a N.N.E. - S.S.W. direction to a N.W. - S.E. direction (fig. 9).

Seann Chruach Synform.

This fold, which is found in the pelitic rocks of Seann Chruach, has a N.N.E. - S.S.W. axial plane trend and an axial plunge of 80° to the S.S.W. (Sub-area 8, fig. 26). There is no closure of the pelitic rocks in the core of the Seann Chruach synform and the fold is indicated only by the change in trend of the foliation planes.

The minor folds of the Seann Chruach synform are folded by a third major fold and their N.N.E. - S.S.W. axial plane trend is folded to a W.N.W. - E.S.E. or W.-E. trend on the summit of An Stac. (Sub-area 9, fig. 26). The orientation of these refolded structures will be discussed later.

To the west and south-west of the Sean Chruach synform the second minor folds do not show the correct movement sense for the fold but instead indicate that they are associated with an antiform that closes to the south of Rois-Bheinn (fig.9). The fold closure of this major antiform does not occur in the area mapped, but the axial plane trend of the antiform is shown by the movement sense of the second minor folds. It is suggested that the Seann Chruach synform is a large "minor" fold, and the second minor folds to the west of An Stac and on Rois-Bheinn are related to a major second antiform that closes to the south.

The movement sense of the second minor folds in other parts of the area indicates the trace of the axial planes of second major folds, the closures of which are not present in the area mapped. It has already been shown that the movement sense of the minor folds in the pelitic rocks to the south west of An Stac and on Rois-Bheinn indicate that the rocks are folded with an anti:form that closes to the south. At Sgurr na Ba Glaise the axial plane trace of an antiform closing to the south is indicated by the movement sense of the minor folds, and on Diollaid Bheag the position of the axial plane trace of the complementary synform to the Garbh Leachd antiform can be mapped. The trace of the axial planes of these second folds is illustrated in fig. 9.

On Diollaid Bheag the minor folds that are related to the synform north of the Garbh Leachd antiform indicate that this synform closes to the west at Creag Dhearg. The limbs of the fold are shown by the two pelitic bands that can be traced from Creag Dhearg eastwards to Sgurr na Paite (Map I). The fold closure of this synform has not been mapped, but the psammitic rocks on Diollaid Bheag thin when traced westwards and the fold closure must lie in the unexposed ground immediately north of Creag Dhearg. The evidence suggests that the closures of two second major folds occur in this region, the folds being the adjacent synforms to the Garbh Leachd antiform. The psammitic rock that is found in the core of the Garbh

Leachd antiform thins rapidly in Coire nan Gall and dies out when traced to Creag Dhearg, so that the pelitic horizons which define the limbs of the two synforms coalesce. Thus at Creag Dhearg two second major synforms are present, the Creag Dhearg synform with a N.N.E. - S.S.W. axial plane trend, and the Coire nan Gall synform, the closure at which is not seen, with a N.W. - S.E. axial plane trend on Diollaid Bheag. The minor folds of the Coire nan Gall synform, like the minor folds of the Garbh Leachd antiform and Creag Dhearg synform, have been refolded during the third fold movement, and their axial plane trend varies from a N.N.W. - S.S.E. direction at Creag Dhearg, to an E. - W. direction on Diollaid Bheag and a N.E. - S.W. direction on Sgurr na Paite.

3. The Third-Fold Movement.

The third event in the tectonic history of the area is the folding of the rocks into broad open folds that refold the structures of the first - and second-fold movements. The style of folding of this third movement period differs from that of the earlier movements, in that the third major folds are broad open structures that give rise to marked changes in the trend of the foliation.

Two major folds of this movement period have been mapped, the Diollaid Bheag antiform and the An Stac anti:form. Third minor structures are common and are found throughout most of the area. The third minor folds are well developed in the pelitic rocks but are less common in the psammitic rocks, where minor structures of the first and second fold movements are well preserved. In the central part of the area, where the third major folds are strongly developed, third minor folds are present in all rock types, but to the eastern and western margins of the area the third minor folds become less common and are present only in the pelitic rocks. In the psammitic rocks west of An Stac minor structures of the third fold movement are absent.

Third Minor Folds.

The third minor folds are open asymmetric folds which, in contrast to the second folds, show no variation in style along the axial plane trend and the folded lithological units do not show marked tectonic thickening or thinning when traced round the fold. The quartz-felspar folia of the migmatised pelitic rocks are folded by the third minor folds and the micas (defining S_2) pass round the folds and have not been oriented parallel to their axial planes (S_4). No axial plane cleavage has been found with the third folds.

The axial planes of the third minor folds are inclined at a high angle to the foliation planes (fig. 13).

The angular relationship between the axial planes of the minor third folds and foliation is not constant and it depends upon the position of the minor fold in relation to the third major fold. On the limb of the major fold the axial planes of the minor folds are inclined to the foliation at an angle of $20^{\circ} - 30^{\circ}$ but at the major fold closure the trend of the axial planes of the minor folds is almost at right angles to the foliation. The style of the minor folds also varies, depending upon the position of the fold in relation to the major structure. On the major fold limbs the minor folds are open, asymmetric in style, while near the major fold closure they become very open, almost symmetrical folds trending nearly normal to the foliation. In the psammitic rocks of Druim Comhnardaig the third minor folds

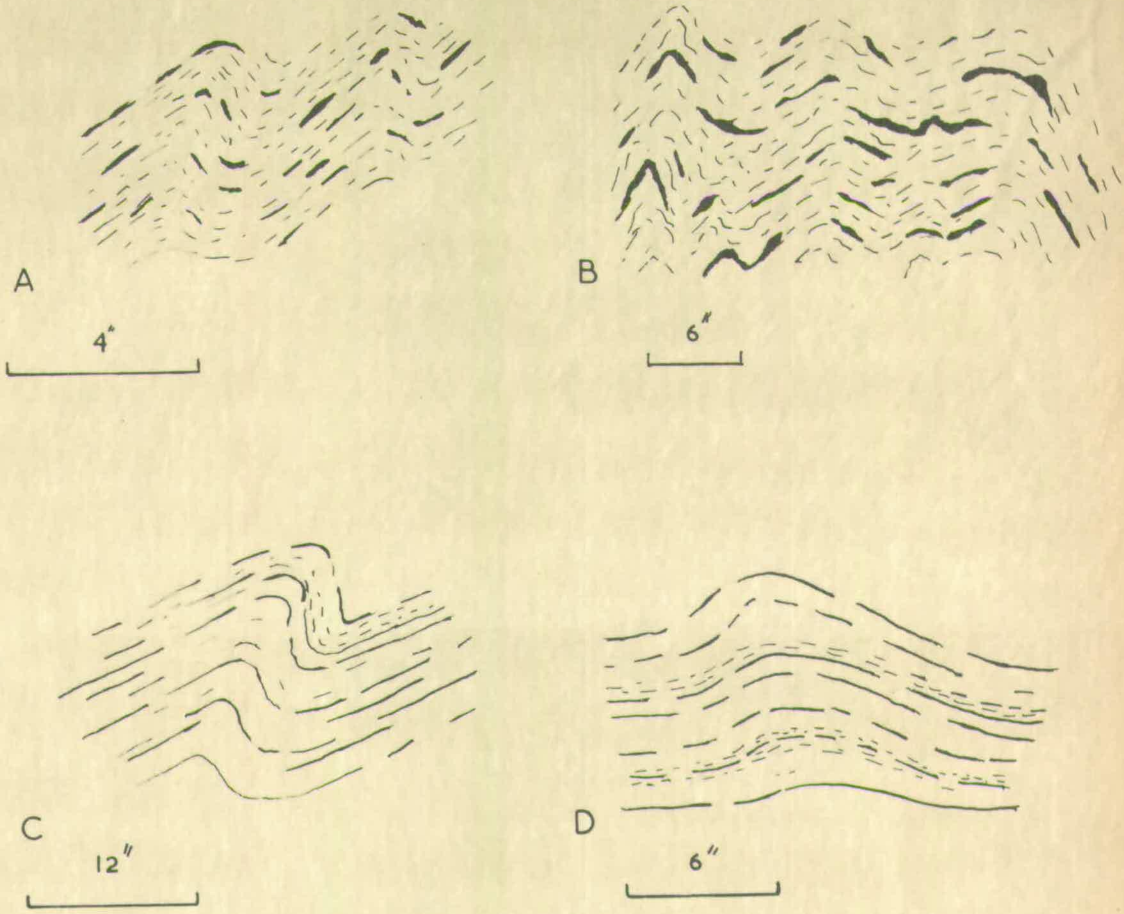


Fig. 13. Profiles of minor structures of the 3rd fold movement.

A from the pelitic rocks at Glenshian.

B from the pelitic rocks of Diollaid Bheag

C from the psammitic rocks E. of Diollaid Bheag

D from the psammitic rocks of Druim Comhnardaig are shallow, open folds (fig. 13) which have a similar axial trend to that of the major fold, the Diollaid Bheag antiform.

Third Linear Structures.

The third linear structure is a mica crinkling (fig. 4), found only in the pelitic rocks. The mica crinkling reflects the style of the third minor folds, being an open, asymmetric crinkle, in contrast to the much tighter mica crinkle formed during the second fold movement.

The axial structures of the third fold movement do not show the great variation in amount and direction of plunge such as shown by the axial structures of the earlier movements. Throughout the area the plunge of the third minor structures remains nearly vertical and only rarely are plunges of less than 70° observed. In any sub-area the direction of plunge remains constant, and the plunge of third minor axial structures reflects the axial plunge of the major folds.

Major Folds.

Diollaid Bheag Antiform.

This is the largest major fold of this movement period present in the area, and is a broad open fold, some two miles wide, the western and eastern limbs of which occur at Creag Dhearg and Garbh Leachd. On Creag Dhearg the foliation trends in a N.N.E. - S.S.W. direction, at Druim Fiaclach the foliation shows a marked change in trend to a N.W. - S.E. direction which continues to the western slope of Garbh Leachd, where the foliation trend changes to a N.E. - S.W. direction. This large scale change in the trend of foliation, which defines the Diollaid Bheag antiform, was described by J.E. Richey (1935) - (see pp8-9). Plotting the change in orientat:ion of the foliation shows that the Diollaid Bheag antiform plunges at more than 80^{o} to the S.S.W. (10^{o} W. of S.) and has a N.N.E. - S.S.W. axial plane trend (fig.14). By using the movement sense of the minor folds the axial plane of the antiform can be traced from Diollaid Bheag southwards.

The style of this major fold changes rapidly when traced in the axial plane direction, the limbes of the fold becoming more appressed from Loch Eilt southwards to the Druim Fiaclach ridge. (Map I). On the southern shore of Loch Eilt the fold is indicated by a change in

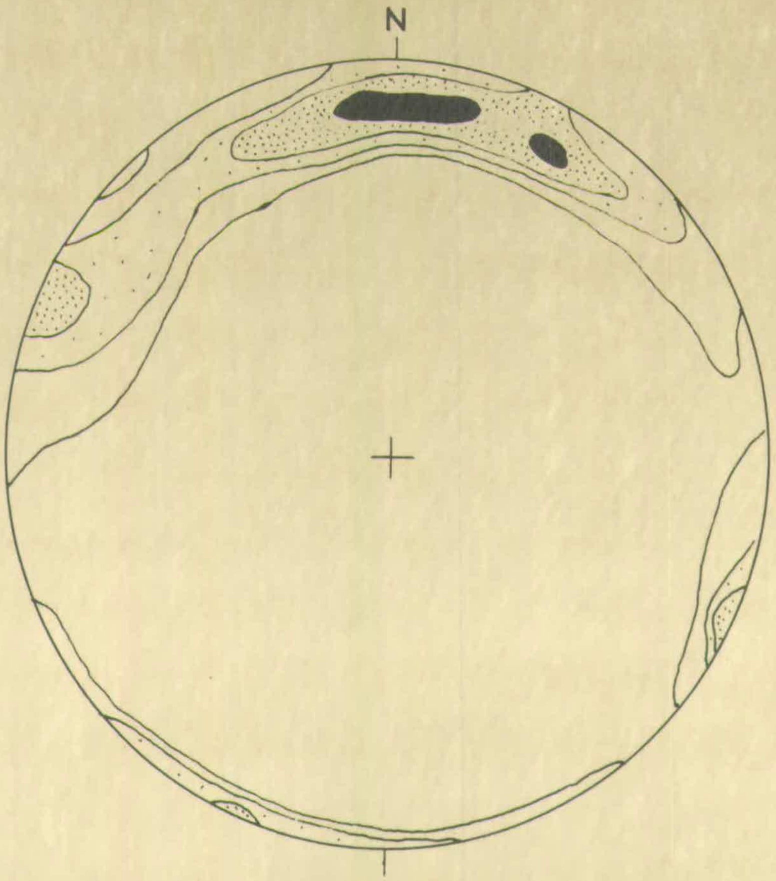


FIG. 14. POLES OF FOLIATION PLANES AROUND THE DIOLLAID BHEAG ANTIFORM. CONTOURS 7, 5, 3, 1% PER 1% AREA

trend of the foliation from a N.N.E. - S.S.W. direction to an E. - W. direction. To the south, on Diollaid Bheag, the antiform has a broad open fold style with the foliation showing only a gradual change in trend. But on Druimm Fiaclach the foliation trend changes rapidly from a N.N.E. - S.S.W. direction to a N.W. - S.E. direction, and a similar rapid change in trend, from a N.W. - S.E. direction to a N.E. - S.W. direction, occurs at Garbh Leachd. The rapid change in foliation trend at Druim Fiaclach and Garbh Leachd gives the fold a rectangular shape, for in the area between Druim Fiaclach and Garbh Leachd, the foliation has a fairly constant trend.

The change in fold style of the Diollaid Bheag antiform has resulted in a marked tectonic thinning of the psammitic rocks present in the core of the Garbh Leachd antiform (second fold). (Map II).

The Diollaid Bheag antiform, although a large structure, dies out very rapidly to the north, and it only refolds the rocks of a restricted area. Reference to the Geological Survey "10 mile" map indicates that the Diollaid Bheag antiform, north of Loch Eilt, is represented only by a gentle swing in the foliation trend, from a N.N.E. - S.S.W. direction to a N.E. - S.W. direction. To the west and south west of Druim Fiaclach, in the valley of Allt a Bhuiridh, the rocks have not been affected by this major fold and the N.N.E. - S.S.W. trend of the foliation is maintained.

The axial plunge of the third minor folds is very steep, and only rarely are plunges of less than 70° recorded.

The dip of the axial planes of the thirdminor folds is nearly vertical, and dips of less than 75° are uncommon. By only slight changes in their orientation, the axial planes of the third minor folds may dip in opposite directions, so that on the limbs of the Diollaid Bheag antiform the axial planes of the third minor folds have variable directions of dip (sub-areas 10,11,12, Fig.26).

The trend of the axial planes of the minor folds varies, for the axial planes "fan" about the axial plane of the major fold. On the western limb of the Diollaid Bheag antiform the axial planes of the minor folds trend in a N.E. - S.W. direction (40° - 50° W. of S.), while on the eastern limb the trend of the axial planes is N.N.W. -

S.S.E. (20° - 30° E. of S.) The axial planes show a variation in trend from a N.E. - S.W. direction to a N.N.W. - S.S.E. direction, fanning some 60° about the axial plane trend of the major fold (10°W. of S.) (Map. II). Only on Diollaid Bheag and Druim Conhnardaig do the axial planes of the minor folds have the same orientation as the axial plane of the major fold. No evidence is present to indicate that the fanning of the third minor folds about the axial plane trend of the major fold is the result of deformation by later movement. Third minor folds in that part of the area have not been seen refolded by later folds, and from Diollaid Bheag southwards to Druim Comhnardaig the axial plane of the third major fold has a constant N.N.E. - S.S.W. trend. It is concluded that the fanning of the third minor folds about the axial plane of the Diollaid Bheag antiform is a primary feature of the third fold movement.

In the south west of the area, at Rois-Bheinn and Sgurr na Ba Glaise, where the rocks have not been refolded by the Diollaid Bheag antiform, the N.E. - S.W. axial plane trend of the third minor folds is still seen. The third minor folds show a regular change in their axial plane trend from a N.E. - S.W. direction to a N.N.W. - S.S.E. direction when traced from the western to the eastern boundary of the area mapped. (Map II).

The Diollaid Bheag antiform refolds the structures of the first and second fold movements, and the orien-:tation of these earlier minor structures can be followed round the antiform. Fig. 9 shows the axial plane traces of the second major folds that have been traced round the Diollaid Bheag antiform.

The An Stac Antiform.

The An Stac antiform, which is about half a mile wide, is found on the north face of An Stac and by plotting the change in the orientation of the foliation planes it is seen that the antiform has an axial plunge of more than 80° to the S.W. The axial plane trends in a N.E. - S.W. direction (sub-area 9, fig. 26). In contrast to the minor folds of the Diollaid Bheag antiform, the axial planes of the third minor folds of the An Stac antiform have a constant trend that is parallel to the axial plane trend of the major fold (sub-area 9, Fig.26). The axial plane trend of the An Stac antiform and associated minor folds is the same as the axial plane trend of the third minor folds found to the south on Rois-Bheinn, and to the east on Druim Fiaclach. Although the axial plane trend of the An Stac antiform differs from the axial plane trend of the Diollaid Bheag antiform, it is suggested that both these major folds are of the same generation. The minor folds and linear structures of each major fold are identical, and minor structures of one major fold are not seen to be refolded by those of the other.

The An Stac antiform dies out within three quarters of a mile in the direction of its axial plane. To the east of Allt a Bhuiridhe no evidence of the fold is seen (Map I). On the western slope of An Stac the antiform disappears, and at the western junction of the pelitic rocks, the trend of the foliation shows a constant N.N.E. - S.S.W. direction.

4. The Fourth-Fold Movement.

Structures of the fourth-fold movement are only found in the south western part of the area. One fourth major fold has been mapped the axial plane of which trends in a N.W. - S.E. direction, a trend that is almost normal to the axial plane trend of the major folds of the earlier movements. The major fold is found on the northern slope of Rois-Bheinn andthe fourth minor structures are common in the region between An Stac and Rois-Bheinn. Fourth minor structures also occur in the psammitic rocks of Sgurr na Ba Glaise, and minor folds which show a similar N.W. - S.E. axial plane trend are present on Seann Chruach.

Fourth Minor Folds.

Fourth minor folds are common in the pelitic rocks and are open asymmetric folds that are very similar in style to the third minor folds. They refold the quartz-felspar folia of the pelitic rocks, the micas of which (defining S_2) pass round the folds and have not been oriented parallel to their axial planes (S_5). The style of the minor folds, which are approximately 6 - 9" wide with an amplitude of about 6", remains constant along the axial plane trace (fig. 15). The fourth

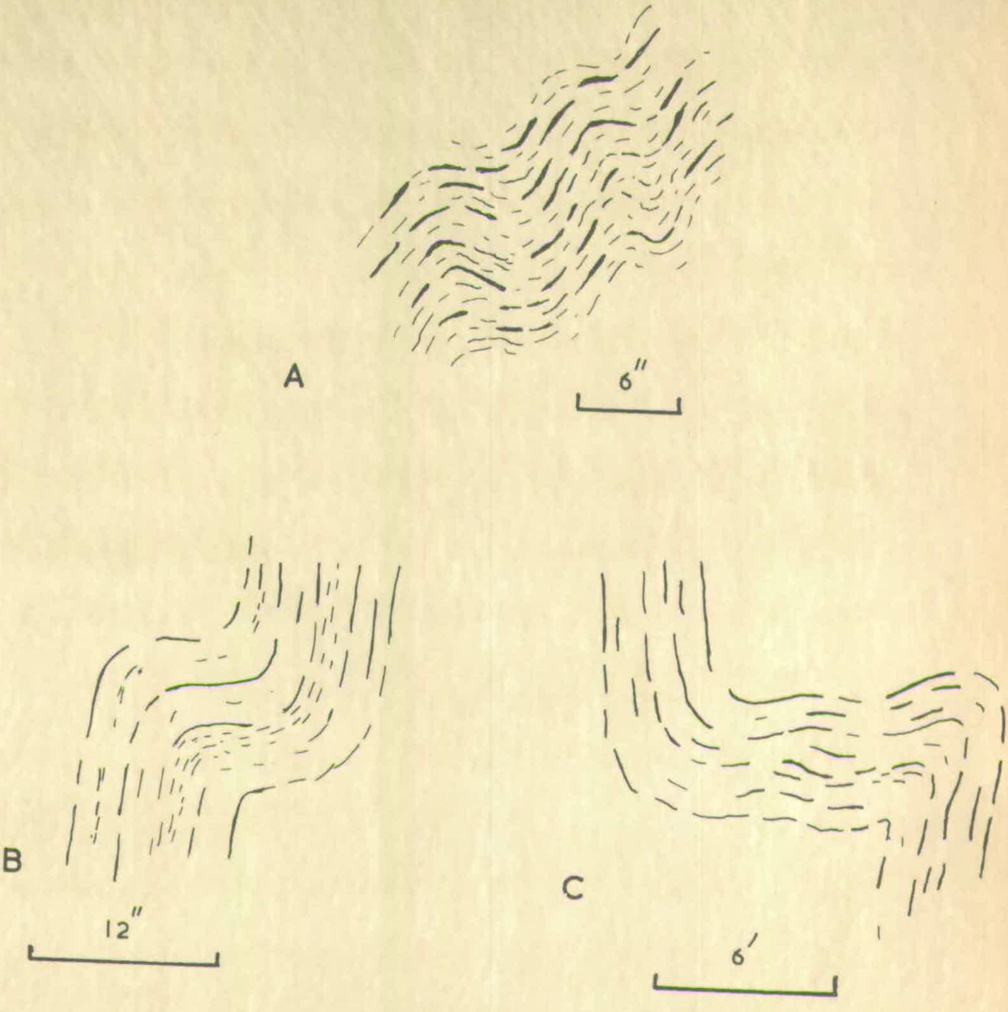


FIG. 15.

A. Fourth minor fold in pelitic rocks.

B.C. Fifth folds in psammitic rocks west of An Stac folds can vary from being open, asymmetric in style on the major fold limbs, to almost symmetrical folds near to the major fold closure. Fourth minor folds are only found in psammitic rocks on Sgurr na Ba Glaise. In some of the folds there is a band, some 2" wide, of pink colouration of the psammitic rock along the axial plane trace. This pink colouration of the rocks is the result of the alteration of the felspars. Occasionally fractur-ing is seen along the axial plane of the fold and the alteration of the felspars may be a result of this fractur-:ing, or the affect of solutions introduced into the plane of fracture.

Fourth Linear Structures.

The fourth linear structure is a mica crinkling, formed in the pelitic rocks, the crinkle showing the same orientation as the fourth minor folds. The crinkling is a broad open crinkle and is very similar to the mica crinkling of the third fold movement. No fourth linear structure has been found in the psammitic rocks.

Fourth Major Fold.

The fourth major fold is an antiform plunging at 80° to the S.E. and having a N.W. - S.E. axial plane trend.

It is found in the pelitic rocks on the northern slope of Rois-Bheinn and the diagrams for sub-area 13 illustrate the orientation of the minor structures of this fold. (fig. 26). The major fold has an open symmetrical style and the affect of it upon the orientation of the foliation and earlier structures is only very slight. It is not a large fold, being some 400 yards wide and it dies out rapidly when traced in the direction of the axial plane. No evidence of the fold is seen in the psammitic rocks to the west and east of Rois-Bheinn.

THE FIFTH STRUCTURES.

The fifth set of structures are only found in the psammitic rocks west of An Stac, where they are quite common.

The fifth folds are open asymmetric folds which in many exposures have the appearance of monoclines, although some folds show a slight overturning (fig. 15). The folds are not consistently overturned in the same direction, and adjacent fifth folds showing opposed movement senses have been mapped. Most of the fifth folds are about 5-10 yds. wide, and on Bealach Breac a fifth fold approximately 200 yds. wide is present, plunging gently to the north.

All the fifth folds have low axial plunges, commonly plunging at less than 20° to the N.N.E., but some folds are found to plunge in the opposite direction. Because they are very open folds the dip of the axial planes is moderate ($40 - 50^{\circ}$), and depending upon the movement sense of the fold, they dip either to the E.S.E. or W.N.W. The axial planes have a N.N.E. - S.S.W. trend, parallel to the trend of the foliation.

The age relationship of these folds with the third and fourth fold movements is not known. In the psammitic rocks minor first and second folds are present and are folded by the fifth folds. Minor structures of the third and fourth fold movements do not occur in these psammitic rocks and their age relationship with the fifth folds is not known. The style, consistently low plunge and axial plane orientation of the fifth folds suggest that they are not related to the third and fourth movement periods.

E. DEFORMATION OF EARLY STRUCTURES BY LATER STRUCTURES.

From the foregoing descriptive account of the major and minor structures of the different fold move:ments, it is evident that the early structures have been strongly deformed by the later fold episodes. The section that follows will describe the geometrical relationship between the earlier structures and those that refold them.

1. Deformation of First-Fold Structures by later movements.

First minor structures are refolded about the axes of the major and minor folds of the later movements. Although first minor structures occur throughout the area they are not common, and the result of refolding the first minor structures about the axes of the later folds is not fully known. During the second and third fold movements recrystallisation took place and second and third linear structures, which overprinted and obliterated most of the first minor structures, were strongly developed.

First minor folds can be traced round the second and third major folds. When the poles of the axial planes of the first folds are plotted on a stereographic net they fall on a great circle, the axis of which is parallel to the axis of the major fold that refolds them. Figs. 16 C,D. shows the orientation of the axial planes and axes of the first minor folds that can be traced round the Creag Dhearg synform (Second Fold) and round the Diollaid Bheag antiform (Third Fold).

During the strong deformation of the second period of folding the first linear structures were destroyed, and refolding of first linear structures by second minor folds is not usually seen. Only in one exposure, which occurs in the psammitic rocks west of An Stac, is a first linear structure seen to be refolded by a second minor fold. The first linear structure is preserved only on one limb of the second fold, and the complete change in the orientation of the early structure is not known.

The amount and direction of plunge of the first linear structures is very variable, even in areas where the axial plane trend of the first minor folds is con:stant, the plunge of the first linear structures shows considerable variation (sub-areas 1, fig. 26). The variation in plunge is the result of deformation by the second and third folds, but from the evidence available, it is not possible to distinguish between the affect of the second folds and the affect of the third folds upon

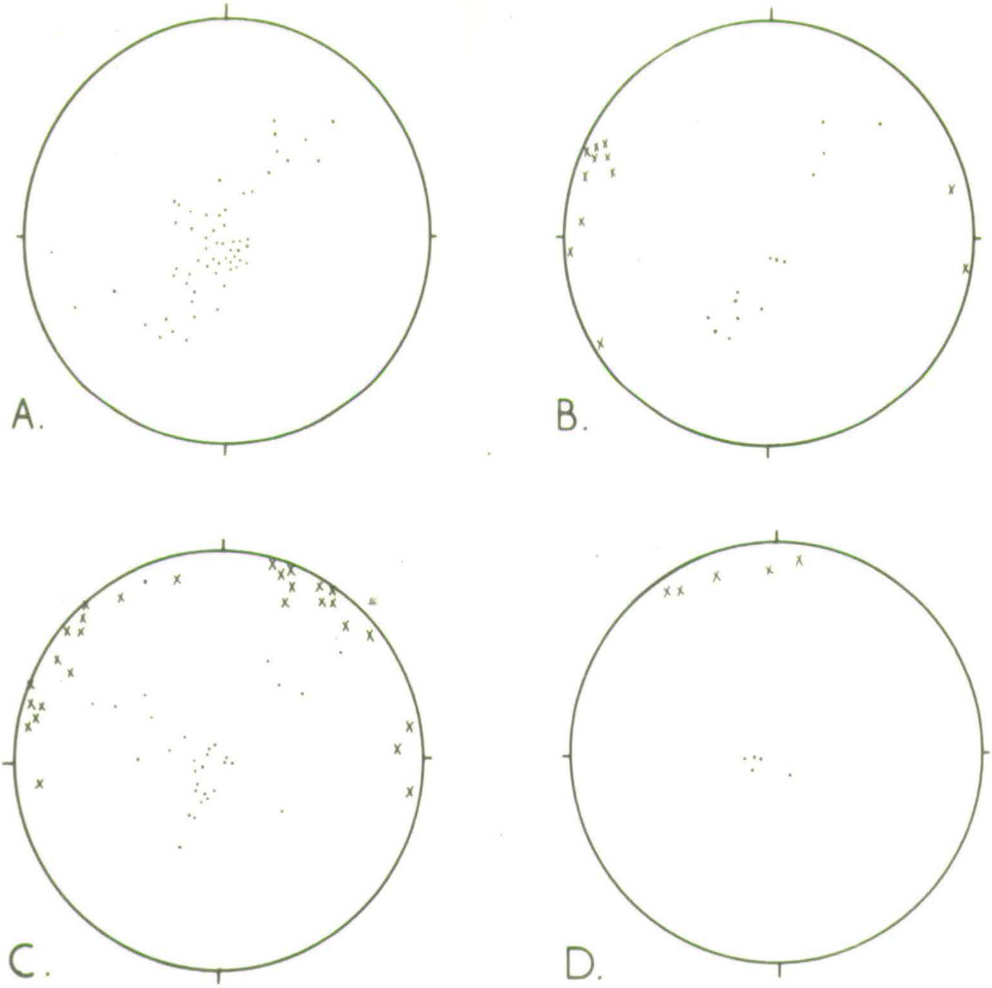


FIG. 16. ORIENTATION OF 1ST. AXIAL STRUCTURES.

· FOLD AXES AND LINEATIONS

x POLES TO AXIAL PLANES

A. FROM WHOLE AREA

B. WHERE NO MAJOR 3RD FOLD IS PRESENT

C. REFOLDED BY THE DIOLLAID BHEAG ANTIFORM

D. REFOLDED BY THE CREAG DHEARG SYNFORM

the orientation of the first linear structures.

First linear structures that are refolded by the Diollaid Bheag antiform (Third Fold), when plotted on a stereographic net, form a N.E. - S.W. trending vertical great circle (fig. 16). The significance of this great circle pattern formed by the first linear structures will be discussed later. The first linear structures that can be traced round the Diollaid Bheag antiform have also been refolded by the second folds, and their orien:tation is the result of deformation by the second major folds as well as by the third major fold.

In areas where no third minor folds are present, and no marked change in foliation trend occurs, the first linear structures show a variable plunge, and when plotted on a stereographic net, form a N.E. - S.W. trending partial vertical great circle (fig.16). In the same areas second linear structures also show great variation in amount and direction of plunge, and on a stereographic net they form a partial vertical great circle, the orientation of which is similar to that formed by the first linear structures (fig. 22). This variation in plunge of the second linear structures is the result of deformation by the third-fold movement, so that the orientation of the first linear structures in the areas where no third folds are found, must be the result of deformation by the third folds as well as by the second folds.

The amount of data available of first structures refolded by the second and third fold movements is insuf:ficient to describe the deformation of the first struct:ures in detail, during the later folding second and third linear structures were formed and the first linear structures were overprinted and destroyed.

2. Deformation of the Second Folds by the Third Folds.

As has already been described, the second major and minor folds have been refolded by the third fold movement. The axial planes of the major and minor folds can be traced round the axes of the third major folds and the second linear structures and fold axes show marked changes in orientation and amount of plunge.

a) Major Second Folds deformed by Major Third Folds.

Two major third folds are present in the area mapped, the Diollaid Bheag antiform and the much smaller An Stac antiform.

The N.N.E. - S.S.W. axial plane trend of the Diollaid

Bheag antiform is similar to the axial plane trend of the second major folds in areas where no third major fold occurs, but whereas the Diollaid Bheag antiform is a large open fold, the second major folds are tight, almost isoclinal folds, and the refolded second major folds show marked changes in their axial plane trend and axial orientation.

The evidence of the structural mapping shows that the Diollaid Bheag antiform refolds at least four second major folds, the Druimm Comhnardaig synform, the Creag Dhearg synform, the Garbh Leachd antiform and the Coire nan Gall synform (fig. 9). By use of the movement sense of the second minor folds, the traces of axial planes of these major folds can be followed round the third major antiform (see pp.115-118).

The orientation of the refolded axial planes of the second major folds reflects the change in style of the Diollaid Bheag antiform (described on pp125-126). Where the Diollaid Bheag antiform is a broad open fold, as on Diollaid Bheag, the axial plane trace of the second major fold in that area reflects that style, but where the Diollaid Bheag antiform is tightly appressed, as on Druim

Fiaclach, and to the South of Garbh Leachd, the trace of the axial plane of the second major fold shows a marked change in trend.

One result of the differing axial plane trends of the major folds is that the fold crests of the complementary synforms to the Garbh Leachd antiform (Second Fold) join together at Creag Dhearg. The evidence of the minor structures indicates that the two synforms at Creag Dhearg show differing axial plane trends, the Creag Dhearg synform having a N.N.E. - S.S.W. axial plane trend while the Coire nan Gall synform shows a N. - S. or N.N.W. - S.S.E. axial plane trend. From their confluence at Creag Dhearg, the axial planes of the synforms diverge (fig. 9).

A result of the refolding of the second major folds about the Diollaid Bheag antiform is that the limbs and axial planes of the refolded major folds have the same direction of dip. The poles to the foliation planes of both limbs of the second folds, when plotted on a stereo-:graphic net, fall on the same great circle, the axis of which is parallel to the axis of the Diollaid Bheag anti-:form. At the crests of the second major folds, the affect of folding about the third major antiform has not resulted in the foliation planes of both limbs of the second folds having the same orientation, and plotting the poles to the foliation planes at the crest of the second folds, a great circle pattern is formed on a stere-:ographic net, the axis of which is parallel to the axis of the second fold. The axial orientations of the Creag Dhearg synform, the Druim Comhnardaig synform and the Garbh Leachd antiform have been determined by plotting the poles to the foliation planes from the crests of these second major folds (sub-areas 5, 16, 7; fig. 26). The axis of the Creag Dhearg synform plunges at 80° to the S.S.W. and that of the Garbh Leachd antiform plunges at 85° to the N.E.

The axial plunge of the second major folds can only be determined from the orientation of the foliation planes at the fold crests, for along the axial plane trace of the major folds, the foliation planes have a constant trend, and the axial plunge to the major folds is indicated by the axial plunge of the associated second minor folds.

Plotting the second minor folds of the Coire nan Gall synform, Garbh Leachd antiform, Creag Dhearg synform, and Druim Comhnardaig synform, shows that the axes of the

Creag Dhearg synform and Druim Comhnardaig synform main-:tain a steep plunge of 80° when refolded by the third major fold, but the axial plunges of the Garbh Leachd antiform and Coire nan Gall synform show great variation. On the western limb of the third major fold the Garbh Leachd antiform and Coire nan Gall synform have very steep plunges (80°), but on the core and eastern limb of the third fold their axial plunges are very variable, and to the west of Garbh Leachd have gentle plunges of 30° to the S.W. (fig. 17).

b) Deformation of Second Minor Folds by Third Major Folds.

Minor second structures are folded about the axes of the third major folds. Minor second folds can be traced round the Diollaid Bheag antiform and their axial planes show changes in orientation through an angle of almost 180°. On fig. 20 are plotted the poles to the axial planes of the second minor folds that are refolded by the Diollaid Bheag antiform, and it can be seen that they fall along a great circle, the axis of which plunges very steeply to the S.S.W., an orientation almost parallel to the axis of the third major fold.

Figure 17.

Orientation of the axial and linear structures associated with the major second folds folded by the third Diollaid Bheag Antiform.

A. Coire nan Gall synform.

B. Garbh Leachd antiform.

C. Creag Dhearg synform.

D. Druim Comhnardaig synform.

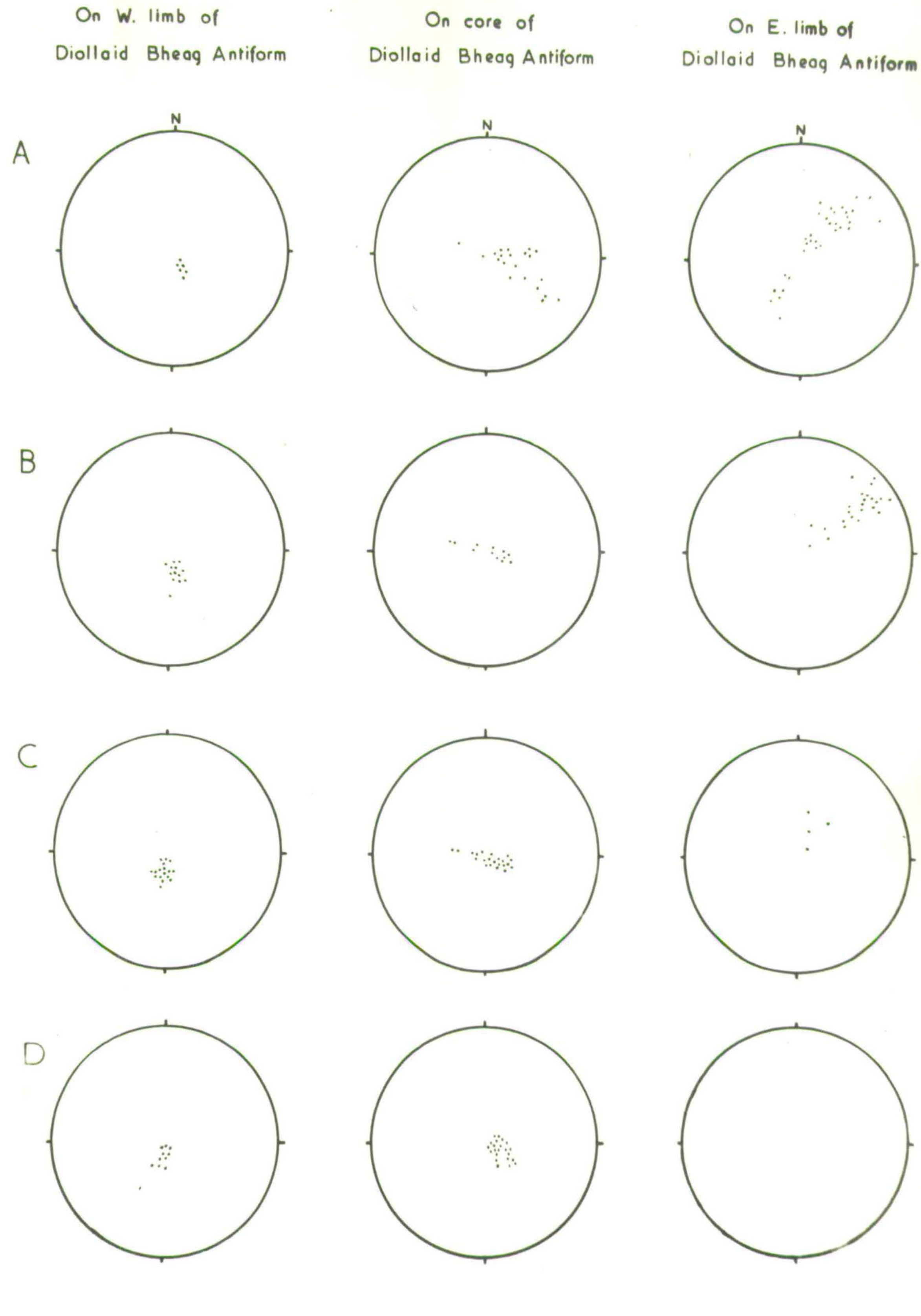

On W. limb of
Diollaid Bheag Antiform
On core of
Diollaid Bheag Antiform
On E. limb of
Diollaid Bheag Antiform
N
N
N
A
B
C
D

FIG. 17.

The axial plane orientation of the refolded second minor folds reflects the change in style of the third major fold (cf. major folds, see above). This can be shown in stereographic nets prepared of the poles to the axial planes of the second minor folds on Druimm Fiaclach, in the area east of Creag Dhearg, and from the area immediately south of Loch Eilt, these areas being found on the western limb of the Diollaid Bheag antiform. (fig.19).

On Druim Fiaclach the second axial planes show a variation in trend between N.N.E. - S.S.W. and N.W. - S.E. direction; to the east of Creag Dhearg the second axial planes show a smaller variation in trend from a N.S. to a N.W. direction; to the south of Loch Eilt the axial planes of the second folds show only a limited variation in trend, having a fairly constant E. - W. trend. This change in the amount of variation of the axial plane trend of the second folds is the result of the change in style of the Diollard Bheag antiform.

Second minor folds are folded about the An Stac antiform, the axial plane of which trends in a N.E. - S.W. direction. On a stereographic net, the poles to the axial planes of the second folds folded about the An Stac antiform form a great circle pattern, the axis of which plunges steeply to the S.W., an orientation that is sub-:parallel to the axis of the third major fold. (Sub-area 9, fig. 26).

Second linear structures and fold axes of second minor folds show great variation in amount and direction of plunge. Individual second minor folds are found that show a variation in plunge from the horizontal to nearly vertical, and "canoe shaped" folds occur. This rapid variation in plunge occurs even in areas where no third minor folds are found, and where second minor folds show a constant axial plane trend. If the variable plunge of the second linear structures is the result of deforma-:tion by the third folds, then the style of the later folding was such that the plunge of the second linear structures could be distorted without the formation of third folds. The evidence suggests that the amount of variation in plunge of the second linear structures depends on the rock type, for in pelitic rocks the plunge of the linear structures is fairly constant, but in psammitic rocks the amount of plunge is much more variable (see pp.112-113).

The influence of rock type upon the plunge of the second linear structures is also apparent in the area that has been refolded by the Diollaid Bheag antiform. In the pelitic rocks of Beinn Coire nan Gall and Druimm Fiaclach the plunge of the second linear structures is consistently steep and plunges of less than 70° are not common. In the psammitic rocks of Diollaid Bheag and Garbh Leachd there is considerable variation in amount and direction of plunge of the second linear structures, the plunge, although commonly steep (70 - 80°), varies from almost horizontal to almost vertical (Map II).

The second linear structures refolded by the Diollaid Bheag antiform, when plotted on a stereographic net, form a N.E. - S.W. trending vertical great circle. (fig. 18). The significance of the orientation of these refolded second linear structures will be discussed later.

Like the second linear structures that have been found in pelitic rocks in other parts of the area, the second linear structures folded by the An Stac antiform have very steep plunges, and structures plunging at less than 70° do not occur. Although these refolded linear structures have a variable trend, because of their con-

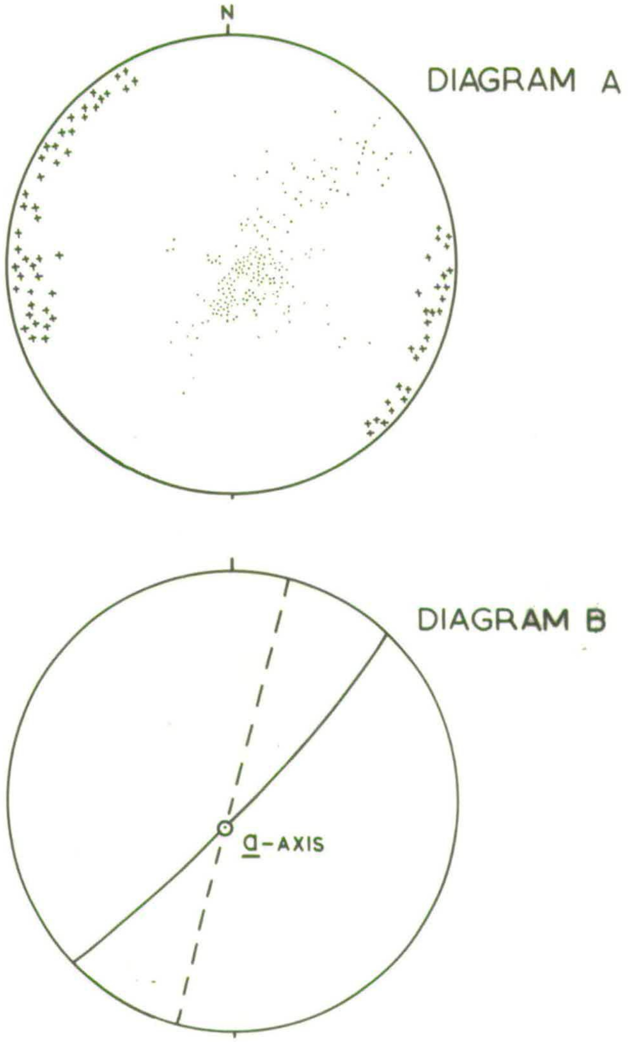


DIAGRAM A

2ND. AXIAL STRUCTURES

\+ POLES TO AXIAL PLANES OF 3RD. MINOR FOLDS ASSOCIATED WITH DIOLLAID BHEAG ANTIFORM.

DIAGRAM B

——— GREAT CIRCLE TRACE OF 2ND AXIAL STRUCTURES

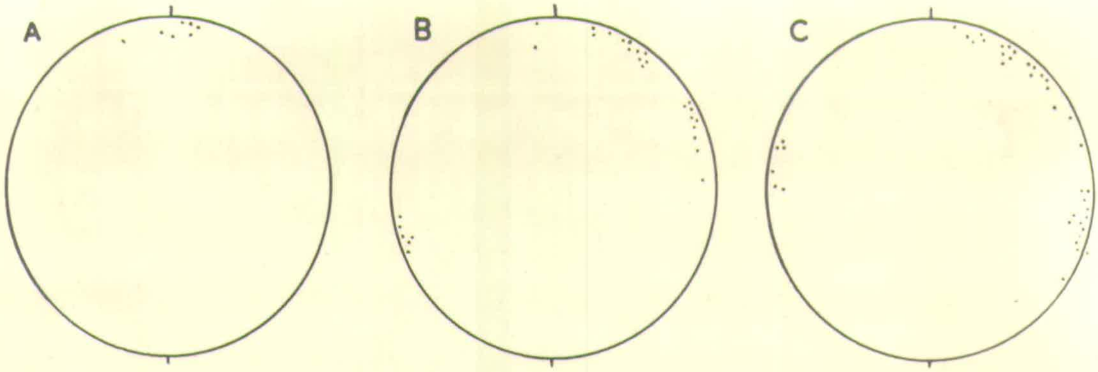
– – – AXIAL PLANE TRACE OF DIOLLAID BHEAG ANTIFORM

a AXIS PLUNGES AT 70° AT 194°

FIG. 18.

:stantly steep plunge they plot as a cluster on the stereographic net, their orientation changing from a steep plunge to the S.S.W. to a steep plunge to the S.E. or E. (Sub-area 9 fig. 26).

Second linear structures have not been seen to be folded by third minor folds, and in exposures where a second minor fold is folded about the axis of a third minor fold, only the third linear structure is present, parallel to the axis of the third minor fold. In areas refolded by the third major folds, most of the second linear structures were destroyed by the intense deforma-:tion of the third folding. Second linear structures are common in areas where the affect of the third fold movement is not strong and in such areas third minor folds are only present in the pelitic rocks. No examples have been seen of second linear structures refolded by these third minor folds. The change in orientation of the second linear structures by the third fold movement is only seen on the major scale, where second linear structures can be traced round the axes of the third major folds.



· - poles to axial planes of second minor folds

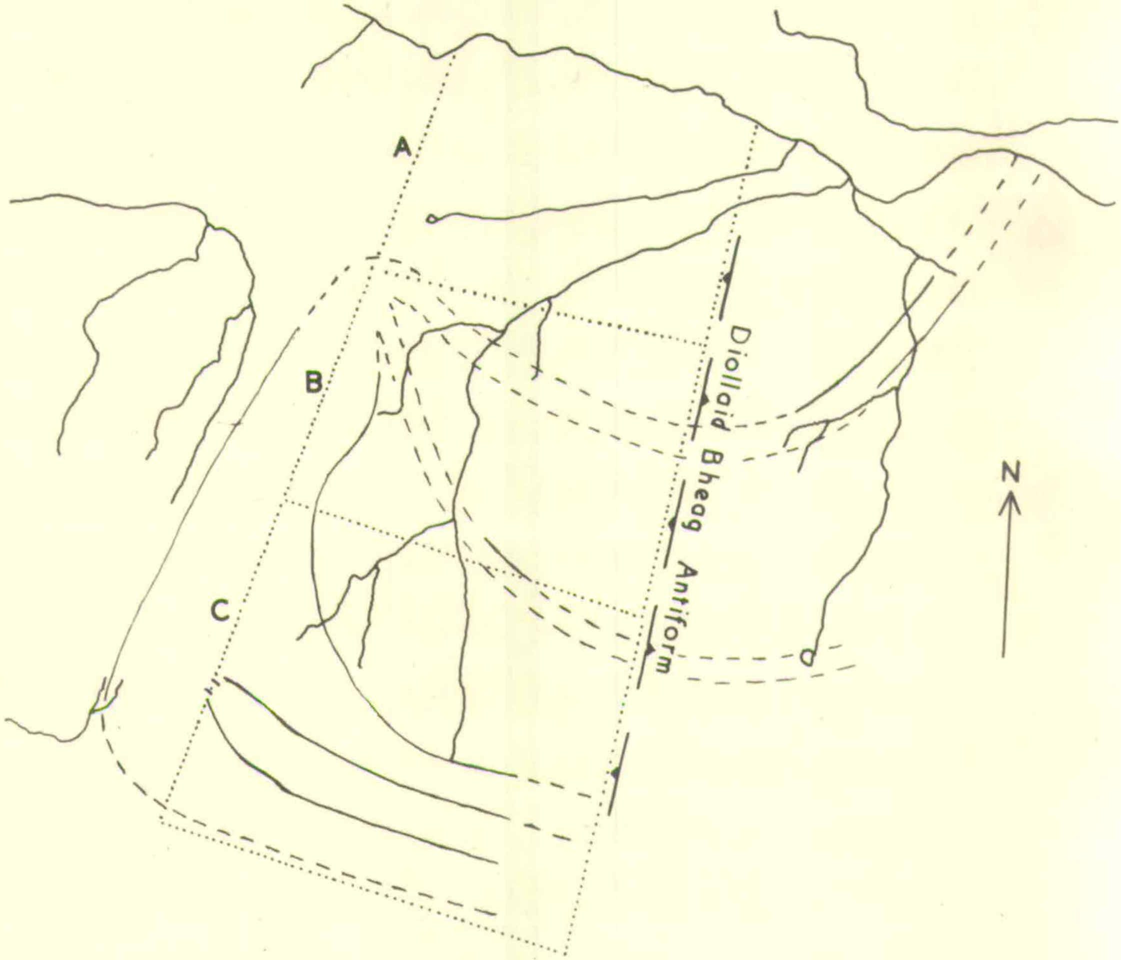


FIG. 19. Variation in trend of axial planes of 2nd minor folds as a result of change in shape of the Diollaid Bheag Antiform.

3. DEFORMATION OF EARLIER STRUCTURES BY THE FOURTH FOLDS.

Deformation of early structures by the fourth folds is restricted to the south western part of the area mapped.

The fourth major fold is a broad, open fold some 250 yds. wide (see pp.132-133), and the refolded early minor folds show only slight changes in their axial plane trend. Only two first, seven second folds and one third fold have been seen to be refolded by the fourth major fold. The trends of the early major folds have not been affected by the major fourth fold, which dies out rapidly in the direction of its axial plane, and the trend of the axial planes of the major second folds present in the south western part of the area have not been deformed.

4. STYLE OF THE SECOND AND THIRD FOLDS.

The results of work by L.E. Weiss (1959) and J.G.Ramsay (1960) show that the geometry of refolded originally rectiliniar structures is governed by the style of the later folding. Linear structures that are deformed by Concentric folding have their locus on a partial cone and when plotted on a stereographic net they lie along a partial small circle. Linear structures that are refolded by Similar folding have their locus on a plane and on a stereographic net they form a great circle pattern. In Similar folding movement takes place in S-planes parallel to the axial plane of the fold, and J.G. Ramsay (1960) states that the movement direction ('a'-axis) can be calculated from the following facts :

a) the axial plane, i.e. the shear surface, of the Similar fold contains the 'a'-axis

b) the plane containing the variably oriented early linear structure is controlled by the movement direction (a-axis) and by the initial orientation of the linear structure.

On a stereographic net the movement direction (a-axis) is given by the intersection of the great circles formed by the refolded linear structures and the axial plane of the later fold.

In Similar folds an axial plane cleavage may be present, and the refolded lithological units usually become thicker on the crest of the fold and thinner on the fold limbs (de Sitter 1956).

In Concentric folding movement takes place in planes parallel to the foliation and the thickness of the folded strata, when measured perpendicular to the foliation,

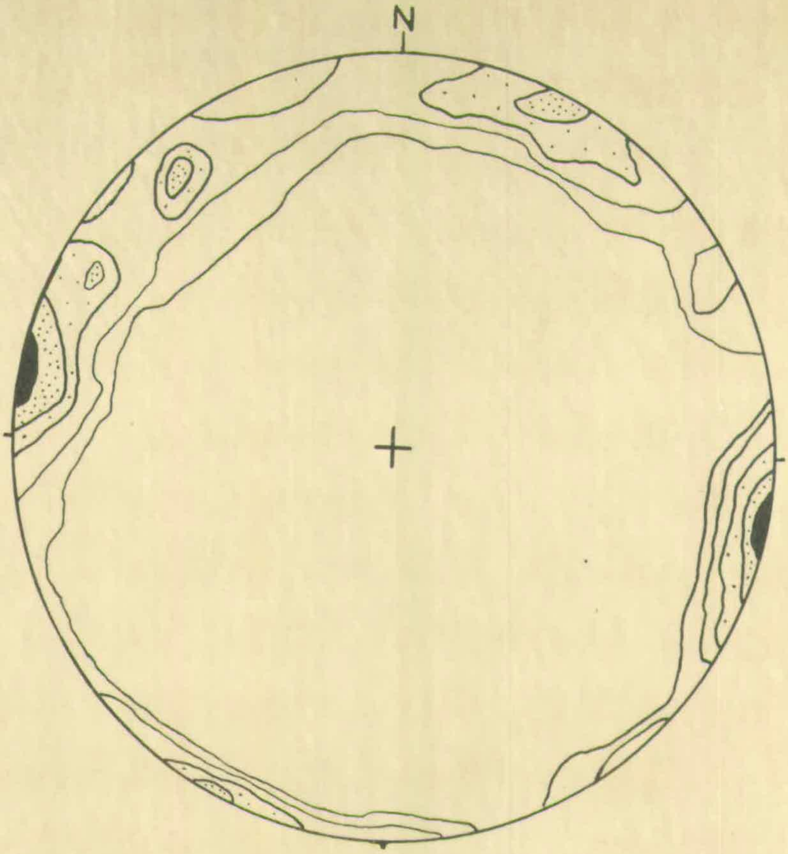


FIG. 20. POLES TO AXIAL PLANES OF 2ND MINOR FOLDS FOLDED BY THE DIOLLAID BHEAG ANTIFORM. CONTOURS: 10, 7, 5, 3, 1% PER 1% AREA.

remains unchanged. Concentric folds tend to die out in the direction of the axial plane (de Sitter 1956).

By applying the results of the work of L.E. Weiss and J.G.Ramsay to the area mapped, an attempt has been made to determine the style of folding and direction of movement of the Second and Third fold movements. J.G. Ramsay (1960) states that Concentric folding is very rare in the Scottish Highlands where most of the folding is of Similar type (1960 p. 76). L.E.Weiss states that the ideal geometry of Similar or Concentric folds will only rarely occur in nature, and most folds are formed by a combination of the two mechanisms of folding (1959 p. 105).

a) Style of the Second Folds.

Certain features of the second folds suggest that they are Similar Folds. The second minor folds commonly show an axial plane cleavage parallel to the second axial planes, and the lithological units folded by the minor second folds show marked thickening on the fold crest, and thinning on the fold limbs (fig. 10). The major second folds are tight, almost isoclinal folds that maintain their shape in the direction of the axial plane.

The style of the second folds cannot be determined from the orientation of the refolded first linear structures (cf. Ramsay, 1960), for the amount of data available of first linear structures refolded by second folds is insufficient to show the geometry of the refolded first linear structures. The movement direction (<u>a</u>-axis) of the second folds cannot, therefore, be calculated.

First linear structures have been refolded by second folds and by third folds and it has not been possible, on the evidence available, to distinguish between the affect of the second folds and that of the third folds upon the orientation of the first linear structures (pp137-139).

<u>Style of the Third Folds.</u>

The foliation planes and the axial planes of the major and minor second folds are nearly vertical throughout the area and these planar structures are vertical in parts of the area where no third major and minor folds are found. It is suggested that before the third fold movement occurred the foliation planes and the axial planes of the second folds were nearly vertical and the third major and minor folds, which have vertical axial planes and axial plunges, were superposed upon already vertical rock. The axial plunge of the second folds before the third folds were formed is not known. Through:out the area the axial plunge of the second minor folds is very variable, and plotting the axial orientation of all the second minor folds on a stereographic net, a N.E. - S.W. trending partial great circle is formed which shows a strong maxima plunging at 75° to the S.S.W. (fig. 21). Major fold axes determined from the change in orientation of the foliation planes have nearly vertical plunges. The axial orientations of the second folds are distorted by the third fold movement and the original axial plunge of these fols cannot be determined.

A stereographic projection of the second linear structures refolded by the Diollaid Bheag antiform (third fold) shows that they fall on a N.E. - S.W. trending vertical great circle (fig. 18), which suggests that the third major antiform is a Similar fold (cf. Ramsay, 1960, p.92). Moreover, the variably oriented second linear structures in areas where no third minor folds are found, and where the axial planes of the second minor folds show a constant trend, lie along a N.E. - S.W. trending vertical great circle. The great circle pattern formed by these second

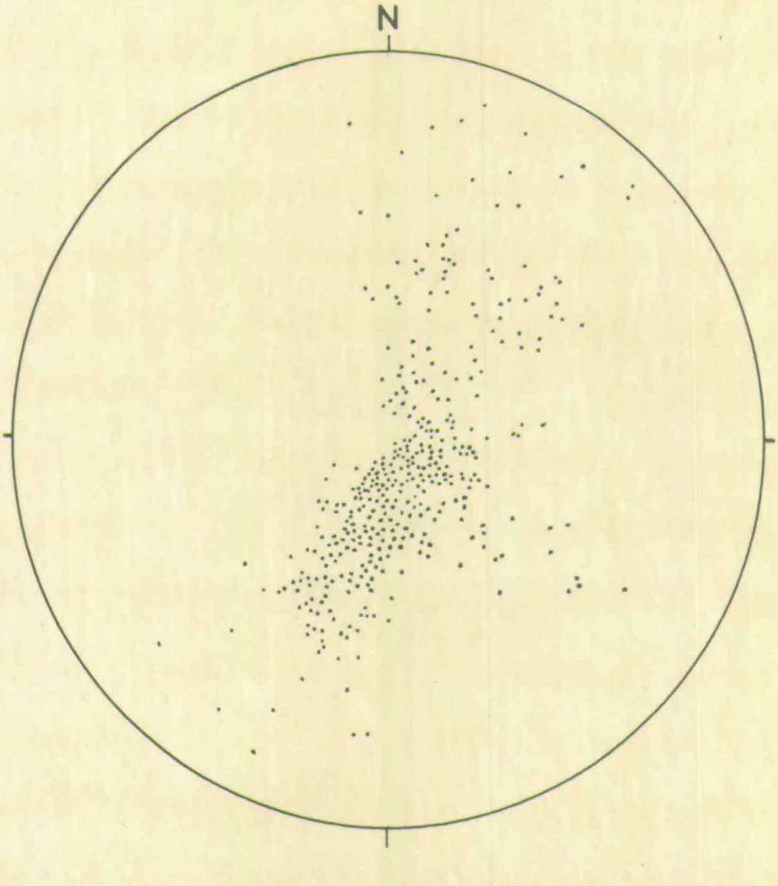


FIG. 21. PLOT OF 2ND. AXIAL STRUCTURES FROM WHOLE AREA.

linear structures has a trend very similar to that of the foliation of the area. By plotting the poles to the foliation planes, it can be seen that they form a strong maximum which is nearly perpendicular to the great circle pattern formed by the second linear structures. (fig.22).

The refolded second linear structures do not form a small circle pattern on a stereographic net, and therefore the third folds are not Concentric in style. (cf. L.E. Weiss, 1959; J.G. Ramsay, 1960).

J.G. Ramsay (1960) stated that if the movement direction (a-axis) of Similar folding was within the plane of foliation, no fold will develop, but earlier linear structures would be distorted. The vertical great circle formed by the second linear structures in areas where no third minor folds occur, may be the result of a third movement lying in, or near to, the plane of foliation and the second linear structures have been distorted, without the formation of third folds. Other features however suggest that the style of the third folds and orientation of the refolded second linear structures is complex.

The intersection of the vertical great circle formed by the refolded second linear structures with the vertical

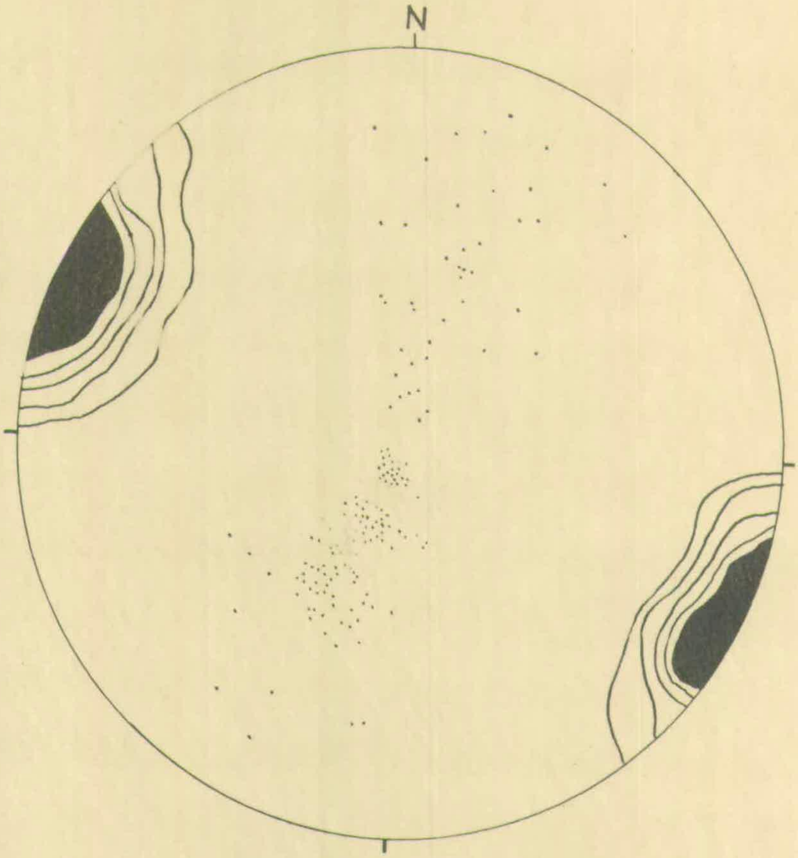


FIG. 22. ORIENTATION OF 2ND AXIAL STRUCTURES IN ALLT A BHUIRIDH, WHERE THE TREND OF FOLIATION IS CONSTANT. POLES TO FOLIATION CONTOURED: 12, 9, 6, 3, 1% PER 1% AREA.

axial plane of the Diollaid Bheag antiform indicates that the movement direction (a-axis) is nearly vertical, and sub-parallel to the axis of the third major fold (fig. 18). The orientation of the 'a-axis' (70° towards 190°) is approximately the same as the axial orientation of the Diollaid Bheag antiform. By a nearly vertical movement direction it is not possible to form third folds, other than very open folds, that have nearly vertical axial plunges and which close sideways. It is also difficult to reconcile an antiform that plunges to the S.S.W. with a movement direction that indicates almost vertical movement from the S.S.W. If the Diollaid Bheag antiform is a Similar fold, it might be expected that movement would take place from a N.N.E. direction towards a S.S.W. direction, i.e. the calculated movement direction (a-axis) would plunge at a moderate angle to the N.N.E. Moreover, as has been mentioned above, the evidence suggests that before the third-fold movement took place, the foliation planes were nearly vertical, and with a nearly vertical movement direction in nearly vertical rock no third folds should form.

Second linear structures refolded by the An Stac antiform do not form a great circle pattern. The plunge of the second linear structures remains steep when traced round the axis of the later fold and they plot as a cluster on the stereographic net. (Sub-area 9 fig.26).

The third minor folds show features which are not consistent with a Similar fold style. The axial plane trend of the third minor folds fan some 60° about the axial plane trend of the major fold, and the refolded lithological units, when traced round the third minor folds do not show marked tectonic thickening on the fold crests and thinning on the fold limbs.

Despite the evidence provided by the deformation of the second linear structures, the third folds cannot be described as ideally Similar folds and the orientation of the refolded second linear structures may be the result of refolding by third folds in which both the mechanisms of Similar and Concentric folding have taken place. The great circle pattern formed by the refolded second linear structures shows a horizontal spread of some 30° (fig.18). This wide spread of the refolded linear structures may be the result of an initial deformation by third folds that were Concentric in style, with the formation of a small circle pattern, but subsequent deformation in a Similar manner re-oriented the deformed second linear structures so that the small circle pattern was destroyed and a partial great circle, having considerable horizontal spread, was formed. During the later phase of Similar folding the second linear structures, in areas where no third minor folds are found, were deformed into a great circle pattern, the orientation of which is nearly simi-:lar to that formed by the second linear structures refolded by the Diollaid Bheag antiform. (fig. 22).

Another possible explanation of the geometry of the second linear structures concerns the original orientation of the second linear structures. The ideal geometrical pattern of linear structures refolded by either Concentric or Similar folds will only be produced if the linear structures were originally rectilinear. In the pelitic rocks of the area the second linear structures have a steep plunge, while in the psammitic rocks the plunge of these structures is very variable. This evidence suggests that the plunge of the second linear structures, as a result of later deformation, was controlled to some extent by rock type. It is possible that the second linear structures had a variable plunge before the third-fold movement took place, and a variation in plunge may be the result of

a) the superposition of the second folds upon already isoclinally folded rock.

b) during the second-fold movement minor folds of variable plunge, but constant axial plane trend, were formed.

Previous work (L.E.Weiss and D.B. McIntyre 1957, J.G. Ramsay 1958a 1959b) has shown that the axial orientation of later folds is governed by the orientation of the fold limbs of the earlier folds. In the area mapped the fold limbs, axial planes of the first isoclinal folds are parallel to the foliation and the second folds were superposed upon rock that contained only one planar structure. Thus it is doubtful if the variable plunge of the second linear structure is the result of their superposition upon rock in which all planar structures were parallel.

It is difficult to envisage a style of second folding that would produce such a rapid variation in axial plunge of the second folds (plate III), and it is assumed that the second linear structures were originally rectilinear.

It must be concluded that the third fold style is complex, and it is not possible to state that the third folds are ideally Similar or Concentric folds. The three suggested explanations of the evidence available may be summarised as follows :-

a) The third folds are pure Similar folds and the second linear structures refolded by the Diollaid Bheag antiform form a great circle pattern, which is presumed to be attributable to the third fold movement. The objection to this explanation is that the calculated movement direction (a - axis) is sub-parallel to the axis of the third major fold. Further, the calculated a-axis indicates movement from a S.S.W. to a N.N.E. direction, and this movement is difficult to reconcile with a third antiform that plunges steeply to the S.S.W.

b) During the third folding both the mechanisms of Similar and Concentric folding took place. If the third folds are not ideally Similar in style then the refolded second linear structures will not form a great circle pattern and the movement direction cannot be calculated.

c) The refolded second linear structures were not originally rectilinear, and the ideal geometry of refolded linear structures by either Concentric or Similar folding will not be produced. But as the small-scale variation and large-scale variation in plunge of the second linear structures agree and are equally large, it is probable that these structures were originally rectilinear.

Concluding Statement. It is evident from the foregoing account that the determination of the style and movement of the later folds by study of the orientation of the refolded early linear structures has led to complicated and conflicting results. Second folds have the appearance of Similar folds, but the amount of data of first linear structures refolded by second folds is insufficient for the style of the second folds to be determined by the method suggested by Weiss (1959) and Ramsay (1960). Second linear structures refolded by the third Diollaid Bheag antiform appear to form a great circle pattern, but the calculated direction of transport is sub-parallel to the axis of the third major fold. It may be that the orient-:ation of the second linear structures and the third folds has been modified by subsequent movement, but there is no evidence to support this suggestion.

It is tentatively proposed that the third folds are not ideally Similar folds. The apparent great circle pattern of the refolded linear structures is the result of the third folds having a style that is a combination of Concentric folding and Similar folding and the orienta-:tion of these linear structures cannot be used to determine a direction of transport for Similar folding.

F. PETROFABRIC ANALYSIS

The quartz and mica fabric of the rocks of the area has only been very briefly investigated. The specimens that have been studied were chosen so that the fabric patterns could be related to distinct megascopic structures of known age. The relationship between the microfabric and the large scale structural features could thus be studied directly.

It is evident that since the area has undergone a complex sequence of deformations, the history of the quartz and mica fabric will be equally complex. As will be shown later, the rocks have undergone recrystallisation during, or after, each fold movement, and the several phases of recrystallisation must have modified the quartz and mica fabric patterns.

The dominant fabric pattern shown by the quartz is a 'cleft' girdle of quartz c-axes at right angles to the megascopic axial structure. With one exception, in the specimens studied there is no clear distinction between the fabric patterns of different ages, and it has not been possible to recognise the influence of the different fold movements upon the present microfabric of the rocks.

Four quartz fabric diagrams have been prepared from a first minor isoclinal fold present in the psammitic rocks some 40 yds. S. of Glenshian. (fig. 23). The quartz of the psammitic rock has completely recrystallised and shows no evidence of a dimensional orientation. Within the same outcrop second minor folds are common. The quartz fabric shows an incomplete girdle pattern containing a strong maximum perpendicular to the fold axis and inclined to the axial plane of the fold at an angle of 10° (diags. B, C, D fig. 23). In the fabric diagrams from the two limbs of the fold the maxima are more strongly developed and the girdle pattern is less obvious.

The quartz-fabric from a first isoclinal fold on

Figure 23.

Quartz orientation diagrams from a first isoclinal fold, 150 yards south of Glenshian.

A. Location of diagrams in first fold.

B. 250 c-axes from field 1.

C. 250 c-axes from field 2.

D. 250 c-axes from field 3.

E. 200 c-axes from field 4.

Contours at 1-2-3-4-5% per 1% area.

AP. - axial plane b - fold axis.

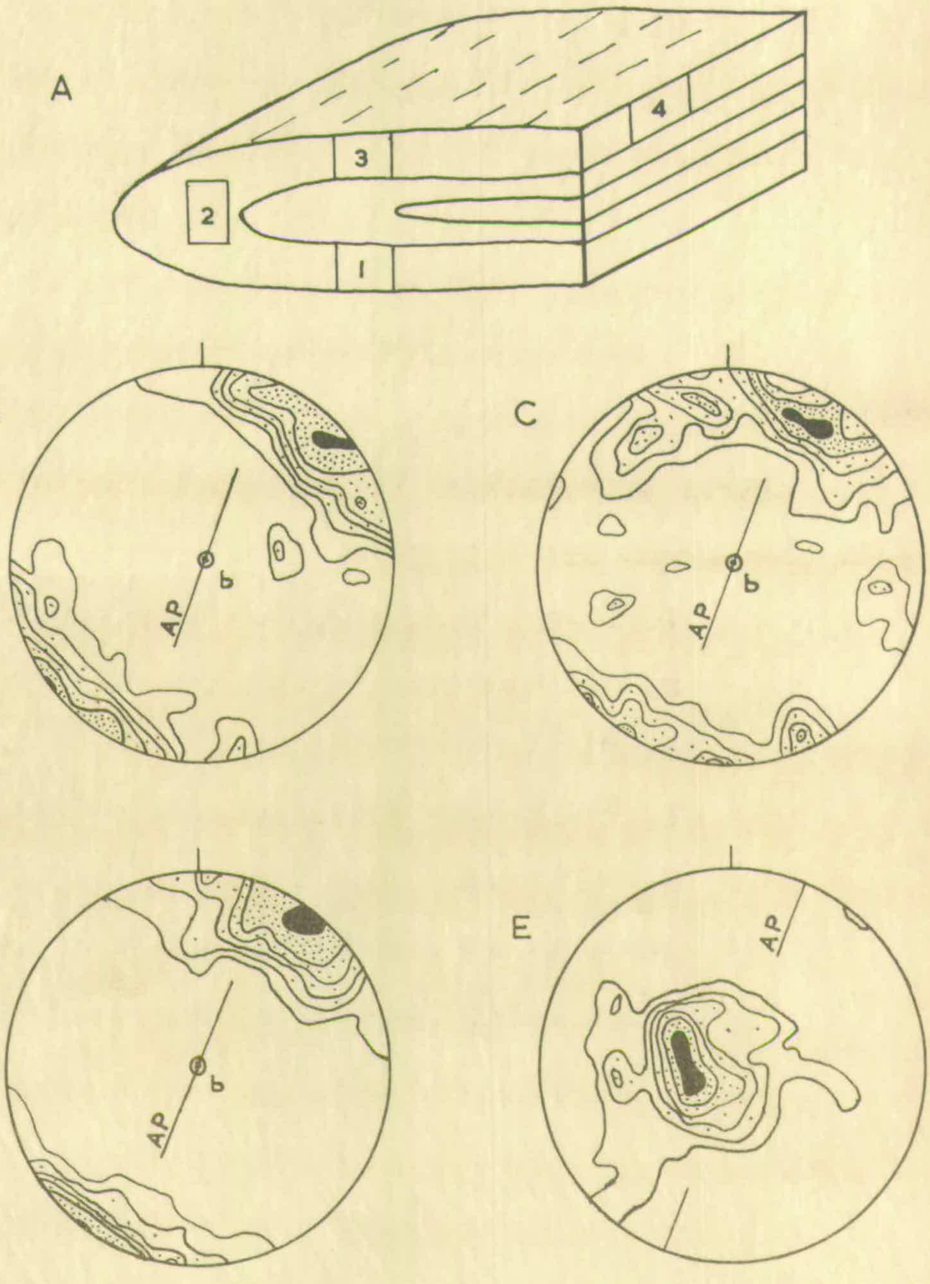


Fig. 23.

Sean Chruach shows a different fabric pattern, in that no strong maximum is present, the quartz c-axes being oriented into an incomplete 'cleft' girdle at right angles to the fold axis (diag. A, fig. 25).

Quartz fabric diagrams have been prepared from four specimens containing second axial structures. Fig. 24 shows the fabric diagrams from a second minor fold present in the psammitic rocks south of Glenshian, and occurring in the same exposure as the first isoclinal fold described above. The specimen is the only example that has been found in which a first linear structure is seen to be refolded by a second minor fold. The quartz fabric shows a strong maximum inclined to the fold axis at an angle of 20 - 30° and an incipient, incomplete girdle at right angles to the second fold axis. On the fold crest the girdle pattern is well developed, but on the limbs of the fold the girdle is less obvious while the maximum is very strong. It is significant that the maximum is oriented perpendicular to the first linear structure (diag. 4, fig. 24). The quartz microfabric of the second axial structures from other parts of the area show a 'cleft' girdle pattern at right angles to the second axial structure

Figure 24.

Quartz orientation diagram from a second minor fold, 150 yards south of Glenshian.

A. Location of diagrams in second fold.

1, 2, 3 250 c-axes, perpendicular to axis of second fold.

4. 200 c-axes perpendicular to first lineation.

Contours at 1-2-4-6-8% per 1% area.

AP - axial plane b_1 - first linear structure.

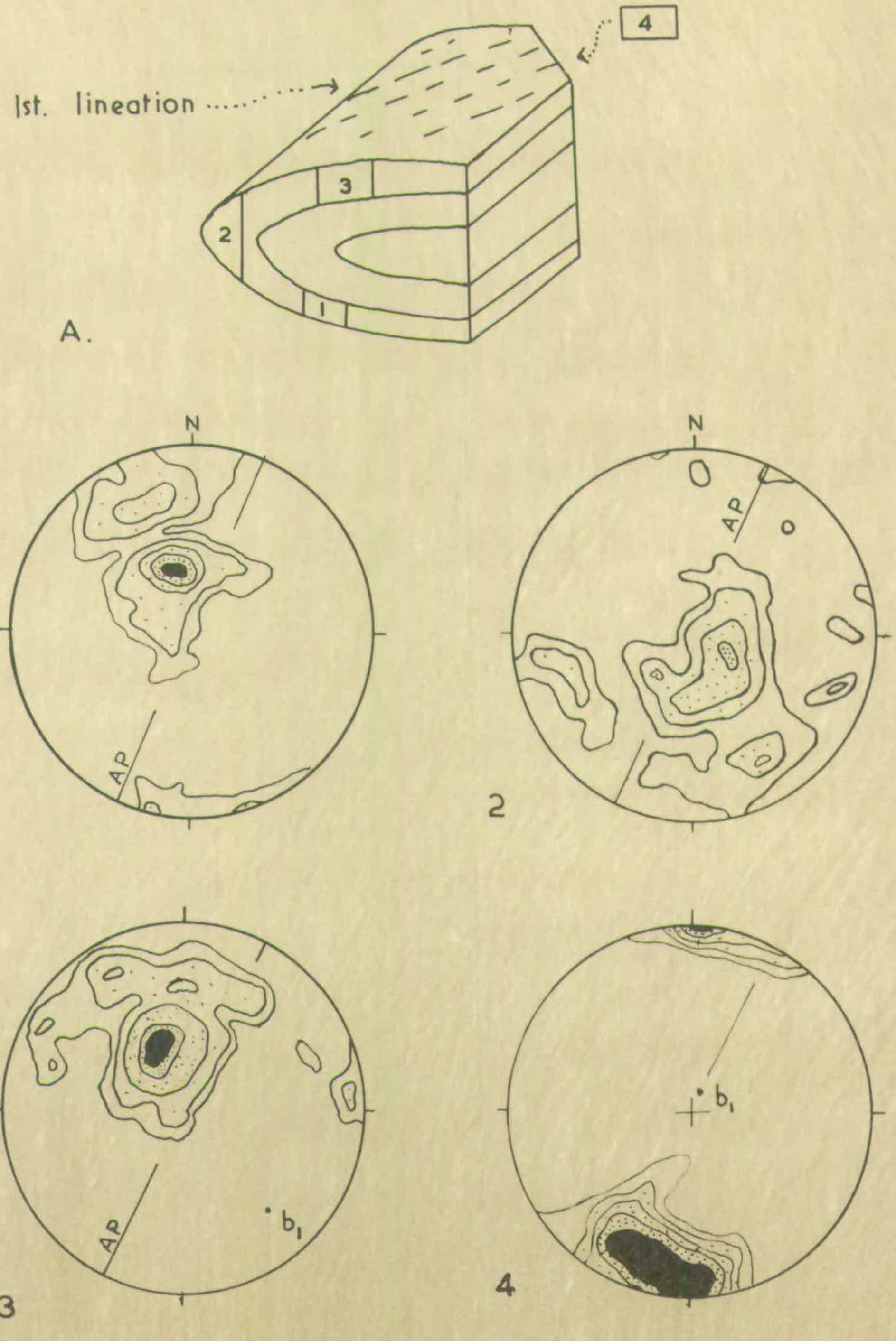


FIG. 24.

(diags. B, C, D fig. 25).

Fabric diagrams of specimens containing third axial structures show incomplete 'cleft' girdle patterns (diags. E, F fig. 25). Diagrams F, G. show the quartz and biotite microfabric from a pelitic rock in which the third mica crinkling is present. The girdle pattern of the biotites is well developed but that of the quartz is less well defined. This may indicate that during subsequent recrystallisation the quartz was more readily re-oriented than the biotite.

Conclusion.

The fabric pattern shown by the isoclinal fold in the psammitic rocks south of Glenshian suggests that in the first fabric there was a development of a maximum lying approximately in the ac-plane. The fabric diagrams of the second minor folds from the same outcrop indicate that this first maximum has been preserved despite the strong deformation of the second fold movement. Elsewhere in the area there is no evidence of this first fabric maxima and the minor isoclinal fold from Seann Cruach shows a 'cleft' girdle fabric, indicating that the quartz has been, at least partially, re-oriented

Figure 25.

Petrofabric diagram from axial structures of different ages.

A. 250 c-axes from a first minor fold in the psammitic rocks of Seann Chruach. Contours 1-2-3-4% per 1% area.

B. 300 c-axes from a second minor fold in a calc-silicate band on Druim Fiaclach summit.
Contours 1-2-3-4-5% per 1% area.

C. 300 c-axes from second minor fold in psammitic rock, east of Diollaid Bheag summit.
Contours 1-2-3% per 1% area.

D. 300 c-axes from specimen showing second linear structure from the valley of Allt a Bhuiridh.
Contours 1-2-3-4-5-6% per 1% area.

E. 250 c-axes from specimen containing third mica crinkle, from pelitic rocks east of Druim Fiaclach summit.
Contours 1-2-3-4% per 1% area.

F. 250 c-axes from specimen containing third mica crinkle, from pelitic rocks east of Druim Fiaclach summit.
Contours 1-2-3-4% per 1% area.

G. 250 poles to cleavage planes of biotites from same specimen as F. Contours 1-2-3-4-5% per 1% area.

AP - axial plane.
b_1 - first fold axis.
b_2 - second axial structure.
b_3 - third axial structure.
F - foliation plane.

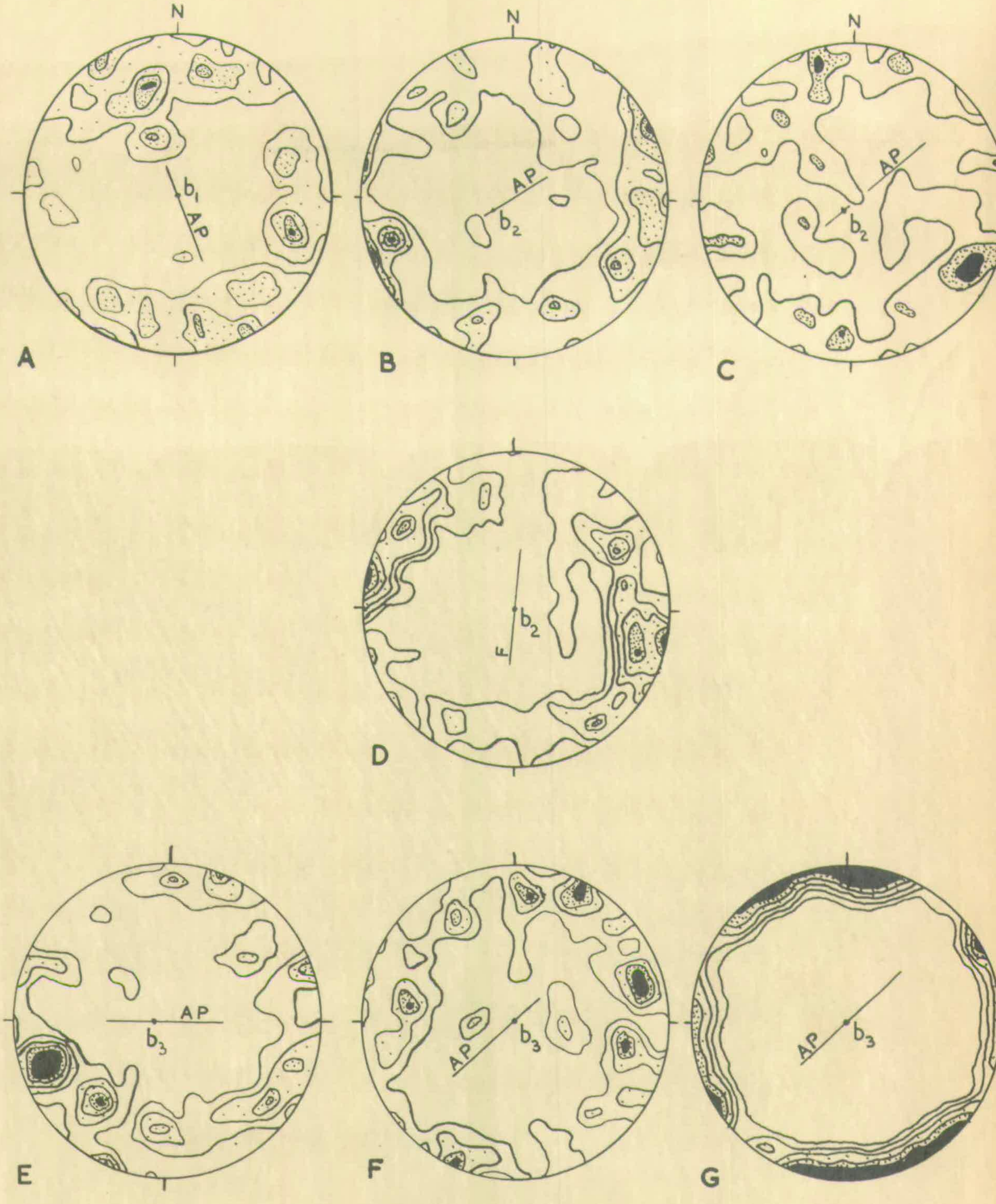


FIG. 25

during the subsequent fold movements. The cleft girdle must post-date this first isoclinal fold but its age-relationship with the girdle fabrics of the second and third movements is not known.

The 'cleft' girdle pattern shown by the axial structures of different ages is difficult to interpret. Although the study of the megascopic structural data indicates four periods of doling, the microfabric associated with these fold movements, except in one example, cannot be clearly distinguished. The girdle fabrics have been described as "cleft" girdles, but it is possible that they may represent double girdles, formed by the superposition of two inclined girdle fabrics of different ages. Definite ac-girdle patterns have not been found, and it may be that the absence of true ac-girdles is due to the complex movement history, the 'cleft' girdles resulting from the complex relationship between fabric patterns of different ages.

G. CONCLUDING STATEMENT.

The structural study of the area mapped shows that the rocks have suffered four periods of folding, and because of the superposition of folds of one generation upon those of another, the geometry of the axial and planar structures of each fold movement is complex. Despite the complexity of the folding however, the structural mapping has shown that there is a constant relationship between the large scale and small scale structures of the same generation. It has been only by the detailed analysis of the structural elements on all scales that the movement history of the rocks has been established.

As a result of the complex movement history the rocks throughout most of the area have a nearly vertical disposition. It is not known at what stage in the movement history the rocks became vertical, but there is sufficient evidence to show that before the third fold movement took place the rocks were vertically oriented. G.P.Leedal (1952) has indicated that the Moine rocks are steeply inclined in a belt of mountain-:ous country that extends from the Sound of Mull in the south, to Ross-shire in the north. To the east of the vertically inclined rocks, in a belt some 10-15 mls. wide, and west of the Great Glen, the Moine rocks are gently inclined into a "flat belt" (op.cit. 1952 p.37).

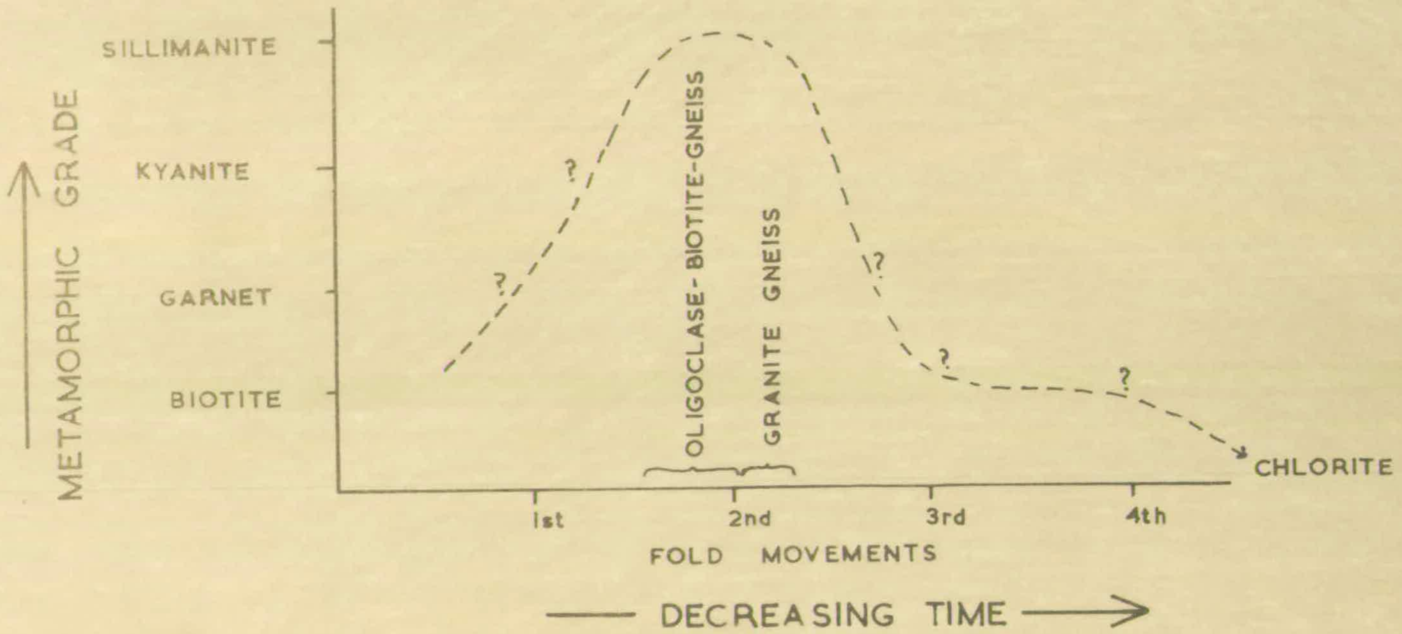


FIG. 27 THE AGE RELATIONSHIPS OF METAMORPHISM MIGMATISATION AND MOVEMENT

It is interesting to note that the western and eastern boundaries of the area of vertically oriented rocks are approximately coincident with the western and eastern boundaries of the zone of regional injection (see also T.N. Clifford, 1957).

W.Q. Kennedy (1955), in his structural interpreta-:tion of Morar, states that the "evelope" of the Morar dome represents the Morar nappe, and is made up of Moine rocks in stratigraphical succession that have been thrust westwards over the rocks of the "core" before regional injection and metamorphism had taken place (see pp.19-20). In the area mapped, the rocks were isoclinally folded before the period of migmatisation, and it may be reasonable to suggest a structural correlation between the first fold movement of the area mapped and the first movement episode of Morar - the formation of the Morar nappe. Further structural correlation with Morar is difficult. Kennedy (1955) states that the Morar dome developed during the time of the formation of the Morar nappe. The Morar Basal Thrust however, is folded by the Morar dome, and this may suggest thatthe formation of the dome post-dates the Morar nappe. Kennedy also concluded that the Morar dome was formed before regional injection and metamor-:phism. The evidence from the area mapped indicates that regional injection and metamorphism took place after the first fold movement (equivalent to the Morar nappe), but preceded and accompanied the second period of folding. It may be suggested that the second fold movement of the area is structurally equivalent to the Morar dome, in which case the formation of the Morar dome may have taken place during the time of regional injection and metamorphism and not, as Kennedy suggested, at an earlier period.

Such a structural correlation is only tentative, and until a detailed structural study is carried out in Morar and the adjacent regions, a definite structural correla-:tion cannot be established. The evidence from the area mapped clearly indicates that the structural history of the rocks is extremely complicated, and, as the work of Richey and Kennedy (1939) and Kennedy (1955) has shown, the structural history of adjacent areas is equally complex.

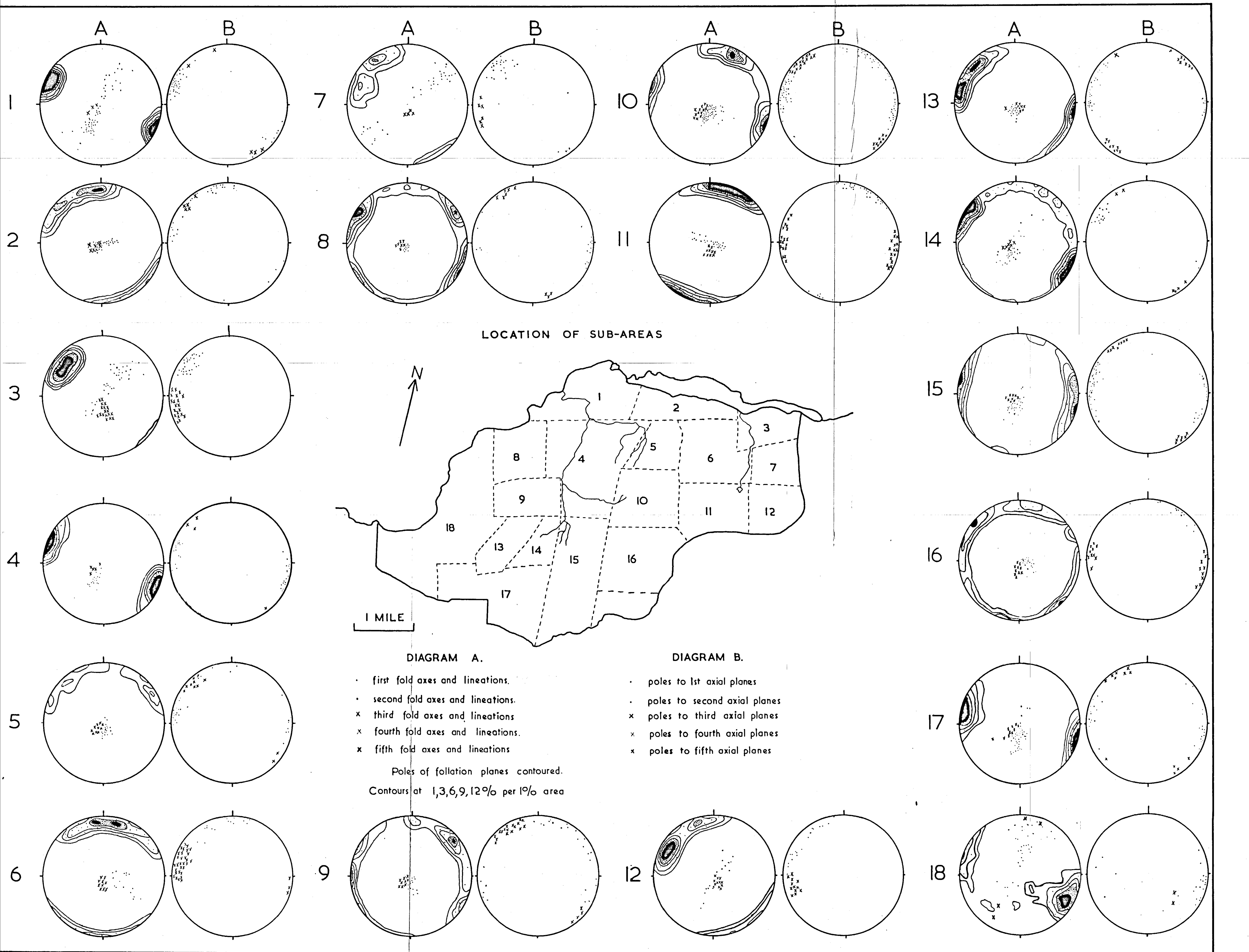


FIG. 26 STRUCTURAL ANALYSIS. FOLIATION PLANES FOLD AXES AXIAL PLANES LINEATIONS

IV. THE AGE RELATIONSHIPS OF METAMORPHISM, MIGMATISATION AND FOLDING

Using the conclusions reached during the structural and petrographical studies of the rocks, an attempt can be made to establish the age relationships of metamorphism, migmatisation and folding.

The petrographical study indicates that all the rocks of the area have undergone complete recrystallisation which must have taken place during or after the last period of deformation. Quartz and felspar crystals only locally show slight evidence of strain and bent or broken mica crystals have not been seen. Moreover, as will be described, the evidence indicates that the rocks, at least in certain parts of the area, have recrystallised during or after each fold movement.

It has already been shown that during the period of migmatisation the pelitic rocks throughout the area were transformed into oligoclase-biotite-gneiss and, locally, granite gneiss. Only in the central and eastern parts of the area do the psammitic rocks show the effects of migmatisation, and in the valley of Allt a Bhuiridh and to the west of An Stac and Rois-Bheinn the psammitic rocks are unmigmatised.

The quartz-oligoclase felspar folia of the gneisses are developed within the foliation plane (S_1) and the axial plane cleavage (S_3) of the second minor folds found in the central part of the area. Rodding structures of the second fold movement, in the area where the rocks are migmatised, consist of quartz, oligoclase felspar and occasional crystals of mica and garnet. The rodding associated with the first fold movement, in contrast to the mineralogical composition of the second rods, consists only of quartz. As Wilson (1953) has shown, rodding structures are formed from the shearing and disruption of pre-existing veins, so that the evidence suggests that migmatisation took place after the first fold movement, but before the second period of folding. The quartz-felspar folia present within the axial plane cleavage of the second minor folds may indicate that migmatisation was still active during the second fold movement and it is concluded that migmatisation preceded and accompanied the second period of folding. In the unmigmatised rocks west of An Stac and Rois-Bheinn the second rodding structures are made up only of quartz, which suggests that the mineralogical composition of the second rodding structure is related to the period of migmatisation.

Within the oligoclase-biotite-gneiss and the striped and banded rocks sillimanite is common as 'knots' elongated parallel to the foliation (S_1) and, locally, on Sgurr na Ba Glaise, sillimanite is present in second quartz-oligoclase felspar rods. The age of the sillimanite is not definitely known. Kennedy (1949) states that the outer limit of the sillimanite isograd conforms with the western boundary of migmatisation (op. cit. p.55) and it is probable that in Moidart, sillimanite is not found west of the zone of migmatisation (Richey, 1930). Although there is no direct evidence for the correlation, it is suggested that the sillimanite developed during the period of migmatisation. At the same time as the formation of the sillimanite, it is probable that, within the calc-silicate rocks, the mineral assemblages characteristic of the anorthite-pyroxene and anorthite-hornblende metamorphic zones (equivalent to the kyanite and sillimanite metamorphic zones of the pelitic rocks) were developed. In the unmigmatised rocks in the western part of the area the mineral assemblage characteristic of the zoisite metamorphic zone (equivalent to the garnet zone of the pelitic rocks) was formed.

The hornblendes and pyroxenes of the calc-silicate rocks, however, are not strongly oriented, but instead, appear to have a rather haphazard arrangement within the plane of the foliation. The lack of a strong dimensional orientation may suggest that these minerals developed when folding was not taking place, and they may have formed before or after the second fold movement. If they grew after the second fold movement, then the formation of the anorthite-hornblende and anorthite-pyroxene mineral assemblages postdates the period of migmatisation. It seems more probable that the anorthite-pyroxene and anorthite-hornblende mineral assemblages developed during migmatisation, after the first fold movement but before the second period of folding. During the second fold movement the metamorphic grade of the rocks must have been such that the hornblendes and pyroxenes were not recrystallised and dimensionally oriented by the folding. It is suggested, tentatively, that the high grade metamorphism of the rocks was attained during the period of migmatisation but before the second period of folding.

It has been concluded that the granite gneiss was developed after the formation of the oligoclase-biotite-gneiss. Third minor structures are present in the granite gneiss and oligoclase-biotite-gneiss, and both gneisses have been folded by the third major fold, the Diollaid Bheag Antiform. Because of the close field relationship between the two gneisses, and the fact that they have both been folded by the minor and major folds of the third fold movement, it is thought that there is no considerable time interval between their formation. The foliation of the granite gneiss is always distinct and well-defined, suggesting that when the granite gneiss was formed the rocks were still subject to considerable stress. There is no evidence to show that the granite gneiss was rodded during the second fold movement and it is concluded that the oligoclase-biotite-gneiss and the granite gneiss were developed during the same period of migmatisation. The granite gneiss was formed subsequent to the oligoclase-biotite-gneiss, during the final stages of the second period of folding.

During the migmatisation amd metamorphism associated with the second fold movement the rocks were completely recrystallised, and it is not possible to establish the metamorphic state of the rocks before migmatisation took place. During the first fold movement recrystallisation must have occurred, for the micas of the rocks are oriented parallel to the axial planes of the minor first folds, but the grade of metamorphism attained by the rocks during this period of folding is not known.

During or shortly after the third fold movement the rocks were again completely recrystallised. The micas of the pelitic rocks are oriented into a well developed mica crinkle, the mica crystals not being bent or broken. Petrofabric analysis of a specimen containing a third mica crinkle shows that the quartz crystals have been re-oriented into a girdle pattern at right angles to the axis of the crinkle (fig. 25).

Although recrystallisation took place there is no evidence to show that regrowth of garnet occurred. It is very difficult to determine the precise age of the garnets of the area. They are hyp-idioblastic, with rounded embayed margins and contain inclusions of unstrained quartz, felspar and occasionally biotite. Sometimes the garnets are reduced to small fragments. 'Snowball' garnets have not been found. These garnets may have developed during the period of recrystallisation associated with the third fold movement, but it is equally possible that they formed during the strong metamorphism associated with the second period of folding and have undergone no subsequent regrowth.

Recrystallisation again took place during or after the fourth fold movement, for in the area affected by the fourth major fold, a fourth mica crinkle is developed and the quartz and felspar crystals do not show any evidence of strain. The major and minor folds of the fourth fold movement are restricted to the southwestern part of the area and the intensity of deformation during the fourth period of folding is not strong. It is not known if all the rocks of the area recrystallised during this last period of movement. In the areas not affected by the fourth folds, third mica crinkling is common and if recrystallisation did take place the micas were not re-oriented.

As has already been described, discordant pegmatite veins and sheets have been found to cut across the minor structures of the third fold movement. In certain parts of the area porphyroblastic muscovite crystals showing random orientation are common and, locally, at Rois-Bheinn and An Stac, sillimanite shows alteration to large muscovite crystals that have no dimensional orientation. It is probable that these features are the result of a late phase of volatile-rich potassic bearing fluid, which became active after the last phase of recrystallisation and when movement had ceased.

All the rocks of the area show slight evidence of retrograde metamorphism, in that the biotites, and occasionally the garnets, show alteration to chlorite. The hornblendes of the calc-silicates rocks may also be chloritised, while the clinopyroxenes appear to be altering to an actinolitic hornblende. These late stage features of retrogressive activity must have developed during or after the late phases of recrystallisation associated with the third and fourth fold movements. The suggested age relationship of metamorphism, migmatisation and folding is illustrated on fig. 27.

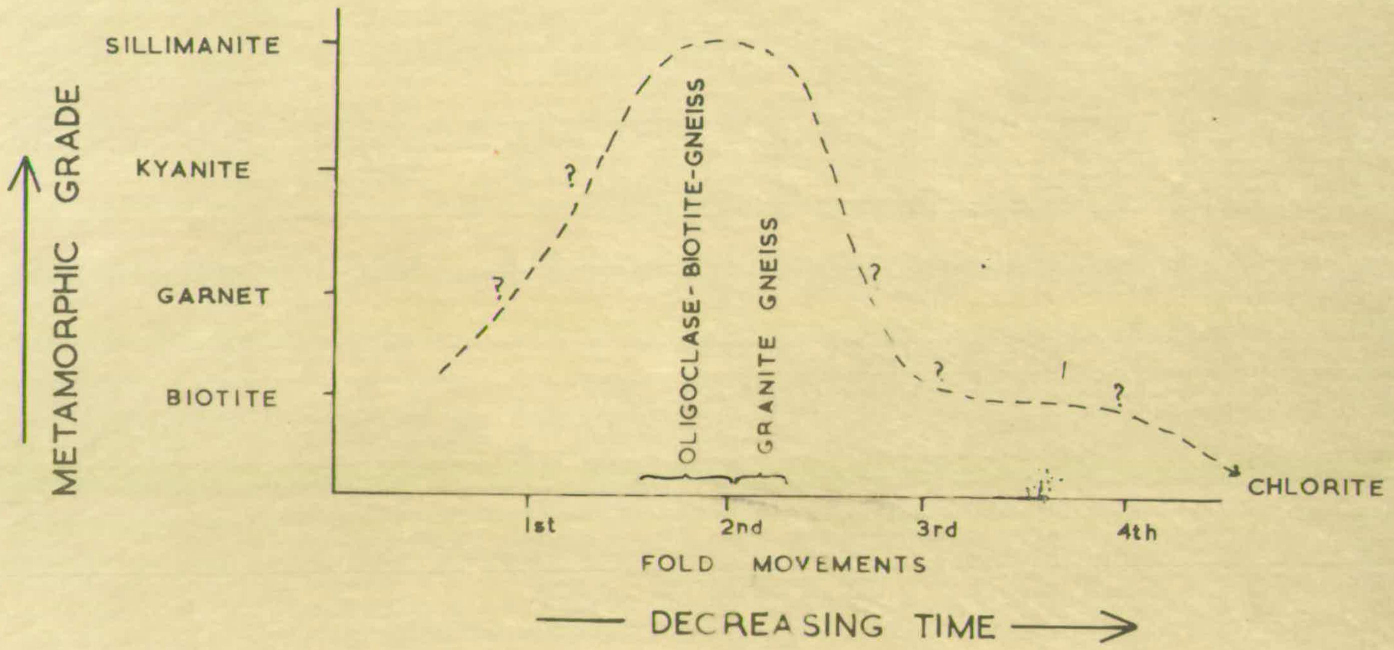


FIG. 27 THE AGE RELATIONSHIPS OF METAMORPHISM MIGMATISATION AND MOVEMENT

V. SUMMARY OF CONCLUSIONS

The metasedimentary rocks of the area have had a complex structural and metamorphic history. The structural analysis indicates that the rocks have suffered four periods of folding, and by study of the major and minor structures of each generation the age relationships of the fold movements can be established. The history of the fold episodes may be summarised:

1. first period of isoclinal folding. No major isoclinal folds have been recognized, but first minor structures are widespread and indicate that the whole area has been isoclinally folded. This first period of folding is probably the structural equivalent to the first movement episode recognized in Morar by W.Q. Kennedy (1955) - the formation of the Morar nappe.

2. period of tight, asymmetric folding during which all the rocks of the area were again folded. The second folds are Similar in style and their orientation has been considerably modified by the third fold movement. The evidence suggests that after the second period of folding had taken place the rocks were vertically oriented.

3. period of open asymmetric folding about a N.N.E-S.S.W.

axial plane trend. The third folds are partly Similar and partly Concentric in style. The Diollaid Bheag Antiform, a fold some two miles wide, formed during this period of folding.

4. period of open asymmetric folding about a N.W.-S.E. axial plane trend. The fourth folds are of local occurrence, and their affect upon the orientation of the rocks and structures of the earlier fold movements is only slight.

It has been found that the stratigraphical succession established by Richey and Kennedy (1939) in the Moine rocks of Morar, could not be extended into the whole of the area mapped. The structural evidence indicates that the rocks have been isoclinally folded, and it is concluded that the stratigraphical succession has been repeated. The few sedimentary structures that have been found indicate that the pelitic rocks of An Stac and Rois-Bheinn are stratigraphically younger than the psammitic rocks which have been correlated with the Upper Psammitic Group of Morar (Richey, 1938). It is suggested that the original stratigraphical succession may have consisted of four main lithological groups. In the area mapped all the psammitic and pelitic bands contain thin calc-silicate ribs. Richey and Kennedy (1939) stated that these calc-silicate ribs are absent in the Lower Psammitic Group and Lower Striped Schists of the Morar succession. It may be suggested therefore that the lower part of the Morar stratigraphical succession is not represented in the area mapped.

The rocks of the central and eastern parts of the area have been strongly migmatised, the migmatisation taking place before and during the second period of folding. In the area of migmatisation the rocks are coarsely crystalline gneisses and the pelitic rocks have been transformed into oligoclase-biotite-gneiss and locally, granite gneiss. Thick discordant pegmatite veins are common.

It is concluded that during migmatisation the rocks were at sillimanite grade of metamorphism, and associated with this period of high grade metamorphism the anorthite-hornblende and anorthite-pyroxene metamorphic zones of the calc-silicate rocks were developed.

Recrystallisation again occurred during or after the third and fourth fold movements, but it is probable that regrowth of garnet did not take place. Throughout the area the biotites, and occasionally the garnets, show alteration to chlorite, and these features of retrogressive activity must have taken place during or after these late phases of recrystallisation.

During the four periods of folding it is evident that the rocks responded to deformation in a very plastic manner, no cataclastic, or brittle structures found in the area can be definitely correlated with the four fold movements. The style of the fold periods is such that the intensity of deformation decreases, from isoclinal folding during the first fold movement, to very open asymmetric folding during the fourth movement episode. It is interesting to note that the metamorphic history shows a similar decrease in intensity. The evidence suggests that at approximately the same time as the first and second fold movements the grade of metamorphism of the rocks was extremely high, but during the later periods of open folding, the rocks only suffered low grade metamorphism. (fig. 27)

The suggested age relationship between metamorphism and movement is only tentative. Because the rocks have undergone recrystallisation several times during their movement history, and that recrystallisation appears to have taken place during or after the final fold movement, an accurate correlation between the metamorphic and structural histories is difficult to establish. The several phases of folding provide important 'marker horizons' in the structural and metamorphic history, and only by comparison and correlation with the structure and metamorphism of adjacent areas will the complete age relationship between metamorphism and movement be determined.

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PLATES

PLATE I

Minor isoclinal fold in the psammitic rocks of Loch Ailort shore, west of Seann Chruach.

Minor isoclinal fold ('tectonic inclusion') in the pelitic rocks of An Stac.

First quartz rodding in the pelitic rocks of Seann Chruach.

PLATE II

Minor second fold in the psammitic rocks south of Arieniskill. Note the thickening and thinning of the folded lithological units, and the change of fold shape in the direction of the axial plane.

Minor second folds in the pelitic rocks of Seann Chruach. The folds are preserved by thin psammitic bands. Note that the folds show opposed movement sense.

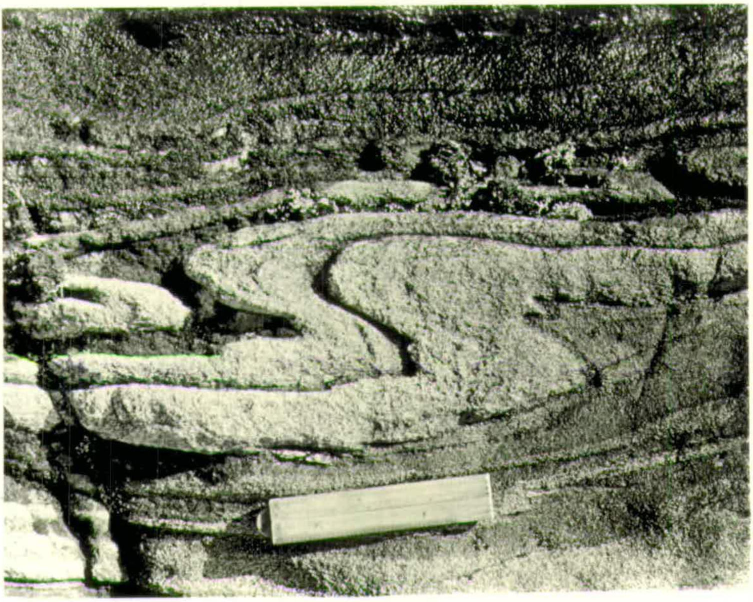
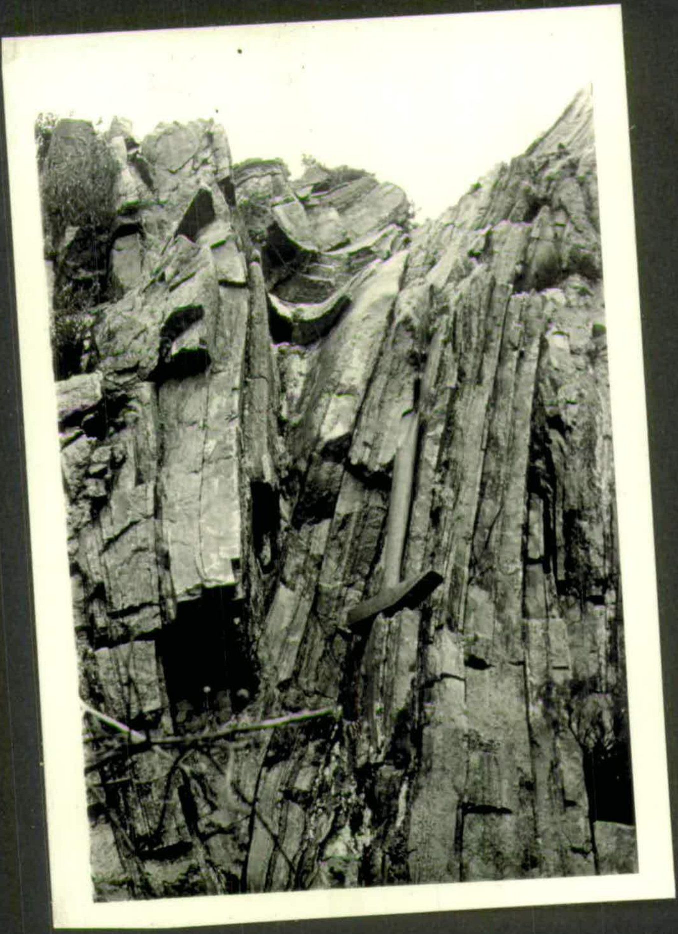


PLATE III

Minor second fold that shows a rapid variation in plunge from almost horizontal to almost vertical. In the psammitic rocks immediately south of Glenshian.

Second folds showing irregular shape and variable plunge. Note the canoe-shaped fold. In the psammitic rocks on Loch Ailort shore, west of Seann Chruach.

II



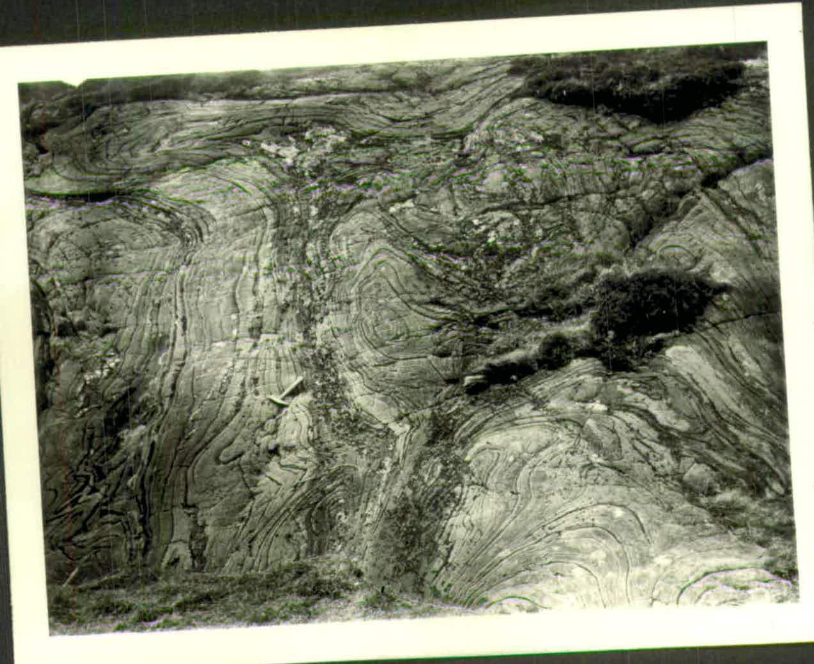


PLATE IV

Double crested minor second fold. From the psammitic rocks immediately south of Glenshian.

Tight, almost isoclinal second fold in the striped and banded rocks of Sgurr na Ba Glaise.

PLATE V

Third minor folds in the pelitic rocks of Rois-Bheinn.

Fourth minor folds in the pelitic rocks on the north face of Rois-Bheinn.

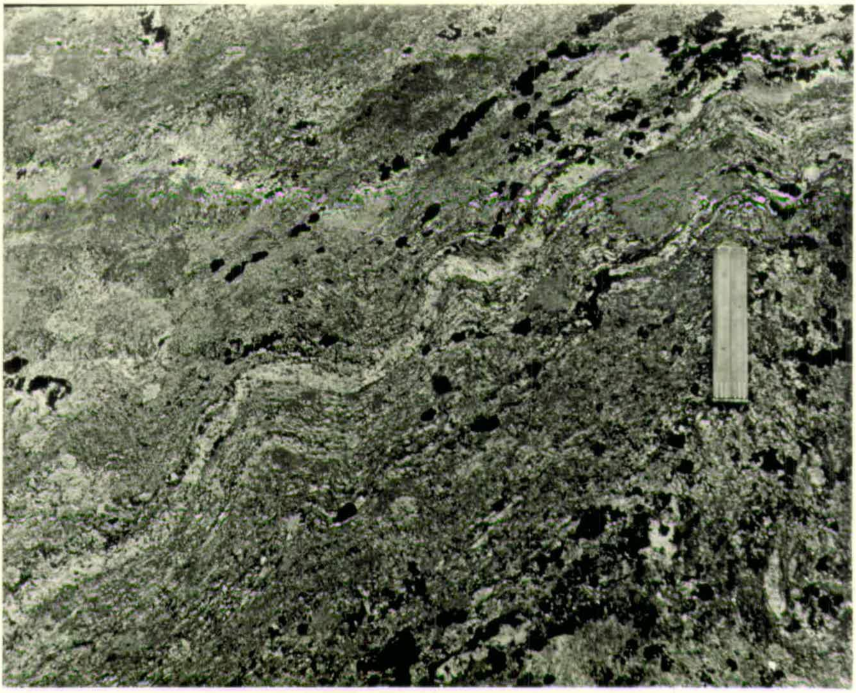


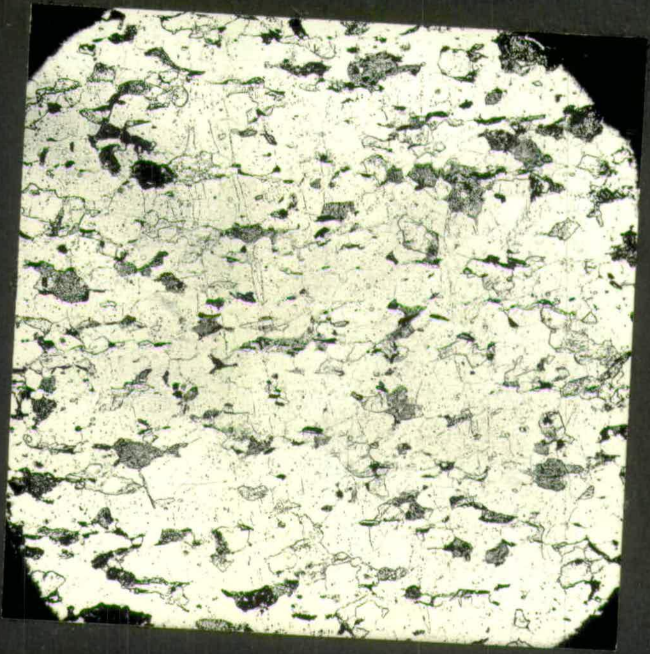
PLATE VI

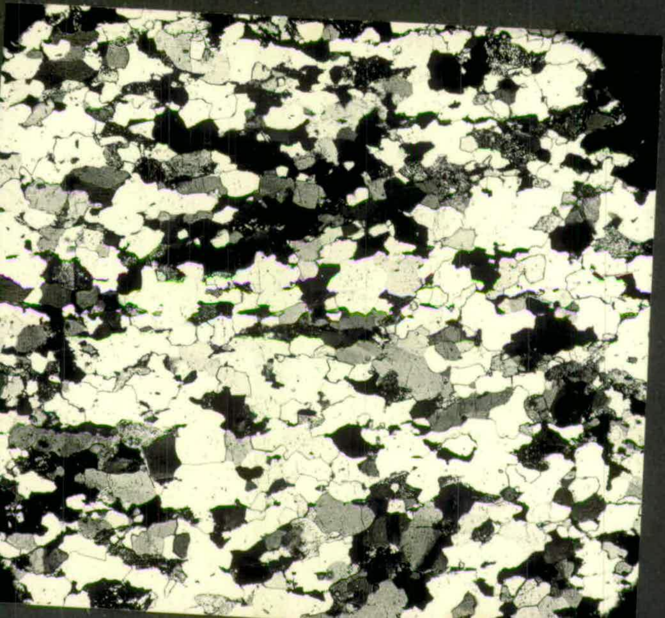
Photomicrograph of the psammitic rock south of Arieniskill. Consists of quartz, felspar (some highly altered), and small laths of muscovite and biotite.

Ord. light. x35.

As above, but under crossed nicols. Note the rounded, smooth margins of the quartz and felspar crystals.

VI





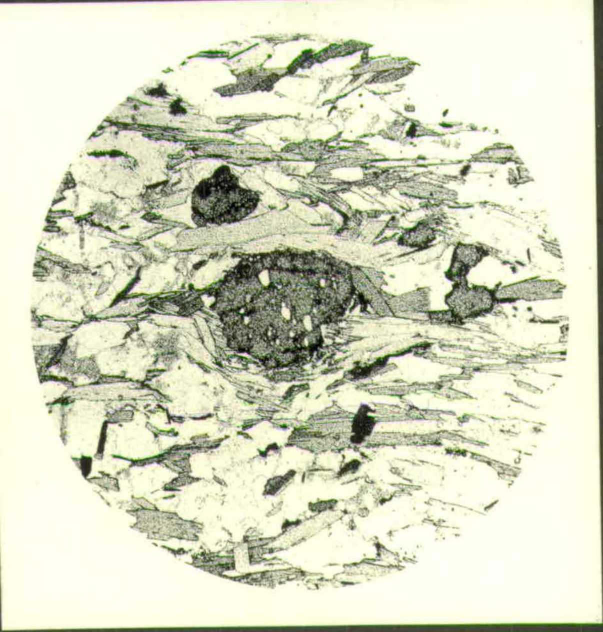
<u>PLATE</u> VII

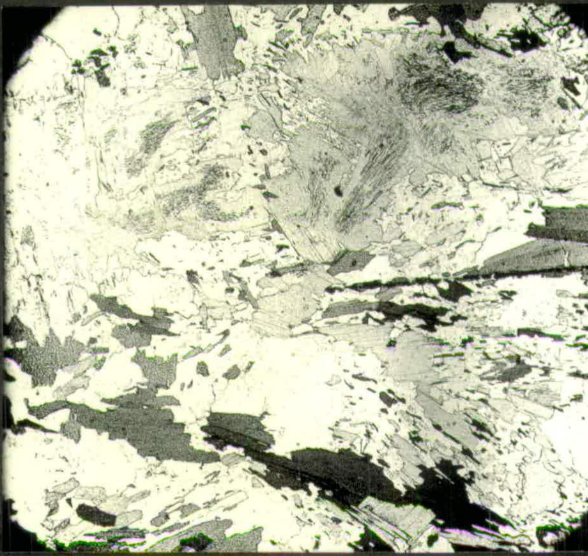
Oligoclase-biotite-gneiss, with quartz, felspar, biotite, muscovite and garnet. The micas, with straight crystal edges, pass round the garnet. Ord. light. x35.

Sillimanite in biotite and muscovite crystals. From the oligoclase-biotite-gneiss of Sgurr na Ba Glaise.
Ord. light. x35.

Granite gneiss, consisting of quartz, potash felspar, oligoclase, and subordinate biotite. Myrmekite and perthitic structure can be seen. Crossed Nicols. x35.

VII





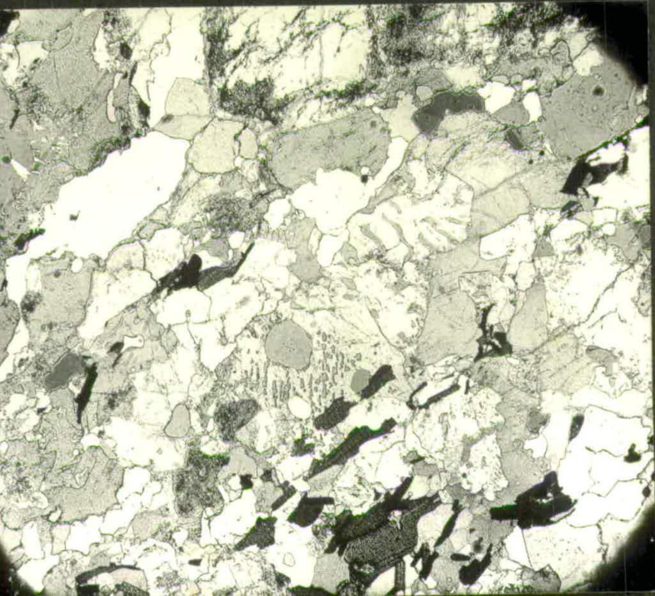


PLATE VIII

Sillimanite present as fibrous masses between the quartz and felspar crystals. From the striped and banded rocks of Sgurr na Ba Glaise. Ord. light. x35.

Hornblende schist body, with abundant hornblende, quartz, and basic felspar. Sphene, iron ore are common accessory minerals. Ord. light. x35.

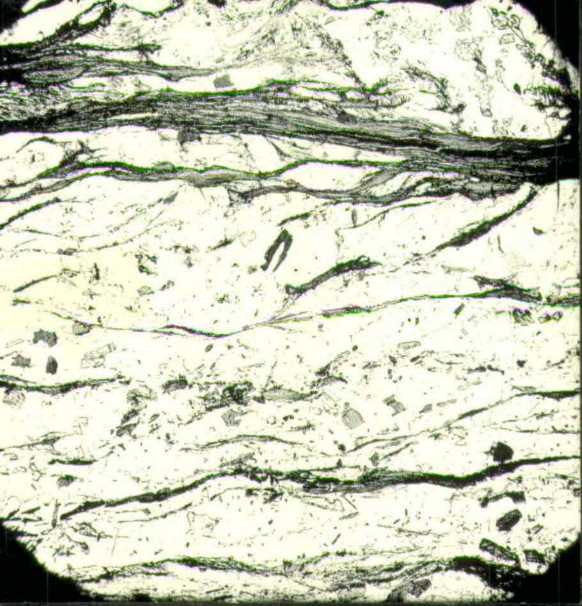
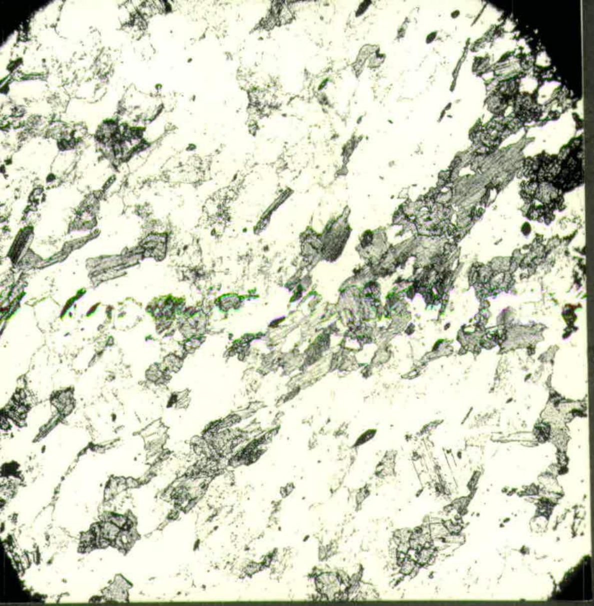


PLATE IX

Calc-silicate band from the zoisite metamorphic zone. Consists of quartz, acid plagioclase, biotite and small hornblende crystals. Ord. light. x40.

Calc-silicate band from the anorthite-hornblende zone. Contains quartz, basic plagioclase and hornblende. Note 'spongy' garnet. Sphene, iron ore occur as accessory minerals. Ord. light. x35.



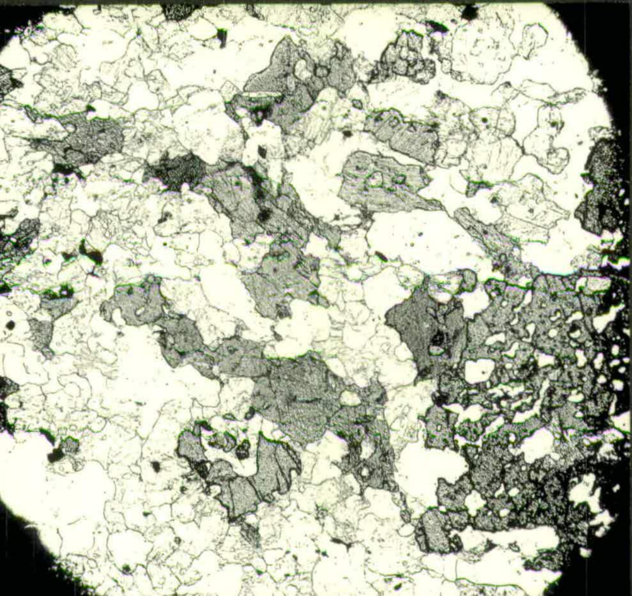
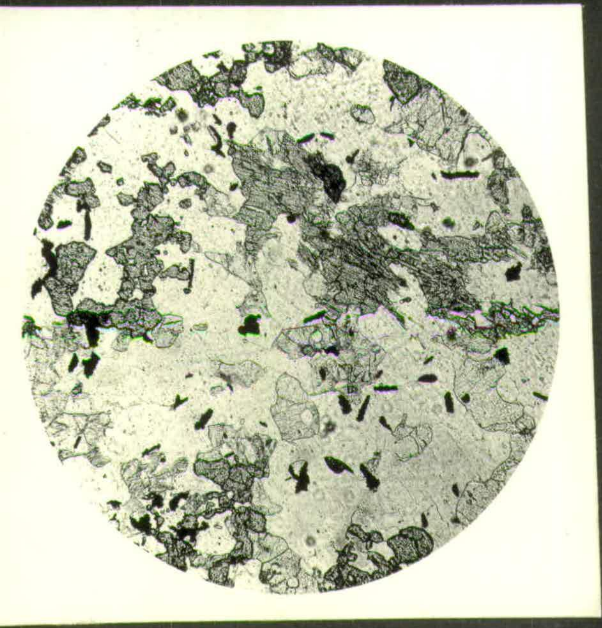


PLATE X

Calc-silicate band from the anorthite-pyroxene metamorphic zone. Consists of Quartz, basic plagioclase, clinopyroxene and garnet. Pyroxene is altering to an actinolitic hornblende, and the garnet is reduced to isolated fragments. Sphene, iron ore occur as accessory minerals. Ord. light. x40.

Intimate intergrowth between zoisite and basic plagioclase, from a calc-silicate in the anorthite-hornbelnde zone. Plagioclase is pale grey, the zoisite dark grey in colour. A 'spongy' garnet is also present.

Ord. light. x40.



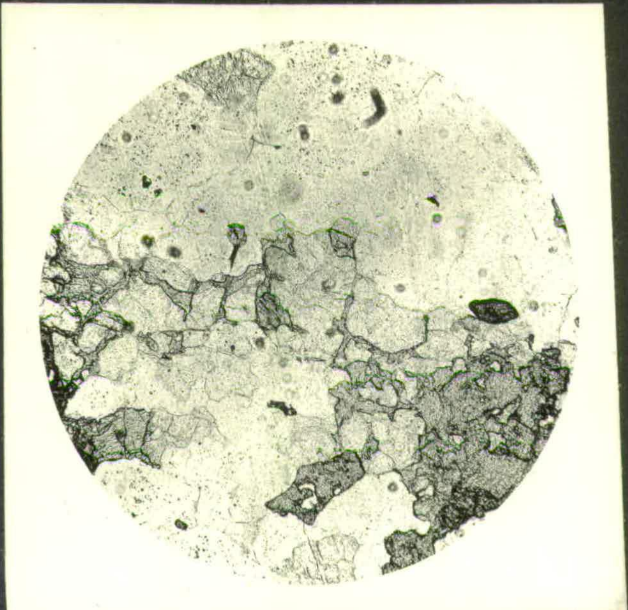
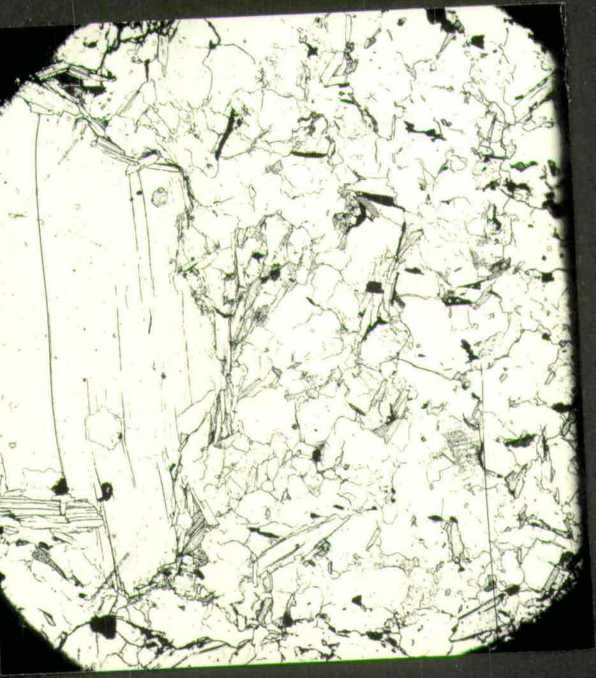
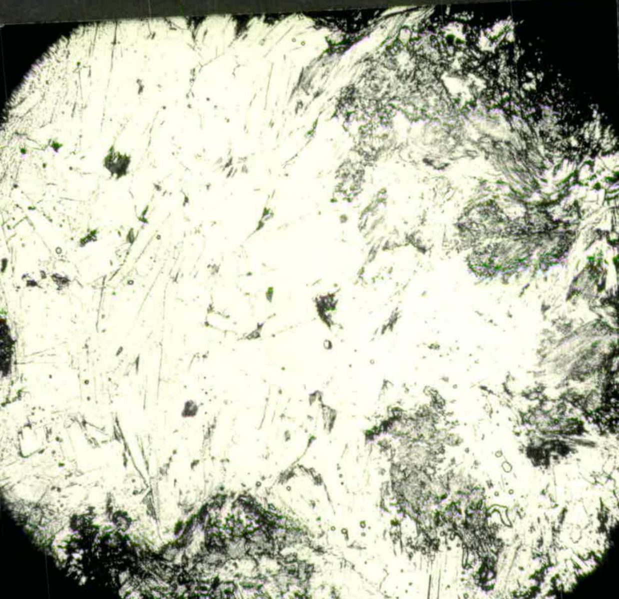


PLATE XI

Porphyroblastic muscovite in the psammitic rocks north of Druim Comhnardaig. Ord. light. x 35.

Sillimanite-muscovite 'knot' from the pelitic rocks on the north face of Rois-Bheinn. Sillimanite is present as dark felted masses, separated by large muscovite crystals. Ord. light. x35.





a.

b.

c.

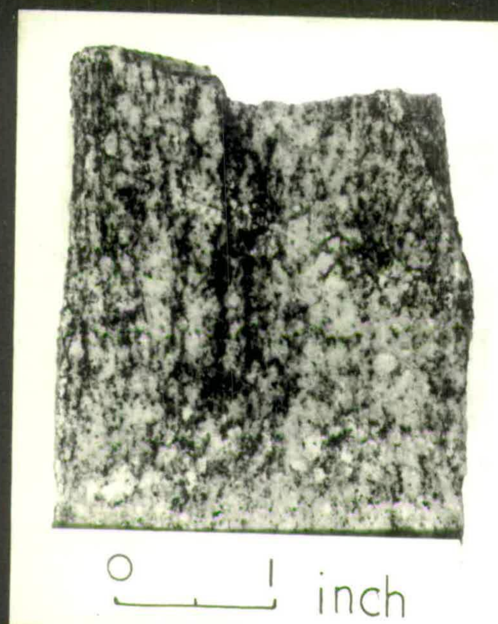


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PLATE XII.

A. Banded oligoclase-biotite-gneiss from Seann Chruach.

B. Oligoclase-biotite-gneiss with a lens of coarsely crystalline quartz and oligoclase felspar. From Sgurr na Ba Glaise.

C. Coarsely banded granite gneiss from the Druim Fiaclach ridge.

D. Well banded granite gneiss from Creag Dhearg.

MAP I

GEOLOGICAL MAP OF THE LOCHAILORT (MOIDART) AREA
LEGEND
OLIGOCLASE BIOTITE GNEISS
GRANITE GNEISS
STRIPED AND BANDED ROCKS
PSAMMITIC ROCKS
ALLUVIUM
PORPHYRITE DYKES
BASALT DYKES
DIP AND STRIKE OF FOLIATION AND BEDDING
VERTICAL STRATA
CERTAIN
UNCERTAIN
GEOLOGICAL BOUNDARIES
FAULT
T TOURMALINE
CS CALC-SILICATE
Pb GALENA
YOUNGING DIRECTION OF CURRENT BEDDING
LOCHAILORT INN
GLENSHIAN
ARIENISKILL
LOCH EILT
LOCH AILORT
ALISARY
SEANN CHRUACH
ALLT A' BHUIRIDH
AN STAC
CREAG DHEARG
SGURR NA PAITE
DIOLLAID BHEAG
DRUIM FIACLACH
ROIS BHEIN
SGURR NA BA GLAISE
GARBH LEACHD
COIRE REIDH
DRUIM COMHNARDAIG
IRINE BURN
ALLT A' CHOIRE BHUIDHE
GLEN ULGARRY
SCALE
0
1 MILE
N


STRUCTURAL MAP OF LOCHAILORT (MOIDART) AREA
LEGEND
AXIAL PLANE TRACE OF THIRD MAJOR ANTIFORM
AXIAL PLANE TRACE OF SECOND MAJOR ANTIFORM
AXIAL PLANE TRACE OF SECOND MAJOR SYNFORM
STRIKE AND DIP OF FIRST AXIAL PLANES
VERTICAL FIRST AXIAL PLANES
PLUNGE OF FIRST AXIAL STRUCTURES
STRIKE AND DIP OF SECOND AXIAL PLANES
VERTICAL SECOND AXIAL PLANES
PLUNGE OF SECOND AXIAL STRUCTURES
STRIKE AND DIP OF THIRD AXIAL PLANES
VERTICAL THIRD AXIAL PLANES
PLUNGE OF THIRD AXIAL STRUCTURES
STRIKE AND DIP OF FOURTH AXIAL PLANES
VERTICAL FOURTH AXIAL PLANES
PLUNGE OF FOURTH AXIAL STRUCTURES
FAULT.
LOCHAILORT INN
GLENSHIAN
ARIENISKILL
LOCH AILORT
LOCH EILT
ALLT A BHUIRIDH
SEANN CHRUACH
AN STAC ANTIFORM
AN STAC
CREAG DHEARG
CREAG DHEARG SYNFORM
SGURR NA PAITE
DIOLLAID BHEAG
DIOLLAID BHEAG ANTIFORM
DRUIM FIACLACH
GARBH LEACHD ANTIFORM
GARBH LEACHD
ALLT A CHOIRE BHUIDHE
IRINE BURN
ROIS BHEINN
ROIS BHEINN ANTIFORM
SGURR NA BA GLAISE
DRUIM COMHNARDAIG SYNFORM
GLEN ULGARRY
SCALE
O
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N