THE TECTONIC AND METAMORPHIC HISTORY OF THE MOINE THRUST ZONE IN SLEAT, ISLE OF SKYE.

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ABSTRACT.

A detailed study has been made of the tectonic and metamorphic histories of the Moine and Caradal nappes in the Sleat peninsula of south-east Skye.

In the Moine nappe, the small folds belong to five successive generations. Large folds belong to the first and second generations only. The third, fourth and fifth generations of small folds are generally confined to a zone of rocks near the Moine thrust plane. Porphyroblastic crystals developed between the third and fourth generations of folds.

In the Caradal nappe, small folds also belong to five successive generations but these are not necessarily the same as those in the Moine nappe. Large folds in the Caradal nappe belong to the first and third generations and these are the same as the first and second generations, respectively, in the Moine nappe.

Because of correlations of fold structures across the Moine thrust plane, it follows that (a) highly deformed rocks developed during two separate periods and (b) major thrusts belong to two separate stages in the structural evolution.

Considerations of the area studied and its relation to adjacent areas allow various hypotheses on the structural

A NOTE ON PRESENTATION.

In a hurry? Then read general summary and conclusions in Part V! (pp354-394).

The remainder of the thesis is divided into four parts:-

Part I: fold structures in the Moine nappe.
Part II: fold structures in the Caradal nappe.
Part III: the rocks in the field.
Part IV: the rocks in section.

The last Chapter in each Part (ie. Chapters 9, 15, 19 and 24) summarises the observations and conclusions of that Part. These summarising Chapters contain most of the important facts and arguments embodied in the thesis.

The remaining Chapters (ie. the main body of the thesis) describe the geological features of the area at great length, contain verbose arguments and discussions, and include instructions on how to reach certain critical coastal exposures at certain difficult states of the tide without wetting one's feet.

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In 1955 Sir Edward Bailey concluded a discussion on Moine tectonics and metamorphism in the Isle of Skye with the following words:-

"I have considered very carefully, with much help from friends, what seems to me the most favourable area in all Scotland for deciding the date of Moine metamorphism. Not only is it endowed with many natural advantages, but also it has been studied by Clough, a geologist of quite exceptional powers. His work, checked and confirmed, has led me to conclude that Moine metamorphism is of Caledonian date. I have, however, pointed out that Clough himself regarded this inference as incompletely proved".

The peninsula called the Sleat of Skye, which was the main subject of Bailey's discussion, is included within the area of figure 0.1. It is a low peninsula, rarely rising above 900ft., with a rounded topography which is common in the west of Scotland. Typical aspects are shown in figure 0.2. The upper photograph was taken on the west side of the peninsula where the degree of exposure is remarkably good. On the east side, however, as the lower photograph shows, the country is less well exposed, being covered by a thick growth of heather and many peat bogs.

Bailey's paper of 1955 is the most recent account of the geology of this part of Skye. The earliest serious attempt to elucidate the geological history was that made by Clough on behalf of the Geological Survey. His work was completed in the summer of 1897 and various accounts of it appear in the "Summaries of Progress" leading up to that

date. As Bailey remarks, Clough must have been "a geologist of quite exceptional powers". The fact that he deduced as much as he did in the relatively short time that he spent in this complicated area can do little but create a deep impression on his readers. To quote his description of part of the Sleat peninsula which was published in the Memoir on "The Geological Structure of the North-West Highlands of Scotland" (Peach et alia, 1907) would be an ideal introduction to the geology of the area treated in this thesis:-

"The last section (Fig.66) (here reproduced as figure 0.3) of this series across the peninsula of Sleat has been drawn along a line still further to the south-west. It presents a much larger area of Lewisian gneiss (A), and of the schists of sedimentary origin associated with them (M'), than that shown in figure 65. These schists have been here carried forward over almost unaltered Torridonian rocks by three thrusts--the Tarskavaig thrust, the outcrop of which is not seen in the section; the Caradal thrust, lying above the Tarskavaig thrust; and the Loch Lamarscaig thrust, which lies partly on the Caradal and partly on the Tarskavaig thrust. These three thrusts have been folded into synclines with axial planes striking towards the north-east. The axis of the Loch Lamarscaig thrust runs some distance to the south-east of those of the others, and this thrust has perhaps been folded after the others, which have possibly received their plication when the mass on the Loch Lamarscaig thrust was being driven over them, while that thrust in its

turn may have been folded before the mass that was advancing on the Moine thrust.

In several places along the Caradal thrust, and in one place along the Loch Lamarscaig thrust, patches have been observed of the Torridonian epidotic grits and conglomerates having phyllites, granulitic schists, or sheared gneiss on both sides. A certain amount of crushing has affected the adjoining Tarskavaig Moine schists as well as the epidotic beds, and has helped to obscure the earlier differences between these two sets of rocks. In a specimen (7649) of granulitic schist collected near a patch of the epidotic conglomerate, the granulitic laminae are repeatedly crushed along lines which cross the foliation. Excepting along some special thrust-like lines the epidotic beds are not granulitic, the outlines of larger pebbles being generally distinct and showing no parallel elongation. Mixed with the epidotic grits, in an area half a mile to the south-west of Loch Lamarscaig outlet, dark-grey gritty shales and purple and green sandy shales may be seen. None of the shales are lustrous, and in this respect they contrast greatly with the adjoining Tarskavaig Moine phyllites.

Just under the Loch Lamarscaig thrust the Beinn na Seamraig grits and shales (Torridonian) are a good deal crushed, but not otherwise appreciably altered. They only cover a small area between the eastern part of that thrust and the Moine thrust, and are not clearly exposed. Further south their width becomes still narrower, and about a mile and a quarter north-west from Tormore the Moine thrust rests directly upon the gneiss on the Loch Lamarscaig thrust.

The materials that overly the Tarskavaig thrust are only exposed at the north-west end of the section, and consist of granulitic schistose rocks, with a few subordinate beds of sandy phyllite which are not shown in the section: the foliation planes generally dip to south-east at between 28° and 50°, but near the Caradal thrust they are nearly flat, or stike to north-west. The phyllites and gneiss rocks which come below the schist on the west limb of the Tarskavaig thrust in Fig. 65 are probably hidden under the sea in this section.

The outcrop of the Tarskavaig thrust is overridden by the Loch Lamarscaig thrust at a place about half a mile south of the outlet of Loch a'Ghlinne, where the latter thrust is gently inclined to south-east. The Tarskavaig thrust is not there distinct, but from the north side of Loch a'Ghlinne to within 200yds. of the Loch Lamarscaig thrust it strikes nearly north and south and is steeply inclined. Nearly a third of a mile south-east of the line of section the inclination of the western limb of the Caradal thrust is 29° south-east, and a quarter of a mile further north-east it is 30° to the south-east. The outcrop of this thrust is overridden by the Loch Lamarscaig nearly half a mile slightly west of south of the Loch a'Ghlinne outlet, and the inclination here is gently westward.

Above the western limb of the Caradal thrust in a few places thin stripes of rock have been noticed which may be regarded as sheared forms of Lewisian gneiss, but they cannot always be confidently separated from the overlying sandy

phyllites. The patch of gneiss shown in the section is not more than 200yds. long, and no other gneiss can be seen for more than a mile to the south-west. The sandy phyllite above the sheared gneiss is about 100yds. broad and generally dips to south-east. About 100yds. east of the top of this phyllite another much thinner band of phyllite of similar material is succeeded by overlying granulitic schists which are generally somewhat pebbly and more massive than those below.

On the east side of the epidotic beds shown in the section, and probably separated from them by an obscure thrust, a flaggy pale-grey mylonised gneiss makes its appearance, the parallel planes of which are much crumpled but generally dip east of south-east. This gneiss may be separated by a minor thrust from the much broader exposure shown above the eastern portion of the Loch Lamarscaig thrust. The rock in this exposure is to a large extent composed of thin pale-green and red streaks, the former probably representing sheared basic laminae, and containing occasional round fragments and lenticles of hornblende and hornblende schist, while the red streaks represent the more feldspathic laminae in the gneiss, or perhaps in some cases veins of pegmatite which have been sheared with the gneiss. Close to the Loch Lamarscaig thrust the planes of the sheared gneiss are in places so much broken that the rock loses its flaggy character.

The rock between the two exposures of sheared gneiss above the Loch Lamarscaig thrust consist of sandy phyllites and siliceous granulitic schist. Next to the gneiss on

the east part of the thrust lies a thin band of granulitic schist, followed by a thick phyllite which is perhaps part of the band seen next to the gneiss in a good many other places on the Caradal and Tarskavaig thrusts. The Moine thrust is not distinct at the south-east end of the section, but in two places in Allt a'Chamairdd some rocks in the thrust are exposed, and include a sheet of basalt and a band of mylonised rock, ten feet thick, which contains eye-shaped pieces swathed round by thin streaks resembling crushed shale. The mylonitic streaks generally dip to south-east at about 20°, and are probably parallel to the thrust".

Following Clough the area was visited from time to time by E. B. Bailey and W.Q. Kennedy. In 1939 Bailey published a short paper summarising their conclusions but this has been superceded by a much fuller account published in 1955, part of which has been quoted already. Among other things Bailey suggested certain changes in Clough's nomenclature of the thrusts as shown in figure 0.4. Later in this thesis a further revision will be suggested but for the time being Bailey's system will be adopted. One great merit of Bailey's 1955 paper is that it gives a very good general picture of the structural relations in the Sleat of Skye. Bailey's field studies allowed him to confirm Clough's "wonderful tectonic features" in Skye and having done so he tabulated Clough's main structural units in descending order, calling them thrust slices or nappes:-

Moine nappe.

----------Moine thrust.

Tarskavaig group of nappes.

(Caradal nappe.

----------Caradal thrust.

(Tarskavaig nappe.

----------Tarskavaig thrust.

Kishorn nappe.

----------Kishorn thrust.

Foreland. (Meaning sub-Kishorn Foreland; the Foreland of the Caledonian Chain as a whole is sometimes taken to include everything below the Moine thrust.)

The rock groups in these nappes can be divided into a simple fivefold scheme: Lewisian, Moinian, Tarskavaig Moinian, Torridonian and Cambro-Ordovician. All of these, apart from possibly the Tarskavaig Moines, are well known in the general geological literature of the North-West Highlands and have been sufficiently clearly described (Peach et alia, 1907) to make all but an outline review unnecessary in this thesis. The rock groups occur in the Foreland and in each of the thrust slices, or nappes, as follows:-

1. The Foreland:

Cambro-Ordovician. This consists of a limestone series (the Durness limestone) resting conformably on a predominantly arenaceous group (the Durness quatrzite).

Torridonian. These are shales and feldspathic sandstones unconformably overlain by the Cambro-Ordovician. They show little or no signs of metamorphic change.

Lewisian. A group of pre-Torridonian gneisses partly igneous and partly metamorphic in their origin. The unconformity separating them from the Torridonian is a very irregular surface.

2. The Kishorn nappe.

Cambro-Ordovician. Fundamentally these rocks are little different from the same group in the Foreland. They have suffered a certain amount of folding and faulting or thrusting.

Torridonian. On the normal limb of the Loch Alsh synform the Torridonian has suffered little or no metamorphic change. On the inverted limb, however, some rocks contain microscopic biotite or show partial granulation and elongation of their constituent grains.

Lewisian. Mylonites and mylonitised gneisses recognised as highly deformed derivatives of the crystalline rocks such as found in the Foreland today. In Skye Lewisian rocks are absent from the Kishorn nappe.

3. The Tarskavaig group of nappes. (Comprising the Caradal nappe and the Tarskavaig nappe).

The Tarskavaig Moines. A series of psammitic and semi-pelitic rocks which, when considered simply as sediments show many features in common with both the Moine and the Torridonian. Their metamorphic state is intermediate between that of the Torridonian and that of the Moine.

Lewisian. Mylonites and mylonitised gneisses derived from crystalline rocks.

4. The Moine nappe.

The Moine series. Sometimes referred to as the

"Standard Moines" to distinguish them from the Tarskavaig Moines. They consist of psammites and semi-pelitic schists of sedimentary origin in a fairly high state of metamorphism.

Lewisian. Crystalline rocks of a wide variety of compositions and their mylonitic derivatives.

The recent study, the results of which are presented in this thesis, consisted mainly of an application of the methods of structural geology which have evolved in the last decade. Briefly, these are concerned with the close study of the geometry of small scale structures in rocks from which deductions can be made relating to the deformational history. Clough was aware that structures which he called "axial planes of small folds" and "lines of stretching" or "elongation lineation" were probably of great importance in the elucidation of the geological history. Nevetheless, he does not comment on this. Bailey, on the other hand, did make an attempt to interpret Clough's "elongation lineation" in 1956.

"While eschewing discussion of lineation as revealed by optics, I may point out that elongation has no simple connection with direction of flow. Flow that is uniform does not cause elongation. Flow that is uniform in cross-section, but variable longitudinally, causes elongation parallel to itself in regions of acceleration, and at right angles to itself in regions of retardation. Flow that is uniform longitudinally, but variable in cross-section, tends in course of time to cause average elongation approximately parallel to itself".

This thesis is an account based on thirteen months field work with supporting laboratory studies. The field

work involved the mapping of a total area approaching fifteen square miles. This was carried out on Ordnance Survey maps to the scale of six inches to one mile. Aerial photographs with the approximate scales of three and six inches to the mile were used to add extra topographical detail to the maps. On these maps were recorded numerous observations of such structures as bedding, foliation, cleavage, elongation and other lineations, axial planes and axes of small folds as well as such attributes of the rocks as presence of certain porphyroblasts, of cross-bedding, of certain types of fissility, of certain detrital grains, etc. The geometry of many structures was analysed on the stereographic projection. Laboratory studies were confined mainly to the textures of rocks as seen in thin section, attempts being made to relate these textures to the macroscopic structures of the rocks.

The arrangement of the subject matter of the thesis is as follows. The thesis is divided into five parts. The first two parts deal with the structures in the Moine and Caradal nappes respectively: some structures which the two nappes have in common being described in the first part. In these first two parts the structures are described in groups. Within each of these groups the evidence suggests that the structures so classified are all of the same age or, at least, are very closely related in time.

Having described the structures and their distribution Part III gives an account of the appearance of the rocks in the field; particular attention being paid to how this varies from place to place and how this may be related to the dis-

tribution of the structures.

In Part IV the results of the petrological study are presented. Inferences are drawn concerning possible connections between mineralogical and textural phenomena as seen in thin section and phases of deformation as deduced from field evidence.

Part V contains two chapters. The first is an integration of the conclusions drawn in the first four Parts and presents a history of the Moine thrust zone in Skye. The second considers the wider implications of this when viewed in relation to the North-West Highlands as a whole.

At the end of the thesis there are ~~(first of all)~~ some notes in explanation of the Plates. ~~(and then a glossary. This latter is a collection of the various definitions which have been made in the body of the thesis.~~

Finally a few notes with regard to the conventions which have been adopted in the preparation of the illustrations:-

1. Figures in the text are numbered such that the first group of digits refers to the number of the chapter in which they are to be found while the second group of digits denotes the position in that chapter. Thus figure 14.10 is the tenth figure in chapter 14.

2. The Schmidt stereographic projection (lower hemisphere) is employed in all stereographic diagrams.

3. The north-south line on all maps and stereograms is parallel to the edge of the page unless otherwise marked. North is towards the top of the diagram.

4. All place names can be found on Plate 1, unless otherwise stated.

EXPLANATION OF FIGURE 0.1.

This map gives the broad outlines of the Caledonian geology of Skye and the neighbouring parts of the Scottish mainland. To show the area of study, vertical ruling has been superimposed upon the ornamentation which shows the distribution of the rock groups.

Geographical and Geological setting of the Sleat of Skye.

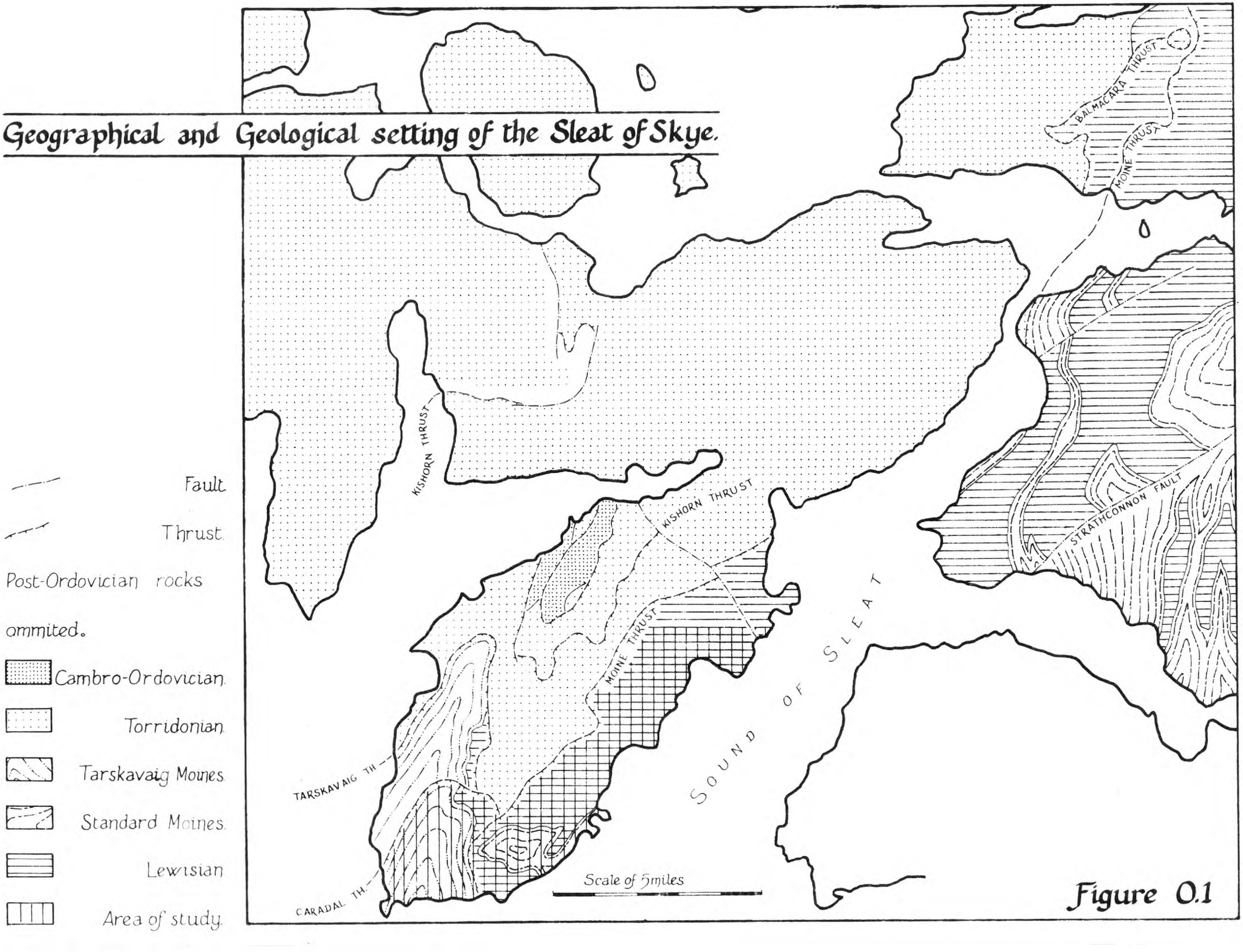


Figure 0.1

EXPLANATION OF FIGURE 0.2.

These pictures illustrate the scenery of the south part of the Sleat peninsula. The well-exposed west side is shown in (a). These are Tarskavaig Moine rocks in the Caradal nappe. On the east side (b), the rocks are not so well-exposed. Scenery such as this is common where the ground is underlain by mylonised Moine and Lewisian rocks in the Moine nappe.

(a) In the west



Typical scenery in the south of Sleat

(b) On the east side



Figure 0.2

EXPLANATION OF FIGURE 0.3.

This is reproduced from the Memoir of the Geological Survey of Great Britain entitled "The Geological Structure of the North-West Highlands of Scotland" published in 1907. It is based on the fieldwork of Clough.

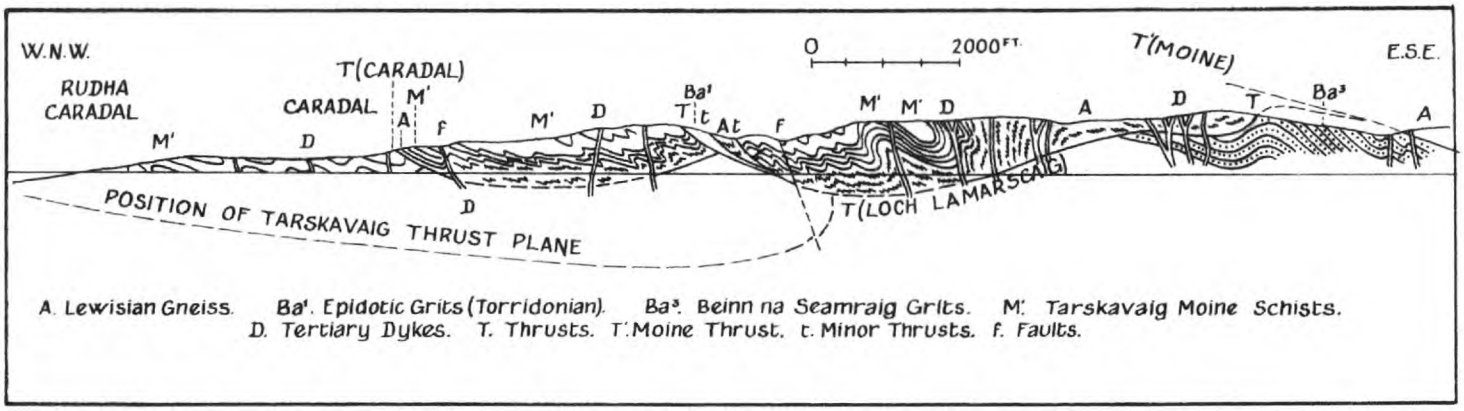
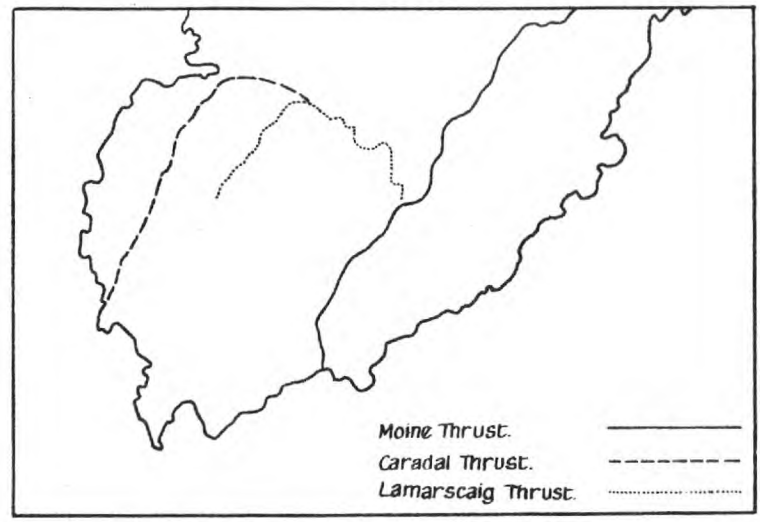


Figure 66 from Peach et alia, 1907.

Figure 0.3

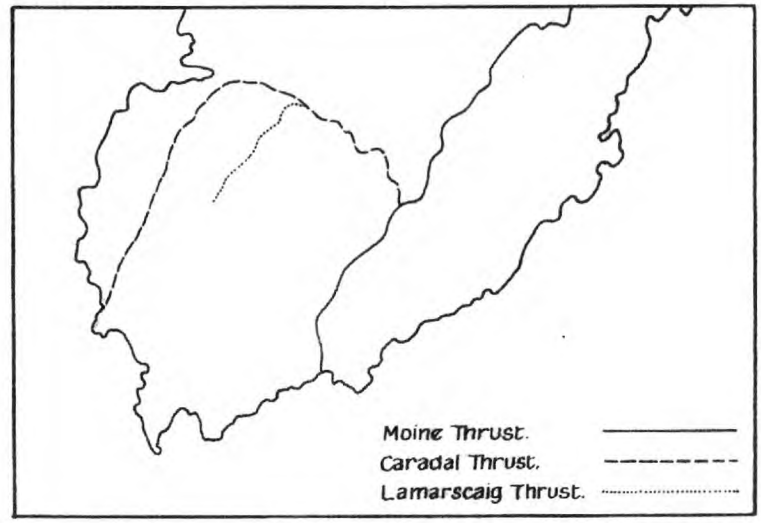
EXPLANATION OF FIGURE 0.4.

The original names of the thrusts in south Sleat as proposed by Clough are shown in (a). The names of these thrusts were revised by Bailey in 1955 in a paper called "Moine Tectonics and Metamorphism in Skye". These revisions are shown in (b).



(a) After Clough

Nomenclature of the Thrusts



(b) After Bailey

Figure 0.4

PART I. THE STRUCTURAL HISTORY OF THE MOINE NAPPE. 23.

CHAPTER 1. THE BARAVAIG FOLDS AND ASSOCIATED STRUCTURES.

This is the earliest group of structures found in the Moine nappe in this part of Skye and it is this group which offers the greatest variety in form. Despite this variety these structures share one characteristic feature which distinguishes them from all others: they are all associated with a very strong elongation lineation. This type of lineation may best be defined in the following way. When the rocks are examined closely the constituent grains of quartz and feldspar are seen to approximate towards an ovoidal shape as opposed to being equidimensional. Furthermore, the long axes of these individual grains, within an area of say 1 sq. cm., are parallel to each other. When such rocks are viewed from a distance this parallel orientation of the grains appears as a number of lines laying on the surfaces of individual rock layers somewhat reminiscent of the graining in wood. Also just as the direction of the graining in wood may change from place to place so also may the elongation lineation. Figure 1.4 is a photograph of a rock exposure which displays an elongation lineation. The distribution of the elongation lineation associated with the Baravaig folds and its variations in direction are shown on Plate 2.

Although the Baravaig structures show an enormous variation in the appearance of their profile, any exposure which demonstrates their three-dimensional shape indicates that they are cylindroidal. The elongation lineation is always parallel to the axes of these cylinders and rock faces which contain these axes always show an apparently uniform, undisturbed foliation. These points should be clarified

by figure 1.1(a). The term foliation as used in this thesis is defined as the arrangement of rocks of different mineral composition into roughly parallel sided layers.

Within the area as a whole these structures are ideally displayed in Lewisian rocks along the coastal section from Ob Snosaig to Knock Bay. Of the various types of structures, folds are most common. In the quartzo-feldspathic, or acid gneisses these folds are of relatively simple profile: tight, tending to isoclinal, with rounded hinges. In the hinge zones of these folds the individual quartz and feldspar grains are not only elongated parallel to the fold axes but also often appear to be flattened parallel to the axial planes of the folds. This flattening of quartz and feldspar is often accompanied by a megascopic preferred orientation of the micas such that their cleavages are also parallel to the axial planes of the folds. Examples of such folds are given in figure 1.1(b-d).

Some of the Lewisian gneisses contain light and dark minerals in approximately equal proportions and in which there are thin bands of almost pure quartzo-feldspathic material. The folds in such rocks are of rather unusual profile and are difficult to describe adequately. Reference is best made to figure 1.2 where the quartzo-feldspathic bands are represented. At the locality at which (a), (b) and (c) occur the thin quartzo-feldspathic bands are extremely abundant and are contained in a host which is rich in crystals of biotite and amphibole often measuring up to 3mm. These large crystals show no preferred orientation which is obvious to the unaided

eye so it must be deduced that they formed at some date after the development of the folds and the very strong elongation lineation. As well as showing this strong elongation lineation the quartzo-feldspathic bands also possess a very crude cleavage structure which is expressed as a series of cracks parallel to the axial planes of the folds. Although there is considerable variation in profile most folds are relatively open and contrast strongly with the tight folds in the acid gneisses of figure 1.1. It is probable that these quartzo-feldspathic bands represent migmatitic veining which was irregular in shape before the Baravaig period of deformation thus explaining the present complexity of their profiles.

So much for the common structures of this group in the coast section from Ob Snosaig to Knock Bay. Figure 1.3 shows examples of some more unusual types of structures found along this coast section. The evidence that these unique structures do owe a measure of their present form to the movements that gave rise to the Baravaig folds lies in the fact that they are all cylindroidal with axes parallel to the elongation lineation as was illustrated diagrammatically in figure 1.1(a).

The first example is shown in figure 1.3(a). In this diagram a small amphibolite body is ornamented with spots while surrounding acid gneisses are left blank. Narrow black lines outside the amphibolite represent cracks; parallel black lines inside the amphibolite are very thin streaks of fine-grained white material. The acid gneisses

contain numerous small folds undoubtedly belonging to the Baravaig group which have the same profile as the apparently folded amphibolite. Both the amphibolite and the foliation in the acid gneisses are transected by straight sided veins with the characteristic green colour of fine-grained epidote. The orientation of these veins is very close both to the very thin white streaks in the amphibolite and also to the axial planes of the small folds in the acid gneiss.

Several important deductions can be made from the evidence presented in this exposure. First and foremost it is clear that the thin white streaks in the amphibolite and the green epidotic veins are later than the period of folding. Furthermore their direction seems to be determined by the axial plane direction of the folds: a direction which must have been a plane of weakness. Presuming that the amphibolite in its present state represents a metamorphosed igneous body then a number of inferences concerning its intrusion can be made. Although it is obviously earlier than the thin white streaks and the epidotic veins it need not be earlier than the folding: it may have been guided as a liquid into its present shape. Proceeding to more tenuous arguments it may be said that the forces which controlled the thin white streaks and the epidotic veins were not significantly different from those which controlled the folds; simply a re-adjustment of the relative values of the stresses acting in the plane of the veins and perpendicular to the plane of the veins. However, any stress pattern controlling the intrusion of a liquid into a cavity of the present

shape of the amphibolite must have been quite different; isotropic of nearly so as compared with strongly anisotropic in the case of the thin white streaks and the epidotic veins. Thus the intrusion of the body between the development of the folds and the introduction of the veins would imply great changes in the stress system affecting the rocks whereas the intrusion of the body before folding would not. Such arguments favour the conclusion that the body was emplaced before folding occured.

Although it is inconclusively proved, the hypothesis that the amphibolite was probably introduced earlier than the folding whereas the thin white streaks are certainly later has an important bearing on very similar white streaks in other very similar amphibolites. The exposure in question is unique in that it is the only one known in which a discordance between the thin white streaks and the amphibolite can be clearly demonstrated. In nearly every other case the thin white streaks are parallel, or very nearly so, to the junctions between the amphibolite and the country rock; these junctions themselves, in nearly every case, being smooth and sub-parallel to each other and to the foliation in the surrounding gneisses. For this class of amphibolites the following sequence can be tabulated:-

1. Introduction of amphibolitic material into host rock.
2. The Baravaig, or first period of folding.
3. Introduction of thin white streaks and epidotic veins.

Detailed descriptions of the amphibolites and their hosts will be given in Chapters 16 and 20.

Another unusual exposure is illustrated in figure 1.3(b). The rock ornamented with spots consists almost entirely of amphibole and contains stringers of coarse quartzo-feldspathic rock shown black. Above this the rocks show a foliation consisting of bands of white quartzo-feldspathic material, shown as black lines, and bands rich in mid-green amphibole with many flakes of dark mica. The rocks above the junction possess a crude cleavage reminiscent of that associated with the folds illustrated in figure 1.2. This is not represented in the diagram but slopes gently from left to right, and for practical purposes is parallel to the junction. In addition to the cleavage the quartzo-feldspathic rocks in both halves of the exposure possess a very strong elongation lineation. The junction between the amphibolite below with the gneiss above is needle sharp.

This exposure seems to be open to two interpretations. Either the junction represents an original igneous contact, or it represents a line of movement. There is no conclusive evidence in either direction. The fact that it is slightly irregular would support the former; the curvature of the foliation in the gneisses above and the approximate parallelism of the junction and the cleavage would support the latter.

The structures figured in 1.3(c) and (d) may conveniently be described together. In (c) an amphibolite body is ornamented with spots. The weathered surface is dark greenish-grey in colour and cleavage faces of crystals up to three millimetres across are visible. Pale-grey rocks of medium grain size are left blank. These contain small crystals of dark minerals and also streaks of quartzo-feld-

spathic material; the latter being shown in black. The two oblique black lines represent cracks. The spotted ornamentation in (d) represents a pale-grey, fine-grained rock with numerous dark-green crystals of prismatic habit laying in all directions and small red garnets. Quartzo-feldspathic rock with a white, sugary textured surface is left blank. In both instances the diagrams are profiles of cylindrical structures which are arranged parallel to the very strong elongation lineation.

Any interpretation of these structures would be purely speculative. They have obviously been modified by movements of the earliest phase which can be recognised in Skye but their present form was probably determined by their history previous to this.

Passing from the north shore of Knock Bay to the west shore certain changes can be seen in the lithology of the Lewisian rocks. It is, however, possible to trace the Baravaig structures through these changes. The prominent ruined castle known as Dun Moravaig stands on a foundation of massive Lewisian gneisses. In these rocks bands of different composition are interleaved on many different scales; their average thickness being about 20cms. An idea of the degree of coarseness of crystallisation of these rocks can be gained from the fact that amphibole crystals up to 1cm long are clearly visible. The foliation at this locality dips gently northwards.

Two hundred yards NNW of the castle good exposures of Lewisian rocks are situated on the shore near a large house

called Knock. The rocks here have a flaggy parting: they split readily along planes which are very closely spaced. These planes are parallel to the foliation. Individual bands of quartzo-feldspathic material in these rocks rarely exceed 2mm in thickness: only one hundredth part of a similar measurement below the castle. Needles of amphibole reach 3mm in length. The foliation in these rocks dips gently east.

Below the castle the first lineation is represented in the acid gneisses as a prominent elongation of the constituent quartz and feldspar grains. In many rocks of basic composition further to the east the first lineation is seen as a "ribbon" structure in thin bands of acid material enclosed in basic hosts. These "ribbons" of acid material lay on foliation planes. They are only a few millimetres thick but may be several centimetres wide. Their constituent grains can often be seen elongated parallel to their length which itself is parallel to the elongation lineation in surrounding acid gneisses. In one or two exposures it may be verified that these ribbons represent the hinge zones of small isoclinal folds the limbs of which seem to have almost entirely disappeared.

Near the large house called Knock and along the west side of Knock Bay these ribbon structures are abundant and they may be traced as far SW as Bagh a'Mhuilinn. In many localities along this coast section the ribbons are discordantly cut by linear arrangements of acicular crystals of amphibole belonging to the group of structures treated in Chapter 3.

The only remaining structures belonging to the Baravaig group occur in Moine rocks on Rudha Phoil and Rudha Dubh, both near Ardvasar. The distribution of the Moine rocks and of the Baravaig, or first structures is shown in figure 3.4. On Rudha Phoil and Rudha Dubh it is easy to distinguish a psammitic horizon from the more common semi-pelites. On Rudha Phoil this horizon dips SE at angles of 30-40° but swings round into a very steep attitude on Rudha Dubh where it strikes NW. The presence of a major fold is thus demonstrated. This major fold probably belongs to the Baravaig group but the discussion of the evidence is best postponed until structures belonging to the other groups have been described. Of more direct interest is the presence of a strong elongation lineation in these psammites. This lineation can also be found in thin psammitic bands which occur in the semi-pelitic rocks on these two peninsulas. It can be shown that this lineation is probably the same as the elongation lineation described previously in the Lewisian rocks but there-again the discussion of the evidence is more conveniently postponed until structures in other groups have been fully described.

EXPLANATION OF FIGURE 1.1.

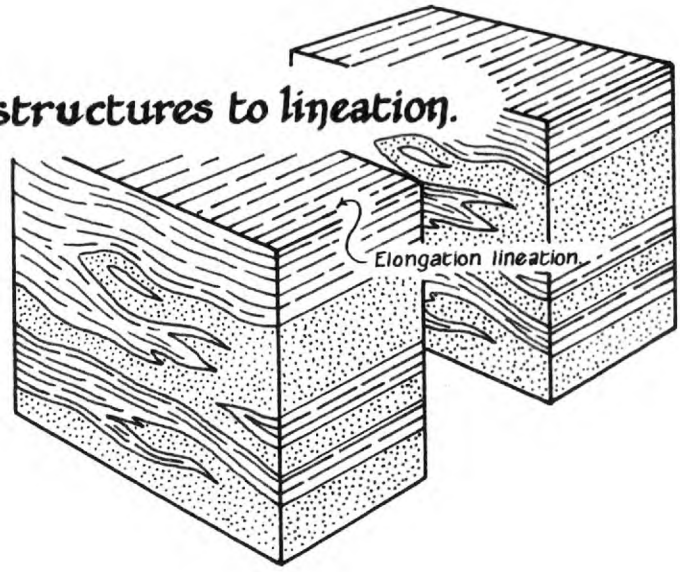
(a) Relation of first structures to lineation.

This diagram illustrates how the elongation lineation is arranged parallel to the axes of the Baravaig, or first structures. No matter what the shape of their profile these structures are always cylindrical.

(b-d) Profiles of first folds in acid gneisses.

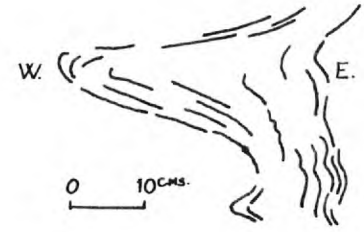
These are examples of small scale folds in acid gneisses consisting essentially of feldspar and quartz. The folds have a very strong elongation lineation parallel to their axes.

(a) Relation of first structures to lineation.



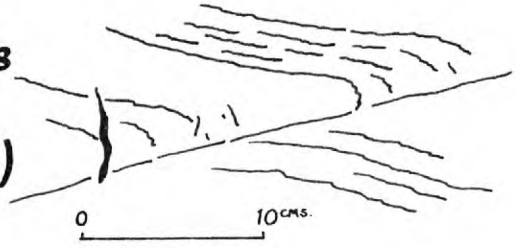
First structures NE of Knock Bay

(b)



Profiles of first folds in acid gneisses

(c)



(d)

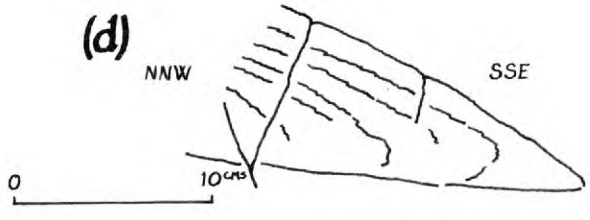


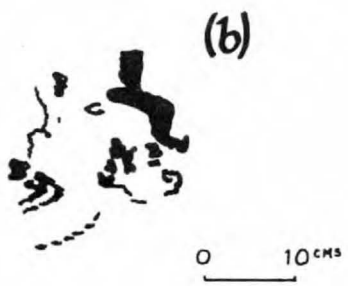
Figure 1.1

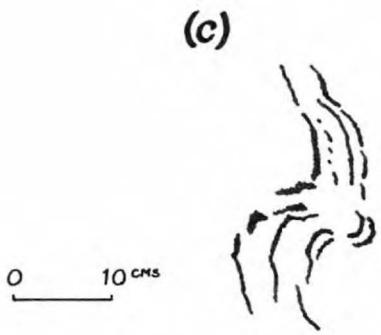
EXPLANATION OF FIGURE 1.2.

(a-d) The black areas represent quartzo-feldspathic material in a host rock of amphibole, biotite gneiss. Profiles of these structures are shown. They are strongly drawn out parallel to the elongation lineation.



First folds NE of Knock Bay





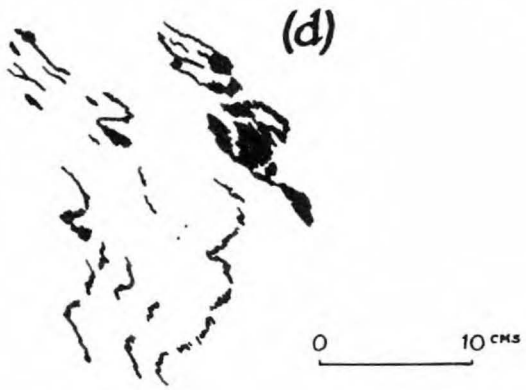


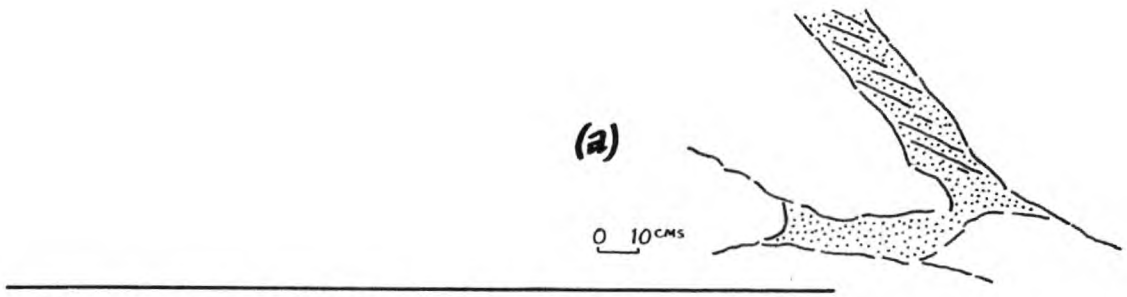
Figure 1.2

EXPLANATION OF FIGURE 1.3.

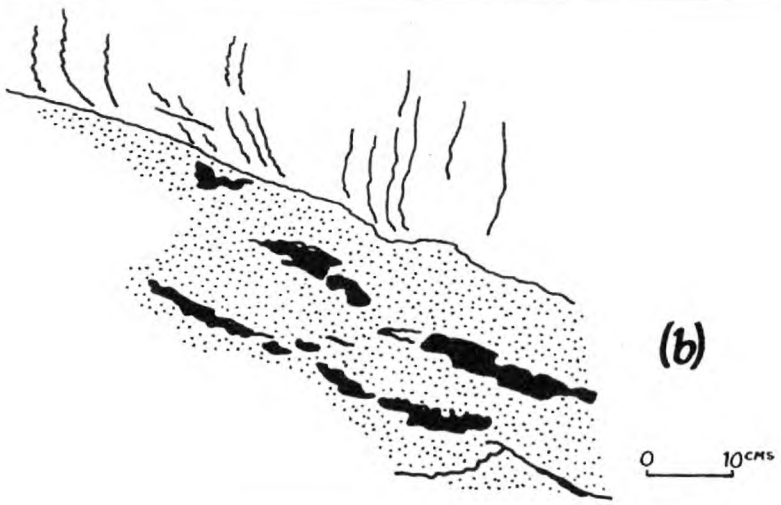
(a) The spotted ornament represents an amphibolite which is enclosed in a host rock of pink acid gneiss. Thin parallel lines in the amphibolite represent very thin streaks of a fine-grained white rock. Other lines represent cracks in the rock face.

(b) An amphibolite is spotted and contains irregular patches of coarse quartzo-feldspathic material which is shown black. The junction with the rock at the top of the diagram is very sharp. This latter rock is an amphibole, biotite gneiss containing bands of white quartzo-feldspathic material which are shown as black lines.

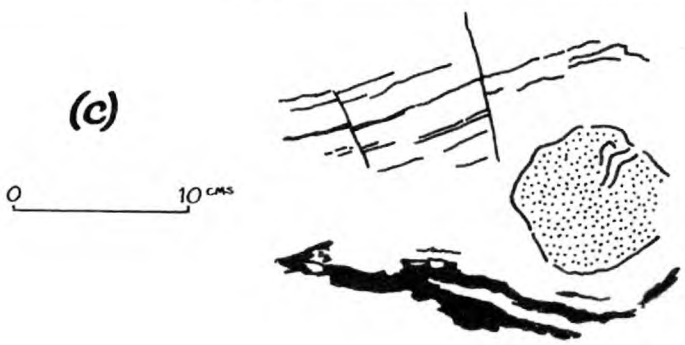
(c) and (d) Profiles of "knots" and "stringers" which are strongly drawn out parallel to the first elongation lineation.



First structures NE of Knock Bay



in Lewisian rocks of mixed lithology



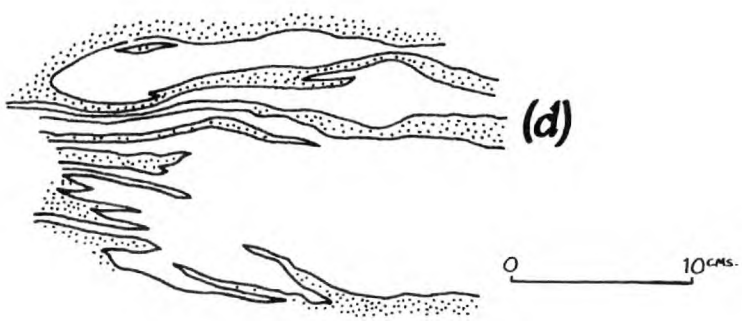
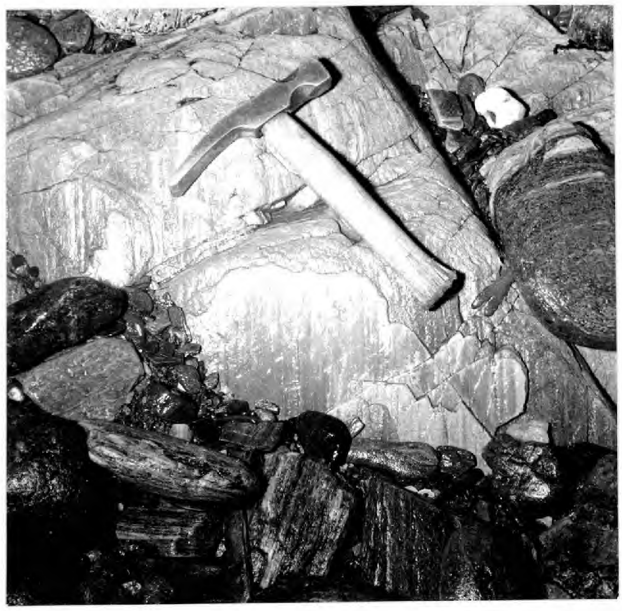


Figure 1.3

EXPLANATION OF FIGURE 1.4.

This photograph was taken with the axis of the camera almost vertical. The foliation planes are dipping gently towards the bottom of the photograph. On these foliation planes a lineation is prominent. It is caused by a linear arrangement of rock material of slightly differing compositions. The individual grains of these streaks or ribbons are elongated along an axis which is oblique to the length of the ribbons; a unique situation since the grains are usually elongated parallel to the ribbons. The handle of the hammer is arranged such that it is parallel to the oblique axis of elongation.



Intersecting lineations near Ferindonald

Figure 1.4

These structures are not very common but provide valuable clues in the elucidation of the structural history of the Moine nappe. They are most easily demonstrated on the peninsulas of Rudha Phoil and Rudha Dubh in Moine rocks and along the north shore of Knock Bay in Lewisian rocks.

An important junction separating psammitic rocks from predominantly semi-pelitic rocks can be drawn across Rudha Phoil as shown in figure 3.4. A typical exposure of the semi-pelitic group SE of this junction is illustrated in figure 2.1(a). This contains two structures: foliation and cleavage. The foliation dips gently to the right, 20-30° ESE, and is defined by layers of rock of different mineral composition. The semi-pelitic members are pale-grey and micaceous with abundant pink, lentil-sized garnets. Within the more micaceous rock there are distinct bands of off-white psammitic material 5-6cms thick with well-defined margins. (The colour "off-white" in this usage falls in the series: white, off-white, pale-grey, mid-grey, dark-grey, black). The cleavage is oblique to the foliation and dips more steeply to the right, 30-40° ESE. It is defined as a tendency for the rock to split along closely spaced planes which are oblique to the foliation. The microscopic structure of the rock which gives rise to the cleavage will be dealt with in Chapter 22. Thin laminæ of psammitic material are often seen to be puckered into small folds along the line of intersection of the foliation and the cleavage. Figure 2.1(b) is a photograph of such a structure in a boulder on the shore at Tormore.

Two hundred yards south of the Armadale Pier, on Rudha Phoil, some folds are excellently displayed. Some of these are illustrated in figure 2.2(a). These folds may be described as moderately tight and slightly asymmetrical with well-rounded hinges. The cleavage planes are spaced at intervals of 1½ to 3mm and their intersection with the bands of psammite give rise to the small "puckers" of figure 2.1(a). The axes of these puckers, that is their lines of maximum curvature, are parallel to the axes of the larger folds and, furthermore, within practical limits the cleavage is parallel to the axial planes of the folds.

Thus there seems to be a direct mechanical connection between the cleavage, the large folds and the "puckers" and it is assumed that they owe their origin to the same mechanical stresses. To discuss this, however, would presume a knowledge of the mechanisms of folding which at present is not available.

At the extreme south of Rudha Phoil more folds can be seen. Drawings of two of these appear in figure 2.2(b) and it will be noticed that they are of distinctly different sizes. Nevertheless they do possess several features which make them directly comparable with the folds of figure 2.2(a). They have the cleavage parallel to their axial planes and small "puckers" parallel to their axes. Not only this but the directions of their axial planes and their axes are practically constant over the whole of the peninsula. Taking these factors into consideration all of these folds have been alloted to the same group.

One fact remains to be mentioned in connection with

these folds. This is their relation to the elongation lineation which was briefly discussed at the end of Chapter 1. It was stated that this lineation could be found in the thin psammitic bands which occur in the semi-pelitic rocks of Rudha Phoil. A close examination of the folds 200yds south of the pier shows that the elongation lineation passes uninterupted and obliquely over the hinges of the folds as illustrated in the diagram at the bottom of figure 3.1.

Taking this evidence into consideration it is possible to erect the following time sequence of events:-

1. Elongation of the grains in the psammitic layers.

2. Folding of the psammitic layers accompanied by the development of the axial plane cleavage.

The angular relations of some of the structures described in the previous paragraphs are shown in the stereogram of figure 3.1. Poles to the foliation planes form a continuous girdle trending NW with a significant concentration in the NW quadrant which represents the larger number of observations made on the longer limbs of the asymmetrical folds. The axis of this girdle, representing the axis of folding, plunges a few degrees to the NE, but is not shown on the diagram. Poles to the axial plane cleavage fall into a neat concentration in the NW quadrant, slightly closer to the edge of the projection than the greatest concentration of poles to foliation. This grouping demonstrates the uniformity in the direction of this structure over the peninsula and the fact that it is closer to the edge of the diagram is a reflection that, on the longer limbs of the folds, the cleavage is steeper than the foliation. The first lineation also falls

on a girdle with a marked concentration in the SE quadrant. This latter concentration is due to the greater number of readings taken on the long limbs of the folds while the points scattered out along the girdle are those readings taken on the short limbs and on the hinges.

Near the end of Chapter 1 the presence of a major fold in the psammite horizon of Rudha Phoil and Rudha Dubh was demonstrated. The first elongation lineation is prominent in these rocks and the cleavage can also be found in semi-pelitic layers on the SE side of Rudha Dubh. The orientation of the cleavage here is exactly the same as on the SE end of Rudha Phoil. The folds in the psammite bands are, however, far more complex than on Rudha Phoil. Figure 2.4 is a stereoscopic pair of photographs showing one example from the SE of Rudha Dubh. The proof that these "contortions" are not the product of later periods of folding lies in the fact that the cleavage in these rocks is undeformed and is parallel to the axial planes of the "contortions".

The development of these structures can be explained as follows. If the major fold in the psammites is earlier than the cleavage then complex fold patterns are to be expected in the rocks at the SE of Rudha Dubh. J.G.Ramaay (1960) has shown how the direction of transport of rock particles during folding can be calculated when certain factors are known. Applying his methods to the folds of Rudha Phoil the direction of transport, or "a" direction can be found. Figure 2.3 illustrates the procedure. This is a stereogram on which is plotted the poles to the axial plane cleavage and the locus

of the first elongation lineation. The plane of the cleavage is represented by a full line while the locus of the first lineation is marked as a pecked line. The direction of transport, or "a" direction is at their intersection. Its plunge is 34° and its direction 114°. Now if this "a" direction were to be superimposed on rocks with very steep dips and a north-westerly strike then there would be a very acute angle between the foliation and the "a" direction. Under such circumstances folds of the type shown at the bottom of figure 2.3 are to be expected.

The foliation, cleavage and folding on Rudha Phoil have very similar counterparts in the Lewisian rocks of Knock Bay. About 400yds ESE of the ruined castle called Dun Horavaig analogous structures are exposed. Figure 2.5(a) is a photograph of a joint face in biotite gneiss on which the foliation and the cleavage are well-displayed. The cleavage in this exposure dips 27° SSE and it can be found in very similar orientations in numerous other exposures along the coast to the east. It is, however, not nearly so well-developed as in the Moine semi-pelites on the SE of Rudha Phoil. This different development of the cleavage is probably governed more by the rock type than the mechanical stresses which gave rise to it.

Near the locality which is the subject of figure 2.5(a) the structures developed at the intersection of the foliation and the cleavage are well-displayed. These take the form of "puckerings" of the foliation surfaces whose axes are parallel to the line of intersection. One such foliation plane is illustrated in figure 2.5(b).

Just over 100yds east of the ruined castle another coastal exposure demonstrates the relation of the cleavage to some folds in acid gneisses. A sketch is given in figure 2.6(a). The cleavage is not so well-developed in this exposure but it can be seen that it is close to the axial plane of the fold. Figure 2.6(b) is another fold of this group about 500yds ESE of the ruined castle. In this diagram the spotted ornament represents rocks of basic composition composed essentially of amphibole. The remainder of this exposure is a rock consisting of irregular bands of coarse, quartzo-feldspathic material up to 3cms thick and dark-green bands of like thickness containing biotite and amphibole. The arrangement of clots and lenticles within these bands gives the impression of a planar structure parallel to the axial planes of the folds. Two or three hundred yards further along the coast these folds become very common indeed. Figure 2.6(c) illustrates a fold from this area. The spotted ornament covers dark greenish-grey weathering rocks of basic composition while acid rocks coloured off-white to pale-grey, are left blank. The foliation planes of the acid rocks show "puckers" or small scale folds of the same type as figure 2.5(b). The last examples of small scale folds in this group are those in the photograph of figure 2.6(d). The exposure shows alternations of acid and basic layers up to 6-7cms thick. On weathered surfaces the acid bands are brownish-yellow to off-white against various shades of medium and dark green of the basic layers. A crude cleavage is developed parallel to the axial planes of the folds. A few yards away from this exposure the relation

of these folds to the elongation lineation and the ribbon structure of Chapter 1 is very clearly displayed. A foliation surface is traversed by the "puckers" which are parallel to the axes of the Rudha Phoil folds; these "puckers" themselves being small scale folds. On this foliation plane the lineation associated with the Baravaig folds is represented by a ribbon structure. This ribbon structure passes over the "puckers" and has clearly been deformed by them. The relationship is, in fact, seen over a very wide area but is nowhere so clearly displayed as here.

Having described examples of small scale structures of this group and their relation to the small scale structures of the Baravaig group attention will now be turned to a large fold which is most likely of this generation. The presence of this fold may best be demonstrated by a traverse of the coastal section laying along the north shore of Knock Bay. Beneath the ruined castle the foliation in the massive gneisses dips at 26° towards 029°. At a point just over half a mile to the east the foliation dips 51° towards 334°. Between these two localities there is a swing of strike through the W-E position while the dip increases uniformly. Beyond this last point and along the coast to Ob Snosaig the attitude of the foliation varies as much as 45° on either side of the vertical but maintains a consistent NE strike. Throughout all these variations in dip the axial planes of the small Rudha Phoil folds are consistent in orientation. Thus they must be contemporaneous with or later than the major fold. The axial trace of this major fold, which has been called the Knock synform, is marked on the map in Plate 2. This line

is difficult to trace for two reasons. Firstly, only one fold hinge is present: there is no evidence to demonstrate a complementary antiform and thus the SE limb of the fold cannot be strictly defined. That area which is being treated as a fold limb in this work may, in fact, be mostly in the hinge zone, the complete SE limb being absent. Secondly, the hinge zone seems to be complicated by folding on a scale intermediate between that of the small scale structures described in the body of this chapter and the major fold. That is, the hinge of the major fold is not a simple curve but may be represented by a number of fold hinges on this intermediate scale.

A cursory examination of Plate 2 and figure 2.7(b) should demonstrate that the Knock synform causes a regional change in the trend of the first lineation associated with the Baravaig folds. Therefore the Knock synform must be later than the Baravaig folds. A structural analysis of part of the Knock synform near Loch an Ime is given in figure 2.7(a). Although the limbs show a large variation in attitude the poles to foliation planes fall on a reasonable great circle on the stereographic projection which indicates an axis of folding plunging at 30-40° towards a bearing of 050-060°. The axial plane of the fold is less easily defined but dips at about 40° towards the SE. The orientation of the axes and axial planes of the small folds described earlier in this chapter are much the same as this and since they are the only group of small folds which do share this orientation it seems fair to correlate them with the Knock synform in age.

EXPLANATION OF FIGURE 2.1.

(a) Foliation and cleavage in semi-pelitic rocks.

(b) A boulder on the shore near Tormore. This is a semi-pelitic rock with thin white psammitic bands. Cleavage planes are prominent in the semi-pelite and the white bands are "puckered" into small folds with axial planes parallel to the cleavage.

(a) On Rudha Phóil



Foliation and cleavage in Moine rocks

(b) In a boulder

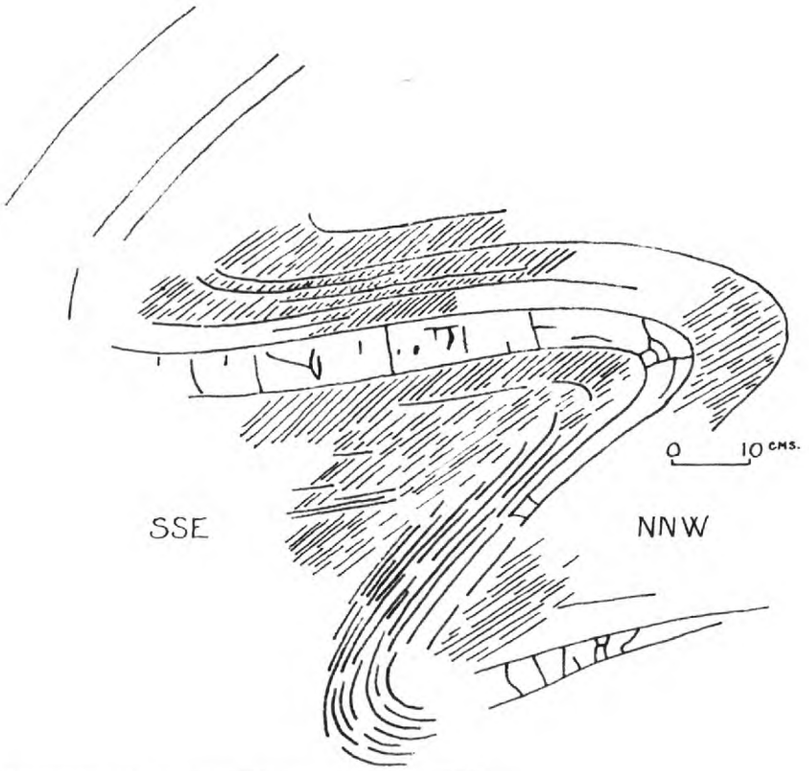


Figure 2.1

EXPLANATION OF FIGURE 2.2.

These are profiles of folds in the type of rocks illustrated in figure 2.1(a). In (a) a band of psammite is prominent.

(a) 200 yards south of the pier.



Profiles of folds on Rudha Phöil.

(b) At the extreme south.

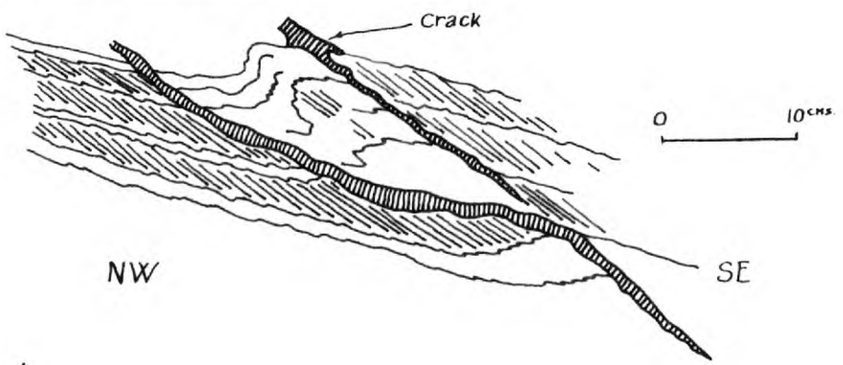




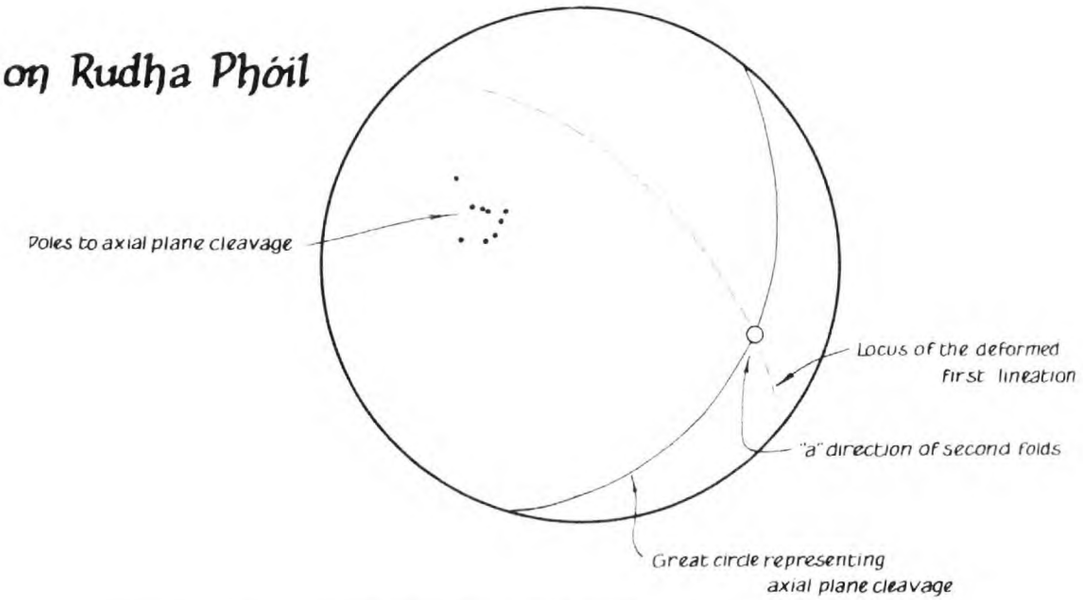
Figure 2.2

EXPLANATION OF FIGURE 2.3.

The diagram in the bottom left-hand corner represents a first fold, unmodified by the second deformation, enclosed in a hypothetical block of rectangular shape. The axial plane of an incipient second fold is represented and the large arrow laying on this plane is the "a" direction of the second folding.

The diagram in the bottom right-hand corner has been accurately constructed. The axial plane of the second fold and the "a" direction laying on it are in the same position as they were before the second deformation. The hypothetical block is heavily outlined and has been distorted into a complex shape. Within this block there is a complicated curved surface which is the resultant of the first and second folds superimposed.

Calculation of the "a" direction of second folds on Rudha Phóil



The mechanism of the formation of complex second folds on Rudha Dubh

Before the second deformation

After the second deformation

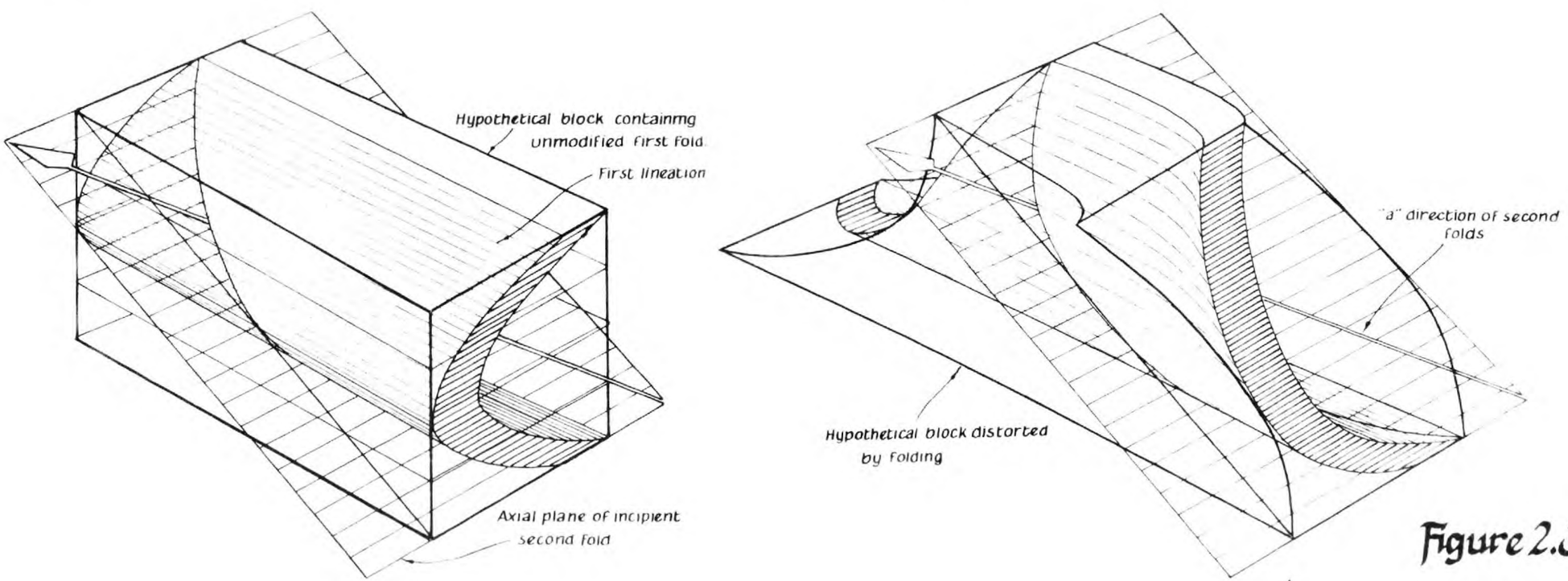
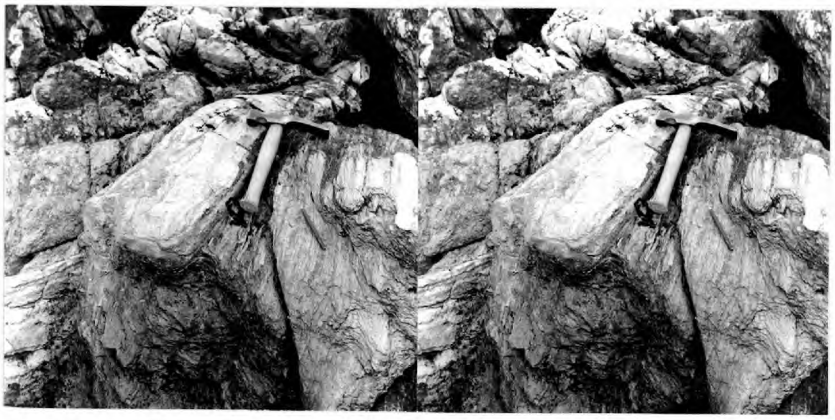


Figure 2.3

EXPLANATION OF FIGURE 2.4.

The pale coloured mass in the centre of the picture is a folded psammite. The curved axis of this complex fold is along the left-hand edge of the mass. Careful study of the photographs should reveal that an elongation lineation passes obliquely over this axis. The pencil is laying on a cleavage plane in semi-pelitic rock and is arranged parallel to a linear structure caused by the microscopic folding of micas.



Stereoscopic photographs of complex folds at the eastern tip of Rudha Dubh

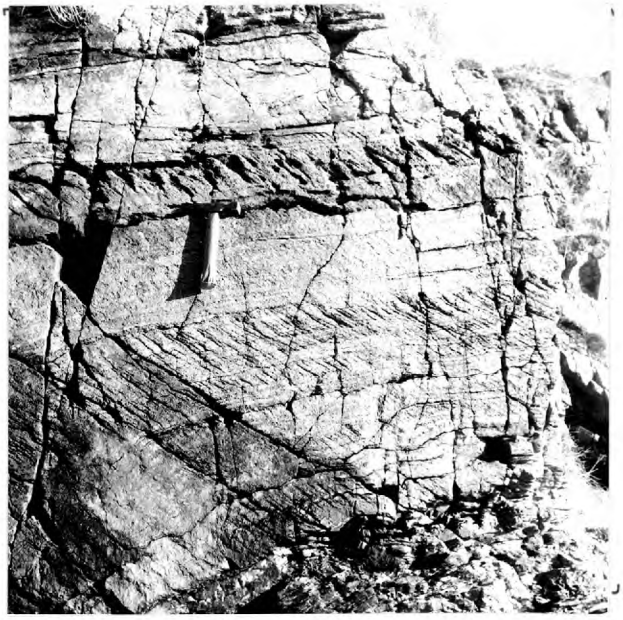
Figure 2.4

EXPLANATION OF FIGURE 2.5.

(a) A vertical joint face in biotite gneiss.

(b) Photograph taken with the camera axis vertical. The foliation plane dips gently towards the bottom of the picture. The small scale folds which plicate the foliation plane belong to the Rudha Phoil generation.

(a) A joint face.



Foliation and cleavage in Lewisian rocks

(b) A foliation plane.



Figure 2.5

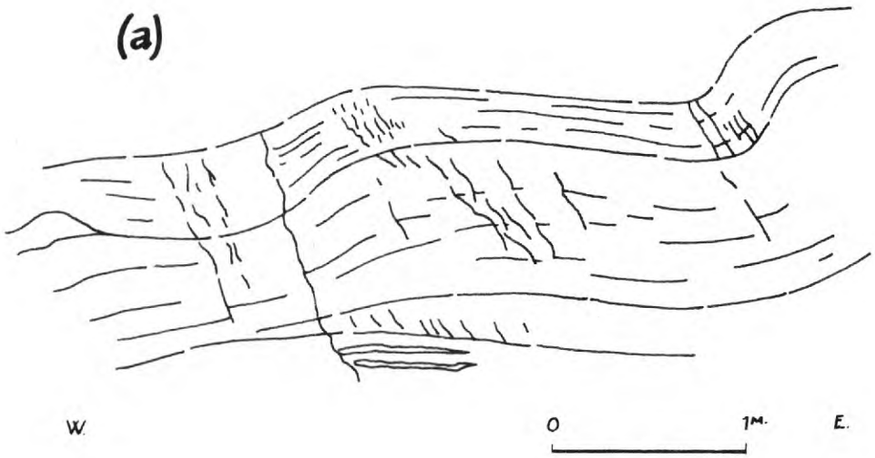
EXPLANATION OF FIGURE 2.6.

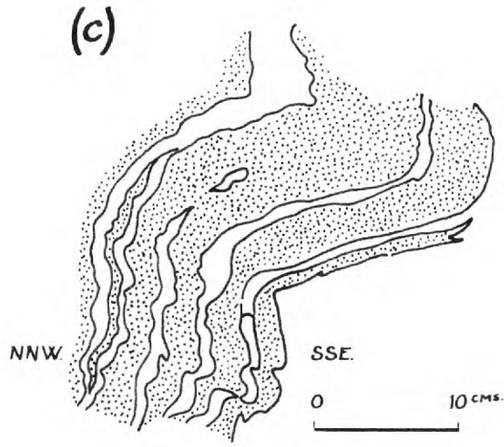
(a) Open folds in acid gneisses.

(b) The spotted ornament represents amphibolite which is enclosed between two layers of amphibole, biotite gneiss.

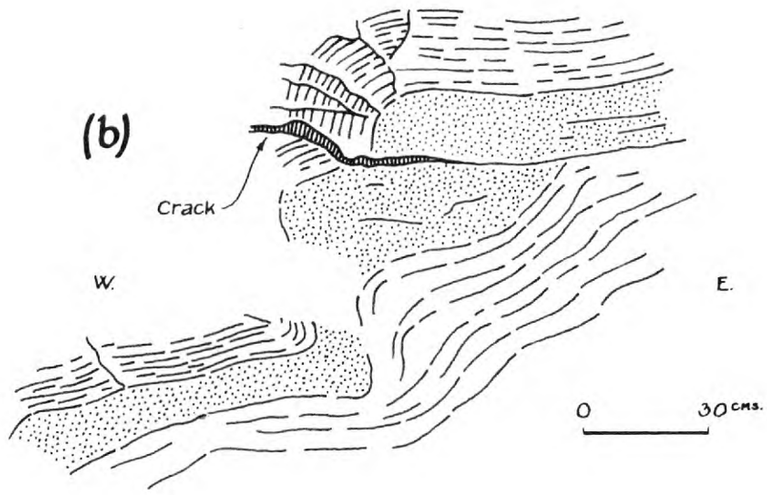
(c) Basic rocks are spotted while acid bands are left blank.

(d) These are alternating layers of acid and basic rocks up to 6-7cms thick. A crude cleavage is developed parallel to the axial planes of the folds.





Folds in the Lewisian rocks of Knock Bay



(d)

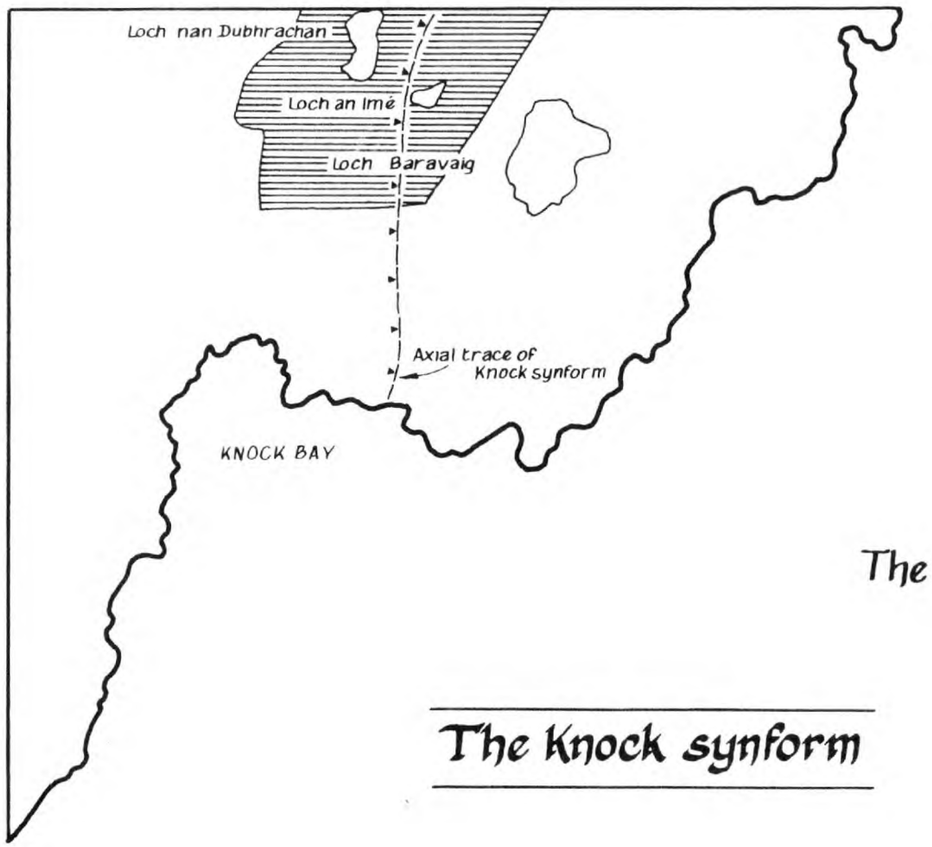


Figure 2.6

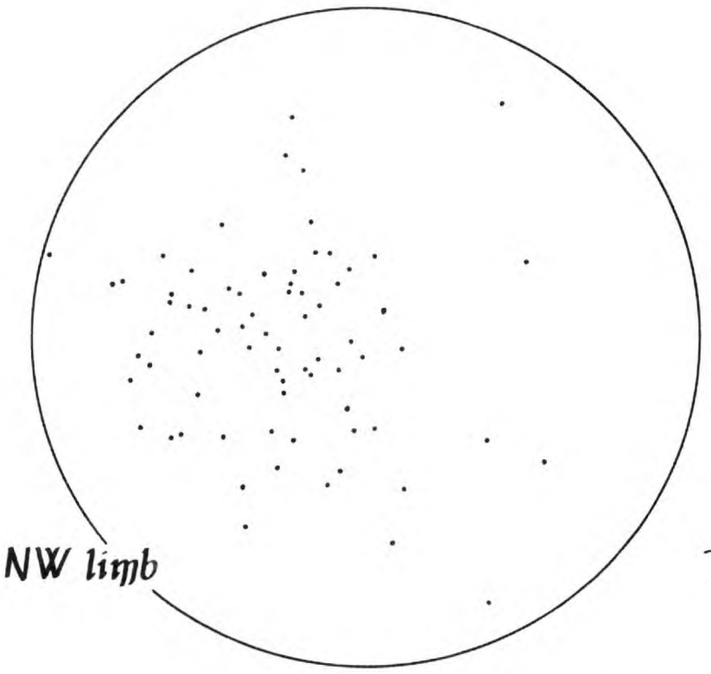
EXPLANATION OF FIGURE 2.7.

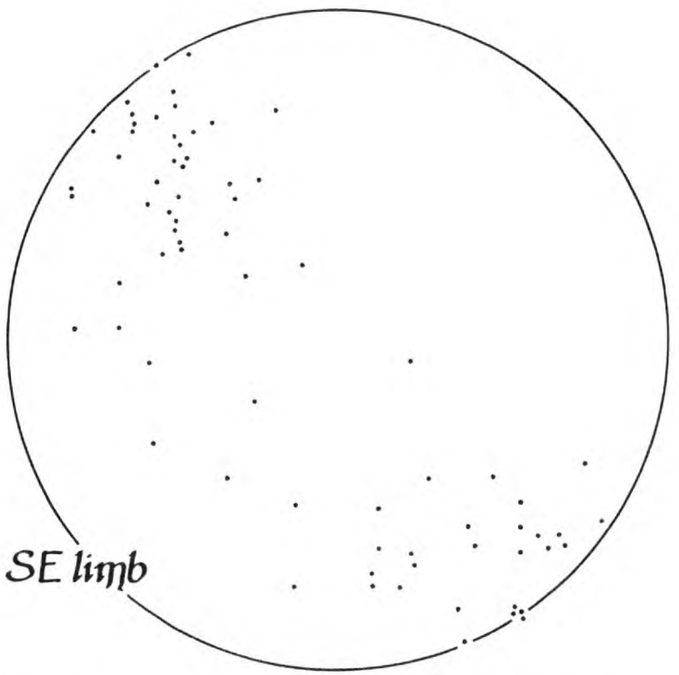
(a) Stereograms showing the angular distribution of poles to foliation planes on the two limbs of the Knock synform within the shaded area of the inset map.

(b) Stereograms showing the angular distribution of first lineation over the total area in which this structure can be confidently identified.

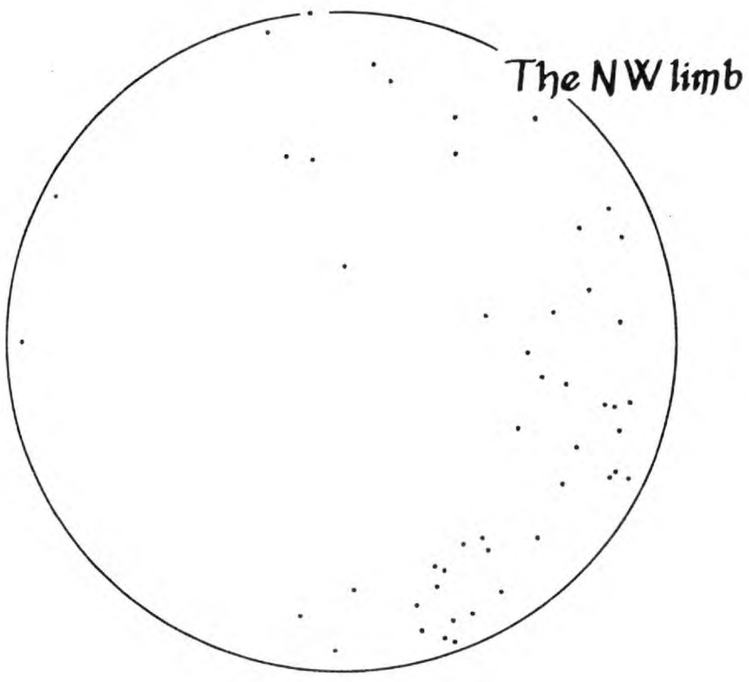


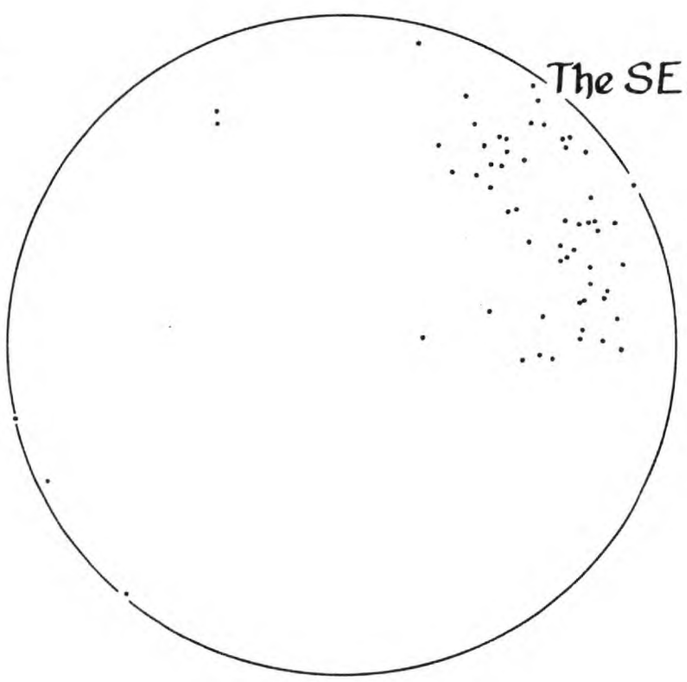
The Knock synform





(a) Poles to foliation planes within the shaded area of the map





(b) An analysis of the first lineation over the total area

Figure 2.7

Structures of this group are best displayed in Moine rocks on a short section of the coast near Tormore, one and a half miles south of Ardvasar. The structures at Tormore can confidently be matched with other structures on the peninsulas of Rudha Phoil and Rudha Dubh where, although the age relations are clearly displayed, the structures are not so well developed. Some structures in Lewisian rocks which may have their analogues in the structures of the Moine rocks at Tormore will also be described in this Chapter. The degree of confidence with which they may be correlated with the Moine structures, especially when only field evidence is taken into consideration, is not so strong as that which may be admitted between the structures in Moine rocks near Ardvasar and those near Tormore. However, the microscopic evidence which will be presented in Chapters 20 and 22 lends weight to these correlations, based on field evidence, that have been made between structures in Moine and Lewisian rocks.

The exposures of Moine rocks in which the Tormore group of structures is developed are confined to the coast. Their approximate extent is shown on the map in Plate 4 by a closely spotted ornament. Inland from these exposures the Moine rocks present a different appearance and contain structures of a completely different style. The age relations of the Tormore structures will be demonstrated first by a consideration of the rocks of Rudha Phoil.

At the beginning of Chapter 2 the "type examples" of the Rudha Phoil folds were described. The age relations

of the folding and the cleavage were discussed and it was concluded that they were contemporaneous. Now the cleavage planes in the semi-pelitic rocks at this locality carry a lineation which is different from that described in the psammite bands. This lineation is expressed only by the orientation of plates of muscovite and biotite into a partial girdle fabric, shown in figure 22.1, whose axis coincides with the lineation.

The geometrical relations of the different strucutres on Rudha Phoil are shown in the diagrams of figure 3.1. In the block at the bottom the foliation is represented as a hypothetical psammite band carrying an elongation lineation which is the first, or Baravaig lineation. This psammite band, and the lineation which it carries, are deformed by a fold of the Rudha Phoil, or second group with the accompanying axial plane cleavage. Upon this axial plane cleavage the lineation described above is represented as a series of parallel lines which are approximately perpendicular to the axial direction of the second folds. Since this lineation is itself an expression of certain mechanical restraints and is clearly not deformed by the second folds it must belong to a later phase of movement. This has been called the Tormore, or third phase of movement. There is no evidence to show that structures intermediate in age between those of the Rudha Phoil group and those of the Tormore group exist anywhere within the area of study.

The strict angular relations of most of the structures have been described in Chapter 2 and are shown in the stereogram of figure 3.1. The only exception in this

description was the third lineation. Measurements of this structure are plotted on the stereogram and fall into a small area in the SE quadrant. These observations were made over a wide area and demonstrate that the third lineation is obviously unaffected by the second, or Rudha Phoil folds.

The cleavage, carrying the third lineation, can be seen in many of the Moine exposures of Rudha Dubh. The right-hand map of figure 3.4 shows how the strike of the cleavage varies slightly over the peninsulas. This variation is probably connected with movements along a large fault which crosses the peninsula of Rudha Dubh in a NE direction as shown in figure 3.4 and is not connected with folding movements: in any one exposure the cleavage is a sensibly plane surface. In figure 2.4 the pencil is laying on one such cleavage surface and is aligned parallel to the third lineation.

Within the psammitic rocks on the NE of Rudha Dubh it is often difficult to recognize the foliation. Nevertheless, in a number of localities folds have been distinguished which are rather different from those of the type illustrated in figures 2.3 and 2.4. One of these different folds is sketched in figure 3.2. This is a profile of the fold and it will be noticed that the cleavage is parallel to its axial plane. Furthermore, the first elongation lineation which is present in these psammitic rocks passes obliquely over the hinges of these folds. The axes of the folds are parallel to the third lineation which is developed on the cleavage surfaces. This last fact would indicate that these folds belong to the third phase of movement and thus

to the Tormore group of structures. The axes of these folds plunge SE and their axial planes also dip in this direction.

A stereographic analysis of some of the structures in the steep belt of psammitic rocks on the NE side of Rudha Dubh is presented in figure 3.2. Where foliation planes could be confidently measured this was done and the poles to these have been plotted on the diagram. These poles fall on a great circle with a concentration in the NNE and an axis which plunges to the SE. The concentration represents the larger number of readings which were made on the predominantly steep rocks whereas the remaining observations were made close to the folds of the type illustrated in the same figure. The cleavage plane poles are well concentrated in the NW quadrant in a very similar position to the analogous structure in the semi-pelitic rocks of Rudha Phoil (see figure 3.1). Likewise the third lineation, laying on the cleavage planes, also forms a concentration in much the same position as the related structure on Rudha Phoil. On the other hand the pattern of the first lineation is quite different. This may be explained as follows. On the hinges of the folds on Rudha Phoil the angle between the lineation and the fold axis is of the order of 80-90°. Thus the deformed lineation, when plotted on the stereogram, will sweep through an angle which is comparable to the angle between the limbs of the fold. However, on the hinges of the Tormore folds just described the angle between the fold axis and the lineation is little more than about 10° so that even if the folds are tight the angle through which the lineation sweeps may not be very great.

In some exposures of Moine rocks on Rudha Dubh about 150yds SE of the Ardvasar Hotel members of the two groups of folds are clearly displayed. In these exposures the psammitic bands are well defined and their thickness may be as much as 30cms. They are contained in a host rock of semi-pelitic material in which the cleavage is well developed. The folds in the psammitic bands can be classified into the two groups according to the following criteria:-

RUDHA PHOIL GROUP	TORMORE GROUP
1. Mostly tight.	1. Mostly open.
2. Axial direction variable.	2. Axial direction constant.
3. First elongation lineation in psammites passes obliquely over their axes which are not parallel to the third lineation on the cleavage planes.	3. First elongation lineation also passes obliquely over their axes but these axes are parallel to the third lineation which lies on the cleavage planes.
4. No relation of axial planes to cleavage.	4. Axial planes and cleavage are parallel.
5. Profiles vary considerably along the axis. Folds die away rapidly.	5. Profiles more or less constant.

Drawings of profiles of some of these folds are presented in figure 3.3. They are worthy of further comment on two counts. Firstly, some very interesting measurements can be made at this locality and, secondly, the fact should be

discussed that at this locality the cleavage is parallel to the axial planes of Tormore, or third folds, whereas at the SE of Rudha Phoil the cleavage is parallel to the axial planes of Rudha Phoil, or second folds.

The interesting measurements referred to are concerned with some of the angular properties of the folds. The first elongation can be seen to pass over the hinges of both Rudha Phoil folds and Tormore folds. It is thus theoretically possible to calculate the "a" directions of these folds using the methods which have already been outlined. However, there are practical difficulties. In the cases of the fold hinges where the elongation lineation makes a very small angle with the fold axis reasonably accurate measurements of the plane within which the lineation is deformed are not possible. In the exposures in question this difficulty rules out measurements on all of the Tormore group of folds and on several of the Rudha Phoil folds. Nevertheless it has been found possible to take measurements on four of the Rudha Phoil folds where the angle between the axial plane of the fold and the plane within which the lineation is deformed (the lineation deformation plane) exceeds 30°. This lower limit is set because in the cases in which the angle is less than 30° the great circles representing the axial plane and the lineation deformation plane of a particular fold, when plotted on the stereographic projection, intersect with a very acute angle so that an error of only a few degrees in the measurement of one of the planes might cause a corresponding error in the calculated "a" direction of 40° or more. The calculated "a" directions

of the four Rudha Phoil folds which were selected as being reasonably accurate are plotted as triangles on the stereogram of figure 3.3. Now the Rudha Phoil folds have been refolded by the Tormore folds. Before this refolding occured, the assumption is made, which may not be valid, that the "a" directions of the Rudha Phoil folds were constant in orientation. Thus, by treating them as a hidden lineation it is possible to calculate the "a" direction of the Tormore folds. The plane in which the "a" direction of the Rudha Phoil folds have been deformed is represented on the stereogram as a great circle marked as a dotted line. It must be noted here that no attempt has been made to assess the statistical validity of this line. Since it is based on only four points this cannot be very high. The axial plane direction of the Tormore folds, as defined by measurements of cleavage, is represented on the stereogram as a great circle marked by a pecked line. The point at which these two planes intersect is the calculated "a" direction of the Tormore folds.

The second point of discussion arising from the description of these exposures is concerned with the relation of the cleavage to the Rudha Phoil and Tormore groups of folds. Over the whole area of Moine rocks exposed on the peninsulas of Rudha Phoil and Rudha Dubh the cleavage can be recognised, and in nearly every case the third lineation can be distinguished on the cleavage surfaces. Both the cleavage and the third lineation maintain a constant orientation over this area; but at the SE of Rudha Phoil the cleavage is parallel to the axial planes of the Rudha

Phoil, or second folds whereas on the NW of Rudha Dubh the cleavage is parallel to the axial planes of the Tormore, or third folds. Thus the various manifestations of the Tormore folds, when considered on all scales, are ubiquitous in this area. However, large scale Tormore folds, as represented in the profiles of figures 3.2 and 3.3, seem to be more restricted. The localities at which large scale Tormore folds have been positively identified are shown on the central map of figure 3.4. Microscopic evidence indicates that some, if not all, of the movement on the cleavage planes was post-crystalline. Now in many of the semi-pelitic rocks in this area megascopic garnets are visible: their distribution being shown in the central map of figure 3.4. Since the western limit of this distribution is obviously discordant to the general trend of the foliation the presence or absence of megascopic garnet cannot be due to variations in chemical composition of the rocks in bands parallel to the foliation. This distribution is thought to be governed by the amount of post-crystalline deformation which the rocks have suffered during the Tormore phase of folding. This theory is supported by the apparent fact that large scale Tormore folds are present where megascopic garnets are absent; these large scale folds being an expression of greater post-crystalline deformation. In the semi-pelitic rocks on the SE of Rudha Phoil there is little indication of post-crystalline deformation. The conclusion to be drawn, therefore, is that the degree of deformation during the Tormore, or third phase of folding increases remarkably in a WNW direction, ie in a direction perpendicular to the cleavage. Not only this,

but the conclusion drawn on page 41 regarding the age relations of the Rudha Phoil folds and the cleavage on the SE of Rudha Phoil needs to be modified slightly. Although the cleavage may have originated as an axial plane cleavage to the Rudha Phoil group of folds it has obviously been modified slightly on Rudha Phoil by the Tormore folding and further to the WNW, as seen in the rocks of Rudha Dubh, it has been modified to a much greater extent; the Rudha Phoil, or second folds in the psammite bands have been completely re-orientated by the Tormore folds while the cleavage in the semi-pelitic rocks, although apparently the same, is in fact a new structure.

The "type locality" of the Tormore structures is on the coast some 300yds east of the farm of the same name. All of the rocks exposed here belong to the Moine series. Very close to the natural arch on this coast section the folds illustrated in figure 3.5 are to be found. The exposure is composed of well defined bands of psammitic rock alternating with bands of semi-pelitic material. Two generations of folds can clearly be separated: a smaller, earlier, tighter set; and a larger, later, more open set. These folds are developed in the psammitic rock: in the semi-pelitic bands a very strong cleavage structure is present. The semi-pelitic rock is very rich in micaceous minerals. The flakes of these minerals trace out very small folds in the rock and on the limbs of these very small folds, where the flakes are brought into approximate parallelism with each other, the rocks have a tendency to part along the cleavage planes of the minerals thus giving

rise to the strongly developed rock cleavage. An illustration of the micro-structure of this rock is given in figure 22.2. The axial traces of these very small folds upon the cleavage planes in the rock gives rise to a strong lineation which plunges in a SE direction parallel to the axes of the larger, later folds of figure 3.5. The geometry of these folds is thus exactly analogous with that of the folds described on Rudha Dubh 150yds SE of the Ardvasar Hotel (page 66) and correlation can be made on the following attributes:-

1. The profiles of both the larger and the smaller folds are very similar at the two localities.
2. The micro-structure of the cleavage is exactly the same at the two localities.
3. The orientation of the cleavage and the lineation which it carries are very much the same at the two places.
4. The axes of the larger folds are parallel to the lineation on the cleavage surfaces.
5. The axial directions of the smaller folds are very variable.

The angular distribution of all of these structures is shown in the stereogram of figure 3.5(b). The predominant feature of this diagram is the great circle which occupies much of the NW half. Poles to both the foliation and the axial planes of the smaller folds, which by analogy with Rudha Dubh must be second folds, are widely scattered along this great circle. Poles to the cleavage and to the axial planes of the larger, or third folds fall within a

small area of this great circle, in positions very close to those occupied by poles to cleavage in the stereograms of figures 3.1 and 3.2. Plotted measurements of the lineation on the cleavage surfaces also occupy the same positions as the analogous structure in these previous diagrams. The axes of the second folds are very widely scattered over the diagram: they do not form any well defined pattern. Had the axes of the second folds been of parallel orientation before the third phase of folding then it would be expected that they would now fall into a fairly well defined pattern. However, since they do not, then it must be assumed that they were not in parallel orientation before the third phase of folding. This deduction is in agreement with the observations set out in connection with figure 3.3 and also with the discussion surrounding the folds of figures 2.3 and 2.4.

Finally, there is one point which distinguishes these strucutres at Tormore from those SE of the Ardvasar Hotel. At Tormore there is no elongation lineation in the psammite bands which passes obliquely over the hinges of either set of folds. Instead there is an elongation lineation which is parallel to the axes of the Tormore, or third folds and thus also to the axes of the very small folds in the semi-pelitic rocks. Since the Tormore folds are never very tight in this area and the Rudha Phoil folds have a very variable axial direction there are many exposures in which the psammite bands make an oblique angle with the axes of the very small folds in the semi-pelitic rocks. This situation is illustrated diagrammatically in figure 3.6

and in such cases the constituent grains of the psammite are elongated in a direction which is not contained within the plane of the foliation.

The fact that at Tormore there is a third elongation lineation which passes through the psammite bands as opposed to the conditions at Rudha Phoil and Rudha Dubh where the first elongation lineation lies on the psammite bands is taken as an indication of a rather higher degree of deformation at Tormore than was reached at Rudha Dubh during the Tormore movement phase. There are no megascopic garnets in the semi-pelitic rocks at Tormore.

In the Lewisian rocks of the Moine nappe there are structures at several localities which invite correlation with the Tormore structures in the Moine rocks. The types of structures involved are either cleavages or linear arrangements of minerals; there are no positively comparable folds.

On a coastal section of about 200yds north of the headland of Rudha Cille-bhig, some two miles NNE of Ardvasar, examples of these structures are very well developed. Two planar structures can be seen in the rocks. One of these is the foliation; the other is a cleavage structure caused by the parallel orientation of the basal planes of micaceous minerals. However, this parallel orientation is not perfect; for along the line of intersection of these two planar structures the micaceous flakes are gently "crinkled" so that a linear structure is formed.

600yds NNE of Rudha Cille-bhig a very similar type of cleavage can again be distinguished in a position which is

oblique to the foliation. The "crinkled" arrangement of the micaceous minerals is clearly displayed but the lineation so formed is not parallel to the line of intersection of the cleavage with the foliation.

In the two exposure noted above both the dip of the cleavage and the plunge of the lineation are directed towards the SE.

Another type of linear structure to be found along the coastal section from the west shore of Knock Bay to Bagh a'Mhuilinn is a preferred orientation of needles of amphibole. Such amphiboles are very common in the basic representatives of the Lewisian series on this coast section; they are very small, rarely more than 5mm long, and are dark-green. In many exposure they lay on foliation planes with an obviously random orientation but there are several localities where they show a very strong preferred orientation. Some of these localities are indicated on Plate 3 together with the direction and amount of plunge of this linear structure.

In Chapter 1 a ribbon lineation associated with the Baravaig folds was described as also occuring along this coastal section. Immediately south of Rudha Cille-bhig the relations of these two lineations are particularly clearly displayed. Ribbons of acid material are contained within a basic host. The needle-like amphiboles in this basic host possess a very strong preferred orientation which is obviously oblique to the ribbon structures. These ribbons show considerable variations in trend along this coast section as demonstrated in Plate 2 whereas the measurements of the preferred orientation of the amphiboles

are fairly consistent as is shown in figure 3.7. The inference to be drawn from these facts is that the mechanical restraints which gave rise to the orientation of the amphibole were later than the Baravaig period of folding.

On the shore immediately below Ferindonald School the ribbon lineation is displayed in acid bands and is illustrated here in figure 1.4. The constituent grains of some of these acid bands are elongated not parallel to the ribbons but oblique to them. This situation is unusual; normally the constituent grains are elongated parallel to the ribbons. The interpretation placed on this observation is that the present elongation of the grains is later than their original elongation and that since this present elongation is parallel to the orientated amphiboles then the same mechanical restraints which controlled the amphiboles also caused the new elongation of the grains in the acid bands.

The exposure in Lewisian rocks on the north shore of Knock Bay which is illustrated in figure 2.6(a) also contains orientated amphiboles. The rocks are massive acid gneisses which have been deformed by folds of the Rudha Phoil group. One of these folds is very prominent in the top, right-hand corner of the sketch. Stout crystals of dark-green amphibole up to 2cms long can be seen in the vicinity of this fold. The long axes of these crystals are contained in planes which are parallel to the axial plane of the fold but almost perpendicular to its axis. Both the dip of the axial plane of the fold and the plunge of the long axes of the crystals is towards the SE.

At a point just over half a mile NE of the ruined castle

their is an exposure in Lewisian rocks in which two planar structures are seen. The exposure shows alternating bands of quartz-feldspar rock and amphibole rich rock which define the foliation. This structure dips at 38° towards the bearing 312°. The amphiboles have a very strong preferred orientation almost perpendicular to this foliation and lay in planes dipping at 40° towards the bearing 099°. The lineation defined by the amphiboles plunges at 40° towards 117°.

The correlation of the large orientated amphiboles in massive acid rocks at the last two localities with the smaller orientated amphiboles in the more fissile Lewisian rocks south of Knock Bay offers little difficulty when account is taken firstly of their direction and secondly of the changes in the metamorphic state of the host rock. With regard to direction, measurements made on the large amphiboles north of Knock Bay have been incorporated in the stereogram of figure 3.7 with no obvious discrepancy of direction from the smaller amphiboles south of Knock Bay. Differences in the size of the amphibole crystals may be accounted for by the decreasing metamorphic grade which microscopic and field studies indicate takes place in a westerly direction. The evidence for this decreasing metamorphic grade will be presented in Chapters 16 and 20.

In the rocks south of Knock Bay the correlation of the lineation defined by the small amphiboles with the elongation and "crinkle" lineations is based on their common directions and the fact that all of these structures occur in rocks which are in the same metamorphic state. As before, this

will be referred to in Chapters 16 and 20.

It is the correlation of the structures in the Lewisian rocks with the structures in the Moine rocks which were described earlier in this Chapter that may be considered as offering the greatest difficulty. The following points, based only on field evidence, can be put forward in support of a positive correlation:-

1. The orientation of the cleavage and other secondary planar structures which have been described in Lewisian rocks in this Chapter agrees fairly closely with the orientation of the cleavage in the Moine rocks of Tormore and Ardvasar.

2. The orientations of the linear structures which lay on cleavage and other secondary planes in the Lewisian rocks are also much the same as those of the third lineation which lays on the cleavage planes in the Moine rocks at Tormore and Ardvasar.

3. The linear arrangement of the amphiboles almost perpendicular to the axes of the Rudha Phoil folds on the north shore of Knock Bay, figured in 2.6(a), but laying in their axial planes is strongly reminiscent of the relations of the third lineation to the Rudha Phoil, or second folds on Rudha Phoil as described at the beginning of this Chapter and illustrated diagrammatically in figure 3.1.

4. The "crinkle" type of lineation in the micaceous minerals of the Lewisian rocks mentioned on page 74 can be compared with the partial girdle orientation of micas in the semi-pelitic rocks of the Moine series although the structure is not nearly so well developed.

EXPLANATION OF FIGURE 3.1.

The stereogram shows the angular distribution of the first and third lineations and also the poles to cleavage and foliation. At the bottom the block diagram shows how the first lineation, carried on the psammite bands, passes over the hinges of the Rudha Phoil, or second folds, the axial plane cleavage of which carries the third lineation.

Diagrams of folds on Rudha Phöil

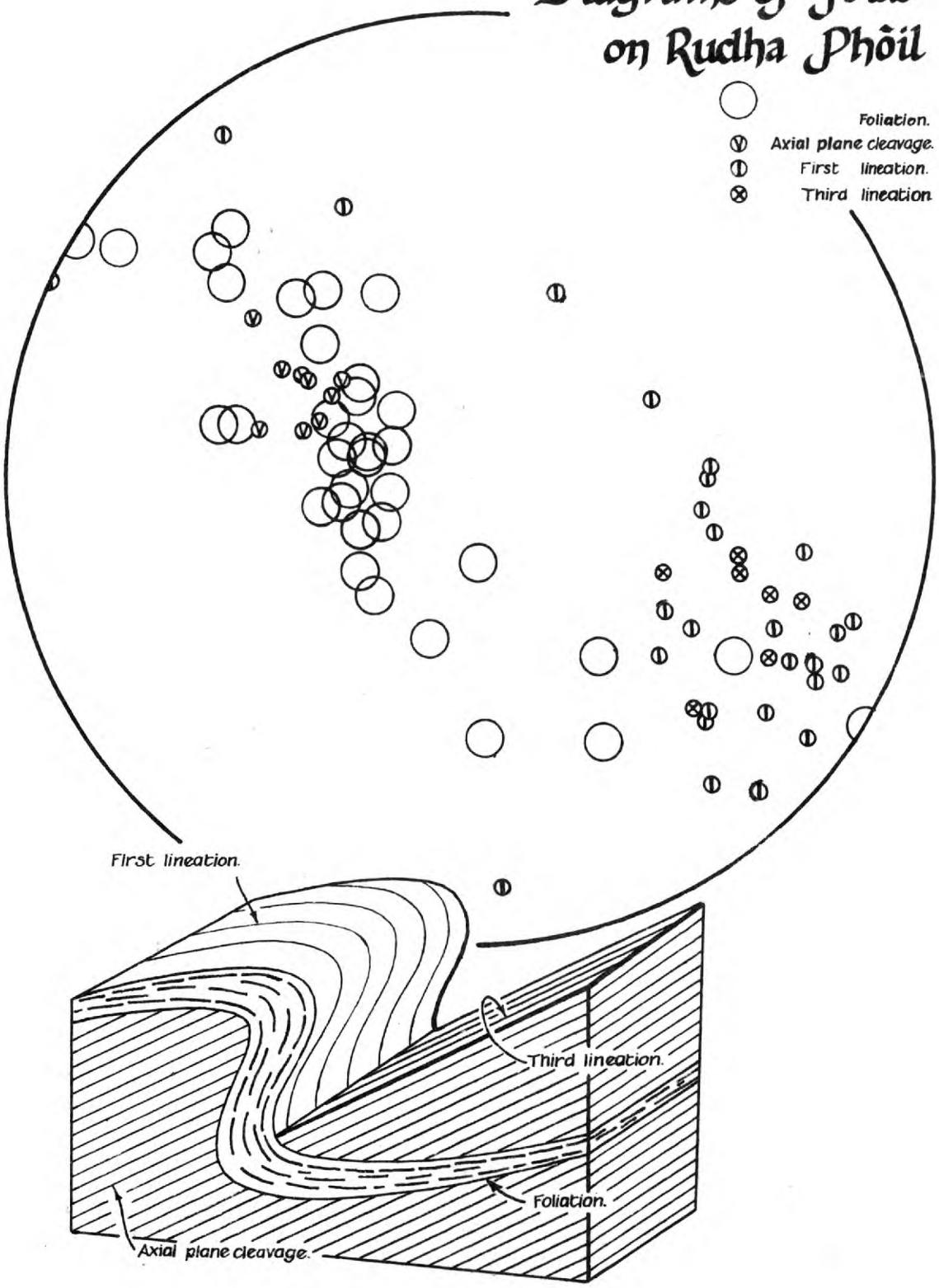
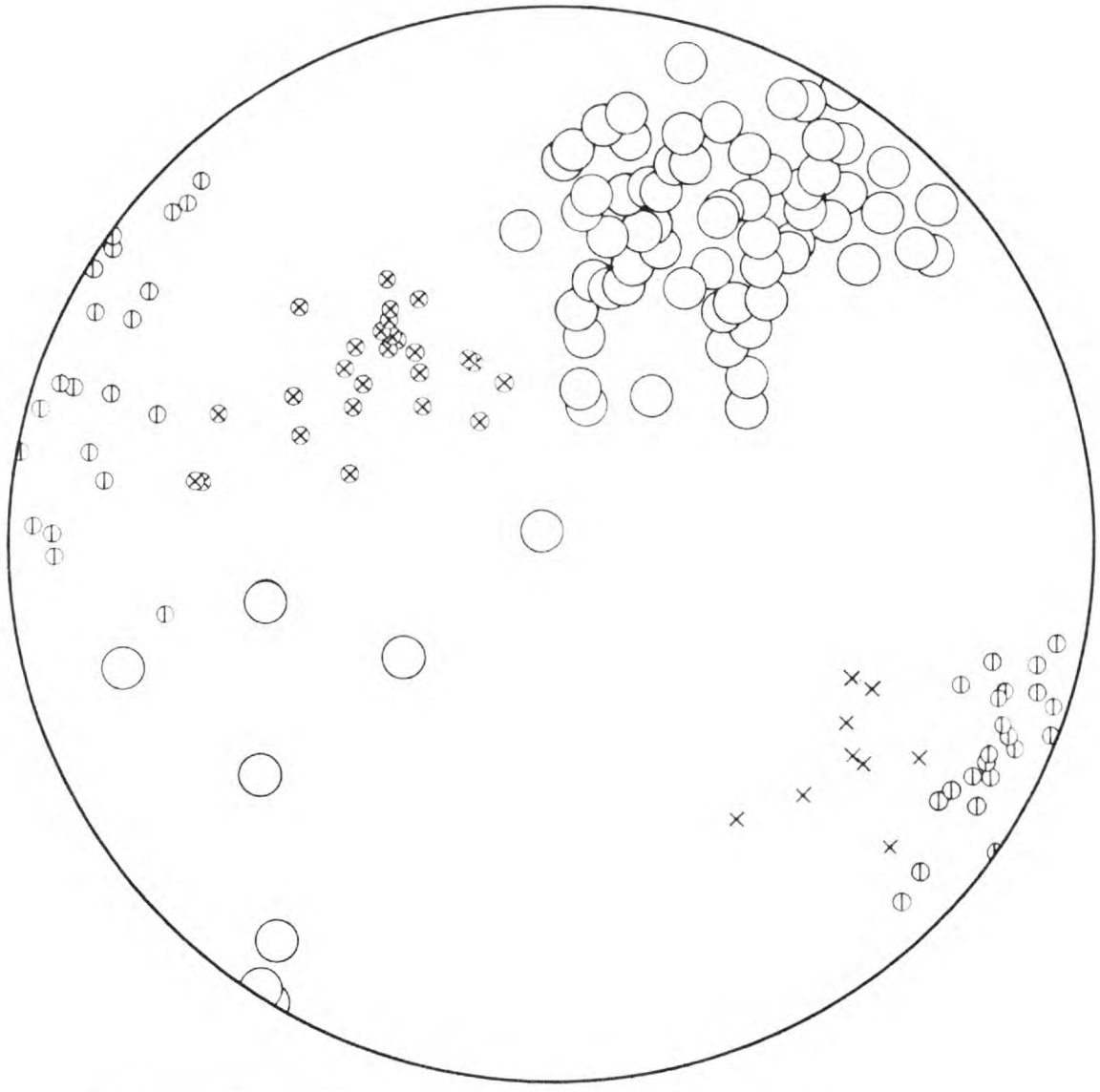


Figure 3.1

EXPLANATION OF FIGURE 3.2.

The stereogram shows the angular relations of the structures on the NE side of Rudha Dubh. Poles to foliation and cleavage planes are represented and the first and third lineations are also shown. At the bottom is a profile of a representative Tormore, or third fold.



Folds on the NE of Rudha Dubh

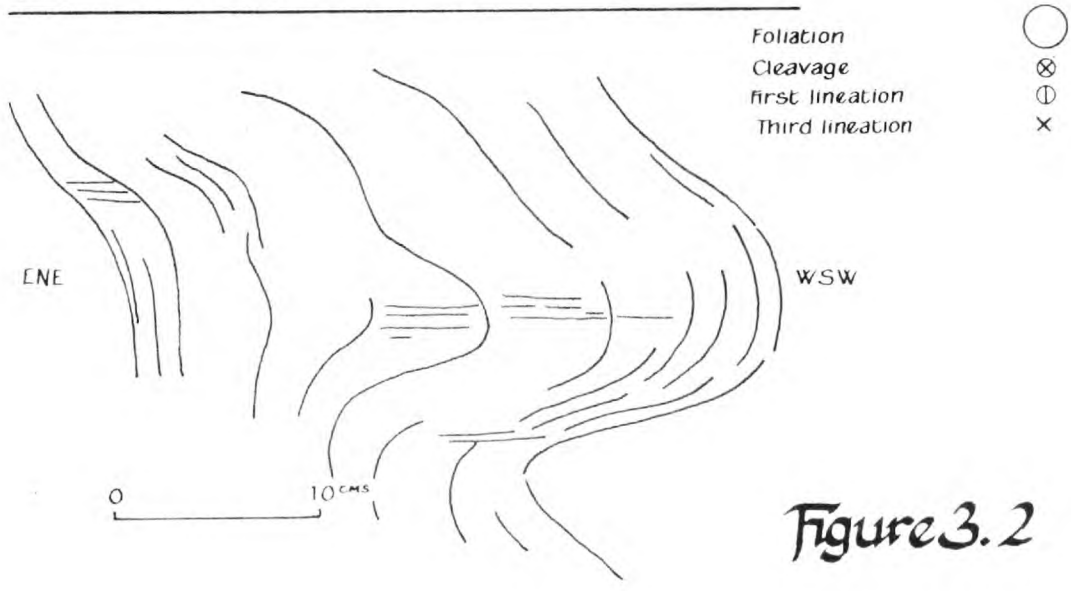
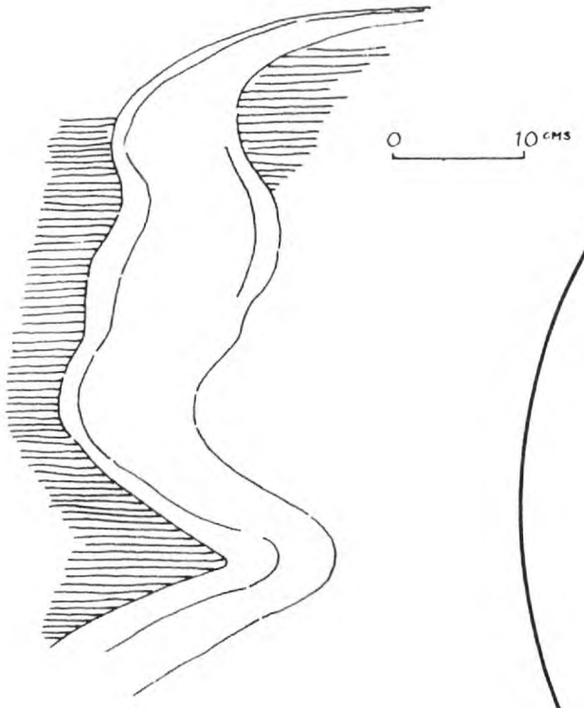


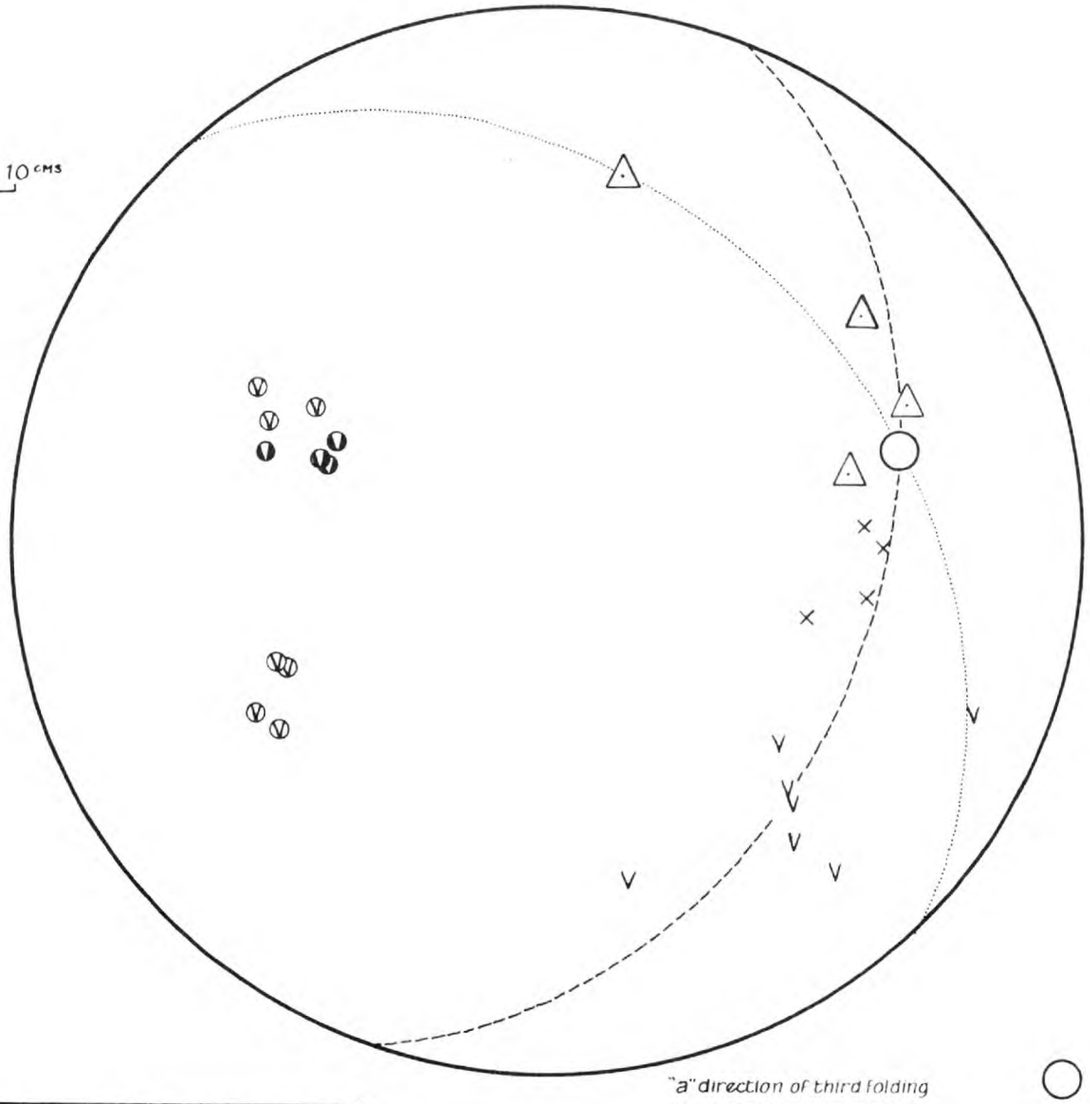
Figure 3.2

EXPLANATION OF FIGURE 3.3.

Profiles of representative second and third folds in Moine rocks are shown from a locality 150yds SE of the Ardvasar Hotel. The "a" directions of these folds can be calculated as demonstrated in the stereogram and explained in the text.

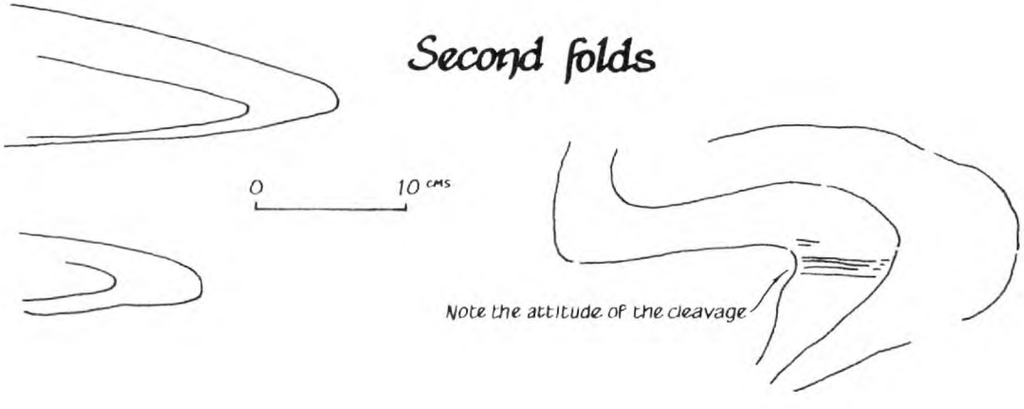


A third fold



"a" direction of third folding
Axial planes of second folds
Cleavage
"a" directions of second folds
Axes of second folds
Third lineation

"a" directions of second and third folds

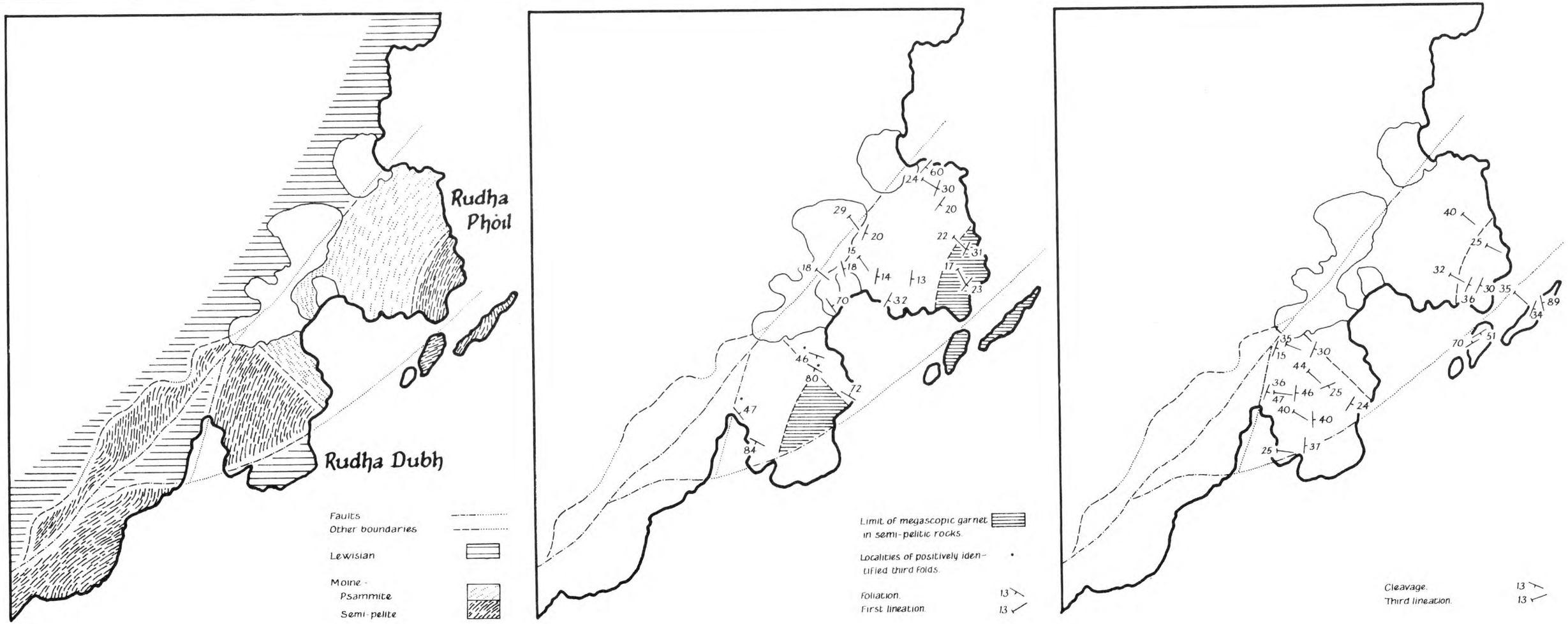


Second folds

Figure 3.3

EXPLANATION OF FIGURE 3.4.

Three maps showing the distribution of different types of Moine rock, different types of structures, and megascopic garnets in the Moine rocks near Ardvasar. All of these are probably inter-related as explained in the text.



First and third structures in Moine rocks near Ardvasar

Scale 1:10,560 or 6ins. to one mile.

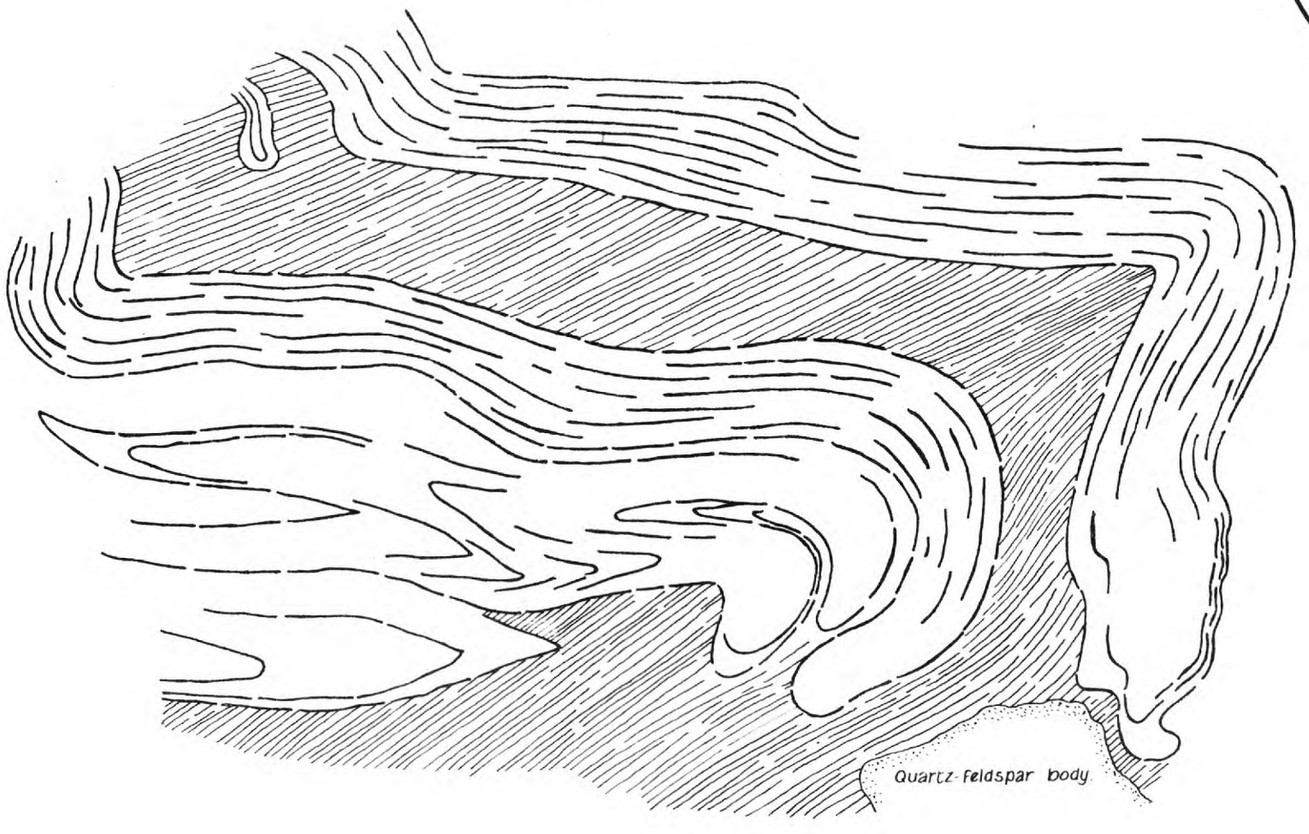
Figure 3.4

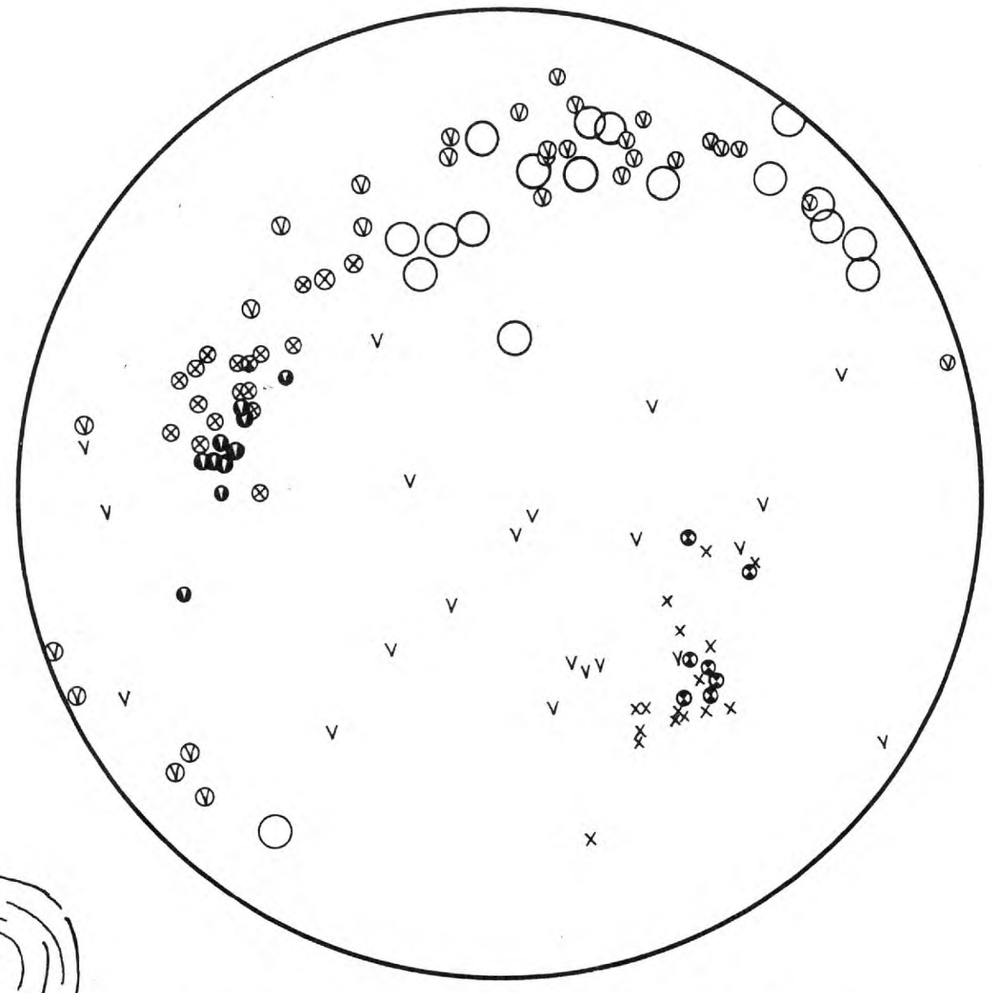
EXPLANATION OF FIGURE 3.5.

These are folds on the coast some 300yds east of the farm of Tormore. Psammites and semi-pelitic rocks of the Moine series are involved; a cleavage being developed in the latter. The stereogram shows the angular distribution of different lineations and fold axes and also the poles to axial planes of folds, foliation and cleavage.

Folds on the coast east of Tormore

(a) Second and third folds in psammites.





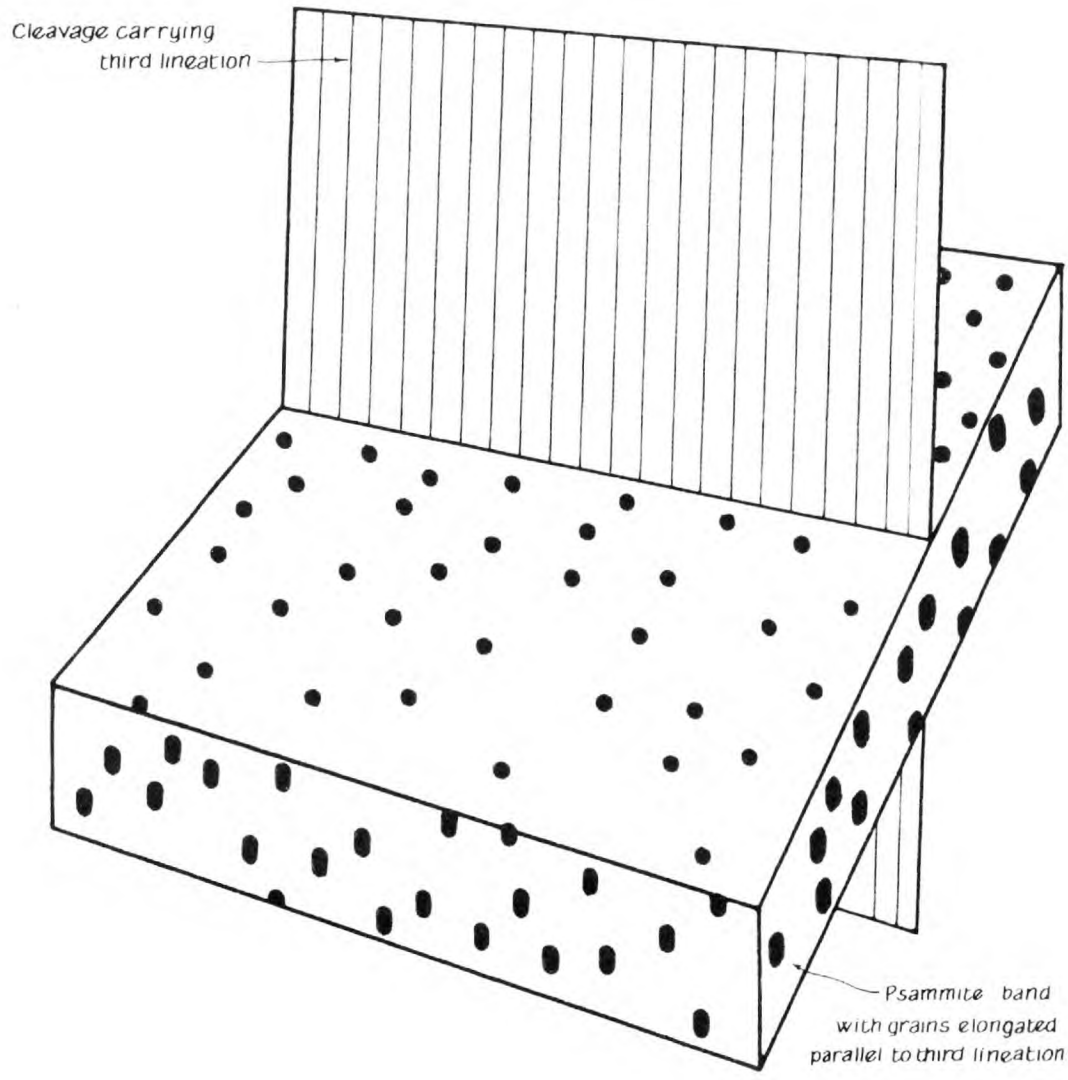
(b) Stereogram of structures near these folds.

Foliation.	◯
Cleavage.	◑
Third lineation.	◒
Axial planes of second folds.	⊘
Axes of second folds.	V
Axial planes of third folds.	⊗
Axes of third folds.	×

Figure 3.5

EXPLANATION OF FIGURE 3.6.

This shows how the direction of elongation of grains in Moine psammites lies outside the foliation plane but is parallel to the third lineation which is contained within the plane of the cleavage.

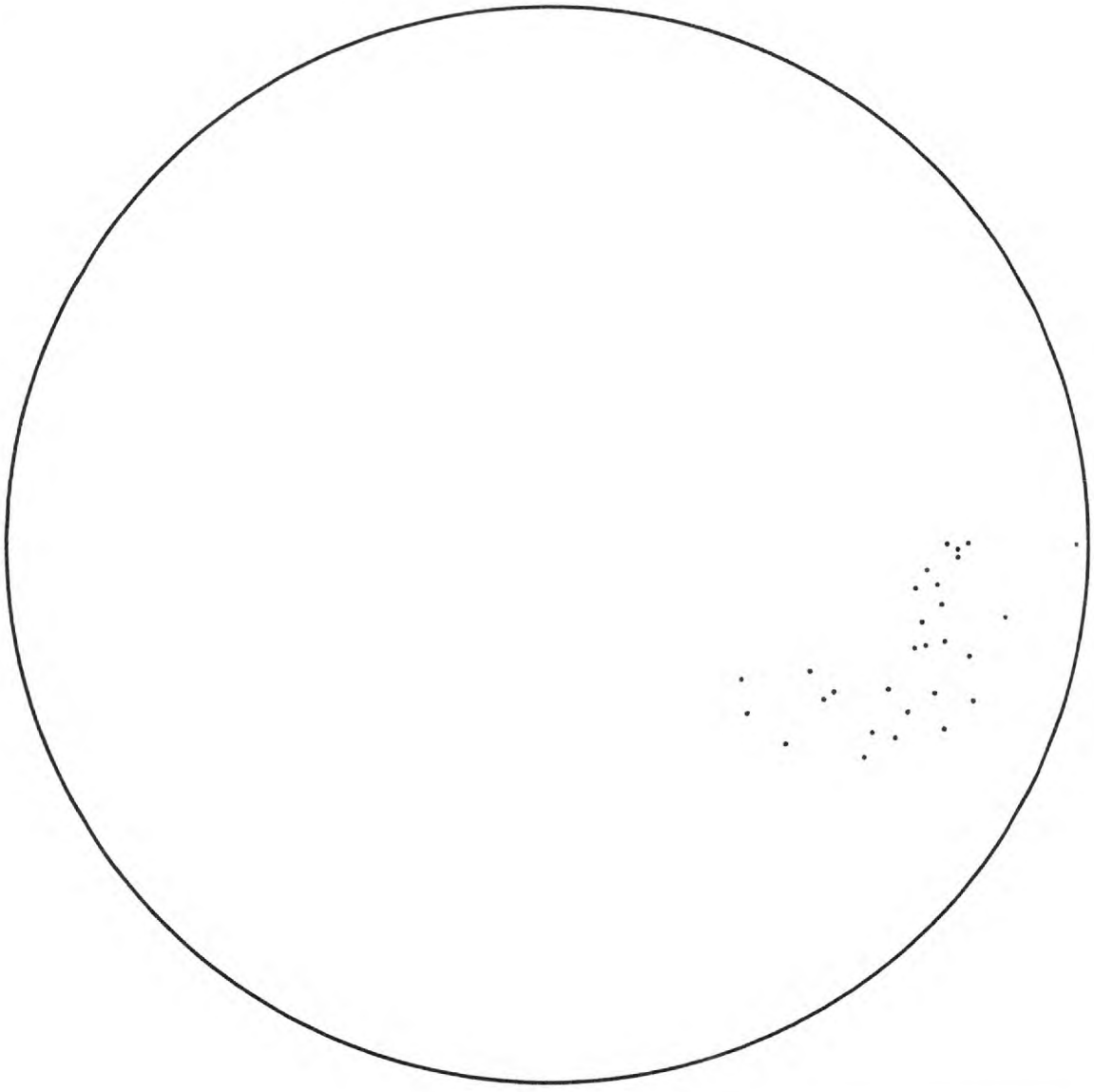


Relation of elongation to foliation and cleavage at Tormore.

Figure 3.6

EXPLANATION OF FIGURE 3.7.

This stereogram shows the angular distribution of measurements made in the field of the preferred orientation of the long axes of acicular and spear-like amphibole crystals in Lewisian rocks.



Orientated amphiboles in Lewisian rocks

Figure 3.7

The rocks which contain these structures differ fundamentally from those in which the structures described in the three previous Chapters are typically found. Thus individual bands of select mineral composition are much thinner and of much finer grain size than the comparable bands in which the previously described structures are found. However, to elaborate on these differences is not the purpose of this Chapter; these points will receive further attention in Chapters 16 and 17.

The location of some of the folds in this group in the southern part of the area are shown in figure 4.1. They also occur in the northern part of the area but they are infrequently exposed here. All the folds which can be positively allocated to this group occur in the areas of Plate 4 that in the Lewisian are ornamented with horizontal lines and in the Moine with widely spaced dots.

The characteristic features of the folds can best be appreciated by an examination of the stereoscopic photographs of figure 4.2. The photographs at the top of the page are of folds developed in the Lewisian rocks at Ard Thurinish, a promontory about three miles SW of Ardvasar. The dominant feature to be seen here is the inconstancy of the axial trends of the folds although the axial planes are reasonably flat. Coupled with this is the extraordinary variations in profiles at different points along the fold axes. To illustrate this fact the handle of the hammer has been arranged so that it lies along the axis of a fold

part of which has been removed by erosion. Nearer to the camera it can be seen that this antiformal axis merges with a complementary synformal axis and disappears.

Some of the acid bands which the Ard Thurinish folds deform contain an elongation or ribbon lineation. This lineation can be seen in the upper photographs where it is clearly oblique to the fold axes but its relation to the folds is probably better demonstrated in the lower photographs. The folds in these photographs are to be found in Lewisian rocks on the fore-shore immediately in front of Macbraye's garage at Ardvasar. The pencil, a few inches to the right of the hammer head, is arranged parallel to the lineation on the hinge of a fold in an acid band. A similar fold hinge can be seen just to the right of the bottom of the hammer handle.

Further examples which demonstrate the curving nature of the fold axes and the relation of the lineation to the folds are presented in figure 4.4. The photograph of figure 4.4(a) is of a tight fold in an acid band with the fold axis nearer to the camera. Figure 4.4(b) is a detailed drawing of the upper limb of the fold showing the relation of the lineation to the fold axis. The axis of the fold is at the lower edge of the diagram. Figure 4.4(c) is a similar drawing of such folds in thin, alternating acid and basic bands. The basic bands do not contain a visible lineation and are ornamented with spots. The acid bands contain an elongation lineation and are ornamented accordingly. These acid and basic bands outcrop on a surface which is approximately parallel to the axial planes of the folds.

Thus the lower boundaries of the acid bands represented on the diagram are the actual fold hinges while the upper boundaries are the broken off limbs of the folds. The folds are very tight and at the top of the diagram a number of fold hinges can be seen converging on each other to the left and fading away to the right.

The profiles of the Ard Thurinish folds, even within a very small area, show a great variety of shapes. Figure 4.3 gives examples of such profiles from a wide area in both Moine and Lewisian rocks. These fold profiles are more often than not of asymmetrical shape. In figure 4.1 the asymmetry of the folds has been indicated by different types of arrows. A cursory examination will show that there is no coherent regional pattern to this asymmetry.

Some structures of a very unusual type associated with the Ard Thurinish folds are illustrated in the stereoscopic photographs of figure 4.5. The lineation in these examples, which are near Ard Thurinish, is represented by a rodding structure (G.Wilson, 1953) in the acid bands rather than by the more typical ribbons or elongation. In this locality the rods are deformed by the folds so that the angle between the fold axis and the rod at the hinge of the fold is very small. The folds are very tight and tend to be masked by the rodding structure so that the impression given to the casual observer is one of acid rods wandering sinuously across the foliation planes. In figure 4.5(a) there is a fold hinge about 10cms below and to the right of the chisel end of the hammer head. All of the rods in the upper part of the photograph are on one limb of the fold,

the remainder are on the other limb. The geometrical relations of this structure can be compared with the fold of figure 4.4(a) & (b) which is exactly analogous. In this analogy the lineation occupies the position taken by the rods in the present example.

At other localities the elongation and ribbons trace out sinuous curves on the foliation planes but the foliation planes are not themselves folded. An example of this type of structure from a point on the coast near Dun a'Chleirich, one mile SW of Tormore, is shown in figure 4.6(a). In this sketch the paper can be considered as representing the foliation plane. The lines drawn on the paper represent cracks and curving elongation lineation. Nearby, similar variations in the direction of the lineation are to be seen. These are illustrated in figure 4.6(b). In this diagram three flat foliation planes are represented; the one at the top dips beneath the one in the middle which in turn dips beneath the foliation plane at the bottom. On these three foliation planes the directions of the lineation are remarkably different. By considering variations in the direction of the lineation and the foliation before the Ard Thurinish folding and variations in the axial plane direction of the Ard Thurinish folds, all of these apparently different types of structures can be closely related. These relations will be discussed later in the Chapter.

Returning to the normal type of Ard Thurinish folds it is a matter of observation that in all of the Lewisian exposures where such folds are developed and in the greater majority of the Moine exposures there is no visible expression of an

axial plane structure. However, in some coastal exposures about 300yds SW of Tormore a type of axial plane structure can be seen in the semi-pelitic members of the Moine series which can be related to the Ard Thurinish folds. This structure is illustrated diagrammatically in figure 4.7. In these diagrams the psammite bands are ornamented with spots. The other components of the exposures are semi-pelitic rocks. The boundaries between the two types of rock are well defined. Within the semi-pelitic rocks there are very small folds only the axial planes of which are represented. The small scale folds in the semi-pelitic rocks of figure 4.7(b) agree in their orientation with the large folds in the psammite bands while in the case of the folds illustrated in figure 4.7(c) the asymmetry of the small scale folds agrees with their position on the limbs of the larger folds. A direct correlation of the small scale folds with the larger folds in the psammite bands is thus indicated. In the psammite bands the quartz grains are flattened within the foliation and are elongated obliquely to the fold axes. This elongation lineation is also developed on the foliation planes in the semi-pelitic rocks where these are not too strongly affected by the very small folds.

The correlation of these folds in the Moine rocks SW of Tormore with the more typical Ard Thurinish folds is based on the following facts:-

1. They deform an elongation lineation.
2. The axial trend is variable in direction.
3. The profiles of the folds are different at various

points along their axes.

4. Typical Ard Thurinish folds can be found within a distance of only a few yards.

On the other hand these folds can be considered as showing a number of points of difference from the typical Ard Thurinish folds. Thes differences are:-

1. The folded psammite bands are unusually thick.
2. The semi-pelitic rocks contain megascopic garnets.
3. The folds are more open in profile than is usual.
4. The axial plane structure is developed.

Before proceeding to the discussion of the age relations of the Ard Thurinish folds to other groups, mention must be made of two localities where the Ard Thurinish folds are seen to refold some folds of an earlier generation. One of these localities is in Moine rocks on the coast approximately 400yds SW of Tormore. The profiles of some folds from this locality are illustrated in figure 4.3(m). A band of psammite is represented in solid black and is enclosed in a semi-pelitic host rock. The psammite band carries a strong elongation lineation which is parallel to the axes of the folds. Nearby, the relation of the Ard Thrinish folds is clearly displayed. The lineation is oblique to the axes of the Ard Thurinish folds and would thus appear to have been deformed by them. Since the profiles of the folds of figure 4.3(m) are so markedly different from those of the more typical Ard Thurinish folds it is concluded that the former folds are related to the lineation and are not merely Ard Thurinish folds whose variable axial direction has brought them into co-incidental parallelism with the lineation.

The second locality at which this relation can be seen is about 500yds SW of Tormore. A large block of fallen rock contains psammite bands in a semi-pelitic host. Some of the folds in these psammite bands have the elongation lineation parallel to their axes and these folds have been refolded by structures of the Ard Thurinish group.

Since there are no exposures where the Ard Thurinish folds occur together with positively identified folds of the groups described in the three previous Chapters their age relations present many problems at first sight. There can be little doubt that the following limited sequence is firmly established:-

1. A period of folding with the development of an elongation lineation parallel to the fold axes.
2. A second period of folding giving rise to the Ard Thurinish group of structures and deforming the earlier folds.

The position of this sequence in relation to the sequence which has already been established in the previous Chapters is not clear. Numerous possibilities seem plausible.

The age relations of the Ard Thurinish folds and the Rudha Phoil, or second folds can be elucidated as follows. If the correlation of the Knock Synform with the small scale Rudha Phoil folds is correct then the Ard Thurinish folds must be later than the Rudha Phoil folds. If the Ard Thurinish folds were to be earlier then the rock types in which they are characteristically found would be expected to occur on the SE limb of the Knock synform at least as far west as a point only 600yds due east of the ruined castle.

However, at this locality and at all points east the rocks are massive gneisses containing Baravaig, or first structures and Rudha Phoil, or second structures the age relations of which are proven. Thus the Ard Thurinish folds cannot be correlated with either the Baravaig (first) or Rudha Phoil (second) groups of structures.

The next correlation to be considered is with the Tormore, or third folds. The profiles of the Ard Thurinish folds in Moine rocks illustrated in figure 4.7 may be compared with the profiles of Tormore folds shown in figures 3.2 and 3.3. Other points of comparison can conveniently be listed as follows:-

1. The two groups of folds possess very similar types of axial plane structure; namely a very small scale folding of the semi-pelitic components of the exposures.
2. The orientation of the axial planes of the Ard Thurinish folds is close to that of the Tormore folds. In figure 4.8(c) the poles of axial planes of Ard Thurinish folds over a wide area are presented and their angular distribution may be compared with the corresponding diagrams for Tormore folds in figures 3.2 and 3.5.

Contrasting features of the Ard Thurinish and Tormore folds are more numerous and can also be conveniently listed:-

1. The axial directions of the Ard Thurinish folds are widely variable as the stereogram of figure 4.8(b) demonstrates. These measurements are from a small area 300yds SW of Tormore. On the other hand the

axial directions of the Tormore folds are much more restricted in their angular distribution as shown in figure 3.5(b).

2. The profiles of the Ard Thurinish folds vary rapidly from point to point along the axis whereas the profiles of the Tormore folds are considerably less variable.
3. The axial planes of the Ard Thurinish folds converge and diverge and frequently meet as the stereoscopic photographs of figure 4.2(a) illustrate.
4. The Ard Thurinish and Tormore folds show strongly contrasting relations to the lineations with which they occur. The Ard Thurinish folds deform an elongation lineation which is found in both the psammite bands and the semi-pelites of the Moine series. At Tormore the Tormore folds have an elongation lineation parallel to their axes in the psammite bands and very small scale folds parallel to their axes in the semi-pelitic rocks while at Ardvasar the Tormore folds deform the first elongation lineation in the psammite bands but have very small folds parallel to their axes in the semi-pelitic rocks. If the Ard Thurinish and Tormore folds are to be correlated then the elongation lineation which the Ard Thurinish folds deform must be earlier than the Tomore folds. In the Moine rocks at Ardvasar the only elongation lineation which can be shown to be earlier than the Tormore folds is the first lineation.

Thus a correlation of the Ard Thurinish and Tormore folds would imply that the lineation which the Ard Thurinish folds deform is either the first lineation or is some other lineation earlier than this. The latter possibility can be ruled out by the same argument that was used to establish the age relations of the Ard Thurinish and Rudha Phoil, or second folds: namely that some of the rocks on the SE limb of the Knock synform are the direct equivalents of those rocks on the NW limb which contain the Ard Thurinish folds but which in fact contain the Baravaig, or first and Rudha Phoil, or second folds.

The numerous points of difference between the Ard Thurinish and the Tormore, or third folds do not make these two groups incompatible if certain concepts can be appreciated and accepted. By far the most important of these is the idea that along lines which are perpendicular to the plane of the Moine thrust the physical and chemical conditions that controlled the structural and metamorphic state of the rocks may have varied quite remarkably. Thus, in the case of two points separated by only ten yards along one such line, the conditions might be such that megascopic garnet is stable at one point but unstable at the other. Or it might be that at one point a certain linear structure is expressed by no more than the orientation of mica crystals into a girdle fabric whereas a score or so yards away the same linear structure is so strongly developed that grains of quartz are much longer than they are wide.

If such concepts are allowed, and there is every indication that they are not at all out of place, then the Ard Thurinish and Tormore groups of folds can be correlated. If this is the case then the balance of physical restraints to which the rocks were subjected must have been very delicate. In the Moine rocks at Tormore this balance must have been such that the formation of a new elongation lineation parallel to the axes of constantly orientated folds (as in figure 3.5) was favoured at one locality while only a short distance away the old elongation lineation remained stable and the folds which distorted it developed curving axes. The large variations in the axial directions and the profiles of the Ard Thurinish folds can be accounted for by relatively small variations in the direction of the axial plane as will be more fully explained later in this Chapter so that the differences between the two groups of folds become less acute.

Another correlation that can be made in connection with the Ard Thurinish folds is that the elongation lineation they deform is the same as the elongation lineation parallel to the axes of the Tormore, or third folds. This correlation involves much less tenuous arguments than were submitted in the preceeding paragraphs but even so does not gain positive supporting evidence from the field relations of the folds. The only field evidence which can be considered to support this correlation in any way is the fact that the grain size of the rocks deceases towards the west and at Ard Thurinish the lineation distorted by the Ard Thurinish folds is in

the form of rodding structures. In Chapter 3 it was argued that the amount of post-crystalline deformation associated with the Tormore folds increased towards the west and the linear structure became stronger in this direction also. Thus, if the correlation of the lineation deformed by the Ard Thurinish folds with the lineation parallel to the axes of the Tormore, or third folds is correct, then the rodding structure at Ard Thurinish could be considered as an advanced stage in the series from the girdle orientation of micas at Rudha Phoil to the strong elongation lineation associated with the Tormore folds on the short coastal section immediately east of Tormore.

Yet another possibility for the age relations of the Ard Thurinish folds is that they are earlier than the Tormore, or third folds but later than the Rudha Phoil, or second folds. Such a position in the sequence of structures involves concepts even more complex than those which were discussed previously. The statement that the Ard Thurinish folds are later than the Rudha Phoil, or second folds hinges on the correct correlation of the Knock synform with the Rudha Phoil folds and was discussed earlier. In the outcrops of Moine rocks in the district east of Tormore the eastern limit of the rocks affected by the Ard Thurinish folds can be defined very closely. It is marked on Plate 3 as a hypothetical line called the Ostaig line. To the east of this line the Moine rocks are coarse grained and contain undistorted lineation associated with the Tormore, or third folds. To the west the rocks are generally fine-grained and contain an elongation lineation distorted by the Ard

Thurinish folds. Further to the west, very close to the Moine thrust, there is another group of folds which, without the slightest element of doubt, are later than the Ard Thurinish folds. Thus if the Ard Thurinish folds are earlier than the Tormore, or third folds then the implication is that a belt of rock some three-quarters of a mile thick remained both structurally and metamorphically "dead" while fairly intense movements took place on either side and garnet, amphibole and biotite porphyroblasts were stable immediately to the east.

A selection of the various directions of the lineation which is deformed by the Ard Thurinish folds is shown on Plate 3 as "elongation and ribbon lineation west of the Ostaig line". It must be emphasised that only a "selection of the various directions" is given since in any one exposure the direction of the lineation may vary as much as 142° and thus a map prepared to show the "regional trend" of the lineation would be misleading. Measurements of the elongation lineation from a very wide area are presented in the stereogram of figure 4.8(a). These are arranged in a very ill defined girdle with a diffuse concentration near the east point.

The variability of the axial direction of the Ard Thurinish folds is graphically represented in figure 4.8(b). These measurements are from a small area in Moine rocks about 300yds SW of Tormore. That there is no relation between the axial directions of the Ard Thurinish folds and the direction of the lineation which they deform is amply proved by the fact that the angle between the axis of the

fold and the lineation takes all values ranging between 0° and 70°.

In the stereogram of figure 4.8(c) poles to the axial planes of 27 selected Ard Thurinish folds are marked. These are the folds upon which a reasonable, accurate calculation of the "a" direction can be made. They are distributed along the coastal section from Ardvasar to Ard Thurinish as indicated in figure 4.9. The slight variations in the axial plane directions of these folds, which can be looked upon as giving rise to the larger variation in the axial direction, are masked in this diagram by a greater dispersion due to gentle later folding.

The data from which the "a" directions of the 27 Ard Thurinish folds have been calculated is presented in a table at the end of this Chapter. The results of these calculations are given in the stereogram of figure 4.8(e) and a selection of these, consistent with clarity, is marked on the map of figure 4.9. The angular distribution of the lineation deformation planes of these 27 folds is shown in the stereogram of figure 4.8(d). The histogram of figure 4.8(f) has been presented primarily to indicate the degree of reliability of the calculations and has been constructed as follows. The angle between the axial plane and the lineation deformation plane of each fold was calculated graphically by the use of the stereographic projection. These results were then classified into intervals of 10° with the origin at 0° (ie. with class boundaries at 0°, 10°, 20°, 30°, etc). Any observations of the angle between the axial plane and the lineation deformation plane which fell

on to a class boundary were counted as a half each for the classes on either side of this boundary. Thus, should the angle have been 50° then this observation was counted as a half for the class 40-50° and a half for the class 50-60°. The total number of observations in each class having been determined the histogram was then drawn according to the generally known methods.

The highest number of observations in any class is $6\frac{1}{2}$ in the class 20-30°. To the left of this the number of observations falls off sharply. The reason for this sharp fall is that no measurements were made on folds where the angle between the axial plane and the lineation deformation plane was obviously too small to yield a sufficiently reliable value for the "a" direction. The fall to the right of the maximum value is more gentle and its uniform slope indicates a decreasing frequency of occurence of folds as the angle between the axial plane and the lineation deformation plane rises to a maximum value in the region of 70°.

Figure 4.8(e) shows that the "a" directions of the Ard Thurinish folds fall on to a well defined partial girdle which appears to be bimodal,(ie. with two separate concentrations). Although the rocks which contain the Ard Thurinish folds have suffered later gentle flexuring the magnitude of the later movement is totally inadequate to explain this distribution of the "a" directions. Thus the variation in the "a" direction of the Ard Thurinish folds must be an inherent condition of the mechanism of their formation, and furthermore, this variation must occur over

a distance of only a few yards since many of the measurements come from such restricted areas as this.

The relation between the folds of the normal type and the structures of figure 4.6 can now be discussed. However, a preliminary review of the mechaniams by which folds with curved axes may arise would not be out of place:-

1. Folds with flat axial planes may be superimposed upon a foliation surface which is already curved. The axes of the superimposed folds are defined as the line of intersection of the new axial plane and the foliation and will thus be curved. Such folds are illustrated diagrammatically in figure 4.10(a)(1) and (b)(1).
2. Folds with curved axial planes may be superimposed upon flat foliation planes. Again the line of intersection of the two surfaces is curved and the resulting folds will thus have curved axes. It is important to bear in mind that the nature of the curvature, the degree of curvature and the different orientations of the curved axial plane with respect to the foliation plane will all have profound effects on the shape of the resulting folds. Thus the axial planes of the folds may be represented as cylindroidally curved surfaces, or as surfaces with culminations and depressions, or as more complex curves than these. It is also important to consider the fact that the axial planes may converge and diverge.
3. Folds with curved axes may also owe their origin to a combination of these two mechanisms.

A more complete discussion of the three above mechanisms is contained within two recent publications by Weiss (1959) and Ramsay (1960). A fourth possible mechanism has been suggested by Ramsay (1962):-

4. Variation in the degree of compression to which the rocks have been subjected.

The accepted theory of the mechanism of growth of similar folds is that they develop by relative movement along planes which are parallel to the axial planes of the folds. The direction of this relative movement is called the "a" direction or direction of transport. Taking into consideration the four possibilities which were given above for the development of folds with curved axes it is quite conceivable that a situation may arise in which the axial plane of folding may be oblique to the foliation but nevertheless the "a" direction is contained within the foliation. The resulting deformation will be such that although considerable movement will take place the foliation will not be bent by virtue of the fact that the "a" direction lies within it (Ramsay, 1960). However, any lineation which lies on the foliation planes will reveal this "hidden" deformation by assuming a curved path. Such conditions are illustrated diagrammatically in figure 4.10. In 4.10(a)(1) later folds have been superimposed on a curved foliation plane which carries a lineation. The strike of the axial planes of the new folds was arranged to be perpendicular to the original strike of the foliation. The foliation has been deformed and since it was originally curved the new folds have curved axes. The diagram has also been drawn so that

the "a" directions of the new folds are vertical. Thus where the foliation was also vertical no folds, in the conventional sense, have been formed but instead the curved path of the lineation reveals that the foliation has suffered a "hidden" deformation. When this foliation is viewed from a point such as represented by the hypothetical eye then the deformed lineations will have the appearance of figure 4.10(a)(2) and the nodal points (N_1, N_2, N_3) on the curved lineations of successive foliation planes will fall one behind the other. Figure 4.10(b) differs in that the strike of the axial planes of the new folds makes an acute angle with the original strike of the foliation. The main differences produced by these changed conditions are twofold. Firstly, the new folds are highly asymmetrical as opposed to the symmetrical folds of figure 4.10(a)(1), and secondly, the nodal points (N_1, N_2, N_3) do not fall behind each other when viewed from the position of the eye.

The structures illustrated diagrammatically in figure 4.10(b) have direct counterparts in the naturally occuring Ard Thurinish group of structures. By far the greater majority of the Ard Thurinish group of folds are strongly asymmetrical; the curved lineations of figure 4.10(b)(2) can be taken as an interpretation of the apparently chaotic arrangement of lineations in figure 4.6(b); and the structures of figures 4.4 and 4.5 would seem to occupy a position on figure 4.10(b)(1) at which the foliation is only slightly folded.

So far the geometry of the Ard Thurinish structures has been explained only in terms of original curvature of

the foliation. However, the axial planes of some of the Ard Thurinish folds must be curved. This fact should be evident from a study of figure 4.2(a) where fold axes may be seen to converge. Such an observation can only be explained in terms of a curving axial plane since no matter what the shape of the foliation before the new folding the axes of the new folds would not converge and meet if the new axial plane were flat. Some indication of the degree of variation in the distribution of poles to the axial planes of the Ard Thurinish folds is given by the stereogram of figure 4.8(c). Some of this variation can be accounted for by later flexuring but the evidence of figure 4.2(a) is sufficient to show that the axial planes are curved even if only to a limited extent. Another possibility which must receive consideration is that the lineation also varied before the Ard Thurinish period of folding. Bearing in mind the fact that many lineation deformation planes were not measured because they were very close in orientation to the axial planes of the folds then the total angular distribution of these planes must be much greater than is suggested by the stereogram of figure 4.8(d). Poles to lineation deformation planes must, therefore, envelop much of the area of the diagram occupied by poles to axial planes shown in figure 4.8(c). The orientation of the lineation deformation plane depends on three independant variables: the original orientation of the lineation, the orientation of the new "a" direction and the amount and degree of variability of the compression accompanying the folding. If the amount of compression varies from place

to place then the axial planes of the folds will also be variable in direction. The orientations of the "a" directions are clearly variable in the case of the Ard Thurinish folds but unfortunately the observations available do not lend themselves to a reliable calculation of the expected distribution of lineation deformation planes. Thus the expected distribution cannot be compared with the observed distribution and no conclusions can be drawn concerning the variability or constancy of the original orientation of the lineation.

A graphic illustration of the variation of the "a" direction is available from a consideration of figure 4.6(a). This is an equal sizes reproduction of the original, carefully made sketch. Figure 4.11(a) is an accurate enlargement of the original sketch. By definition the "a" direction of a fold structure lies in its axial plane. The axial plane of a fold can be defined as the surface which joins together the fold axes on the different folded surfaces; the axis of a fold being the line of maximum curvature. In the case of the curved lineations of figure 4.11(a) the traces of the axial planes of the folds on the flat foliation surface can be drawn so that they pass through the points of maximum curvature in the lineation (cf figure 4.10). But the flat foliation surface, carrying the curved lineation, is obviously also the lineation deformation plane. Therefore the traces of the axial planes on the foliation surface are also the limes of intersection of the lineation deformation plane with the axial plane, that is, the "a" directions. These "a" directions are clearly curved.

The mechanism of formation of the Ard Thurinish folds seems to be very complex. They have variable axial planes, axes and "a" directions, and are probably superimposed upon a variable foliation carrying a variable lineation. A possible explanation of their shades of variation can be evolved by postulating culminations and depressions in the axial planes which are elongated in the general trend of the "a"direction. However, these ideas will not be presented here since it is considered that their factual basis is too flimsy.

TABLE OF DATA FROM WHICH THE "A" DIRECTIONS OF 27 ARD THURINISH FOLDS WERE CALCULATED

An explanation of the system of grid reference used in the column "locality" will be found below ~~in the appendix dealing with the index of place names~~. In the remaining columns, except that headed "angle between axial plane and lineation deformation plane", the two sets of figures completely specify the angular position of the given line in space. Thus the first grouping in the column "axis" means that the axis of the fold in question plunges at 18° towards a true bearing of 288°.

THE GRID REFERENCE SYSTEM.

The first letter and number refer to one of the rectangles on Plate 1. Each of these rectangles is then sub-divided into squares measuring 3/16 inches along the side. There are 18 such squares along the bottom of a large rectangle and 16 up the side.

A reference such as D4:154:095 is in rectangle D4 on Plate 1. The precise location in that rectangle is 15.4 x 3/16 inches from the western margin of the rectangle and 09.5 x 3/16 inches from the southern margin of the rectangle.

The introductory note to this table is on page 113.

Locality.	Axis.	Pole to Axial Plane.	Pole to Lin. Def^{m} Plane.	Calculated "A"^{n} Dir^{n}.	Angle between lineation deformation plane and axial plane.
C6:051:148	18:288	65:027	34:070	--:---	08
----do----	11:339	15:059	34:039	08:114	20
----do----	09:158	24:084	75:013	23:096	69
----do----	16:155	29:110	38:050	28:097	33
----do----	10:124	18:076	37:017	19:080	31
D5:081:159	33:081	44:114	27:091	20:046	22
D5:077:155	32:117	35:137	31:037	22:084	49
SW of	--:---	61:112	31:032	31:042	60
Tormore.	--:---	40:135	05:100	04:050	36
----do----	--:---	49:139	34:026	25:073	68
----do----	--:---	22:123	05:106	02:038	17
----do----	--:---	29:099	24:052	24:062	20
----do----	--:---	45:120	08:070	06:038	40
----do----	--:---	42:150	22:187	06:112	27
----do----	--:---	15:192	18:317	08:252	29
----do----	--:---	39:131	04:000	02:045	41
----do----	--:---	50:156	13:217	12:236	45
----do----	--:---	25:129	12:151	07:203	14
----do----	--:---	48:080	23:018	23:012	45
----do----	--:---	18:106	29:056	18;110	20
----do----	--:---	37:138	16:302	04:224	52
D4:154:095	--:---	24:113	46:021	22:089	52
----do----	--:---	45:100	39:046	38:061	36
----do----	--:---	46:081	39:041	39:042	27
----do----	--:---	13:096	27:040	12:102	34
----do----	--:---	36:096	67:040	35:114	52
D5:035:105	--:---	29:149	34:092	--:---	29

EXPLANATION OF FIGURE 4.1.

A map showing the variations of plunge, trend and profile of some of the Ard Thurinish folds in the southern part of the Moine nappe. The axial planes of these folds dip consistently SE (see figure 4.8(c)).

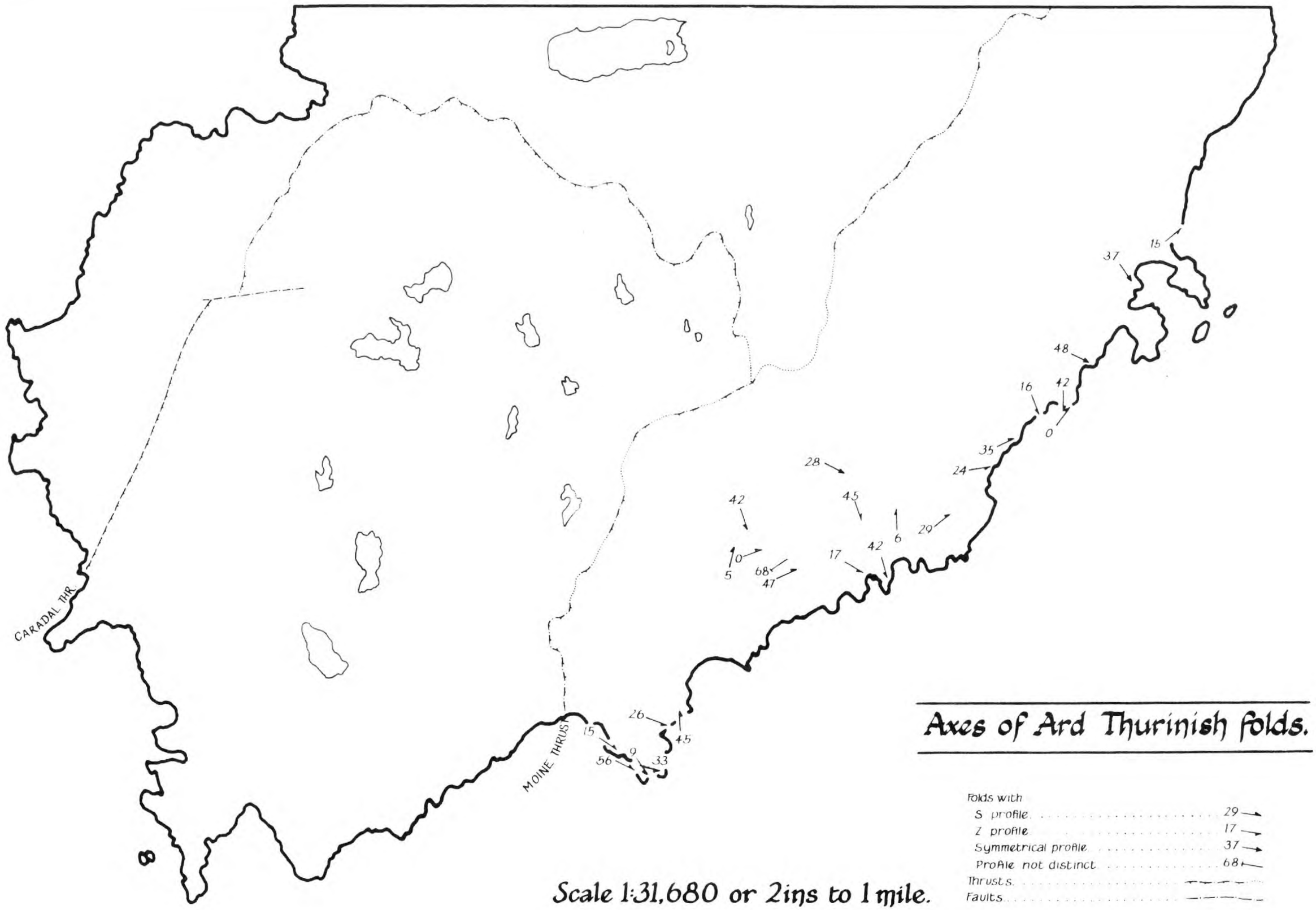

CARADAL THR.
MOINE THRUST
37
15
48
16
42
0
35
24
28
45
6
29
42
10
5
68
47
17
42
26
45
15
9
56
33
Axes of Ard Thurinish folds.
Folds with
S profile 29
Z profile 17
Symmetrical profile 37
Profile not distinct 68
Thrusts
Faults
Scale 1:31,680 or 2ins to 1 mile.

Figure 4.1

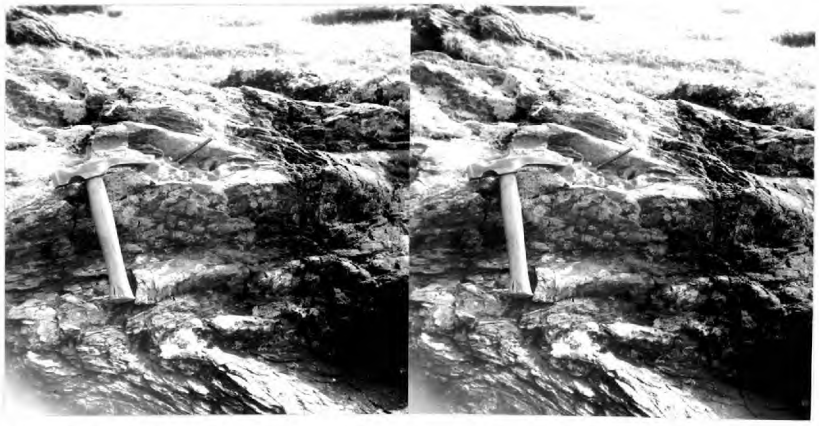
EXPLANATION OF FIGURE 4.2.

Stereoscopic photographs of typical Ard Thurinish folds.
(a) In Lewisian rocks at Ard Thurinish. These photographs show how the axial trend changes over very short distances and also how the axes of adjacent folds converge upon each other.
(b) In Lewisian rocks near Macbrayne's Garage at Ardvasar. These photographs show clearly the elongation lineation passing obliquely over the hinges of the Ard Thurinish folds.



(a) At Ard Thurinish.

Ard Thurinish folds.



(b) At Macbrayne's Garage.

Figure 4.2

EXPLANATION OF FIGURE 4.3.

Profiles of Ard Thurinish folds.

(a) In Lewisian rocks at Ard Thurinish. Alternations of thin, fine-grained acid and basic bands.

(b) In basic Lewisian rocks at Ard Thurinish.

(c) In Moine semi-pelitic rocks approximately one half mile SW of Tormore. The rocks are pale to medium grey and contain small garnets up to 2mm in diameter. Bands of psammite up to 1cm thick occur. These are of medium grain size and the quartz grains are elongated in the foliation. Many of the thinner psammite bands are drawn out into lenticles and some of the bands are discontinuous. The lenticles are flattened within the foliation except near the axial plane of the fold where they are aligned parallel to the axial plane.

(d) In Moine psammites about 100yds SE of Tormore. A thin psammite band is indicated. It is fine grained and pink in colour. The surrounding semi-pelitic rocks are pale grey and micaceous.

(e) and (f) In Moine psammite about 100yds SE of Tormore. The psammite is similar to that described under (d).

(g) In Moine psammite about 300yds SW of Tormore. The rocks are of medium grain size with parting planes of micaceous material spaced at intervals of up to 1cm. Quartz grains are flattened and elongated within the foliation; the elongation lineation is oblique to the fold axes.

(h) In Lewisian rocks about 300yds ENE of Dun a'Chleirich.

EXPLANATION OF FIGURE 4.3 (CONTINUED).

(h) (continued) Alternations of pink and white quartzo-feldspathic material with pale green micaceous bands form laminæ up to 2mm thick.

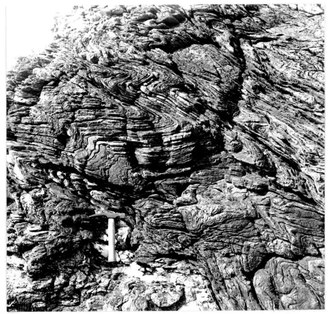
(i) In Lewisian rocks about 300yds ENE of Dun a'Chleirich.

(j) In Lewisian rocks close to the junction with the Moine rocks on the hill slopes 600yds NNE of Dun a'Chleirich.

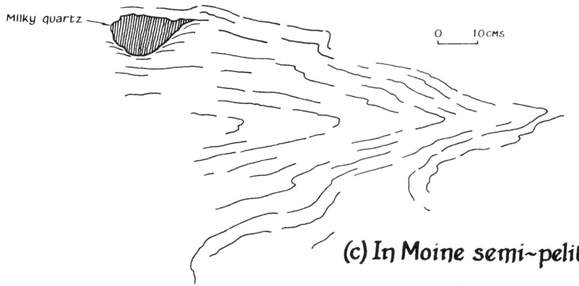
(k) Small fold in Moine rocks 700yds NNE of Dun a'Chleirich.

(l) Small fold in Moine rocks 450yds WNW of Tormore.

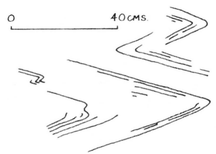
(m) Moine rocks 400yds SW of Tormore. A psammite band is shown as solid black and is enclosed within semi-pelitic host rock. A strong elongation lineation is parallel to the axes of the folds.



(a) In Lewisian.



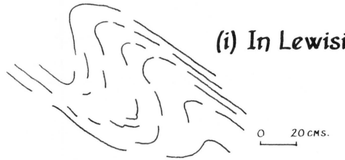
(c) In Moine semi-pelite.



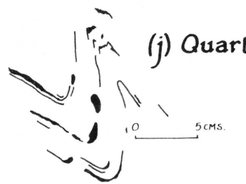
(g) In Moine psammite.



(h) In Lewisian.



(i) In Lewisian.



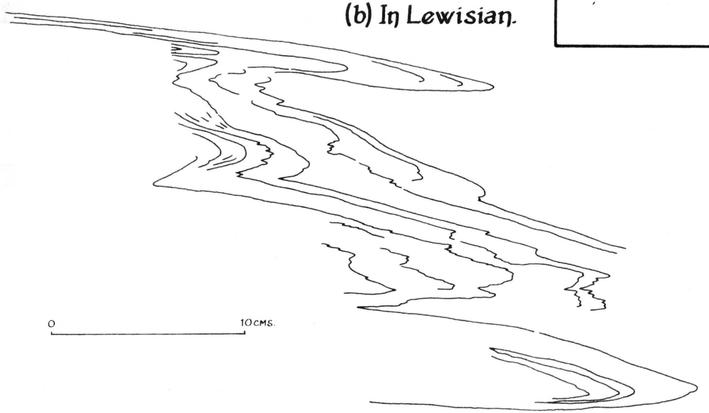
(j) Quartz veinlets in Lewisian.



(m) In Moine. Precise scale unknown ~ approximately natural size.

Profiles of Ard Thurinish folds.

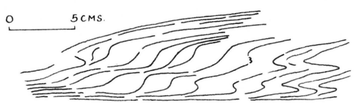
(b) In Lewisian.



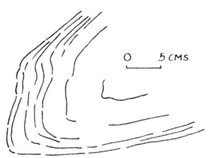
(d)



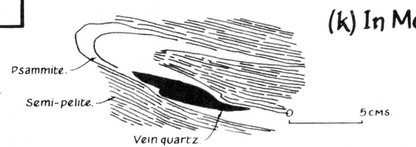
(e)



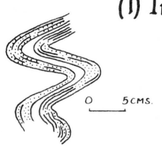
(f)



In Moine psammite.



(k) In Moine.



(l) In Moine psammite.

Folds parallel to the elongation lineation.

Figure 4.3

EXPLANATION OF FIGURE 4.4.

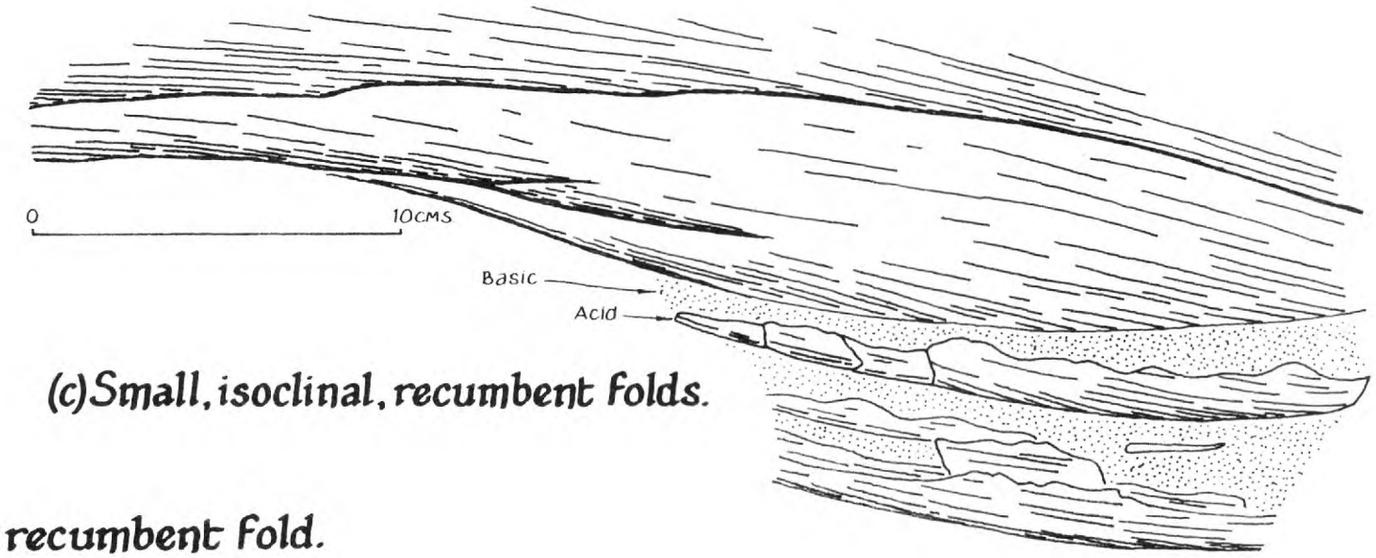
(a) This is a photograph of a small Ard Thurinish fold in Lewisian rocks at Ard Thurinish. The pale coloured rocks in the centre of the photograph are less acid than their hosts. The boundary of the pale coloured area which is nearer to the camera is the axis of a fold and is strongly curved. The fold is recumbent, so that the margin of the band which is distant from the camera is the broken upper limb of the fold.

(b) The lower section of the diagram is a plan view of the fold shown in (a). The lines on the diagram represent cracks and elongation lineation in the rock. The elongation lineation makes a very small angle with the axis of the fold. The upper part of the diagram is a section along the line AB.

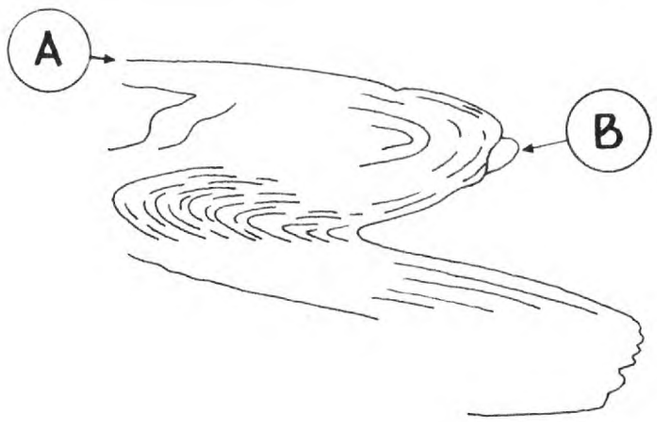
(c) The folds represented here are very similar to those shown in (b). They occur on Ard Thurinish in thin alternating bands of acid and basic material ornamented with lines and spots respectively. The lines on the acid layers also represent the elongation lineation. The axes of the recumbent folds in the acid layers are towards the bottom of the diagram while the irregular upper boundaries of the acid layers are the edges of the broken limbs of the folds.



(a) Small recumbent fold.



(c) Small, isoclinal, recumbent folds.



(b) Drawings of the fold shown in (a)

Relation of Ard Thurinish folds to lineation in Lewisian rocks.

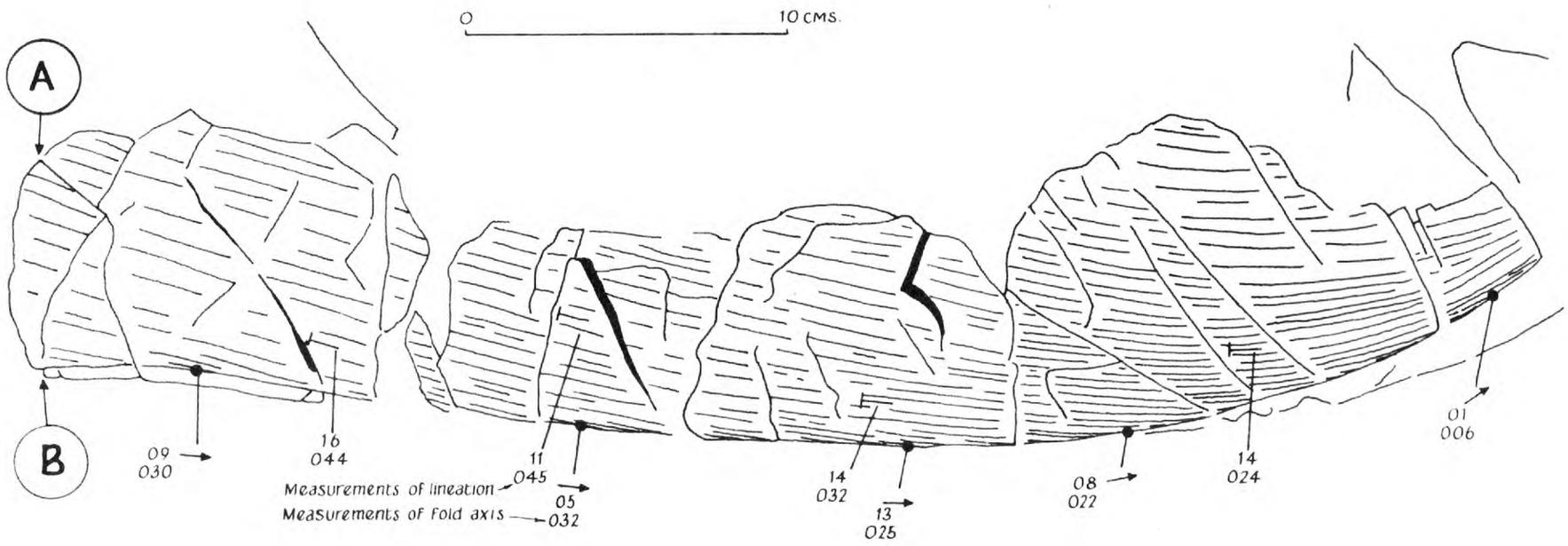


Figure 4.4.

EXPLANATION OF FIGURE 4.5.

Rod-like structures in acid Lewisian gneisses at Ard Thurinish deformed by Ard Thurinish folds. For full explanation see text.

(a)



Folded lineations at Ard Thurinish.

(b)

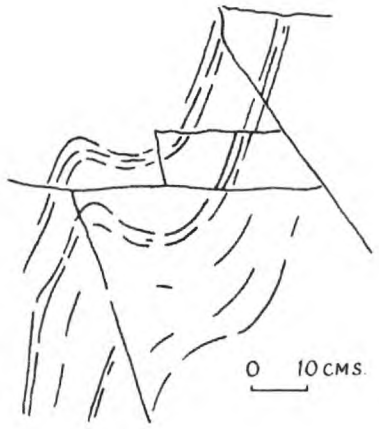


Figure 4.5.

EXPLANATION OF FIGURE 4.6.

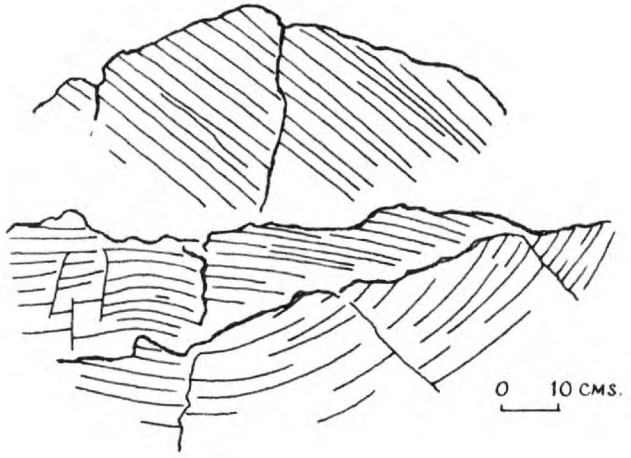
Meandering lineations on flat foliation planes. Both examples are from Lewisian rocks near Dun a'Chleirich. The deformation is such that the "a" direction of the Ard Thurinish folds lays in the foliation plane. A full interpretation is given in the text.

(a)



Lineation deformed on flat foliation planes.

(b)



Examples from Lewisian rocks near Dun a' Chleirich.

Figure 4.6

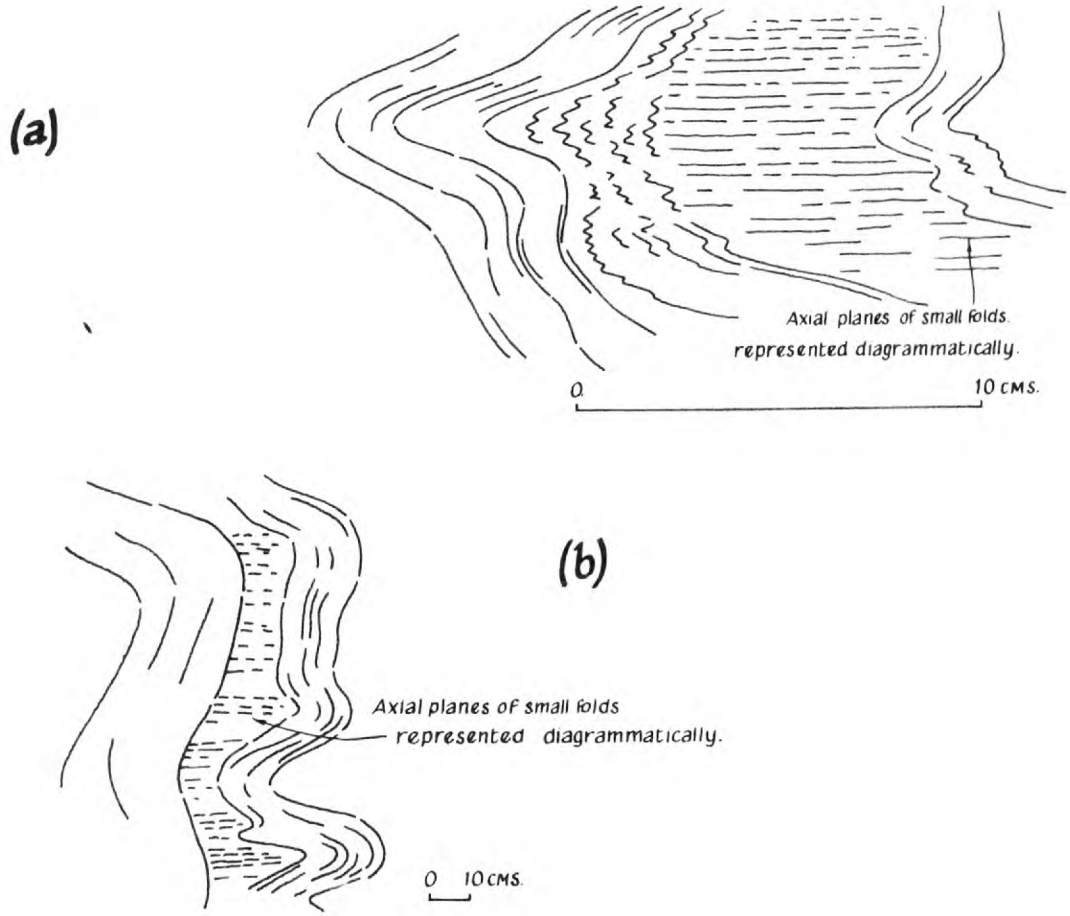
EXPLANATION OF FIGURE 4.7.

Ard Thurinish folds in Moine rocks 300yds SW of Tormore.

(a) Off-white psammite bands are represented as tracing folds with smooth outlines. Quartz grains are flattened within the foliation and are elongated oblique to the axes of the folds. The semi-pelitic rocks contain thin laminae richer in quartz which are folded on a very small scale. Only the axial planes of these small folds are represented. Small, pink garnets are also visible.

(b) The psammite bands are of medium grain size and are deformed into folds of a moderate scale. An elongation lineation is oblique to the axes of these folds. The semi-pelitic rocks between the psammite bands show very small scale folds which have the same orientation as the larger folds in the psammite bands. These smaller folds are represented only by their axial planes.

(c) Part of a psammite band is ornamented with spots, a small body of milky quartz is left blank; the remainder of the exposure is composed of semi-pelitic rocks. This latter contains narrow zones in which very small folds are developed. These zones share the same orientation as the axial planes of the larger folds in the psammite bands nearby. An elongation lineation oblique to the fold axes can be seen both on the psammite bands and on those parts of the semi-pelitic rocks not affected by the very small folds. The asymmetry of the very small folds agrees with their position on the limbs of the larger folds.



Folds in Moine rocks 300yds. SW of Tormore.

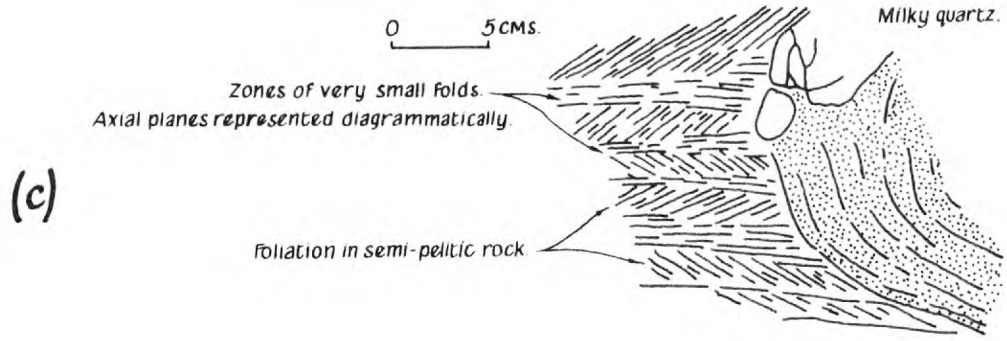


Figure 4.7

EXPLANATION OF FIGURE 4.8.

Angular measurements of Ard Thurinish folds.

(a) 143 observations of elongation lineation west of the Ostaig line in both Moine and Lewisian rocks.

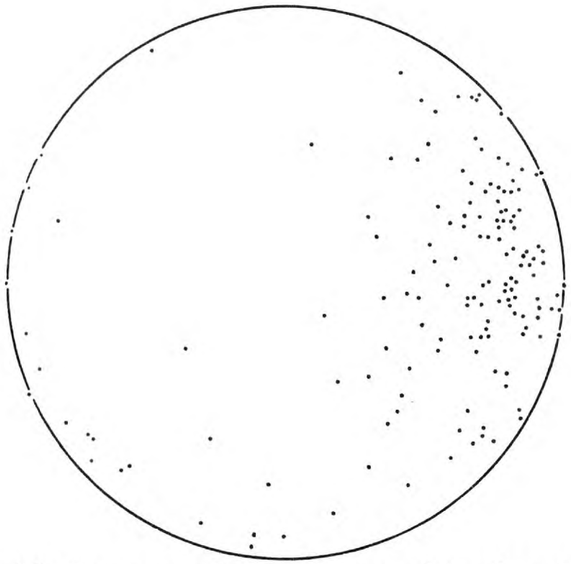
(b) 31 observations of axes from a restricted area in Moine rocks 300yds SW of Tormore.

(c) 27 poles to axial planes of folds the "a" directions of which have been calculated.

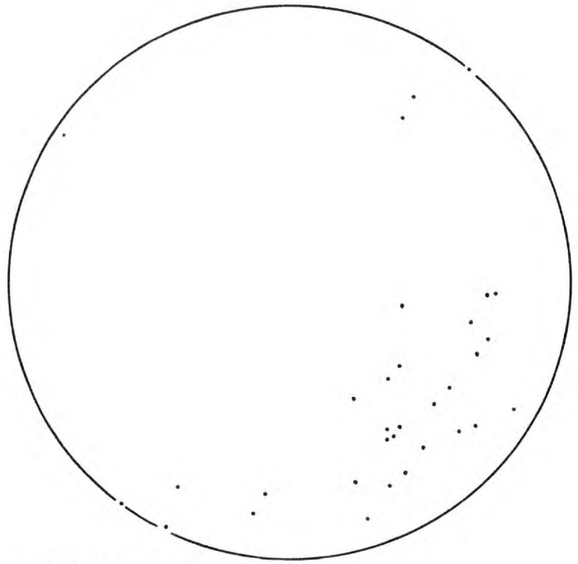
(d) Poles to the 27 lineation deformation planes which have been used in the calculations of "a" directions.

(e) 27 calculated "a" directions contoured at intervals of 1, 2, 4, and 8 points per unit area. The area of the unit circle is defined as the total area of the diagram divided by the number of observations.

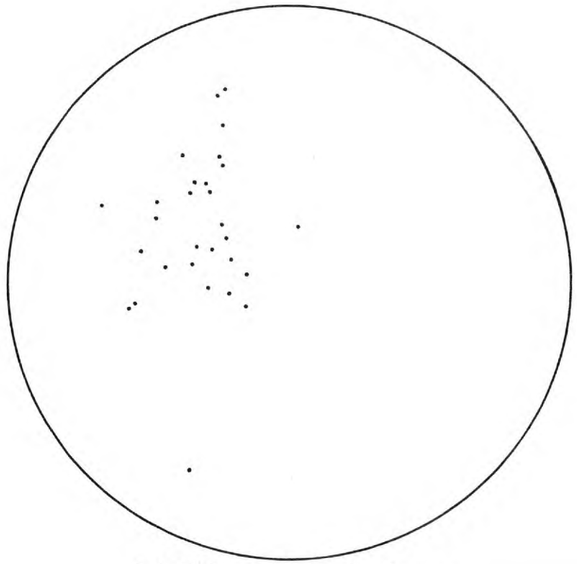
(f) A histogram showing the number of observations within class intervals of 10° in the angle between the axial plane and the lineation deformation plane of each fold, the "a" direction of which has been calculated.



(a) Elongation lineation west of the Ostaig line.



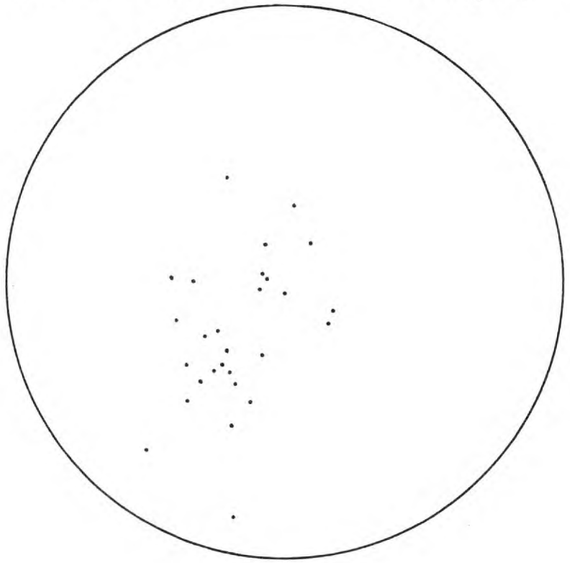
(b) Axes SW of Tormore.



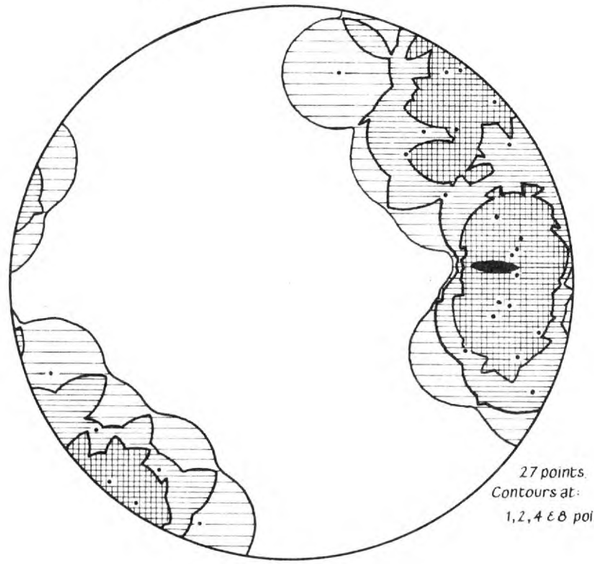
(c) Poles to axial planes.

Measurements of Ard Thurinish folds.

(d) Poles to lineation deformation planes.



(e) "a" directions.



(f) Histogram.

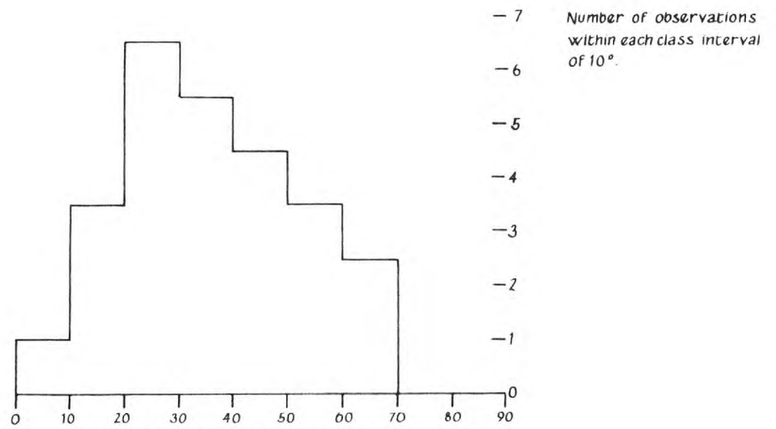


Figure 4.8.

EXPLANATION OF FIGURE 4.9.

A map showing selected "a" directions of Ard Thurinish folds. The selection has been carried out with the object of presenting as many "a" directions as possible consistent with clarity.

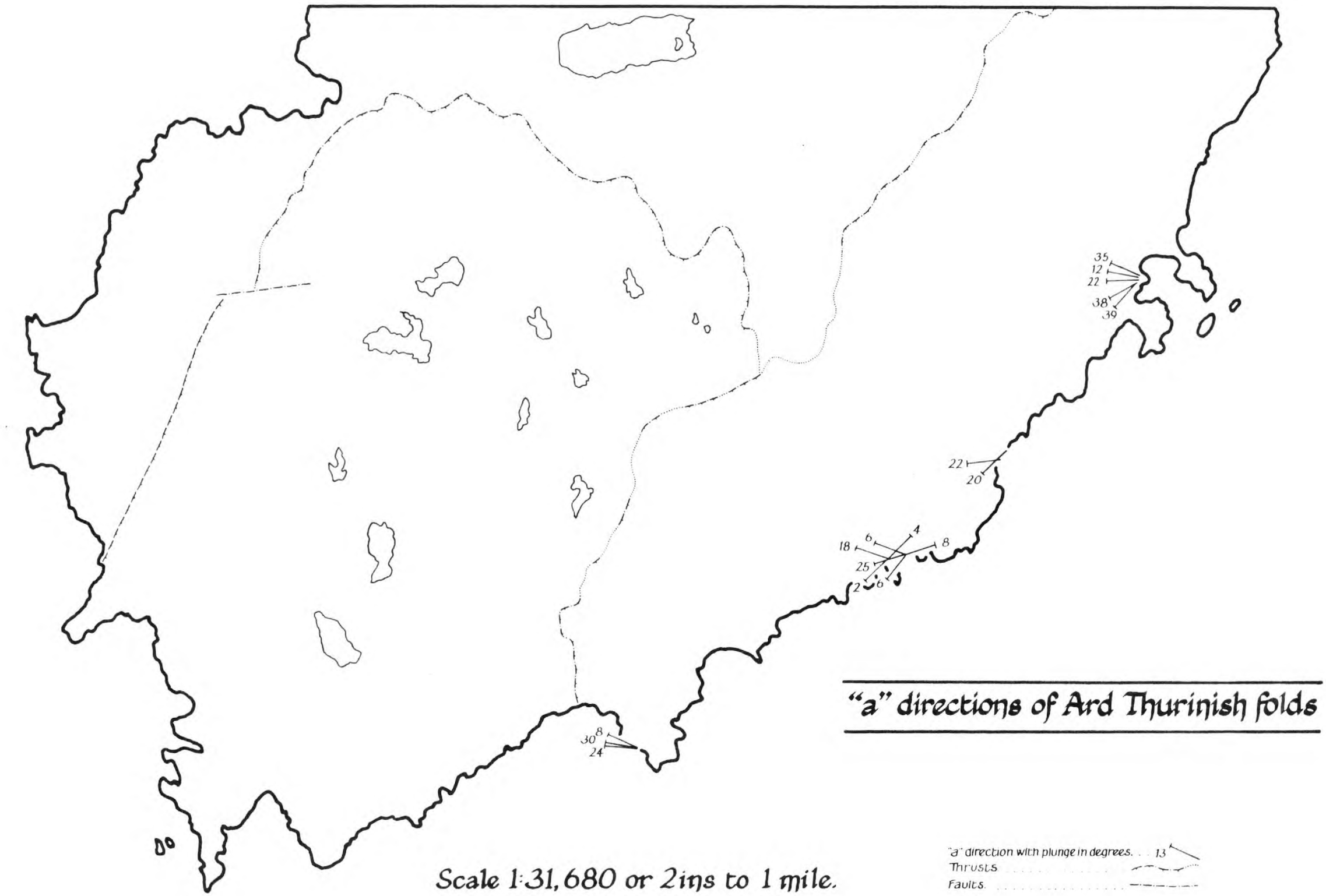
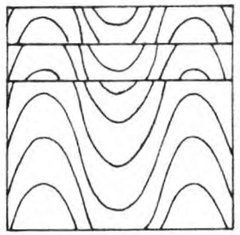

35
12
22
38
39
22
20
18
6
4
8
25
2
6
30
8
24
"a" directions of Ard Thurinish folds
"a" direction with plunge in degrees. . . 13
Thrusts
Faults
Scale 1:31,680 or 2ins to 1 mile.

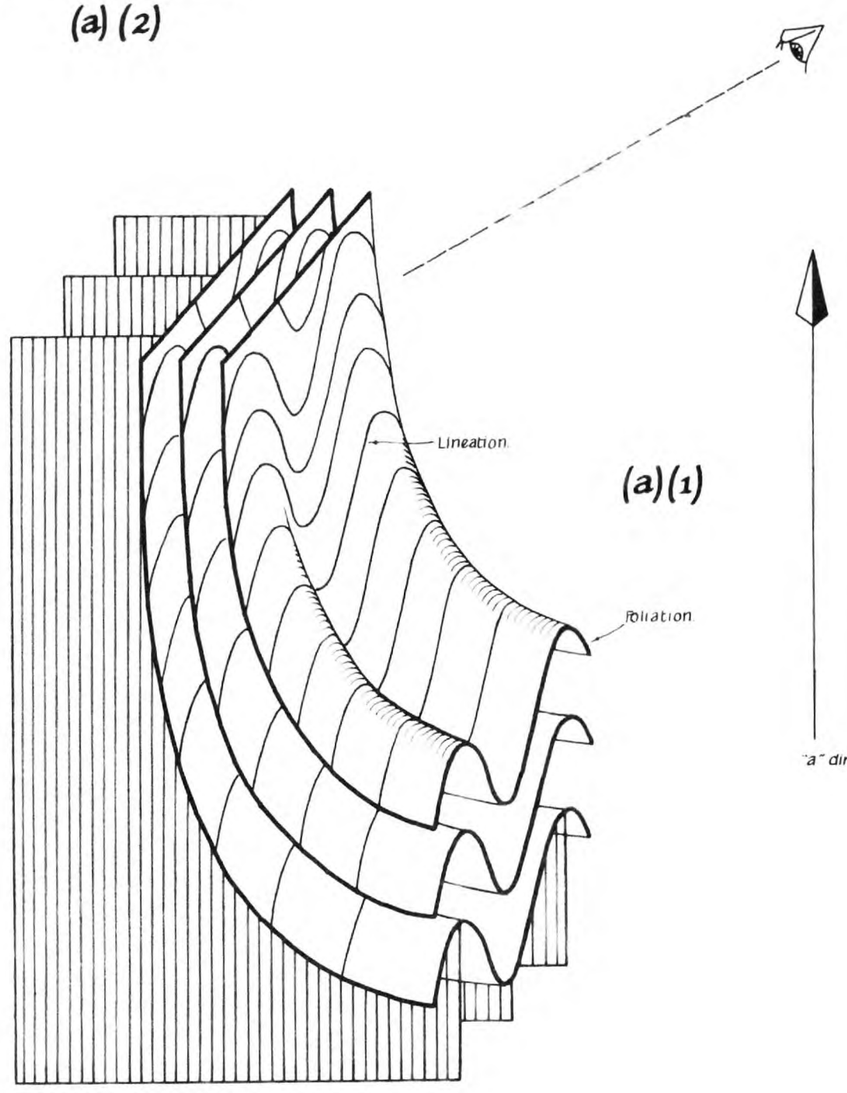
Figure 4.9.

EXPLANATION OF FIGURE 4.10.

Hypothetical block diagrams showing the inferred relationship between the normal Ard Thurinish folds and the structures illustrated in figures 4.5 and 4.6.

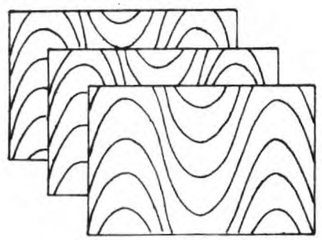


(a) (2)



(a)(1)





(b)(2)

(b)(1)

Relation of Ard Thurinish folds to deformed lineation.

Figure 4.10.

EXPLANATION OF FIGURE 4.11.

This is derived from figure 4.6(a) by enlargement. It is argued in the text that the lines joining the points of maximum curvature of the lineation, as shown in (b), are the traces of the "a" directions which gave rise to these structures.



(a)

Folds with curved "a" directions.

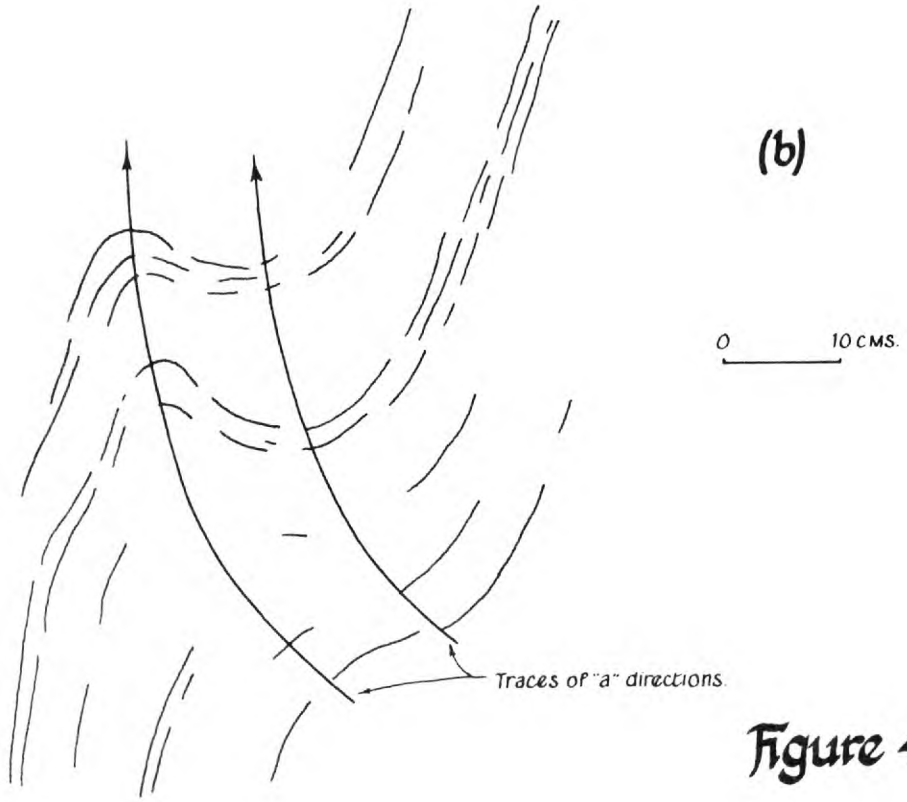


Figure 4.11

According to the tradition of the local people Port a'Chuil is the small bay laying to the SW of the village of Aird of Sleat and another small bay to the SE is called Port na Long. However, both the one inch and six inches to the mile maps of the Ordnance Survey name these two bays vice versa. Nevertheless, venerable residents of the village of Aird of Sleat strongly maintain that the Ordnance Survey maps are wrong and in this thesis there views will be respected. Thus on Plate 1 the bays are marked contrary to the Ordnance Survey maps.

Seventy yards SW of the Schoolhouse at Aird of Sleat, now converted into a dwelling house, the Moine thrust is exposed close to some thick dykes of the NW Tertiary swarm. At this locality the Moine thrust can be defined as a sharp plane dipping to the east. Above this plane the rocks are in the Moine nappe and are of Lewisian derivation, consisting of pink and green mylonised gneisses. Below the thrust the rocks in the Caradal nappe are of psammitic composition and belong to the Tarskavaig Moine Series.

On the coastal section in Port a'Chuil the structures belonging to the Port a'Chuil group can be recognised in both the Lewisian rocks above the Moine thrust and in the Tarskavaig Moine rocks below the thrust. Although this Part of the thesis is primarily concerned with the structures of the Moine nappe, whose western boundary is the Moine thrust, the Port a'Chuil structures in the Tarskavaig Moine rocks of the Caradal nappe will be described here for completeness.

In the Tarskavaig Moine rocks the structures of the

Port a'Chuil group are confined to a group of rocks laying between the Moine thrust and another well-defined dislocation 200yds further west. All of the psammitic rocks in this section contain a very strong elongation lineation. This elongation lineation is parallel to the axes of folds and of fold mullions (Wilson, 1953). Profiles of some of these folds are illustrated in the photographs of figures 5.1(a) and (b). In these exposures bands of coarse psammite are of paler colour than the surrounding rocks of finer grained psammite or semi-pelite. Figure 5.1(c) shows examples of the fold mullions of the Port a'Chuil group of structures. They have been photographed with the camera axis approximately perpendicular to the axis of the mullions. The rocks are of similar composition to those shown in figures 5.1(a) and (b). The angular distribution of the elongation lineation and the mullion structures in the Tarskavaig Moine rocks is shown in the stereogram of figure 5.3(a).

Above the Moine thrust, in the Lewisian rocks of the Moine nappe, folds of the type shown in figure 5.2(b) are fairly common in the coastal section between the Moine thrust and a point about 300yds to the SE. The distribution of the Port a'Chuil folds in the Moine nappe does not seem to be limited by the same type of well-defined dislocation as is the case in the Caradal nappe. The Lewisian rocks in which these folds occur are green chlorite schists with thin laminæ of pink quartzo-feldspathic material. A lineation is developed in these rocks which takes the form of very narrow ribbons of different mineral composition which are rarely more than 2mm wide. This lineation is

parallel to the axes of the folds, and its angular distribution is shown in the stereogram of figure 5.3(b).

The correlation of the folds described in the Tarskavaig Moine rocks with the folds in the Lewisian rocks of the Moine nappe is based on the following evidence:-

1. The folds in both the Lewisian and the Tarskavaig Moine rocks possess an axial lineation.
2. The trends of these lineations are practically identical in both of the groups of rocks as is demonstrated in the stereograms of figures 5.3(a) and (b).
3. The folds in both rock groups have tight profiles.
4. The axial planes of the folds dip towards the east; the folds are nearly reclined, ie. the plunge of the axes is almost down the dip of the axial planes.

Away from the shores of Port a'Chuil, lineations can be found in rocks which lie very close to the Moine thrust but in the majority of exposures it is difficult to demonstrate whether this lineation belongs to the Port a'Chuil group of structures or is the lineation which is deformed by the Ard Thurinish folds: both lineations, although of different age, are of similar appearance. In the bed of the Allt Leth-shithein, a stream in the far north of the area of study, an exposure in Lewisian rocks close to the Moine thrust shows two lineations. It is possible that one of these lineations is that which is deformed by the Ard Thurinish folds (see Chapter 4) while the other is the Port a' Chuil lineation.

The age relations of the Port a'Chuil folds can be

clearly demonstrated on Ard Thurinish. On this peninsula, and in many coastal localities to the NW as far as Bagh a' Mhuilinn, veins consisting essentially of quartz but with accessory amounts of calcite, chlorite and feldspar are fairly common. These veins, one of which is illustrated in figure 16.4(a), are clearly discordant to the foliation which is distorted by the Ard Thurinish folds. On several of these quartz veins a linear structure can be distinguished which consists of a series of fine grooves and ridges. Measurements of this lineation are presented in the stereogram of figure 5.3(c). Their trend is so remarkably close to that of the lineation associated with the Port a' Chuil folds that a direct correlation of these two lineations is suggested. That the lineation on the quartz veins is different from the elongation lineation which is deformed by the Ard Thurinish folds is clearly demonstrated by the exposure on Ard Thurinish illustrated in figure 5.2(a).

In this sketch the rocks with closely spaced spots are chlorite schists with a fissile parting. This fissile parting is a property of the rocks which allows them to break into very thin, flat slivers along parallel planes. This parting is parallel to the axial planes of the Ard Thurinish folds and in the case of figure 5.2(a) is also parallel to the plane of the paper. At the top of the sketch a band of quartzo-feldspathic rock is ornamented with widely spaced spots. This band dips towards the bottom of the sketch at a steeper angle than the fissile parting in the chlorite schist and is, in fact, the upper limb of an Ard Thurinish fold whose axis passes from left to right and

which closes towards the bottom of the sketch. Lines drawn on the quartzo-feldspathic band represent cracks in the rock and elongation lineation. Near the bottom (top) of the sketch the blank areas represent the quartz veins which were the subject of the previous paragraph. The lineation on these veins is shown as a series of lines running from top to bottom and in the case of the quartz vein on the left a number of rod-like structures can also be distinguished.

Since the quartz veins cut discordantly through the rocks which contain the Ard Thurinish folds the quartz veins must be of later date. They carry a lineation the trend of which is constant over a wide area and suggest a connection in time with the Port a'Chuil folds. If the correlation of the lineation on the quartz veins with the lineation associated with the Port a'Chuil folds is correct then the Port a'Chuil folds must be later than the Ard Thurinish folds.

Supplementary evidence for this age relation is afforded by the exposure illustrated in figure 5.2(c). This is a fold structure which was drawn to the attention of the author by Professor J.Sutton. That part of the sketch which is not ornamented is a parting plane in chlorite schist which carries the lineation associated with the Port a'Chuil folds. This lineation is represented as a series of approximately parallel lines running from left to right. The rock ornamented with spots is composed essentially of quartz and feldspar. This body of rock has no appreciable third dimension and contains a lineation deformed about a fold-like structure.

The interpretation of this exposure is as follows. The fold structure appears to belong to the Ard Thurinish group; Ard Thurinish folds being very common in quartzo-feldspathic rocks in this neighbourhood. The lineation on the parting plane in the chlorite schist belongs to the Port a'Chuil group and is rectilinear. It must, therefore, be contemporaneous with, or later than the fold structure in the quartzo-feldspathic rock.

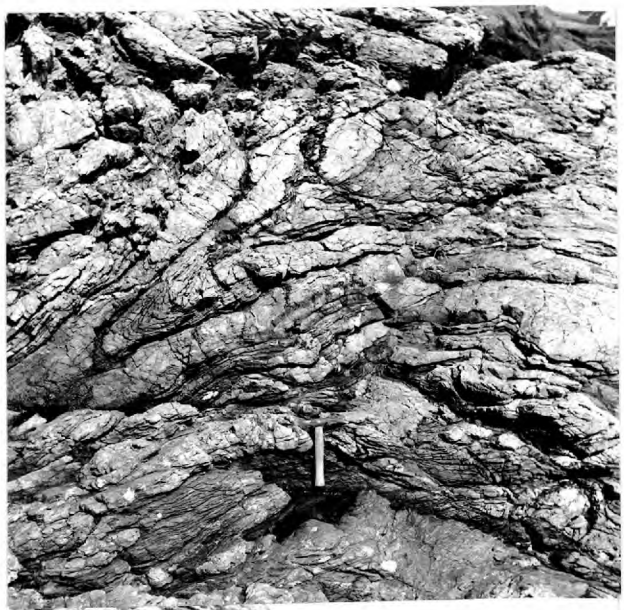
Evidence that the Port a'Chuil structures occur in a very narrow zone close to the Moine thrust throughout its entire length in Skye can be found where the coast intersects the thrust at Camas a'Mhuilt, north of Isleornsay. This is outside the area involved in the present study but is contained within the district in which Mr.D.Matthews has found very similar structures. At Camas a'Mhuilt both Moine and Lewisian rocks of the Moine nappe are exposed near the Moine thrust. These rocks contain structures which are analogous to those that have been described in this Chapter with the exception of the fold of figure 5.2(c). Not only do the structures at Port a'Chuil and Camas a'Mhuilt agree in style but there is also a measure of agreement in their orientation. It would appear logical, therefore, to presume that the Port a'Chuil structures are developed in a narrow zone of rocks immediately adjacent to the Moine thrust.

EXPLANATION OF FIGURE 5.1.

(a) and (b). Profiles of Port a'Chuil folds in Tarskavaig Moine rocks approximately 100yds west of the Moine thrust. Pale coloured rocks are of psammitic composition while darker colouring indicates a trend towards increasing semipelitic composition.

(c). Mullion structures parallel to the axes of Port a'Chuil folds. The axis of the camera is approximately perpendicular to the axes of the mullions which run from top to bottom of the photograph. The rocks are mainly of psammitic composition.

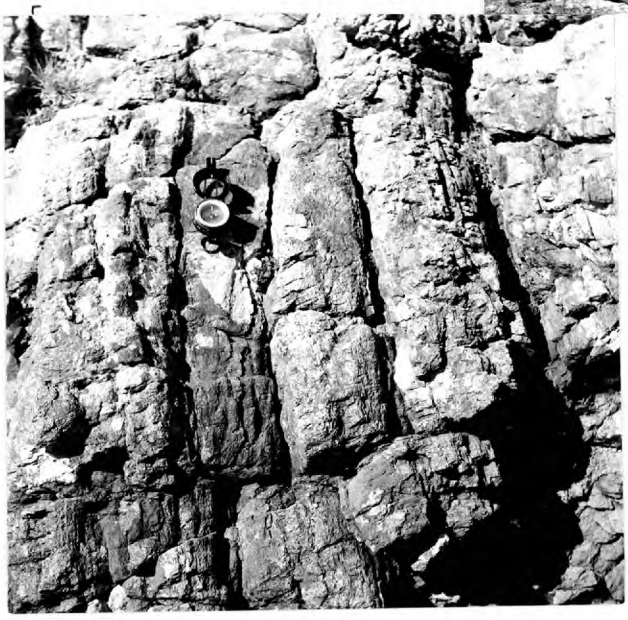
Port a'Chuil folds in Tarskavaig Moine rocks.



(a)



(b)



(c)

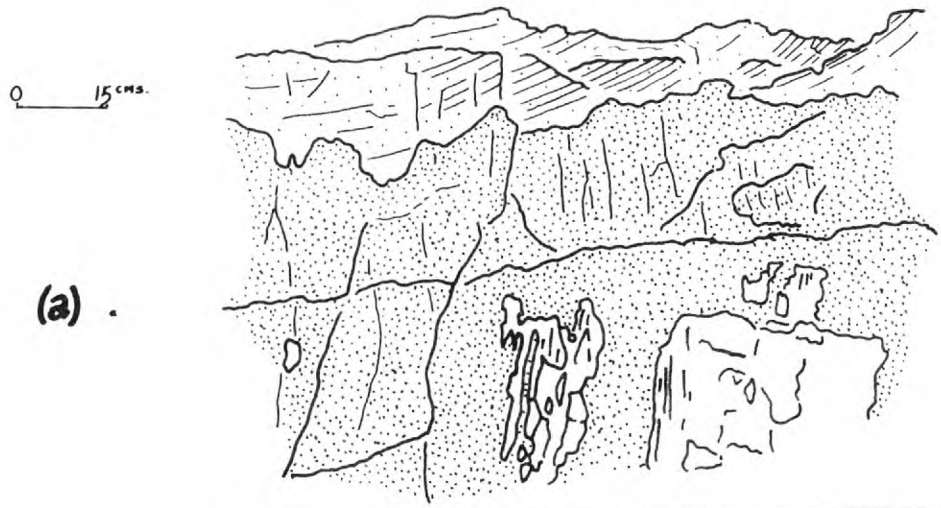
Figure 5.1.

EXPLANATION OF FIGURE 5.2.

(a) Structures 200yds NW of the extremity of Ard Thurinish. At the top of the diagram the rocks ornamented with widely spaced spots are quartzo-feldspathic in composition. These quartzo-feldspathic rocks are on the upper limb of a recumbent Ard Thurinish fold whose axis passes from left to right and which closes downwards. The dark lines represent cracks and elongation lineation. Rocks ornamented with closely spaced spots are chlorite schists in which a fissile parting is developed parallel to the axial plane of the fold. The diagram has been drawn such that this fissile parting is parallel to the plane of the paper. The un-ornamented rocks are discordant bodies of milky quartz containing a lineation which passes from top to bottom of the diagram.

(b) Profiles of Port a'Chuil folds 300yds SE of the Aird of Sleat Schoolhouse. The folds are developed in Lewisian rocks rich in chlorite.

(c) A structure about 350yds SE of the Aird of Sleat Schoolhouse. The rocks ornamented with spots are of quartzo-feldspathic composition and, together with the elongation lineation which they contain, are deformed into a type of fold structure which has no appreciable third dimension. The lineation which is parallel to the axes of the Port a' Chuil folds is well developed and is represented by straight lines sloping gently from left to right.



Structures in Port a'Chuil.



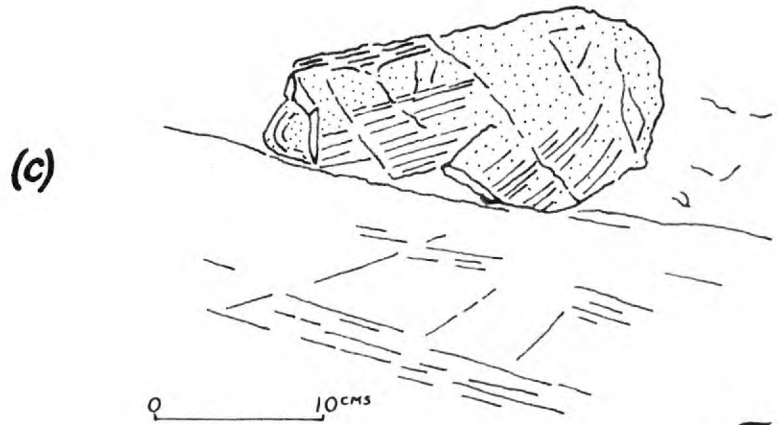
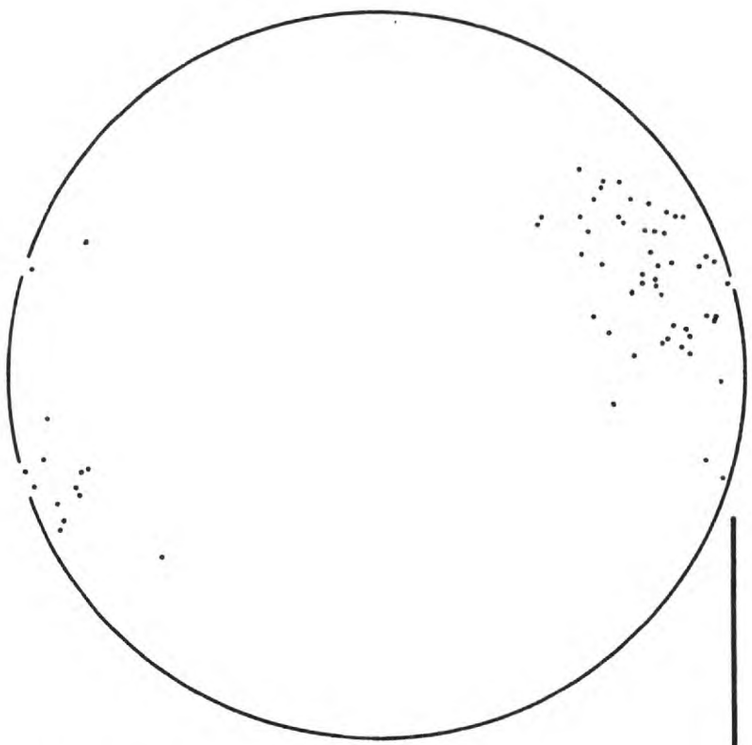


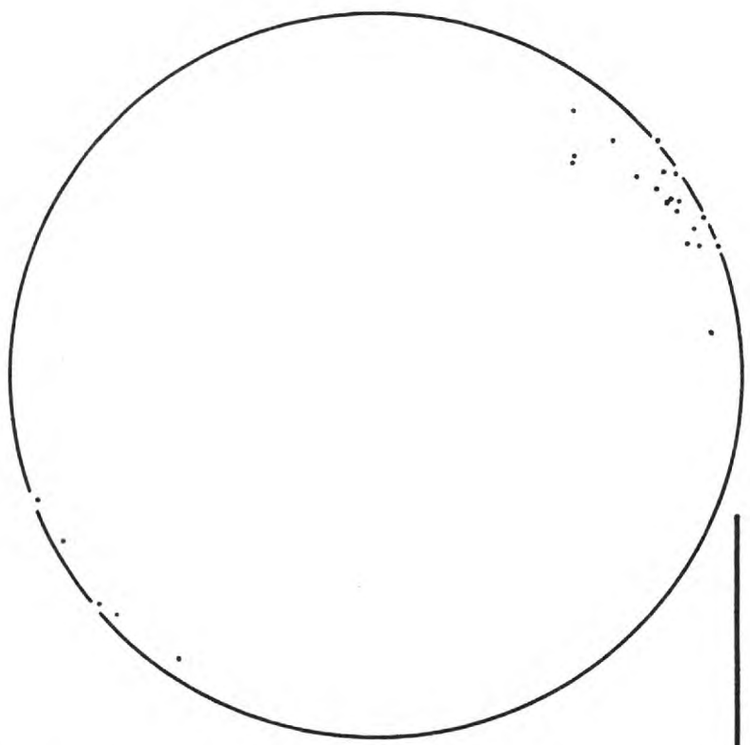
Figure 5.2.

EXPLANATION OF FIGURE 5.3.

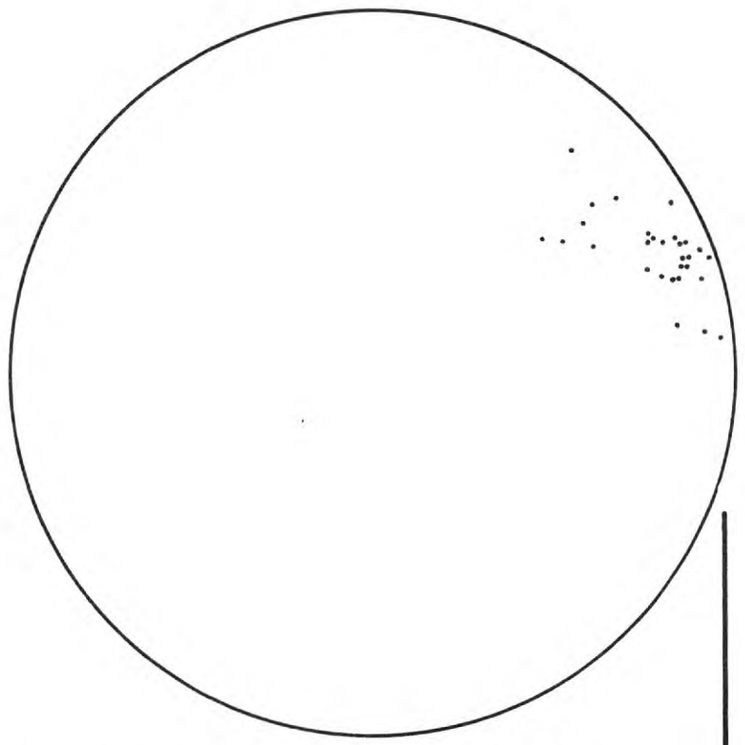
(a), (b) and (c). Stereograms showing the angular distribution of the linear structures associated with the Port a'Chuil folds.



(a) Elongation lineation and mullions in the Tarskavaig Moine rocks.



(b) Lineation in Lewisian rocks.



(c) Lineation on quartz veins in the Moine nappe.

Angular distribution of linear structures associated with the Port a' Chuil folds.

Figure 5.3.

Conjugate folds were first defined and collectively described by Johnson (1956). In reference to part of the Moine thrust zone in Wester Ross, Scotland, he says: "On a regional scale axial planes of the E-W folds in the thrust zone have no preferred orientation; they may dip north and south in adjacent folds within a single exposure. Clearly no consistent sense of translation of upper beds relative to lower can be deduced from the folds which, considered as a whole, have orthorhombic symmetry. Folds with single axial planes cannot be considered individually; they form part of a fold system in which the inclinations of the axial planes are opposed. Such a fold system is termed by the writer a "Conjugate Fold System"."

In the present study no systematic measurements were made on the conjugate folds so that this Chapter is merely a record of their distribution and abundance. For this reason the conjugate folds of both the Moine and Caradal nappes will be mentioned in this Chapter although this Part of the thesis is primarily concerned with the structural history of the Moine nappe.

In the Caradal nappe there are four main groups of rocks as shown on Plate 5. The Laidhe na greine group consists of thin interlaminated pelites, semi-pelites and psammites in approximately equal proportions. Conjugate folds are very widespread and very common in this group. Along the coastal section 400yds WSW of the Aird of Sleat School-house the Laidhe na greine group is well exposed and some very fine examples of conjugate folds can be seen. Two of

these are illustrated in figure 6.1(a) and (b). The former clearly demonstrates the two axial plane directions of the folds. Inland exposures of the Laidhe na greine group are fairly good and the conjugate folds are very common in them. Figures 6.1(c) and (d) show examples where the complexity of the folding reaches a markedly high degree. The latter is from the narrow outcrop of the Laidhe na greine group between Loch Ben nan Caorach and Loch Fada. Here the conjugate folds are developed to an extraordinary degree over a wide area whereas the flanking psammites are virtually free of them. Among the psammites of the Caradal nappe two localities are notable in the development of the conjugate style of folds. At the head of Bealach na Ceardaich (Bealach: a Gaelic word refering to a kind of valley leading up to a gap or pass in the hills) the conjugate style of folding is very common. Again, along the western margin of the Caradal nappe where the rocks dip eastwards, angular folds are very common in the lowermost of the psammites. By far the greater majority of these folds have horizontal axial planes; the complementary set with steep axial planes dipping westwards being less commonly seen.

The Lewisian rocks of the Caradal nappe contain many closely spaced parting planes; a factor which appears to make the rocks more susceptible to the conjugate style of folding. The conjugate folds are very common in these Lewisian rocks, especially above the head of Allt a'Cham-aird, three-quarters of a mile east of Loch Ben nan Caorach.

In the Moine nappe the conjugate folds are almost entirely confined to the belt of fissile, thinly foliated rocks

occuring within about one and three-quarter miles of the outcrop of the Moine thrust, ie. west of the Ostaig line of Plate 3. Within this area conjugate folds are uniformly distributed and fairly common. The fissile, semi-pelitic Moine rocks of the Eilean Sgorach and Eilean Maol, however, contradict these generalisations. These islands are east of the Ostaig line yet the complexity of the conjugate folds far exceeds any to be found in the Moine nappe west of this line.

The age relations of the conjugate folds in the Caradal nappe obviously cannot be discussed here but will receive attention in Chapter 12 when all of the fold structures in the Caradal nappe have been described. In the Moine nappe some of the conjugate folds are clearly later than the Port a'Chuil and Ard Thurinish folds; evidence for this being fairly widely available. Thus figure 6.1(e) shows an Ard Thurinish fold which has been distorted by a conjugate fold. However, all of the conjugate folds are not necessarily of the same age. 400yds SSW of the Ardvasar Hotel two sets of conjugate folds with axes approximately perpendicular were noted. In the rocks which characteristically contain the Baravaig, Rudha Phoil and Tormore (or first, second and third) groups of structures the conjugate folds are not commonly developed. Nevertheless there are a number of exposures where the relation of the conjugate folds to the other structures can be seen. In every soluble case the conjugate folds are later.

EXPLANATION OF FIGURE 6.1.

(a) Small scale conjugate folds in semi-pelitic rocks of the Tarskavaig Moine series 400yds WSW of the Aird of Sleat Schoolhouse.

(b) Large scale conjugate fold at the same locality as (a).

(c) Complex conjugate folds in the Laidhe na greine group 750yds ENE of the Bealach Garbh.

(d) Folds in the Laidhe na greine group near the summit of Ben nan Caorach.

(e) Small folds in Moine rocks of the Moine nappe 600yds NE of the summit of Meall Buidhe. These are Ard Thurinish folds modified by later conjugate folds.

(f) A boulder of Lewisian chlorite schist, or phyllonite, on the shore at Ard Thurinish. The curving and intersecting lines on the foliation surface are the axial traces of conjugate folds.



(a)



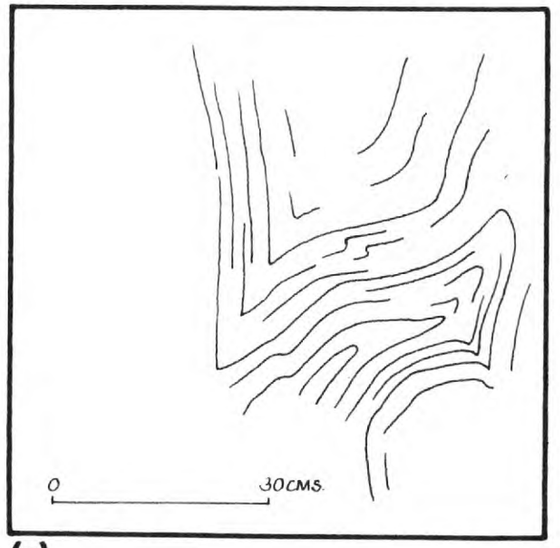
(b)



(c)



(d)



(e)



(f)

Conjugate folds in the Moine and Caradal nappes.

Figure 6.1

CHAPTER 7. OTHER FOLDS OF DUBIOUS OR UNKNOWN GROUPING.

The structures so far described have been classified into well defined groups. In each of these groups, with the exception of the conjugate folds, the structures share such features in common as to strongly suggest that they are all of the same age and were developed by the same mechanical restraints. The relations of folds of one group to the folds of another group in certain fortuitous exposures have been used to determine the relative ages of the different groups of folds.

However, there are a number of exposures containing folds which do not show a sufficient number of characteristic features to allow them to be unquestionable related to any particular group. It is the purpose of this Chapter to record the presence of these folds and to suggest correlations.

Several folds of questionable connection occur in the Moine rocks near Tormore which are ornamented with closely spaced spots on Plate 4. These rocks are predominantly semi-pelitic but contain thin, sharply defined bands of psammite, usually of coarse grain size. The semi-pelitic rocks contain the very small scale Tormore, or third folds which were described in Chapter 3 together with the cleavage which is the dominating structure in these rocks. In some of the exposures the large scale Tormore, or third folds can be seen in the psammite. Examples of these large scale folds are illustrated in figure 3.5 where they can be seen to refold some structures which must be of an earlier generation. It was argued in Chapter 3 that these earlier folds are of the Rudha Phoil, or second group. The large

scale Tormore, or third folds are, however, the exception rather than the rule along this coastal section. The majority of the folds are of the type illustrated in figure 7.1. In these sketches the psammite bands are either left blank or are ornamented with spots. The lines in the surrounding semi-pelitic rocks in the case of (a) represent the axial plane cleavage of the Tormore folds and in the case of (b) and (c) an indistinct foliation. In all three examples the very small scale Tormore folds are present in the semi-pelitic rocks. Figure 7.1(a) clearly demonstrates that the folds in the psammite must be earlier than both the cleavage and the very small folds in the semi-pelite because the cleavage is a plane surface and is strongly oblique to the axial planes of the folds in the psammites. It is possible that the folds of figure 7.1 are the same as the earlier generation illustrated in figure 3.5; that is, of the Rudha Phoil or second generation.

More folds of dubious relationship occur on the coast near Rudha Cille-bhig, two miles NNE of Ardvasar. The rocks belong to the Lewisian group and consist of alternations of acid and basic material with the latter predominating. The rocks are of fine grain size. On some sea stacks, isolated at all but the lowest of tides, about 150yds NE of Rudha Cille-bhig some of these folds are very well exposed. A selection of profiles is shown in figure 7.2. The Baravaig, or first lineation, which can be found in these rocks passes obliquely over the hinges of the folds. The axial direction of the folds is variable but generally plunges SE. The axial planes dip towards the east.

The geometry of the folds and their orientation suggest a possible correlation with the Ard Thurinish group of folds. However, the folds at this locality and at another locality 200yds SW of Rudha Cille-bhig are the only examples of this type along the whole of the coastal section from Bagh a' Mhuilinn to Knock Bay. Not only this but the rocks exposed along this coastal section are rather different from those which characteristically contain the Ard Thurinish group of folds; they are intermediate between the acid gneisses of the north shore of Knock Bay, containing the Baravaig, or first and the Rudha Phoil, or second structures and the fissile schists or phyllonites nearer to the Moine thrust which contain the Ard Thurinish and Port a'Chuil folds.

The massive gneisses north of Knock Bay and east of the Knock line marked on Plate 4 contain large folds of unknown grouping at four localities. Two of these are on the east coast 450yds NE and 500yds SSW respectively of Camas Baravaig. At the former locality a single large fold plunges at 25-30° towards the east. Parallel to the axis of the large fold there are numerous shallow small folds resembling ripple marks in sediments. At the latter locality a dislocation follows a band of dark-green micaceous rock contained within acid gneisses. The acid gneisses on either side of the dislocation are flexed into shallow folds. A third locality at which folds of unknown age occur is at the mouth of the stream called Allt Gairistan Neill, about 500yds east of the ruined castle in Knock Bay. As before, the folds seem to be associated with a dark-green micaceous band.

At these first three localities the folds mentioned can be seen to deform the Baravaig, or first structures and in the third case the Rudha Phoil or second structures as well. However, at the fourth locality no relationship whatsoever can be seen with the structures of known groups. This last locality is in the new road cutting west of Loch nan Dubh-racain. The profile of a fold with a vertical axial plane is visible in the west side of the new section.

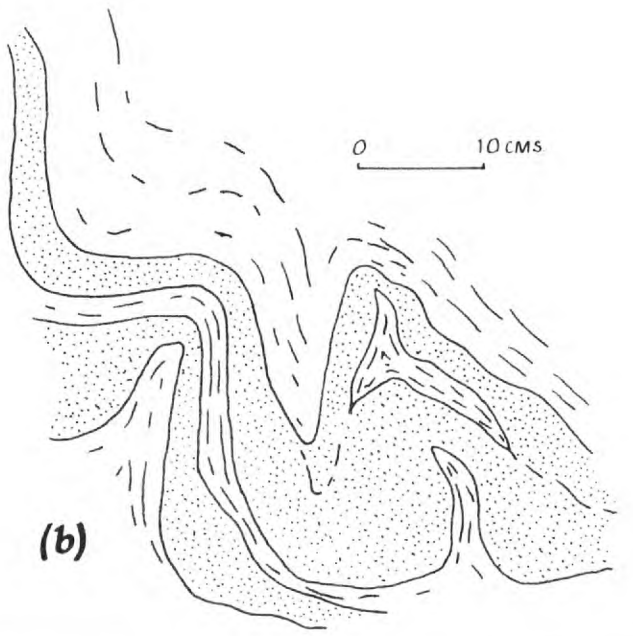
EXPLANATION OF FIGURE 7.1.

Profiles of small folds in Moine rocks east of Tormore.

(a) Psammite abnds are left blank. The structure in the semi-pelitic rocks, is a cleavage that elsewhere is parallel to the axial planes of the large scale Tormore, or third folds. In the semi-pelites this cleavage is seen to be parallel to the axial planes of very small Tormore folds with an amplitude of only a few millimetres.

(b) and (c) Psammitic rocks are shown spotted. Semi-pelitic rocks form the remainder of the exposures; the lines on the sketches representing an indistinct foliation. The semi-pelites are crossed by a later series of folds, similar to those described above, which are too small to illustrate on this scale.





Folds in Moine rocks east of Tormore.

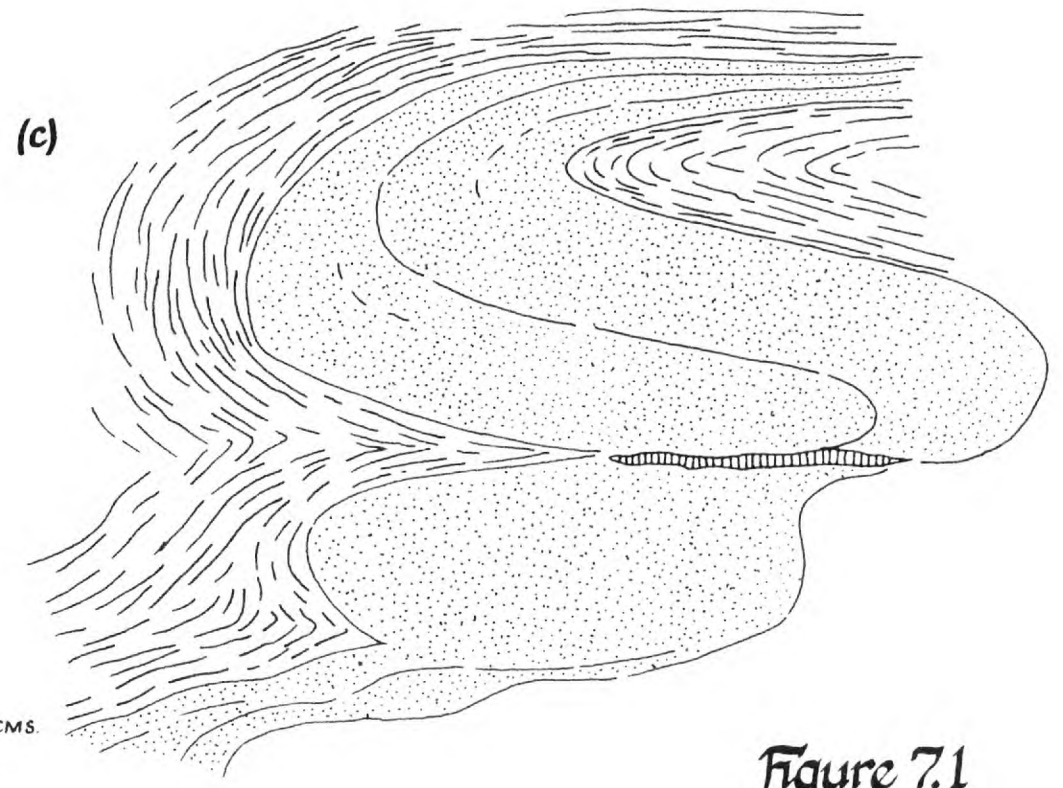


Figure 7.1

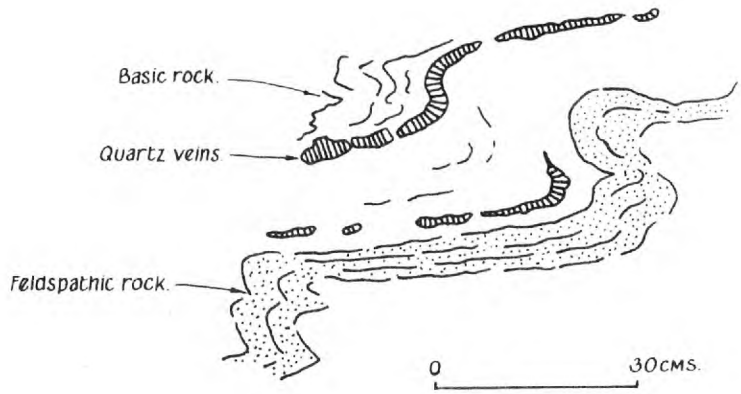
EXPLANATION OF FIGURE 7.2.

Profiles of small folds in Lewisian rocks near Rudha Cille-bhig.

(a) Rock types as indicated in the figure.

(b) Folds in fine grained rocks of basic composition.

(a)



Folds near Rudha Cille-bhig.

(b)

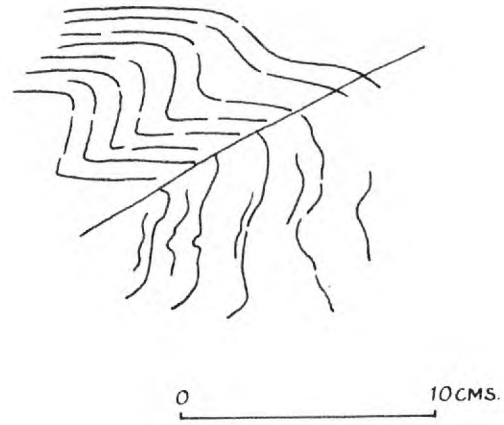


Figure 7.2

IN THE MOINE NAPPE.

A very good account of the discovery of the Moine thrust throughout the NW Highlands of Scotland and various theories which have been proposed in connection with it was given by McIntyre (1954). In this Chapter the local details of the Moine thrust in Skye will be given while the extended discussion of the development and significance of this structure will be presented in Part V.

In the Sleat of Skye the Moine thrust is a plane surface which separates the Moine and Lewisian rocks of the Moine nappe from the Tarskavaig Moine and Lewisian rocks of the Caradal nappe and the Torridonian rocks of the Kishorn nappe (Bailey, 1955).

The Moine thrust is exposed on the coast 50yds SW of the Aird of Sleat Schoolhouse. This is the southernmost known exposure of the Moine thrust in Scotland. At this locality the nature of the thrust can be very clearly demonstrated. Figure 8.1(a) is a general view of the exposure. The wooden boat rests on a ledge which slopes up towards the left at an angle of about 20°. This ledge is composed of greyish-yellow flinty rocks of the Tarskavaig Moine Series in the Caradal nappe. The overhanging rocks are brecciated pink mylonite and green phyllonite belonging to the Lewisian of the Moine nappe. In the background, on the extreme right and at the level of the water, a Tertiary dyke can be seen.

A closer view of the contact of the Lewisian and Tarskavaig Moine rocks is shown in figure 8.1(b). The junction is very sharp: the head of the hammer is lodged in the Moine thrust.

About 900yds north of the Aird of Sleat Schoolhouse the Moine thrust has given rise to a distinct ledge. This is illustrated in figure 8.1(c). The ledge is composed of rocks of the Tarskavaig Moine group which have been "planed off" by the Moine thrust. The less durable brecciated mylonites above the thrust have suffered a greater degree of erosion.

These are the only two localities where the Moine thrust is exposed within the area of study. Between the village of Aird of Sleat and the northern boundary of the area of the survey the Moine thrust is marked by a subdued topographical feature often in the form of an asymmetrical valley. The gentler sides of these valleys slope to the SE and represent the eroded surface of the Moine thrust; the steeper slopes facing NW are the escarpments of the soft Lewisian mylonites.

This topographical feature is not continuous. It is not easily traced for half a mile north of Allt a'Cham-aird and again between Cnoc Fall and Loch nan Uamh.

The age relations of the brecciation near the Moine thrust to the Port a'Chuil folds is quite clear. The mylonites and phyllonites which contain the Port a'Chuil structures are brecciated. Some of the breccia fragments also appear to contain conjugate folds, although these fragments are never very big. The nearby Tertiary dykes are intact. Thus the process of brecciation must have occured between the time of formation of the conjugate folds and the time of intrusion of the Tertiary dykes.

Second only in importance to the Moine thrust among

the dislocations associated with the Moine nappe is a system of fractures running SW from Ardvasar. These are shown in figure 8.2 together with the trace of a monoclinal fold with which they appear to be associated.

The best exposure of one of these fractures is on the south of Rudha Dubh. At this locality the fault separates Moine from Lewisian rocks. A belt of brecciated Moine rocks about 12yds wide, containing slices of Lewisian rocks, can be traced in a straight line across the peninsula. This line passes very close to a prominent erratic boulder of Moine rock and as far as can be ascertained the fault is vertical or nearly so. The same fault can also be seen on the foreshore immediately to the SW, across a small bay, where it follows a slightly sinuous course.

Other exposures of this fault system are to be seen on the NE bank of the Allt Creag Uisdean, 50yds above the high water mark, and on both banks of the Allt a'Cham-aird about 100yds above the high water mark. The delineation of the remainder of the length of the faults is based on step-like and linear topographical features.

Evidence for the direction of the movement on one of these faults is clearly afforded at the south of Rudha Dubh and on the foreshore immediately to the SW. To the SE of the fault the foliation is locally bent into a large fold plunging at 30-50° to the NE. The SE limb of this fold dips at 30-80° to the SE while the other limb is disrupted by the fault. On the NW side of the fault on Rudha Dubh the foliation in the Moine rocks shows a less well marked swing than does the foliation in the Lewisian rocks on the

other side. Nevertheless the sense of movement indicated is the same.

The fault system as a whole cannot be traced across the road to the NNE of Tormore. However, in these rocks there is a monoclinal fold with a steep limb dipping NW and a shallow limb dipping SE. This fold follows a curving trace from Tormore towards the Moine thrust near the summit of Meall Buidhe.

The connection of this fold with the fault system described in the previous paragraphs is suggested on two grounds. Firstly, there is complete continuity of trend of the two sets of structures; and secondly, the attitude of the fold at Tormore is closely comparable with that of the fold associated with the fault at the south of Rudha Dubh.

An examination of the published one-inch maps of the Geological Survey of Scotland and of the Ordnance Survey suggests the possibility that this fault system in Skye is a continuation of the Strathconon fault system on the mainland of Scotland. The two systems are in direct line but even so the major branch of the Strathconon fault system may skirt the coast of the Sleat of Skye and be concealed beneath the waters of the Sound of Sleat.

In the context of the last paragraph it would be of interest to examine the age relations of the system of fold and faults on the one hand to the Moine thrust on the other. In the Moine nappe the monoclinal fold can be traced with certainty to within 300yds of the Moine thrust. In the Caradal nappe the rocks are unfortunatly disturbed by large scale flexures which are certainly earlier than the Moine

thrust so that it becomes very difficult to distinguish between structures which belong entirely to the Caradal nappe and those which could belong to the system of fold and faults. Owing to the poorness of exposure it is impossible to determine whether the Moine thrust has been flexed or not by the monoclinal fold but the possibility can by no means be ruled out.

Other dislocations in the Moine nappe are almost negligible in comparison with those so far described but are important in that they sometimes make the interpretation of small scale structures difficult. Many of these small dislocations are faults which are vertical or nearly so. These faults occur on many different trends. Other dislocations, occuring especially in the fissile rocks closer to the Moine thrust, make much smaller angles with the foliation and along some of these a small amount of rotation seems to have occured so that the foliation in the two blocks on either side of such a dislocation is discordant.

EXPLANATION OF FIGURE 8.1.

(a) General view of the exposure demonstrating the Moine thrust on the coast in Port a'Chuil close to the Aird of Sleat Schoolhouse. The boat, which belonged to the late John Macgilivary, rests on a ledge of Tarskavaig Moine rocks. The overhang is composed of brecciated Lewisian mylonites at the base of the Moine nappe.

(b) A close view of the Moine thrust. The head of the hammer is wedged in the thrust plane.

(c) Topographical feature formed by the Moine thrust about 900yds north of the Schoolhouse.



(a)

(b)



(c)

The Moine thrust.

Figure 8.1

EXPLANATION OF FIGURE 8.2.

A map of the environs of Ardvasar and Tormore showing a fold and some faults which are possibly connected with the Strathconon fault of the Scottish mainland.

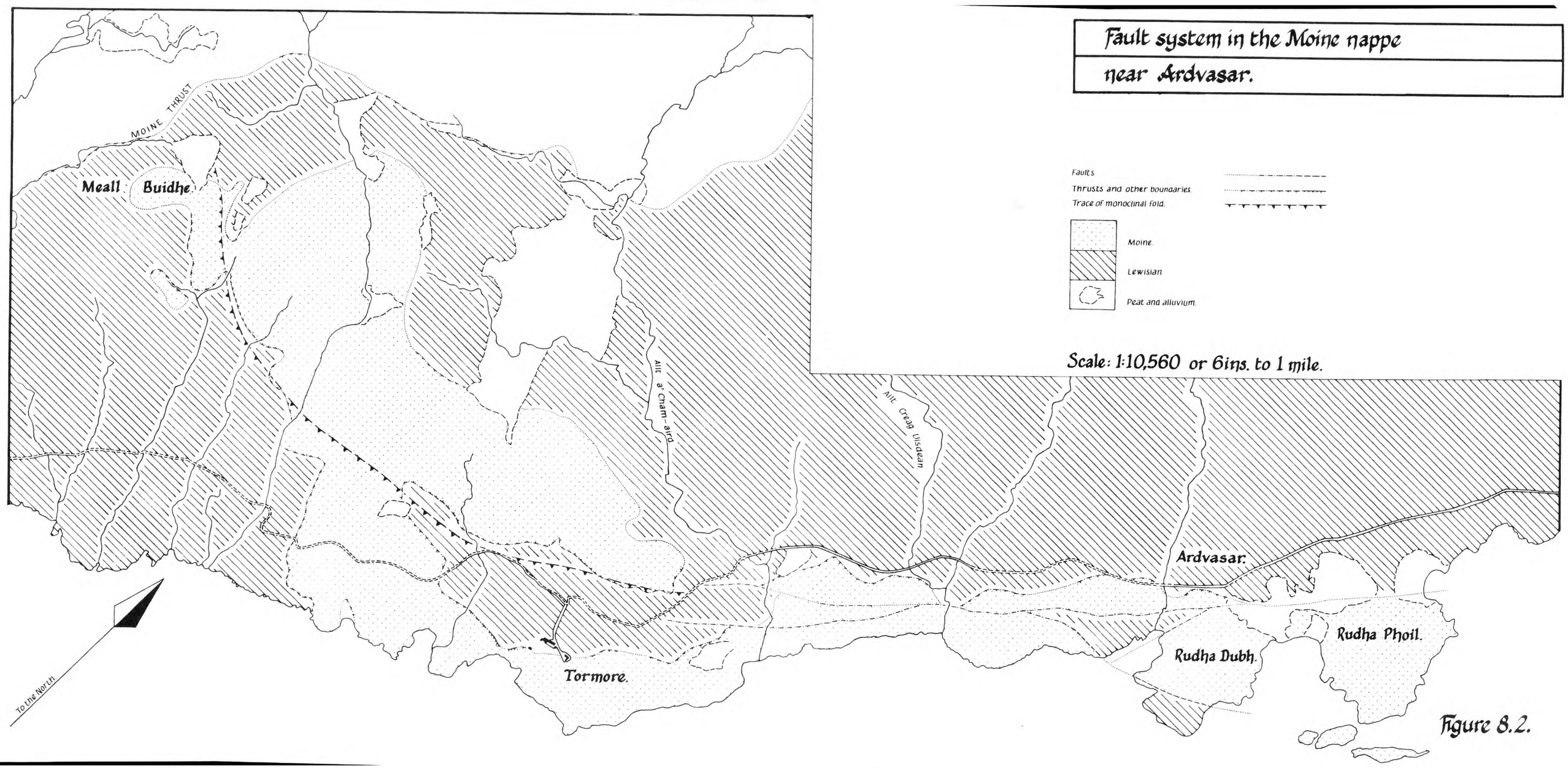

Fault system in the Moine nappe
near Ardvasar.
Faults.
Thrusts and other boundaries.
Trace of monoclinal fold.
Moine.
Lewisian.
Peat and alluvium.
Scale: 1:10,560 or 6ins. to 1 mile.
MOINE THRUST
Meall Buidhe.
Allt a' Cham-aird.
Allt Creag Uisdean
Ardvasar.
Rudha Phoil.
Rudha Dubh.
Tormore.
To the North.

Figure 8.2.

OF THE MOINE NAPPE.

Part I of this thesis has been concerned mainly with the small and large scale folds of the Moine nappe and their attendant structures such as cleavage and lineation. The distribution, geometry and age relations of these structures have been described and discussed and incidental reference has been made to the metamorphic state of the rocks. The final Chapter was devoted largely to the Moine thrust and an important fault system in the Moine nappe. Nearly all of the evidence presented and the discussions based thereon are the result of fieldwork. The purpose of this Chapter is to give a brief outline of this field evidence and the conclusions based upon it in such a way as to summarise the structural history of the Moine nappe.

The earliest folds in the Moine nappe have been called the Baravaig, or first folds. Structures in the Lewisian rocks such as those illustrated in figures 1.2 and 1.3 indicate that these folds were superimposed on an already complex series of metamorphic rocks. All of the structures which are shown in figures 1.2 and 1.3 are associated with the very characteristic and very strong elongation lineation which is parallel to the axes of the Baravaig, or first folds. The shapes of these structures are far removed from true folds; they can only have reached their present state by the modification of structures such as migmatites, intrusive basic rocks and agmatites which existed in the rocks prior to the Baravaig, or first fold movements.

The present distribution of rocks containing the Baravaig, or first structures is shown approximately on Plate 4. In

the Lewisian rocks, ornamented with vertical lines, the elongation lineation associated with the Baravaig folds is very common and many exposures show folds and other structures with axes parallel to this lineation. Examples are illustrated in figures 1.1, 1.2 and 1.3. In the Moine rocks the Baravaig structures are represented only by the elongation lineation and one major fold and are limited to the peninsulas of Rudha Phoil and Rudha Dubh near Ardvasar. These structures are represented on the left hand and centre maps of figure 3.4.

The distribution of the Rudha Phoil, or second structures follows that of the Baravaig structures very nearly with the addition of the small area of Moine rocks near Tormore which is ornamented on Plate 4 with closely spaced spots. The profiles of Rudha Phoil, or second folds differ considerably from those of the Baravaig, or first folds. Figure 2.2 illustrates examples from the Moine rocks and figure 2.6 from Lewisian rocks. The Rudha Phoil, or second folds possess an axial plane cleavage which is very prominent in some exposures as is shown in figures 2.1(a) and 2.5(a). The cleavage planes are spaced at rather wide intervals in the order of 2-5mm and where these intersect the foliation very small folds or "puckers" are developed. These are illustrated in section in figure 2.1(b) and in plan in figure 2.5(b).

The age relations of the Rudha Phoil and Baravaig structures are clearly displayed in practically every exposure where both can be seen. Without the slightest element of doubt the Rudha Phoil structures are later.

Some complex folds in Moine rocks on the eastern tip

of Rudha Dubh are difficult to classify into the age groups without detailed study of much of the surrounding area. These folds are shown in figures 2.3 and 2.4 and it seems most probable that they are formed by the superimposition of Rudha Phoil, or second folds upon small and large scale Baravaig, or first folds.

Apart from the folds mentioned in the last paragraph the orientation of the small scale Rudha Phoil folds is fairly constant: the axial plane dips at 20-40° to the SE and the axes at very shallow angles to the NE. It is mainly such directions as these that invite a correlation of the small scale Rudha Phoil folds with the large scale Knock synform in the Lewisian rocks of the ground north of Knock Bay. This fold is analysed in figure 2.7 and produces a regional change in the direction of the Baravaig, or first lineation as illustrated on Plate 2 and in figure 2.7(b).

The Tormore, or third folds and their associated structures are rather more restricted in distribution than the first and second groups of structures. On Plate 4 they are confined, in the Moine rocks, to those areas ornamented with closely spaced spots and, in the Lewisian rocks, mainly to those areas crossed by both horizontal and vertical lines.

The characteristic feature of the Tormore group of structures is the new lineation with which they are associated. This lineation takes different forms in different rocks but always plunges to the SE and lays on planes dipping to the SE. On the peninsula of Rudha Phoil the Tormore, or third lineation lies on the axial plane cleavage of the Rudha Phoil, or second folds. The age relation of the Tormore structures

to the Rudha Phoil structures is thus clearly demonstrated. The cleavage on Rudha Phoil is excellently developed in the semi-pelitic rocks of the Moine series. In these rocks the third lineation is represented by a girdle arrangement of the poles to flakes of mica such that the axis of the girdle is parallel to the third lineation. The direction of the intersection of these flakes of mica with the cleavage planes is thus always constant and gives the megascopic appearance of a lineation plunging SE. The cleavage and the lineation are very widespread over the peninsulas of Rudha Dubh and Rudha Phoil and can also be found in the semi-pelitic rocks near Tormore. On the two peninsulas the elongation lineation in the psammite bands belongs to the Baravaig group of structures but at Tormore the arrangement is rather different. The grains in the psammite bands are elongated but the direction of elongation is oblique to the foliation and parallel to the third lineation in the semi-pelites. This very unusual situation is illustrated diagrammatically in figure 3.6. It is not, however, unique but finds a remarkable parallel in the Lewisian rocks of Knock Bay. Many of these Lewisian rocks contain stout, prismatic crystals of amphibole and in some of these rocks the crystals possess a very high degree of preferred orientation. Although this amphibole lineation may lay on the foliation planes in some localities, in others it occurs oblique to the foliation; the prismatic crystals being aligned such that they transect the foliation planes. Along the coastal section from Knock Bay to Bagh a'Mhuilinn the amphibole crystals in the Lewisian rocks are somewhat smaller than

those north of Knock Bay but they do possess the same preferred orientation and can be seen to cut through the Baravaig, or first lineation. In other rocks along this coastal section the third lineation is displayed as an elongation of quartz and feldspar, or a girdle orientation of flakes of micaceous minerals similar in every respect to that described in the semi-pelitic rocks of Rudha Phoil.

Folds of the same generation as this lineation are rare and have been found only in Moine rocks. Profiles of some of these are shown in figures 3.2, 3.3 and 3.5. In psammite bands at Tormore (figure 3.5) and 150yds SE of the Ardvasar Hotel (figure 3.3) the Tormore, or third folds can be seen to refold some folds which have been identified as being of the Rudha Phoil, or second group.The cleavage is developed in the semi-pelitic rocks at these two localities and is parallel to the axial planes of the Tormore folds. This cleavage can be traced through practically continuous exposures to the SE of Rudha Phoil where it is apparently the axial plane cleavage of the Rudha Phoil, or second folds. Thus at Tormore and at the Ardvasar Hotel the cleavage must be a fundamentally different structure from the cleavage at the SE of Rudha Phoil. At Tormore and at the Ardvasar Hotel the cleavage is a completely new structure cutting across the Rudha Phoil, or second folds whereas at the SE of Rudha Phoil the cleavage is a modified axial plane cleavage of the Rudha Phoil folds. There is complete transition between the two localities.

The group of folds called the Ard Thurinish folds are restricted in their distribution to those areas of the

Lewisian which, on Plate 4, are ornamented with horizontal lines and in the Moine with widely spaced spots. They possess curving axes and converging axial planes as shown in the stereoscopic photographs of figure 4.2. On the regional scale the axes show a very wide angular distribution as demonstrated by figure 4.1. The Ard Thurinish folds are characteristically asymmetrical in profile as shown in figure 4.3 and deform an elongation lineation as shown in figures 4.2, 4.4 and 4.5. Certain very special geometrical situations arise in connection with these folds such that the elongation lineation is deformed but the foliation is not buckled. These structures are illustrated in figure 4.6 and the possible relationship to the normal type of folds is illustrated in figure 4.10. Certain other theoretical considerations, illustrated by figure 4.11, indicate that, even as these folds developed, their "a" directions were curved.

The age relations of the Ard Thurinish folds to those of the first three episodes of folding is not at all clear from the available field evidence. It has been shown that the Ard Thurinish folds cannot be earlier than the Rudha Phoil, or second folds since the Ard Thurinish folds do not occur on the SE limb of the Knock synform in the position in which they would be expected to do so if they were indeed earlier than the Rudha Phoil folds. An age for the Ard Thurinish folds intermediate between that of the Rudha Phoil folds and that of the Tormore, or third folds is rejected on the grounds that it is very unlikely that a large part of the belt of rocks which contain the Ard Thurinish folds remained in a static metamorphic condition while active

metamorphism and folding occured in the rocks on either side: the Tormore folds to the east and the Port a'Chuil folds to the west.

It is feasible, however, that the Ard Thurinish folds could be correlated with the Tormore, or third folds and that the lineation they deform is the first lineation. Such a correlation invokes the concept that the physical restraints which controlled the development of the folds varied very considerably along lines perpendicular to the Moine thrust. The consideration of the Tormore structures has already provided evidence in this direction so that the correlation of the Ard Thurinish folds could be looked upon as a further logical step in support of the concept outlined above.

However, it is equally logical to correlate the lineation which the Ard Thurinish folds deform with the elongation lineation which is parallel to the axes of the Tormore folds. Unfortunately there is no evidence either to support or refute such a statement in spite of the excellent coastal exposures available. Therefore in the sequence of structures so far discussed the Ard Thurinish folds may be either third, and equivalent in time with the Tormore folds, or fourth and thus be the result of a series of completely different movements.

An interesting group of folds occurs very close to the Moine thrust in both the Moine and Caradal nappes. These folds are very well displayed in the coast sections in Port a'Chuil after which they are named. They are angular in profile as shown in figures 5.1 and 5.2(b) and many of them approach an isoclinal condition. An elongation lineation is developed parallel to their axes. These structures are

confined to a narrow belt of rocks very close to the Moine thrust in Port a'Chuil and the presence of identical structures where the Moine thrust intersects the coast north of Isleornsay is taken as an indication that this belt of rocks is continuous throughout the entire length of the outcrop of the Moine thrust in Skye.

The age relations of the Port a'Chuil folds are demonstrated by a series of quartz veins which are emplaced discordantly into the rocks which contain the Ard Thurinish folds. These quartz veins are clearly later than the Ard Thurinish folds and carry a lineation which is parallel to the elongation lineation associated with the Port a'Chuil folds, shown diagrammatically in figure 5.3. The Port a'Chuil folds are thus later than the Ard Thurinish folds and occupy a position either fourth or fifth in the sequence of fold episodes in the Moine nappe in Skye.

A conjugate series of folds is very common in the fissile and thinly foliated rocks which characteristically contain the Ard Thurinish folds and they also occur less commonly in the more massive rocks to the east. Where the conjugate folds occur in the same exposure as members of the groups of folds previously mentioned in this Chapter the conjugate folds are always seen to be younger.

Near the Moine thrust the mylonites and phyllonites of the Moine nappe are partially brecciated. Some of the fragments contain recognisable conjugate folds so that the last movements on the Moine thrust must be later than the final phase in the growth of the conjugate folds.

Near Ardvasar there is a system of important, near

vertical faults. These faults trend towards the NE and it is suggested that they form an extension of the Strathconon fault system. They are associated with a monoclinal flexure which seems to be a continuation of the fault system. This flexure curves westwards, towards the Moine thrust, as shown in the map of figure 8.2 and it is possible that this flexure deforms the Moine thrust. Even if this should not be the case, the flexure is clearly later than the conjugate folds, so that a close connection between the last movements on the Moine thrust and on the Strathconon fault system is indicated.

CARADAL NAPPE.

The purpose of Part II of this thesis is to treat the structures of the Caradal nappe in exactly the same way as the structures of the Moine nappe were dealt with in Part I. To begin with there are three Chapters describing those folds which fall into well-defined age groupings. These Chapters are followed by two more dealing respectively with folds of dubious or unknown connection, and the Caradal thrust and other dislocations associated with the Caradal nappe.

Some of the statements in Part I indicated that, to a certain extent, there seems to be in the Moine nappe a correlation between the appearance of the rocks and the age groupings of the structures which they contain. These possible correlations will be elaborated in Part III. In the Caradal nappe the connection between the structures and the appearance of the rocks is not so well marked so that a concise description of the latter becomes much easier than is the case with the rocks of the Moine nappe.

The rocks involved in the Caradal nappe can be broadly classified into three groups: Lewisian, Tarskavaig Moine and Torridonian. The Lewisian rocks are very fine grained and are flaggy or thinly foliated. In the east of the outcrop (see Plate 5) they are recognisably pink and green but to the NW they are barely distinguishable in the hand specimen from pale-grey rhyolites. The Tarskavaig Moine rocks are metasediments. They consist largely of coarse psammites, often rich in feldspar, associated with the thinly bedded psammites, semi-pelites and pelites of the Laidhe na greine group. The Torridonian rocks belong to the basal Epidotic

Grit of the Torridonian succession. They are composed of coarse, angular grains and contain scattered pebbles. They are separated from the surrounding Tarskavaig Moine rocks on all sides by dislocations.

One of the most striking features in the Tarskavaig Moine rocks of the Caradal nappe is the widespread elongation lineation. This structure is particularly well developed in the Upper and Lower Psammites and in the psammitic bands of the Laidhe na greine group but tends to be somewhat obscure in the semi-pelites and the pelites and in the Lewisian rocks. The variations in the direction and amount of plunge of this lineation are shown on Plate 2. These variations can be shown to be due to later periods of folding.

In the Upper Psammite and, locally, in the Lower Psammite feldspar is very abundant and the rocks as a whole may reach such a grain size that individual fragments of quartz or feldspar measure 4-5mm across. The feldspar in these rocks is more often than not coloured a very deep orange and contrasts strongly with the off-white, pale-grey or pale-blue quartz. Not only this, but the degree of elongation of the quartz may be totally different from that of the feldspar; individual grains of quartz being two or three times longer than wide whereas the feldspar retains much of the characteristic shape of the original detrital fragments. This observation leads to the conclusion that the crystal lattices of the quartz and of the feldspar reacted somewhat differently to the mechanical processes which gave rise to the elongation lineation.

Rare quartzite pebbles, occuring in the Upper Psammite in the southern part of the outcrop of the Caradal nappe and well away from the junctions with the Laidhe na greine

group, are also elongated in the same direction as the quartz grains of their matrix. Many of the exposures show that the quartz grains are flattened within the foliation as well as being elongated. In short; the grains approximate in shape to a tri-axial ellipsoid. The two longest axes of this ellipsoid lie in the foliation and the longest axis of all is parallel to the elongation lineation. However, in the eastern part of the outcrop of the Caradal nappe, particularly in the Lower Psammite, the flattening of the quartz grains is commonly oblique to the foliation. This oblique flattening does not produce a schistose property. Some measurements of this oblique flattening are recorded on the map of figure 10.3 and at each of these localities the foliation is also marked.

The relation of the flattening of the quartz grains and the small scale Capistal folds is clearly demonstrated in some exposures of the Lower Psammite about 200yds south of Loch Capistal. Photographs of the profiles of some of these folds are shown in the figures 10.1(a-d). The elongation lineation, prevalent in the rocks of the Caradal nappe, is parallel to the axes of these folds and the flattening of the quartz grains is parallel to their axial planes. These relationships indicate a very close connection between the lineation, the flattening and the folds, and it appears, therefore, that all three types of structure resulted from the same mechanical restraints.

Further examples of folds which show exactly the same relationships between the axial plane and the flattening are fairly common and a selection of these is shown in

figure 10.1. The fold in figure 10.1(e) is from a point 400yds NNE of the main inlet to Loch Capistal, (f) is from the Lower Psammite 400yds NW of the Loch Ben nan Coarach outlet and (g) is in the Lower Psammite 500yds north of Loch Capistal.

In addition to the elongation lineation which is very commonly seen in the psammitic rocks of the Caradal nappe another type of small scale structure that shares the same abundance is a system of quartz veins. An exposure of the Lower Psammite in which there are numerous such veins is illustrated in figure 10.1(h). This exposure is 300-350 yds SSW of the Loch Capistal outlet, not far from the folds illustrated in figures 10.1(a-d), and shows many of the features which characterise this system of quartz veins. To the unaided eye the veins contain little but milky quartz with very rare crystals of feldspar. They are either flat or slightly sigmoidally curved and, where abundant, form complex intersecting patterns. The margins of the veins are usually strongly lineated in a direction parallel to the elongation lineation in the host rock. In this exposure the angle between the flat veins and the flattening of the quartz grains is very small and experience of large numbers of exposures where both types of structures are developed indicates that they are nearly always approximately parallel. Less commonly the veins can be seen to be roughly parallel to the axial planes of small Capistal folds possessing the axial elongation lineation, as shown in figure 10.1(b), (c) & (f).

The evidence outlined in the previous paragraph thus seems to indicate a connection between the quartz veins on

one hand and the folds, flattening and elongation on the other. It would appear that this connection is such that the quartz veins were emplaced at a late stage in the development of the folds; some of the quartz veins are flat, eg figure 10.1(f), and thus seem to be entirely later than the folding. Others, however, are sigmoidally curved, eg figure 10.1(h), in such a manner as to suggest that they have been slightly deformed by the Capistal fold movements. Many of the veins, even those which are flat, are strongly lineated. This fact hints that the lineation forming processes outlasted the period during which the foliation was buckled.

The distribution of the small scale Capistal folds and their associated structures is of interest. The elongation lineation and the quartz veins are common and widespread in all of the psammitic rocks. The occurence of flattened quartz grains is fairly common but grains flattened oblique to the foliation are less abundant and are to be found mostly in the area of outcrop of the Lower Psammite. The small folds with axial elongation lineation and grains flattened parallel to their axial planes seem to be entirely confined to the outcrop of the Lower Psammite and the Laidhe na greine group.

Figure 10.3 is a map of the greater part of the area covering the Lower Psammite and the Laidhe na greine group and is centred on the hill called Ben nan Caorach; about three miles WSW of Ardvasar. Among the small scale structures shown on this map particular interest surrounds the observations of foliation and flattening of quartz grains. The strikes

of these two planar structures are clearly marked on the map at localities where both have been measured. These localities can be classified according to whether the acute angle measured from the strike of the flattening to the strike of the foliation is clockwise or anticlockwise. Two lines can be drawn which separate the area into three parts. These lines are shown by a series of dots. In the central area the foliation is clockwise to the flattening while in the lateral areas the foliation is anticlockwise to the flattening.

In a previous paragraph it was shown that, where the two structures occur together, the flattening and the quartz veins are approximately parallel. The flattening and the quartz veins could thus be considered as homologous planar structures and the relation of the quartz veins to the foliation in any one exposure can be treated in the same way as were the flattening and the foliation in the preceding paragraph. Throughout any one of the three areas the foliation shows a consistent relationship to the quartz veins which is the same as that to the oblique flattening.

Study of the small scale folds shows that the quartz veins and the flattening are approximately parallel to their axial planes. The consideration of the relation of the foliation to both the flattening and the quartz veins not only demonstrates that the dotted lines represent the axial traces of large scale folds but also that these large scale folds belong to the same generation as the small scale folds.

The western trace is of an antiformal fold while the eastern trace is of a complementary synformal fold. These two folds are called the Capistal antiform and synform

respectively. In the area of Ben nan Caorach both folds are clearly very tight in profile but south of Loch Capistal the Capistal antiform appears to be more open. The tightness of the antiform in the region of Ben nan Caorach is illustrated in the stereograms of figure 10.2 which show the angular distribution of poles to foliation planes on the two limbs of the folds.

The axial directions of the small Capistal folds are also shown in figure 10.3, the asymmetry of these folds being indicated by the asymmetry of the arrows. If these small folds were to show the normal parasitic (de Sitter 1958 after Shearman) relationship then all small folds with S-shaped profiles would be expected to occur in the central area while all folds with Z-shaped profiles would be found in the lateral areas. This, however, is clearly not the case. One possible explanation of the anomaly is that folds exist which are intermediate in size between the large Capistal antiform and synform on the one hand and the small scale folds that can be appreciated in the single exposures on the other. According to this explanation those small folds in the central area with Z-shaped profiles and in the lateral areas with S-shaped profiles are on the short limbs of the postulated intermediate folds.

Outside the area of figure 10.3 there is no evidence for the presence of large scale Capistal folds. The relations of the quartz veins to the foliation over the entire outcrop of the Upper Psammite indicate that these rocks are all on the western limb of the Capistal antiform. Similarly, to the east of the axial trace of the Capistal synform there is no indication of other large folds of the same generation.

EXPLANATION OF FIGURE 10.1.

(a), (b), (c) and (d) are folds from within a small area about 200yds south of Loch Capistal. The rocks are coarse members of the Lower Psammite, containing little but quartz. The quartz grains are flattened parallel to the axial planes of the folds and are elongated parallel to their axes.

(e) Small fold in exposure of Lower Psammite 400yds NNE of Loch Capistal.

(f) Profile of small fold in an exposure of a psammitic member of the Lower Psammite 350-400yds NW of the Loch Ben nan Caorach outlet. The sheet-like quartz veins are approximately parallel to the axial plane of the fold.

(g) Small fold 450yds north of Loch Capistal in a fine grained layer of the Lower Psammite. The quartz grains are flattened in the axial plane of the fold.

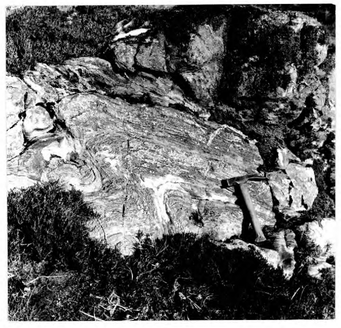
(h) Exposure of coarse rocks of the Lower Psammite about 400yds south of Loch Capistal. The constituent grains of the rock are flattened and the sheet-like quartz veins are approximately parallel to this flattening.



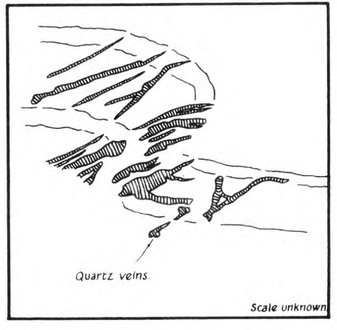
a)



b)



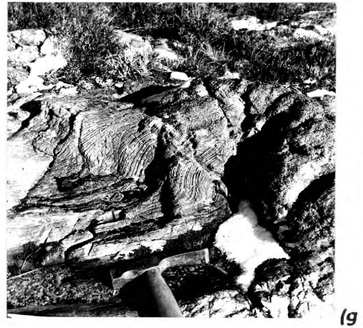
c)



f)



d)



g)



h)



Profiles of small Capistal folds.

Figure 10.1

EXPLANATION OF FIGURE 10.2.

The points on the stereogram represent poles to foliation planes on the two limbs of the Capistal antiform in the region of Ben nan Caorach and Loch Ben nan Caorach (Named on figure 10.3).

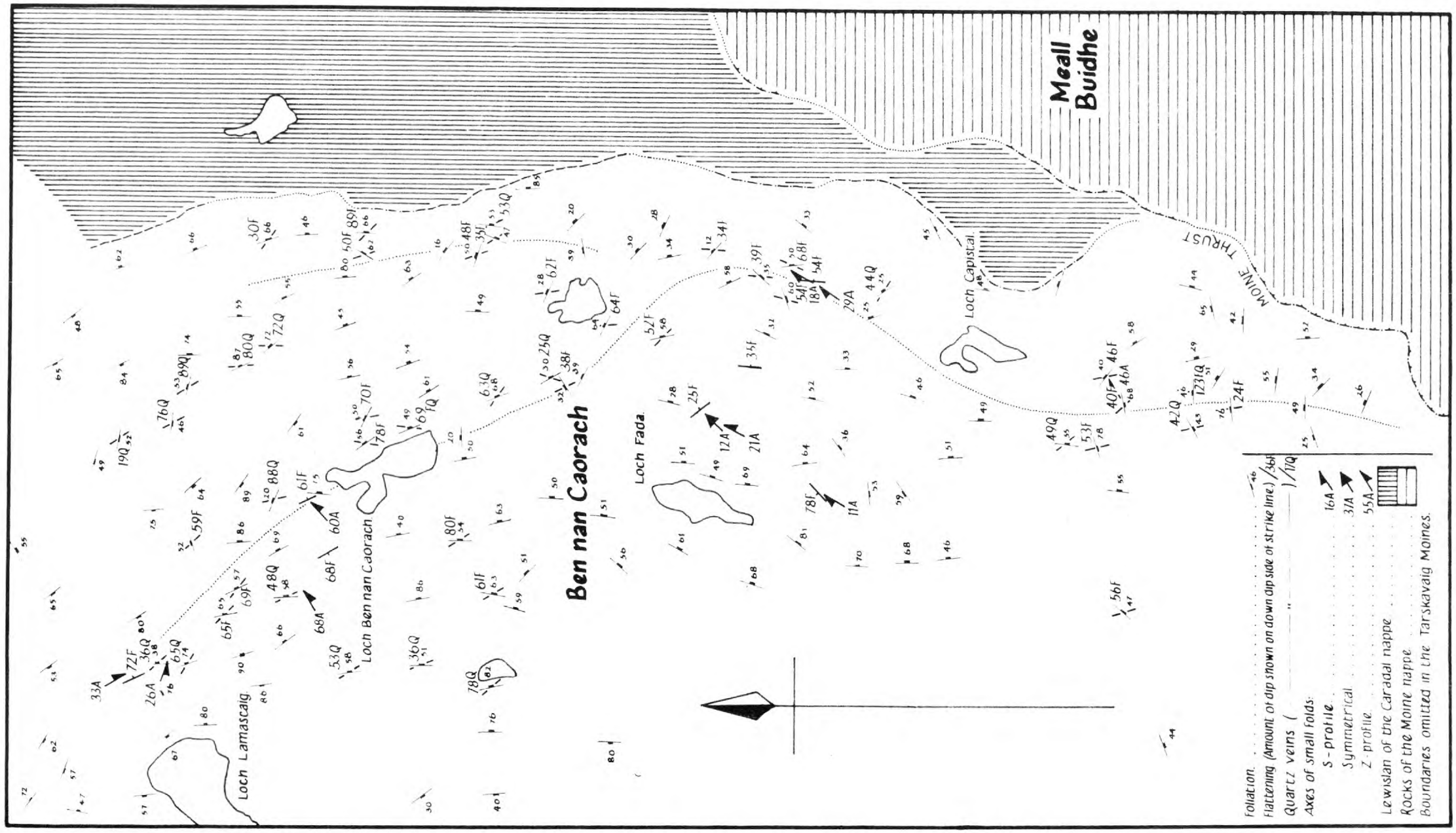
Analysis of the Capistal antiform.

Figure 10.2

EXPLANATION OF FIGURE 10.3.

Map of the area near Ben nan Caorach, about three miles WSW of Ardvasar. Different members of the Tarskavaig Moine succession are not distinguished on the map. The long and short dotted lines within the area of outcrop of the Tarskavaig Moine rocks are the axial traces of the Capistal antiform and synform respectively. Suffices A, F and Q following some of the observations denote small fold axes, planes of flattening, and measurements of flat quartz veins.

The delineation of the traces of the major folds depends largely on considerations of the relation of the foliation to the quartz veins and the flattening.



Capistal structures

in the Ben nan Caorach district.

Scale: 1:10,560 or 6ins. to one mile.

Figure 10.3

The folds belonging to this group are very easily distinguished from those of the Capistal group on the basis of the three criteria: size, type of rock in which they occur, and relations to the elongation lineation.

Photographs of profiles of a selection of the Doire na h-Achlais folds are presented in figure 11.1. Their size, as measured in terms of wavelength and amplitude, is clearly very much smaller than that of the small Capistal folds illustrated in figure 10.1 which are typical members of their group.

The rocks in which the Doire na h-Achlais folds are best developed are of very fine grain size. Apart from uncommon feldspars, possibly in augen, the mineral grains of these rocks cannot be resolved with a hand lens. The foliation planes follow very smooth, liquid curves giving the rock as a whole what Clough would probably have called an unctuous appearance. The mineral bands which are deformed by the folds are never more than about 3-4cms thick. In the Tarskavaig Moine rocks these bands are off-white or cream coloured and are set in a host rock of semi-pelitic composition that is coloured pale-green or various hues of grey. The corresponding Lewisian rocks contain pink, quartzo-feldspathic bands in pale of mid-green basic rocks. In the semi-pelitic members of the Tarskavaig Moines and in the basic members of the Lewisian a cleavage is developed which is parallel to the axial planes of the Doire na h-Achlais folds. The parting planes of this cleavage are very closely spaced; there being several to the millimetre.

In the field a complete gradation can be seen in some properties between the Tarskavaig Moine rocks described in the previous paragraph and the coarse grained members of the Lower Psammite and Laidhe na greine group. The properties referred to are: the degree of development of the elongation lineation; grain size of the rocks as a result of deformation and spacing of the cleavage planes associated with the Doire na h-Achlais folds. The strong elongation lineation in the coarse psammites can be traced in a weakened form into the mylonised rocks in which the Doire na h-Achlais folds are so common. This elongation lineation passes obliquely over the hinges of the Doire na h-Achlais folds thus demonstrating the age relations of the Doire na h-Achlais and Capistal groups of structures.

The distribution of the Doire na h-Achlais folds and their axial plane cleavage is shown in the map of figure 11.2. The cleavage is always anticlockwise to the foliation. The folds are only abundantly developed within about 50yds of the junction of the Tarskavaig Moine rocks with the Lewisian. In the remainder of the outcrop of the Lewisian rocks they are fairly common and tend to have a tighter profile and a more angular hinge as shown by the folds illustrated in figure 11.1(a). Where such folds are absent in the Lewisian rocks of the Caradal nappe it is only rarely possible to distinguish the cleavage from the foliation and it would seem that these two structures are practically parallel. A series of exposures where a distinction is possible between the foliation and the cleavage are to be found in some low crags 1,200yds NE of Loch Lamascaig. Another isolated

exposure is situated 100yds SW of the southern tip of the un-named loch 900yds ENE of Loch Ben nan Caorach.

In the Tarskavaig Moine rocks no Doire na h-Achlais folds have been found to occur more than about 150yds from the nearest exposure of Lewisian rocks. The cleavage too, is not nearly so commonly, or so well developed in the Tarskavaig Moine rocks away from the junction with the Lewisian. Thus, although the cleavage planes are very closely spaced near to the Lewisian junction, the exposures in the high crags 300yds east of the northern tip of Loch Lamascaig show cleavage planes of the same generation in semi-pelitic rocks which are spaced at intervals of 2-3mms. Similar widely spaced cleavage planes can be seen in the semi-pelitic members of the Laidhe na greine group to the south and east of Loch Fada. In short, the spacing between the cleavage planes seems to bear a direct relation to the distance from the junction of the Tarskavaig Moine rocks with the Lewisian.

EXPLANATION OF FIGURE 11.1.

(a) Small folds in mylonised Lewisian gneiss 200yds east of the southern tip of the un-named loch 750yds ENE of Loch Ben nan Caorach.

(b-e) Folds in mylonised Tarskavaig Moine rocks 650yds NE of the Loch Ben nan Caorach outlet.



a)



b)



c)



d)



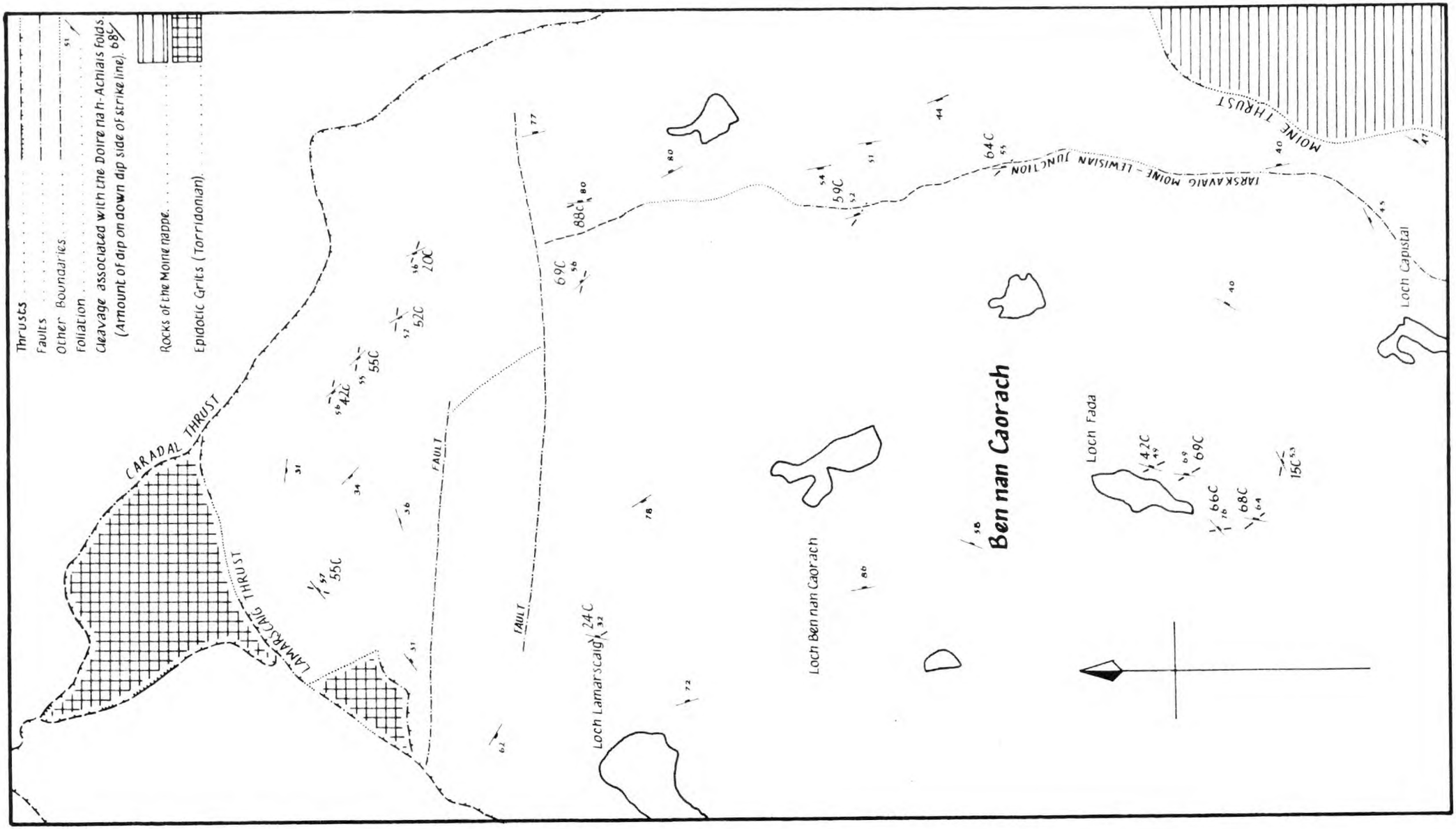
e)

Profiles of
Doire
na-h-Achlais
folds

Figure 11.1

EXPLANATION OF FIGURE 11.2.

Map of the district from Loch Capistal to the outcrops of the Epidotic Grit showing the orientation of the axial plane cleavage of the Doire na h-Achlais folds in relation to the foliation. In the Caradal nappe neither the Lewisian nor the Tarskavaig Moine rocks are ornamented.



Axial plane cleavage of Doire na h-Achlais folds.

Scale 1:10,560 or 6 ins. to one mile.

Figure 11.2

Size is the dominating feature of the large Caradal folds. In terms of wavelength and amplitude they are easily the biggest folds in the Caradal nappe and they clearly dictate the line of outcrop of the Caradal thrust as shown in figure 12.2(a). Clough was aware of this fact when he said (see page 4 of the Introduction) in reference to the Tarskavaig, Caradal and Lamarscaig thrusts: "These three thrusts have been folded into synclines striking towards the north-east. The axis of the Loch Lamarscaig thrust...(see figure 0.4)...runs some distance to the south-east of those of the others,..." By the word "axis" he seems to mean the term "axial trace" of modern usage and, although he does not specifically say so, he thus implied in the latter sentence that he recognised that the rocks that lay on top of the Lamascaig thrust have been folded as well as the thrust itself.

Thus Clough seems to have possessed a clear concept of the structure that, in this thesis, is called the Caradal synform, but his communication of this concept was by no means complete. In fact his section, reproduced as figure 0.3, tends to confuse rather than clarify his ideas since it shows several seemingly hypothetical folds for which there is no field evidence and which Clough does not explain in his text.

The first clear recognition of the Caradal synform is probably that due to John Murray who, while engaged in an undergraduate excursion, was able to map part of the trace of the Caradal synform in the neighbourhood of Sgurran Seilich and Creag Mhor.

However, the Caradal synform is probably best demonstrated near Loch an t-Seilich. A traverse in an easterly direction along the south shore of the Loch and up the prominent gully which runs almost due east from the eastern end of the Loch passes through a well rounded hinge zone where there are many exposures of the Upper Psammite in which the bedding is flat lying or dips gently westwards. A much less spectacular hinge zone can be seen in the crags above the footpath that connects the Point of Sleat to the hamlet of Aird of Sleat. The crags are on the north side of the footpath and are situated on the southern slopes of Sgurran Seilich about 400yds SE of the Loch Aruisg outlet. The fold hinge is seen to be very tight here and is probably complicated by faults. A very similar hinge can be seen near the top of Creag Mhor and is depicted in figure 12.1(a). Where the trace of the Caradal synform intersects the southern shore near Leir Mhoadail faults are abundant and in spite of the magnificent cliff exposures the hinge of the fold is completely obscured. Part of the cliff section is shown in figure 12.1(b).

North of Loch Lamascaig the axial trace of the Caradal synform is very difficult to follow. In addition to the Loch Lamascaig thrust many other dislocations are present and the rocks contain abundant folds of the conjugate style as mentioned in Chapter 6. These folds occur on many different scales and completely confuse the regional pattern of the orientation of the bedding in the Upper Psammite. Nevertheless north of Bealach na Ceardaich a large scale synformal fold can be traced and it is thought that this is the continuation of the Caradal synform.

Another fold of the same generation and of comparable dimensions to the Caradal synform occurs in the mylonised Lewisian rocks in the eastern part of the Caradal nappe. The axial trace of this fold is shown in figure 12.2(a). The fold is antiformal and has been called the Caradal antiform. The trace is limited to the south by the Moine thrust which transects the structures of the Caradal nappe and to the north by the Caradal thrust which is the boundary of the area of study. The hinge zone of this fold which, like the Caradal synform is fairly tight in profile, is never clearly displayed. The best indication of any kind of fold turnover is given by the exposures on the southern margin of a large peat bog about 450yds north of the un-named loch which is 900yds ENE of Loch Ben nan Caorach.

A stereographic analysis of the Caradal folds is presented in figure 12.2(b-d). On these diagrams poles to bedding planes in three separate areas are plotted. The data in figure 12.2(b) is from the western limb of the Caradal synform, in figure 12.2(c) from the common, or structurally inverted limb, of the Caradal synform and antiform and in figure 12.2(d) from the eastern limb of the Caradal antiform. The orientation of the bedding planes in the western limb of the Caradal synform and the foliation in the eastern limb of the Caradal antiform are very much the same; a cluster in the NW quadrant with points scattered towards the E, NE, or SE. The cluster is interpreted as reflecting fairly uniformly dipping fold limbs while the scattered points come either from localities close to the hinge zone of from flexures in the limbs which have the same axial direction as the large folds.

The data from the common fold limb are much more scattered than in the previous cases. Although there seems to be a concentration in the NW and W of the diagram this is considerably less well marked than in the previous instances. This distribution does not indicate a gradual change in the orientation of the foliation from one part of the common limb to another and neither does it indicate variations due to the large scale Capistal folds since it is shown in figure 10.2 that the degree of scatter on the two limbs of the Capistal antiform completely maskes any divergence which there may be between the limbs of this fold. The interpretation based on the pattern in figure 12.2(c) is that the scatter is due to random flexures in the common limb on a relatively small scale although small scale folds of the same generation could not be systematically mapped in the field.

The axial planes of the large scale Caradal folds dip at 30-40° to the ESE and the axes plunge at not more than about 10° to the SSW.

The angular distribution of the elongation lineation associated with the Capistal folds is shown in figure 12.2 (e-g) and changes in the regional trend are indicated on Plate 2. The interpretations of the patterns in the projections follows very much the same course as that of the poles to bedding planes. Thus, on the western limb of the Caradal synform and on the eastern limb of the Caradal antiform, observations of the elongation lineation are fairly well concentrated and it seems that any slight variation is due to a mild flexuring of the respective fold limbs. Likewise, on the common limb of the two folds, the angular

distribution of the elongation lineation is governed by random flexures on a relatively small scale.

The pattern of the angular distribution of the elongation lineation associated with the Capistal folds indicates that this lineation has been deformed by the Caradal folds and thus demonstrates their age relations. It was shown in Chapter 11 that the Doire na h-Achlais folds are also later than the elongation lineation so that the only remaining problem requiring solution is the connection between the Caradal folds and the Doire na h-Achlais folds. Figure 11.2 provides the necessary information. The map demonstrates that the axial plane cleavage of the Doire na h-Achlais folds shows changes in strike and dip which consistently follow the changes in dip and strike of the foliation that define the Caradal folds. In short, the Caradal folds are later than the Doire na h-Achlais folds.

Small scale folds which can definitely be correlated with the Caradal antiform and synform are unknown. However, in the sea cliffs below Creag Mhor small scale folds are present in the Upper Psammite whose orientation suggests that they may well possess a parasitic relationship to the major Caradal folds. They are illustrated in figure 12.3. Over most of this cliff section the rocks are coarse, well bedded psammites with thin parting planes of mid-grey semi-pelitic material. At some horizons these layers of semi-pelitic material reach much greater thickness and may contain thin psammitic bands within them. In such rocks the small scale folds are best developed and they may be accompanied by a widely spaced fracture cleavage which is parallel to

their axial planes. This axial plane cleavage dips to the SE and the axes of the folds are sub-horizontal: these factors suggesting a correlation with the large scale Caradal folds. Apart from these exposures on Creag Mhor similar small scale folds are completely unknown.

EXPLANATION OF FIGURE 12.1.

(a) A photograph of the rocks of the Upper Psammite in the hinge zone of the Caradal synform near the summit of Creag Mhor. The scale can be judged by the ruck-sack in the foreground resting on rocks in the structurally un-inverted limb of the synform. Most of the rocks in the background are in the structurally inverted limb and small, angular folds of the conjugate style are common.

(b) Rocks in the hinge zone of the Caradal synform at the southern extremity of Leir Mhaodail. The fold is totally obscured by faults and, but for the evidence seen elsewhere, might easily pass un-noticed. The scale is again given by the ruck-sack which stands immediately in front of a dark-coloured Tertiary dyke.

Hinge zone of the Caradal synform.

(a

(b

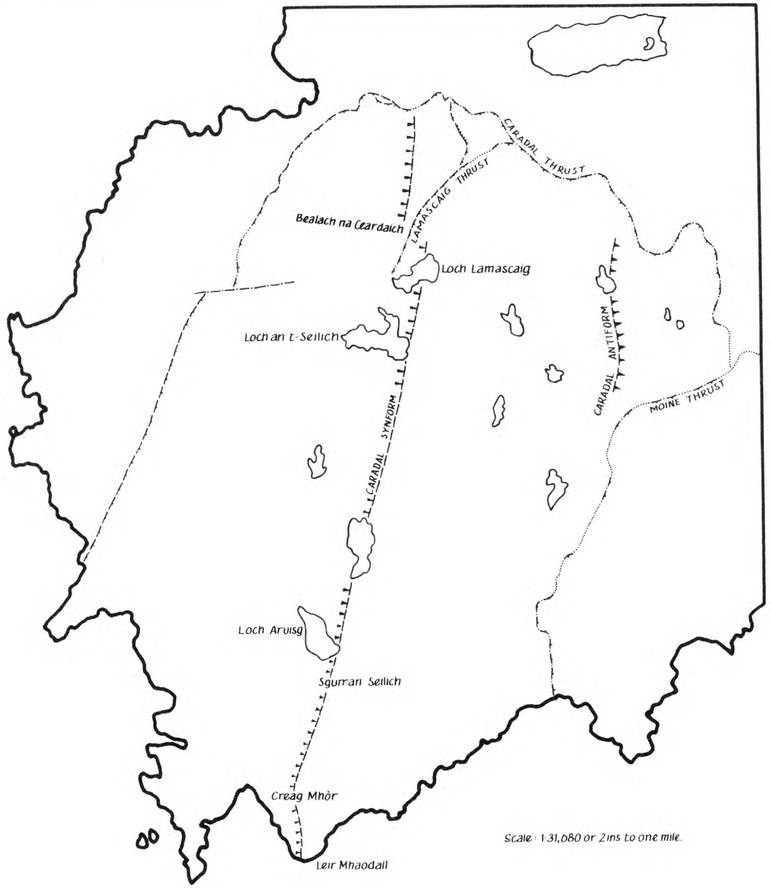
Figure 12.1

EXPLANATION OF FIGURE 12.2.

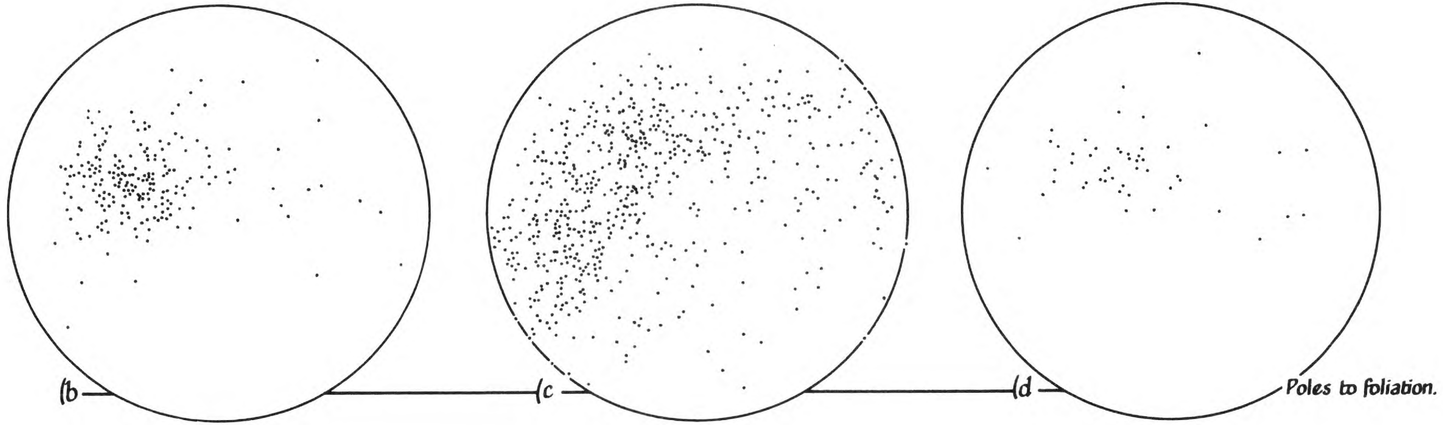
(a) A map showing the axial traces of the Caradal antiform and synform and the names of the localities mentioned in the text.

(b-d) Stereograms showing the angular distribution of the poles to bedding planes on the west limb of the Caradal synform, the common limb of the two folds, and the east limb of the Caradal antiform.

(e-g) Stereograms showing the angular distribution of the elongation lineation on the same three fold limbs.



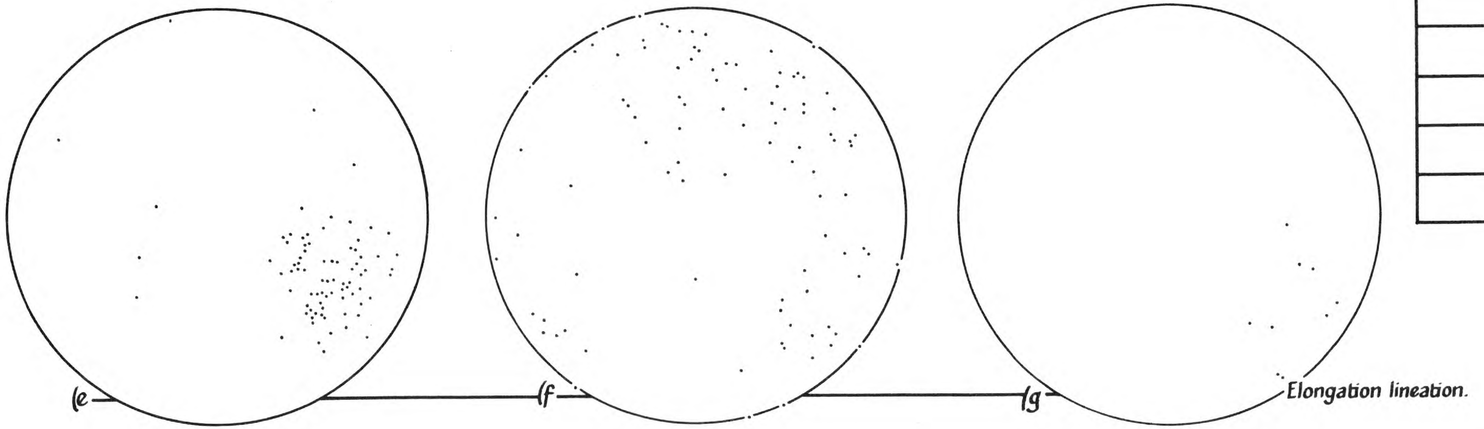
a) Axial traces of Caradal folds in the Caradal nappe.



West limb of the Caradal synform.

The common limb.

East limb of the Caradal antiform.



Analysis of the Caradal folds

Figure 12.

EXPLANATION OF FIGURE 12.3.

(a) Profile of a small fold 300yds west of the summit of Creag Mhor. The rocks belong to the Upper Psammite. An axial plane cleavage is well developed in the semi-pelitic rocks.

(b) Small folds about 350yds south of the summit of Creag Mhor. The alternating bands of pink or buff coloured psammite and mid-grey semi-pelite belong to the Upper Psammite.

Small folds on Creag Mhòr

(a)

(b)

Figure 12.3

OF DUBIOUS OR UNKNOWN GROUPING.

Taking into account the conjugate folds which are described in Chapter 6 the folds in the Caradal nappe have been classified into four groups. In comparison with the seven groups of folds in the Moine nappe therefore, the problem of classifying any individual fold in the Caradal nappe is correspondingly smaller than in the Moine nappe because there are fewer classes which it may occupy. For this reason the number of folds of dubious or unknown grouping in the Caradal nappe is necessarily smaller than in the Moine nappe. Not only this but the four groups of folds in the Caradal nappe occur in distinctly different relationships to the lineation, the quartz veins and the cleavages; a factor which also eases the problems of classification.

Most of these folds which cannot be grouped confidently are shallow in profile. The largest are two in number and can be seen approximately 900yds SW of Loch Aruisg in the exposures on the hill above the north side of the footpath that connects Aird of Sleat and Point of Sleat. The distance between the axial traces of these two folds is a little over 100yds, the synformal trace laying to the west of the antiformal trace. These flexures are clearly later than the elongation lineation associated with the Capistal folds and can hardly be classified with the Doire na h-Achlais folds on account of their size. It is possible, however, that they may be contemporaneous with the Caradal folds: in which respect it can be noted that their profile would agree with a parasitic position on the structurally un-inverted limb of the Caradal synform.

Further examples of even shallower flexures are to be found in the rocks of the Upper Psammite west of Loch Ben nan Caorach. One pair, consisting of an antiformal and a synformal flexure, occurs 300yds SW of the outlet to the Loch while another pair occur 450yds WSW of the same outlet. Both examples are on the same scale which is smaller than the folds described in the previous paragraph but are sufficiently large to encompass exposures over a distance of 100yds. In both cases the flexuring post-dates the Capistal fold movements since the elongation lineation is deformed and a correlation with the Doire na h-Achlais folds is extremely questionable on account of the great differences in their respective sizes and profiles. A correlation with the Caradal folds is dubious because of the fact that, at both localities, the synformal trace lies to the west of the antiformal trace and the folds do not, therefore, show a parasitic relation to the major Caradal folds.

Other flexures of a similar nature but occuring only as a single antiform or synform are to be found in the Lower Psammite 500yds NNW of the Loch Ben nan Caorach outlet, in the Laidhe na greine group 800yds NNW of the same outlet, and in the Upper Psammite 450yds NE of the summit of Sgurrah Seilich. All three examples are later than the elongation lineation associated with the Capistal folds but their relation either to the Doire na h-Achlais folds or the Caradal folds is completely unknown. Such flexures are very rare and no great weight is attached to their presence.

LOCATIONS IN THE CARADAL NAPPE.

This Chapter sets out to present a description of the dislocations which define what Bailey called the Caradal nappe and the dislocations which disrupt the rocks that it contains. Conclusions are drawn about the character and also the relative ages and importance of these dislocations which are considerably at variance with the concepts of Clough and Bailey. This re-interpretation involved the introduction of a nomenclature which is different from that of both Clough and Bailey. The names that they applied are shown in figure 0.4 in the Introduction while the revised nomenclature resulting from the present study is shown in figure 14.2. In order to avoid confusion in the discussion of these planes of dislocation the convention is adopted of qualifying the name of the dislocation with the name of the geologist whose definition is implied. Thus, in respect of one of these dislocation, the names Lamarscaig thrust (Clough), Lamarscaig thrust (Bailey) and Lamascaig fault (Cheeney) will be used according to the definition which is under discussion.

The dislocations which have been recognised in the present work are broadly classified into three groups; thrusts, faults and slides. No exact boundary can be defined between thrust and faults but the concepts adopted here are as follows.

Thrusts are characterised by a distinct metamorphic break. The rocks on one side of the thrust plane have been modified to a much greater extent by processes of deformation and metamorphism. On this side of the thrust plane the

dominant foliation in the rocks is parallel, or very nearly parallel, to the thrust plane and there is also a conformity between the thrust plane and zones of rock which are characterised by groups of folds and by states of regional and dislocation metamorphism. All of these concepts are admirably illustrated by the rocks of the Moine nappe in relation to the Moine thrust. In this case zones parallel to the Moine thrust can be defined, each of which is characterised not only by remarkably different states of metamorphism but also by different groups of folds such as the Port a'Chuil folds, the Ard Thurinish folds, etc.

Faults separate rocks of the same or of different metamorphic states and they may also be concordant or discordant to the foliation in these rocks. On the basis of these criteria, therefore, some faults may resemble thrusts as outlined above. They can be distinguished, however, in that they are discordant to the zones which are characterised firstly by groups of folds and secondly by different states of regional or dislocation metamorphism.

Slides, as defined for the purpose of the present work, are associated with flexure during folding. They are curved surfaces of movement which follow the junctions between rocks of different lithology or competence. They arise when a layered sequence of rocks buckles under the influence of stress such that the mode of deformation involves flexure.

The Caradal thrust (Bailey) can be clearly mapped over most of its length of outcrop and along the western margin of the Caradal nappe it is very well defined. Between Geur Rudha and Bealach Garbh the Caradal thrust (Bailey) is marked

by long lines of SE dipping rock faces which are almost perfectly flat. A stereoscopic view of some of these rock faces is shown in the photographs of figure 14.3. This is a view from a point about one mile NNE of Geur Rudha and faces NNE. Beyond the earth wall in the left foreground the flat surfaces defining the thrust can be seen in shadow dipping to the right. They can be traced as a long straight feature on the left side of a flat bottomed valley which recedes into the distance for nearly three-quarter miles. Between Bealach Garbh and the largest outcrop of Torridonian Epidotic Grit the Caradal thrust (Bailey) crosses several deep NW valleys. It is not well exposed in the valley floors but in most cases it can be clearly demonstrated on the intervening spurs. One such exposure is situated 200yds SSW of the old footbridge which crosses Allt a'Ghlinne at a sharp bend some 450yds from the sea. The surface of an exposure in coarse psammite makes an almost perfect plane dipping SE. This surface does not show the characteristic features of a bedding plane and it is concluded that it represents the Caradal thrust or some subsidiary plane parallel to this. An undercut feature occurs at the bottom of a small crag about 10yds to the SE and is unpleasantly contaminated by sheep. However, an igneous rock can be discerned here which has been intruded into a pale-green, fine-grained rock with closely spaced parting planes. This rock contains abundant cubes of pyrite and several irregularly shaped quartz or quartzo-feldspathic viens. Only one margin of the igneous body is exposed. This is a plane surface dipping to the SE and is concordant with the parting planes in the green rock.

The green rock lies above the igneous rock. The igneous rock is pinkish-grey on the weathered surface and contains large, brick-red phenocrysts in a fine-grained groundmass. It would appear that the igneous body has been intruded along the plane of the Caradal thrust (Bailey). The green rock may be a thermally metamorphosed derivative of granulated Epidotic Grit or Tarskavaig Moine rock of the Laidhe na greine group. It is, however, rather different in appearance from the Lewisian mylonite.

Along the northern boundary of the largest Torridonian outcrop the thrust is exposed at a number of places. One of these is illustrated in figure 14.4(b). Igneous rocks similar to those described above can also be found in these exposures. However, further to the SE the thrust is exposed at only four localities before the outcrop of the Moine thrust is reached and three of these are very close together as figure 14.1 shows.

The Lamarscaig thrust (Bailey), like the Caradal thrust (Bailey) along the western margin of the Caradal nappe, is exposed as a line of flat surfaces in the Upper Psammite which dip to the SE. In this form it can be traced from a point a few yards NNE of the Loch Lamascaig outlet as far as the southern tip of the largest Torridonian outcrop. Between here and the junction with the Caradal thrust (Bailey)it is indistinct apart from some excellent exposures in the bed of the stream close to where the two thrusts meet.

The three outcrops of the Torridonian Epidotic Grit, which Bailey (1955) conveniently called the main, western and southern outcrops, are all separated from the surrounding rocks

by dislocations. In the case of the western outcrop the rocks are well exposed but the junctions between the Epidotic Grit and the surrounding Tarskavaig Moine rocks are not revealed. Nevertheless, sharp lines can be drawn which separate the two groups of rock and the elongation lineation that characterises the Tarskavaig Moines is quite absent from the Epidotic Grits; a fact which indicates at once some distinction in the metamorphic grade of the two groups of rocks.

The southern outcrop is clearly separated from the underlying Upper Psammite by the Lamarscaig thrust (Bailey) but its junction with the overlying Lewisian mylonites is very indistinct although the rocks are fairly well exposed. The Epidotic Grit appears to have been more highly deformed than elsewhere and the grey and green Lewisian mylonites are somewhat brecciated. In these states the two groups of rocks tend towards the same appearanee so that a hard and fast boundary cannot be drawn in the field. Nevertheless, the metamorphic states of the two groups away from the junction gives every indication that a thrust intervenes between them: coarse, angular fragments of sedimentary origin can be recognised in the Epidotic Grit while the Lewisian mylonites show a very fine and uniform grain size and contain an elongation lineation.

In connection with the main outcrop of the Epidotic Grit Clough was in no doubt that this body was separated by dislocations from the Tarskavaig Moines to the north and the Lewisian mylonite to the SE: there being abundant field evidence for these conclusions. He was dubious, however, about the junction with the Tarskavaig Moine rocks to the

south-west. In the "Summary of Progress for 1897" of the Geological Survey Geikie, the Director, wrote (page 35):-

"At the southern end of the chain of observers, Mr. Clough was led to bestow renewed attention to the determination of some of the relations in the peninsula of Sleat at the southern end of the island of Skye. In re-examining part of the ground already surveyed, he obtained evidence that will to some extent modify conlusions which previously seemed fairly deducible from the facts. ..... The grits and associated strata brought forward by the Caradal and Tarskavaig thrusts were not examined microscopically until after the Report for 1896 was written, and the extent to which these rocks have been granulitised was not sufficiently recognised in the field. On further investigation these grits were found to possess a state of crystallisation essentially different from the matrix of the epidotic conglomerate, which occurs here and there near the base of the Caradal rocks. A re-examination of the areas where this conglomerate occurs was therefore made, and it was seen that the largest patch of conglomerate is in reality separated from the Caradal grits and phyllites on all sides by thrusts and crush lines. The epidotic conglomerate is undoubtedly Torridonian, and contains bands exactly like the epidotic grit which lies at the base of this formation between Kylerhea and Loch na Dal. But it must be admitted that the grits and phyllites which surround the conglomerate cannot be shown to be Torridonian. They may be so, but, in Mr. Clough's opinion, it is far from certain that they are."

Bailey (1955 p138) also paid a great deal of attention

to this junction and made the followihg comment:

"It is the western boundary of the main exposure of Epidotic Beds which decieved Clough and later myself. It is steep; and towards the south, it seems to transgress Tarskavaig Moine outcrops. Halfway along it is bare of cover. At one place Epidotic Beds and fine-grained semi-siliceous Tarskavaig Moine are separated by a knife-edge plane, which may easily be interpreted as a fracture. At another, however, the junction is irregular and vague. If, as we must, interpret this junction as the site of a very considerable displacement, we must at the same time admit that the accompanying shearing is very much less conspicuous than it is, say, along the Lamarscaig or Caradal Thrusts."

The "knife-edge plane" to which Bailey refers is almost certainly the same as that shown in figure 14.4(a). The head of the hammer is lodged in the plane of the dislocation which separates the Epidotic Grits in the right from psammites of the Tarskvaig Moines on the left. A measurement of the inclination of the plane recorded close by was 46° and is marked on figure 14.1. Further to the north the inclination of the plane becomes steeper until, near its junction with the Caradal thrust (Bailey), it is almost vertical. To the south of the exposure illustrated in figure 14.4(a) the dislocation becomes progressively less steep; the factor which is mainly responsible for the curving nature of its outcrop. In these exposures at the southern tip of the main outcrop of the Epidotic Grit the bedding in this formation is very nearly concordant to the plane of the dislocation, while

the bedding in the Tarskavaig Moine beneath is distinctly not. At the north-western tip of the same outcrop of Epidotic Grit the reverse is true: the bedding in the Epidotic Grit is discordant whereas that in the Tarskavaig Moines is approximately concordant. Furthermore the plane of the dislocation is not parallel to any well marked zones of folding or metamorphism and the dislocation itself therefore shows all the characters of a fault as outlined earlier in this Chapter.

It is also of interest to apply the criteria of distinction between faults and thrusts to the Caradal thrust (Bailey) and the Lamarscaig thrust (Bailey). In Chapter 11 it was shown that the Doire na h-Achlais folds were confined either to the Lewisian or to the fine-grained Tarskavaig Moine rocks close to the junction with the Lewisian. Furthermore the tightness of the folds increases and the distance between the associated cleavage planes decreases towards the Caradal thrust (Bailey). However, it is very important to note that neither Doire na h-Achlais folds nor associated structures are found adjacent to that part of the Caradal thrust (Bailey) between the easternmost tip of the main outcrop of Epidotic Grit and the sea at Geur Rudha. Even more significant than this is the fact that, during the recent survey of the area, no Lewisian rocks were positively identified on this section of the Caradal thrust (Bailey) as claimed by Clough in Peach et alia (1907). Clough said that "Above the western limb of the Caradal thrust in a few places thin stripes of rock have been noticed which may be regarded as sheared forms of Lewisian gneiss, but they cannot always be confidently separated from the overlying sandy phyllites. The patch of

gneiss shown in the section (reproduced here as figure 0.3) is not more than 200yds long, and no other gneiss can be seen for more than a mile to the south-west." On the contrary the descriptions of the rocks in Chapter 18 show that there are no rocks along this section of the Caradal thrust (Bailey) which are directly comparable to the Lewisian mylonites in the eastern part of the Caradal nappe. The present studies indicate, in fact, that there are several points of difference between that section of the Caradal thrust (Bailey) which lies east of the easternmost tip of the main outcrop of Epidotic Grit and that section which lies west of this point. The differences between these eastern and western sections can be conveniently listed as follows:

1. As stated earlier in this paragraph there are no Doire na h-Achlais structures along the western section whereas they are very common in the rocks along the eastern section of the dislocation.

2. There are coarse grained psammites within a few yards of the western section but all rocks within at least 500yds of the eastern section are mylonised.

3. There are notable discordances between the rocks of the Caradal nappe and the western section of the plane of dislocation in the vicinity of the Torridonian outcrops: on the prominent spur 100yds west of the main outcrop of Epidotic Grit this discordance reaches a very high angle. On the eastern section there is no evidence for major discordances between the foliation in the mylonites and the dislocation.

4. There is no positively identified Lewisian rock lying

on the western section. Rocks with a greenish tint, which might be interpreted as being of Lewisian derivation, are not more than 4m thick. In contact with the eastern section of the dislocation there is a minimum thickness of 350m of rock which has been confidently identified as being of Lewisian derivation. Thus the eastern and western sections of the dislocation that Bailey called the Caradal thrust are fundamentally different. The western section falls within the concept of a fault as outlined at the beginning of this Chapter. The eastern section is very clearly a thrust according to the same concepts. The Lamarscaig thrust (Bailey) is also much closer to the current definition of a fault than to a thrust; it is discordant to the zones of rocks defined by the Doire na h-Achlais folds, it is discordant to the mylonised rocks, there are no rocks lying upon it which bear any resemblance to Lewisian south of the southernmost outcrop of Epidotic Grit, and it is discordant to the Tarskavaig Moine psammites on either side.

Having considerably modified the concepts of Clough and Bailey it becomes important to consider the implications over a wider area than was studied in detail during this work. A number of exposures in the Tarskavaig nappe were examined but no systematic observations were made. However, it was noticed that there are very considerable similarities between the Caradal nappe and the Tarskavaig nappe. The most important of these are:

1. All the rock groups of the Caradal nappe are represented in the Tarskavaig nappe.

2. All of the groups of structures which have been des-

cribed from the Caradal nappe have equivalents in the Tarskavaig nappe.

3. Lewisian and Tarskavaig Moine rocks close to the Tarskavaig thrust (Clough) are mylonised and contain structures which are indistinguishable from the Doire na h-Achlais structures of the Caradal nappe.

4. The rocks of the Tarskavaig nappe are folded by a major synform which has the same attitude and scale as the Caradal synform and which shows the same relations to the small scale structures. A correlation of these two major folds in time is suggested.

The zone of mylonised rocks close to the Tarskavaig thrust (Clough) which contains Doire na h-Achlais structures are directly comparable with the same rocks in the Caradal nappe. It is postulated, therefore, that these zones of rocks in the two nappes were once continuous and thus the thrust upon which they are lying must also have once been in continuity. The Tarskavaig thrust (Clough), by inference, is a continuation of the eastern section of the Caradal thrust (Bailey); and the western section of the Caradal thrust (Bailey) together with the Lamarscaig thrust (Bailey) are faults which disrupt the zone of mylonised rocks and the thrusts upon which it lays.

The interpretation presented above is fundamentally different from that proposed by Clough and Bailey. They thought that as the rocks of the Caradal nappe travelled forward on the Caradal thrust (Bailey) the rocks of the Tarskavaig nappe and the Tarskavaig thrust (Clough) became folded. The rocks of the Caradal nappe were then folded by the Moine nappe advancing on the Moine thrust.

Thus it becomes necessary to propose a system of nomenclature which is consistent with the new concepts introduced in this thesis. This revised nomenclature is presented in figure 14.2. The Tarskavaig thrust (Clough) is extended to embrace the eastern section of the Caradal thrust (Bailey). The western section of the Caradal thrust (Bailey) is now called the Caradal fault and the Lamarscaig thrust (Bailey) becomes the Lamascaig fault. The dislocation along the western boundary of the main outcrop of Epidotic Grit is called the Lower Lamascaig fault.

The major synform which folds the rocks of the Tarskavaig nappe is thought to be of the same generation as the Caradal synform and can be conveniently called the Tarskavaig synform. The distribution of the Torridonian outcrops and the displacement of the Tarskavaig thrust (Cheeney) suggest that the Lamascaig fault is of the reverse type and so also must be the Caradal fault. The Tarskavaig synform cannot, therefore, be the same fold as the Caradal synform since the faults are less steeply inclined than the axial planes of the folds. Thus there must be an antiform between the two synforms. This antiform is probably, in the most part, obscured by the Caradal fault which may follow its hinge zone. The displacements along the faults may well have occurred in association with the movements which gave rise to the Caradal generation of folds as, in the Caradal nappe, the Caradal folds show a dominantly flexural mode of deformation with which disruption of the strata is often associated. It would also be during this phase in the structural history of the Caradal nappe that the Torridonian rocks became separated from their stratigraphical

neighbours and took their present position.

All of the Tarskavaig Moine rocks are, therefore, bounded by one thrust, the Tarskavaig thrust (Cheeney), This thrust is associated with, but is later than, a zone of mylonites which contain a unique group of folds, the Doire na h-Achlais folds. All of the Tarskavaig Moine rocks should be considered as belonging to one thrust slice or nappe, not two as Clough and Bailey proposed. It seems most convenient to call this the Tarskavaig nappe and to discard the name Caradal nappe altogether. But, for the convenience of presentation in the current work, these two divisions of the Tarskavaig thrust slice will be retained.

There is one large scale representative of the type of dislocation classified as a slide in the area of study. It is apparently associated with the Caradal synform and separates the Upper Psammite from the Laidhe na greine group on the common limb between the Caradal synform and antiform.

This dislocation is best exposed at the southern tip of Loch Fada. Here it is a clean-cut plane dipping at 45-55° to the ESE and occurs entirely within the Laidhe na greine group. To the south of Loch Fada it can be traced over a distance of about 200yds but is then lost in poorly exposed ground. The same dislocation emerges from Loch Fada at a point mid-way along the western shore where it sharply defines the boundary between the Upper Psammite and the Laidhe na greine group. The latter rocks, consisting of semi-pelites with thin beds of psammite, are strongly distorted by folds of the conjugate style, some of which are illustrated in figure 6.1(d). It is possible that these folds may be associated

with the movements on the slide. The slide follows a NNE direction from Loch Fada past the summit of Ben nan Caorach until intersecting an ENE fault about 100yds NE of the same summit. The outcrop of the slide is displaced a distance of 150yds towards the east by this fault. Northwards from this point the rocks near the slide are not well-exposed but a prominent topographical feature suggests that the slide, in this area, is still an important line of dislocation. As explained previously, it is possible to interpret this slide as an accommodation structure which arose in response to flexuring during the Caradal period of folding.

Other dislocations in the Caradal nappe are relatively un-important. On the coastal section west of Port a'Chuil a number of low angle dislocations can be seen in the rocks of the Laidhe na greine group below the Moine thrust. These dislocations are clearly later than the Port a'Chuil folds which they disrupt. Examples of two such dislocations are shown in figure 14.4(c). One prominent plane is in the middle of the photograph while the other is near the bottom and is marked by the head of the hammer.

Near-vertical faults are common in the rocks of the Caradal nappe and are prominently displayed on aerial photographs of the region. They are developed along NW-SE and W-E trends. Their age relations are displayed by an igneous sheet just outside the area of detailed study. This sheet is situated on the west shore of the peninsula of Sleat near to the headland called Rudha Charn nan Cearc. It is of basic composition and is divided by joints into near-vertical columns. The sheet dips gently to the west and rest upon a

conglomerate 1-2m thick. The pebbles of this conglomerate are large and very well rounded. They are composed of representatives of the Cambrian dolomite and quartzite, exposed at Ord, a few miles to the NE of Tarskavaig; dark reddish-brown and chocolate coloured Torridonian grits and sandstones; and Tarskavaig Moine psammites. This conglomerate lays unconformably on the psammites of the Tarskavaig nappe. The sheet of igneous rock is probably the lowermost lava flow from the Skye Tertiary centre in this part of the Island and is cut by faults and dykes on the NW-SE trend. Two faults on the W-E trend in the Tarskavaig Moine rocks are, however, unconformably overlain by the conglomerate and the Tertiary lava. The inference drawn, therefore, is that the faults on the NW-SE trend are associated with the swarm of Tertiary dykes which pass through the area of study whereas the faults on the W-E trend are earlier than the conglomerate and lava. These W-E faults are later than the Caradal folds but their connection, if any, with the system of faults in the Moine nappe described in Chapter 8 is not known. Their relation to the Moine thrust is also unknown.

EXPLANATION OF FIGURE 14.1.

A map showing the direction and amount of dip of the dislocations in the Caradal nappe and the approximate distribution of mylonised Tarskavaig Moine and Lewisian rocks.

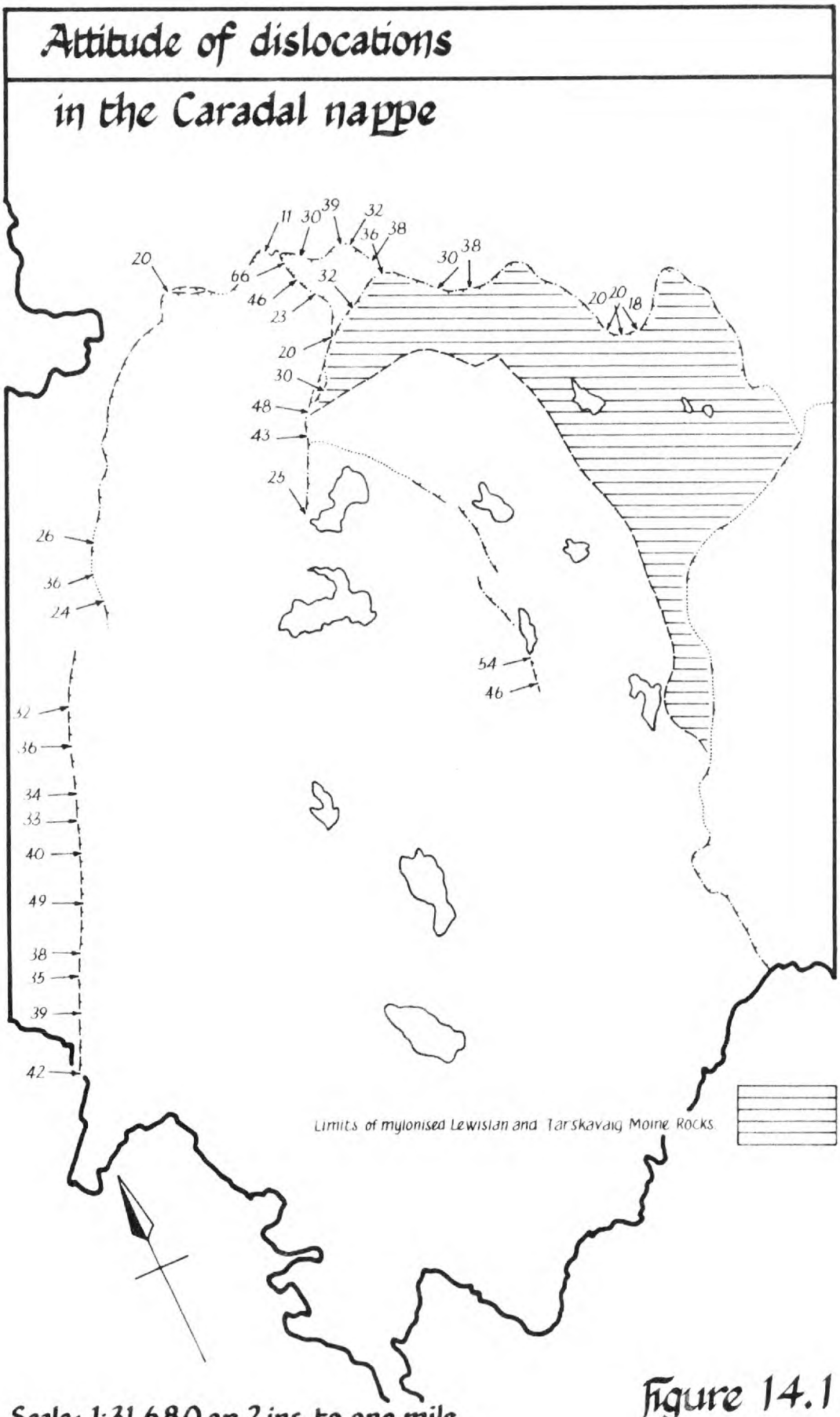
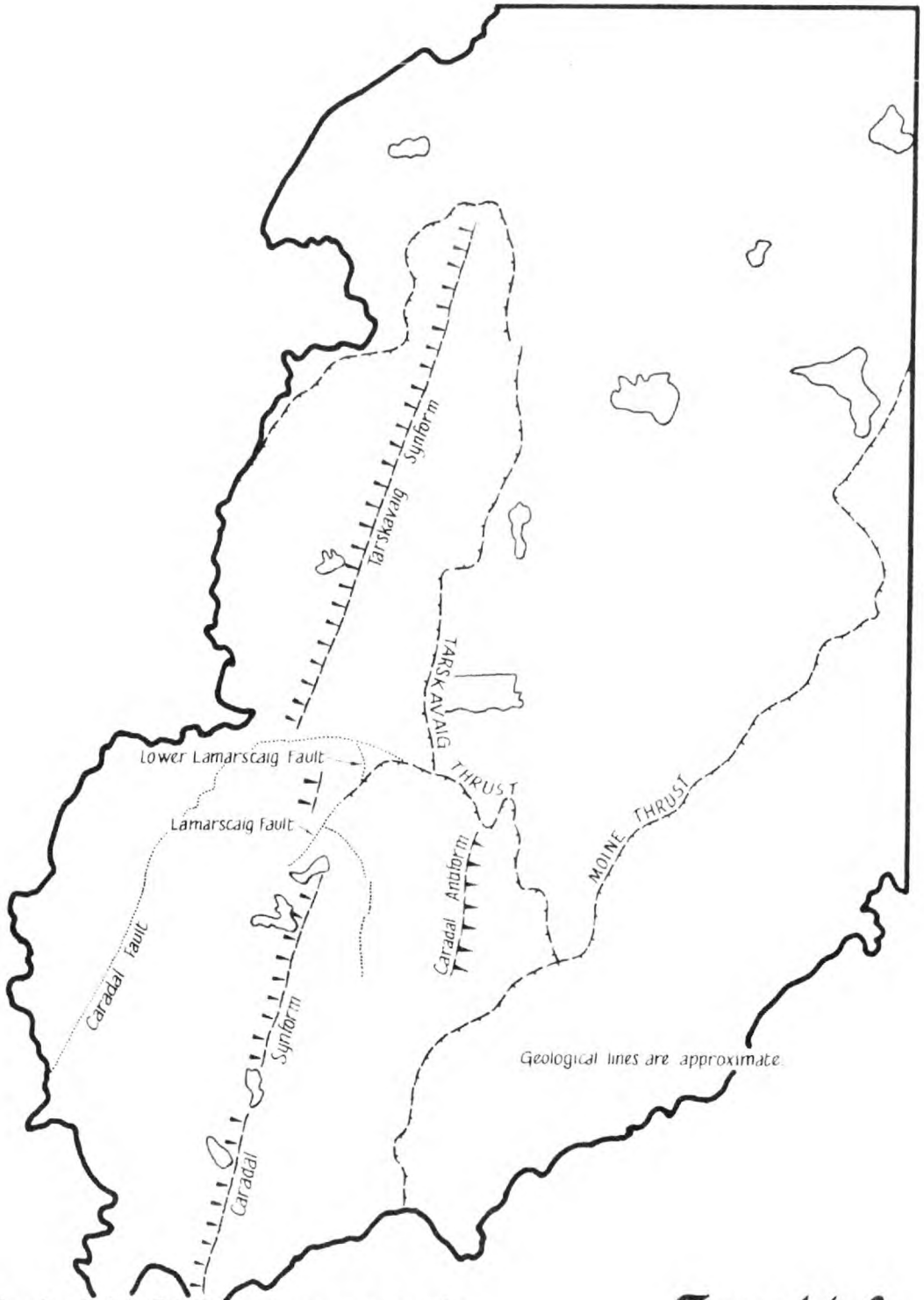

Attitude of dislocations
in the Caradal nappe
11 30 39 32 36 38
30 38
20
66
46
23
32
20 20 18
20
30
48
43
25
26
36
24
54
46
32
36
34
33
40
49
38
35
39
42
Limits of mylonised Lewisian and Tarskavaig Moine Rocks.
Scale: 1:31,680 or 2 ins to one mile.

Figure 14.1

EXPLANATION OF FIGURE 14.2.

A map showing the revised nomenclature suggested for some of the major dislocations in the Sleat of Skye. Note that the line of the axial trace of the Tarskavaig synform is largely conjectural.

Revised nomenclature of the dislocations



Scale: 1:63,360 or 1in to one mile.

Figure 14.2

EXPLANATION OF FIGURE 14.3.

A stereoscopic view in a northerly direction along the line of the Caradal fault from a point about one mile NNE of Geur Rudha. The fault plane can be seen in the foreground on the left side, just beyond the earth wall, and defines the left side of the valley which recedes for three-quarters of a mile into the distance. The rocks in the exposure on the right side of the picture belong to the Laidhe na greine group. They are semi-pelites and coarse and fine grained psammites and are partially brecciated.



Stereoscopic view
of the Caradal fault

Figure 14.3

EXPLANATION OF FIGURE 14.4.

(a) The Lower Lamascaig fault 200yds south of its junction with the Caradal fault. The head of the hammer is lodged in the fault plane; the rocks on the right belong to the main outcrop of the Epidotic Grit; those on the left to the Laidhe na greine group of the Tarskavaig Moine series. At this locality brecciation appears to be confined to a zone no more than 3cms wide but further to the south and to the north the zone of brecciation appears to be 10-20cms wide.

(b) The Caradal fault 150yds SE of its junction with the Lamascaig fault. The overhanging rocks belong to the Epidotic Grit and are lying on an igneous rock cut by an irregular joint system. The igneous rock is pinkish-grey on the weathered surface and contains large brick-red phenocrysts in a fine-grained groundmass. The scale can be judged by the icicles, the longest of which is about 33cms.

(c) A low angled dislocation in the rocks of the Laidhe na greine group. The location is in the coastal section 200yds WSW of the Aird of Sleat Schoolhouse.

a)

b)

c)

Dislocations in the Caradal nappe

Figure 14.4

OF THE CARADAL NAPPE.

The rocks of the Caradal nappe are classified as Tarskavaig Moine, Lewisian or Torridonian. The Tarskavaig Moine rocks are further sub-divided into the Upper and Lower Psammites and the Laidhe na greine group between these two. This latter group is composed of thinly interbedded psammites, semi-pelites and pelites. The Lewisian rocks are mylonised and pass from thinly interlaminated pink and green rocks in the east of the outcrop to grey rocks in the NW which are hardly distinguishable from rhyolites in the hand specimen. The Torridonian rocks belong to the basal Epidotic Grit and contain angular detrital fragments and pebbles. They are separated from the surrounding Tarskavaig Moines by dislocations on all sides.

The psammitic members of the Tarskavaig Moine rocks possess a very strong elongation lineation. The variations in direction and plunge of this lineation are shown in Plate 2. The constituent grains of these psammites are often seen to be flattened as well as being elongated. Most commonly this flattening is parallel to the foliation but within the outcrop of the Lower Psammite there are many exposures where the flattening is clearly oblique to the foliation. Less commonly small folds can be found and in such exposures the flattening can be seen to be parallel to their axial planes and the elongation lineation parallel to their axes. Such exposures demonstrate a clear correlation between the elongation, the flattening and the folds and thus these three types of structure have been classified together in the Capistal group. The Capistal group of structures is the

earliest that is recognisable in the rocks of the Caradal nappe.

A system of quartz veins is common in the psammites. An example of an exposure in which these are well developed is illustrated in figure 10.1(h). The margins of these veins are strongly lineated in a direction parallel to the elongation lineation in the host rock and they are also approximately parallel to the flattening and the axial planes of the Capistal, or first folds. These veins demonstrate (see pages 186-187) that the lineation forming processes outlasted the period of folding.

Two lines can be drawn in the eastern part of the Caradal nappe; they are shown dotted in figure 10.3. Between these two lines the strike of the flattening and the quartz veins is clockwise to the strike of the foliation while in the two remaining areas it is anticlockwise. These two lines, therefore, must represent the axial traces of large scale folds which are of the same generation as the small scale Capistal folds. The westernmost of the two folds is called the Capistal antiform; the eastern fold, the Capistal synform.

The elongation lineation associated with the Capistal, or first folds is less well marked in the Lewisian rocks and is totally absent from the Torridonian Epidotic Grits. All of the Lewisian rocks and a narrow zone of the Tarskavaig Moine rocks in contact with them are in the state of mylonites. The mylonised Tarskavaig Moine rocks grade into recognisable metasediments away from the Lewisian junction. In these mylonised rocks structures of the Doire na h-Achlais,

or second group are fairly common. The elongation lineation associated with the Capistal, or first folds passes over the hinges of the Doire na h-Achlais folds so that the same relations are well established. The Doire na h-Achlais folds are associated with a cleavage which is parallel to their axial planes. This cleavage is developed in the semi-pelitic rocks of the Tarskavaig Moine group and in the basic members of the Lewisian. Over the whole of the area of the Caradal nappe in which these folds are developed the strike of the axial plane cleavage of the folds is anticlockwise to the general strike of the foliation. The spacing between the cleavage planes apparently increases in the Tarskavaig Moine rocks away from the junction with the Lewisian.

Near Loch an t-Seilich a large scale fold can be demonstrated in the rocks of the Upper Psammite. The axial trace of this fold runs to the SSW as is shown in figure 12.2(a) and intersects the coast at Leir Mhaodhail. Figures 10.3 and 11.2 show that variations in the trend of axial plane structures associated with the Capistal, or first, and the Doire na h-Achlais, or second folds follow the same pattern as the variations in the foliation which define this large synform. Both of these groups of structures must, therefore, be earlier. The large scale synform belong to a third group of structures and is called the Caradal synform. Within the area of outcrop of the Lewisian mylonites a corresponding antiform, the Caradal antiform, can also be demonstrated. The axial planes of these large folds dip to the ESE at angles of 40-50°. Small folds associated with the Caradal antiform and synform are not known but fold structures

on Creag Mhor, illustrated in figure 12.3, may be of this generation.

On the common limb between the Caradal synform and antiform there are indications of a dislocation at the boundary of the Upper Psammite and the Laidhe na greine group. This dislocation has been called a slide and is thought to be due to slip during the Caradal, or third period of folding.

The remaining dislocations associated with the Caradal nappe have been interpreted in a manner which differs fundamentally from that of Clough (in Peach et alia, 1907) and Bailey (1955). The Caradal thrust, as defined by Bailey, (see figure 0.4) can be divided into two sections which possess completely different characteristics. These two sections meet at the easternmost tip of the largest outcrop of Epidotic Grit. East of this point all rocks within 500yds of the dislocation are mylonised but to the west coarse grained psammites are found within a few yards of the dislocation. The mylonised rocks along the eastern section contain structures of the Doire na h-Achlais, or second group which are quite absent from the rocks along the western section. There are no discordances between the dislocation and the foliation in the Lewisian mylonites on the eastern section whereas along the western section such discordances are common in the vicinity of the Torridonian outcrops. Finally, and contrary to the opinions of Clough, there is no positively identified Lewisian rock lying on the western section while a thickness of at least 350m of rock on the eastern section has been confidently identified as Lewisian.

These differences between the eastern and western sections

of the dislocation are thought to be sufficiently great for the nomenclature to be altered. The western section shows the characters which are more normally associated with a fault and has thus been called the Caradal fault. The eastern section, on the other hand, is more typically thrust-like. In the Tarskavaig nappe of Bailey (1955) there is a zone of mylonised rock close to the Tarskavaig thrust which is mostly Lewisian but which does contain representatives of the Tarskavaig Moine rocks. These mylonised rocks also contain structures which are identical with the Doire na h-Achlias, or second folds described previously. It is assumed, therefore, that the eastern section of the dislocation in question is an extension of the Tarskavaig thrust which, along with the zone of mylonised rock, has been disrupted by the Caradal fault.

The Lamarscaig thrust of Bailey (1955) also shows features which are considered to be more akin to a fault and has been re-named accordingly. The relation of the Caradal fault and the Lamascaig fault to the Torridonian outcrops suggests that these two dislocations are faults of the reverse type and most probably arose during the Caradal, or third period of folding. If so, then the rocks of the Torridonian outcrops reached their present position only during the third period of folding and not during the development of the thrusts as suggested by Clough and Bailey.

Two more facets of the new interpretation are as follows. Firstly, the rocks of the Tarskavaig nappe of Bailey (1955) are folded in a large scale synform which is almost certainly of the same age as the Caradal synform and its

approximate axial trace is shown in figure 14.2. Because of the relative inclinations of the Caradal fault and the axial planes of the Caradal and Tarskavaig synforms these two folds could not have been in continuity before the movements on the Caradal fault took place. As a result it is concluded that a complementary antiform exists between the two synforms but that this antiform has been largely obscured by the Caradal fault.

The second aspect of the new interpretation is that the Tarskavaig Moine rocks as a whole are more correctly placed in one nappe rather than two as suggested by Bailey (1955) since they are bordered by only one thrust; the Tarskavaig thrust, as shown in figure 14.2. Thus it is suggested in the current work that the name Tarskavaig nappe be applied to the thrust slice in which all of the Tarskavaig Moine rocks lay and that the name Caradal nappe be discarded. However, for convenience in the presentation of this thesis the name Caradal nappe will be retained since detailed study of the rocks of the Tarskavaig nappe of Bailey was not undertaken.

The remaining dislocations in the rocks of the Caradal nappe are all later than the Caradal, or third period of folding. These dislocations are vertical or near vertical faults which can be classified into a NW-SE group and a W-E group. The relations of these faults to a sheet of igneous rock which is thought to be a lava flow from the Tertiary centre in the Cuillins and Red Hills allows the deduction to be made that the NW-SE group of faults are post-lava flow while the W-E group is entirely earlier than the eruption of the flow.

The three Chapters that are included in this Part of the thesis are designed to present an account of the rocks based on field descriptions. They do not constitute a complete petrological account of the rocks within the Moine and Caradal nappes but are intended to provide a connecting link between the conclusions which were drawn in the first two Parts concerning the fold histories of the two nappes and the microscopic studies of Part IV the material for which is drawn from selected thin sections of widely scattered samples.

In the first two Parts, and especially in the case of the Moine nappe, it was noted that there exists a close parallel between the distribution of certain groups of folds and the distribution of rocks in a particular metamorphic condition. These rocks, however, were described only in outline. In the three succeeding Chapters the nature of the different types of rocks will be more sharply defined with the aid of photographs and additional descriptive notes.

Unfortunately such descriptions are rarely inspiring and for this reason a fairly comprehensive summary of this Part will be presented in Chapter 19 which it is hoped will be of use to the more general reader.

The rocks of the Moine nappe are excellently displayed in sections along the shores of the Sound of Sleat and thus by far the greater number of illustrations and descriptions in this Chapter are of rocks in coastal exposures. Elsewhere, the degree of exposure is only tolerably good to the north of Knock Bay and in the ground laying to the south of a line drawn to the west through Tormore. Apart from stream sections, exposures in the remainder of the area of the Moine nappe are very widely scattered.

The Lewisian rocks of the Moine nappe, even without the aid of thin section study, can be seen to show an amazing variety of compositions and metamorphic states far in excess of that indicated by Clough's descriptions (Peach et alia, 1907, p262 et seq) In order to simplify their description, therefore, a classification into three zones will be adopted. It must be emphasised, however, that this classification is purely conventional; there being complete gradation between the rocks in the three zones.

The lines which are chosen to define the three zones are called the Ostaig and Knock lines and their courses are illustrated on Plate 4. In the Lewisian rocks the Ostaig line joins together the westernmost known exposures which contain coarse grained, massive acid gneisses with randomly orientated porphyroblasts of amphibole. The Knock line joins together the easternmost known exposures in which the rocks of basic composition possess a closely spaced, fissile type of parting rather similar to that of slate.

To the north-west of Knock Bay these two lines approach very closely to each other. This ground is, however, very

poorly exposed and it is thought that ideal complete exposure would demonstrate that these two lines more nearly approach a sub-parallel trend.

Following the pattern of Part I, the rocks in the zone east of the Knock line will be described first. These are the rocks that contain the Baravaig, or first and Rudha Phoil, or second groups of folds as well as structures which are attributable to the Tormore, or third group. The rocks laying between the Knock line and the Ostaig line are generally of finer grain size with prominent porphyroblasts. They are more fissile and contain structures which are thought to be of the Baravaig and Tormore groups. In this zone many of the rock types which characterise the zone east of the Knock line are also represented. However, to the west of the Ostaig line such rocks are absent with the exception of some limited outcrops of amphibolitic aspect; the vast majority being very fine grained and completely free of megascopic porphyroblasts. In this zone west of the Ostaig line the folds of the Ard Thurinish group are very common. These folds are of the third or fourth generation.

The general characters of the rocks in the zone to the east of the Knock line are as follows. They are of coarse grain size; most of the constituent minerals can be recognised in the hand specimen with the aid of a magnifying glass. They may be called "massive" in that they do not split very readily along plane parallel to the foliation and are relatively free of joints. They are divisible into three well defined groups which, in terms of outcrop areas, are of distinctly different size. The smallest outcrop area is occupied by

a sheet-like body of ultrabasic gneiss, or serpentine, which is marked on Plate 5. Another, smaller exposure on the other limb of the Knock synform is situated about 450yds west of Loch nan Dubhracan. These ultrabasic gneisses, or serpentines, were the subject of an extended description by Clough (in Peach et alia, 1907, p262 et seq) but since they seem to provide very little evidence in the elucidation of the metamorphic history of the Lewisian rocks they will not be described further here.

The second group is a series of amphibolites which are readily separated from the remainder of the Lewisian complex. Some of the larger of these outcrops are shown on Plate 5. Both these larger outcrops and those of smaller size have sharp boundaries with their neighbours. The third group is by far the most intricate and widespread. These rocks contain a colourful variety of minerals in extremely variable proportions and exhibit numerous different textures. They may possess sharp boundaries or may grade completely from one to the other. They are interbanded on all scales.

This latter and larger group will be described first. Because of the amazing variety which these rocks show this brief description must necessarily give an impression which is far from comprehensive. In order to avoid misconceptions which may well arise from any attempt to generalise on this topic a few selected exposures will be described in detail while remarks of a general nature will be confined to the summary in Chapter 19.

Near the headland which defines the eastern end of Camas Baravaig a lenticle of an almost unique type of amphibolite

is exposed on the foreshore. This lenticular body measures about 2 metres long by about half a metre wide and is composed of a beautiful aggregate of radiating acicular amphibole crystals of an apple-green colour. This amphibolite is enveloped by a thin zone of mid-grey micaceous rock which is 3-4cms thick. Within this envelope and within the nearest centimetre or so of the country rock there are euhedral crystals of translucent pink feldspar up to 5mm across. The country rock itself consists of pink, quartzo-feldspathic layers up to 15cms thick which are separated by very dark green amphibolitic bands up to 3cms thick. The foliation in the country rock follows a streamlined course around the lenticle.

An exposure on the opposite headland of Camas Baravaig consists mostly of pink acid rocks with narrower bands and streaks of greenish-grey basic material. The acid bands are up to 30cms thick and contain layers 1-2mm thick which are rich in biotite set in a groundmass possessing the characteristic yellowish-green colour of fine grained epidote. Larger crystals of almost black biotite up to 2mm across occur in the acid bands. They are scattered uniformly throughout the rock with an apparently random orientation. The basic layers contain very many paper thin streaks very rich in epidote. Very dark biotite is an important constituent and there are layers containing larger crystals of quartz and/or feldspar. These basic layers are discontinuous and commonly pass laterally into very thin lenticles. They are never more than 15cms thick and weather into a curious surface covered with small pits up to 1cm across.

400yds to the SSW there are a number of zoned basic bodies of unusual mineral composition enclosed in acid gneisses. These are again lenticular in shape; the lenticle being of the order of 3 metres long and ½ metre wide. At these widest parts the following zones can be recognised:-

1. In the centre the rocks is made up almost entirely of pale-green fine grained amphibole with disseminated crystals of dark mica becoming more common towards the country rock. Discrete patches consisting of aggregates of dark mica are also found in this central zone. These patches are up to 2cms long.
2. A zone with attractive flakes of dark mica measuring up to 1cm constituting most of the rock. Quartzo-feldspathic material becomes more common towards the outer edge of the zone and pale-green amphibole towards the inner. Large patches of olive-green material are also present and in some cases one cleavage plane may completely cover one of these patches thus suggesting that they are single crystals. If so then they are exceptionally large, being 3-4cms across. They are possibly crystals of a carbonate mineral.
3. The outermost zone consisting mostly of quartz and feldspar with obliquely orientated crystals of dark amphibole and dark mica. Discordant streaks of pale-green material, possibly epidotic, can be seen.

These basic bodies are cut by a number of quartz veins which are also discordant to the foliation in the country rocks.

On the headland at the eastern extremity of the broad

sweep of Knock Bay acid gneisses are much in evidence. On fresh surfaces the foliation is marked by numberless thin laminæ of different tints of pink and pinkish-grey. These laminæ are very smoothly flowing. In one restricted band large rose-pink spots of feldspar up to 5cms in diameter occur in the rock. Small, dark-green crystals of mica traverse the foliation and seem to show a preferred orientation related to the axial planes of nearby folds of the Rudha Phoil or second generation. On foliation surfaces the first lineation can be seen as a parallel arrangement of streaks of quartz.

500yds east of the ruined castle acid and basic rocks have been deformed by folds of unknown generation. The distinction between acid and basic rocks at this locality is very sharp. The acid rocks are composed of little else than quartz and feldspar but the basic rocks have a very unusual composition. They consists of nothing but a bottle-green chloritic mineral which has the "soapy" surface texture of talc. The basic rock is deformed into small, angular folds.

An exposure which provides some of the most important evidence towards the elucidation of the structural and metamorphic history of the Moine nappe is situated about 200yds east of the ruined castle in Knock Bay, immediately above the high water mark. Here, the acid and basic bands alternate and are interleaved on many different scales. The acid rocks consist essentially of quartz and feldspar with fairly common crystals of amphibole measuring as much as 5mm in length. The basic bands are very rich in dark-green crystals of amphibole and small, brownish-red garnets are also visible.

Some folds, belonging to the Rudha Phoil, or second generation, are present in the acid bands of this exposure and are illustrated in figure 2.6(a). In the hinge area and within the limbs of the fold at the top right-hand corner of the exposure the amphibole crystals possess a strong preferred orientation such that their longest axes lay parallel to the axial surface of the fold but are arranged almost perpendicular to its axis. The elongation lineation associated with the Baravaig, or first group of folds passes obliquely over the hinge of the fold in question.

The conclusions to be drawn from this exposure are as follows. The age relations of the folds and the lineation are clearly demonstrated and have been discussed in Chapter 2. The amphibole crystals, which show a porphyroblastic habit, have not been deformed during the Rudha Phoil, or second period of folding since they share a preferred orientation which is independant of the fold of the Rudha Phoil generation. Thus the amphibole crystals have grown after the Rudha Phoil, or second folds had developed. The direction in which the amphiboles are orientated is very similar to that of many other minerals of porphyroblastic habit in the Lewisian and Moine rocks of the Moine nappe and this direction is also parallel to the axes of the Tormore, or third folds. A connection between the orientated amphibole porphyroblasts and the Tormore group of folds is thus suggested.

The amphibole porphyroblasts of the type described above are often very prominent in the pink, quartzo-feldspathic gneisses but they rarely show the preferred orientation which was discussed above. An exposure in which such crystals have no

obvious preferred orientation is illustrated in figure 16.3. This exposure is situated between the Knock line and the Ostaig line but such rocks are more abundant to the east of the Knock line.

The foliation in the rocks immediately below the ruined Knock Castle is smooth and wavy. Bands of acid rock which weather to a pinkish-orange colour predominate over the very dark basic layers. Fresh surfaces of the acid rocks are streaked with pink and dark-grey and contain partings of black mica with flakes up to 1½mm across. Newly exposed surfaces of the basic rock show much dark amphibole in stout crystals and also off-white bands and streaks of quartzo-feldspathic material. Within such quartzo-feldspathic layers clusters of amphibole crystals form radiating aggregates up to 1cm in diameter. The acid and basic layers are interlaminated on many different scales.

100yds SE of the southernmost tip of Loch Baravaig rocks of a composition intermediate between acid and basic are exposed. On the weathered surface ribs of rock that are rather more quartzo-feldspathic in composition stand out slightly from those which are more basic in character. Such individual bands are of the order of ½cm thick and are very uniform in thickness in a direction parallel to the first elongation lineation. In sections oblique to the first lineation, however, they show much more irregular variations in thickness. Fresh surfaces show numerous crystals of biotite and rather smaller crystals of amphibole and garnet can also be seen.

Megascopic garnet, contrary to the statement of Bailey (1955, p156), is a very common constituent of the Lewisian

rocks to the east of the Knock line and has been recorded in numerous exposures.

One of these exposures is situated about 1200yds NE of Knock Castle but is of particular interest for a different reason. In this exposures alternating bands of quartz-feldspar rock and amphibole rich rock can be seen. Certain of the bands have various intermediate compositions but all bands have well defined margins. Small megascopic garnets are visible in some of the intermediate bands. The amphiboles have a very strong preferred orientation such that their long axes are almost perpendicular to the foliation. The direction of the orientation at this locality is close to that which was described previously near Knock Castle.

An exposure which provides a valuable clue to the condition of the Lewisian complex previous to the Baravaig, or first phase of folding and deformation is located 300yds ENE of the easternmost tip of Camas Baravaig. Some of the structures in this cliff face are illustrated in figure 1.2 and 1.3(d). Quartzo-feldspathic rocks are represented in the former as black areas while in the latter they are left blank. These quartzo-feldspathic rocks are enclosed in a host rock of amphibole, biotite gneiss in which the dark minerals constitute approximately one third of the rock. The grains of quartz and feldspar in both types of rock share the elongation lineation which accompanies the Baravaig, or first group of folds. The crystals of amphibole and biotite, which measure 3-4mm, do not show any preferred orientation which is detectable to the unaided eye.

The deductions which can be made about the metamorphic

history of the Lewisian complex from the evidence presented in this last exposure are as follows. The relation between the quartzo-feldspathic material and the amphibole, biotite gneiss can only be explained in two ways. Either they are the result of a process of differentiation from a common parent or they are the product of injection of one type of rock into the other. In any case the mechanisms are very obscure but such processes may, however, be classified under the term "migmatisation" and their products may be called migmatities. Such a process of migmatisation must have occured before the deformation associated with the Baravaig, or first folds since the elongation lineation is shared by both types of rock. However, the amphibole and biotite crystals in their present state of growth are later than the Baravaig period of folding since they cut obliquely across the lineation. The following sequence of events can thus be recognised:-

1. Migmatisation.
2. Deformation during the Baravaig, or first period of folding.
3. Crystallisation or re-crystallisation of amphibole and biotite.

The second group of rocks in the Lewisian outcrop east of the Knock line is a series of amphibolites. All of these appear to be sheet-like bodies and the larger outcrops are shown on Plate 5. The sheet-like nature of these amphibolites is best appreciated in the case of the thinner examples which can be seen in the single exposure. The sheets vary in thickness from a few centimetres to several scores of metres

but are very uniform in composition in comparison with the previously described group.

A typical exposure of an amphibolite of this group is to be found immediately south of the outlet of the stream called Allt Gairistin Neill, 600yds east of Knock Castle. The junction of the amphibolite with surrounding acid gneisses is well exposed just on the high water mark and is parallel to the foliation in both groups of rock. On the weathered surface the amphibolite is dark-greenish-grey with very thin streaks and very irregular patches of fine grained white material. The straight sided streaks are parallel or sub-parallel to the margins of the amphibolite. On fresh surfaces dark-green, rather fine grained amphibole and very small black flakes of mica can be seen.

Other members of the same group of rocks differ only slightly from the above. In some, the content of feldspar reaches appreciable proportions and gives the rock a mottled appearance. Irregular bodies of coarse, quartzo-feldspathic material, such as those illustrated in figure 13(b), are a common feature and carry the elongation lineation associated with the Baravaig folds.

Two unique exposures, however, merit further attention since they demonstrate interesting features which tell more of the genesis of these rocks. Both of these are illustrated in figure 1.3. The exposure illustrated in figure 1.3(a) has been the subject of a lengthy discussion in Chapter 1, page 25, and it can be argued that it demonstrates the following sequence of events:-

1. Injection of basic magma into a gneissose host rock.

This magma is at present represented by the amphibolite.

2. The Baravaig, or first period of folding.

3. Introduction of thin white streaks and epidotic veins.

The exposure of figure 1.5(b) shows the junction between an amphibolite and an amphibole, biotite gneiss of the type illustrated in figure 1.2 and discussed on page 251. The amphibolite is discordant to the foliation in the gneisses and contains irregular patches of coarse, quartzo-feldspathic material carrying the first elongation lineation.

The amphibole, biotite gneisses at the top of the exposure have been shown to demonstrate the sequence:-

1. Migmatisation.
2. Deformation during the Baravaig, or first period of folding.
3. Crystallisation or re-crystallisation of amphibole and biotite.

To this sequence may be added facts which are deducible from the relations of the amphibolite. The amphibolite is discordant to the foliation in the amphibole, biotite gneiss and therefore the basic magma which it doubtless represents must have been intruded after the migmatisation of the host rocks. The amphibolite; and the quartzo-feldspathic bodies which it contains, have been deformed during the Baravaig, or first period since they show structures belonging to this group. The coarse, quartzo-feldspathic bodies can be looked upon as being the result of processes of migmatisation which must, therefore, be of a different age from the migmatisation of the country rocks.

The collected evidence from the exposures so far discussed

in this Chapter thus shows the following events in the structural and metamorphic history of the Lewisian rocks:-

1. Migmatisation giving rise to quartzo-feldspathic bodies in a rock which is now amphibole biotite gneiss.
2. Intrusion of basic magma which is now represented as amphibolite.
3. Migmatisation of the amphibolite or the rock which it now represents.
4. The Baravaig, or first period of folding and deformation. The earliest which can be recognised in the Lewisian rocks of the Moine nappe in Skye.
5. Introduction of thin white streaks into the amphibolite and epidotic veins into the amphibolite and its host rocks parallel to the axial surfaces of the Baravaig folds.
6. The Rudha Phoil, or second period of folding.
7. Crystallisation or re-crystallisation of amphibole and biotite apparently at the time of the deformation associated with the Tormore, or third folds. This topic is to be more fully discussed in Chapter 24.

The description and discussion of the rocks east of the Knock line is concluded here.

The rocks laying between the Ostaig line and the Knock line are extremely well exposed in easily accessible coast sections from Knock Bay to Bagh a'Mhuilinn. As well as some of the rock types so far described others of a rather different character also occur.

An exposure which received a great deal of attention from both Clough and Bailey is situated 250yds NW of the

ruined castle not far from the mouth of the stream called Allt Gleann Horavaig (Bailey, 1955, p153). Clough said: "Near a line between Isle Ornsay and Knock the flaggy soft rocks give place south-eastwards to more massive, less finely granulitic types. In Knock Bay, near the mouth of Allt Gleann Horavaig, the change between the two types is somewhat sudden".

The exposure in question can be described as follows. A band of pale-green weathering rock about 30cms thick appears to divide massive rocks above from fissile rocks below. This band dips at a low angle towards the east and seems to have localised some dislocation. On the pale-green weathered surface flakes of an olive-green chlorite up to 2mm in diameter can be seen in a host of finer grain size. Parting planes are very closely spaced but very irregular, and in places the band gives rise to an undercut feature. Immediately above this band the rocks are massive and weather to a medium-grey colour tinged with lilac. On fresh foliation surfaces large, bottle-green chlorite flakes up to 4mm in diameter lay in a host of pale-grey micaceous rock with pink feldspathic spots. Below the pale-green band the rocks have a flaggy parting and on the weathered surface they show thin pale-grey quartzo-feldspathic layers 1-2mm thick set in a medium greenish-grey host. Parting palnes are very closely spaced and are parallel to the foliation. The rocks are hard and do not cleave easily. Some bands are dark-green in colour. Fresh surfaces are dark-greenish-grey and 3mm needles of amphibole lay on the foliation planes with an apparently random orientation. Dark-green flakes of chlorite

are also present and measure up to 3mm in diameter.

For the following reasons it is thought that this exposure does not warrant the emphasis which has been placed upon it by both Clough and Bailey:-

1. Exposures on this section of the coast are far from continuous.
2. Many exposures of massive acid and basic rocks free of porphyroblasts can be found further to the west.
3. All three types of rocks within this exposure are of fine grain size and contain conspicuous micaceous porphyroblasts.
4. No sharply defined junction between "flaggy soft rocks" and "more massive, less finely granulitic rocks" can be drawn in fairly well exposed inland country.

The concept which emerges from the present survey is that this exposure belongs to a wide transition zone between the massive gneisses to the east and the fine grained, fissile rocks to the west. This transition zone is bounded approximately by the Knock and Ostaig lines and contains typical representatives from the two extremes as well as rocks of intermediate type. The impression given by Clough and Bailey of a sharp line of demarkation is misleading.

On the shore, below the Schoolhouse at Ferindonald, alternating acid and basic bands vary in thickness from 1cm to 15cms. The rocks are highly epidotic but contain no megascopic amphibole porphyroblasts. The first lineation is present in the form of a ribbon structure in finely alternating acid and basic bands. The constituent grains of these bands are elongated along lines which are oblique

to the direction of the ribbons. It is thought that this oblique elongation is a structure belonging to the Tormore, or third period of folding and deformation. The rocks possess a fissile parting.

1500yds to the SSW of the last mentioned exposure rocks showing the following features can be seen. On the weathered surface ribs of pink acid material stand out from the more basic layers, neither of these being more than 3cms thick. Parting planes parallel to the foliation are also similarly widely spaced. A development of some flaky minerals in planes which are oblique to the foliation gives the rock another fracture direction. On fresh surfaces the fine grained acid bands are seen to be less prominent than on the weathered surfaces and enclose thin, continuous laminæ of very dark mica. Basic layers are mottled; containing dark olive-green or bottle-green biotite flakes about 1mm across set in a pale bluish-green host. The micaceous minerals throughout the rock are aligned with cleavages oblique to the foliation.

About 100yds north of Rudha Cille-bhig the rocks are mostly dark greyish-green with a good parting concordant to the foliation. Fresh surfaces are dark-green and lustrous but no mineral grains can be distinguished. Thin layers of pale-grey feldspathic material up to 10cms occur. The lineation associated with the Baravaig, or first group of folds can be distinguished and, together with some concordant veins of milky quartz in the basic rocks, has been distorted by the folds illustrated in figure 7.2.

In addition to the rocks described above, which are fairly representative of the zone laying between the Knock and Ostaig

lines, rocks of the type found to the east of the Knock line are reasonably common. An exposure of such a rock is illustrated in figure 16.3 and it is rocks of this type which are used to define the Ostaig line. This is situated in a new road cutting 10-20yds south of the Teangue Post Office. The dark mineral is amphibole and forms blade-like crystals which are either scattered with random orientation throughout their host or are concentrated in thin layers within which their longest axes are haphazardly arranged. The host rock is pink and is composed of coarse quartz and feldspar the grains of which demonstrate the elongation lineation associated with the Baravaig, or first folds.

Next to the massive acid rocks in the exposure mentioned above there are some rocks which are dark-green in colour. These are fine grained and possess a closely spaced, fissile parting which is parallel to the foliation. The junction between the two types of rock is quite sharp.

Massive basic rocks akin to those found east of the Knock line are common in the vicinity of Rudha Cille-bhig. They are cut by sparse joints running in many different directions; they are dark-green in colour and they contain scattered pink feldspathic spots. However, they do show a few points of difference from their counterparts east of the Knock line. Bottle-green flakes of a micaceous or chloritic mineral, measuring up to 4mm, can be distinguished on fresh surfaces and there are also abundant minute needles of amphibole. The rocks possess a foliation which is more obvious than in similar rocks east of the Knock line but they are reluctant to split along such planes. Nearer to

the junctions of these basic bodies, which are very ill defined, the foliation becomes increasingly obvious and the rocks more fissile. They grade ultimately into dark-green, fine grained and very fissile type of rock.

The minute needles of amphibole that were mentioned in the preceding paragraph are a common constituent of the rocks between Knock Bay and Bagh a'Mhuilinn and are worthy of a separate description. They can be distinguished in many rocks of basic aspect and occur either scattered throughout the more massive types or on foliation planes in the fissile rocks. They are always dark-green and are rarely more than 3mm long. In the fissile types of rock they usually lay on the foliation planes with random orientation. However, in places they possess a marked degree of preferred orientation and measurements of the structure so defined are presented in Plate 3 and figure 3.7. It is thought that the orientation of these crystals was governed by the mechanical conditions which were responsible for the development of the Tormore, or third group of folds.

Crystals of flaky minerals showing a porphyroblastic tendency are also notable constituents of the rocks within the zone defined by the Knock and Ostaig lines. They show a variety of colours such as bottle-green, blue-green, dark-brown and almost black. Subsequent examination has shown that they are either biotite or different varieties of chlorite. In the fissile rocks the flakes nearly always lay on the foliation planes but in more massive rocks the cleavage planes of the minerals may be either randomly orientated or may show a distinct preferred orientation. Such a preferred

orientation is towards a girdle or partial girdle of the poles to cleavage and the axis of the girdle may lay in the foliation or may be oblique to the foliation. As in the case of the minute amphibole needles it is thought that such preferred orientations are governed by the mechanical restraints operative at the time of the Tormore, or third folding.

Introduced material in the form of veins is not over-abundant in the coast section from Knock Bay to Bagh a'Mhuilinn. Such veins as do exist invariably contain quartz or calcite as the essential mineral. In the case of the quartz veins subordinate amount of calcite, chlorite, feldspar and amphibole may also occur. Veins consisting predominantly of calcite are confined to fault planes and show a crustified structure with several layers of calcite coloured by different disseminated minerals.

The facts presented by the exposures laying between the Knock and Ostaig lines can now be discussed and certain conclusions can be drawn about the development of the Lewisian rocks in the Moine nappe. One of the most striking of these facts is that, especially in the neighbourhood of Rudha Cille-bhig, large, lens-shaped bodies of coarse amphibolite can be seen to grade imperceptibly into fine grained fissile types of rock. The massive acid gneisses which are also characterisitic of the zone laying to the east of the Knock line are likewise found in lens-shaped bodies surrounded by rocks of fine grain size. The conclusion to be drawn, therefore, is that the fine grained rocks between the Knock and Ostaig lines have developed from coarse grained rocks such as those

which lay to the east of the Knock line by a process of grain size reduction. If the Knock line, which forms a boundary confining the rocks that have suffered this grain size reduction process, had been folded by the Knock synform it would now be expected to re-emerge only about 400yds to the east of the ruined castle as shown in the section of figure 25.1. The Knock line does not re-emerge even 1500yds east of the ruined castle and thus the processes of grain size reduction must have occured after the development of the Knock synform. The possibility could be suggested, however, that the grain size reduction pre-dates the Knock synform and that the Knock synform developed such that the predominantly fine grained rocks occured on the NW limb and the coarse grained rocks on the SE limb. This possibility must be dismissed by the following argument which is illustrated by the section of figure 25.1. There is a minimum thickness of three-quarters of a kilometre of massive Lewisian gneisses on the SE limb of the Knock synform which do not occur on the NW limb of the same fold. On the NW limb there is no measurable discordance between the foliation in the massive Lewisian gneisses and the foliation in the fine grained rocks to the west of the knock line. However, if the grain size reduction were to pre-date the Knock synform then a discordance of at least 50° would be expected between the foliations in these two types of rock. The calculation of the angle of 50° is based on an estimation of the thickness of the massive gneisses on the SE limb of the Knock synform and an estimation of the minimum distance measured along the foliation and perpendicular to the axis of the Knock synform between the point at which

the Knock line outcrops in Knock Bay and the point at which it would be expected to outcrop to the east of the castle if it had been folded by the Knock synform.

The reduction in grain size of the rocks to the west of the Knock line must have occured before the growth of the minerals of porphyroblastic habit since in many localities these minerals are orientated in patterns which are oblique to the foliation. Some porphyroblasts of amphibole in both the coarse, massive rocks to the east of the Knock line and in the fine grained, fissile rocks to the west of this line are orientated in similar directions and there are no facts which dispute the assumption that the same restraints controlled the crystallisation of the porphyroblasts in both zones. The metamorphic history of the Lewisian rocks of the Moine nappe as deduced so far can thus be summarised as follows. This table is an extension of that presented on page 255:-

1. Migmatisation.
2. Basic igneous intrusion.
3. Migmatisation of the amphibolites or the basic igneous rocks which they now represent.
4. The Baravaig, or first period of folding.
5. Introduction of thin white streaks &c.
6. The Rudha Phoil, or second period of folding; the development of the Knock synform.
7. Reduction of grain size among many of the coarse grained rocks on the NW limb of the Knock synform.
8. Crystallisation or re-crystallisation of amphibole, biotite and chlorite apparently at the time of the deformation associated with the Tormore, or third folds.

The rocks laying to the west of the Ostaig line are much less revealing with regard to their metamorphic history than are the rocks to the east of this line. They are almost invariably fine grained and are completely free of megascopic porphyroblasts. Nevertheless, microscopic porphyroblasts are shown to be present by microscope examination. The folds which they contain have been classified as belonging to the Ard Thurinish and Port a'Chuil groups. The rocks are well exposed in almost continuous coast sections from Bagh a'Mhuilinn to the outcrop of the Moine thrust near the Aird of Sleat Schoolhouse.

In exposures near the high water mark north of the stream which drains into Bagh a'Mhuilinn the foliation shows very few irregularities. Layers of acid composition are a very pale grey colour and measure up to ½m in thickness. They contain thin partings as much as 2cms thick of basic material which is dark green on the weathered surface. Clots of feldspathic material are elongated. Thicker layers of basic material rarely exceed 15cms. They are of uniform dark green colour and of fine grain size. On fresh surfaces small flakes of dark green chlorite can be seen. A few layers weather to a pale green colour with very thin, discontinuous, silvery micaceous intercalations. Fresh surfaces of such rocks are dark green and lustrous. Parting planes are more closely set than in either the neighbouring acid or basic layers. One thin band within a pale green layer contains larger, stouter prisms of a dark grey mineral and is interleaved with streaks of pale green matter.

An exposure located 1050yds NNE of the Armadale Pier

is illustrated in figure 16.2(a). The parting planes in the rocks are very irregular but the rocks are not noticeably fissile. The parting planes are concordant with the foliation and a rough divisioh into acid and basic bands can be made. The acid bands consist of pale, brownish-pink quartzo-feldspathic material of fine grain size which is interleaved with thin layers of very dark green material containing small, lustrous flakes of dark mica. The quartzo-feldspathic layers outline very small folds of the Ard Thurinish group that are irregular in profile and which are later than a prominent elongation lineation. The fine grained quartzo-feldspathic layers contain concordant lenticles of white translucent quartz which have transitional boundaries with their host. Some of these lenticles can be distinguished in figure 16.2(a) in a band above the head of the hammer. The thicker basic layers are a paler green than those which are closely associated with the acid layers and they contain thin streaks of the same brownish-pink quartzo-feldspathic material. Parting palnes are more regular than in the acid rocks. No quartz lenticles are present.

Basic rocks similar to those described above constitute a greater part of a nearby roadside cutting. Part of this is shown in figure 16.2(b). These rocks contain lenticular veins of milky quartz which are quite different from those contained within the acid bands of the last described exposure. The boundaries of the quartz veins of figure 16.2(b) are sharp and are concordant with the foliation in the host rock.

The exposures to the west of the Ostaig line which are

most reminiscent of the massive rocks to the east of the Knock line are to be found on the coast 300yds WSW of Dun a'Chleirich. These are of basic composition and are illustrated in figure 16.1(b). Joint planes of rather irregular orientation are widespread but the rocks possess a distinct foliation parallel to which they may be broken with difficulty. On weathered surfaces the rocks are dull and dark greyish green in colour with pale grey to off white streaks of feldspathic material parallel to the foliation. On other weathered surfaces this feldspathic material is gathered into spots and small lenticles which are elongated within the foliation. The dimensions of these spots and lenticles are up to 3mm thick and up to 10mm long. Small pods of exclusively feldspathic material also occur and two of these are illustrated in figure 16.4(b). In addition to the feldspathic spots and lenticles and the larger pods the remainder of the rock can be seen to consist of some layers of dark green colour and others of pale bluish-green. These layers rarely exceed 5cms in thickness. An elongation lineation is only seen in the feldspathic parts of the rock. Veins of milky quartz cut discordantly across the foliation and are very irregular in cross section. These veins may be as much as 15cms wide. Parts of them are stained reddish brown with hematite and they contain streaks of dark green, fine grained chloritic minerals.

Massive acid gneisses of the type found to the east of the Knock line do not occur to the west of the Ostaig line.

Figure 16.1(c) is a photograph of an exposure 100yds

NE of Dun a'Chleirich. The rocks are composed of pale green chloritic material of slightly varying tints and pink, quartzo-feldspathic bands. Individual layers vary in thickness from a fraction of a millimetre to several centimetres. The thicker quartzo-feldspathic bands have a very smoothly flowing foliation but on the whole the foliation is irregular and parting planes on weathered surfaces are widely spaced. Some thin, quartzo-feldspathic layers give the appearance in section of being clotted; the clots being drawn out parallel to the elongation lineation in the host rock. Numerous rather irregularly shaped quartz veins are emplaced discordantly to the foliation. The quartz is milky and can sometimes be seen to possess a foliation. A steady lineation on the quartz veins, trending towards the ENE, is common and is thought to be associated with the Port a'Chuil folds. Small bodies of dark green, lustrous chloritic minerals are found in the quartz veins and where the veins are thick they also occur in the host rock. The quartz veins and the bodies of chlorite, although occuring together, remain discrete from each other.

Quartz veins of the type described above are very common in the Lewisian rocks near to the Moine thrust. As well as chlorite they may also contain calcite. Their discordant nature is without doubt and details of a typical discordant contact are shown in figure 16.4(a). A lineation associated with the Port a'Chuil folds is commonly apparent on the surfaces of the veins.

Rocks within 20yds of the outcrop of the Moine thrust at the Aird of Sleat Schoolhouse are illustrated in figure

16.1(a). These are of very fine grain size and consist of alternating layers of pink and mid green rock. They are very fissile and part readily along planes parallel to the foliation. They contain a lineation which is associated with the Port a'Chuil folds.

Owing to the almost complete absence of megascopically determinable minerals from the rocks to the west of the Ostaig line very little of their metamorphic history can be deduced from evidence gathered in the field. They undoubtedly are derived from coarse grained rocks of the type now exposed to the east of the Knock line since remnants of these are to be seen near Dun a'Chleirich. Apart from this the only clue to their metamorphic history is provided by the quartz veins such as are illustrated in figure 16.1(c), 16.2(b) and 16.4(a). The material of which these quartz veins are composed was emplaced after the development of the Ard Thurinish folds. These folds, as concluded in Chapter 4, are either of the same generation as the Tormore, or third folds or belong to a separate fourth generation. However, the quartz veins carry a lineation which is thought to be associated with the Port a'Chuil folds and must thus predate these folds.

EXPLANATION OF FIGURE 16.1.

(a) Pink and pale green Lewisian rocks within 20yds of the outcrop of the Moine thrust in Port a'Chuil. The areas of darker tone are submerged in shallow water.

(b) A coast exposure of amphibolite 300yds WSW of Dun a'Chleirich. The rocks are mottled dark green(mostly amphibole) and off white (feldspar and sub-ordinate quartz) and are difficult to break. They contain feldspathic "pods" as illustrated in figure 16.4(b).

(c) An exposure 100yds NE of Dun a'Chleirich. The rocks are phyllonites, containing much chlorite, and are discordantly cut by veins consisting essentially of quartz with minor amounts of dark green chlorite, small bodies of which can be distinguished in the photograph. The quartz veins carry a lineation associated with the Port a'Chuil folds.

a)

b)

c)

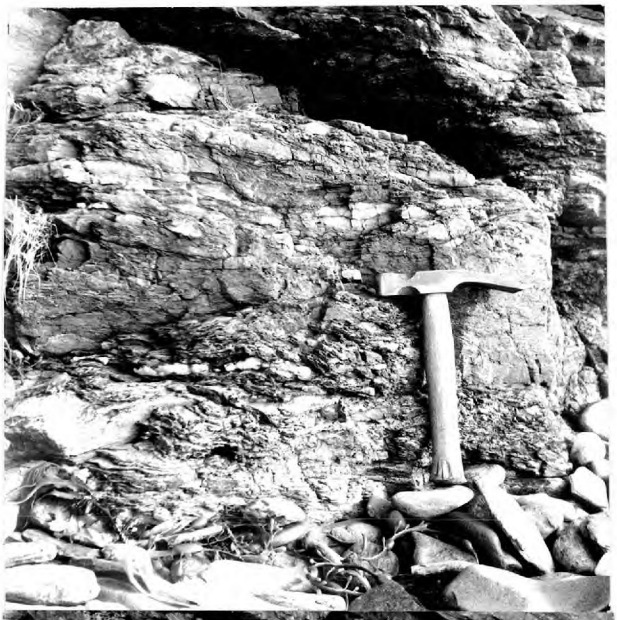
Lewisian rocks in the Moine nappe

Figure 16.1

EXPLANATION OF FIGURE 16.2.

(a) Lewisian rocks on the coast 1050yds NNE of the Armadale Pier. Lenticles of white, translucent quartz can be distinguished immediately above the head of the hammer.

(b) Rocks of more basic composition in a nearby roadside cutting. These are dark green in colour and contain veins of milky quartz.



a)



b)

Lewisian rocks in the Moine nappe

Figure 16.2

EXPLANATION OF FIGURE 16.3.

Road side exposure about 20yds south of Teangue Post-Office. The rocks are acid Lewisian gneisses containing dark green amphibole porphyroblasts. These porphyroblasts occur either scattered in random orientation through the host rock or in well defined layers parallel to the foliation. In this latter case the long axes of the crystals are contained within the foliation plane as can be seen in the lower right corner of the combined photographs. The host rock is pink and the foliation is indicated by layers of various tints.



Amphibole porphyroblasts in Lewisian gneiss

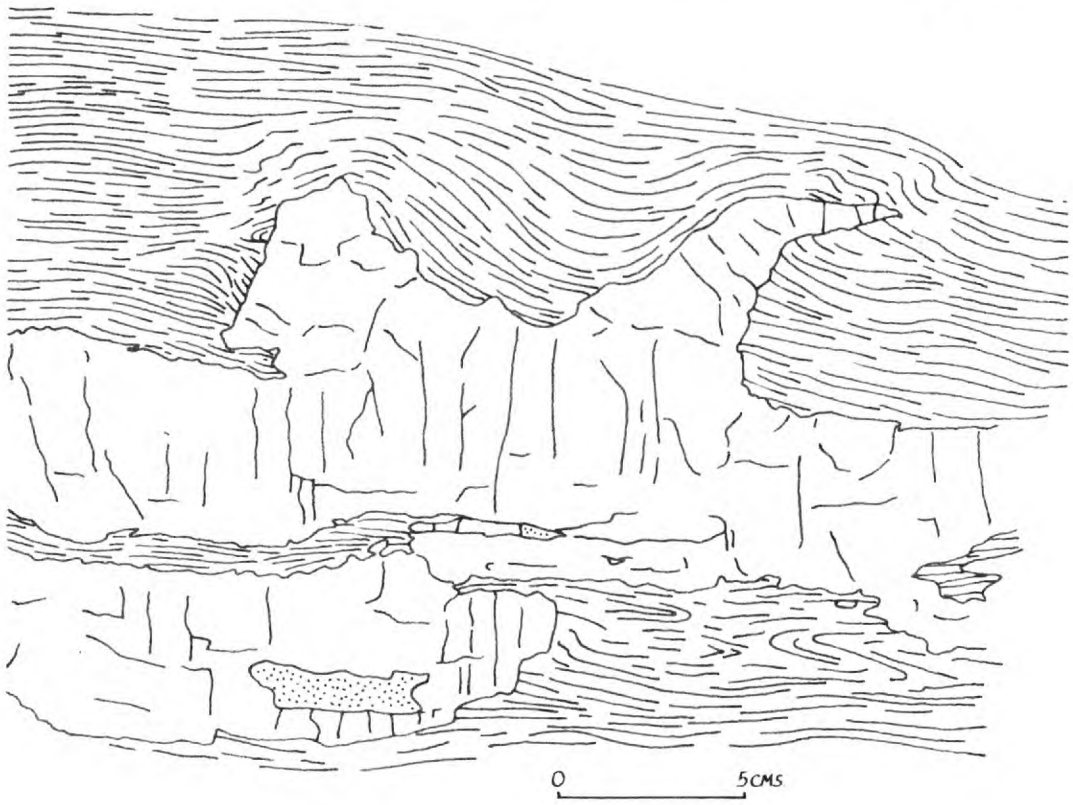
Figure 16.3

EXPLANATION OF FIGURE 16.4.

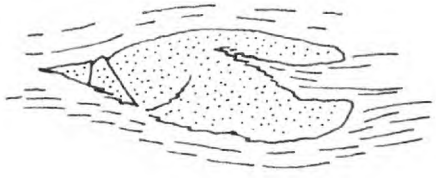
(a) Quartz veins in phyllonite near the southern tip of Ard Thurinish. The veins are composed almost entirely of milky quartz but contain small bodies of calcite which are indicated by spots. The host rock is green and is evidently rich in chlorite.

(b) "Pods" of feldspathic material in the rocks illustrated in figure 16.1(b).

a) Quartz veins with calcite in phyllonite



Veins and pods in Lewisian rocks of the Moine nappe



b) Pods of feldspathic rock in amphibolite



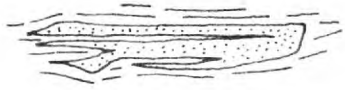


Figure 16.4

The Moine rocks laying above the Moine thrust, or the "Standard Moine" rocks (so called in order to distinguish them from the Tarskavaig Moine rocks which lay below the Moine thrust) outcrop over a small part of the area of study. These outcrops are shown on Plate 5 and stretch from Rudha Phoil, near Ardvasar, almost to the Moine thrust at Meall Buidhe, three quarter miles to the NW of the Aird of Sleat.

The degree of exposure is highly variable. On the peninsulas of Rudha Phoil and Rudha Dubh it is excellent. One and a half miles to the SE, at Tormore, high sea cliffs and a rocky fore-shore provide almost complete exposure. Inland, however, among the hills to the west of Tormore the exposure of the Moine rocks is less complete and in the northern part of this outcrop area the rocks exposed are very few and very small.

Generally, the most striking division of the Moine rocks that can be made is that which is indicated on Plate 4. On this map a distinction has been drawn between areas in which the semi-pelitic rocks possess a very fissile parting, parallel to the foliation, from those areas in which the semi-pelitic rocks are without such a fissile parting. In the former area the psammitic rocks are of very fine grain size; the individual mineral grains being rarely distinguishable to the unaided eye. In addition these fine grained psammitic rocks are confined to thin layers which rarely exceed 4-5cms thickness. To the SE, where the semi-pelitic rocks lack a fissile parting, the psammitic rocks are usually of coarse grain size and occur in bands measuring 10-20cms in thickness.

These two areas of different types of Moine rock can be separated by a fairly well defined line which is indicated on Plate 4. It is of interest to note that this line also separates those Moine rocks to the NW which contain the Ard Thurinish group of folds from the rocks to the SE which are characterised by the Tormore and Rudha Phoil groups of folds.

Because this line separates two areas of rock of differing grain size containing different groups of structures it is correlated with the very similar Ostaig line in the Lewisian rocks to the NE. As is the case in the Lewisian rocks, no structures of the Rudha Phoil or Tormore groups occur to the west of the Ostaig line which is extended through the Moine rocks in this fashion. In the account which follows, the Moine rocks to the east of the Ostaig line will be described first. These rocks are exposed in two small areas: in the vicinity of Ardvasar and near Tormore.

At Ardvasar, on the peninsulas of Rudha Phoil and Rudha Dubh, the Moine rocks which outcrop SE of the Ostaig line can be classified into a psammitic group with two flanking semi-pelitic groups. These are shown in figure 3.4. The pattern of foliation in the psammitic group outlines a part of a major fold, plunging SE, which is thought to be of the Baravaig, or first generation. The location of this fold is clearly displayed in figure 3.4. Apart from the two major faults which trend to the NE shown on the map the psammite group is not disrupted by any other major dislocations.

Two possibilities arise, therefore, in the interpretation of the structural geometry of the psammite group. Briefly

these are that it either represents the hinge zone of a large scale isoclinal fold or that it is a continuous stratigraphic unit and that one of the flanking semi-pelites is older while the other is younger than the psammitic group. The complete absence of sedimentary structures indicating direction of younging makes a decisive choice impossible.

The two outcrops of semi-pelitic rocks which flank the psammite are identical within the limits of the method of study that were adopted. A typical exposure of such rocks is illustrated in figure 2.1. This exposure consists largely of semi-pelitic rocks with bands of psammite up to 4-5cms thick. These psammite bands are separated by semi-pelitic beds which have an average thickness of 20-40cms. The semi-pelitic rock forming the bulk of these exposures is pale to medium grey in colour and is of fine to medium grain size. On fresh surfaces muscovite is prominent. The remainder of the megascopic fraction of the rock is composed of quartz and feldspar but the relative proportions of these two minerals cannot be seen. In certain parts of the outcrop of the semi-pelites pinkish-brown garnet crystals up to 3-4mm in diameter are very common. The psammite bands within the semi-pelite are off white to pale grey and consist largely of quartz of medium grain size with only very small amount of feldspar. Some small crystals of biotite are also distinguishable.

The main group of psammitic rocks between the two outcrops of semi-pelite is made up of bands of 5-30cms thickness separated by very thin partings of micaceous material. These banded psammites are of a buff or orange-pink colour,

probably rich in potassium feldspar, and thus contrast strongly with the thinner bands of grey psammite in the semi-pelitic groups. The grain size ranges from medium to very coarse; the average rock being medium-coarse. In the very coarse rocks the grains of quartz and feldspar are visibly elongated; a structure thought to be associated with the Baravaig, or first period of folding. The quartz is coloured in various shades of blue-grey as distinct from the feldspar which is a bright orange colour. The micaceous partings between the bands of psammite are of medium grain size and yellowish-grey in colour. With the exception of the muscovite in these partings no other minerals can be distinguished in these rocks.

In the high sea cliffs near Tormore by far the greater proportion of the rocks laying to the east of the Ostaig line are of semi-pelitic composition and no major division into psammitic and semi-pelitic outcrops can be made. These semi-pelitic rocks are very similar to those at Ard-vasar and only minor points of difference have been noted: the Tormore rocks have no megascopic garnets and the thin psammitic bands are much more variable in texture. These bands of psammite are up to 10cms thick and tend to be concentrated together in zones one or two metres in thickness. These zones of psammitic bands are separated by semi-pelitic rocks several metres thick in which there are occasional psammitic intercalations.

On weathered surfaces some of the psammite bands have smooth, compact marginal zones which grade into rough interior zones from which the large individual grains of quartz project.

Feldspar is not prominent except in some of the bands where it is coloured deep orange. In general, the thinner the psammite bands, the coarser are the constituent grains. Very rarely the coarse psammite bands, in which the grains may be 2-3mm across, can be seen to pass laterally into curious bands composed of isolated grains of white quartz up to 13mm in diameter in a fine to medium grained semi-pelitic host rock.

To the west of the Ostaig line the Moine rocks are of a much finer grain size and only very rarely can individual mineral grains be distinguished. Although both psammitic and semi-pelitic types of rock are present they are inter-laminated on a small scale. Individual laminæ vary from about 3mm to 3cms. The psammitic layers are usually yellowish-grey but may be pink. Alternating laminæ cloudy and translucent represent layers with various proportions of quartz and feldspar. In the semi-pelitic rocks the micas are much less dominant than in the rocks to the east of the Ostaig line. Such rocks are pale to medium grey, tinged with yellow.

In a few exposures to the west of the Ostaig line very small garnets are visible in the Moine rocks. Folds of the Ard Thurinish group from one such locality are illustrated in figure 4.7.

The junctions between the Moine rocks and the Lewisian rocks to the east of the Ostaig line are all faulted and have been described in Chapter 8. To the west of the Ostaig line, however, there are several localities where the junction between these two groups of rocks does not

appear to have been the site of late stage faulting. The lines of junction are disturbed by conjugate folds and must, therefore, be of an earlier date than these.

On the fore-shore, about 100yds to the SW of the Tormore farmhouse, the contact between the Moine and the Lewisian is well exposed. At this locality, however, breccias would seem to indicate that the junction has been faulted. The plane of dislocation is approximately parallel to the foliation in both groups of rock.

An un-faulted Moine-Lewisian contact is exposed at the head of a small gully which rises above the road some 200yds NW of the Tormore farmhouse. There is perfect concordance between the two groups of rock at this place but no indication of dislocation movements which post-date the conjugate folds. The plane of the junction dips at about 20° to the ENE. and the Moine rocks lay above the Lewisian.

Another good exposure of the contact lays on the east bank of the small stream which enters the sea near Dun a' Chleirich. This exposure is about 900yds from the mouth of the stream and is about 30ft above the stream bed. Foliation planes in both groups of rock are concordant with the contact which dips towards the north at about 20°. The Moine rocks lay above the Lewisian.

Along the greater length of the outcrop of the junction between the Moine and the Lewisian, where this is not obviously disrupted by large vertical faults, the Moine rocks lay above the Lewisian. However, along that part of the contact which passes for a distance of 500yds to the west of a point 600yds NNE of Tormore, there can be little doubt that the

Moine rocks are dipping beneath the Lewisian. Bailey (1955, p150) noted this. Further to the west, as far as a point 900yds NE of Meall Buidhe, the rocks are so poorly exposed that the relations at the junction cannot be deduced with certainty. Nearer to Meall Buidhe the Moine rocks lay above the Lewisian.

Bailey postulated (1955, p150) that the Moine rocks in the hills to the west of Tormore were sandwiched between two layers of Lewisian. It seems that this layer of Moine rock must be discontinuous otherwise it should be traceable in a NE direction until cut off by the Moine thrust or some other dislocation. To account for this discrepancy it is suggested that the Moine rocks may occupy the core of a large scale isoclinal fold. This fold must close to the NE with axial plane dipping to the SE and must have been refolded by the large scale monoclinal fold of figure 8.2. If such a large scale isoclinal fold exists then it is probably a member of the Baravaig, or first generation. Another large scale fold of the Baravaig generation appears to be present in the Moine rocks of Ardvasar and has been described in Chapter 3.

Very few conclusions with regard to the metamorphic history of the Moine rocks can be drawn simply from a study of their megascopic properties in the field. Mention has already been made in Chapter 3 (page 71) of the orientation of mica and the elongation of quartz and feldspar which is seemingly associated with the Tormore, or third group of folds. It is assumed that the fine grained Moine rocks to the west of the Ostaig line are the result of a grain size

reduction after the development of the Knock synform (second generation) in the same way as are their Lewisian counterparts further to the north.

The conclusions of Clough and Bailey with regard to the relative ages and importance of the different planes of dislocation in the rocks of the southern part of the Sleat peninsula were discussed in Chapter 14 and alternative ideas were presented. The original concepts of Clough and Bailey are outlined in figure 0.4 and a newly formulated nomenclature of the dislocations is presented in figure 14.2. These new hypotheses are fundamentally different from those of Clough and Bailey in that all of the Tarskavaig Moine rocks and the Lewisian with which they are associated are thought to belong to one thrust slice, or nappe, as opposed to the two separate nappes of Clough and Bailey. Nevertheless, the term "Caradal nappe" is retained, for convenience of presentation, to denote those rocks which are bounded by the Tarskavaig thrust and the Caradal fault as shown in figure 14.2. The rocks to be described in this Chapter are, therefore, exactly the same as those which Bailey (1955, p140) defined as laying above the Caradal thrust.

Neither Clough (in Peach et alia, 1907), nor Bailey (1955) seem to have recognised more than one generation of folding in the rocks of the Caradal nappe. As stated in Chapter 12, Clough undoubtedly saw that his "Caradal thrust" and "Lamarscaig thrust" had been distorted by large scale folds which are now classified as belonging to the Caradal, or third group within the Caradal nappe. However, the evidence presented in Chapter 10 indicates that an earlier generation of major folds has affected the rocks of the Caradal nappe. These early major folds, the Capistal or first generation, are isoclinal. The establishment of the presence

of the Capistal folds would, therefore, seem to invalidate or partially invalidate the stratigraphical succession which was erected by Clough in the Tarskavaig Moine rocks (Peach et alia, 1907 and also Bailey, 1955, p142). Thus many of the lithological descriptions which were written by Clough (in Peach et alia, 1907) and by Bailey (1955) would now seem to be somewhat haphazard in their arrangement. The stratigraphical succession which takes into account the complex geometry of the polyphase folding and which is based on sedimentary structures indicating "way up" is as follows:-

Upper Psammite	Tarskavaig Moine Series
Laidhe na greine group	
Lower Psammite	
Lewisian	

These stratigraphical units will be described in this Chapter in ascending order, beginning with the Lewisian. A few notes will also be included on the Torridonian outcrops to the SW of Loch a'Ghlinne. These Torridonian rocks are separated on all sides from the Tarskavaig Moine rocks by dislocations and do not form part of their stratigraphical succession. It is postulated in Chapter 14 that the Torridonian rocks reached their approximate present position during or later than the Caradal period of folding.

The degree of exposure which allows the sequence of deposition and the sequence of structures to be elucidated in the Tarskavaig Moine rocks is indicated in figure 0.2. Except near to the Caradal fault and the Tarskavaig thrust this degree of exposure is fairly representative, Close

to these dislocations the rocks are normally very poorly exposed.

The area of outcrop of undoubted Lewisian rocks is restricted to the east of the Caradal nappe and is indicated on Plate 5. Rocks typical of the southern part of the exposure are illustrated in figure 11.1(a). These rocks consist of alternating laminæ 3-4mm thick of different colours. The pale coloured layers, which are too fine grained to allow megascopic identification of the minerals, are probably composed of quartz and feldspar. They are pink or reddish-pink while the darker layers are various shades of green. The various depths of this green colouration suggest that the rocks contain varying proportions of epidote and chlorite. The different laminæ in these rocks follow very smooth, streamlined curves.

Towards the northern part of the Lewisian outcrop the rocks grade from being predominantly pink and green into rocks which are pale-grey and greenish-grey. These rocks are of very fine grain size and the different minerals cannot be identified in the field. In all parts of the Lewisian outcrop thin, straight sided veins of milky quartz follow both the foliation and the axial plane cleavage of the Doire na h-Achlais, or second generation of folds.

Clough mentioned 'particles of pea-sized hornblende' in his description of the Lewisian rocks of the Caradal nappe. Clough also reported long, narrow outcrops of Lewisian rocks laying directly upon his "Caradal thrust" (see figure 0.4 for Clough's definition of Caradal thrust). Certainly there are fine grained green rocks in these positions but for the

reasons stated in Chapter 14, pages 225-226, Clough's identification of these rocks is disputed. The rocks in question are thought to be members of the Laidhe na greine group and will be described subsequently under this title.

The Tarskavaig Moine rocks have been sub-divided into three stratigraphic units. Within each unit there are alternating beds of psammite, semi-pelite and pelite so that hard and fast boundaries cannot be drawn on the map between a psammite outcrop and a semi-pelitic outcrop. To overcome this difficulty and to construct a map which may be readily reproduced by independant surveyors the convention has been adopted of drawing boundaries at the limits of occurence of beds of a particular type. Thus the boundaries of the Laidhe na greine group are so constructed that they enclose practically all the bands of semi-pelitic rock of measurable thickness. Thus, although the Laidhe na greine group is dominantly semi-pelitic, it also includes considerable areas of psammite near to its borders which are quite indistinguishable from the typical rocks of the Upper and Lower Psammites.

The area of outcrop of the Lower Psammite is indicated on Plate 5 by close spaced dots. This outcrop is confined to the common limb between the Caradal synform and the Caradal antiform and borders on most sides against the Laidhe na greine group. To the east, however, the junction against the Lewisian is somewhat different and will be described and discussed separately after an account of the rocks of the Upper Psammite.

The rocks of the Lower Psammite are illustrated by photographs in figures 10.1, 14.4(c) and 18.1(a&b). Over

the greater part of the outcrop these psammites are of medium or coarse grain size and contain pebbles of milky quartz either in layers or scattered throughout the host rock of smaller grain size. Such pebbles are shown in figures 10.1(h) and 18.1(a&b). The pebbles are the only particles in the Lower Psammite which retain a shape which is distinctive of sedimentary origin. As opposed to the smaller grains in the rock the pebbles are well rounded and are not noticeably elongated. The smaller particles are, on the other hand, considerably elongated and may also appear to be "flattened" as described in Chapter 10. These tectonic features are associated with the Capistal, or first group of folds. Grains of feldspar are rarely obvious among the Lower Psammites.

In a few localities very dubious false bedding may be seen in the Lower Psammite. Only in one exposure can there be no doubt. This is illustrated in figure 18.1(b). Here, a series of alternating layers of pale-grey and mid-grey psammite at the bottom of the exposure is sharply truncated by a bed of pebbles near the top of the exposure. This bed of pebbles is overlain by a layer of much finer grain size. The exposure illustrated is located 450yds SW of the Loch Capistal outlet, very close to the axial trace of the Capistal antiform. From the evidence presented at this exposure it may be suggested that within the area of Loch Capistal the Capistal antiform is indeed an anticline and the rocks of the Laidhe na greine group are younger than those of the Lower Psammite.

The only remaining notable feature of the rocks of the Lower Psammite is the abundance of veins of milky quartz.

These were mentioned in Chapter 10 where it was stated that the great majority of these veins carry the elongation lineation associated with the Capistal, or first group of folds in the Caradal nappe. Some veins do, however, transect the axial planes of the Doire na h-Achlais, or second folds and must, therefore, be later than these structures. These quartz veins do not carry a lineation.

The area of outcrop of the Laidhe na greine group includes practically all the semi-pelitic bands of measureable thickness as well as a fairly high proportion of psammitic rock and a very small amount of rock of pelitic composition. The rocks of the Laidhe na greine group fall into two main areas of outcrop as shown on Plate 5. These may conveniently be called the western and eastern outcrops. The latter will be discussed first.

By far the best exposures in the Laidhe na greine group are to be found along the coastal section to the SW of the village of Aird of Sleat. Some of these will be described in detail and will be followed by more general remarks concerning the eastern outcrop.

Approximately 1650yds to the WSW of the Aird of Sleat a part of the coastal exposure shows alternating bands or beds of grit, siltstone and semi-pelitic rock. The latter is by far the most abundant and the two former constitute together only about 10% of the exposure. The beds of coarse grit contain large grains of quartz and feldspar distributed in a finer grained matrix. The proportion of these coarser grains varies from about 5% to about 50% of the rock. The quartz, which is much more abundant than the feldspar, is

very angular and is coloured pale-blue. The size range is variable but seems to average 2-3mm. The feldspar is likewise rather angular and is coloured a deep orange. The groundmass appears to consist essentially of the same minerals.

The beds of siltstone are hard and are of uniform grain size. No individual mineral grains are identifiable although quartz is almost certainly dominant. The rock cleaves fairly readily along planes parallel to the bedding and on some of these surfaces a feint lineation can be seen. On fresh, wet surfaces, thin alternating layers of dark-grey and olive-green rock can be seen.

The pelitic rock, making up most of the exposure, is composed of thin laminæ of siltstone of the type described above alternating with finer grained more micaceous bands. On the more micaceous bedding planes small elongate crystals, about 3mm by ½mm, can be seen. These have no preferred orientation.

About 100yds to the ENE of the last locality the cliff exposure is dominated by psammite. These rocks comprise about 80% of the exposure and of the remaining 20%, coarse grits are about 15 and pelites 5.

The psammite is too fine grained to allow the ratio of quartz to feldspar to be reasonably estimated in the field. Both on weathered and on fresh surfaces the rock has a greasy appearance.

The coarse grit contains rounded to sub-rounded grains of quartz and feldspar which make up about 60% and 30% of the rock respectively. The quartz is milky-white, often tinted

grey. The feldspar is a very deep orange colour. Both of these minerals occur in grains measuring up to 1cm in their longest dimension. The matrix is fine grained and dark-green and is possibly rich in chlorite.

The pelitic rocks occur in thin layers alternating with both grit and psammite. They form hollows in the suface of the exposure and contain very closely spaced planes of parting.

Veins of milky quartz with subordinate quantities of chlorite form an irregular network cutting the psammitic rocks but terminate abruptly at the pelitic layers.

The next exposure to be described is on the coast some 1200yds to the WSW of the Aird of Sleat. Here, the rocks are mostly semi-pelite with psammite making only about 30% of the exposure. The semi-pelitic rocks are hard and possess a medium-grey tint. They are fairly fine grained but biotite and quartz can be distinguished with a magnifying glass. The psammite is of uniform grain size and has a greasy appearance on the weathered surfaces. On these surfaces the rocks show alternating bands coloured pale-yellow and greyish-brown.which average 4-5mm thickness. The psammites are in beds 4-10cms thick.

Inland exposures of the Laidhe na greine group are abundant. One typical exposure is situated 450yds NW of the Loch Capistal outlet. In this exposure beds of psammite alternate with beds of semi-pelite. The psammites are coarse and well sorted. Both quartz and feldspar grains are of the same size and are strongly elongated. The quartz is bluish-grey; the feldspar is salmon-pink. A few irregularly

spaced parting planes of medium-grey pelitic material divide the psammite beds into layers 1-10 cms thick. The beds of semi-pelite consist of layers of medium-grey pelitic material and of very fine-grained psammite in approximately equal proportions. These layers are in the order of a few millimetres thickness. The total thickness of any semi-pelitic bed is not greater than about 0.6-0.7 metres.

General remarks on the eastern outcrop of the Laidhe na greine group may be arranged under two headings: sedimentary structures and porphyroblasts.

Over much of the wide part of the eastern outcrop, to the west of the Aird of Sleat, semi-pelitic rocks containing thin alternations of siltstone and pelite are common. These alternating layers are measureable in millimetres. The boundaries between the two are sometimes sharp and sometimes gradational and some are highly suggestive of graded bedding. Evidence of "way up" of a more reliable nature is, nevertheless, forthcoming in the form of false bedding. One such exposure is illustrated in figure 18.2(a). This exposure is situated 320yds SE of the summit of Sgurran Seilich, immediately south of the footpath from the Aird of Sleat to the Point of Sleat. The attitude of the sedimentary structures indicate that the beds are inverted. This observation is in accord with the observation of false bedding in the Lower Psammite quoted already in this Chapter and also with the interpretation of the major fold structures in the Caradal nappe as discussed in Part II.

As both Clough (in Peach et alia, 1907) and Bailey (1955) noted, there are porphyroblasts of biotite in the Tarskavaig

Moine rocks of the Caradal nappe. These porphyroblasts appear to be limited to the SE part of the eastern outcrop of the Laidhe na greine group, immediately to the west of the Aird of Sleat. As Clough stated, the porphyroblastic crystals of biotite are better developed in the "sandy" layers of the "phyllites". The study of these rocks in thin section has shown the presence of small garnets first seen by Clough and later by Phillips (1939). Since a thorough discussion of these porphyroblastic minerals depends on a knowledge of their microscopic properties further consideration will be postponed until Chapter 23, where the specific localities of the minerals are recorded.

Bailey (1955, p147), talking of the rocks which are now classified as the Laidhe na greine group in the eastern outcrop, stated that the "phyllites" south of Sgurr nan Coarach (or Ben nan Coarach) were enclosed within an anticline. The evidence quoted in support of this was that, although the grits flanking the phyllite dipped to the east on both sides, those to the west dipped at a steeper angle than those to the east. The evidence accumulating from the study of sedimentary structures and small and large scale folds and associated structures which is presented in this thesis contradicts the hypothesis of Bailey. It is suggested that the outcrop of "phyllite" clearly shown on the map in Bailey (1955, p124) is part of a continuous, not-folded stratigraphical sequence.

The western outcrop of the Laidhe na greine group is little more than 150yds wide and follows the trace of the dislocation that is called the Caradal fault on figure 14.2. Within this outcrop the rocks are predominantly psammites

and, even where exposure is good, the semi-pelitic rocks are not abundant. By far the best exposures are on the coast near the mouth of the Allt na Doirionnaich, approximately 2200yds NNW of the Point of Sleat.

At a distance of 100yds to the east of the fault plane the rocks of the Laidhe na greine group consist of alternations of pelite and fine-grained, pale-grey psammite with little or no megascopic feldspar. These alternating beds are 20-50cms thick. Further to the east these rocks grade into typical members of the Upper Psammite. To the west, towards the fault plane, the alternating beds of psammite and semi-pelite or pelite gradually become thinner until they are of the same thickness as sheets of cardboard. Within about 4 metres of the fault plane, although the gradation is scarcely perceptible, the semi-pelitic rocks become greyish-green in colour while the feldspathic bands carry a pinkish tinge. Apart from these differences in colour the other properties of the rocks, such as the thickness of the alternating layers and the grain size, are much the same as the rocks further from the fault.

It is almost certain that the colours of the alternating layers of rock close to the dislocation prompted Clough to identify them as Lewisian. However, they do show certain differences (page 225) from those rocks in the eastern part of the Caradal nappe which have been identified as Lewisian with far greater confidence. These differences are thought to be of sufficient weight to cast doubt on Clough's identification of these rocks as Lewisian.

The Upper Psammite occupies much the largest area of

outcrop of the four groups of rocks in the Caradal nappe. The main reasons for this seem to be twofold. Firstly it is a formation which must be considerably thicker than any of the others and, secondly, it occupies the core of the very large Caradal synform.

Some general views of the nature of the exposure in the Upper Psammite are shown in figures 0.2(a) and 12.1. Closer views of beds near to the middle of the succession are show n in figure 18.3(b&c). These are typical of the greater part of the present area of outcrop.

As shown in figure 18.3(b), most of the Upper Psammite is divided into beds 10-20cms thick by thin partings of semi-pelitic material. These beds are pink, pinkish-white or buff coloured on weathered surfaces and where these surfaces are waterworn, as in figure 18.3(b), dusty-grey streaks may become prominent. The grain size is usually fine or medium but occasional coarse layers are encountered. One of these is illustrated in figure 18.3(c) which is a closer view of the bottom right corner of the exposure illustrated in figure 18.3(b). Quartz is the most abundant constituent of these rocks and nearly always occurs as elongate grains. Grains of feldspar are ubiquitous but are less frequently elongated. The elongation of the grains is parallel to the axes of the Capistal group of folds. The quartz grains are coloured white, pale-grey, or more rarely pale-blue. Most of the feldspar grains are a striking orange colour.

Deviations from the typical lithology of the Upper Psammite are three-fold.

Firstly, near to the stratigraphical bottom of the

succession the partings of semi-pelitic material tend to become more closely spaced. This feature is illustrated in figure 18.3(a). Apart from the closer spacing of the semi-pelitic partings, the grain size, colour, and other properties of the rocks are, within practical limits, the same as in the higher parts of the succession.

Secondly, near to the top of the exposed succession, some psammite bands have abnormally coarse clastic texture. The Caradal synform plunges towards the south and thus the highest exposed beds of the Upper Psammite are to be found in the far south of the Sleat peninsula. Among these exposures, there are many which contain sizeable pebbles both of quartz and of feldspar. These pebbles are usually of elongate shape with their longest axes parallel to the elongation lineation in the host rock. The pebbles may be as much as 2cms in their longest dimension. The quartz is usually milky white; the feldspar brilliant orange.

Lastly, a third kind of difference from the common aspect of the Upper Psammite is the presence of semi-pelitic beds of appreciable thickness. Although the position of these beds has not been recorded in detail, the overall impression is gained that they are most common near to the middle of the exposed succession than elsewhere. There are, for example, several such bands in the cliff exposures below Creag Mhôr. One of the semi-pelitic beds can be seen in figure 18.3(b) not far above the handle of the hammer. These beds are of medium grey colour and of uniform fine-grain size. The thicker semi-pelitic beds, up to one metre, may contain well-defined, thinner beds of psammite as shown in figure 12.3(b).

Sedimentary structures indicative of "way-up" are present in the Upper Psammite. However, partly because of the deformation the rocks have suffered and partly because of their original nature, they are not usually sufficiently distinct to allow a completely unambiguous interpretation to be made. The dusty grey streaks shown in figures 18.3(b&c) may, in places, be suggestive of false bedding. One example of false bedding which may be accepted as being reasonably conclusive is illustrated in figure 18.2(b). This is situated on the right bank of the Allt na Doirionnaich about 950yds from the coast and demonstrates that the beds in the vicinity are "right way up".

False bedding was noted in the rocks of the Tarskavaig Moine series by Clough (in Peach et alia, 1907, p590, p620) and by Bailey (1955, p143, p146, p149). Bailey (1955, p146) noted that rather poorly preserved current bedding in Group (3) (see page 286) supported the conclusion that the order of deposition was from Group (1) to Group (3).

False bedding from which the direction of younging of the strata may be confidently deduced has been observed in all three stratigraphic units of the Tarskavaig Moine rocks in the Caradal nappe. These localities, as well as the directions of younging and the axial traces of the major folds are shown in figure 18.4.

Before passing on to a discussion of the relation of the Tarskavaig Moine rocks to the Lewisian rocks in the Caradal nappe, an attempt will be made to estimate the stratigraphical thicknesses of the three units in the sedimentary succession. Because of the strong deformation,

this is difficult. The results that are attainable may bear little relation to the original thicknesses of the units. The first problem is that the rocks have been twice folded by structures of large scale and, furthermore, that the inclination of the bedding, as shown in figure 12.2, is subject to curious deviations. A second problem is that the rocks contain a very strong elongation lineation. It seems reasonable to assume that the elongation of quartz and feldspar is an indication that the rocks have suffered deformation. The character and amount of this deformation cannot be reliably estimated by any present method.

Making no allowance for the second of these problems, the present stratigraphic thicknesses of the three units of the Tarskavaig Moine rocks are very approximately as follows:-

Upper Psammite	2000-2500ft (Top not seen)
Laidhe na greine Group	1200ft
Lower Psammite	600ft

The junctions between the Tarskavaig Moine rocks and the Lewisian are of two types in the Caradal nappe. No discussion will be included of junctions which are obviously the site of faults which post-date, or are possibly contemporaneous with the Caradal, or third generation of folds. The other type of junction is clearly of much greater fundamental importance.

Unfaulted junctions are well exposed in many places and, as was noted in Chapter 14, the Tarskavaig Moine rocks close to this junction, as well as all of the Lewisian, are mylonites. The distribution of these mylonised rocks is shown in figure 18.4.

Some good exposures of the mylonised Tarskavaig Moine rocks are situated 500yds ENE of the Loch Sgurr nan Caorach outlet. These may be taken as typical of the group as a whole. In one of these, the exposures are mostly of very fine grained rocks in which it is quite impossible to distinguish individual grains. Judging by the colours of these rocks, which are different shades of yellow and greyish-yellow, they are composed essentially of quartz and feldspar. The individual foliae, which may be very thin, follow smoothly flowing paths and outline in places small, tight folds of the Doire na h-Achlais, or second generation. Less common layers are of a bluish-green colour and contain veins of milky quartz with subordinate clots of bright orange feldspar. These veins are also folded.

Some illustrations of such rocks from other localities are presented in figure 11.1(b-e) and in figure 18.1(c). Further away from the junction with the Lewisian, these rocks of mylonitic aspect grade into the normal rocks of the Tarskavaig Moine succession. To the SE of Loch Ben nan Coarach, where the Capistal synform is most easily demonstrated, the rocks of the Lower Psammite grade from almost their normal appearance in the hinge zone of the fold into the mylonites close to the Lewisian on the limb of the fold. The orientation of the mylonite zone is much the same as that of the axial plane of the Capistal synform and all of the Lower Psammite, therefore, could conceivably be present in the mylonite zone. Thus there is no reason to postulate any major dislocation between the Tarskavaig Moine rocks and the Lewisian: the Lower Psammite, the youngest member of the Tarskavaig Moine

succession, may well be present, in a mylonised form, along the entire length of this junction.

The Epidotic Grits of the Torridonian to the SW of Loch a'Ghlinne are not thought to belong strictly to the Caradal nappe. The evidence for this statement is contained in Chapter 14. Both Clough (in Peach et alia, 1907) and Bailey (1955) bestowed a great deal of attention to these rocks and nothing of value can be added to their excellent petrographic descriptions. Although bedding may be seen in these rocks, they are completely devoid of any other structures such as folds or elongation lineation. A short description of the microscopic appearance of these rocks will be presented in Chapter 23.

In the rocks of the Caradal nappe, three important metamorphic events have been established. These are: the production of the elongation lineation, the mylonisation of the Lewisian and some of the Tarskavaig Moine rocks, and the growth of the porphyroblasts in the Laidhe na greine Group in the SE part of the Caradal nappe. On the basis of evidence gathered in the field and summarised so far in this thesis, it is possible to draw some correlation between these metamorphic events and the structural history of the Caradal nappe.

There can be little doubt that the elongation lineation is genetically connected with the development of the Capistal, or first folds in the Caradal nappe. The grains of quartz and feldspar in the psammites are so shaped that they are elongate parallel to the axes of the small Capistal folds and in many cases the grains can also be seen to be flattened parallel to the axial planes of these folds. It was argued

in Chapter 10, page 187, that the processes by which the elongation lineation was formed must have outlasted the development of the Capistal folds.

The mylonitic banding in the Lewisian rocks, and in some of the Tarskavaig Moine rocks, is distorted by folds of the Doire na h-Achlais generation. The quartzo-feldspathic bands in these mylonites also carry the lineation parallel to the axes of the Capistal group of folds. The process of mylonisation must, therefore, be earlier than the Doire na h-Achlais folds but its age relation to the elongation lineation remains obscure. The lineation can be seen in the mylonised rocks but is much less obvious than in the normal Tarskavaig Moine rocks. This could suggest that the mylonites and the elongation lineation may have been produced at the same time. Another observation which adds weight to this conclusion is that, on the regional scale, the mylonite belt in the Tarskavaig Moine rocks is parallel to the axial planes of the Capistal folds.

The porphyroblasts of biotite in the SE part of the Caradal nappe are certainly later then the elongation lineation since they cut across it. Small microfolds in these porphyroblasts seem to be associated with very locally developed strain-slip structures.

EXPLANATION OF FIGURE 18.1.

(a) Coarse members of the Lower Psammite with a layer rich in pebbles of milky quartz. 200yds SW of the Loch Capistal outlet.

(b) False bedding in the Lower Psammite. 400yds SW of the Loch Capistal outlet. The layer containing pebbles of milky quartz at the top of the exposure truncates the bedding planes in the coarse grained rocks of the Lower part of the exposure.

(c) Mylonised Tarskavaig Moine rocks 550yds NW of the Loch Ben nan Caorach outlet.



a)

b)

c)

Lower Psammite and mylonised rocks

Figure 18.1

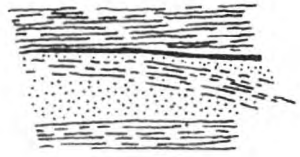
EXPLANATION OF FIGURE 18.2.

(a) False bedding in the Laidhe na greine Group. 350 yds SE of the summit of Sgurran Seilich. At the top and bottom of the sketch, the rocks are semi-pelites. Between them is a finer grained, feldspar-free psammite on the upper (or younger) side of which is a thin yellow layer indicated by a thick black line.

(b) False bedding in the Upper Psammite on the right bank of the Allt na Doirionnaich about 950yds from its mouth. The dark lines represent groove-like indentations in the surface of the exposure.

a)

Scale not known: approximately one sixth.



False bedding in Tarskavaig Moine rocks

b)

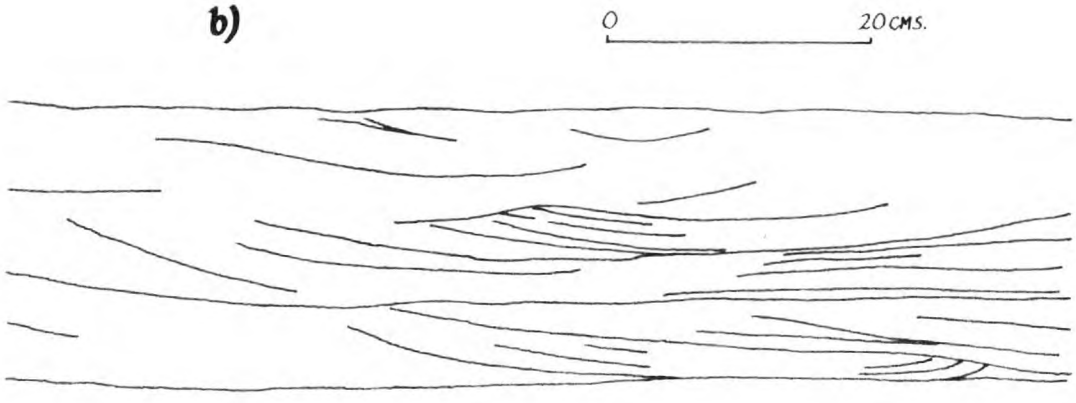


Figure 18.2

EXPLANATION OF FIGURE 18.3.

(a) Rocks of the Upper Psammite 120yds WSW of the NW tip of the main outcrop of Torridonian Epidotic Grit. These rocks are near the bottom of the Upper Psammite and demonstrate the closer spacing of the semi-pelitic partings as compared with the rocks near the middle of the exposed portion of the Upper Psammite illustrated in (b) and (c).

(b) Exposure in the Upper Psammite in the northernmost part of the bay to the west of Creag Mhôr. These rocks are close to the middle of the exposed Upper Psammite succession. Semi-pelitic beds, such as that shown near the middle of the photograph, are common in this part of the Upper Psammite.

(c) A close view of the lower, right corner of the exposure illustrated in (b) showing dusty grey streaks and a coarser grained layer.

a)

b)

c)

The Upper Psammite

Figure 18.3

EXPLANATION OF FIGURE 18.4.

Map showing the distribution of mylonites in the Caradal nappe as well as the axial traces of major folds and the localities at which "way-up" of the strata has been determined.



False bedding and mylonites in the Caradal nappe

Figure 18.4

CHAPTER 19. SUMMARY OF THE FIELD DESCRIPTIONS OF THE ROCK GROUPS. 311.

Part III of this thesis has been concerned with the appearance of the different groups of rocks in the field as observed megascopically and with the aid of a magnifying glass. From the textures that have been observed and described, it is possible to make numerous deductions and to recognise several events in the metamorphic history of the rocks. The purpose of this Chapter is to summarise these descriptions and deductions. The Chapter is organised on the same plan as the Part of the thesis that it summarises: the rocks of the Moine nappe are treated first, the rocks of the Caradal nappe second.

In the Moine nappe the outcrops have been divided into three areas by two lines: the Ostaig and Knock lines. These lines are shown on Plate 4 and the factors which define them precisely are shown in the key. These lines are also shown on Plate 5 in a more generalised form. On this latter map allowance has been made for the poor degree of inland exposure and the lines are drawn in positions where they would most likely be found if the exposures were complete.

To the east of the Knock line only Lewisian rocks are to be found in the area of study. These rocks contain structures belonging to the Baravaig, or first and Rudha Phoil, or second groups as well as a few structures of the Tormore, or third group. These Lewisian rocks are, on the whole, massive and coarse grained and contain porphyroblasts.

Between the two lines, both Lewisian and Moine rocks occur. In these rocks the Baravaig, Rudha Phoil, and Tormore structures are developed and are particularly well displayed in the Moine series. The rocks are in part massive and coarse

grained and in part fissile and fine grained. Porphyroblasts are present here as well as to the east of the Knock line and are particularly prominent in the fine grained rocks because of the contrast in grain size.

West of the Ostaig line, both Lewisian and Moine rocks are represented. Apart from small outcrops of massive ampibolite, the rocks are fine-grained or very fine-grained and are completely free of megascopic porphyroblasts. Folds of the Ard Thurinish group are very common.

The Lewisian rocks east of the Knock line fall into three well defined groups distinguished on Plate 5. In terms of area of outcrop, the smallest of these is the serpentinite. This rock forms a massive, dark coloured, unfoliated body which in places contains brown spots (possibly of carbonate), garnets and magnetite veinlets. A second and larger group is designated "unmigmatised amphibolites" on Plate 5. These amphibolites have sharp boundaries with the country rocks and in places may be seen to be discordant. They are sheet-like in form and vary in thickness from a few cms to several scores of metres. The composition of the amphibolites is very uniform. They contain dark green amphibole sometimes accompanied by pink, feldspathic spots. Irregular veinlets of white, quartzo-feldspathic material are common.

The country rocks which form the greater part of the Lewisian outcrop to the east of the Knock line are widely variable in composition and the boundaries between these different rock types are mostly gradational and very ill-defined. Some of the different types of rocks are: apple-green amphibolite, pink acid gneisses, greenish-grey biotite epidote rocks, quartzo-feldspathic rocks with orientated and

not so obviously orientated porphyroblasts of biotite and amphibole in widely varying abundances, zoned basic lenses, rose-pink feldspar porphyroblasts in acid gneiss, and bottle-green chlorite rocks. Small, pinkish brown garnets are commonly seen in the amphibole-biotite gneisses and pale-green epidotic streaks are often found in acid and basic rocks. Curiously shaped bodies of quartzo-feldspathic rocks indicate that migmatisation occured before the Baravaig, or first period of folding. The unmigmatised amphibolites cross-cut these migmatites and presumably represent igneous sheets. The unmigmatised amphibolites are also earlier than the Baravaig period of folding.

Between the Knock and Ostaig lines both Lewisian and Moine rocks occur. Among the Lewisian rocks the types which characteristically occur to the east of the Knock line are found in pod-like and lens-shaped bodies. The most common types of massive, coarse grained rocks in these pods and lenses are acid gneisses with amphibole porphyroblasts and unmigmatised amphibolites. The massive rocks are surrounded by fine-grained, fissile rocks with closely spaced parting planes. The fine-grained rocks vary in composition from pink or pale-grey quartzo-feldspathic rocks to dark-green chloritic schists. The alternating bands are rarely more than 3cms thick. Veins of milky quartz may contain subordinate amounts of calcite, chlorite, feldspar and amphibole. The Porphyroblasts, which are prominent in the fine-grained rocks, include several varieties of chlorite, small needles of amphibole (up to 3mm long), and biotite. The amphiboles invariably lay on the foliation planes and within these planes they may have a preferred orientation or may be random. The micaceous minerals usually occur

with their cleavage aligned parallel to the foliation but there are cases where they are clearly oblique to the foliation and may also be orientated into a girdle fabric which defines a lineation associated with the Tormore, or third group of fold structures.

The boundaries between the massive, coarse-grained rocks and the fine-grained fissile rocks are of interest. The contacts of massive acid rocks are sharp but those of the massive unmigmatised amphibolites grade almost imperceptibly into fine-grained chlorite schists. This latter fact seems to indicate that the fine-grained rocks to the west of the Knock line were derived from rocks of the type now outcropping to the east of the Knock line by a process of grain size reduction. This process must post-date the Rudha Phoil, or second period of folding but is earlier than the Tormore, or third period of folding because some of the micaceous porphyroblasts in the fine-grained rocks define a girdle fabric which seems to be associated with the Tormore folds.

The Moine rocks between the Knock and Ostaig lines are exposed on the peninsulas at Ardvasar and on a short coastal section near Tormore. At the former locality there is a well-defined outcrop of psammite and two separate areas of semi-pelite which are shown in figure 3.4. There are no detectable differences between the two outcrops of semi-pelite and a typical exposure is shown in figure 2.1. The rocks are pale to medium-grey and of fine to medium grain size. Muscovite is prominent, and garnets measuring up to 3-4mm are visible in some parts. The psammite bands, usually 5-6cms thick, contain only a low proportion of feldspar. In the main outcrop of psammite, the

individual bands are 5-30cms thick and are separated by thin micaceous partings. They are of medium to coarse grain size. The feldspar, which is stained bright orange, forms a high proportion of the rocks.

At Tormore, the Moine rocks which lie between the Knock and Ostaig lines are mostly semi-pelitic and contain only a few, thin psammite bands. The semi-pelitic bands are similar to those at Ardvasar but the psammite bands show a wider variety of textures. Some psammite bands are coarse, and possess compact marginal zones but interior zones which are very roughly weathered and which probably contain a high proportion of calcite. Rarely, well-defined coarse bands can be seen to pass laterally into layers containing widely scattered grains of milky quartz (up to 13mm long) which are contained within a fine-grained semi-pelitic host. Features such as this are almost certainly remnants of an original sedimentary texture.

To the west of the Ostaig line, both Moine and Lewisian rocks are represented. They are of much finer grain size and only very rarely can individual mineral grains be distinguished. Both groups are free of megascopic porphyroblasts. The representatives of the Lewisian series are composed mostly of pink or pale-grey acid rocks interlayered with dark-green chloritic schists. A few layers are tinged with the characteristic pale-green of epidote. The massive rocks are represented only by a few bodies of foliated amphibolites containing feldspathic lenticles which grade almost imperceptibly into the dark-green fissile rocks. Discordant veins of milky quartz enclose small bodies of dark-green chlorite

and some calcite. The psammitic and semi-pelitic types of the Moine series are intercalated on a very small scale. In a few localities, small garnets are visible.

The contact between the Moine and Lewisian groups in the Moine nappe is exposed in a number of places. However, to the east of the Ostaig line all such exposures demonstrate a contact that has been affected by late-stage faulting. Thus nothing of the more fundamental relations of the Moine and Lewisian groups can be seen. To the west of the Ostaig line there are several localities where the Moine-Lewisian contact is free of late-stage dislocation. In all of these exposures, the foliation in both groups is perfectly concordant with the plane of contact and the Moine and Lewisian rocks immediately adjacent to the contact are in no way different from comparable Moine and Lewisian rocks at a considerable distance.

Over most of the length of the contact, the Moine rocks lie above the Lewisian; both formations dipping SE. Along the poorly exposed northern part, however, the Moine rocks clearly dip beneath the Lewisian. Bailey (1955) postulated a sandwich arrangement with a slice of Moine rocks flanked by Lewisian. This hypothesis may be elaborated in that the Moine rocks are probably contained in the core of a large scale isoclinal fold of the Baravaig, or first generation which closes to the NE and plunges to the SE.

Many of the metamorphic events which affected the rocks of the Moine nappe and which have been discussed in the earlier Chapters of Part III can be related to the sequence of folds established in part I. A brief summary of the inter-relations

of structural, metamorphic, and igneous events in the rocks of the Moine nappe can be conveniently tabulated:-

1. Migmatisation in the widely variable rocks of the Lewisian complex.
2. A phase of igneous activity during which basic sheets were intruded. These sheets are now represented by unmigmatised amphibolite.

The Moine rocks contain no amphibolite and have not been migmatised. However, they are of such small extent in the present area of study that no far reaching conclusions can be drawn from this observation. They have been affected by the Baravaig folding.

3. The first, or Baravaig period of folding.
4. The Rudha Phoil, or second period of folding.
5. Considerable reduction in grain size of the rocks on the NW limb of the Knock synform.
6. The Tormore , or third period of folding. This may have been accompanied by the crystallisation of the prophyroblasts in both Moine and Lewisian rocks. If not, then the porphyroblastic crystals certainly grew at a later stage.

Because of the difficulty of determining the age relations of the Ard Thurinish and Tormore, or third folds (a topic that was discussed in Chapter 4) this table cannot be continued directly. On the basis of the evidence presented in Part I it is possible that the Ard Thurinish folds are of the same generation as the Tormore, or third folds. If not, then the Ard Thurinish folds are certainly later. Taking these considerations into account, the table may be continued thus:-

A. Development of the Ard Thurinish group of folds. A third or possibly fourth generation.

B. Introduction of veins of milky quartz with subordinate calcite and chlorite.

C. The development of the Port a'Chuil group of folds.

D. The conjugate group of folds.

E. Movement on the Moine thrust plane.

The rocks of the Caradal nappe are fairly well-exposed over most of the area of their outcrop. In Chapter 14 the dislocations which affect these rocks were discussed at length and a new hypothesis was put forward. According to this view, the "Caradal nappe" is composed of those rocks which are contained within the area enclosed by the Tarskavaig thrust, the Caradal fault and the west coast of the Sleat peninsula as shown in figure 14.2. The fold structures in the Caradal nappe are complex but an elucidation of the geometry of these fold structures together with a knowledge of the few sedimentary structures which reliably indicate "way-up" has allowed the following stratigraphical succession to be recognised:-

Upper Psammite 2000-2500ft. (Top not seen)
Laidhe na greine Group 1200ft.
Lower Psammite 600ft.
Lewisian.

The thicknesses quoted in this table take no account of deformation due to the development of the elongation lineation or of the folding. They indicate the present thicknesses and may bear little relation to the original stratigraphical thicknesses.

The Lewisian rocks of the Caradal nappe are fine-grained mylonites. In the wide southern part of the outcrop they are composed of alternating laminae coloured pink and green by chlorite and epidote. In the narrow northern part of the outcrop shades of grey or greenish-grey are more common. Thin, straight sided veins of milky quartz are abundant. Clough claimed to have recognised Lewisian rocks in the extreme west of the Caradal nappe, next to the dislocation which is called the Caradal fault on figure 14.2. This identification is disputed in Chapter 14 and the rocks in question are thought to be members of the Laidhe na greine Group.

The Lower Psammite is illustrated in the photographs of figures 10.1, 14.4(c), and 18.1(a&b). The rocks are mostly of medium to coarse grain size and may contain pebbles of milky quartz either in layers or scattered through the host rock. Grains of feldspar are rarely obvious in the Lower Psammite. False bedding is present in some localities but at only one of these is the order of deposition unambiguous.

The boundary between the Lower Psammite and the Laidhe na greine Group is transitional and is defined on Plate 5 at the lowermost appearance of semi-pelitic bands of measureable thickness. The area of outcrop of the Laidhe na greine Group, in fact, includes nearly all semi-pelitic bands which are more than a few millimetres thick. It also includes a high proportion of [illegible]-psammitic rocks as well as a few of pelitic composition. The feldspar in the psammites is often stained deep orange while the quartz is milky-white or tinted pale-grey or pale-blue. Both of these minerals may occur in grains up to 1cm long. Most of the rock types appear to be well

sorted. In the SE part of the outcrop, many of the exposures are composed of rapid alternations of siltstone and pelite and among these, a graded bedding relationship is very common. False bedding is not common in the Laidhe na greine Group and only one exposure has been observed at which the direction of younging can be determined with certaihty. The SE part of the outcrop of the Laidhe na greine Group is also notable for the presence of porphyroblasts of biotite. None of these appear to demonstrate a well-marked preferred orientation. Small lath-shaped crystals, which may be ilmenite, are scattered with random orientation over some of the dark-grey pelitic parting planes and, very rarely, small pin-head garnets can be seen.

Rocks of the Upper Psammite are illustrated in the photographs of figure 18.3(b&c). They are typically pink or buff coloured and are of fine to medium grain size. Towards the top of the exposed succession coarse or very coarse layers become more common. The feldspar grains are often of a striking orange colour. Towards the bottom of the Upper Psammite the beds bcome thinner and near the middle of the exposed succession there are a few beds of semi-pelite which may be as much as one metre thick. False bedding is very common in the Upper Psammite but on account of the deformed state of the rocks it can rarely be used to determine the "way-up" conclusively.

The contact between the Tarskavaig Moine rocks and the Lewisian rocks is very well-exposed in many places. All of the Lewisian and a narrow strip of the Tarskavaig Moine rocks are mylonised as shown in figure 18.4. The foliation in both

groups is perfectly concordant with the plane of the contact. Some of the mylonised rocks are illustrated in figures 11.1(b-e) and 18.1(c). These rocks of mylonitic aspect grade imperceptibly into the normal rocks of the Tarskavaig Moine series further away from the contact with the Lewisian.

The Lower Psammite is probably represented, in a mylonised form, along the whole length of the junction between the Tarskavaig Moine rocks and the Lewisian and it is not necessary to postulate any dislocation between the two groups.

The Epidotic Grits of the Torridonian series, which occur in three small outcrops near the north of the Caradal nappe, do not strictly belong to the Caradal nappe, They are separated from the Tarskavaig Moine rocks by dislocations on all sides and contain no folds or elongation lineation.

Microscope investigations of thin sections are concentrated on the observation of the textures rather than the analysis of their mineral composition. The rocks of the Moine and Caradal nappes show a wide range of texture and mineral composition. Some of these textures can be related to metamorphic and structural events.

Relatively little space will be given here to the details of the mineralogy of the rocks and the implications they carry. These are the main aspects of research being carried out by David Matthews of Cambridge University.

In preference to describing many thin sections in detail, each mineral species will be discussed in turn with specific reference to selected thin sections which show particular features of interest. The localities from which the material was collected will not usually be given but may be quickly found by reference to appendix 1 and Plate 6.

CHAPTER 20. THE LEWISIAN ROCKS OF THE MOINE NAPPE. 323.

In Chapter 16, the Lewisian rocks of the Moine nappe were allocated to one of three groups according to their position relative to the Knock and Ostaig lines shown on Plate 4. To the east of the Knock line, the rocks were described as ultra-basic 'gneisses' (or serpentinites), amphibolites, and the third and largest group, the country rocks of widely variable composition. Between the Knock and Ostaig lines, massive rocks of the type more usually found east of the Knock line are represented in scattered lenses of different sizes. These lenses are surrounded by fissile and flaggy rocks, generally of finer grain size. Porphyroblasts are prominent in some of these fissile and flaggy rocks. To the west of the Ostaig line, there are no megascopic porphyroblasts and coarse grained gneisses are only represented in rare outcrops of amphibolitic composition.

The Rocks East of the Knock Line: The Country Rocks.

The groups of rocks are of widely variable composition and are ornamented with vertical lines on Plate 5. The most common minerals are: quartz, feldspar, epidote, orthite, apatite, biotite, muscovite, chlorite, garnet, calcite, pyrite and other opaque minerals. These will be briefly described in this order.

Quartz varies widely in abundance in these rocks. Light coloured rocks are often composed largely of quartz whereas in some mafic rocks it appears to be totally absent. In most of the rocks, the extinction position of the quartz grain often varies from one part of the grain to another . This phenomenon is known by several different names but "undulose extinction" is probably the best descriptive term.

Undulose extinction varies from a type in which there are no distinct internal boundaries in the grain (so that the extinction position varies continuously from one part of the grain to another) to a type in which there are distinct internal boundaries within the grain (so that the extinction position varies discontinuously.) In the latter case, the extinction positions of the individual sub-grains (the blocks of the crystal lattice that are defined by the internal boundaries, or sub-boundaries) are slightly different from one sub-grain to the next so that the lattices of the sub-grains differ only slightly in their orientation relative to each other. Sander (see Griggs and Bell, 1938, p1728) has measured the variation in the extinction position of many single quartz grains and reports that it may exceptionally be as much as 70°. In deformation experiments, Griggs and Bell, 1938, induced undulose extinction in quartz grains in an unconsolidated powder. The angle over which the extinction position varied was not greater than 7°.

Very similar structures to those described above are well-known in other crystalline solids. The existence of sub-grains in crystals of polycrystalline aggregates was first reported in 1927 in ferrite. Beck (1952) reviewed the then current knowledge on this subject and in figures 20-22 of his paper he shows excellent microphotographs of sub-grain structure in aluminium which compare very closely with sub-grains in quartz. Cahn (1950) investigated the development of the structure in single crystals and reported it in aluminium, mild steel, alpha brass, zinc, lead, sodium, magnesium, rock-salt, and cadmium. The process, which Cahn called

"polygonisation", was further investigated by Cottrell (1953) who accounted for it in terms of a theory of lattice dislocations. Cottrell's theory is now widely accepted.

The result of these, and other experimental studies indicate that the sizes of sub-grains are determined by:-

1. The temperature at which deformation takes place.
2. The rate of strain during deformation.
3. The amount (if any) of sub-grain growth after the deformation.

Voll (1960) suggested that the sub-grain structure of quartz might be a result of polygonisation and Harris and Rast (1960) have based a theory of evolution of quartz fabrics on this idea. However, arguments put forward by Beck (1952) do not support either of these hypotheses.

The textures and patterns of preferred orientation in polycrystalline solids are determined largely by the way in which the grain boundaries move, and the conditions under which new grain boundaries may be formed (eg, Beck, 1952; Burke, 1949,; Burke and Shiau, 1947; and Maddigan and Blank, 1940). The formation of new grain boundaries and the movement of grain boundaries through crystal lattices would appear to be governed by:-

1. Temperature.
2. Degree of strain in the crystal lattices.
3. Initial grain size.
4. Time.
5. Differences in composition, or composition gradients.

There are many different phenomena associated with the movements of grain boundaries which may be classified as:-

1. Recrystallisation (strict sense)
2. Grain growth.
3. Discontinuous grain growth.
4. Strain-induced grain boundary migration.

Burke (1949), Beck (1952), and Smith (1953) have described these phenomena very clearly and no further discussion will be given here.

The relevance of these different processes of re-crystallisation, grain growth, etc. to the interpretation of the textures of quartz in thin section is as follows. With very few exceptions, it is found in experiments that a recystallised, polycrystalline substance is free of any kind of sub-grain structure. Even in the exceptional cases (such as aluminium) it is found that only a few of the newly recrystallised grains possess a sub-grain structure; the sub-grain structure is usually completely eliminated when the recrystallisation takes place. However, sub-grain structure is common in the quartz of the Moine and Caradal nappes of Skye. Probably, therefore, the presence of sub-grains in such large numbers indicates that the quartz is not in a recrystallised state. Quartz with sub-grain structure in the rocks east of the Knock line is common and well-displayed in sections 18789, 18800, 18801, 18806, 18973, 19249 and 19250.

In some of the sections, eg 19250, the quartz occurs in a very wide range of grain sizes. The large grains and the small grains tend to be segregated into bands that define the foliation. The large grains are clearly divided into sub-grains whereas the small grains are usually free of sub-boundaries. Also the large grains often have much more complex

boundaries than the small grains: the boundaries of the small grains commonly meeting each other at triple points where the boundaries subtend angles of approximately 120°. It is possible that under the conditions of the metamorphism the boundaries of all the grains migrated a distance comparable to the grain size of the small grains (cf, the results of Burke and Shiau, 1947). The sub-grain structure of the small grains, assuming it to have existed in the first place, would thereby be eliminated while it would persist in the larger grains. Also a certain amount of ordinary grain growth among the smaller grains would lead to the production of a mosaic texture of grain boundaries meeting at triple points of 120°.

Feldspar is common but varies considerably in abundance in the rocks east of the Knock line. Most of the grains are very small (ca. 0.3mm) and are not twinned. A few albite twins occur in sections 18801, 18802, 18803, 18969, 19249 and 19250. In 19249 the twin lamellae are distorted.

The range of grain size of the feldspar is usually similar to that of the quartz in the same section. Boundaries between adjacent feldspar grains are simpler than those between adjacent quartz grains. Undulose extinction is both less common and less striking than that to be seen in the quartz. Feldspar sub-grains are to be seen only in 18801 and 18802.

Inclusions of sericite and epidote are prominent in the coarser feldspar grains. The inclusions are often localised in certain parts of the feldspar crystals, the remaining parts being clear.

The most usual interpretation of this phenomenon is that

the feldspars have suffered alteration by solution penetrating along the grain boundaries, cleavages and other lattice planes. An alternative possibility is that the feldspars have suffered a process of discontinuous precipitation during grain boundary migration such as illustrated by Smith (1954) figure 26. Those parts of the feldspar crystal that are crowded with inclusions have been swept by a moving grain boundary and have thus been able to adjust their chemical composition to the prevailing metamorphic conditions. The clear parts of the feldspar crystals are thus possibly in a relatively metastable state.

Porphyroblasts of feldspar are seen only in section 18959. They are much larger than the other minerals of the host rock and possess a curious undulose extinction. The inclusions are only of quartz and are arranged in strings parallel to the foliation in the host rock. The quartz grains are round or elliptical with their long axes parallel to the foliation.

The shape of the quartz inclusions is almost certainly an indication that the quartz-feldspar boundary was freely mobile. Smith (1953) points out that, under the influence of interfacial tension, the equilibrium shape of a crystal which is totally enclosed in another crystal is spherical, assuming that the grain boundary is free to move and that the interfacial tension is the same in all directions. In the case of the quartz-feldspar texture thus described, it cannot be fairly deduced that the feldspar is replacing or corroding the quartz in any way: the volume of the quartz included in the feldspar may remain constant as the boundary migrates, the spherical shape representing the lowest state

of free energy.

Epidote is a prominent constituent of all rocks east of the Knock line. As well as the inclusions in feldspar, it also occurs in small granular or prismatic crystals rarely longer than 0.25mm. These crystals are usually concentrated in trails defining the foliation and in sections 18800 and 19249 these trails outline microscopic folds of the Rudha Phoil, or second generation. Near these microfolds, the prisms of epidote are undistorted and similar undistorted prisms often occur in close association with quartz and feldspar which show indications of internal strain such as sub-grain structure and undulose extinction. The present state of crystallisation of the epidote thus appears to post-date the Rudha Phoil, or second folds while the highly deformed state of the quartz and feldspar probably dates to the time of the Baravaig, or first folding, when a strong elongation lineation was induced throughout the area.

Orthite occurs in sections 18789 and 19249. Some of the orthite occurs in the cores of euhedral epidote crystals. The orthite cores are sub-rounded and very few remains of the crystal structure may be seen. The rounded shapes of the orthite cores, reminiscent of augen, seem to suggest that the mineral was present at an early stage in the deformational history of the rocks and was possibly strained at the same time as the quartz and feldspar.

Apatite is rare. The crystals are of the same size as the more common epidote and the occurence in trails is also very similar.

Biotite is very widespread but is not so persistent in

occurence as epidote. The colour varies widely between different types of green and brown. The crystals are larger than the co-existing quartz, feldspar, or epidote and are of porphyroblastic habit. In sections 18800, 19249 and 19250, the biotite porphyroblasts may be seen to have overgrown small second folds outlined by epidote trails.

Rarely, in some localities in the field (described in Chapter 3), and in some thin sections (eg 18789) there is an obvious pattern of preferred orientation of the biotite. These patterns of preferred orientation are thought to be of the same origin as similar muscovite patterns in the Moine semi-pelitic rocks at Ardvasar where they define the third lineation.

The evidence in the Moine rocks indicates a close connection between the development of the third folds and their associated elongation lineation and the development of the patterns of preferred orientation in the biotite (and the muscovite of the Moine rocks). However, the biotite crystals as they exist now need not have been present at the time of development of the third folds: the porphyroblasts may have grown from nuclei which owe their orientation to the strain system reponsible for the third folds. These nuclei may have been biotite, but the possibility of amphibole or pyroxene nuclei cannot be ruled out. When different polycrystalline solids are deformed experimentally and then recrystallised it is found that various preferred orientations may or may not develop depending on the degree of deformation, temperature at deformation, etc. The impersistent nature of the preferred orientation of the biotite from place to place may be a result of variations in the degree of deformation.

At some localities, biotite porphyroblasts are distorted in close vicinity to what appear to be cleavage planes associated with the Rudha Phoil, or second folds (eg figure 2.5(a)). In thin section, movement on the cleavage planes is indicated by the distortion of biotite crystals. The cleavage planes, however, follow the attenuated limbs of microfolds of the second generation and it seems that the distortion of the biotite crystals is due to posthumous movement on these fold limbs. The structure is thus similar to that described as "Totfalten" by Ampferer (1938).

Muscovite has been noted in 18803, 18959, and 18969. It is not common and seems to be generally of smaller grain size than the co-existing biotite.

Chlorite occurs in sections 18789 and 18970 in contact with biotite, amphibole, or garnet.

Amphibole occurs in many of the rocks east of the Knock line but is not so abundant as biotite. The other common associates of amphibole are garnet and pyrite. Crystals of these mafic and opaque minerals often occur together in clusters of up to about six individuals. The amphibole crystals are usually of porphyroblastic, blade-like habit and may be 6cms long. In some sections, eg 18970, the amphiboles are twinned on (100).

Inclusions in the amphibole crystals are mostly of quartz, feldspar and epidote. The smaller inclusions are more abundant in the central zones while the marginal zones are relatively clear. The larger quartz and feldspar inclusions are round or elliptical in section. The epidote trails described above can be traced through the amphibole porphyroblasts.

The relation of the amphiboles to the epidote trails and the patterns of preferred orientation that are developed at some localities suggest that the amphibole porphyroblasts developed at the same time as the biotite porphyroblasts.

Garnets have been seen at many localities and appear in sections 18789, 18970 and 18971. They are always accompanied by either amphibole, or biotite, or both. The crystals are rounded or euhedral and up to 1mm in diameter. The inclusions in garnet crystals are usually very small and comprise quartz, epidote, and opaque minerals. These inclusions are nearly always confined to the central zones of the garnets.

Calcite occurs in some of the Lewisian rocks east of the Knock line (eg sections 18800 and 18802) and pyrite and other opaque minerals occur in single crystals or aggregates of crystals up to 2mm long.

The Rocks East of the Knock Line: The Amphibolites.

Some aspects of these rocks have been described and discussed on pages 25-28 and pages 252-254. The amphibolites are represented in sections 18957 and 18972.

In both sections, the blue-green amphibole has two modes of occurence. The first group comprises many of the larger crystals, and some of the small ones also. They have a ragged outline, curved cleavage traces, and a type of sub-grain structure. The second group comprises most of the smaller crystals, which are more blade-like than the other group, have sharp boundaries, are not curved, and do not possess sub-grain structure. Some of the crystals in the latter group are twinned.

It seems that the texture of the amphibole in these rocks represents an arrested state of recrystallisation. The texture is very closely comparable to stages in the recrystallisation illustrated by Burke (1949, figure 2). Thus, the large amphibole crystals with ragged boundaries, sub-grain structure, and curved cleavage traces, have been deformed. In this matrix of deformed crystals, new nuclei with different orientations have developed and have grown under the prevailing metamorphic conditions. This process has been arrested so that the old, deformed matrix has not been entirely consumed by the new, growing crystals. The new crystals can be recognised because they show no indication of having been distorted even though they are often decidedly acicular. The old amphibole crystals possibly suffered most of their defomration at the time of the Baravaig, or first folding when the quartz and feldspar of the country rocks was also deformed. The new amphibole crystals probably grew at the same time as the amphibole and biotite porphyroblasts in the counrty rocks, ie after the Tormore, or third generation of folds.

Apatite is common in section 18957 and occurs close to the quartz and feldspar. Epidote is not very common; many of the medium-sized crystals possess orthite cores. The quartz is very fine grained. The feldspar is not twinned and has undulose extinction. It occur in a wide range of grain sizes.

The Rocks Between the Knock and Ostaig Lines.

Some description of these rocks is given in Chapter 16, pages 255-263. These rocks are essentially fine-grained and

fissile with alternating bands of quartzo-feldspathic rocks and chlorite schists which rarely exceed 3cms thickness. Porphyroblasts of micaceous minerals are prominent because of their large grain size in comparison with the crystals of the matrix. Among the fissile rocks there are a number of lenticular bodies of the massive gneisses of the types which predominate east of the knock line. The mode of occurence of these lenticular bodies suggests that they are relics of a grain size reduction process which has produced the fine-grained fissile types. This process probably operated between the second and third periods of folding. The mineral species which occur between the Knock and Ostaig lines are very similar to those which occur east of the Knock line, but the textures are rather different.

Quartz and feldspar are usually difficult to distinguish because of their fine grain size and the general absence of twins among the feldspars. In section 16462, there are lenticular patches composed almost entirely of quartz. These patches are of coarser grain size, the individual crystals are elongate, possess highly sutured boundaries, and display a well-developed sub-grain structure. These patches of coarser grained quartz are a fairly common feature of the rocks between the Knock and Ostaig line and also occur to the west of the Ostaig line.

Feldspar occurs not only in the fine-grained quartz-feldspar aggregates but also in a porphyroclastic habit. This is seen in sections 16483, 16484, 18795, 18796 and 18965. Coarse grained feldspar is abundant in section 16482. The feldspar crystals are up to 1mm diameter, possess shadowy

extinction and contain many inclusions of epidote and other minerals in ultra-microscopic crystals. Very narrow albite twin lamellæ are present in some of the larger feldspar crystals.

In the fine-grained quartzo-feldspathic aggregates of some of these rocks (eg sections 16482 and 16483) the proportion of quartz is very low.

The mode of occurrence of epidote between the Knock and Ostaig lines is very similar to that east of the Knock line irrespective of the degree of fissility of the rocks. The epidote is very widespread and forms trails, parallel to the foliation, of small, granular or sometimes prismatic crystals. Section 16488 contains zoned epidote crystals.

Sphene and apatite are each found in one section only. These are, respectively, 18964 and 16457.

Biotite is green or brown and always encloses the epidote trails in a porphyroblastic habit. In some sections, the orientation is apparently haphazard (eg 16486) whereas in others the biotite crystals lie along the foliation (eg 16482). In section 16482, some of the biotite crystals are oblique to the foliation and such crystals often contain small kinks. Sections 16457 and 18795 show biotite in parallel growth with chlorite.

Muscovite or talc makes up rather fine-grained aggregates in section 18795.

Chlorite has a similar mode of occurrence to biotite and forms porphyroblasts enclosing epidote trails in sections 16484, 18795, 18798 and 18799. In 16484, the chlorite porphyroblasts are 3mm long, are curved, and have polysynthetic twinning developed. The colour of the chlorite varies widely in these porphyroblastic rocks.

Amphibole seems to have two distinct modes of occurrence in the rocks between the Knock and Ostaig lines. Sections 16484, 18795 and 18798 contain distinct amphibole porphyroclasts set in fine-grained amphibole matrices. The porphyroclasts in 16484 show undulose extinction.

The amphibole of porphyroblastic habit is generally of smaller grain size than the corresponding occurrences on the east side of the Knock line. These amphibole crystals are frequently acicular and are aligned parallel to the foliation as seen in sections 16459, 16482, 18799 and 18956.

The Rocks West of the Osatig Line.

These rocks are essentially the same as the fine-grained rocks which occur between the Knock and Ostaig lines. Although no megascopic porphyroblasts can be distinguished in the field, crystals with this habit are seen in thin section.

Amphibole occurs in two modes: as porphyroblasts and porphyroclasts. The former are much smaller than in the corresponding rocks east of the Ostaig line.

Biotite prophyroblasts are also smaller and less common. The biotite crystals occur in close proximity to both the coarse quartz lenticular patches (mentioned above) and the fine-grained quartzo-feldspathic aggregate. In both of these settings, the biotite crystals are generally undistorted whereas the enclosing quartz or quartzo-feldspathic aggregate possesses strongly undulose extinction. In section 16227, foliation (defined by banding of the coarse quartz lenses and the quartzo-feldspathic aggregates) is folded by an Ard

Thurinish fold. The small biotite prophyroblasts show a preferential alignment of their cleavage traces towards the axial plane direction of the fold.

These are represented in two sections: 18807 and 18808. In both of these rocks, there is a quartzo-feldspathic matrix of very fine, sometimes irresolvable grain size. Some lenticular patches of quartz, with gradational boundaries, are of slightly larger grain size. Undulose extinction is common.

Epidote is common in 18808 and occurs mostly as small, granular crystals. Some larger crystals of epidote appear to be of porphyroclastic habit. Section 18808 also contains a number of feldspar porphyroclasts. These are without twinning and have strongly undulose extinction. The diameter of the epidote and feldspar porphyroclasts reaches 1mm.

Micaceous minerals are represented by muscovite and chlorite. Some of the muscovite crystals in 18807 are 2-3mm long and have a lenticular outline as if deformed. The more delicate crystals of both muscovite and chlorite, which may be seen scattered widely through the matrix, appear to be undistorted. A few thin layers in 18807 about 1mm thick are composed almost entirely of micaceous minerals.

The mineral composition of these rocks is much less complex than that of the Lewisian rocks of the Moine nappe. A continuation of the Ostaig line into the area of the Moine outcrop can be recognised (see Plate 4) but the Knock line has no equivalent. The rocks east of the Ostaig line are exposed along two coastal strips: one on the headlands near Ardvasar, the other near Tormore.

The Rocks East of the Ostaig Line: Ardvasar.

Quartz occurs in all rocks and always shows undulose extinction to varying degrees. Sub-grain structure is also common. The range of grain size shown by the quartz is often very wide but small and large grains occur together haphazardly as opposed to being segregated into bands and lenticles as in many of the Lewisian rocks. In sections 16476 and 16478, the quartz is particularly coarse.

Feldspar is not so common as quartz and in most sections is generally of finer grain size than the quartz. Twinning of the feldspar is exceptionally rare. Epidote and sericite inclusions are sometimes present, but not in the same abundance as in the Lewisian rocks of the Moine nappe. Epidote in trails of small granular and prismatic crystals parallel to the foliation has the same mode of occurrence as the epidote in the Lewisian rocks.

Of the micaceous minerals, muscovite is most common. In some sections, eg 16464, there is a preferred orientation of the muscovite. A girdle, or partial girdle fabric of micas is very common in the rocks on the peninsulas of Rubha Dubh and Rubha Phoil. An example is shown in figure 22.1

and others were derived from sections 16473, 16475 and 16476. The megascopic lineation defined by this girdle fabric is parallel to the axes of the Tormore, or third generation of folds.

Biotite is usually less common than muscovite but its mode of occurrence is very similar. In section 16477, from the islands opposite Ardvasar, biotite, together with muscovite and sphene, is very common. The colour of the biotite is widely variable. In sections 16475, 16477 and 16481 it occurs in parallel growth with chlorite.

Garnet is present in many sections and varies in form from small euhedral crystals largely free of inclusions to larger, ragged crystals crowded with inclusions. In sections 16468 and 16478 the trails of inclusions inside the garnets have a different orientation to the foliation outside. Section 16478 is cut perpendicular to the axial direction of a fold of the Rudha Phoil, or second generation. The rotation of the foliation inside the garnets relative to the foliation outside is thus probably connected with the development of the second folds. If so, then the garnets must have existed in the Moine rocks at the time of the second folding.

Sphene, apatite and calcite are rare constituents. Sphene occurs in section 16476 in a band together with garnet. Apatitie has a mode of occurrence similar to that of epidote. The calcite is found in section 16469.

The Rocks East of the Knock Line: Tormore.

Most of the microscopic features, such as the internal structure of the quartz grains and the epidote trails, are similar to those described in the rocks at Ardvasar. These rocks are interesting, however, in that the Tormore, or third

lineation and some small folds of the same generation are much better developed.

Section 16339 is a muscovite, biotite schist with microscopic Tormore folds. The micas in this section, instead of being bent into conformity with the folds, form polygonal arches around them and thus indicate crystal growth after the development of the folds.

Sections 16159 and 16341 also contain undistorted muscovite crystals which, in the former, are orientated into a girdle fabric, the axis of which is parallel to the Tormore lineation.

Calcite is present in quantity in coarse psammitic rocks represented in sections 16340 and 16341.

The Rocks West of the Ostaig Line.

As in the case of the fine-grained, fissile Lewisian rocks to the west of the Ostaig line, the corresponding Moine rocks contain small, lenticular patches, composed largely of coarse-grained quartz (up to 1mm), embedded in a fine-grained, quartzo-feldspathic matrix. These lenticular patches of quartz are seen in sections 16230, 16338 and 16401. The quartz usually has a shadowy extinction.

Feldspar occurs in the fine-grained groundmass and as porphyroclasts. The groundmass feldspar usually lacks twinning although some polysynthetic twins are seen in sections 16244 and 16338. The porphyroclastic feldspar in 16231 is plagioclase. Section 16338 contains only one, untwinned feldspar porphyroclast but there are several in 16401.

Mica in the rocks west of the Ostaig line is more usually

muscovite although biotite may be seen in 16466. The mica crystals, both in the lenticular patches of coarse quartz (eg 16338), and in the finer grained quartzo-feldspathic matrix (eg 16244, 16338 and 16466), are often straight. However, bent crystals are also present. The biotite in 16466 is dark green.

Epidote, in various proportions, is ubiquitous and often occurs in trails of small crystals. Very small garnet crystals are found in section 16244. Small chlorite crystals are fairly common in 16338.

EXPLANATION OF FIGURE 22.1.

A girdle fabric of micas in section 16470. The section is cut perpendicular to the third lineation.

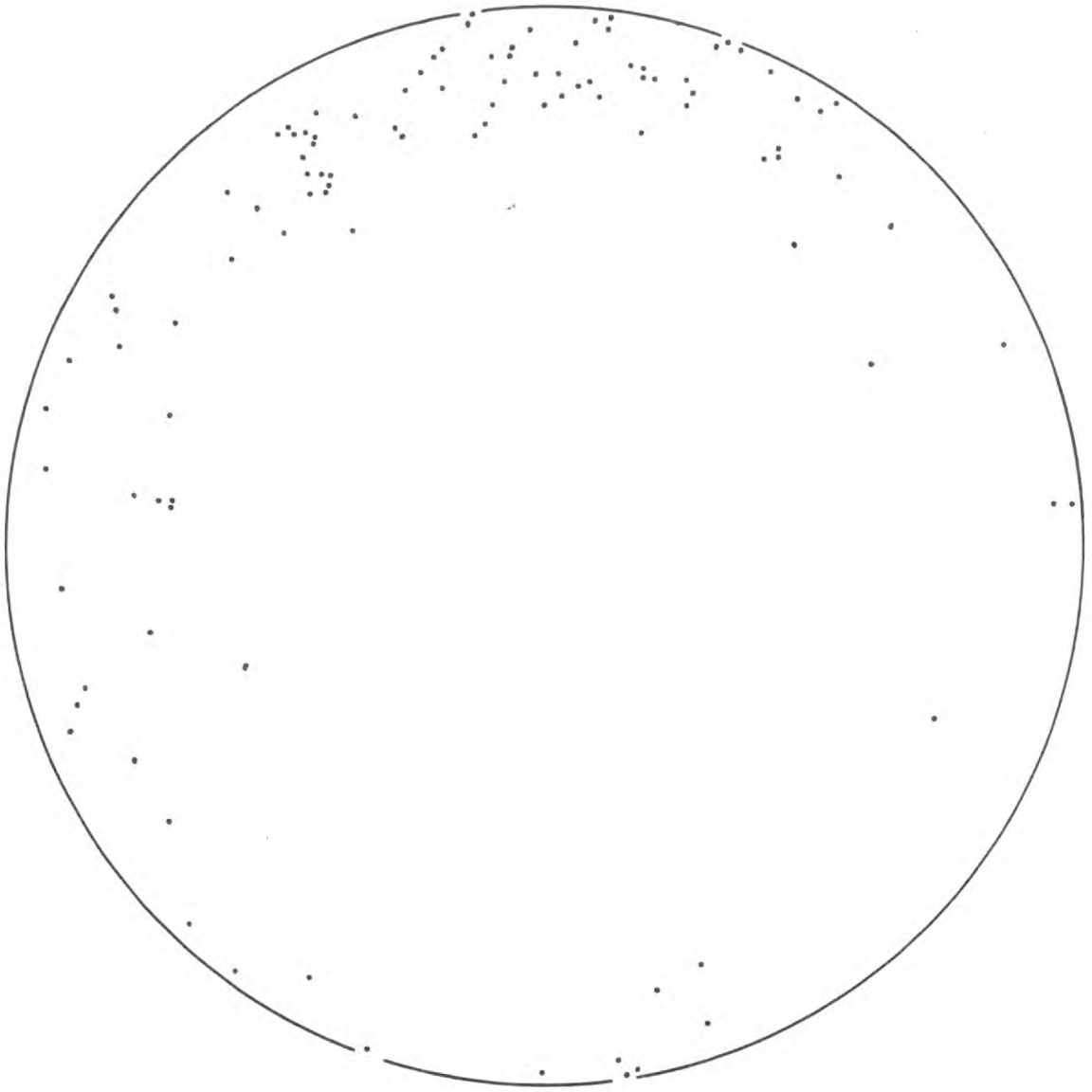


Figure 22.1

Quartz and feldspar predominate in these rocks. Other minerals such as biotite, chlorite and muscovite are important in some semi-pelitic and pelitic rocks and epidote, garnet, sphene and ilmenite are accessory minerals. There is no cementing material in these rocks. The grain boundaries are usually tortuous and undulose extinction is common in the quartz. The mylonitic rocks which occur immediately adjacent to the Lewisian rocks of the Caradal nappe will be described first, the Lower Psammite next, and the Laidhe na greine Group and the Upper Psammite will follow respectively. The development of porphyroblastic biotite, chlorite and ilmenite in the Laidhe na greine Group and the Lower Psammite in the SE corner of the Caradal nappe will be described and discussed last.

The Mylonised Tarskavaig Moine Rocks of the Caradal Nappe.

These are represented in sections 18790 and 18791. Both show very fine-grained quartzo-feldspathic aggregates with irregularly shaped patches of quartz of slightly larger grain size. Undulose extinction is well-developed throughout but the grains are not markedly elongate. Epidote and muscovite are fairly widespread. The epidote occurs in very small granular crystals: the muscovite in very small laths which are mostly aligned parallel to the foliation. The muscovite laths are not noticeably distorted even though some cross the foliation at high angles.

The Lower Psammite.

There is a wide range of grain size between different horizons of the Lower Psammite although individual beds (eg section 16334) appear well-sorted. Quartz commonly

shows undulose extinction in the coarser grained rocks. Feldspar varies widely in composition and content of inclusions (eg section 16393). The grains are probably of clastic origin. The potassic feldspars are represented by orthoclase, microcline, and various types of perthite. Plagioclase is not common. Sericite, as very small crystals, is especially common in the finer grained beds but occurs widely throughout. Small granular epidote crystals are very widely distributed.

The Laidhe na greine Group.

Chlorite is more important in the rocks of the Laidhe na greine Group than in the Lower Psammite; especially in the semi-pelitic and pelitic beds. In the coarse, psammitic beds near the top of the Laidhe na greine Group the feldspar is more usually microcline. In finer grained beds (eg in sections 16242 and 16333)graded bedding is seen. Small garnets are rare but have been found in sections 16206, 16210, 16392 and 16394. Apart from these characters, and the porphyroblasts described below, the rocks of the Laidhe na greine Group are very similar to the corresponding rocks in the Lower Psammite.

The Upper Psammite.

The feldspar in the Upper Psammite is usually perthite or microcline. Plagioclase is sometimes found. These feldspars are sometimes stained red or orange (eg section 16232) by innumerable microscopic inclusions : possibly hematite. The feldspar grains have more simple outlines than the quartz and are usually larger. Feldspar crystals only rarely show undulose extinction. Sericite and epidote inclusions in the feldspars vary widely in concentration

from one grain to the next. Chlorite and epidote are common accessories and occur in crystals up to 1mm long. The chlorite crystals, together with small muscovite crystals, form rims, or partial rims around the major quartz and feldspar grains. In the semi-pelitic rocks interbedded in the Upper Psammite, chlorite is an important component but feldspar is rare.

The Porphyroblastic Minerals: Biotite, Chlorite and Ilmenite.

The biotite and chlorite porphyroblasts occur separately in some sections, in parallel growth in others. The colour of the biotite varies between olive-green and dark-brown. Pleochroic haloes around inclusions are present in the biotite in section 16242. The chlorite porphyroblasts are pale to dark green.

In some sections, the biotite and chlorite porphyroblasts are bent. This bending is possibly connected with certain "strain-slip" structures in the rocks which also have a limited development. Most thin sections containing biotite and chlorite porphyroblasts give little indication of preferred orientation of these minerals.

The ilmenite porphyroblasts are blade-shaped. They occur typically in the more pelitic layers, eg sections 16210, 16242, 16333, 16385 and 16394. No preferred orientation is evident. The inclusions in the ilmenite are of quartz, epidote, biotite and chlorite.

In section 16385, a veinlet of coarse grained quartz contains large crystals of biotite. The emplacement of this vein is possibly associated with the development of the porphyroblasts.

For descriptions of microscopic features, the Knock and Ostaig lines (Plate 4) conveniently divide the Moine nappe into three parts. The rocks east of the Knock line are generally coarse-grained. Between the Knock and Ostaig lines there are various sizes of lenticular outcrops of coarse rocks embedded in fine-grained, fissile rocks. West of the Ostaig line nearly all rocks are fine grained and fissile and only very rare lenticles of coarse amphibolite occur. Megascopic porphyroblasts occur widely to the east of the Ostaig line but porphyroblasts are only detectable microscopically to the west of this line.

Trails of small granular or prismatic epidote crystals parallel to the foliation are common throughout the rocks of the Moine nappe. Practically all quartz shows undulose extinction. In the fissile, fine grained rocks to the west of the Knock line the quartz commonly occurs either in a very fine grained quartzo-feldspathic matrix or in coarser grained, lenticular patches (up to 2cms by 1-2mm) aligned parallel to the foliation. These lenticular patches are composed almost entirely of quartz with strong undulose extinction.

The Rocks of the Moine Nappe: East of the Knock Line.

Only Lewisian rocks occur east of the Knock line. Their mineralogical composition varies very widely. Quartz grains nearly always possess undulose extinction and are commonly divided into sub-grains by sub-boundaries which are approximately parallel to the c-axes. Experimental studies of other poly-crystalline aggregates show that these sub-grains are only induced by deformation and that their size depends on:-

1. The temperature at the time of deformation.

2. The rate of strain during deformation.

3. The amount of sub-grain growth after deformation.

The presence of sub-grains in crystals usually indicates that they are not in a recrystallised state. Foliation in thin sections of the Lewisian rocks is defined by bands in which the grain size of the quartz differs markedly from one band to the next. Feldspar crystals are usually small and not twinned. Sericite and epidote inclusions are prominent in the larger feldspar grains. Feldspar porphyroblasts have been found in one section only. Trails of undistorted epidote crystals outline microfolds of the Rudha Phoil, or second generation. The present state of crystallisation of the epidote thus appears to post-date the development of the second folds. Some of the larger epidote crystals have cores of metamict orthite.

Pophyroblastic amphibole and biotite crystals are common. These overgow the epidote trails and the second generation microfolds. Rarely the biotite crystals are orientated into a girdle fabric and the amphibole crystals into a fabric with long axes parallel. The megascopic lineations thus formed are parallel to the axes of the Tormore, or third generation folds. The variation in the degree of preferred orientation from place to place is possibly an indication of variation in the degree of deformation associated with the third folds. Garnet occurs in euhedral or rounded crystals.

In the amphibolites, the amphibole has a bimodal occurence. A matrix of large, deformed crystals contains smaller, often acicular, undeformed crystals. This texture probably represents an arrested state of recrystallisation. During this process

the small, undeformed crystals were growing at the expense of the larger, deformed crystals. Apatite is common in these amphibolites.

The deformation of the large amphiboles in the amphibolites and the deformation of the quartz and feldspar in the other rocks probably dates to the time of the Baravaig, or first folds, which have a very strong elongation lineation parallel to their axes. The small, undeformed crystals in the amphibolites and the biotite and amphibole porphyroblasts in the other rocks certainly post-date the second folds and, from the evidence in the Moine rocks, probably post-date the Tormore, or third folds also.

The Rocks of the Moine Nappe: Between the Knock and Ostaig Lines.

The coarse grained Lewisian rocks, occurring in lenses, are similar to those found east of the Knock line. In the fissile rocks, feldspar occurs in distinct porphyroclasts which sometimes show albite twinning. In the Moine rocks, feldspar crystals are smaller than the co-existing quartz and are not so common. They are rarely twinned and do not contain as many inclusions as the Lewisian feldspars. Garnet is common in the Moine rocks and forms crystals which vary in shape from small and euhedral to large and ragged.

Muscovite is the most common mica in the Moine rocks. Together with biotite, it commonly forms girdle fabrics with axes parallel to the axes of the Tormore, or third folds. Near Tormore, the micas form polygonal arches of undistorted crystals around microfolds of the third generation. Thus the growth of the micas in the Moine rocks post-dates the third folds but the fabric seems to have been controlled

by strains induced during the third period of folding.

Porphyroblasts in the Lewisian rocks are of biotite, chlorite and amphibole. The first two ofter form sandwich-like parallel growths. The amphibole porphyroblasts in the fine grained fissile rocks are smaller than those in the coarser Lewisian rocks and are commonly aligned with long axes parallel to the foliation. Amphibole porphyroclasts, with undulose extinction, also occur in the fissile rocks.

The Rocks of the Moine Nappe: West of the Ostaig Line.

Porphyroclastic minerals in these rocks are feldspar in both Moine and Lewisian, and amphibole in the Lewisian. Microscopic porphyroblasts occur in both groups: amphibole and biotite in the Lewisian, muscovite and biotite in the Moine rocks. Undistorted porphyroblasts occur very close to small folds of the Ard Thurinish group and almost certainly post-date them. Deformation of some of these porphyroblastic crystals is possibly connected with the development of the Port a'Chuil folds, the conjugate folds, or even the Moine thrust. The prismatic crystals in the epidote trails also apparently post-date the Ard Thurinish folds.

The Rocks of the Caradal Nappe.

These are metasedimentary rocks, the Tarskavaig Moine rocks, with a group of mylonised rocks at the base. The mylonised rocks are derived partly from the Tarskavaig Moine rocks and partly from Lewisian gneisses.

The Rocks of the Caradal Nappe: The Mylonites.

These rocks have a very fine-grained quartzo-feldspathic matrix in which undulose extinction is common. Irregularly shaped patches, with vague margins, are composed mostly of

quartz. Muscovite laths in the Tarskavaig Moine mylonite and muscovite and chlorite laths in the Lewisian mylonite are widespread. Small granular crystals of epidote occur in both groups. In the Lewisian mylonites, there are porphyroclasts of feldspar and epidote up to 1mm in diameter. The former are without twinning and exhibit strong undulose extinction.

The Rocks of the Caradal Nappe: The Less-deformed Metasediments.

No cementing material is present; the interlocking grains have tortuous boundaries. There is a wide range of grain size overall, but individual beds are well-sorted. The feldspar is usually orthoclase, perthite, or microcline. The microcline is more abundant in the Upper Psammite where much of the feldspar is stained red or orange by ultramicroscopic inclusions. Plagioclase is not common. Chlorite is more common in the semi-pelitic and pelitic rocks and in some of the latter, graded bedding can also be seen. In the Laidhe na greine Group, small garnets are rarely seen.

The Rocks of the Caradal Nappe: The Porphyroblasts.

The porphyroblasts are of biotite, chlorite and ilmenite and are confined to the SE corner of the outcrop of the Caradal nappe. The biotite and chlorite porphyroblasts occur separately, or in sandwich-like parallel growths. There is no obvious preferred orientation of these porphyroblasts. The ilmenite crystals are blade-shaped and are most common in the pelitic layers. Veinlets of coarse quartz, containing biotite crystals, are possibly connected with the development of the porphyroblasts.

In some localities the porphyroblasts are bent. This

bending is probably associated with certain "strain-slip" structures which have a very localised development.

The movements on the Moine thrust plane were the last of the series of complex, inter-related phases of deformation and metamorphism that occured in the Moine and Caradal nappes on both sides of the Moine thrust. In Chapter 25, the structural and metamorphic histories of the Moine and Caradal nappes will be summarised separately and then correlations of events will be made across the Moine thrust plane. In this way, the thesis will be summarised and some conclusions on the evolution of the Moine thrust zone will be presented. Chapter 26 is intended to relate the recent work firstly to the detailed studies of previous workers in the same area; and secondly, to similar recent detailed studies in areas nearby.

The Moine Nappe: General Description of the Rocks.

From east to west across the Moine nappe, there are distinct changes in the megascopic and microscopic textures of the rocks. East of the Knock line (Plate 4) only Lewisian rocks occur. These Lewisian rocks are generally massive and coarse grained. The largest group is of widely variable composition and there are very few distinct lithological boundaries. Mafic minerals form porphyroblasts, generally randomly orientated, of amphibole or biotite. There are some small lenticular bodies in which exotic minerals are arranged zonally. A smaller group of rocks comprises amphibolite sheets of more uniform composition. These sheets have sharp contacts and some of them cross-cut the foliation in the country rocks. Between the Knock and Ostaig lines (Plate 4) there are both Moine and Lewisian rocks. The Lewisian rocks are mostly fine-grained and fissile and contain small porphyroblasts of amphibole, biotite and chlorite. In these fissile rocks, there are embedded pods and lenses, up to 10m wide, of coarse-grained rocks of the type that occur east of the Knock line. The boundaries to the pods and lenses of acid composition are sharp. The amphibolitic pods and lenses have transitional boundaries. The Moine rocks are coarse-grained psammites and finer grained, garnetiferous semi-pelites. Sedimentary textures are preserved at Tormore. Discordant quartz veins in the Lewisian contain amphibole, biotite and chlorite. West of the Ostaig line, with the exception of a few large amphibolite lenses in the Lewisian, all the rocks are fine-grained and fissile. Lewisian rocks

are represented by interlayered pink acid rocks and chlorite schists. The Moine rocks are muscovite schists with occasional small garnets. Microscopic porphyroblasts are of muscovite, biotite, chlorite and amphibole. In discordant quartz veins, chlorite is very common. The Moine-Lewisian junction is only clearly exposed west of the Ostaig line where the foliation in both groups is concordant to the plane of contact.

Thin sections of nearly all of the rocks of the Moine nappe contain small granular or prismatic crystals of epidote arranged in trails. Practically all of the quartz has undulose extinction. West of the Knock line, the fissile rocks have a fine-grained, quartzo-feldspathic matrix in which there are lenses, up tp 2 x 0.2cms, composed essentially of coarser grained quartz.

The Moine Nappe: The Initial State of the Rocks.

Before the first recognisable period of folding both Moine and Lewisian rocks were present. The Moine rocks were bedded psammitic and pelitic sediments. The Lewisian rocks were foliated, migmatised gneisses of widely varying composition with cross-cutting sheets of amphibolite.

The Moine Nappe: The Baravaig, or First Structures.

The Baravaig, or first folds have a very strong axial lineation. This lineation was produced by the intense deformation and elongation of quartz and feldspar in both Moine and Lewisian rocks. The Baravaig structures occur throughout the Moine nappe but only in the area east of the Ostaig line are they relatively unmodified by later periods of deformation. Except for one large fold in the Moine rocks at Ardvasar, all of the folds are small. The profile

shape varies from isoclinal to open and the orientation of axes and axial planes are variable because of later periods of folding.

Intense deformation during the Baravaig period of folding induced undulose extinction in the quartz, feldspar and some of the amphibole in the rocks east of the Knock line.

The Moine Nappe: The Rudha Phoil, or Second Structures.

These structures occur only in rocks east of the Ostaig line. The small folds are more open in profile than many of the small first folds and they have deformed the strong elongation lineation associated with the first folds. The large scale Knock synform (Plate 2) is of the second generation and has produced a regional change in trend of the first lineation (Plate 2 and figure 2.7). The axial planes of the Knock synform and the associated small folds dip 20 -40° SE. The axes are near horizontal except on Rudha Dubh where interference with the large first fold has introduced complications. Microfolds of this generation are outlined in thin section by trails of small epidote crystals.

The Moine Nappe: Deformation of the NW Limb of the Knock Synform.

The pods and lenses of coarse rocks between the Knock and Ostaig lines seem to be the remnants of a process which produced the fine-grained fissile rocks from the coarse-grained rocks of the type found east of the Knock line. The avarage thickness of compositional banding in the fine-grained rocks is much less than that of the corresponding bands in the coarse-grained rocks and thus considerable deformation has occurred. The banding in the fine-grained rocks is folded by small folds of the third generation and thus the deformation process must

be earlier. On the other hand, the fine-grained rocks do not emerge on the SE limb of the Knock synform (see figure 25.1) in a position that would indicate that the deformation process pre-dates the second generation folds. The conclusion is that either the NW limb of the Knock synform suffered much more deformation than the SE limb during the second folding, or the deformation process is entirely later than the development of the Knock synform.

The Moine Nappe: The Tormore and Ard Thurinish Structures of the Third Generation.

The field evidence is ambiguous and suggests that the Tormore and Ard Thurinish structures might be of different generations. Additional microscope evidence, however, indicates that the Tormore and Ard Thurinish folds have more in common than the writer originally realised and it seems very probable that they are of the same generation.

The Tormore group of structures are most common between the Knock and Ostaig lines but are also occasionally found east of the Knock line. The most common type of structure is a megascopic lineation plunging SE which is either parallel to the axis of a girdle fabric of micaceous porphyroblasts in Moine and Lewisian rocks or is defined by the parallel orientation of the long axes of amphibole porphyroblasts in Lewisian rocks. Near Tormore, there are small folds of this generation developed in Moine psammitic rocks and they have an elongation lineation developed parallel to their axes also plunging SE. These folds, and some similar folds at Ardvasar, have deformed small folds of the second generation. The Moine semi-pelitic rocks at Tormore contain microfolds of the third

generation. These microfolds are outlined by undistorted muscovite crystals which thus form polygonal arches. The rock tends to split preferentially along the limbs of these microfolds and thus a crude kind of cleavage is developed parallel to the axial planes of the Tormore folds.

The Ard Thurinish folds mostly occur west of the Ostaig line but there are a few representatives in the Lewisian rocks between the two lines. These are small folds with axial planes dipping SE. The axes are often strongly curved, but the average direction of plunge lies in the SE quadrant. Microscopic micaceous porphyroblasts are aligned approximately parallel to their axial planes. These folds have deformed the first lineation in such a way that the "a" directions (Ramsay, 1960) are frequently measureable. Some small folds near Tormore seem to be transitional between the characteristically open-profiled Tormore folds with straight axes and the tighter-profiled Ard Thurinish folds with curved axes. In the pelitic rocks near some of these transitional folds, there is developed a crude axial plane cleavage of the type described above.

The Tormore/Ard Thurinish folds and associated structures show interesting changes in style from east to west. In the Lewisian rocks east of the Knock line, orientated porphyroblasts are rare: most are random. Between the Knock and Ostaig lines orientated prophyroblasts are more common and close to the Ostaig line, in the Moine rocks, small folds with axial elongation lineation are developed. West of the Ostaig line, there are no lineations of this generation, the folds are tighter in profile, and have curved axes.

The Moine Nappe: The Growth of the Porphyroblastic Minerals.

Biotite porphyroblasts in Lewisian rocks enclose second generation microfolds outlined by epidote trails. Amphibole porphyroblasts in Lewisian rocks, and micaceous porphyroblasts in both Moine and Lewisian rocks define megascopic lineations and outline microfolds of the third generation and yet are not distorted. In their present form, therefore, the porphyroblastic crystals have grown since the development of the third folds. Their orientation, however, seems to have been governed by strains which were set up during the third period of folding. The porphyroblastic minerals have thus probably grown from sub-microscopic nuclei which themselves took up a preferred orientation as a result of the strains induced during the third folding.

Quartz veins in the Lewisian rocks of the Moine nappe, which cut discordantly across (and thus post-date), structures of the first, second and third generations carry crystals of chlorite, biotite and amphibole. There is possibly a direct connection between the emplacement of these veins and the growth of the chlorite, biotite and amphibole porphyroblasts in the host rocks.

The Moine Nappe: The Port a'Chuil, or Fourth Folds.

These folds only occur within 100m of the Moine thrust plane. They are small folds with tight angular and isoclinal profiles. A delicate ribbon lineation is developed parallel to their axes. The trend of this lineation is ENE. Further from the Moine thrust, a lineation of this trend is found upon the quartz veins which cross-cut the first, second and third structures (see above).

The Moine Nappe: The Conjugate, or Fifth Folds.

These are small, angular folds with multiple axial plane directions which occur widely in the fissile, fine-grained rocks west of the Knock line. They have deformed structures of the fourth and all previous generations.

The Moine Nappe: The Moine Thrust.

The Moine thrust plane dips SE. Near the thrust plane, the rocks are brecciated and in some fragments, conjugate folds are seen. The final, if not all of the movement on the thrust plane must have occured after the development of the conjugate folds.

The Moine Nappe: Faults.

Vertical faults in the Moine nappe (see figure 8.2) are probably a continuation of the Strathconon fault system on the mainland. The faults die out near Tormore but the system is continued in a monoclinal flexure. The relation of this flexure to the Moine thrust plane is not known.

The Caradal Nappe: General Description of the Rocks.

The rocks of the Caradal nappe comprise the Tarskavaig Moine rocks, a series of metasediments, which rest upon derivatives of the Lewisian gneiss. All of the Lewisian rocks in the Caradal nappe are mylonites and a narrow belt of Tarskavaig Moine rocks immediately adjacent to them are also mylonites. The Lewisian mylonites are banded pink and green and contain porphyroclasts of feldspar and epidote and relic lenses of pyroxenite (Clough, in Peach et alia, 1907, p17). The Tarskavaig Moine mylonites are banded yellow, grey and green and contain no porphyroclasts. In the rest of the Tarskavaig Moine rocks, the only remaining sedimentary

microtexture is graded bedding in the more pelitic rocks of the Laidhe na greine Group.

The Tarskavaig Moine succession begins with the Lower Psammite which, in a mylonised form, is possibly continuous along the whole length of the contact with the Lewisian. The Lower Psammite is generally coarse and contains some pebble beds. The Laidhe na greine Group consists of inter-bedded psammites, semi-pelites and pelites. The Upper Psammite is feldspathic. The upper and lower boundaries of the Laidhe na greine Group are transitional. In the SE corner of the outcrop of the Caradal nappe, porphyroblastic crystals are developed.

The Caradal Nappe; The Early Events.

Previous to the Capistal, or first folds, both the Tarskavaig Moine and Lewisian rocks were present. The Lewisian rocks were probably gneissose and contained rocks of pyroxenitic and hornblendic composition (Clough, in Peach et alia, 1907, p594). The Tarskavaig Moine rocks were well-sorted psammitic, semi-pelitic and pelitic sediments cross-cut by a system of quartz veins.

The Caradal Nappe: The Capistal, or First Structures.

These structures occur throughout the Caradal nappe. The strong axial elongation lineation and axial plane foliation associated with the Capistal folds indicate a very high degree of deformation. Distorted pebbles are several times longer than wide.

There are two large folds of this generation (Plate 2). During the formation of these folds, it is possible that extreme deformation on the east limb of the Capistal synform produced

the mylonitic rocks and caused the bedding in the Tarskavaig Moine rocks to be dragged into parallelism with the foliation in the Lewisian mylonites. The present orientation of the Capistal structures is largely governed by deformation they suffered during the third phase of folding.

The Caradal Nappe: The Doire na h-Achlais, or Second Folds.

These fold structures are virtually limited to the mylonitic rocks. They are small, tight folds with rounded hinges and an axial plane cleavage. They have deformed the Capistal axial lineation.

The Caradal Nappe: The Tarskavaig Thrust. (Figure 14.2)

Near the Tarskavaig thrust, structures of the second generation are disrupted. Thus the movements on the Tarskavaig thrust plane occurred after the development of the second folds.

The Caradal Nappe: The Caradal, or Third Structures.

These folds have occurred on a large scale only (Plate 2) and have deformed the first and second folds and the Tarskavaig thrust plane. The axial planes of these large folds dip 40-50° ESE and the axes plunge gently south. The folds have produced regional changes in the trend of the first axial lineation (Plate 2 and figure 12.2) and in the orientation of the second axial plane cleavage (figure 11.2).

The Caradal Nappe; Faults and Slides.

A short length of the boundary between the Upper Psammite and the Laidhe na greine Group on the east limb of the Caradal synform (figure 14.2) is unusually sharp. It seems that during the third period of folding, flexural slip occurred at this horizon and a slide developed.

The Caradal and Lamascaig faults (figure 14.2) cut across

the axial plane of the Caradal synform but are only gently curved. Movement on these faults seems to largely post-date the development of the third folds. The rocks in the outcrops of Torridonian Epidotic Grits (Plate 5) seem to have reached their present position as a result of these fault movements.

The Caradal Nappe: The Growth of the Porphyroblastic Minerals.

The porphyroblasts are of chlorite, biotite and ilmenite and occur only in the SE corner of the outcrop of the Caradal nappe. Their distribution is not controlled stratigraphically because, further north, the Laidhe na greine Group is free of porphyroblasts. They seem to be confined to a zone which cross-cuts the large third folds and thus were developed later.

The porphyroblasts do not show any preferred orientation. Locally, the porphyroblasts are deformed by a late stage "strain-slip" structure of very restricted occurence. Some quartz veins with large crystals of biotite and chlorite are probably connected with the development of the porphyroblasts.

The Caradal Nappe: The Port a'Chuil Folds.

These folds occur in a narrow zone immediately below the Moine thrust plane. They are small scale only and have strong elongation lineations and mullions parallel to their axes. The axial trend is ENE and the folds are almost certainly of the same generation as similar structures immediately above the Moine thrust plane.

The Caradal Nappe: The Conjugate Folds.

Conjugate folds are fairly widely distributed, and occur especially in the mylonitic rocks and in the thinly bedded metasediments. They have deformed all other folds structures in the Caradal nappe.

The Correlation of Structural and Metamorphic Events across the Moine Thrust Plane

The most likely correlations across the Moine thrust plane appear to be as follows:-

CARADAL NAPPE	MOINE NAPPE
Capistal folds (with development of mylonites?)	Baravaig folds
Doire na h-Achlais folds	-----
Movements on the Tarskavaig thrust plane	
Caradal folds (with slide and faults?)	Rudha Phoil folds
-----	Deformation of the NW limb of the Knock synform
-----	Tormore and Ard Thurinish folds
Growth of porphyroblastic minerals and emplacement of quartz veins containing the same minerals	
Port a'Chuil folds	Port a'Chuil folds
Conjugate folds	Conjugate folds
Movements on the Moine thrust plane	

The Capistal and Baravaig folds have very strong axial elongation lineations and indicate widespread and rather intense deformation throught the Moine and Caradal nappes. The Doire na h-Achlais folds and the mylonites in which they occur are resricted to the Caradal nappe.

Caradal and Rudha Phoil folds occur as large structures.

Their axial directions, and more important, the orientations of their axial planes are very similar. The Caradal synform and the Knock synform produce very similar changes in the regional trends of the lineations associated with the Capistal and Baravaig folds respectively.

The deformation of the NW limb of the Knock synform, and the Tormore and Ard Thurinish fold structures, are restricted to the Moine nappe and appear to have no equivalents in the Caradal nappe.

The size of the porphyroblastic crystals in the Moine nappe decreases markedly from east to west. In the Caradal nappe, the porphyroblastic crystals also decrease in size from east to west.

The Port a'Chuil folds and the conjugate folds are found on both sides of the Moine thrust plane. They seem to indicate the final stages of the Caledonian deformation before the rocks yielded by brittle rupture along the Moine thrust plane.

EXPLANATION OF FIGURE 25.1.

A schematic cross-section through the south part of the Sleat peninsula, showing the Tarskavaig and Moine nappes.

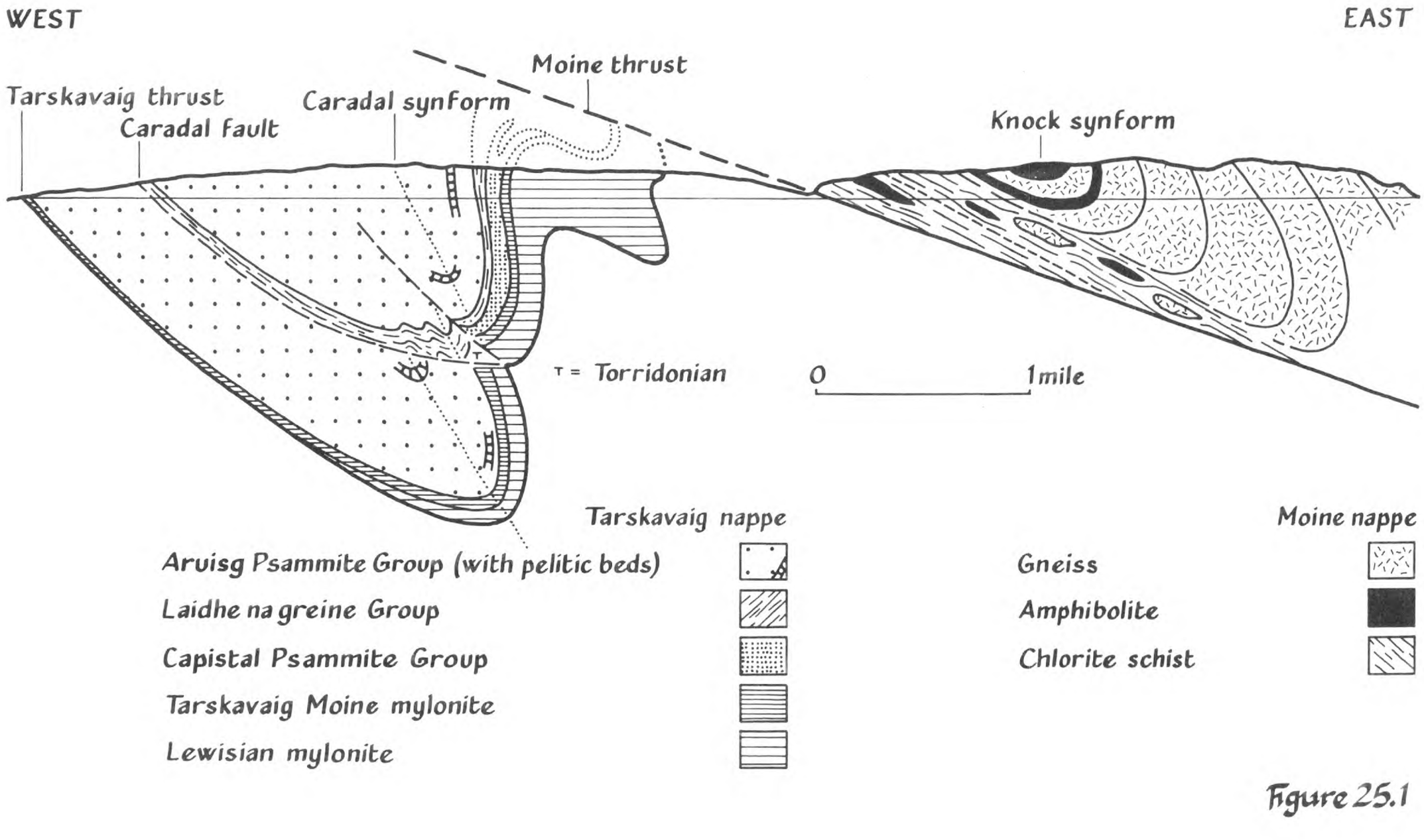

WEST
EAST
Moine thrust
Tarskavaig thrust
Caradal synform
Caradal fault
Knock synform
T
T = Torridonian
0
1 mile
Tarskavaig nappe
Aruisg Psammite Group (with pelitic beds)
Laidhe na greine Group
Capistal Psammite Group
Tarskavaig Moine mylonite
Lewisian mylonite
Moine nappe
Gneiss
Amphibolite
Chlorite schist

Figure 25.1

Between Skye and the Achnashellach Forest, published geological accounts of the areas near the Moine thrust plane fall into two groups: those written before 1956, and those written during or after 1956. The earliest full accounts (Peach and others, 1907, 1910) contained much that was descriptive but upon the many details that they record, many of the more recent investigations have been based. Bailey (1939, 1955) discusses further some of the problems raised by the earlier surveyors, particularly with regard to the relative ages of metamorphism, deformation, and thrust movements. Phillips (1937, 1939, 1945) applied the technique of fabric analysis to similar problems and also (1939) to the question of Moine-Torridonian correlation. Kennedy (1951) discussed the chemical features of the Moine and Torridonian rocks as sediments and argued a possible correlation. Later, (1954), Kennedy described the structure of the southern part of the Moine thrust zone in terms of large nappe structures and indicated comparisons with current interpretations of the structure of the Alps.

The more recent accounts of the areas near the southern part of the Moine thrust zone, those written since 1955, have demonstrated how the detailed study of small and large fold structures may resolve many of the problems that puzzled earlier workers. The understanding of the geometry and sequence of fold structures assists in the determination of stratigraphical succession, and shows that metamorphism, mylonisation, porphyroblastic growth, migmatisation, thrusting, etc. are events which are often clearly separable from each

other in a well-defined sequence. These sequences of events form the main part of recent publications and it is possible, in this final Chapter, to make correlations of the tectonic and metamorphic history of the Moine and Tarskavaig nappes in Skye with the tectonic and metamorphic histories of adjacent areas.

The conclusions drawn as a result of the present work may be set out as under the headings below. These conlusions are based partly on the observations recorded during the present work and partly on observations recorded by workers in adjacent areas.

1. The origin of the Lewisian rocks at the base of the Tarskavaig nappe.
2. A correlation of stratigraphic groups between Moine, Tarskavaig Moine, and Torridonian rocks.
3. Regional correlation of generations of fold structures.
4. The age of the Lochalsh fold.
5. The evolution of the large scale structures.

1. The Origin of the Lewisian rocks at the base of the Tarskavaig nappe

Clough demonstrated the remarkable continuity of the thin sheet of mylonised Lewisian rocks at the base of the Tarskavaig nappe. He thought (Peach and others, 1907, p591) that the Tarskavaig thrust was a fracture that developed near the top of the Lewisian gneiss. He concluded that the Lewisian rocks were already soft and granulitic before the thrust developed because he found many small folds in the Lewisian rocks that

had not folded the thrust plane.

Bailey (1955) suggests that the Lewisian rocks at the base of the Tarskavaig nappe were picked up in the form of scales and slices as the Tarskavaig Moine rocks moved forward on the Tarskavaig thrust.

Dr. J.V.Watson has suggested (private communication) that when the Tarskavaig thrust first developed, the Lewisian sheet was of uniform thickness. Further movement on the Tarskavaig thrust plane caused attenuation of the sheet, especially those parts more distant from the root of the nappe.

Clough (in Peach and others, 1907, p591) also suggested that the Lewisian gneiss formed part of a belt of weakness along the plane of which the Tarskavaig thrust developed, and the present work adds more evidence in suppcrt. The Tarskavaig thrust plane has developed in a zone of rocks which had already been mylonised and folded by small Doire na h-Achlais folds. This zone of rocks is unique in age in the Sleat of Skye. There are no structures of comparable age in the Moine nappe (see table p365).

The small Doire na h-Achlais folds are all overturned in the same direction. This may suggest that the mylonite zone may form:-

(a) one limb of a very large scale Doire na h-Achlais fold.

(b) one limb of a Capistal fold.

(c) part of a zone of special deformation of Caledonian age in the Lewisian basement rocks.

2. A Correlation of Stratigraphic Groups between Moine, Tarskavaig Moine, and Torridonian Rocks.

The stratigraphical succession in the Torridonian rocks of SE Skye was described at length by Clough (in Peach and others, 1907, pp348-362) and more briefly by Clough (in Peach and others, 1910, pp57-61). In the Glenelg and Knoydart districts of the Scottish mainland, the stratigraphical succession in the Moine rocks has been described by Ramsay and Spring (1962).

(a) Comparison with the Moine succession of Glenelg and Knoydart.

The most likely correlations between the Moine sequence in Knoydart/Glenelg and the Tarskavaig Moine sequence in Skye are shown in figure 26.1. The Laidhe na greine Group is asymmetrical, like the Rubha Ruadh Semi-pelite: there is much more interbedding with the underlying Lower Psammite than there is with the overlying Upper Psammite. Both the Laidhe na greine group and the Rubha Ruadh Semi-pelite comprise alternating beds of psammite, semi-pelite, and pelite.

False bedding is very common in both the Upper Psammite and the Barrisdale Psammite, but is not so common in either the Lower Psammite or the Arnisdale Psammite. Both the Arnisdale Psammite and the Lower Psammite are highly quartzitic

and have only rare semi-pelitic bands. Heavy minerals are common in the Lower Psammite, but they do not occur in many, well-defined bands as in the Arnisdale Psammite. Unlike the Arnisdale Psammite, the Lower Psammite contains some thin psephitic beds with white quartzite pebbles. Both the Upper Psammite and the Barrisdale Psammite are notably more feldspathic than the underlying Lower Psammite and Arnisdale Psammite respectively.

The Basal Pelitic member of the Moine succession in Glenelg and Knoydart would appear to be absent from the Tarskavaig Moine succession in Skye. Near the Tarskavaig Moine-Lewisian boundary in Skye, it seems that the Lower Psammite and the lower part of the Laidhe na greine group pass laterally into a zone of mylonised Tarskavaig Moine rocks about 50yds wide along the contact with the Lewisian. In Skye, therefore, the fine grained rocks at the base of the Tarskavaig Moine succession are of tectonic origin. Barber and Lambert (in discussion of Ramsay and Spring, 1962) suggest that the Basal Pelite may be partly, if not wholly, of tectonic origin. The character of the Tarskavaig Moine-Lewisian contact in Skye lends support to this suggestion.

(b) Comparison with the Torridonian Succession of SE Skye.

A correlation of the Torridonian and the Tarskavaig Moine sequences in Skye is shown in figure 26.1. Both the Epidotic Grits and the Lower Psammite are essentially coarse grained groups although both have pelitic intercalations. Chlorite

and epidote are abundant in the two groups. The Epidotic Grits and the Lower Psammite have psephitic beds but these are much less common in the latter. False bedding does not have the same abundance in either the Epidotic Grit or the Lower Psammite as it does in the higher Beinn na Seamraig Grits or the Upper Psammite.

The Epidotic Grits and the Loch na Dal beds are interstratified in a similar way to the Lower Psammite and the Laidhe na greine group. Both the Laidhe na greine group and the Loch na Dal beds consist of interbedded psammites, semi-pelites, and pelites. The psammites are often coarse. Thin units, grading from silt to pelite, are common. Near the top of both the Loch na Dal beds and the Laidhe na greine group, there are psammitic beds of the type that make up most of the overlying psammitic groups.

The Beinn na Seamraig Grits and the Upper Psammite are both composed largely of psammitic beds and there are only very few intercalated shale or semi-pelitic beds.

3. Regional Correlation of Generations of Fold Structures.

The Structural History of the Moine and Lewisian rocks of Glenelg has been described by Ramsay (1958) and by Sutton and Watson (1959). There is a close similarity between this structural history and the early stages in the structural history of the Moine nappe in Skye.

The Baravaig folds in the Moine nappe of Skye are almost certainly of the same generation as the first folds of Ramsay (1958) and the folds of the second movement phase of Sutton and Watson (1959). Let these folds in Glenelg be called the Beinn a'Chapuill folds. Both the Baravaig and Beinn a' Chapuill folds are characterised by a very strong axial lineation, usually defined by quartz rodding, or ribbon lineation, etc. (Ramsay, 1958, p504; Sutton and Watson, 1959, p239). The small folds are usually tight in profile and are "generally long-limbed" (Ramsay, 1958, p504). An axial plane foliation is commonly developed and often takes the form of a flattening of quartz and feldspar grains or quartz aggregates (Sutton and Watson, 1959, p239).

The second folds of Ramsay (1958) are the same generation as the folds of the third movement phase of Sutton and Watson (1959) and the third folds of Ramsay (1960, p82). The Morar-Loch Hourn antiform (Kennedy, 1954, p369; Spring, 1960) and the Beinn a'Chaoinich-Beinn Mhialairidh fold (Ramsay, 1958) are also of this generation. These could be called the Loch Hourn folds. These Loch Hourn folds are probably of the same generation as the Rudha Phoil folds in the Moine nappe of Skye. Ramsay (1958, p507) notes that the small folds of this generation are "usually very different in style from the first (Beinn a' Chapuill) minor folds." These small folds are "straight-limbed structures with angular hinges" (Sutton and Watson, 1959, p245) and the axial plane structure, where developed, takes the form of a "crude cleavage" (Ramsay, 1958, p508). The Knock synform, which is of the Rudha Phoil generation in Skye, is probably

of the same generation as the Morar-Loch Hourn antiform.

The first folds and associated structures of Ramsay (1960, p82) have not been recognised in Skye. If these folds are called the Arnisdale generation of folds, then a correlation of the fold generations between the Moine nappe in Skye and the districts of Glenelg, Knoydart and Morar takes the form:-

Moine nappe in Skye.	Glenelg, Knoydart and Morar.
---	Arnisdale folds.
Baravaig folds.	Beinn a'Chapuil folds.
Rudha Phoil folds.	Loch Hourn folds.

The Tormore, Ard Thurinish, and Port a'Chuil folds of the Moine nappe in Skye (see page 365) do not seem to be represented in Glenelg, unless some of the small folds in the extreme west of the area described by Sutton and Watson (1959) are of these generations. A lineation defined by the orientation of hornblende crystals which cut across an earlier ribbon lineation (Sutton and Watson, 1959, p244) may be of the Tormore group of structures.

On the south side of Loch Carron, between Stromeferry and Attadale, the geology of an area which includes the Moine thrust has been studied by May (1959). There are no large folds in this area earlier than the Moine thrust. Small folds belong to three generations.

The first folds (May One) seem to be very similar to the Baravaig folds of the Moine nappe in Skye. These folds are

"well preserved in the main Lewisian mass of Attadale" (May, 1959, p104) and have various axial lineations. Feldspar (May, 1959, p34) "often occurs as aggregates which are sometimes drawn out parallel to L1". "In the hornblende gneisses south of Attadale (May, 1959, p114) the first lineation (is) a quartz pencil structure." A foliation parallel to the axial planes of the May One folds is also found.

May's description of the second (May Two) folds and associated structures, especially the microscopic features, many of which I have examined, is very similar to the description of Tormore structures from the Moine nappe of Skye.

The third fold system of May (1959) does not appear to have any directly comparable equivalent in Skye. The correlations of fold structures between the Moine nappe in Skye, and the area south of Loch Carron appear to be:-

Moine nappe in Skye.	Stromeferry-Attadale area.
Baravaig folds.	May One folds.
Rudha Phoil folds.	---
Tormore folds.	May Two folds.
----	May Three folds.

To the north of Loch Carron, much of the area has been studied by Johnson (1957, 1960A, 1960B). Johnson recognises three, widely developed generations of small folds in both the Moine and Kishorn nappes. The first (Johnson One) folds and associated structures are very similar to the Beinn a'Chapuill,

May One, and Baravaig folds further south. Johnson describes axial lineations (1960A, p150) such as rodding, mullions and elongated augen as well as cleavage, bedding intersection and mineral alignment.

The correlation of the second (Johnson Two) folds is less easy. Superficially, they all resemble the folds of the Rudha Phoil generation further south. However, in the area immediately north of Loch Alsh, A.J.Barber (personal communication) has described small folds in the Lewisian mylonites of the Balmacara nappe and in the immediately adjacent, highly deformed Torridonian rocks which have a similar style and orientation to the Johnson Two folds. Because of the very closely comparable deformational history and features of the Balmacara nappe and the Tarskavaig nappe, there can be little doubt that the small, N-S trending folds in the Balmacara nappe are of the same generation as the Doire na h-Achlais folds of the Tarskavaig nappe (see page 365). These Doire na h-Achlais folds are superficially similar to the small Rudha Phoil folds of the Moine nappe in Skye not only in style but also in their relations to the Capistal/Baravaig lineation. But the Doire na h-Achlais folds and the Rudha Phoil folds are of different generations (see page 365). It is possible, therefore, that the remarkable parallelism of the rock groups in Lochcarron (Johnson, 1960A, p145) and the absence of large folds has introduced a false simplicity into the fold history of the Lochcarron area. In Skye, the Moine thrust has separated two areas with rather different structural history. It may be possible that the Johnson Two folds below the Moine thrust

are of the Doire na h-Achlais generation whereas the Johnson Two folds above the Moine thrust are of the Loch Hourn generation.

4. The Age of the Loch Alsh Fold.

The regional correlation of the fold structures in the south part of the Moine thrust zone raises the problem of the age of the Loch Alsh synform. In the Lochcarron district, (Johnson, 1960A) the Torridonian of the Kishorn nappe is inverted and dips ESE below the Lewisian. This inversion is a result of the formation of the Loch Alsh synform. Johnson thinks (1960A, p146, p147, p164, p167) that the inversion occurred before any of the small fold structures in the area were developed. The evidence is , however, scanty. The Loch Alsh fold has no congruent parasitic folds and only one limb is exposed in the Lochcarron district. The full geometrical relationship of the Loch Alsh fold to the Johnson One folds and lineations cannot be seen.

I think it more likely that the Loch Alsh fold is of the same generation as the Caradal folds of the Tarskavaig nappe, the Knock synform, and the Loch Hourn folds of Glenelg, etc. The axial plane of the Loch Alsh synform in Skye dips ESE (Dr. J.V.Watson, personal communication) and the axis has a very low plunge. The fold is relatively open in profile and tightens slightly at deeper structural levels. In its orientation and style it is very similar to the Tarskavaig, Caradal, and Knock synforms further south and also to several major folds in the Cambrian and Torridonian rocks of the Ord

district of Skye (Karscz, 1963). To the north of the Lochcarron district, Johnson (1960B, p92) mentions large, open folds with axial planes dipping SE to ESE and with near horizontal axes which he suggest may be of the generation that is called here the Loch Hourn generation. All of these tentative correlations suggest that the Loch Alsh fold is a relatively late structure in the development of the Moine thrust zone.

5. The Evolution of the Large Scale Structures.

This last section comprises largely speculative hypotheses concerning the possible development of the area on a regional scale. The most recent comparable synthesis was made by Kennedy (1954). Kennedy thought that the Glenelg-Morar area consisted of two major elements: (a) a pre-Caledonian, or Lewisian, basement with autochthonous Moine cover and (b) the thrust Moine of the Morar nappe, The Tarskavaig nappe was supposed to represent the over-ridden, less highly metamorphic frontal portion of the Moine nappe. Kennedy (p376) also says that the work of Clough and Bailey shows that the entire Sleat peninsula consists essentially of a great recumbent syncline of Cambrian and Torridonian rocks closing towards the south-east. This fold has been disrupted by clean-cut thrusts and refolding of the nappe has introduced certain complexities. Thus, Kennedy distinguishes two phases of movement: (a) deep-seated recumbent folding of crystalline basement and Torridonian and Cambrian cover, and (b) superficial, clean-cut thrusting.

The data presented in this thesis has shown that the major

folds belong to at least three separate generations and that there are at least two phases of clean-cut thrusting (see page 365). Thus Kennedy's regional synthesis needs substantial modification. One of the most difficult problems in working out a viable alternative is to estimate the amount of displacement on the thrust planes. There are often distinct breaks in the metamorphic state across these planes and the first impression is of large scale displacement. However, the internal structure and metamorphism of the individual structural units indicate that this may not necessarily be the case.

First consider the Tarskavaig thrust. In the Tarskavaig nappe, the general scheme is that the Tarskavaig Moine rocks rest upon Lewisian and "young" away from the Lewisian. Beneath the Tarskavaig thrust, the Torridonian rocks, in general, also "young" away from the Tarskavaig thrust, and, although no Lewisian rocks are exposed at present, the Torridonian rocks are low in the stratigraphic sequence. Thus, the Lewisian basement rocks of the Kishorn nappe, upon which these Torridonian sediments once lay, are probably not very far below the main mass of Lewisian mylonites in the south part of the Tarskavaig nappe. It has already been suggested (section 1 above) that the Lewisian mylonites of the Tarskavaig nappe may have once occupied part of the core of a large isoclinal fold (figure 26.2). Maybe the Torridonian rocks immediately below the Tarskavaig thrust are the remnants of the other limb of the same fold. Figure 26.2 is a diagram showing a possible reconstruction of the folds before the Loch Hourn-Caradal period of folding and before the Tarskavaig thrust movements.

The Torridonian horizons which lie immediately below the Tarskavaig thrust in the south of the Sleat peninsula can be traced almost un-interupted in a NE direction, across the Loch Alsh synform, to the north shore of Loch Alsh (Geol. Surv. Sheet 71). In the vicinity of the Balmacara thrust (A.J. Barber, personal communication), the Torridonian rocks are highly deformed and have foliation parallel to that of the Lewisian mylonites in the Balmacara nappe. A few miles further north, the rocks near the junction between the Torridonian Epidotic Grit and the Lewisian of the Kishorn nappe are highly deformed. If there are more Lewisian rocks below the Tarskavaig thrust in south Sleat, then they are probably very like the Lewisian rocks exposed north of Loch Alsh in the Balmacara and Kishorn nappes (figure 26.3). They may also be in structural continuity with the Lewisian of the Kishorn nappe. Lewisian rocks immediately below the Tarskavaig thrust would indicate that the displacement on the Tarskavaig thrust plane would not necessarily be very great to give the present outcrop pattern.

Figure 26.3 is a map which shows the possible geological structure below the level of the Moine thrust (ie. with the Moine nappe stripped away). At this stage, all of the large folds in the region had developed. Karscz (1963) has shown that there are large, isoclinal folds in the ~~Lewisian~~ Torridonian rocks of the Kishorn nappe which are very probably of the Capistal (=Beinn a'Chapuil generation). There is no evidence, either in the Tarskavaig nappe or the Kishorn nappe, for any large folds of an earlier generation. The Arnisdale folds (section 3 above) seem to be confined to the area east of the Moine

thrust. Indeed, even in the Kishorn nappe, the large Capistal generation folds seem to occur just beneath the Tarskavaig thrust but not elsewhere. Further to the west in the Kishorn nappe, and in the Cambrian and Torridonian foreland rocks north of Lochcarron, the only large folds belong to the Loch Hourn generation. Thus, successive generations of large folds may have occupied progressively wider areas.

Following the development of the Loch Hourn folds, further deformation and small scale folding was confined to the immediate vicinity of what is now the Moine thrust. The first of these rather special generations of folds was the Tormore/Ard Thurinish group of structures (see page 365). These have a limited occurence in the Moine nappe of Skye (Chapter 3 and figure 26.4). Further north, on the inverted limb of the Loch Alsh fold, Sutton and Watson (1959, p247) and Dr. J.V.Watson (personal communication) have described lineation and cleavage structures in Torridonian rocks which post-date the Loch Alsh fold and which have a strong resemblance to Tormore structures which occur in Moine rocks at Tormore. May (1959 - see section 3 above) also describes a lineation and fold generation which may be of this age. The distribution of all these supposed Tormore structures, before movement occurred on the Moine thrust plane, is shown in figure 26.4.

After the development of the Tormore folds, further folding was either confined to a very limited area (Port a'Chuil folds) or did not involve very great crustal shortening (Conjugate folds).

The Moine nappe in Skye is composed largely of Lewisian rocks. If figure 26.3 is a reasonable description of the distribution of the rocks beneath the Moine thrust, then, in the Skye area, there must already have been a considerable expanse of Lewisian rocks before the Moine thrust developed. Indeed, the present axial trace of the Knock synform is remarkably close to a southward extrapolation of the axial trace of the Loch Alsh synform. Could they be the same fold? If so, then it is possible to arrive at a figure for the amount of displacement on the Moine thrust plane. This has been used in the construction of figure 26.4. The direction of movement must have been parallel to the line of intersection of two planes; the axial plane of the Knock synform, and the Moine thrust plane. That is, the rocks above the Moine thrust plane have possibly moved 7 miles NNE relative to the rocks beneath.

R.T. Cheeney.

Monday, 31st August, 1964.

EXPLANATION OF FIGURE 26.1.

A table showing the supposed correlation of stratigraphic sequences in the Torridonian, Tarskavaig Moine, and Moine rocks of the Skye region.

Torridonian Rocks of Skye

PELITIC BEDS OF BEN ASLAK

FALSE BEDDING COMMON

Beinn na Seamraig Grits

PSAMMITE BEDS INCREASING

INTERSTRATIFIED PSAMMITE, SEMI-PELITE AND PELITE.

GRADED BEDDING COMMON

Loch na Dal Beds

BROAD TRANSITIONAL CONTACT

EPIDOTE EXTREMELY ABUNDANT
CHLORITE ABUNDANT

INCREASING PELITIC BEDS

PSAMMITES AND PSEPHITES

Epidotic Grits

Tarskavaig Moine Rocks of Skye

VERY COARSE BEDS UP HERE

SEMI-PELITE BEDS OF LOCH NIGHEANN FHIONNLAIDH

MORE FELDSPAR, LESS EPIDOTE THAN CAPISTAL PSAMMITE GROUP

FALSE BEDDING COMMON, BUT USUALLY PARTIALLY OBSCURED BY TECTONIC DEFORMATION

PELITIC BEDS OF CREAG MHOR

Aruisg Psammite Group

PELITIC BEDS OF LOCH LAMASCAIG

CONTACT SHARP IN PLACES, TRANSITIONAL IN OTHERS

GRADED BEDDING COMMON

PSAMMITIC BEDS INCREASING

INTERSTRATIFIED PSAMMITE, SEMI-PELITE AND PELITE.

Laidhe na greine Group

TRANSITIONAL CONTACT

SOME PELITE BEDS

A FEW HEAVY MINERAL BANDS. EPIDOTE, CHLORITE, ETC ABUNDANT

FALSE BEDDING RARE
POOR IN FELDSPAR

RARE PELITE BEDS

Capistal Psammite Group

WHITE QUARTZITE PEBBLES

T. Moine mylonite

Moine Rocks of Glenelg and Knoydart

FELDSPATHIC QUARTZITES
NO HEAVY MINERAL BANDS
ABUNDANT FALSE BEDDING
RARE SEMI-PELITIC BEDS

Barrisdale Psammite

CONTACT SHARP IN PLACES, TRANSITIONAL IN OTHERS

PSAMMITIC MATERIAL INCREASING

Rubha Ruadh Semi-pelite

TRANSITIONAL CONTACT

LARGELY QUARTZITIC
HEAVY MINERAL BANDS COMMON

Arnisdale Psammite

Basal Semi-pelite

Figure 26.1

RTC 16 SEP 64

EXPLANATION OF FIGURE 26.2.

A supposed cross-section through parts of the Tarskavaig and Kishorn nappes before the development of the Tarskavaig thrust plane and before the development of the Caradal folds. In the Tarskavaig Moine rocks, the following names are equivalent:-

Aruisg Psammite Group	=Upper Psammite.
Laidhe na greine Group	=Laidhe na greine group.
Capistal Psammite Group	=Lower Psammite.

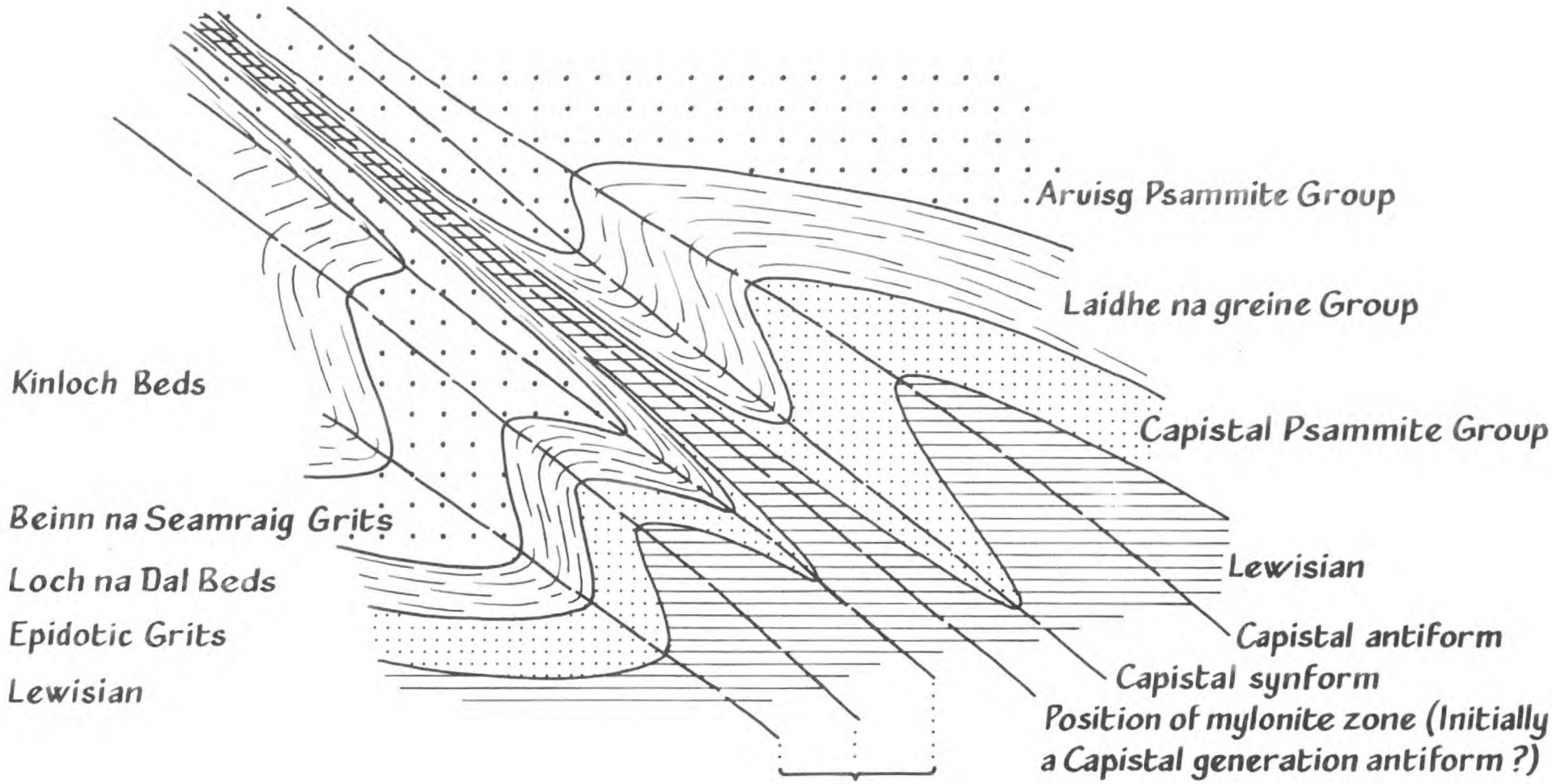

Aruisg Psammite Group
Laidhe na greine Group
Kinloch Beds
Capistal Psammite Group
Beinn na Seamraig Grits
Loch na Dal Beds
Lewisian
Epidotic Grits
Capistal antiform
Capistal synform
Lewisian
Position of mylonite zone (Initially
a Capistal generation antiform ?)
Early folds in the Kishorn nappe

Figure 26.2

EXPLANATION OF FIGURE 26.3.

A map showing how the major rock groups may be expected to be distributed if the rocks of the Moine nappe could be stripped away.

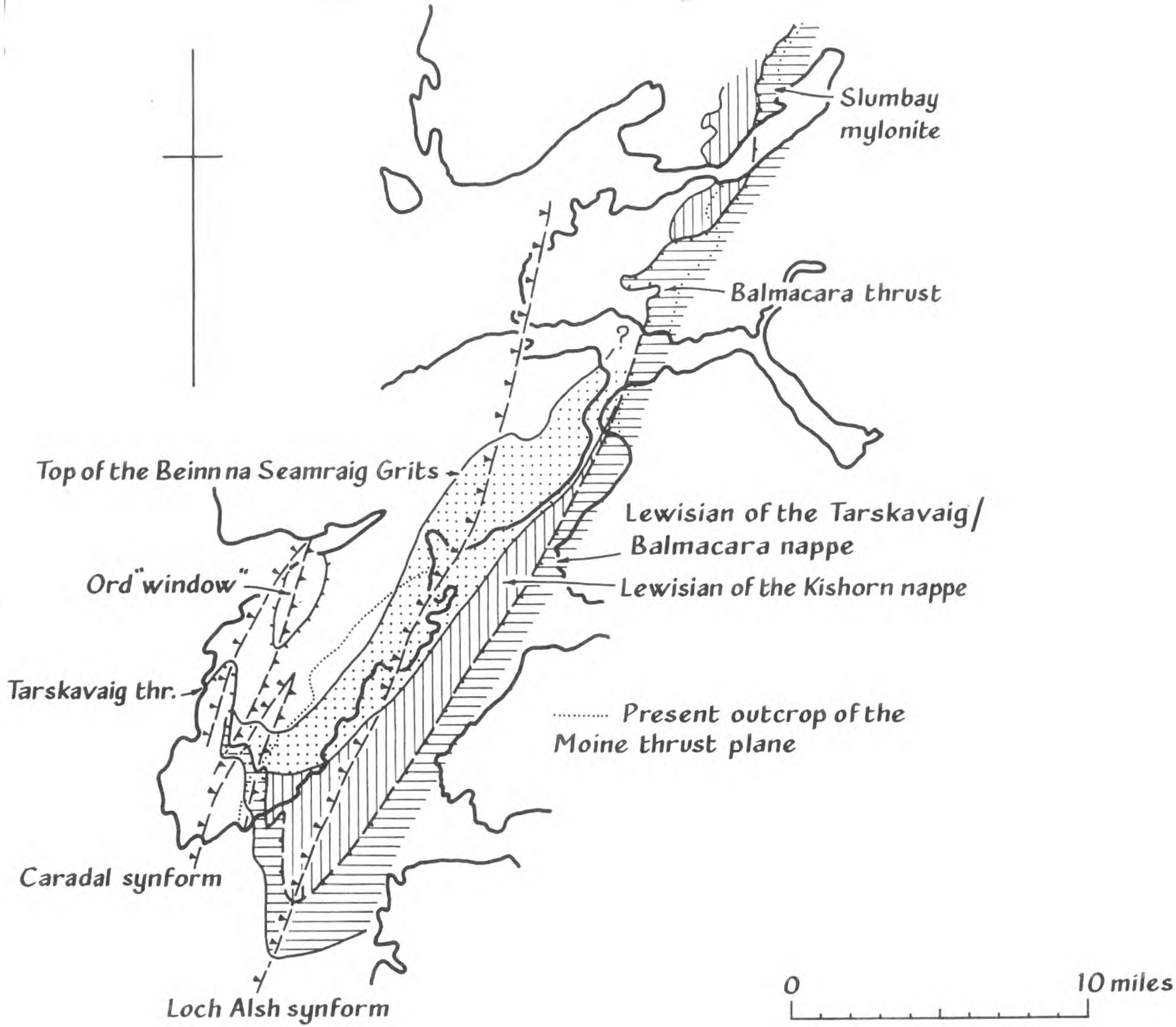

Slumbay mylonite
Balmacara thrust
?
Top of the Beinn na Seamraig Grits
Lewisian of the Tarskavaig/ Balmacara nappe
Ord "window"
Lewisian of the Kishorn nappe
Tarskavaig thr.
..... Present outcrop of the Moine thrust plane
Caradal synform
Loch Alsh synform
0
10 miles

Figure 26.3

EXPLANATION OF FIGURE 26.4.

A possible distribution of Tormore structures before the Moine thrust plane developed.

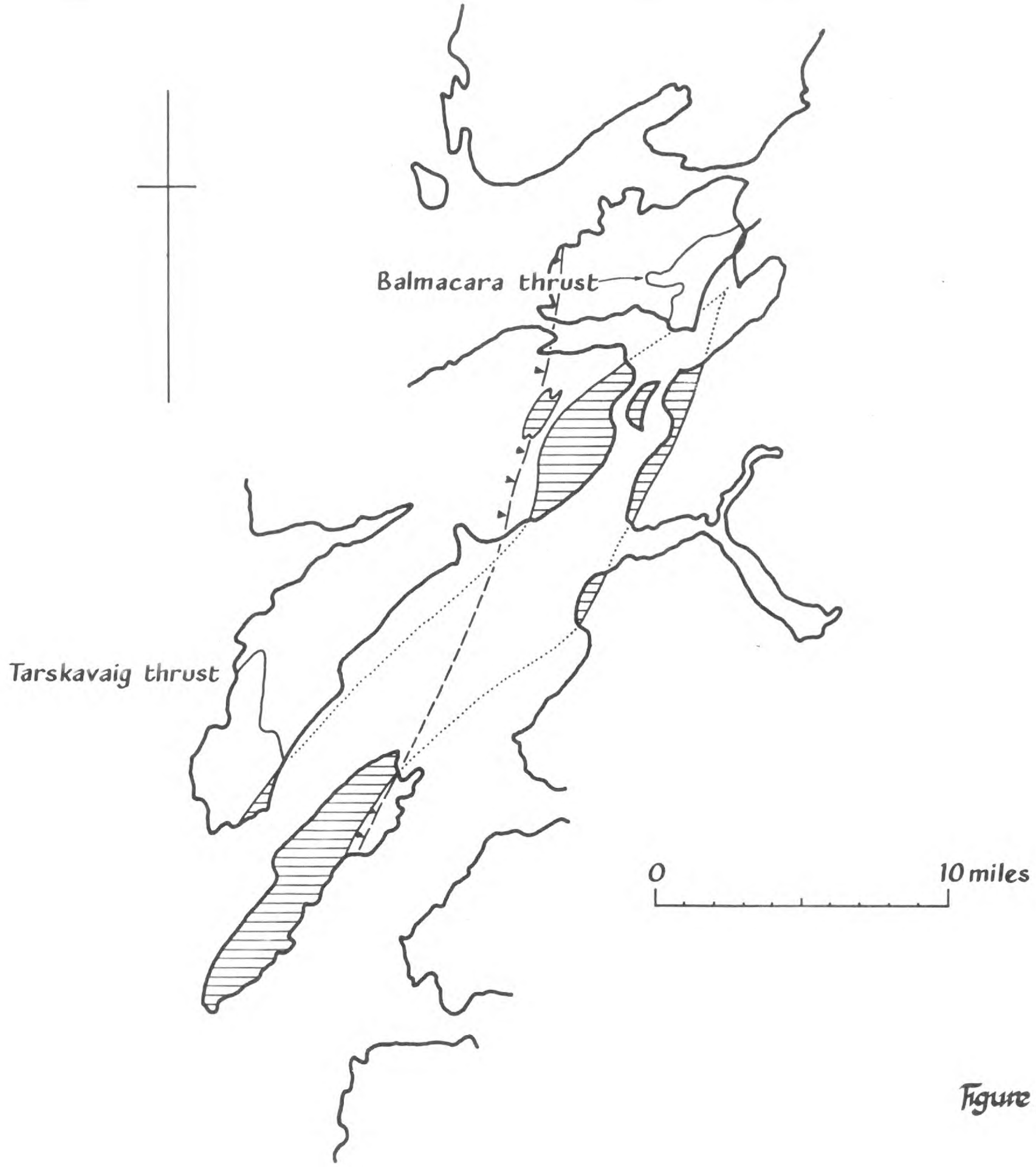


Figure 26.4

PLATE 1. This shows the location of places mentioned in the text. The alphabetical list of place-names, together with the reference to the grid square on Plate 1 in which they can be found, is as follows:-

A	Aird of Sleat	C5
	Allt a'Cham-aird	C4
	Allt a'Ghlinne	B3
	Allt Garistan Neill	F1
	Allt Leth Sithean	E1
	Ard Thurinish	C6
	Ardvasar	D4
	Armadale Pier	E4
B	Bagh a'Mhuilinn	E3
	Baravaig	G1
	Bealach Garbh	B3
	Bealach na Ceardaich	B4
	Ben nan Caorach	B4
C	Camas Baravaig	G1
	Cnoc Fall	D3
	Creag Mhor	B6
D	Dun a'Chleirich	C5
	Dun Horavaig	F1
E	Eilean Maol	E4
	Eilean Sgorach	E4
F	Ferindonald	E2
G	Geur Rudha	A5
K	Knock	F1
	Knock Bay	F1
	Knock Castle (=Dun Horavaig)	F1
L	Leir Mhaodail	B6
	Loch a'Ghlinne	C3
	Loch an Ime	F1
	Loch an t-Seilich	B4
	Loch Aruisg	B5
	Loch Baravaig	F1
	Loch Ben nan Caorach	C4
	Loch Capistal	C5
	Loch Fada	B4

	Loch Lamascaig	B4
	Loch nan Dubhrachan	F1
	Loch nan Uamh	D2
M	Meall Buidhe	C5
O	Ob Snosaig	G1
P	Point of Sleat	A6
	Port a'Chuil	C6
	Port na Long	C5
R	Rudha Charn nan Cearc	A4
	Rudha Cille-bhig	E3
	Rudha Dubh	D4
	Rudha Phoil	E4
S	Sgurran Seilich	B5
T	Tarskavaig	B1
	Teangue	E1
	Tormore	D5

PLATE 2. Self explanatory.

PLATE 3. Self explanatory except for the Ostaig line. See Plate 4.

PLATE 4. Self explanatory.

PLATE 5. Self explanatory.

PLATE 6. This shows the localities from which specimens were collected and the thin sections of which were subsequently mentioned in Part IV. The list of numbers and grid references is as follows:-

16159	D5
16206	B5
16210	B5
16227	C5
16230	C5
16231	D5
16232	D5
16224	D5
16333	B5
16334	B5
16338	D5
16339	D5
16340	D5
16341	D5
16385	B5
16392	B5
16393	B5
16394	B5
16401	D5
16457	D4
16459	D4
16462	D4
16464	D4
16466	D4

16467 D4
16468 D4
16469 D4
16473 D4
16475 E4
16476 E4
16477 E4
16478 E4
16481 E4
18789 F1
18790 C4
18791 C4
18795 E3
18796 E3
18798 F1
18799 F1
18800 F1
18801 G1
18802 G1
18803 G1
18806 G1
18807 C4
18808 C4
18956 E2
18957 F1
18959 F2
18964 F1
18965 F1
18969 F1
18970 F1
18971 F1
18972 F1
18973 G1

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ACKNOWLEDGEMENTS. 403.

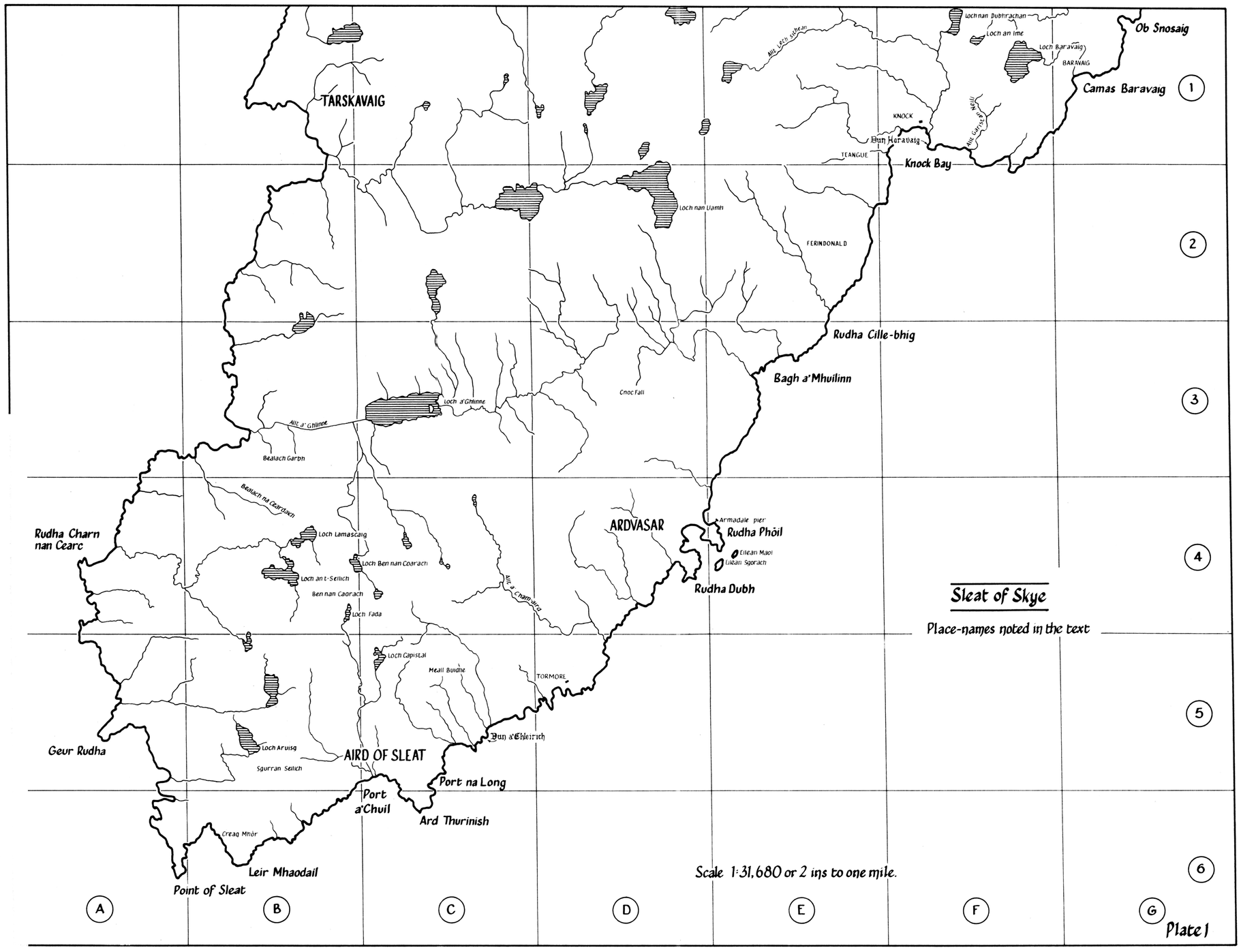
Assistance and advice, both technical and otherwise, as well as the interest, discussion, and encouragement of others have been essential in both the research work and the preparation of the thesis. To all these people, many thanks.

Dr. T.J.Dhonau.
Dr. M.J.Fleuty.
E.J.Hill.
Alan Hill.
Yakov Karscz.
David Matthews.
Dr. J.McManus.
Dr. J.G.Ramsay.
Dr. P.Simony.
Professor J.Sutton.
Geoff. Tanner.
Dr. O.T.Tobisch.
L.W.Vaughan.
Dr. G.P.L.Walker.
Dr. J.V.Watson.
Gilbert Wilson.

During my stay in Skye, many friends gave hospitality generously.

Mr. and Mrs. C.Macdonald.
Mr. and Mrs. R.G.Hunter.
Hugh Macdonald.
Elsie Fraser.
Donald and Susan Robertson.
The Mackinnons of Aird.
Neil Anderson, for promised loan of boat.
Donald Maclean, missionary, for promised loan of boat.
Donald Maclean, transport manager, for promised loan of boat.
Norman, the policeman, for actual loan of boat.

R.T.C.



Knock Bay

Rudha Cille bhig

Bagh a'Mhuilinn

Ardvasar

Tormore

Ard Thurinish

Point of Sleat

CARADAL THRUST

MOINE THRUST

Sleat of Skye

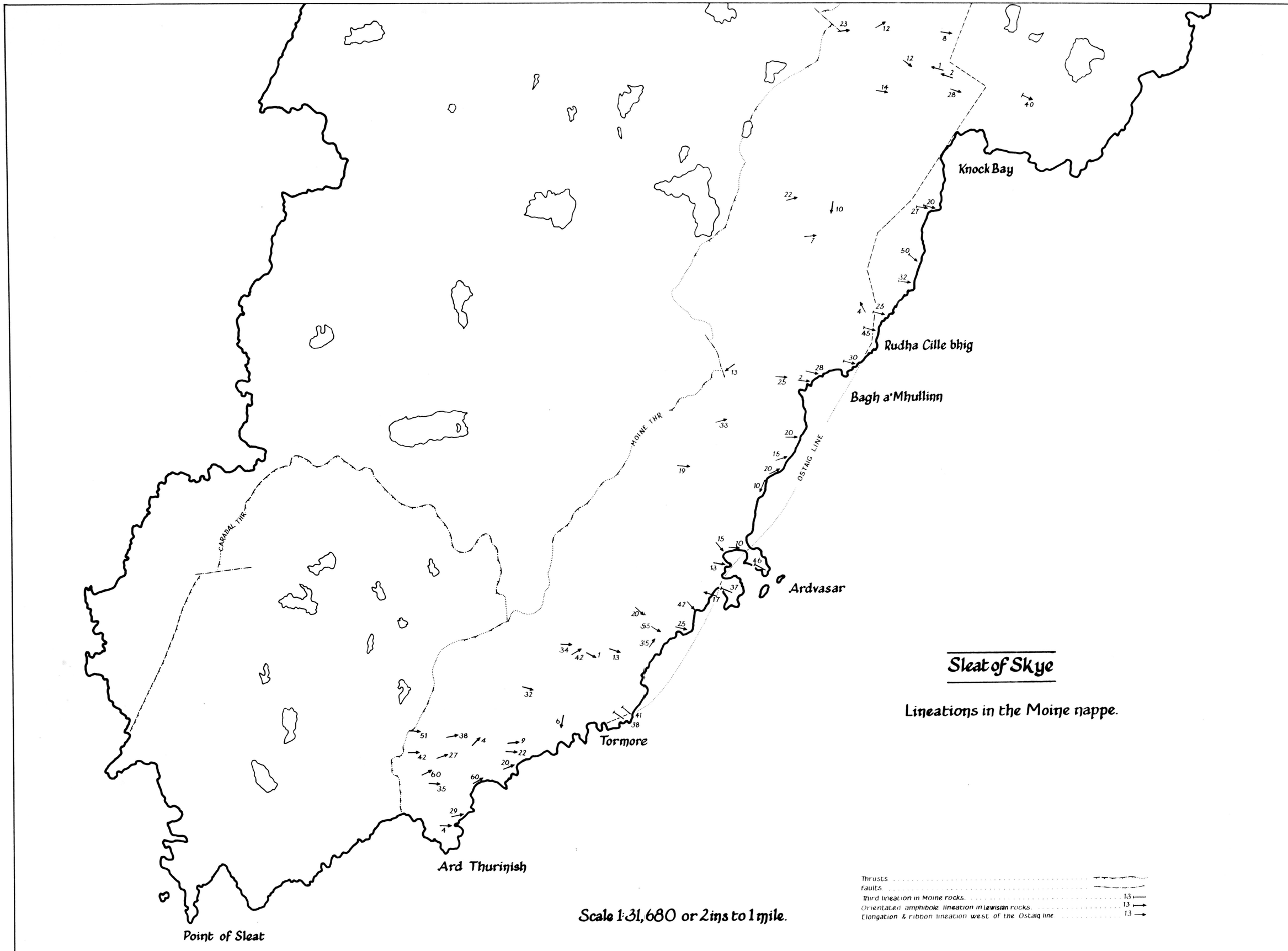
First and third structures in the Caradal nappe
First and second structures in the Moine nappe

Key

Thrusts .....
Faults .....
Caradal nappe
First lineation 13
Axial trace of Caradal synform .....
and antiform .....
Axial trace of Capistal synform .....
and antiform .....
Moine nappe
First lineation 13
Axial trace of Knock synform .....

Scale 1:31,680 or 2ins to 1mile.

Plate 2



Sleat of Skye

Lineations in the Moine nappe.

Scale 1:31,680 or 2ins to 1 mile.

Thrusts
Faults
Third lineation in Moine rocks. 13
Orientated amphibole lineation in Lewisian rocks. 13
Elongation & ribbon lineation west of the Ostaig line 13

Plate 3

Knock Bay

KNOCK LINE

Rudha Cille bhig

Bagh a'Mhuilinn

OS TAIG LINE

Ardvasar

Tormore

Ard Thurinish

Point of Sleat

Sleat of Skye

Metamorphism of the Moine nappe.

Scale 1:31,680 or 2 ins. to 1 mile.

Lewisian

Limits of phyllonites. Black spots are the easternmost localities observed in which basic rocks have a closely spaced, fissile parting.

Limits of massive acid rocks containing randomly orientated porphyroblasts of amphibole. Black spots represent the westernmost observed exposures of such rocks.

Moinian

Extent of fissile parting in semi-pelitic rocks. Psammite bands "thin"

Extent of semi-pelitic rocks without fissile parting. Psammite bands "thick"

Plate 4

Knock Bay

Rudha Cille bhig

Bagh a'Mhuilinn

Ardvasar

Tormore

Ard Thurinish

MOINE THRUST

Point of Sleat

Sleat of Skye

Lithological map of the Moine and Caradal nappes.

Scale 1:31,680 or 2ins to 1 mile.

Dip in degrees of dominant planar structure.
Dominant planar structure horizontal.
Dominant planar structure vertical.
Faults.
Thrusts.
Other boundaries.

KEY TO ORNAMENTATION.

Tarskavaig Moines.
- Upper Psammite.
- Laidhe na gréine group.
- Lower Psammite.

Torridonian.
- Epidotic grit.

Standard Moine.
- Psammite and semi-pelites undifferentiated.

Lewisian.
- Mylonite in the Caradal nappe.
- Mostly mylonite and phyllonite.
- Mostly mylonitised gneiss.
- Amphibole, biotite gneisses and migmatised amphibolites.
- Unmigmatised amphibolites.
- Ultrabasic gneiss.

Plate 5

Sleat of Skye

Thin-section localities

18965
18964
18972
18971
18789
18970
18806
18801/18802
18803
18798/18799
18969
18973
18957
18800
18959
18956
18795/18796
16481
16473
16475
16476
16478
16477
16468/16469
16464/16467
16459
18457
16462/16466
18807
18790/18791
18808
16341
16244
16338
16339
16159/16340
16232
16401/16231
16230
16227
16394
16334/16393
16333
16392
16206
16210
16385
16242

1 2 3 4 5 6

A B C D E F

Plate 6