Keele University

The Geology of the Moine rocks of the Loch Eil area, West Inverness-shire

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ABSTRACT

Detailed mapping of 120 sq.km. has been carried out within the Moine rocks of the Loch Eil area, West Inverness-shire. The metasedimentary rocks of the Loch Eil Division Moine are composed of a series of psammites, quartzites and 'banded' units with minor semi-pelites. This sequence has been lithologically subdivided into ten lithostratigraphic units. Sedimentological analysis suggests that the metasediments accumulated in a shallow-marine environment.

The Loch Eil Division has been subjected to five phases of deformation (D1-D5). Minor recumbent folding and tectonic sliding occurred during D1, and resulted in the interleaving of the Loch Eil Division rocks with gneissose lithologies of the underlying Glenfinnan Division Moine. Major folding occurred during D2-D4, and brittle faulting and thrusting during D5.

Amphibolite facies metamorphism (M1) accompanied D1: grade was of upper to mid-amphibolite facies in the W of the Loch Eil area and declined eastwards to mid- to low amphibolite facies. Subsequent metamorphic events (M2-M4) only involved the recrystallisation and local retrogression of M1 assemblages during metamorphism of amphibolite and greenschist facies.

The Loch Eil Division lies in tectonic contact with the underlying Glenfinnan Division which, in the Loch Eil area, is composed mainly of migmatitic semi-pelitic gneiss. Structural observations along the E margin of the Glenfinnan Division suggest that it possesses an earlier structural history than that which is apparent in the Loch Eil Division.

The granitic gneisses and amphibolites of the Loch Eil area are considered to be meta-igneous bodies emplaced at an early stage in the tectono-metamorphic history outlined above.

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CHAPTER 1: INTRODUCTION

1. LOCATION AND GEOGRAPHY OF THE LOCH EIL AREA

1.1. Location and extent of the Loch Eil area

Loch Eil lies approximately 3 kilometres to the NW of Fort William, Inverness-shire, and is situated in the eastern part of the Western Highlands. The area mapped, henceforth referred to either as 'the area' or as 'the Loch Eil area', covers approximately 110 square kilometres, and extends westwards from the Great Glen as far as a line linking Glen Dubh Lighe with Meall nan Damh (Fig. 1). The southern boundary of the area is delimited by Cona Glen, and the northern limit by a curved line linking Gulvain, the summit of Meall Onfaidh and Glen Loy (Fig. 1).

1.2. Topography and superficial deposits

The physical geography of the area is dominated by Loch Eil, which is paralleled by two wide 'U'-shaped E-W trending valleys, Cona Glen and Glen Loy. The intervening hills have been dissected by N-S to NE-SW trending valleys such as Glen Garvan, Glen Suileag and Glen Fionnlighe. In the eastern part of the area relief is comparatively gentle, whereas in the western part gradients are somewhat steeper and hills rise rather more sharply from the shores of Loch Eil and the valley bottoms. Most of the hills attain elevations of between 650 and 750 metres, and the highest point is the summit of Gulvain (987 metres) in the extreme north of the area. Corries are well-developed on the north-facing slopes of Meall nan Damh and Druim Fada.

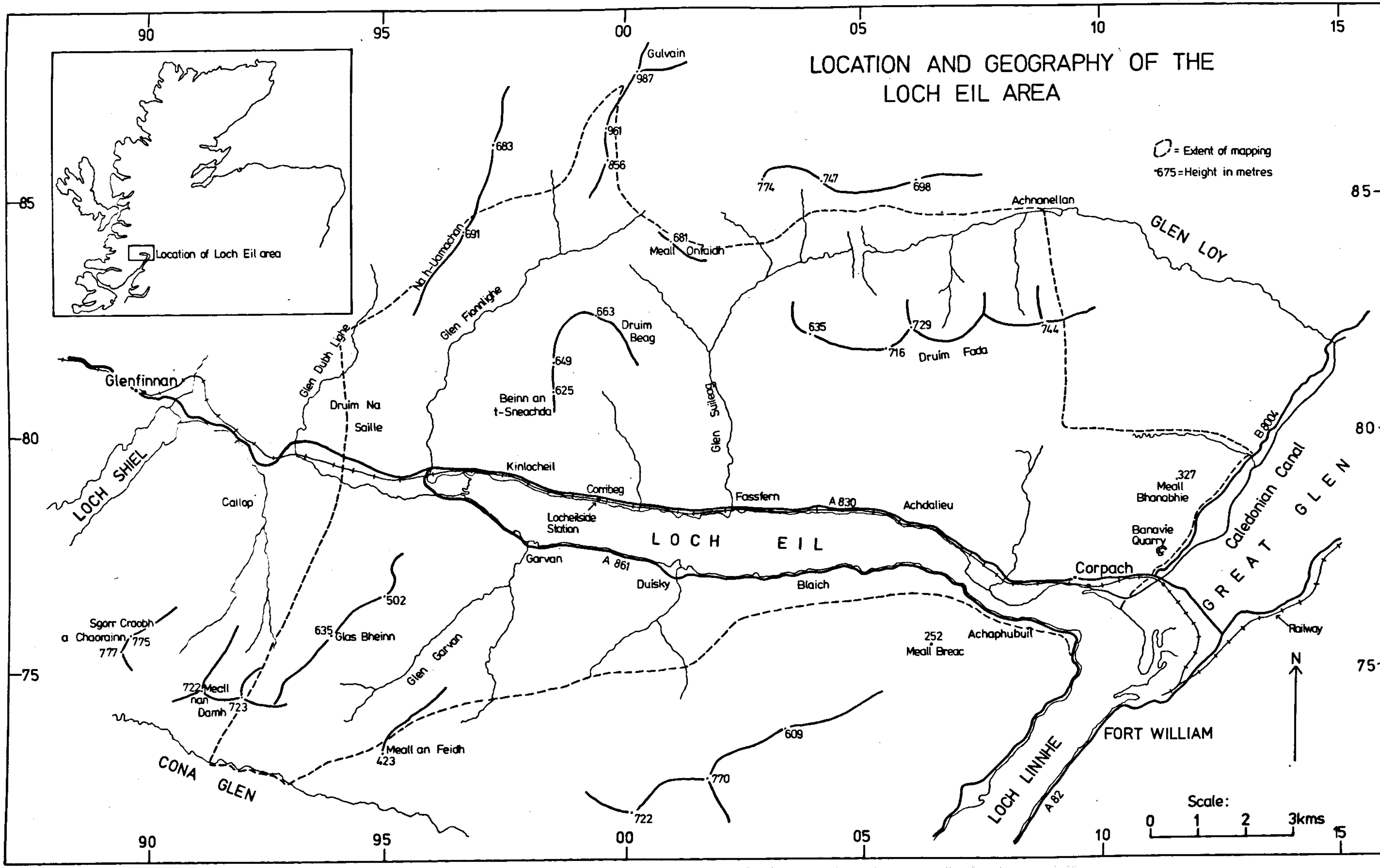


Figure 1: Location and geography of the Loch Eil area.

Morainic drift is extensively developed on the hills to the east of Glen Suileag, north of Loch Eil, and on the low slopes between Garvan and Meall Breac, south of Loch Eil. In the remainder of the area morainic drift is confined to the valley bottoms and lower slopes. Peat is developed on the low ground between Garvan and Duisky. Fans of alluvium are present where the major rivers and streams enter Loch Eil, and alluvium fills the through valley which links Glenfinnan and Loch Eil. Post-glacial submergence of land relative to sea-level resulted in the formation of a raised beach with a back feature about 12 metres O.D. along Loch Eil side. The level of exposure is directly related to the development of superficial deposits and is thus excellent in the westerly parts of the area, but tends to be poor on the southern slopes of Druim Fada and virtually nonexistent on the slopes to the SE and E of Duisky.

1.3. Land use and economic geology

Most of the area is now devoted to deer forest and sheep grazing. A small amount of cultivation occurs at Fassfern. Forestry Commission conifer plantations are present on Druim Na Saille and near Callop, Garvan, Fassfern and to the N of Corpach. Moine psammite is excavated at Banavie Quarry and crushed for roadstone. The landscape at the E end of Loch Eil is dominated by a large pulp-mill, the economic future of which is in considerable doubt at the time of writing. The main settlement in the area is Corpach at the E end of Loch Eil.

A number of houses and farms are present along the N side of Loch Eil at Achdalieu, Fassfern, Corribeg and Kinlocheil, and along the S side of the Loch at Garvan, Duisky, Blaich and Achaphubuil.

1.4. Access within the area

The main source of access is the A830 Fort William-Mallaig road which runs along the north side of Loch Eil. At Kinlocheil this links with the A861 Kinlocheil-Strontian road which provides access to the area south of Loch Eil. Access to Glen Loy is by means of B8004 road from Banavie to Glen Loy Lodge, and thereafter on a tarred road to Achnanellan. The most direct route into the W end of Cona Glen is via a track which runs southward from Callop, between Meall nan Damh and Sgorr Craobh a Chaorainn, and thence into Cona Glen. Most of the valleys in the area have tracks along their floors and these provide the main means of access onto the hills. The Fort William-Mallaig railway runs along the N side of Loch Eil and trains regularly stop at Kinlocheilside Station, thus providing limited access to the western part of the area.

2. GENERAL GEOLOGY

Most of the Loch Eil area is underlain by the variably-inclined, but often gently-dipping, psammites and quartzites of the Loch Eil Division of the Moine Succession which give rise to comparatively gentle relief and rounded hills. The sharper and more marked relief in the west of the area marks the outcrop of the steeply-inclined pelitic and psammitic gneisses of the Glenfinnan Division Moine which enclose two large granitic gneiss bodies. Phanerozoic rocks are poorly represented in the area and are represented by a series of small 'late-Caledonian' igneous and meta-igneous intrusions together with more extensive granite vein complexes. The Great Glen fault zone, of which much has been written (e.g. Kennedy 1946; Winchester 1973; and many others) forms the eastern limit of the area. The nature and extent of the possible lateral and vertical movements associated with the fault do not, however, form any part of this study.

3. AIMS AND SCOPE OF RESEARCH

A total of 11 months fieldwork, involving detailed mapping on a scale of 1:10,000, was carried out in the Loch Eil area between September 1978 and October 1980 with the aim of mapping a complete across-strike section through the relatively unknown Loch Eil Division Moine in its type area. Major objectives of this study were:

(a) The subdivision of the Loch Eil Division on a lithostratigraphic basis.

(b) Elucidation of the structural and metamorphic history of both the Loch Eil Division and the easterly part of the Glenfinnan Division.

(c) A close examination of the contact of the two Divisions, and the correlation of structural and metamorphic events across this contact, in an attempt to establish the nature of the relationship between the Glenfinnan and Loch Eil Divisions.

(d) Clarification of the conditions and environment(s) of deposition of the Loch Eil Division rocks.

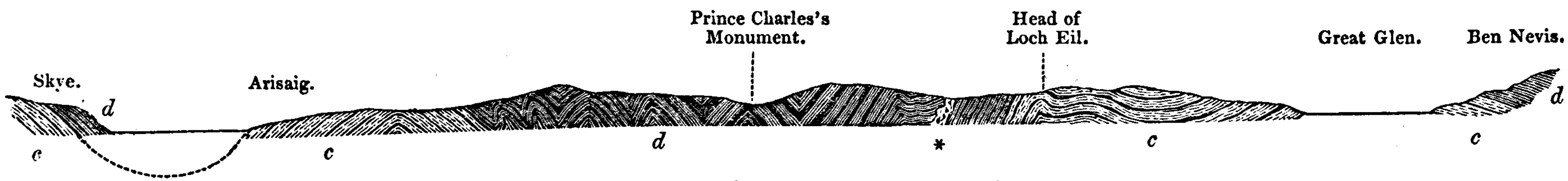
4. PREVIOUS RESEARCH AND GENERAL GEOLOGICAL BACKGROUND

4.1. Early work

One of the first recorded accounts of the geology of the eastern part of the Western Highlands is that of MacKnight (1811) who traversed a considerable portion of the Western and Central Highlands of Scotland, and visited many points of interest in the West Inverness-shire area. He viewed all geological phenomena from the viewpoint of Wernerian doctrine and traced a succession from the clay-slate of Ballachulish, through the mica-slate of the Fort William shore of Loch Linnhe and the gneisses of Ardgour to the 'granite' at the west end of Glen Tarbert. This he evidently regarded as a normal downward sequence of deposits.

Murchison and Geikie (1861) studied the area between Arisaig and the Great Glen. In their cross-section across this area (Fig. 2) they recognized two basic metamorphic rock types: 'quartz-rock' and 'micaceous and gneissose schist'. They concluded that the regional structure was dominated by a large syncline, the axis of which was located between Lochailort and Glenfinnan. The quartz-rocks of the Arisaig and Loch Eil areas were correlated and considered

Fig. 19.—*Diagram-section from Skye to the South End of the Great Glen.*



. Quartz-rock. *d.* Micaceous and gneissose schists. * Granitic rock.

Figure 2: Structure of the area between Skye and Ben Nevis according to Murchison and Geikie (1861).

to underlie the 'highly contorted' micaceous and gneissose schists of the Lochailort-Glenfinnan area. The rocks of the Loch Eil area were gently-inclined and broadly synformal in structure. They postulated that an 'anticlinal arch' ran along the Great Glen, linking the northwesterly-dipping quartz-rocks of the Banavie area with the easterly-dipping quartz-rocks of the Fort William-Spean area.

The term "Moine Schists" was first used by Geikie (1888, p.436) in the Northwest Highlands. The name was gradually extended to apply to the assemblage of psammites and pelites which extends from the Moine Thrust into the Grampian Highlands, including those of the Loch Eil area.

4.2. Tectono-stratigraphy

The earliest systematic geological mapping in the Loch Eil area was carried out at the end of the last century by J.S.G. Wilson of H.M. Geological Survey, and his work is summarized by Bailey and Maufe (1960). Wilson mapped the majority of the metamorphic rocks of the Ardgour district northwest of Loch Linnhe in the Geological one-inch Sheet 53, including those of the area between Cona Glen and Loch Eil. He subdivided the metamorphic rocks of this area into a broad belt of gently-dipping 'siliceous gneisses' of 'Moine-type', which occupy the ground between Meall nan Damh and the Great Glen, and a relatively narrow approximately north-south trending belt of steeply-inclined 'highly micaceous gneisses' which crop out in the western part of

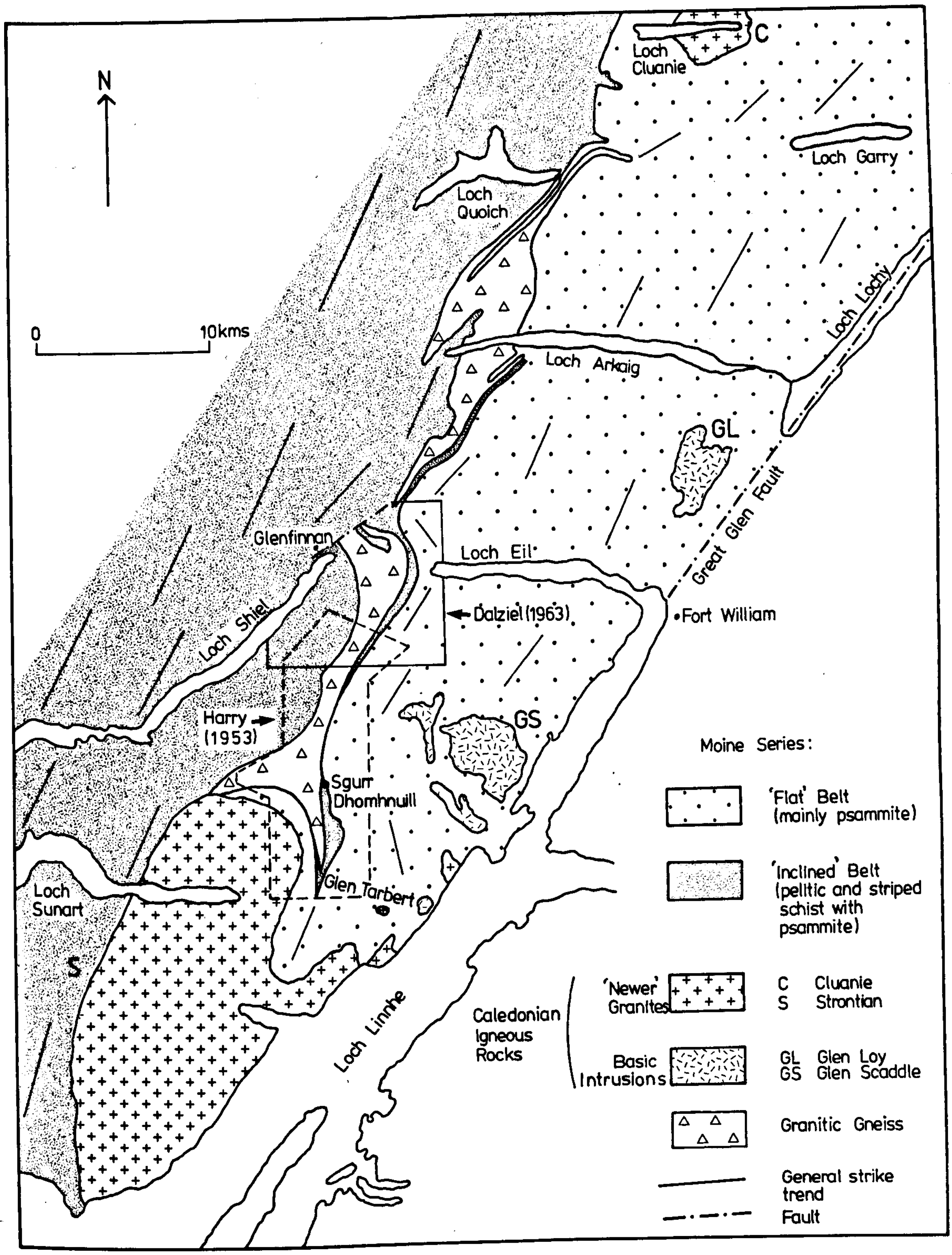
Cona Glen. In the Sgurr Dhomhnuill area the highly micaceous gneisses enclose a granitic gneiss which was termed by Wilson the "augen-gneiss of Sgurr Dhomhnuill". The highly micaceous gneisses form easterly members of a large 'injection-complex' which was subsequently recognized in the Moidart and Sunart areas to the west (Richey 1931; Kennedy 1946; Phenister 1948). Drever (1940) suggested that the siliceous gneisses described by Wilson might correlate with the upper Psammitic Group of Moines established by Richey and Kennedy (1939) in the Morar district.

The mapping of the Geological 1:50,000 Sheet 62 was largely completed within the period 1951-65 (Summ. Progr. Geol. Surv. Gt.Br. 1951-65). This mapping confirmed the presence of a broad belt of flat-lying 'psammitic granulites' which were equivalent to Wilson's siliceous gneisses and extended from the head of Loch Eil as far east as the Great Glen. Current-bedding present within these rocks near the western margin of the psammitic belt suggested that they were younger than the pelitic rocks to the west. These older rocks were equated with Wilson's highly micaceous gneisses, and comprised a varied assemblage of steeply-dipping 'striped psammitic and injected pelitic schists' which extended westwards from the head of Loch Eil to the western margins of Sheet 62.

Leedal (1952), in his study of the Cluanie igneous intrusion, published a generalised geological map of the southern portion of the Northern Highlands in which he demonstrated that the structural and lithological trends observed in the Ardgour and Loch Eil areas by previous workers persisted at least as far north as the Cluanie area (Fig. 3). He subdivided the Moine rocks of the area into an easterly 'flat' belt, composed of psammites which were correlated with the Upper Psammitic Group of Morar, and a westerly 'steeply-inclined' belt, composed of a heterogeneous assemblage of striped and pelitic schists and psammites which were correlated with the Upper Psammitic, Pelitic and Lower Psammitic Groups of Morar. The first main outcrop of the Pelitic Group along the western margin of the flat belt was taken to define the limits of the 'flat' and 'steeply-inclined' belts. Between Strontian and Loch Quoich the boundary between the two belts was depicted as being approximately coincident with the outcrop of two large granitic gneiss bodies which were correlated with, and were in part an extension of, Wilson's "augen-gneiss of Sgurr Dhomhnuill". The boundary between the 'flat' and 'steeply-inclined' belts was subsequently termed the 'Loch Quoich line' by Clifford (1957) who suggested that it might represent the root zone of the Kintail nappe.

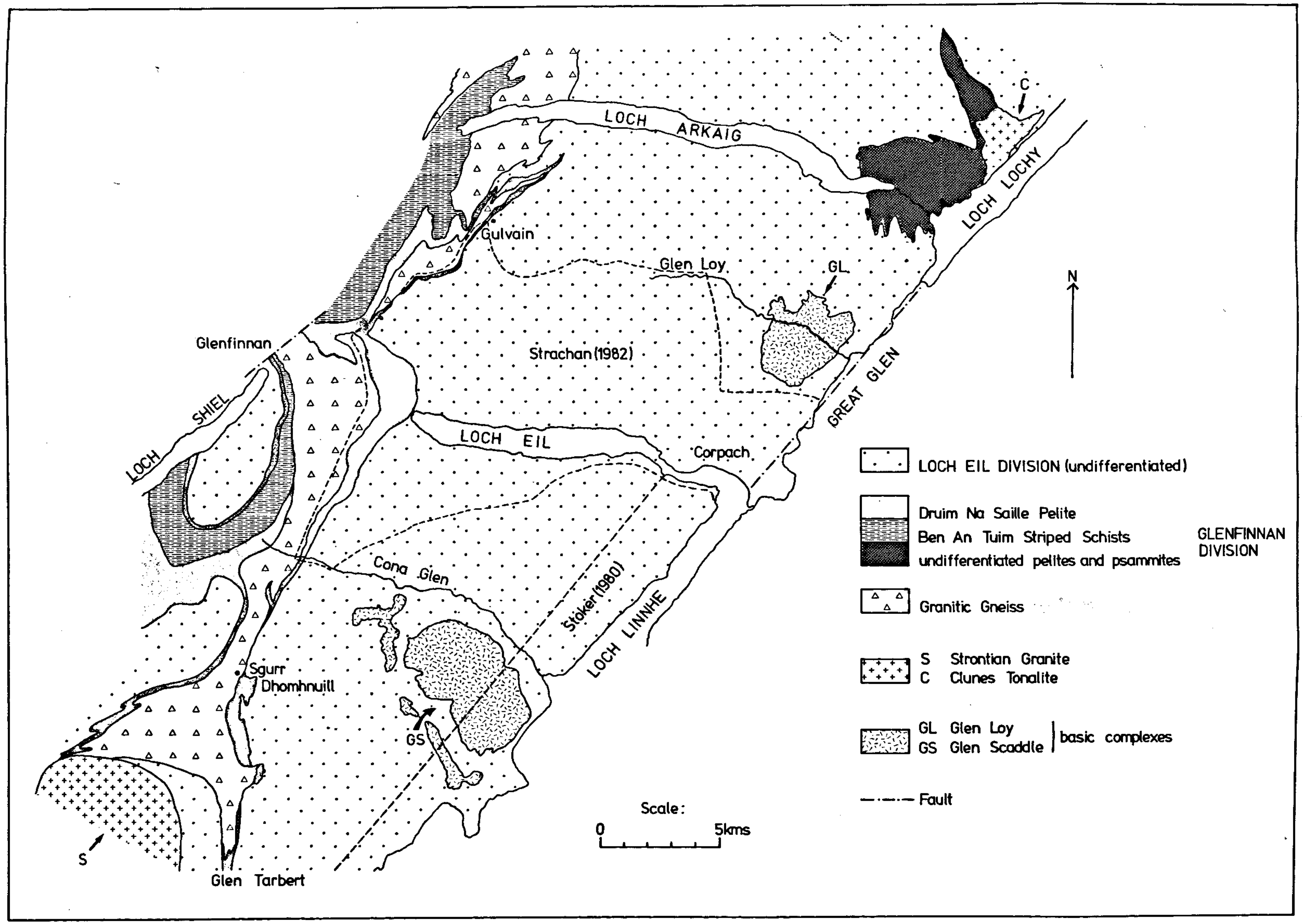
Leedal's map incorporated the work of Harry (1953) who had mapped the southerly portion of the southern granitic gneiss depicted by Leedal (Fig. 3) which, as Harry had shown, was contiguous with the augen-gneiss of Sgurr Dhomhnuill. Harry renamed this body the "composite granitic gneiss of western Ardgour". The granitic gneiss was flanked to the east and west by pelitic gneisses which were succeeded by psammitic rocks (Fig. 4) and Harry postulated that the areal structure was antiformal, the core of the antiform lying along the outcrop of the granite gneiss. The psammitic rocks of western Ardgour were again correlated with the Upper Psammitic Group of Morar, and Harry suggested that the pelitic

Figure 3: Major geological features of the southern portion of the Northern Highlands according to Leedal (1952), also delimiting the areas mapped by Harry (1953) and Dalziel (1963).



N
0
10kms
Loch Cluanie
C
Loch Garry
Loch Quoich
Loch Lochy
Loch Arkaig
GL
Great Glen Fault
Glenfinnan
Loch Eil
Dalziel (1963)
Fort William
Loch Shiel
Harry (1953)
GS
Sgurr Dhomhnuill
Glen Tarbert
Loch Sunart
S
Loch Linnhe
Moine Series:
'Flat' Belt (mainly psammite)
'Inclined' Belt (pelitic and striped schist with psammite)
Caledonian Igneous Rocks
'Newer' Granites
C Cluanie
S Strontian
Basic Intrusions
GL Glen Loy
GS Glen Scaddle
Granitic Gneiss
General strike trend
Fault

Figure 4: Geology of the area between Glen Tarbert and Loch Arkaig, compiled from Harry (1953), Dalziel (1963, 1966) and Institute of Geological Sciences Sheets 53 and 62. The map also delimits the areas subsequently mapped by Stoker (1980) and the present author.


LOCH ARKAIG
LOCH LOCHY
C
Gulvain
Glen Loy
GL
Glenfinnan
Strachan (1982)
GREAT GLEN
N
LOCH SHIEL
LOCH EIL
Corpach
Cona Glen
Stoker (1980)
LOCH LINNHE
Sgurr Dhomhnuill
GS
S
Glen Tarbert
Scale:
0
5kms
LOCH EIL DIVISION (undifferentiated)
Druim Na Saille Pelite
Ben An Tuim Striped Schists
undifferentiated pelites and psammites
GLENFINNAN DIVISION
Granitic Gneiss
S Strontian Granite
C Clunes Tonalite
GL Glen Loy
GS Glen Scaddle
basic complexes
Fault

gneisses, which he considered to occupy a lower structural level, were the highly metamorphosed and 'injected' equivalents of the Pelitic Group of Morar.

Dalziel (1963; 1966) mapped an area which incorporated the northern part of the granitic gneiss body described by Harry (Fig. 3). The stratigraphy of this area had much in common with that of the adjacent area to the south (Fig. 4). The pelitic gneisses which tended to flank the granitic gneiss were termed the Druim Na Saille Pelitic Group, and the younger psammites of the 'flat' belt were named the Glen Garvan Psammitic Group. Dalziel also identified an assemblage of striped psammites, termed by him the Ben An Tuim Striped Group, which occupied a lower structural level than the Druim Na Saille Pelitic Group. Following the work of Powell (1964), Dalziel (1966) disputed the generally accepted correlation of the Glen Garvan Psammitic and Druim Na Saille Pelitic Groups with the Upper Psammitic and Striped and Pelitic Groups of the Morar succession. In the Lochailort area Powell (1964) had demonstrated that the equivalents of the Upper Psammitic Group appeared to be considerably thinner than the Glen Garvan Psammitic Group, and the Druim Na Saille Pelitic Group was distinguished by numerous amphibolite pods and bands which are absent from the Striped and Pelitic Group, but common in the Lochailort Pelitic Group. Dalziel (1966) therefore proposed that the Lochailort Pelitic, Ben An Tuim Striped and Druim Na Saille Pelitic Groups are probable correlatives, and that the Glen Garvan Psammitic Group forms the basal part of a psammitic sequence which extends as far east as the

Great Glen and is stratigraphically higher than the entire Morar and Lochailort successions.

Johnstone et al. (1969) subdivided the Moine of West Inverness-shire into three structural-stratigraphic units, each of which was structurally and lithologically distinctive. These units were named the Morar, Glenfinnan and Loch Eil Divisions. The Glenfinnan and Loch Eil Divisions broadly correspond to Leedal's 'highly-inclined' and 'flat' belts respectively, and the base of the Loch Eil Division in the Loch Eil area was drawn at the eastern margin of the Druim Na Saille Pelitic Group (Fig. 4). Following the work of Harry (1953) and Dalziel (1963; 1966) the two Divisions appear to be tightly interfolded in the area to the S and SE of Loch Shiel (Fig. 4) but are, according to Johnstone et al. (1969), sharply demarcated in the area to the north of Glenfinnan.

The most recent detailed mapping within the Loch Eil Division is that of Stoker (1980) who mapped an area parallel to the Great Glen extending from Loch Eil southwards to Glen Tarbert (Fig. 4). The rocks of this area were subdivided into a series of lithostratigraphic units which were characterised by the large-scale alternation of psammite and quartzite.

4.3. Structural history

According to Dalziel (1963; 1966) and Brown et al. (1970) both the Glenfinnan and Loch Eil Divisions exhibit a common structural history, involving four main episodes of folding (F1-F4). The first of these, F1, is characterized by minor isoclinal structures. F2 and F3 involved major folding and interfolding of the two Divisions along NE-SW to N-S trending axes, and F4 resulted in minor folds with E-W trending axes. During F2 and F3 the lithologically heterogeneous Glenfinnan Division absorbed a considerably higher proportion of the regional strain than the lithologically more homogeneous Loch Eil Division. Thus F2 and F3 structures within the Glenfinnan Division are typically close to isoclinal in style with steeply-plunging axes, whereas structures of the same generation within the Loch Eil Division are open to tight in style with gently-plunging axes. It is this areal variation in the intensity of F2 and F3 folding which was responsible for the generation of the 'highly-inclined' and 'flat' belts.

Stoker (1980), working within the Loch Eil Division of E. Ardgour, identified a four-phase deformational history which is similar in its major aspects to that described by Dalziel from the western part of the Loch Eil Division.

4.4. Origin and timing of formation of the granitic gneiss belt

Harry (1953) concluded that the granitic gneiss of western Ardgour represented the "highly-granitised" equivalents, at a lower structural level, of the enclosing pelitic gneisses. Dalziel (1963; 1966) presented an essentially similar interpretation and suggested that the granitic gneiss was formed during F2, broadly synchronous with regional migmatisation and sillimanite-grade metamorphism, and was the intensely metasomatised and recrystallised equivalent of the Ben An Tuim Striped Group which appeared to occupy the same stratigraphic horizon further west. The Loch Quoich line was inferred to represent the boundary between a mobile infrastructure, represented by the migmatitic pelites and striped psammites of the Glenfinnan Division, and the more rigid cover of the Loch Eil Division, and to have been the locus of "intense shearing movements" during F2. Dalziel (1966, p.149) suggested that "transfer of material (?from a zone of partial melting at depth) and recrystallisation would both be assisted by such movements", and thus explained the localised occurrence of the granitic gneiss along the Loch Quoich line.

Other workers suggested, however, that the granitic gneiss might be magmatic in origin. Mercy (1963, p.214) commented on the "quite remarkable magmatic features" of the granitic gneiss and suggested that it might represent a "distinct kind of magma emplaced amongst high-grade metamorphic rocks". Gould (1966) subsequently showed that the granitic gneiss has a uniform minimum melt composition and suggested that it was formed at a depth not far below the present exposure level.

Johnstone et al. (1969) demonstrated that the outcrop pattern of the granitic gneiss bodies NE of Glenfinnan (Fig. 4) is rather more complex than depicted by Leedal. In addition to those bodies outcropping near the junction between the Glenfinnan and Loch Eil Divisions, granitic gneisses crop out entirely within the Loch Eil Division in the River Loyne - Glen Garry - Invergarry area. The precise timing of granitic gneiss formation with respect to major fold episodes only appeared to differ slightly within the area, and consequently the granitic gneisses were inferred to represent a single suite of migmatitic origin.

The granitic-gneiss of western Ardgour has attracted the attentions of a number of geochronologists. Lambert (1969) recorded a "preliminary isochron" indicating a Rb-Sr whole rock age of 810 m.y. for this granitic gneiss body. Brook et al. (1976) subsequently obtained a Rb-Sr whole rock age of 1050 ± 46 m.y. from the granitic gneiss at Glenfinnan, which they interpreted as the age of its formation. If the conclusions of previous workers concerning the mode and timing of granitic gneiss formation with respect to the tectono-metamorphic history of the surrounding Moine are correct, then it appears that the main early metamorphism of the Moine of the Glenfinnan and Loch Eil Divisions took place at about 1050 m.y., broadly coeval with events of 'Grenvillian' age in Norway and Canada. This suggestion is broadly substantiated by the average Rb-Sr age of c.1000 m.y. obtained from the granitic gneiss in the Loch Quoich area (Piasecki 1980). Aftalion and Van Breemen (1980) prefer to regard the granitic gneiss belt as representing a suite of syn-tectonic granites emplaced at 1050 m.y., and suggest a 1,1000 m.y. age for the peak metamorphism of semi-pelitic paragneisses adjacent to the granitic gneiss at Glenfinnan.

4.5. 'Late-Caledonian' igneous activity

The 'late-Caledonian' igneous and meta-igneous rocks of the Loch Eil area have been described in varying degrees of detail.

Fettes and MacDonald (1978), in their study of the late-Caledonian granite vein complexes of West Inverness-shire, identify two such vein complexes in the Loch Eil area. The "Loch Eil complex", situated at the west end of Loch Eil, consists of a ramifying network of granite, aplite and pegmatite veins. The "Banavie complex", adjacent to the Great Glen, consists of a suite of potassic granite veins and subordinate amounts of pegmatite and aplo-pegmatite. Smith (1979), in his study of the minor intrusions of the Northern Highlands, included maps illustrating the distribution, orientation and metamorphic grade of "post to late-tectonic" micro-diorite intrusions in West Inverness-shire, and drew attention to the concentration of meta-gabbros and meta-dolerites along the Loch Quoich line.

4.6. Status of the Loch Eil Division within the Moine Succession

Isotopic evidence derived from pelitic metasediments of the Morar Division, and granite gneisses enclosed within the Glenfinnan division, (Brook et al. 1976, 1977; Brewer et al. 1979) suggests that both divisions have been deformed and metamorphosed at ca.1000-1100 m.y. and subsequently reworked during the Caledonian orogeny (Powell et al. 1981). The inclusion of members of the granitic gneiss belt within the Loch Eil Division further suggests that the Loch Eil Division has also undergone a similar tectono-metamorphic history (Harris et al. 1978). Lambert et al. (1979) and Winchester et al. (1981) claim, however, that the Loch Eil Division is structurally simpler than either the Morar or Glenfinnan divisions, and that it contains certain geochemical features which indicate

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that it is a second-cycle sediment. These observations lead them to suggest that the Loch Eil division was probably deposited unconformably upon already deformed and metamorphosed 'Old Moine' of the Morar and Glenfinnan Divisions, and thus constitutes a 'Young Moine' sequence which accumulated entirely within the Grenvillian-Caledonian interval. In this case the Loch Eil Division could be considered broadly correlative with the lithologically similar Grampian Division, E of the Great Glen, which passes transitionally upwards into the Dalradian Supergroup (Piasecki 1980).

CHAPTER 2: STRATIGRAPHY OF THE MOINE METASEDIMENTS

2.1. INTRODUCTION

The metasediments have been subdivided into five main lithologies on the following petrographic basis:

Quartzite	-	> 80% quartz
Psammite	-	> 80% quartz + feldspar (but percentage of quartz not to exceed 80%)
Semi-Psammite	-	60 - 80% quartz + feldspar
Semi-Pelite	-	40 - 80% mica
Pelite	-	> 80% mica

Where any of these may be classified on textural grounds a 'gneiss', then the appropriate lithology is referred to as such (e.g. semi-pelitic gneiss). The reliable identification of bedding within the gneissose lithologies of the Glenfinnan Division is rendered difficult by intense deformation and the complete lack of preserved sedimentary structures. Mesoscopic lithological variation within these gneisses, although often inferred to broadly relate to original bedding, is therefore referred to as 'interbanding'.

In contrast, sedimentary structures are commonly preserved within the rather less deformed rocks of the Loch Eil Division and the gradational lithological variations which are commonly present on a mesoscopic scale appear to relate closely to original bedding.

This study follows Johnstone et al. (1969) in the subdivision of the rocks of the Loch Eil area into two major Divisions, the Glenfinnan and Loch Eil, and further arranges their constituent lithologies into lithostratigraphic units according to the principles outlined by Holland _et al._ (1978). The common preservation of sedimentary structures within the Loch Eil Division permits the arrangement of these units in stratigraphic order (Table 1) and this is the approximate order in which they are described here. Where lithostratigraphic units correspond directly to, or are lateral correlatives of, units described by previous workers, the names previously assigned to these units have been retained. A broad outline of the stratigraphy and structure of the Loch Eil area is presented in Enclosure 1, and elements of the stratigraphy are presented in greater detail in Enclosure 2.

2.2. GLENFINNAN DIVISION

2.2.1. Druim Na Saille Pelite

The Druim Na Saille Pelite crops out in the western part of the area as a narrow NNE-SSW trending belt which extends from the Cona River northwards to Gulvain. Type lithologies are well exposed on Druim Na Saille and also in Cona Glen, on the western slopes of Glas Bheinn and in the Allt a Choire Reidh. The Druim Na Saille Pelite is in contact with members of the West Highland granitic gneiss in the extreme W of the area between Cona Glen and Glen Dubh Lighe, and the summits of Na-h-Uamachan and Gulvain. Contacts with the granite gneisses are poorly exposed but may be examined in the Allt a Choire Chruinn (NM 927753) and the Allt a Choire Reidh (NM 986835). At both localities a transition from granite gneiss to semi-pelitic gneiss occurs quite rapidly over a distance of 1-2 metres. The eastern margin of the Druim Na Saille Pelite is marked by a tectonic contact which separates the Glenfinnan and Loch Eil Divisions (see Chapter 4, p. 60).

DIVISION	LITHOSTRATIGRAPHIC UNIT	THICKNESS (approximate, in metres)
	Inverscaddle Psammite	1500
	Stronchreggan Mixed Assemblage	1100
	Cona Glen Psammite	400
	Druim Fada Quartzite	100-500
LOCH EIL	Glen Suileag Banded Psammite	0-150
DIVISION	Glen Garvan Psammite	1500-2000
	Kinlocheil Banded Quartzite	70-250
	Druim Fearna Semi-Pelite	0-250
	Kinlocheil Cross-Bedded Quartzite	590-1220
	Basal Psammite	90-145
	Approximate total	6000-7500
GLENFINNAN	Gulvain Psammitic Gneiss	0-200
DIVISION	Druim Na Saille Pelite	140-350

Table 1: Moine Stratigraphy of the Loch Eil area

The Druim Na Saille Pelite typically consists of coarse-grained, often migmatitic, semi-pelitic gneiss (Plate 1) which may occasionally pass transitionally into medium to coarse-grained semi-pelitic and pelitic schist. In the Druim Na Saille area these lithologies are commonly interbanded on a centimetric scale with psammite, semi-psammite (Plate 2) and psammitic gneiss. The psammite and semi-psammite tend to be characterised by a strong penetrative mica striping, developed on a millimetric scale. No sedimentary structures have been identified within any of the constituent lithologies of the Druim Na Saille Pelite. Calc-silicates are occasionally present within psammite bands. Semi-pelitic gneisses in the Cona River (NM 915781) and the Allt a Choire Reidh (NM 986853) enclose bands and pods of amphibolite, the nature and origin of which are discussed in Chapter 5. The Druim Na Saille Pelite is 140 metres thick in Cona Glen, thickening northwards to 350 metres on Druim Na Saille, and thinning to 60 metres on Gulvain. Extensive minor folding suggests that these should be interpreted as maximum stratigraphic thicknesses.

Psammite units, 50-100 metres thick, are present on Druim Na Saille and in Glen Dubh Lighe. Contacts with the enclosing semi-pelitic gneiss are transitional over distances of up to 2 metres. These relatively thick psammite bands frequently contain calc-silicates, usually lack the mica striping developed within thinner psammite bands, and are consequently indistinguishable from the psammites of the Loch Eil Division.

Plate 1: Migmatitic semi-pelitic gneiss, deformed by a D2 structure. (Druim Na Saille Pelite, Cona River, NM 915781).

Plate 2: Interbanded semi-psammite (upper) and semi-pelitic gneiss (lower). (Druim Na Saille Pelite, adjacent to A830, NM 95157910).

2.2.2. Gulvain Psammitic Gneiss

The Gulvain Psammitic Gneiss crops out in the NW of the area, between the summits of Na h-Uamachan and Gulvain, and is largely enclosed by the Druim Na Saille Pelite. Type lithologies are well exposed on the W slopes of Gulvain, the NE slopes of Na h-Uamachan and in the Allt a Choire Reidh. Gradational contacts between the Gulvain Psammitic Gneiss and the Druim Na Saille Pelite are well developed along the northern boundary of the Gulvain Psammitic Gneiss: in the Allt a Choire Reidh this boundary is marked by a transitional zone, 20 metres thick, which is characterised by the interbanding, on a centimetric scale, of psammitic and semi-pelitic gneiss. The southern boundary between the two units is, on Na h-Uamachan, transitional in a similar manner, but tectonic on Gulvain. The Gulvain Psammitic Gneiss is also in tectonic contact along its southern boundary with units of the Loch Eil Division.

The Gulvain Psammitic Gneiss typically consists of a coarse-grained, sharply-banded psammitic or semi-psammitic gneiss (Plate 3) which occasionally encloses bands of quartzite and semi-pelitic gneiss, 2-3 metres thick. Bands and pods of amphibolite are locally common. Calc-silicates and sedimentary structures are entirely absent from these type lithologies. The Gulvain Psammitic Gneiss attains a maximum thickness of 200 metres in the Allt a Choire Reidh and thins rapidly both to the W and NE.

At several localities in the Allt a Choire Reidh the gneissosity developed elsewhere is less prevalent (Plate 4), and the dominant lithology consists of interbanded psammite, semi-psammite and semi-

Plate 3: Sharply banded semi-psammitic gneiss. (Gulvain Psammitic Gneiss, Na-h-Uamachan, NM 978845).

Plate 4: Interbanded psammite, semi-psammite and semi-pelite. (Gulvain Psammitic Gneiss, Allt a Choire Reidh, NM 986851).

pelite. Original bedding may still be identified, albeit in highly attenuated form. This lithology encloses calc-silicate pods and bands, and possible cross-lamination is present at one locality (NM 986851). A lithologically identical psammitic gneiss is entirely enclosed within rocks of the Loch Eil Division on Na h-Uamachan, and is considered to represent a tectonically-emplaced slice of the Gulvain Psammitic Gneiss (see Chapter 4, p.64).

2.3. LOCH EIL DIVISION

2.3.1. Basal Psammite

The Basal Psammite constitutes a well-defined base to the Loch Eil Division of the area, and overlies the Druim Na Saille Pelite from Cona Glen (NM 927721) northwards to the southern slopes of Na h-Uamachan (NM 965837) and on Gulvain. Between the southern slopes of Na h-Uamachan and Gulvain the outcrop of the Basal Psammite is tectonically disrupted and it is only present as a lenticular body detached from the main outcrop. Type lithologies are well exposed in the Cona River, on the western slopes of Glas Bheinn and on Cala na Creige. The lower boundary of the Basal Psammite is marked by a tectonic contact. South of Loch Eil the Basal Psammite is overlain by the Kinlocheil Cross-Bedded Quartzite: their junction is well exposed on the western slopes of Glas Bheinn and Druim Fearna and is marked by the gradation of psammite to quartzite over a distance of 3-4 metres. North of Loch Eil, the upper boundary of the Basal Psammite is defined by a tectonic contact which separates the Basal Psammite from the Kinlocheil Banded Quartzite.

The Basal Psammite typically consists of fine-grained psammite with occasional interbeds of semi-pelite and quartzite. Calc-silicate pods and bands are common, particularly N. of Loch Eil. Cross-stratification and cross-lamination are present within psammite on the western slopes of Glas Bheinn (NM 933753) and in stream section outcrops in Glen Fionne Lighe (NM 96158095) and the Allt a Choire Reidh (NM 98608465). Psammite and quartzite beds are usually 10-30 centimetres thick; semi-pelite occurs most commonly as thin laminae, 2-10 millimetres thick, which separate psammite and quartzite beds, and also as more well-defined beds, 3-4 centimetres thick.

Between Cona Glen and Cala na Creige the Basal Psammite varies in thickness from 90-145 metres, tectonically thickening to 520 metres in the hinges of the Glen Fionne Lighe antiform and the Ben Am Tuim synform. Thereafter it is tectonically thinned on the northern limb of the Ben An Tuim synform and is absent for a distance of 1500 metres along strike NE of (NM 965837). In the extreme N of the area on Gulvain the Basal Psammite is approximately 50 metres thick.

The Basal Psammite is well-exposed on washed surfaces in the Cona River, where it is characterised by interbedded psammite, semi-psammite and semi-pelite. Beds of semi-pelite, approximately 1 centimetre thick, occur at intervals of 3-4 centimetres and are laterally traceable for up to 4 metres. This lithology passes laterally northwards into more thickly bedded psammite which, on the E ridge of Meall nan Damh, encloses a unit of banded psammite.

This unit, which attains a maximum thickness of 20 metres, consists of psammite and semi-pelite thinly and regularly interbedded on a scale of less than 1 centimetre. This unit has gradational contacts with the enclosing psammite. Units of quartzite and semi-pelite, 5-20 metres in thickness, are present on the western slopes of Druim Fearna and Glas Bheinn. North of Loch Eil the Basal Psammite is well exposed on crags at Cala na Creige (NM 963804); here it consists of psammite with frequent interbeds of semi-pelite (1-2 centimetres thick) and quartzite. The quartzite may be identical in its field characteristics to the Kinlocheil Banded Quartzite. The Basal Psammite is poorly exposed N of Cala na Creige. On the eastern slopes of Glen Dubh Lighe the psammite encloses units of semi-pelitic gneiss, up to 1 metre thick. These have gradational contacts with the enclosing psammite, which may locally have a gneissose fabric.

2.3.2. Kinlocheil Cross-Bedded Quartzite

The Kinlocheil Cross-Bedded Quartzite only crops out to the S of Loch Eil, between the Cona River and the northern slopes of Druim Fearna. Excellent exposures of type lithologies occur on Druim Fearna and Glas Bheinn and in Cona Glen. The boundary between the Kinlocheil Cross-Bedded Quartzite and the overlying Kinlocheil Banded Quartzite is well exposed on the eastern slopes of Druim Fearna and the northern slopes of Cona Glen, where it is clearly gradational, involving the interbedding of the two lithologies over a distance of 3-5 metres.

The Kinlocheil Cross-Bedded Quartzite is typically represented by fine to medium-grained, variably feldspathic quartzite which is occasionally interbedded with psammite and semi-pelite. Calc-silicates are poorly developed and only present at a few localities, e.g. (NM 943747). Cross-stratification and cross-lamination are commonly present, and are particularly well developed on the eastern slopes of Druim Fearna. Quartzite beds range in thickness from 10 centimetres to 1 metre and are frequently separated by thin laminae of semi-pelite; where these are poorly developed the recognition of individual quartzite beds is often extremely difficult.

The Kinlocheil Cross-Bedded Quartzite attains a maximum thickness of approximately 1220 metres at the northernmost extent of its outcrop, and progressively thins southwards until it is only 590 metres thick in the Cona River. This southward thinning is not accompanied by any attenuation of bedding, and sedimentary structures are well-preserved on washed surfaces in the Cona River: the reduction in thickness is therefore thought to be a result of lateral facies variation during sedimentation and not to be tectonic in origin.

Units of psammite and semi-pelite, up to 60 metres thick, are developed to the S of Druim Fearna and at (NM 943647). The psammite units often contain calc-silicate pods and may preserve cross-stratification. These units have gradational contacts with the enclosing quartzite.

2.3.3. Druim Fearna Semi-Pelite

The Druim Fearna Semi-Pelite crops out to the NW of the Glas

Bheinn-Druim Fearna ridge, and is largely enclosed by the Kinlocheil Cross-Bedded Quartzite. Type lithologies are well exposed on Druim Fearna. The lower boundary of the Druim Fearna Semi-Pelite is marked by a gradation from quartzite to semi-pelite over a distance of 2-3 metres. In contrast, the upper boundary is characterised by a more extensive gradation which takes place over approximately 100 metres. The transitional beds between the Druim Fearna Semi-Pelite and the Kinlocheil Cross-Bedded Quartzite consist of a distinctive series of thin to medium-bedded quartzite, psammite and semi-pelite.

The type lithology is a fine to medium grained quartz-muscovite-biotite semi-pelite, which occasionally encloses beds of quartzite, 10-20 centimetres thick. At certain localities e.g. (NM 954775) the two lithologies rapidly alternate. Sedimentary structures are only present within quartzite beds which may contain abundant cross-lamination. Calc-silicates are poorly-developed and their occurrence is similarly restricted to quartzite where they are present as pods, 1-2 centimetres thick. The Druim Fearna Semi-Pelite attains a maximum thickness of approximately 250 metres; extensive minor folding suggests that this greatly exceeds original stratigraphic thickness.

Such lithological variation as there is within the Druim Fearna Semi-Pelite is confined to the southwestern part of its outcrop, where quartzite units, up to 20 metres thick, are developed. These units have gradational contacts with the enclosing semi-pelite.

2.3.4. Kinlocheil Banded Quartzite

The Kinlocheil Banded Quartzite crops out between the Cona River and Gulvain. South of Loch Eil it overlies the Kinlocheil Cross-Bedded Quartzite; N of Loch Eil, however, it directly overlies the Basal Psammite. Type lithologies are well exposed at Kinlocheil (NM 971793) and on Na-h-Uamachan. The boundary between the Kinlocheil Banded Quartzite and the overlying Glen Garvan Psammite is well exposed on Na-h-Uamachan and in the Cona River, and is marked by the gradation of quartzite to psammite over a distance of 2-3 metres.

The Kinlocheil Banded Quartzite is represented by a medium to coarse-grained variably feldspathic quartzite which is characterised by the presence of sharply-defined, parallel-sided interbeds of quartz-muscovite semi-pelite. These are occasionally only 1-2 millimetres thick and diffuse, but more commonly attain thicknesses of 1-2 centimetres, spaced 4-10 centimetres apart, and are so frequent and extensive as to impart a highly banded appearance (Plate 5). No current or wave-formed sedimentary structures, or calc-silicates have been identified within the type lithologies of the Kinlocheil Banded Quartzite. Despite the striking absence of sedimentary structures it seems unlikely that the banding is tectonic in origin. Apparently undeformed cross-stratification is preserved at a number of localities e.g. (NM 930733) within a distance of 5 metres from the boundaries of the Banded Quartzite, and consequently it seems that the level of strain immediately adjacent to the Banded Quartzite is low. Furthermore, the nature

Plate 5: Typical appearance of Kinlocheil Banded Quartzite (Na-h-Uamachan, NM 96358345).

and intensity of the banding does not show any systematic variation with respect to any major lithostratigraphic boundary, and neither is the banding axial planar to any folds. It is therefore concluded that the banded nature of this quartzite is a reflection of an original sedimentary fabric.

Immediately S and N of Loch Eil the Kinlocheil Banded Quartzite is 200-250 metres thick, thinning to approximately 70 metres in the Cona River, and tectonically thickening to 760 metres in the hinges of the Glen Fionne Lighe antiform and the Ben An Tuim synform. On the northern limb of the Ben An Tuim synform the Banded Quartzite is 250-400 metres thick, thinning tectonically on the southwestern slopes of Gulvain to approximately 40 metres.

Units of psammite and semi-pelite, up to 30 metres thick, are developed within the Kinlocheil Banded Quartzite on the southwestern slopes of Druim Fearna and in the Allt Beithe. The psammite units incorporate calc-silicate pods and display possible cross-lamination. On the western slopes of Na-h-Uamachan the Banded Quartzite encloses units of coarse-grained semi-pelitic schist and gneiss, up to 4 metres thick. The contacts between all these subsidiary units and the Kinlocheil Banded Quartzite are gradational over distances of 2-5 metres. Two lenticular bodies of lithologically identical quartzite crop out on Na-h-Uamachan and Gulvain, and are considered to represent slices of the Kinlocheil Banded Quartzite which have been emplaced during tectonic sliding (see Chapter 4, p. 65).

2.3.5. Glen Garvan Psammite

The Glen Garvan Psammite has an approximately triangular outcrop, the apices of which are the Cona River, Gulvain and Achnanellan. Type lithologies are well-exposed in the North and South Garvan Rivers, and on Beinn an t-Sneachda. The boundary between the Glen Garvan Psammite and the overlying Druim Fada Quartzite is exposed in the An t-Suileag at Fassfern (NN 02157900) where it is marked by the gradation of psammite to quartzite over a distance of 3-4 metres. Elsewhere the boundary is poorly exposed; however, in Choire Dubh the proportion of quartzite enclosed within the Glen Garvan Psammite increases markedly as the boundary is approached, and this may be an indication that it is gradational in this area also.

The type lithology is a fine to medium-grained psammite which is occasionally interbedded with quartzite and semi-pelite. Calc-silicates are commonly present (Plate 6) and are particularly well developed in the North Garvan River-Sron an t-Sluichd area. Where best developed they form bands or pods which may be up to 15 centimetres thick and extend for distances of up to 1 metre in the plane of the bedding foliation. Smaller lenticles, only 1-2 centimetres long, are common and may be associated with diffuse calcareous streaks which occasionally 'overprint' cross-lamination and cross-stratification. The Glen Garvan Psammite incorporates a wide range of sedimentary structures. Cross-stratification is present (Plate 7), but tends to be poorly

Plate 6: Faintly laminated psammite with calc-silicate pods. (Glen Garvan Psammite, adjacent to A830 road Nm 988788).

Plate 7: Cross-stratified psammite with calc-silicate band. (Glen Garvan Psammite, Cona River, NM 926729).

developed; more common are small scale structures such as cross-lamination, convoluted bedding, 'dish' structure and rippled surfaces, all of which are present in the North Garvan River and the Allt Choire nan Laogh. Individual psammite beds range in thickness from 5 centimetres to 1 metre and are separated by thin semi-pelitic laminae.

The Glen Garvan Psammite is approximately 1500 metres thick in the area between Kinlocheil and Fassfern. It is more difficult to ascertain its thickness elsewhere, due to a lack of exposure S of Loch Eil, between Garvan and the Dubh uisqe, and to extensive folding N of Loch Eil, between Druim Beag and Meall Onfaidh.

Units of quartzite, up to 150 metres thick, are present within the Glen Garvan Psammite on Sron an t-Sluichd and Beinn an t-Sneachda. The quartzite is typically fine to medium grained and variably feldspathic, and may preserve cross-stratification. The extent and frequency of quartzite units decreases in a north-eastward direction and few occur to the NE of Druim Beag. Units of semi-pelite and banded psammite, up to 100 metres thick, crop out on the northeastern slopes of Druim Beag. All these subsidiary units have gradational contacts with the enclosing psammite.

2.3.6. Glen Suileag Banded Psammite

The Glen Garvan Psammite encloses the Glen Suileag Banded Psammite, which crops out in Glen Suileag and on Meall Onfaidh. Type lithologies are well exposed in the Ant t-Suileag and on crags on the SE side of Meall Onfaidh. Contacts between the Glen Suileag Banded Psammite and the Glen Garvan Psammite are exposed on Meall

Onfaidh, where they are gradational and marked by the interbedding of the two lithologies over distances of 1-5 metres.

The Glen Suileag Banded Psammite is typically represented by the interbedding of psammite, semi-psammite and semi-pelite in random sequence on a scale of 1-3 centimetres. This imparts a strongly banded appearance which is enhanced at several localities by the presence of abundant thin (less than 1 centimetre) laterally extensive calc-silicate bands. Cross-lamination, graded bedding and slump structures are also present, both in the Ant t-Suileag and on Meall Onfaidh. The presence of these sedimentary structures clearly indicates that the banding is not tectonic in origin, but reflects an original sedimentary fabric. The Glen Suileag Banded Psammite is 150 metres thick in Glen Suileag and 100 metres thick on Meall Onfaidh.

Beds of quartzite and semi-pelite, 5-20 centimetres thick, are well-developed on Meall Onfaidh and this constitutes the only lithological variation within the Glen Suileag Banded Psammite.

2.3.7. Druim Fada Quartzite

The Druim Fada Quartzite crops out in poorly exposed ground immediately to the S and N of Loch Eil, at Duisky and Fassfern, and also along Druim Fada where the type lithologies are well exposed. Contacts with the overlying Cona Glen Psammite are poorly exposed and are inferred to be gradational.

The type lithology is a fine-grained, variably feldspathic quartzite with rare interbeds of psammite and semi-pelite.

Sedimentary structures are poorly developed and it is this feature which distinguishes the Druim Fada Quartzite from the Kinlocheil Cross-Bedded Quartzite. Cross stratification and cross-lamination are occasionally present e.g. (NN 08508240), and at Fassfern (NN 02157900) rippled surfaces are preserved on bedding planes. Quartzite beds generally range in thickness from 50 centimetres to 1 metre, although at several localities e.g. (NN 06108225) the quartzite is thinly interbedded with semi-pelite in a manner similar to that seen in the Kinlocheil Banded Quartzite. Bedding is usually defined by thin semi-pelitic laminae and occasionally by planar concentrations of pink feldspar. On Druim Fada the quartzite is 500 metres thick; it thins southwestwards and is approximately 100 metres thick at Fassfern, and in the Dubh Uisge.

2.3.8. Cona Glen Psammite

The Cona Glen Psammite crops out to the N of Loch Eil, on the southern slopes of Druim Fada, and sporadically along the S. side of Loch Eil, E. of Duisky. It is best exposed in the Allt Dogha, the Dubh Uisqe and at roadside localities adjacent to the A830. Contacts with the overlying Stronchreggan Mixed Assemblage are poorly exposed and are inferred to be gradational.

The Cona Glen Psammite is typically represented by a fine-grained psammite which is locally interbedded with quartzite and semi-pelite. Calc-silicates are present in the Allt Dogha, but are rare elsewhere. Cross-stratification and cross-lamination are well-developed at roadside localities between 1 and 2 kilometres east of Fassfern, but are only sporadically developed elsewhere. Psammite beds are usually 5-20 centimetres thick, and separated by thin semi-pelitic laminae (Plate 8). These lithologies are identical in most respects to the type lithologies of the Cona Glen Psammite which have been described by Stoker (1980) from the Cona Glen area. A measurement of the thickness of the Cona Glen Psammite is difficult to obtain from the eastern limb of the Loch Eil synform, due to its highly folded nature; however a cross-section across the gently-dipping western limb indicates a thickness of approximately 400 metres.

There is little lithological variation within the Cona Glen Psammite; units of quartz-muscovite semi-pelite, up to 10 metres thick, crop out in the Allt Dogha (NN 081775) and adjacent to the A830 at (NN 07958200) but due to poor exposure it is impossible to trace these laterally.

2.3.9. Stronchreggan Mixed Assemblage

The Stronchreggan Mixed Assemblage forms a narrow NNE-SSW trending belt which crops out on poorly-exposed ground immediately to the N of Corpach, and it also crops out on the N shore of Loch Eil in the core of the Loch Eil Synform. The type lithologies have been described by Stoker (1980) from the Stronchreggan area to the S of Loch Eil, and they are identical to those lithologies cropping out in the Loch Eil area. Contacts with the overlying Inverscaddle Psammite are exposed on the southwestern slopes of

Plate 8: Slightly banded psammite with calc-silicate pods. (Cona Glen Psammite, adjacent to A830 road, (NM 079770).

Meall Bhanabhie, and are marked by the gradation of quartzite to psammite over a distance of 5-10 metres.

The type lithology is a variably feldspathic quartzite which is frequently interbedded with psammite and semi-pelite on a scale of 1-4 centimetres, and it is this feature which distinguishes it from the other major quartzite units further to the west. Calc-silicates are only occasionally present, as small pods and bands less than 1 centimetre thick. Sedimentary structures are similarly rare and were only observed at two localities. The Stronchreggan Mixed Assemblage is approximately 1100 metres thick. It does not display any marked lithological variation from the type lithology.

2.3.10. Inverscaddle Psammite

This is the highest lithostratigraphic unit of the Loch Eil Division of the area, and is bounded to the E by the Great Glen Fault zone. The Inverscaddle Psammite crops out in poorly exposed ground on, and to the S of, Meall Bhanabhie, and also along the northwestern shore of Loch Linnhe. Many exposures are extensively brecciated and granite-veined; a few excellent localities are, however, present in Banavie Quarry.

The dominant lithology is a fine-grained psammite which is often interbedded with semi-psammite, and occasionally with semi-pelite, on a scale of 1-4 centimetres, and it is this which serves to distinguish the Inverscaddle Psammite from the three other major psammite units. Calc-silicates are uncommon, and only a few pods were observed in Banavie Quarry. Cross-lamination and graded sequences are also present in Banavie Quarry, but in general sedimentary structures are rare. This lithology is broadly comparable to the type lithology of the Inverscaddle Psammite as described by Stoker (1980) from the Inverscaddle area S of Loch Eil.

The Great Glen Fault zone cuts obliquely across the stratigraphy and as a result the Inverscaddle Psammite attains its maximum thickness at the northern limit of its mapped extent where it is approximately 1500 metres thick.

Lithological variation within the Inverscaddle Psammite is uncommon: a unit of quartzite, 25 metres thick, is enclosed within the psammite 1500 metres S of Meall Bhanabhie. Contacts between the psammite and quartzite are not exposed and are inferred to be gradational.

2.4. COMPARISON WITH PREVIOUS WORK

2.4.1. The validity of Glenfinnan and Loch Eil 'Divisions'.

This study follows Johnstone *et al.* (1969) in the subdivision of the rocks of the Loch Eil area into two major Divisions, the Glenfinnan and Loch Eil. This subdivision is clearly justified on lithological grounds alone, as there are obvious differences between the coarse-grained, dominantly pelitic, gneiss which crops out along the western margin of the area, and the finer-grained psammite and quartzite which are exposed between the head of Loch Eil and the Great Glen.

2.4.2. The location of the boundary between the Glenfinnan and Loch Eil Divisions

In the area between the southern slopes of Na-h-Uamachan and the Cona River the boundary between the two Divisions is marked by the mutual contact of the Druim Na Saille Pelite of the Glenfinnan Division and the Basal Psammite of the Loch Eil Division. This contact is a prominent horizon which previous authors (Johnstone *et al*. 1969; Brown *et al*. 1970; Johnstone 1975) have also considered to represent the boundary between the two Divisions.

However, previous work in the area between Na-h-Uamachan and Gulvain is considered to be incorrect with regard to the location of this boundary. It is apparent that rocks previously assigned to the Loch Eil Division in this area (Institute of Geological Sciences 1:50,000 Sheet 62W) are, in fact, members of the Glenfinnan Division, to which they have therefore been assigned in this study (Fig. 5).

2.4.3. Relationship of lithostratigraphic units with those erected in previous studies

This is summarised in Table 2, and it is clear that many of the lithostratigraphic units established in this study correspond directly to those described by previous workers.

It seems simplest and most appropriate to refer informally to

Fig. 5: A: Geology of the Na h-Uamachan-Gulvain area according to Institute of Geological Sciences Sheet 62.

Pelite
Psammite
Loch Eil Division

Pelite
Granitic Gneiss
Glenfinnan Division

— — — Stratigraphic boundary

B: Geology according to present author.

Glen Garvan Psammite
Kinlocheil Banded Quartzite
Basal Psammite
Loch Eil Division

Gulvain Psammitic Gneiss
Druim Na Saille Pelite
Granitic Gneiss
Glenfinnan Division

— — — Stratigraphic boundary

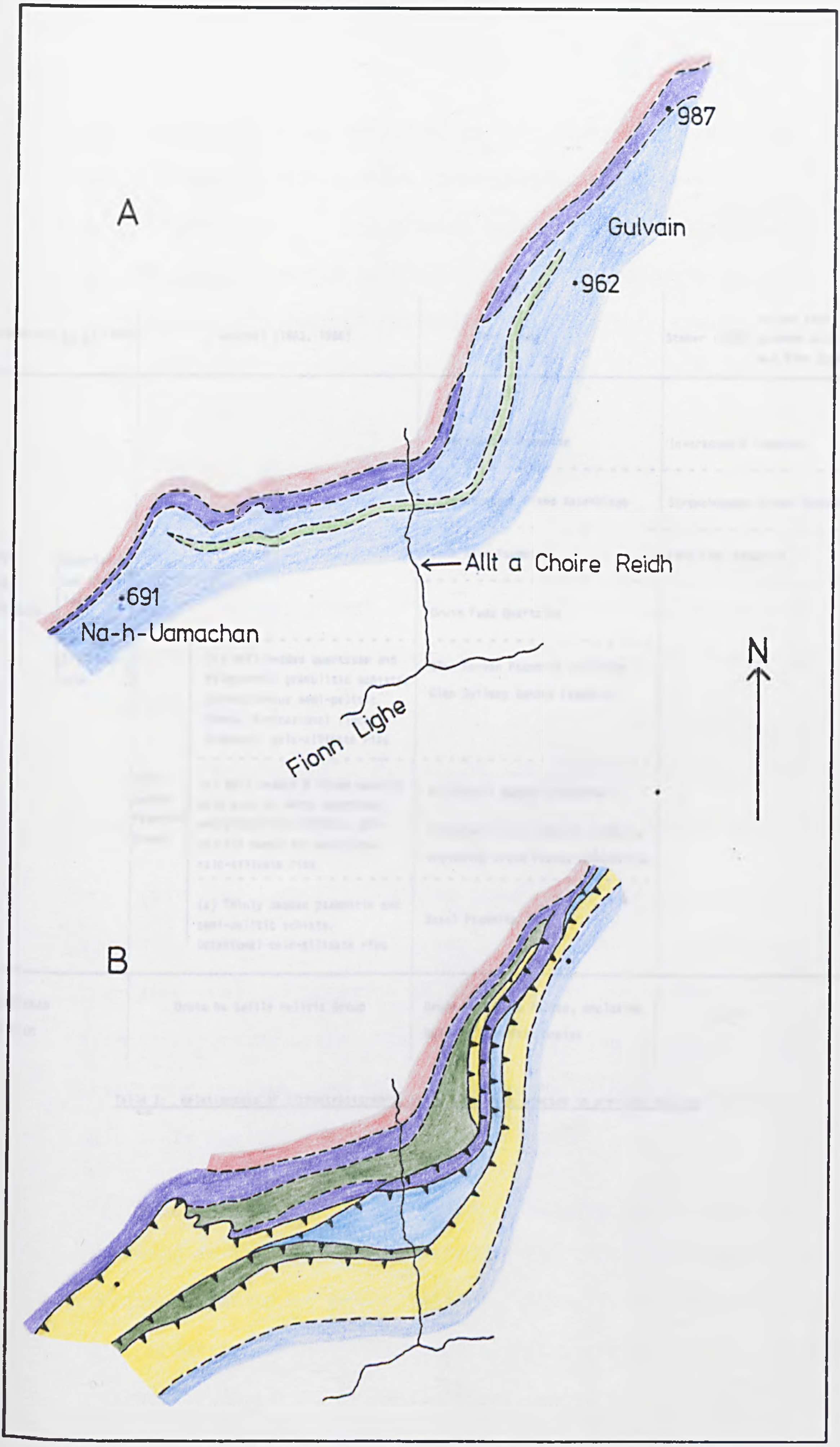
▼—▼ Tectonic slide

The reinterpretation (B) of the stratigraphy of the Na h-Uamachan-Gulvain area is based on:

(a) The continuity of the 'Loch Eil Division pelite' of (A) with the main outcrop of the Druim Na Saille Pelite on Gulvain.

(b) The lithological dissimilarity of the Gulvain Psammitic gneiss to any of the Loch Eil Division units.

(c) The gradational contacts linking the Gulvain Psammitic Gneiss with the pelitic units.



A
987
Gulvain
962
Allt a Choire Reidh
691
Na-h-Uamachan
Fionn Lighe
N
B

Johnstone et al. (1969)		Dalziel (1963, 1966)		This study	Stoker (1980) in the area between Loch Eil and Glen Scaddle
				Inverscaddle Psammite	Inverscaddle Psammite
				Stronchreggan Mixed Assemblage	Stronchreggan Mixed Assemblage
LOCH EIL DIVISION	Comprising one lithologic formation, the Loch Eil Psammite			Cona Glen Psammite	Cona Glen Psammite
				Druim Fada Quartzite	
			(c) Well bedded quartzose and feldspathic granulitic schists, garnetiferous semi-pelitic bands, & occasional (locally frequent) calc-silicate ribs	Glen Garvan Psammite enclosing Glen Suileag Banded Psammite	
		Glen Garvan Psammitic Group	(b) Well bedded & often massive pale grey or white quartzose and granulitic schists, semi-pelitic bands and occasional calc-silicate ribs	Kinlocheil Banded Quartzite Kinlocheil Cross-Bedded Quartzite enclosing Druim Fearna Semi-Pelite	
			(a) Thinly bedded psammitic and semi-pelitic schists. Occasional calc-silicate ribs	Basal Psammite	
GLENFINNAN DIVISION		Druim Na Saille Pelitic Group		Druim Na Saille Pelite, enclosing Gulvain Psammitic Gneiss	

Table 2: Relationship of lithostratigraphic units with those erected in previous studies

each one of the units described in this study as a 'formation'. This is in keeping with current stratigraphic practice which regards a formation as ".... the primary local rock unit which should possess some degree of internal lithological homogeneity, or distinctive lithological features that constitute a unity by comparison with adjacent strata" (Holland et al. 1978, p.8).

2.5. CONCLUSIONS

These may be summarised thus:

(a) The assignment of the rocks of the Loch Eil area to two major Divisions (Johnstone et al. 1969) is confirmed on lithological grounds.

(b) This study is in broad agreement with previous work concerning the location of the boundary between the two Divisions.

(c) The Loch Eil Division comprises a metasedimentary sequence, approximately 6-7.5 kms thick, which is dominated by the large-scale alternation of psammite and quartzite. The lithostratigraphy within the Loch Eil Division 'youngs' in an eastward direction, and thus the youngest lithostratigraphic unit abuts against the Great Glen.

(d) The Loch Eil Division lithostratigraphic sequence presented in Table 1 is considered to represent the product of a continuous period of sedimentation. There is no evidence of any major break in sedimentation within this succession, although the presence of localised disconformities cannot be entirely discounted.

CHAPTER 3: PETROLOGY OF THE METASEDIMENTS

3.1. INTRODUCTION

The purpose of this chapter is to describe the petrology of the major lithologies encountered within the Loch Eil area, together with a widely distributed minor metasedimentary facies, the calc-silicates. Representative modal analyses of each major lithology are presented in table form and were derived from the point-counting of thin-sections (1000 points per section). The compositions of twinned plagioclase were ascertained using the Michel-Levy method.

3.2. QUARTZITES

Quartzites vary in colour from white or pale grey to pale pink, depending upon the relative proportions of plagioclase and potash feldspar, and may occasionally present a speckled appearance due to the presence of fine-grained flecks of biotite. Often, no internal schistosity or fabric is readily apparent in hand specimen, although some samples display local concentrations of feldspar or biotite which form bands no more than 2-3 millimetres thick, and invariably parallel to bedding. Quartzites are the dominant lithology in three major lithostratigraphic units, the Kinlocheil Cross-Bedded and Banded Quartzites, and the Druim Fada Quartzite, and form an important part of the Stronchreggan Mixed Assemblage. They are also present as relatively thin impersistent bands within major psammite and psammitic gneiss units.

Thin section analysis of the quartzites indicates that they are composed primarily of quartz, in association with varying proportions of plagioclase and muscovite. Microcline, biotite, and chlorite occur sporadically, and epidote, apatite, garnet and haematite are all present as accessories. Representative modal analyses are shown in Table 3.

Quartz and plagioclase are intergrown as xenoblastic, approximately equidimensional grains. Most display straight extinction, although undulose extinction and deformation bands are locally found within quartz grains. Plagioclase is distinguished by the albite twinning and varies in composition from oligoclase An_{12} to andesine An_{36}. Most plagioclase is fresh, although considerable sericitic alteration is locally found. Quartz grains range in diameter from 0.1 - 2.0 millimetres and grain boundaries vary in morphology from straight or slightly curved to highly intricate. Plagioclase grains are, in contrast, generally smaller, only varying in diameter from 0.1-0.5 millimetres, and usually have smooth grain boundaries. Distinct textural differences are present within the quartzites of the Loch Eil area and these appear to relate to areal variations in metamorphic grade. The distribution, nature and significance of these textures are discussed in detail in Chapter 6 (p. 126).

Muscovite is the most abundant mica present, and occurs as sub-idioblastic laths which are usually 0.1-0.3 millimetres long, occasionally attaining 0.5-0.8 millimetres in some sections. Muscovite laths generally occur singly, although they may be intergrown in sheaves. Most laths display straight extinction. Where muscovite content is relatively high laths are typically sub-parallel and impart a weak

Specimen	*Quartz*	*Plagioclase*	*Muscovite*	*Biotite*	*Chlorite*	*Microcline*	*Epidote*	*Apatite*	*Garnet*	*Haematite*
7937	86	8	5	0.3	-	-	0.6	-	-	0.1
7939	88	7	3	0.5	0.1	1	0.2	-	-	0.2
(Kinlocheil Cross-Bedded Quartzites)										
7969	89	3	7	-	-	-	0.3	0.4	-	0.3
79121	82	8	8	-	-	1	0.5	0.5	-	-
79122	82	4	10	-	-	2	1	0.5	-	0.5
(Kinlocheil Banded Quartzite)										
8117	84	4	7	2.5	1	-	0.5	0.4	-	0.6
8118	86	10	2	1	0.5	-	0.4	-	0.1	-
(Druim Fada Quartzite)										

Table 3: Modal analyses of Quartzites

lepidoblastic fabric; conversely, when muscovite is less abundant, individual laths are commonly disoriented and there is no obvious schistosity visible either in hand specimen or thin-section.

Microcline occurs occasionally, intergrown with quartz and plagioclase. It is frequently twinned in the characteristic gridiron pattern. Microcline grains are of the same size and habit as nearby plagioclase grains.

Biotite is sporadically present, as small weakly oriented laths of the same habit as muscovite, with which it is occasionally intergrown. Biotite is typically pleochroic from buff to red-brown and, less commonly, from pale to dark green.

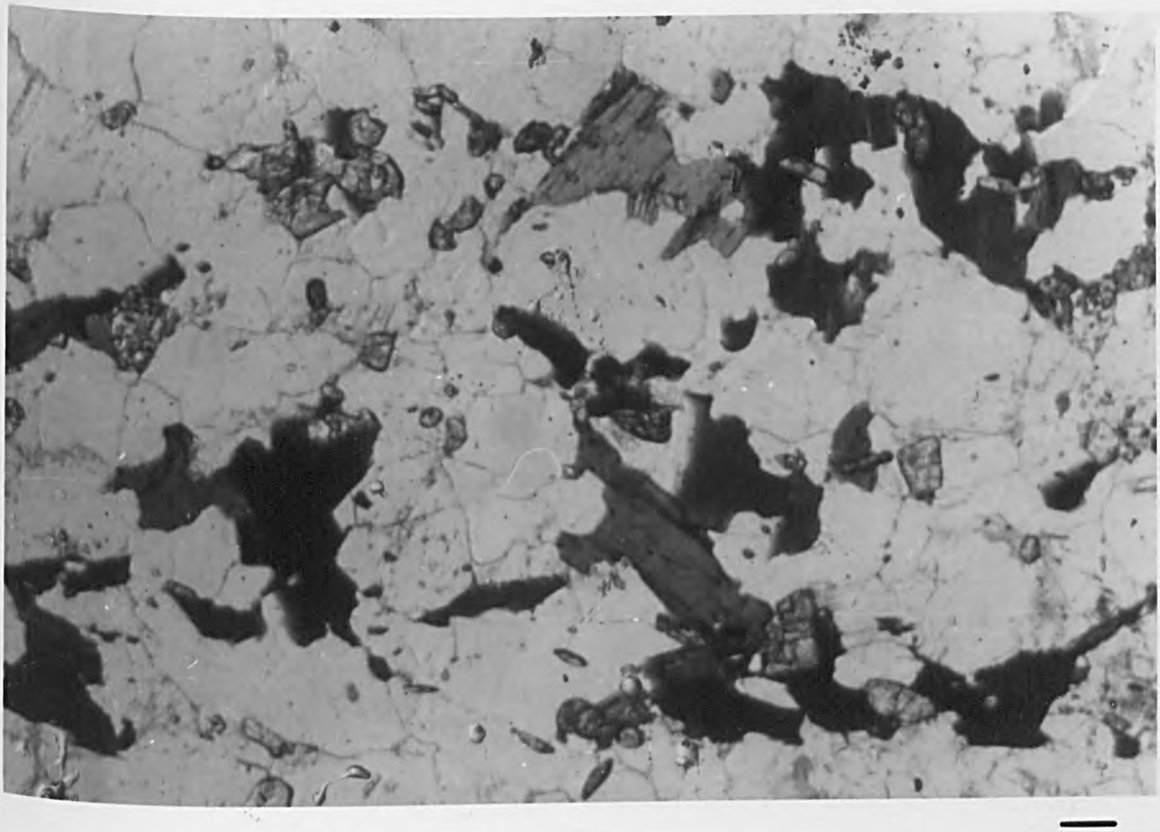
Chlorite is only found as an alteration product of biotite and occurs as wispy, xenoblastic slightly pleochroic aggregates.

Accessory Minerals. Epidote and apatite occur as xenoblastic equidimensional grains up to 0.5 millimetres in diameter. Both have a slightly rounded form, and their margins are often penetrated by lobate growths of quartz. Epidote and apatite are common in the Kinlocheil Banded Quartzite, but are less common in the Kinlocheil Cross-Bedded Quartzite and Druim Fada Quartzite. They may be concentrated in narrow bands, in association with muscovite and biotite (Plate 9), and possibly represent heavy mineral bands of sedimentary origin. However, they are more commonly randomly scattered through any given thin-section. Garnet has been recorded from only one section,

Plate 9: Possible heavy mineral band composed of epidote, apatite, biotite and haematite. (Kinlocheil Banded Quartzite, NM 96358345, plane polarised light).

Plate 10: 'Late poorly oriented muscovite porphyroblasts strongly oblique to 'early' aligned muscovite laths. (Glen Garvan Psammite, NM 988788, crossed nicols).

Scale bar represents 0.1mm.



occurring as an equidimensional xenoblastic grain, 0.2 millimetres across. Its margins are highly embayed by quartz, and it contains a large number of very small irregularly scattered quartz inclusions. Haematite occurs both as xenoblastic aggregates, 0.3-0.4 millimetres across, and as finely disseminated dust. Both varieties tend to be associated with biotite.

3.3. PSAMMITES AND SEMI-PSAMMITES

Psammites and semi-psammites vary in colour from pale to dark grey and tend to present a monotonous speckled 'salt and pepper' appearance due to the random distribution of flecks of biotite. An obvious schistose fabric develops where the proportion of biotite is relatively high. Variations in the proportions of quartz, feldspar and biotite often leads to the production of macroscopic banding on a centimetric scale. Psammites are the dominant lithology within the Loch Eil area, and form the bulk of five major lithostratigraphic units. They also occur as thin bands within major quartzite units and the Druim Na Saille Pelite. Semi-psammites tend only to be locally developed within major psammite units.

The constituent minerals of the psammites and semi-psammites are identical with those of the quartzites, differing mainly in their relative proportions (Table 4). The results of the modal analyses indicate that psammites differ from quartzites primarily in the ratio of quartz to plagioclase, and secondarily in the predominance of biotite

Psammites:

Specimen	Quartz	Plagioclase	Muscovite	Biotite	Chlorite	Microcline	Epidote	Apatite	Garnet	Haematite
793 (Druim Na Saille Pelite)	63	24	3	9	0.5	0.5	-	-	-	-
7977	66	25	1	6	0.3	0.4	0.3	0.2	0.2	0.6
7991 (Basal Psammite)	64	33	0.3	1.2	0.2	0.5	-	0.3	-	0.5
816 (Glen Garvan Psammite)	65	31	-	3	0.2	-	0.1	-	0.3	0.4
8110	77	15	-	7	0.3	-	0.2	0.2	-	0.3
8114 (Cona Glen Psammite)	68	23	2	6	-	0.5	-	-	-	0.5

Semi-Psammites:

Specimen	Quartz	Plagioclase	Muscovite	Biotite	Chlorite	Microcline	Epidote	Apatite	Garnet	Haematite
7998 (Basal Psammite)	50	16	6	26	1	0.5	0.3	-	-	0.2
8112 (Inverscaddle Psammite)	58	21	5	14	0.5	-	0.4	-	0.1	1
8115 (Glen Garvan Psammite)	46	22	8	21	0.2	-	0.1	0.1	2	0.6

Table 4: Modal analyses of Psammites and Semi-Psammites

over muscovite. Semi-psammites differ from quartzites and psammites largely in the increased proportion of mica.

Quartz and plagioclase are again intergrown as xenoblastic, approximately equidimensional grains, the majority of which display straight extinction. Average grain size is comparable to that of the quartzites. Plagioclase varies in composition from oligoclase An_{18} to andesine An_{40}. A small degree of textural variation corresponds to areal changes in metamorphic grade (Chapter 6, p. 126). Microcline and orthoclase are occasionally present and are of the same size and habit as plagioclase grains. Subidioblastic biotite laths are randomly distributed and tend to be rather larger than those in the quartzites, ranging up to 0.5-1.0 millimetres long in many sections. They are usually subparallel and where they are relatively abundant impart a lepidoblastic fabric. Muscovite occurs primarily as small subidioblastic laths which are often intergrown with, and subparallel to, larger biotite laths. It is also present as porphyroblasts which range from 1-2 millimetres in length. These are typically disoriented and clearly 'overgrow' the earlier generation of aligned muscovite laths. The porphyroblasts are usually subidioblastic and often include small quartz grains (Plate 10), but occasionally are isolated by replacive quartz into a series of separate but optically continuous areas. Chlorite occurs in greater proportions than in the quartzites, mainly as a result of the greater proportion of biotite with which it is closely associated as secondary fibrous aggregates. It is occasionally present as isolated and disoriented xenoblastic aggregates up to 2.0 millimetres across.

3.4. SEMI-PELITES AND PELITES

Semi-pelites and pelites vary in colour from black to pale green, and some may be slightly lustrous, depending upon the relative proportions of biotite, muscovite and chlorite. They are characterized by a strong lepidoblastic fabric, due to the approximately parallel alignment of mica laths. Semi-pelites constitute the dominant lithology within one major lithostratigraphic unit, the Druim Fearna Semi-Pelite, and are also present as relatively thin impersistent bands within major quartzite and psammite units. Pelites are only locally developed.

In thin-section they consist principally of biotite and muscovite in association with varying proportions of quartz, plagioclase and chlorite. Garnet, alkali-feldspar, and fibrolite are important constituents of some sections. Epidote, sphene, zircon, pyrite and haematite are common accessories. Representative modal analyses are presented in Table 5.

Biotite and muscovite most commonly occur as aligned subidioblastic laths which are typically intergrown, and define the strong lepidoblastic fabric characteristic of the semi-pelites and pelites. Within each thin-section the size of laths is generally uniform, although within the area they show a great variation in length from 0.2-0.3 millimetres to 2.0 millimetres. Grain size does not, however, show any systematic variation with respect to stratigraphic level. Biotite is pleochroic from buff to dark bown, and both micas display straight extinction. Biotite and muscovite are also present

Semi-Pelites:

Specimen	Biotite	Muscovite	Quartz	Plagioclase	Chlorite	Garnet	Alkali-Feldspar	Fibrolite	Epidote	Sphene	Zircon	Haematite	Pyrite
7933 (Kinlocheil Cross-Bedded Quartzite)	40	25	11	17	0.9	3	2	-	0.3	-	0.2	0.5	0.1
7948 (Druim Fearna Semi-Pelite)	32	20	33	9	2.8	3	-	-	-	-	-	-	0.2
8067	23	22	46	4	1	2	-	-	-	0.3	0.1	1	0.6
81127 (Glen Garvan Psammite)	20	14	31	12	-	1	2	19	-	0.2	0.5	0.1	0.2
8012	26	23	30	10	-	0.5	-	-	-	-	-	0.2	0.3
8081 (Cona Glen Psammite)	28	16	32	9	3	1	-	-	-	0.6	0.1	-	0.3

Pelites:

Specimen	Biotite	Muscovite	Quartz	Plagioclase	Chlorite	Garnet	Alkali-Feldspar	Fibrolite	Epidote	Sphene	Zircon	Haematite	Pyrite
8158 (Druim Fearna Semi-Pelite)	45	35	12	3	2	2	-	-	-	0.2	0.3	0.4	0.1
8142 (Cona Glen Psammite)	40	32	15	2	5	3.5	2	-	0.1	-	-	0.2	0.1

Table 5: Modal analyses of Semi-Pelites and Pelites

as a 'late' phase typified by randomly oriented, often xenoblastic, porphyroblasts which 'overgrow' the smaller aligned micas.

Quartz and plagioclase are intergrown in equigranular aggregates between mica-rich bands and sheaves. Grains are xenoblastic and generally equidimensional, although some may be elongate in sections with a strong lepidoblastic fabric. Quartz-quartz and quartz-plagioclase boundaries are typically slightly curved. Most grains display straight extinction. Average grain size is 0.2-0.4 millimetres; there is, however, a tendency for grain size to increase along the western margin of the area, W of the Garvan River and Fionn Lighe. Here, quartz grains are typically 0.3-0.8 millimetres in diameter. Plagioclase is rather more sericitised than in the quartzites, psammites or semi-psammites, but nonetheless frequently displays albite and pericline twinning, and ranges in composition from oligoclase An_{18} to andesine An_{35}. Plagioclase is occasionally antiperthitic with patchy exsolution of alkali feldspar.

Plagioclase also occurs, less commonly, as porphyroblasts within semi-pelite bands enclosed by the Kinlocheil Cross-Bedded Quartzite. These are up to 2.0 millimetres in diameter and of the same habit as the plagioclase already described. Pericline twinning is ubiquitous and they often poikiloblastically enclose muscovite laths and small ovoid quartz grains (Plate 11).

Garnet occurs primarily as subidioblastic equidimensional porphyroblasts, 0.1-0.5 millimetres in diameter (Plate 12). Theyfrequently incorporate numerous fine-grained quartz inclusions which rarely show any systematic distribution. Consequently, the garnets are not characterised by any obvious internal structures. Garnet also occurs,

Plate 11: Plagioclase porphyroblast displaying pericline twinning and enclosing numerous ovoid quartz grains aligned in S1. (Kinlocheil Cross-Bedded Quartzite, NM 959768, crossed nicols).

Plate 12: Subidioblastic garnet. (Cona Glen Psammite, NN 079770, plane polarised light).

Scale bar represents 0.1 mm.

less commonly, as skeletal growths, up to 2.5 millimetres long which are intergrown with quartz and mica. Both types of garnet may be elongate in the plane of the dominent foliation.

Alkali Feldspar Orthoclase is occasionally present as xenoblastic equidimensional grains, 0.1-0.4 millimetres across, and intergrown with quartz and plagioclase. At several localities within the Kinlocheil Cross-Bedded Quartzite (e.g. NM 943746) semi-pelite bands enclose ovoid or circular aggregates of microcline and quartz. They are usually closely-spaced and impart a highly spotted appearance to the rock (Plate 13), varying in size from 1-2 millimetres to over 1 centimetre in their longest dimension. In thin-section these display every gradation from aggregates which consist of a few large grains of microcline, 0.5-1.0 millimetres across (Plate 14) to those which consist of a mass of finer-grained microcline and quartz.

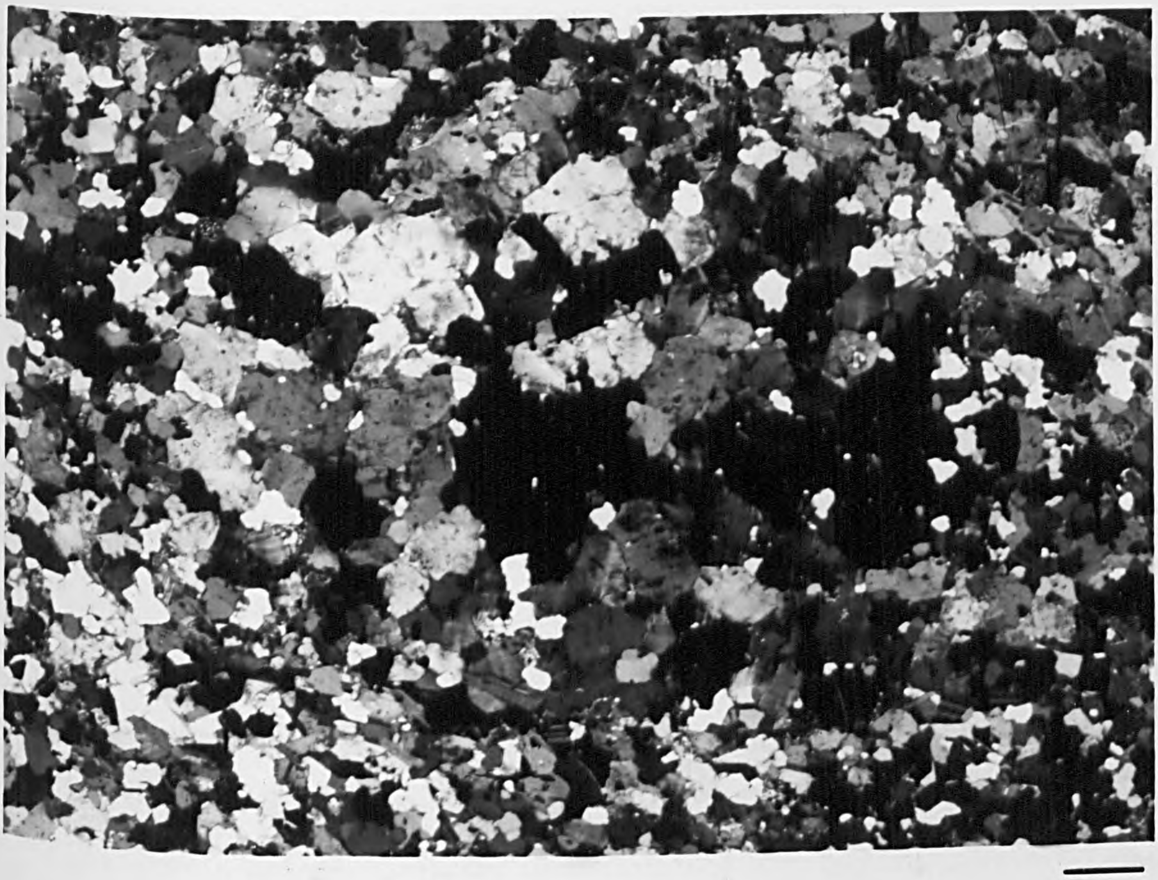
Fibrolite is locally abundant within semi-pelite bands enclosed by the Glen Garvan Psammite. Pods ('faserkiesel') of fibrolite, muscovite and quartz are well-developed on Sron Ant-Sluichd (NM 954740) and 1 kilometre NNE of Cala na Creige (NM966815). These are usually aligned parallel to the dominant bedding-parallel foliation and the majority are 2-5 millimetres long, although some may exceptionally attain 1 centimetre in length. The pods vary in colour from pale yellow to a lustrous hue depending upon the relative proportions of fibrolite and muscovite. Fibrolite has also been recorded from a semi-pelite band within the Basal Psammite in the Allt a Choire Reidh (NM 986848). In thin-section the faserkiesel comprise wispy aggregates of fibrolite in association with quartz, muscovite and biotite (Plate 15). The fibrolite displays

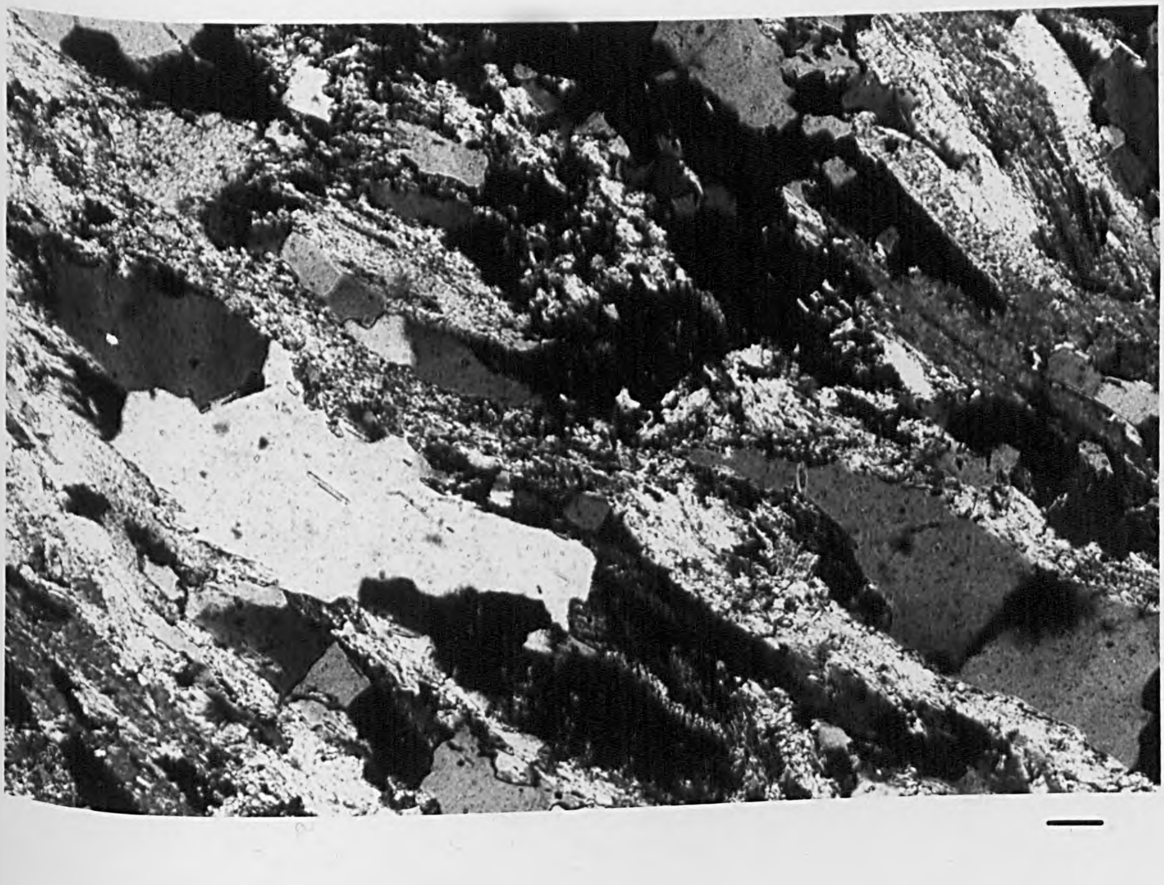
Plate 13: Typical field appearance of alkali-feldspar-quartz aggregates. (Kinlocheil Cross-Bedded Quartzite, NM 942747).

Plate 14: Microscopic appearance of an alkali-feldspar aggregate, here consisting mainly of grains of microcline. (Kinlocheil Cross-Bedded Quartzite, NM 942747, crossed nicols).

Plate 15: Anastomosing trails of fibrolite in association with elongate quartz grains and small biotite laths. (Glen Garvan Psammite, NM 954740, crossed nicols).

Scale bar represents 0.1mm





a strong preferred orientation parallel to the dominant foliation and individual aggregates may attain 1 centimetre in length.

Chlorite is commonly found as an alteration product of biotite, and occasionally garnet, and is identical in habit and form to its previously recorded occurrences.

Accessory Minerals Epidote and sphene occur as randomly distributed, xenoblastic equidimensional grains 0.1 - 0.2 millimetres across. They are rather less common in the semi-pelites and pelites than in the quartzites and psammites. Zircon occurs as small rounded grains, 0.1 millimetres across, poikiloblastically enclosed by biotite which develops pleochroic haloes. Pyrite and haematite are locally common, both as finely disseminated dust and as large xenoblastic aggregates which may be greater than 1 millimetre in diameter.

3.5. SEMI-PSAMMITIC AND PSAMMITIC GNEISSES

These differ from the psammites and semi-psammites in their increased grain-size and well-differentiated compositional banding. The latter is defined by the regular alternation, on a scale of 1-3 centimetres, of bands which predominantly contain quartz and plagioclase in association with small amounts of mica, with bands which contain a relatively higher proportion of mica. Individual bands are often traceable laterally for distances of up to 3 metres. Migmatitic structures are rarely developed. Semi-psammitic and psammitic gneisses comprise the dominant lithology in the Gulvain Psammitic Gneiss, are

Psammitic Gneisses:

Specimen	Quartz	Plagioclase	Muscovite	Biotite	Chlorite	Microcline	Epidote	Apatite	Sphene	Haematite	Pyrite
7982	58	25	-	10	2	4	0.1	0.2	-	0.4	0.3
7985	75	17	0.5	4.5	0.5	2	-	0.1	-	0.3	0.1
7986	68	20	0.5	11	-	0.5	-	-	-	-	-
7990	65	31	-	3.5	-	0.2	-	-	-	0.1	0.2
7996 (Gulvain Psammitic Gneiss)	62	24	2	10	1	-	0.3	0.1	0.1	0.3	0.2

Semi-Psammitic Gneisses:

Specimen	Quartz	Plagioclase	Muscovite	Biotite	Chlorite	Microcline	Epidote	Apatite	Sphene	Haematite	Pyrite
7997	52	10	-	35	1	1.5	0.1	-	-	0.2	0.2
8092	45	20	1	30	0.6	3	-	0.1	-	0.3	-
8097 (Gulvain Psammitic Gneiss)	57	18	-	22	2.5	-	-	-	0.1	0.2	0.2

Table 6: Modal analyses of Psammitic and Semi-Psammitic Gneisses

locally developed within the Druim Na Saille Pelite, and also, in the Na-h-Uamachan area, within the Basal Psammite and Kinlocheil Banded Quartzite. They are virtually identical in composition to the psammites and semi-psammites, and representative modal analyses are presented in Table 6. Quartz and plagioclase are intergrown in a granoblastic aggregate, the average grain-size of which is typically 1-2 millimetres, and less commonly, 3 millimetres. Average grain-size is somewhat smaller within the micaceous bands than within the quartzo-feldspathic bands. Grain boundaries are commonly complex, and there is often a considerable variation in grain size from, for instance, 0.2-2.0 millimetres. Albite twinning is well-developed within the plagioclase, which is oligoclase An_{23-30}.

Biotite is present within the micaceous bands as aligned subidioblastic laths which tend to be separate and not intergrown. Laths are 0.5-1.0 millimetres long, pleochroic from buff to dark brown, and are occasionally altered to chlorite. Biotite is also present within quartzo-feldspathic bands where they are characteristically poorly oriented. Muscovite is rare, and is of the same form, habit and size as the biotite. Orthoclase may be locally present, and myrmekitic intergrowths occur along plagioclase-orthoclase boundaries. Epidote, haematite and pyrite occur sporadically as xenoblastic grains, 0.1-0.3 millimetres across, and usually associated with biotite.

3.6. SEMI-PELITIC AND PELITIC GNEISSES

These differ in hand specimen from semi-pelites and pelites by virtue of increased grain-size and their distinctive gneissose texture.

The latter is defined by the alternation on a millimetric to centimetric scale of dark mica-rich bands with lighter quartzo-feldspathic augen or bands. This gneissose texture is extremely variable and ranges from the relatively fine interbanding of quartzo-feldspathic and micaceous components on a scale of 2-3 millimetres to a more coarsely-developed gneissosity developed on a scale of 1-2 centimetres. Increase in the proportion of quartzo-feldspathic material leads to a more massive appearance and the foliation, normally defined by the alignment of quartzo-feldspathic augen or bands, is less conspicuous. Semi-pelitic and pelitic gneisses form the bulk of the Druim Na Saille Pelite, and are also present as thin bands within the Gulvain Psammitic Gneiss. Sporadic occurrences of semi-pelitic gneiss are present within units of the Loch Eil Division on Na h-Uamachan. Compositionally, they are identical to the semi-pelities and pelites, and representative modal analyses are presented in Table 7.

Biotite and muscovite are present in varying amounts, intergrown as discrete bands and sheaves which wrap around quartz-plagioclase augen and bands. Individual laths are commonly 0.7-2.0 millimetres long but otherwise are identical in their petrographic characteristics to those already described from the semi-pelites and pelites. Both micas also exist as 'late' randomly oriented xenoblastic porphyroblasts. Chlorite is confined to the mica-rich bands where it is occasionally present as an alteration product of biotite.

Quartz and plagioclase are intergrown in discrete augen and bands. Both are xenoblastic and broadly equidimensional, and occasionally display undulose extinction. Most quartz-plagioclase aggregates tend to be characterized by smooth grain boundaries and a range in grain-size of 0.7-1.5 millimetres. Sections obtained from the Na h-Uamachan area

Semi-pelitic Gneisses:

Specimen	Biotite	Muscovite	Quartz	Plagioclase	Alkali Feldspar	Garnet	Epidote	Haematite	Pyrite
792	17	30	27	21.5	-	4	0.3	0.1	0.1
7913	22	20	35	9	12	1.8	-	0.2	-
7980	26	17	26	10	8	3	-	-	-
79106	35	18	30	9.5	2	5	0.2	0.1	0.2
8025 (Druim Na Saille Pelite)	33	20.5	32.2	12	-	2	0.1	-	0.3

Table 7: Modal analyses of semi-pelitic gneisses

are, however, texturally more complex and display a range in grain size of 0.2-2.0 millimetres and intricate grain boundaries. Plagioclase grains are generally fresh and only locally sericitised; albite and pericline twinning are well developed and plagioclase ranges in composition from oligoclase An_{18} to An_{28}.

Subidioblastic porphyroblasts of garnet are locally common, particularly within micaceous bands. They are usually equidimensional and 0.5-1.0 millimetres across. They commonly include numerous disoriented fine inclusions of quartz, scattered randomly across the garnets which only rarely display any visible internal zonation. A few examples do, however, display a preferential concentration of quartz inclusions around the core of the garnet. Garnets are rarely retrogressed; and exception to this is illustrated in Plate 16 where a garnet has been thoroughly replaced by a complex aggregate of quartz, chlorite and muscovite.

Orthoclase is occasionally present as grains of the same habit and size as the plagioclases. Epidote, zircon, pyrite and haematite occur as common accessory minerals which are of the same habit and size as their occurrences in the semi-pelites and pelites.

Commonly, the semi-pelitic gneisses of the Glenfinnan Division are clearly migmatites, sensu Mchnert (1968), defined by him as "megascopically composite rocks consisting of two or more petrographically different parts, one is the country rock in a more or less metamorphic stage, the other is of pegmatitic, aplitic, granitic or generally plutonitic appearance". Accordingly, they may be subdivided into a

Plate 16: Complex replacement of garnet by an aggregate of quartz, chlorite and muscovite. (Druim Na Saille Pelite, NM 986849, plane polarised light).

Scale bar represents 0.1mm

palaeosome of semi-pelitic or pelitic gneiss, and a neosome which comprises augen or sheets of quartzo-feldspathic leucosome which may be bordered by a biotite-rich melanosome (Plates 17 and 18).

Stream sections in the Cona River and the Allt a Choire Reidh display a variety of migmatitic structures which may be compared with the classification of Mchnert (1968, p. 10-11). For the most part these are either opthalmitic (augen) or stromatic (layered) structures. The former is characterised by the distribution of leucosomes in the from of elongate augen ranging in size from 2-3 millimetres to 3-4 centimetres in length. Stromatic structures are characterised by elongate laterally extensive leucosomes which are regularly interlayered with the palaeosomes and melanosomes. Individual leucosomes may be traced laterally for distances of up to 1 metre. Both these types of structure are common and are often intimately associated and interwoven on outcrop scale.

The degree of migmatisation varies considerably both on outcrop scale and throughout the area. Migmatisation is readily apparent and well-developed in the area N of Druim Na Saille. S of Loch Eil, however, loci of well developed migmatitic structures only occur sporadically.

Melanosomes are often poorly developed and indistinguishable from palaeosomes. Leucosomes are composed almost entirely of intergrown quartz and plagioclase (oligoclase An_{12} to An_{29}), in association with small disoriented laths of biotite, and tend to be

Plate 17: Migmatitic semi-pelitic gneiss. In this example the thin sheet of quartzo-feldspathic leucosome above the compasss is only locally bordered by a biotite-rich melanosome. (Druim Na Saille Pelite, NM 95407915).

Plate 18: Migmatitic semi-pelitic gneiss, featuring well-developed melanosomes adjacent to the leucosomes. (Druim Na Saille Pelite, NM 95407915).

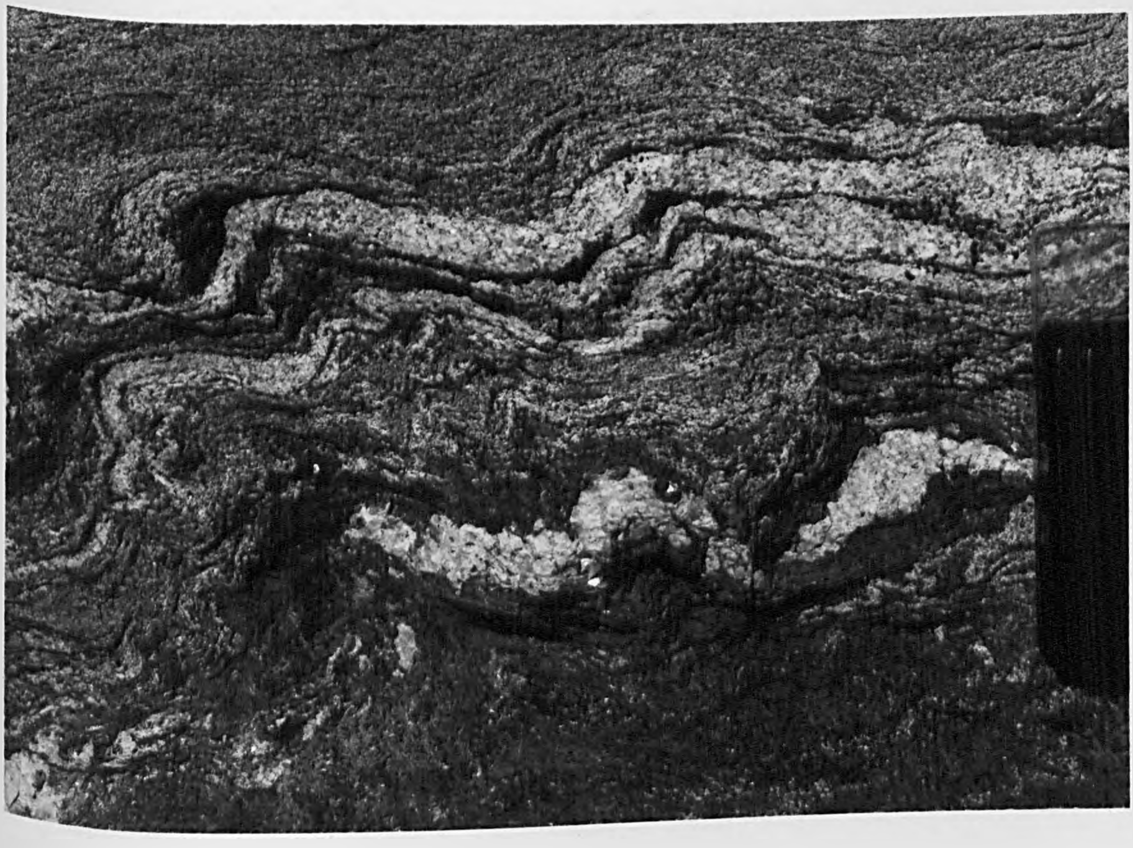
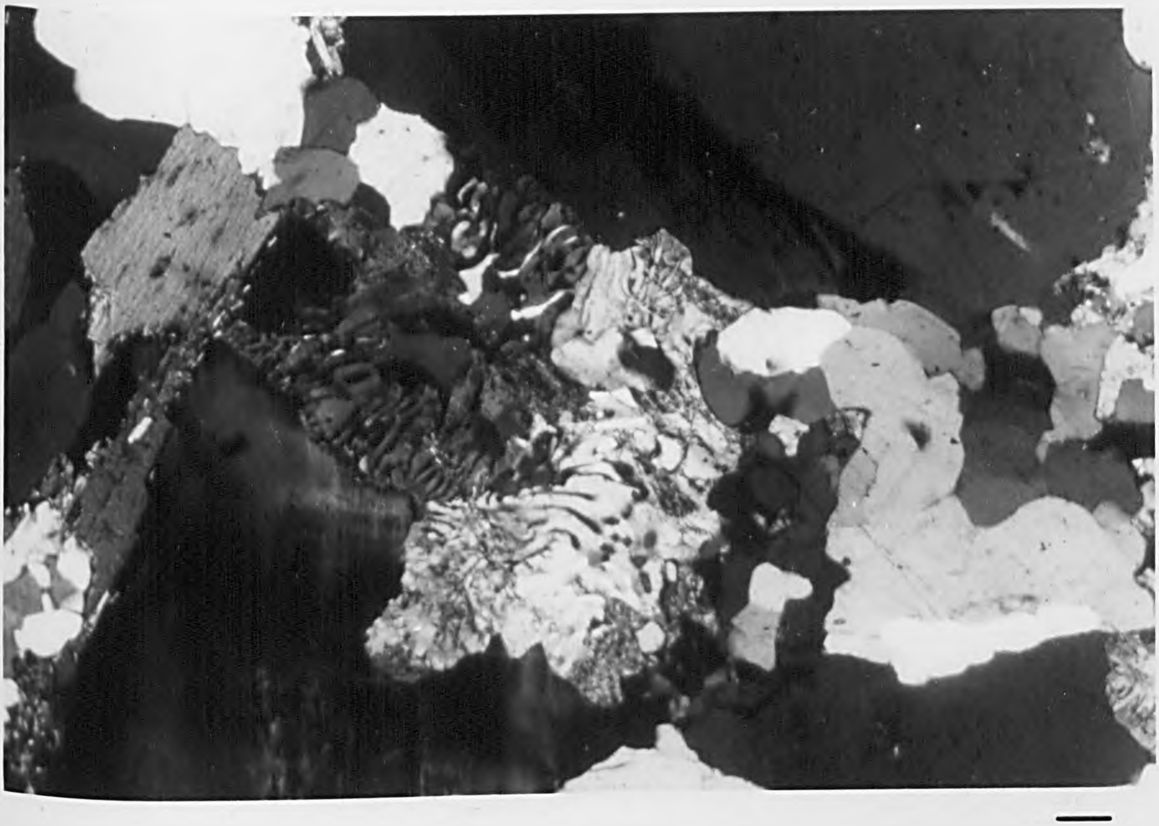
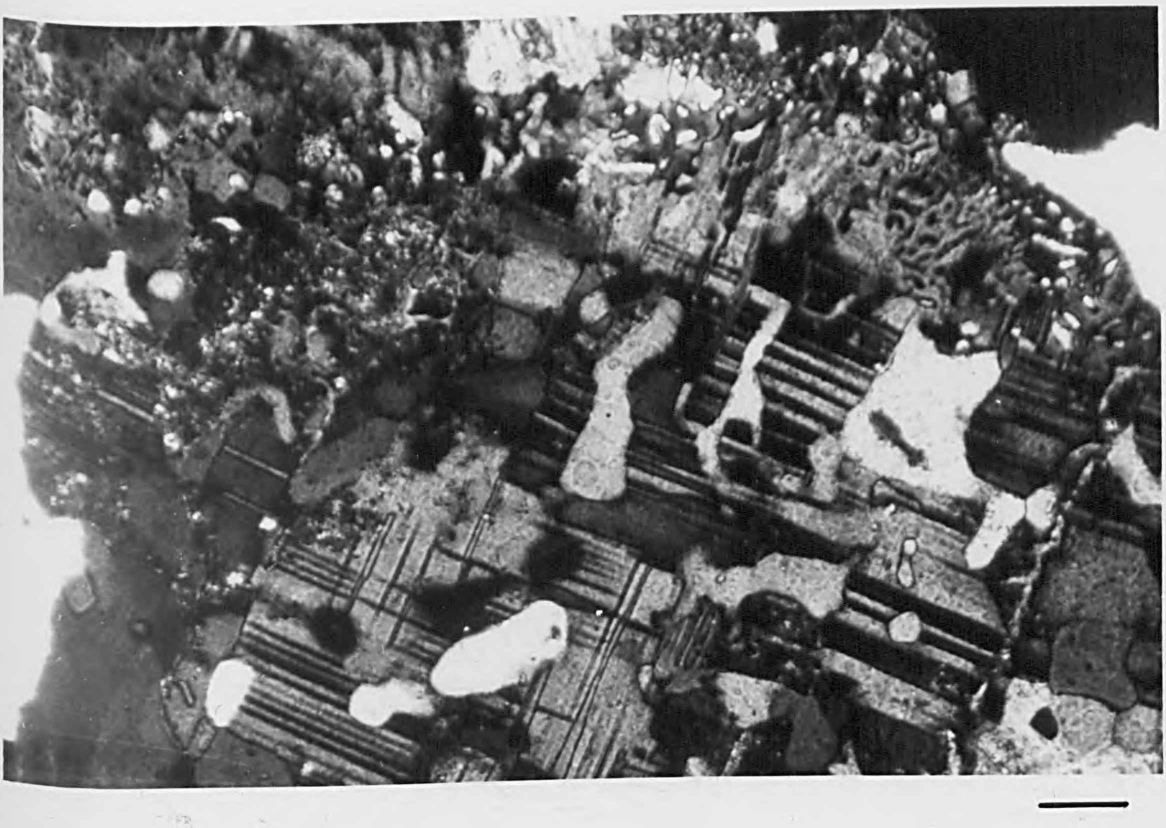


Plate 19: Complex myrmekitic intergrowths at a microcline (bottom left) - plagioclase (top) boundary, within a leucosome. (Druim Na Saille Pelite, NM 973848, crossed nicols).

Plate 20: 'Exsolution-type' texture within a plagioclase grain which incorporates vermicular blebs of quartz. (Druim Na Saille Pelite, NM 973848, crossed nicols).

Scale bar represents 0.1mm





compositionally and texturally similar to the quartz-plagioclase aggregates in the palaeosomes. Small amounts of microcline are locally present within leucosomes. Complex textures are developed in leucosomes sampled from the northeastern slopes of Na h-Uamachan (e.g. NM 973848) and feature:

(a) Myrmekitic intergrowths at plagioclase-microcline boundaries (Plate 19).

(b) Complex symplectic intergrowth of quartz and plagioclase, and quartz and biotite, resulting in textures which vary from vermicular to myrmekitic, dendritic and granophyric.

(c) 'exsolution-type' textures within plagioclase grains which may incorporate vermicular blobs of quartz (Plate 20).

These features are, however, only locally developed and are therefore unlikely to be of any major petrogenetic importance.

3.7. CALC-SILICATES

Most calc-silicates occur as pale-grey to white pods or bands, the morphology of which is described in greater detail in Chapter 7. They typically occur within psammites and are readily distinguishable from them by virtue of their colour and slightly coarser grain-size. In hand specimen they consist of an aggregate of quartz and feldspar within which are randomly scattered porphyroblasts of garnet, biotite, and either hornblende or pyroxene. This type of calc-silicate is commonly recorded from numerous localities within the Moine Succession (Kennedy 1949; Winchester 1974; Tanner 1976; Powell et al. 1981). A second, less common type of calc-silicate is poorly developed and appears as pale-green bands and lenses. Compositionally they are distinguished from the first type by the absence of garnet and zoisite and the presence of large quantities of epidote. These are calc-silicates of Arnipol type (MacGregor 1948; Winchester 1975). As a result of the thin-section study of calc-silicates, the following mineral assemblages have been recognized.

1. (a) Hornblende + biotite + andesine + garnet + zoisite + quartz

   (b) Hornblende + andesine + garnet + quartz ± biotite ± zoisite ± calcite

   (c) Hornblende + bytownite + garnet + quartz ± zoisite ± biotite ± clinozoisite.

   (d) Pyroxene + bytownite + garnet + quartz ± hornblende ± zoisite ± clinozoisite

2. Hornblende + epidote + andesine-oligoclase + quartz ± garnet ± zoisite.

Assemblages 1a, b, c and d are referable to the first and more important type of calc-silicate described above. Epidote, apatite, zircon and sphene occur in many sections as irregularly distributed accessories. Assemblage 2 represents calc-silicates of Arnipol type, and includes some transitional garnet and zoisite-bearing assemblages. Each of these assemblages will be described in detail.

1(a) <u>Hornblende + biotite + andesine + garnet + zoisite + quartz</u>

Thin-sections carrying this assemblage have been obtained from a small quarry adjacent to the A830 road, 1 kilometre W of Corpach, at (NN 075774).

<u>Hornblende</u> occurs as randomly scattered equidimensional xenoblastic grains which are typically 0.1-0.5 millimetres in diameter. They are strongly pleochroic from pale to dark green and only rarely display good cleavage. Grain boundaries are usually slightly curved. Occasionally hornblende may poikiloblastically enclose small quartz grains.

<u>Biotite</u> laths show a strong preferred orientation and appear to be intergrown with hornblende (Plate 21). Individual laths vary in size from 0.1-0.5 millimetres in length and are pleochroic from buff to dark brown. They are typically subidioblastic in form and often display good cleavage. Some laths may show partial alteration to chlorite.

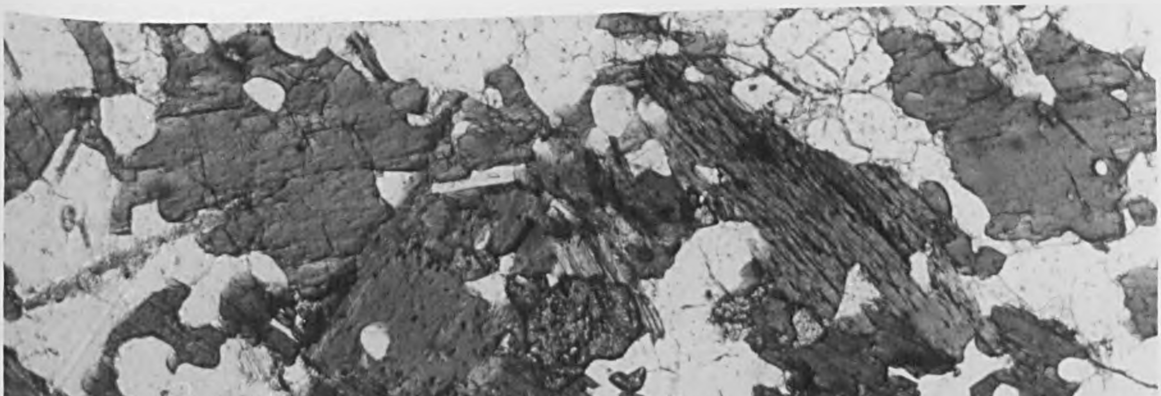
<u>Garnet</u> occurs as equidimensional, xenoblastic or subidioblastic grains which range in diameter from 0.2-0.7 millimetres. Most grains have smooth boundaries and rarely incorporate any inclusions of quartz.

<u>Andesine</u> in the range An_{40-50} is present in association with quartz with which it is intergrown as a granoblastic mosaic. Most andesine grains are equidimensional and xenoblastic in form, varying from 0.2-0.4 millimetres in diameter. Albite twinning is well developed and most grains are fresh.

Plate 21: Intergrowth of hornblende grains and biotite laths aligned in S1, within a calc-silicate of assemblage 1(a). (Cona Glen Psammite, NN 075774, plane polarised light).

Plate 22: A hornblende porphyroblast aligned in S1 overgrown by randomly oriented biotite laths, within a calc-silicate of assemblage 1(b). (Glen Garvan Psammite, NM 988788, plane polarised light).

Scale bar represents 0.1mm



<u>Zoisite</u> commonly occurs as stumpy prismatic xenoblastic grains 0.2-0.3 millimetres across. They display both normal and anomalous interference colours, and may be internally zoned. The zoisite grains are usually randomly scattered through any given section, and show no preferred association with any other mineral.

<u>Quartz</u> is common as small grains of the same habit and size as the plagioclase. Most grains display straight extinction.

1(b) <u>Hornblende + andesine + garnet + quartz ± biotite ± zoisite ± calcite</u>

Thin sections carrying this assemblage have been obtained from a roadside locality near Kinlocheil at (NM 988788). Although the mineral assemblage is broadly similar to that of 1(a), the calc-silicates of 1(b) possess distinct textural differences from those already described.

<u>Hornblende</u> is typically coarser than in 1(a) and porphyroblastic in habit, occurring as large aligned subidioblastic laths 1-4 millimetres long (Plate 22). Many laths occur in discrete elongate aggregates. A large proportion of hornblende laths are poikiloblastic in form with irregular embayed margins, and enclose numerous small quartz grains. Laths usually display good cleavage and are pleochroic from light to dark green.

<u>Garnet</u> grains tend to be larger than in 1(a), and are usually 1-2 millimetres in diameter. They are less well formed, however, and have irregular embayed margins. Many enclose numerous randomly distributed quartz inclusions.

Biotite laths differ from those of 1(a) in several important respects. Those of 1(b) are randomly oriented and overgrow hornblende laths with marked obliquity (Plate 21). They are typically xenoblastic to subidioblastic in form, vary in length from 1-2 millimetres, and only rarely display good cleavage.

Quartz, andesine and zoisite are all similar in their size, form and occurrence to those of 1(a). Calcite occurs rarely as small xenoblastic patches, 0.1-0.5 millimetres across.

1(c) Hornblende + bytownite + garnet + quartz ± zoisite ± biotite ± clinozoisite

Thin-sections carrying this assemblage have been obtained from five localities:

(i) Cona Glen (NM 918731)

(ii) Glas Bheinn (NM 939757)

(iii) W end of Loch Eil, adjacent to A830 (NM 954793)

(iv) North Garvan River (NM 97009655)

(v) Sron an-t-Sluichd (NM 958743)

Hornblende is similar in form and optics to that of 1(b). At the North Garvan River locally aligned hornblende laths are overgrown by variably oriented secondary fibrous amphibole.

Garnet grains are usually 2-3 millimetres across, and usually consist of spongy networks in which the garnet is either continuously linked or consists of an aggregate of separate granules in optical continuity with each other.

Bytownite (An_{70-86}) and quartz are in granoblastic intergrowth as in 1(a) and (b). Average grain size tends, however, to be slightly larger and most grains are 0.4-0.8 millimetres in diameter.

Zoisite is considerably less common than in 1(a) and (b) and only occurs as small interstitial patches in the quartz-bytownite mosaic.

Clinozoisite appears sporadically as small irregular rounded granules which may show zoning and twinning. Most grains are 0.2-0.4 millimetres long, resulting from the partial alteration of hornblende.

1(d) Pyroxene + bytownite + garnet + quartz ± hornblende ± zoisite ± clinozoisite

Thin-sections carrying this assemblage have been obtained from numerous localities along the crest of Sron an-t-Sluichd between (NM 95157380) and (NM 95997430).

Pyroxene commonly occurs as equidimensional, xenoblastic to subidioblastic grains irregularly scattered throughout the sections. Individual grains range in diameter from 0.5 to 3.0 millimetres. In some sections the pyroxene may be present as a series of clusters which may be 3-4 millimetres in diameter. The pyroxene is typically faintly pleochroic from colourless to pale-green; good cleavage is often preserved. The pyroxene is salite (Winchester, pers. comm.). Inclusions of groundmass-

-size quartz and epidote are common.

Garnet is common in all sections examined and is essentially identical in form and size to the garnet described in 1(c).

Bytownite (An_{73-88}) and quartz are again in granoblastic intergrowth grain size is more variable in this assemblage than those already described, there being every variation from an average grain size of 0.2-0.3 millimetres to one of 0.5-1.0 millimetres.

Hornblende is present in many sections and is texturally quite distinct from that already described. It is typically pale-green and occurs as wispy fibrous aggregates which rarely show any preferred orientation. In all cases it appears to be a product of the partial alteration of pyroxene grains (Plate 23), which are themselves usually xenoblastic in form and often isolated by replacive quartz into optically continuous areas.

Zoisite and clinozoisite are both similar in their size, form and occurrence to those of 1(c). Calcite was again observed as small interstitial xenoblastic patches, 0.1-0.5 millimetres across.

2. Hornblende + epidote + oligoclase-andesine + quartz ± garnet ± zoisite

Thin-sections carrying this assemblage have been obtained from five localities:

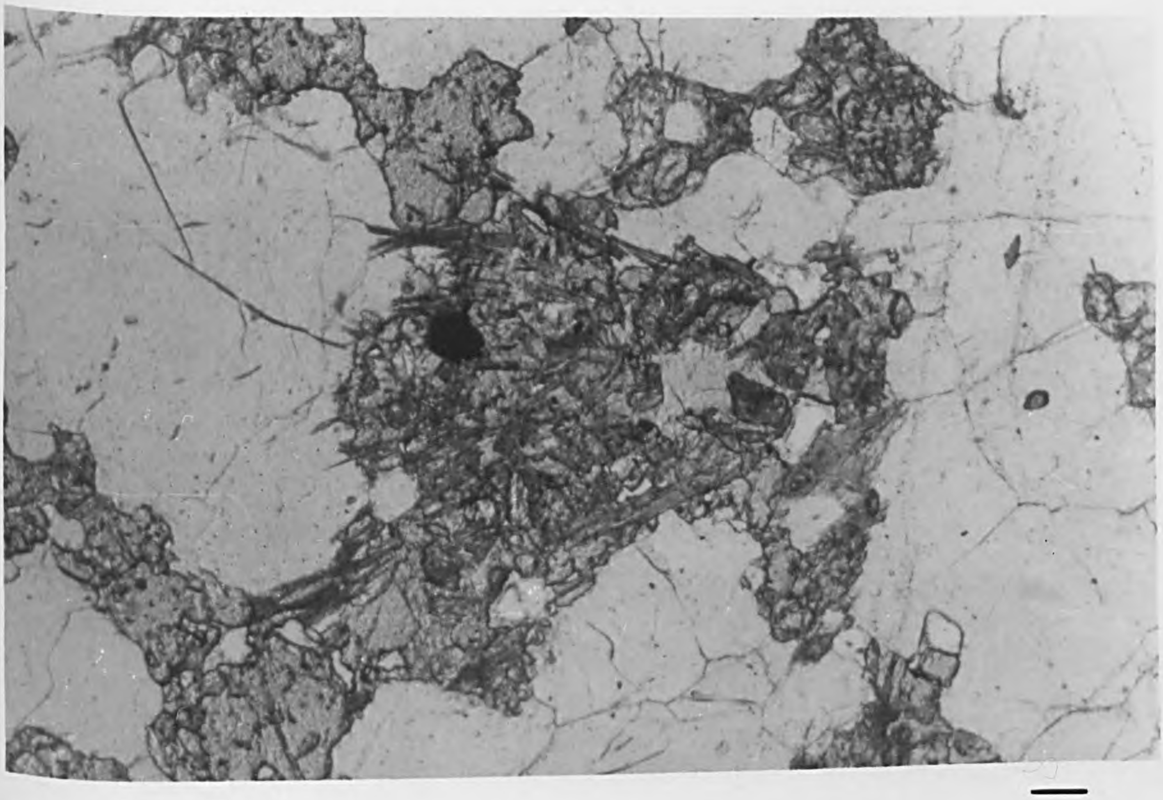
(i) Kinlocheil, adjacent to A830 road (NM 988788).

(ii) Fassfern (NN 022795).

(iii) Quarry adjacent to A830 road, 1 kilometre W of Corpach (NN 075774).

Plate 23: Partial replacement of pyroxene grains by wispy fibrous aggregates of hornblende, within a calc-silicate of assemblage 1(d). (Glen Garvan Psammite, NM 95157380, plane polarised light).

Scale bar represents 0.1mm



(iv) Adjacent to A830 road, 700 metres W of Corpach (NN 07957700).

(v) Banavie Quarry (NN 113774).

Hornblende is present as aligned randomly scattered laths, optically identical to those of assemblage 1. They are somewhat smaller than those previously described, however, and most are only 0.2-0.4 millimetres long. Rarely, in some sections from Banavie Quarry, the hornblende is of the same form and size as in assemblage 1(b) and (c).

Epidote is abundant in most sections as randomly scattered, equidimensional grains. Most are xenoblastic or subidioblastic in form and range in diameter from 0.2-1.0 millimetres.

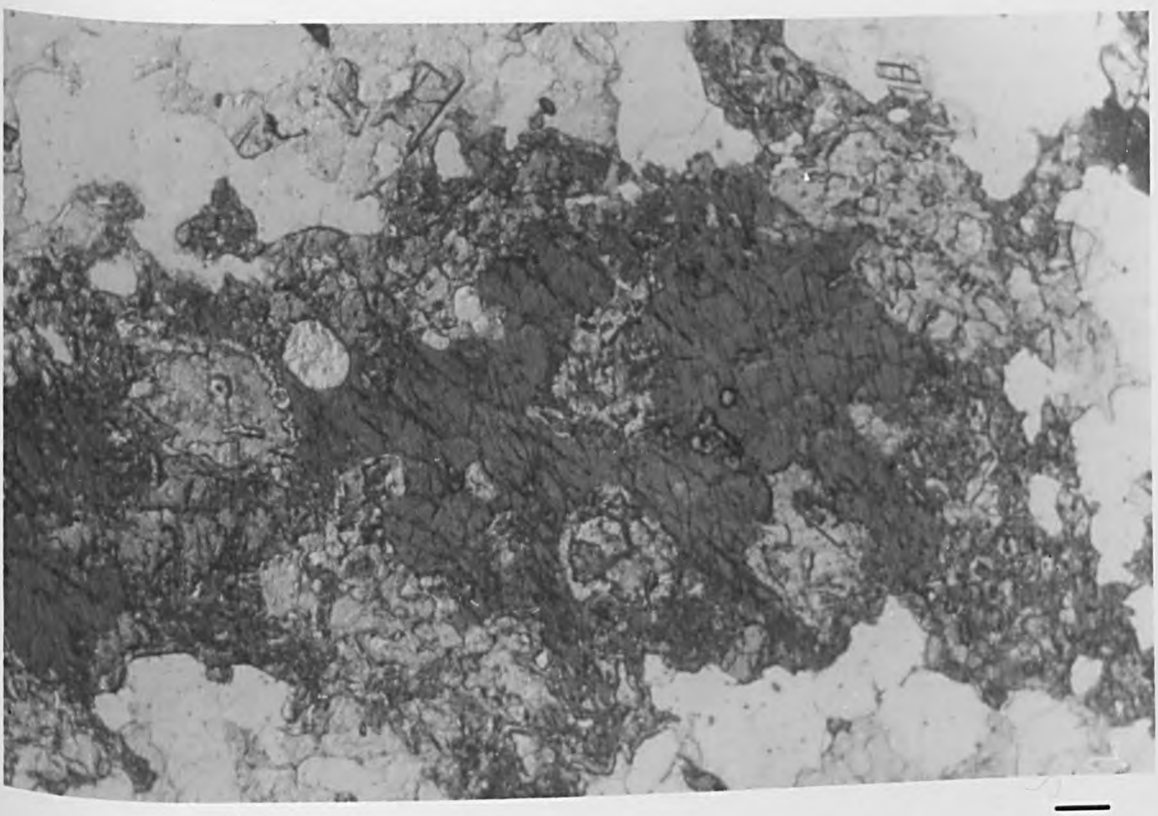
Oligoclase-andesine (An_{22-40}) and quartz are intergrown as a granoblastic mosaic, and are identical in form and habit to those of assemblage 1. Grain-size varies from 0.1-0.5 millimetres. Plagioclase is characteristically more sodic than in the calc-silicates of assemblage 1.

Garnet and zoisite are occasionally present in calc-silicates which appear to be transitional in composition between assemblages 1 and 2. Both are only present as small poorly-developed grains 0.1-0.2 millimetres across. They show no systematic distribution within any section and are generally petrologically similar to those described from assemblage 1.

Although the majority of sections carrying assemblage 2 are characterised by the virtual random distribution of the minerals described above, certain sections obtained from Banavie Quarry display more complex textures. In these sections hornblende and epidote occur in association

Plate 24: Large granular aggregate of hornblende and epidote within an Arnipol type calc-silicate. (Inverscaddle Psammite, Banavie Quarry NN 113774, plane polarised light).

Scale bar represents 0.1mm



as large granular aggregates which are often 3-4 millimetres across (Plate 24). These aggregates are separated by granoblastic intergrowths of plagioclase and quartz. Where such hornblende-epidote aggregates are present they often occur in association with finely disseminated garnet, and tend to occupy the central portion of compositionally-zoned calc-silicates which are rimmed by an epidote-poor zone consisting mainly of aligned hornblende laths, plagioclase and quartz. It is possible that the occurrence of the hornblende and epidote in the form of granular aggregates may be a result of the total replacement of a pre-existing mineral phase (pyroxene?). This will be discussed further in Chapter 6 (p. 140).

CHAPTER 4: STRUCTURAL HISTORY OF THE LOCH EIL AREA

4.1. INTRODUCTION

4.1.1. Terminology

The term 'foliation' is used to denote the compositional layering or lithological banding of the rock. Often this is a bedding-foliation, as shown by sedimentary structures. The terms 'schistosity' and 'gneissosity' relate to planar fabrics defined by the parallel arrangement of platy and tabular minerals or aggregates. Often they are parallel to the foliation, and may only be distinguished from it in the hinge zone of folds where they are referred to as the 'axial-plane schistosity/gneissosity'. The textural differences between 'schist' and 'gneiss' have already been outlined in Chapter 3 (p.44). 'Facing' is used with reference to beds or rock units as originally defined by Shrock (1948). The fold terminology is that of Fleuty (1964) and Ramsay (1967). The term 'fold vergence' is used in the sense of Roberts (1974, p.123) who defined it as "the horizontal direction within the plane of the fold profile, towards which the upper component of ..... rotation is directed". The definition of a tectonic slide proposed by Hutton (1981) is that used in this study.

4.1.2. Aims and method

Given that the Moine rocks of the Loch Eil area have undergone polyphase deformation, the aim of this study is to establish a sequence of deformation with particular reference to the style, orientation and sense of vergence of minor folds, their mutual interference, and the nature of their associated linear and planar structures. The Loch Eil area has been divided into ten sub-areas (Fig. 6) and the field measurements of planar and linear structural elements from each sub-area have been plotted on separate stereograms (Fig. 7). The distribution and nature of major structures, together with representative data relating to their associated minor structures, are presented in Enclosure 3. A series of cross-sections drawn across different parts of the area are presented in Enclosure 4.

4.2. STRUCTURAL HISTORY OF THE LOCH EIL DIVISION

Five deformational events (D1-D5) have been recognized within the Loch Eil Division; the structures produced during each event, together with the nature and style of deformation, will be described and discussed in turn.

4.2.1. D1

4.2.1.1. Minor structures

Minor D1 folds are commonly found within the Loch Eil Division: they are only observed to fold bedding (S0) and pre-D1 quartz veins, and possess a penetrative axial planar schistosity (S1). D1 folds vary from close (Plate 25) to isoclinal in style, and invariably possess thickened hinge zones and attenuated limbs. They range in size from folds which are only 10 centimetres long, to those which may be traced for distances of up to 20 metres. D1 folds are characterised by a high λ/A ratio, and in many cases it is not possible to measure amplitude within a single outcrop. Fold hinges are usually cylindrical where exposed. S1 is the dominant regional schistosity within the Loch Eil Division, and is usually parallel or

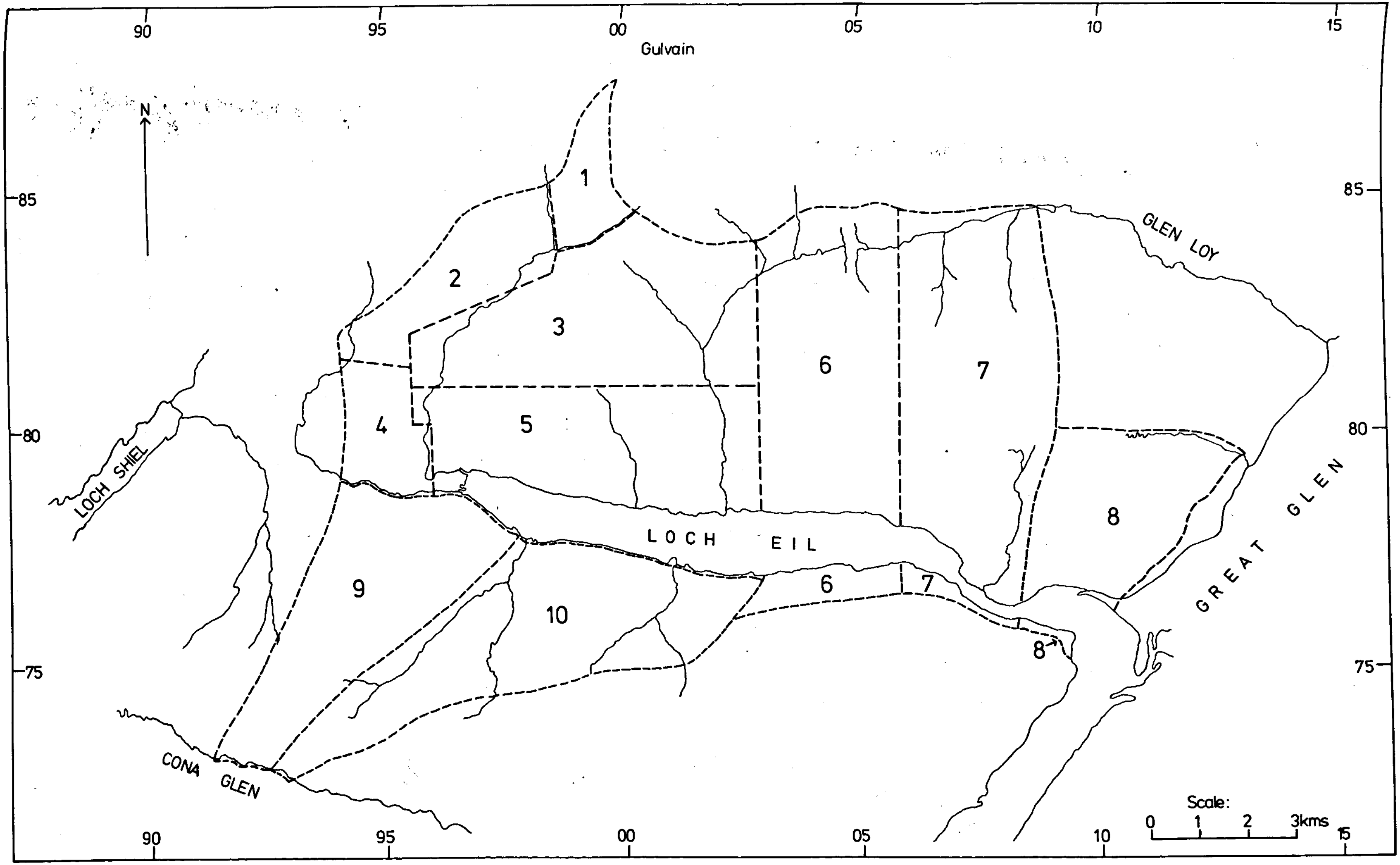


Figure 6: Location of structural sub-areas.

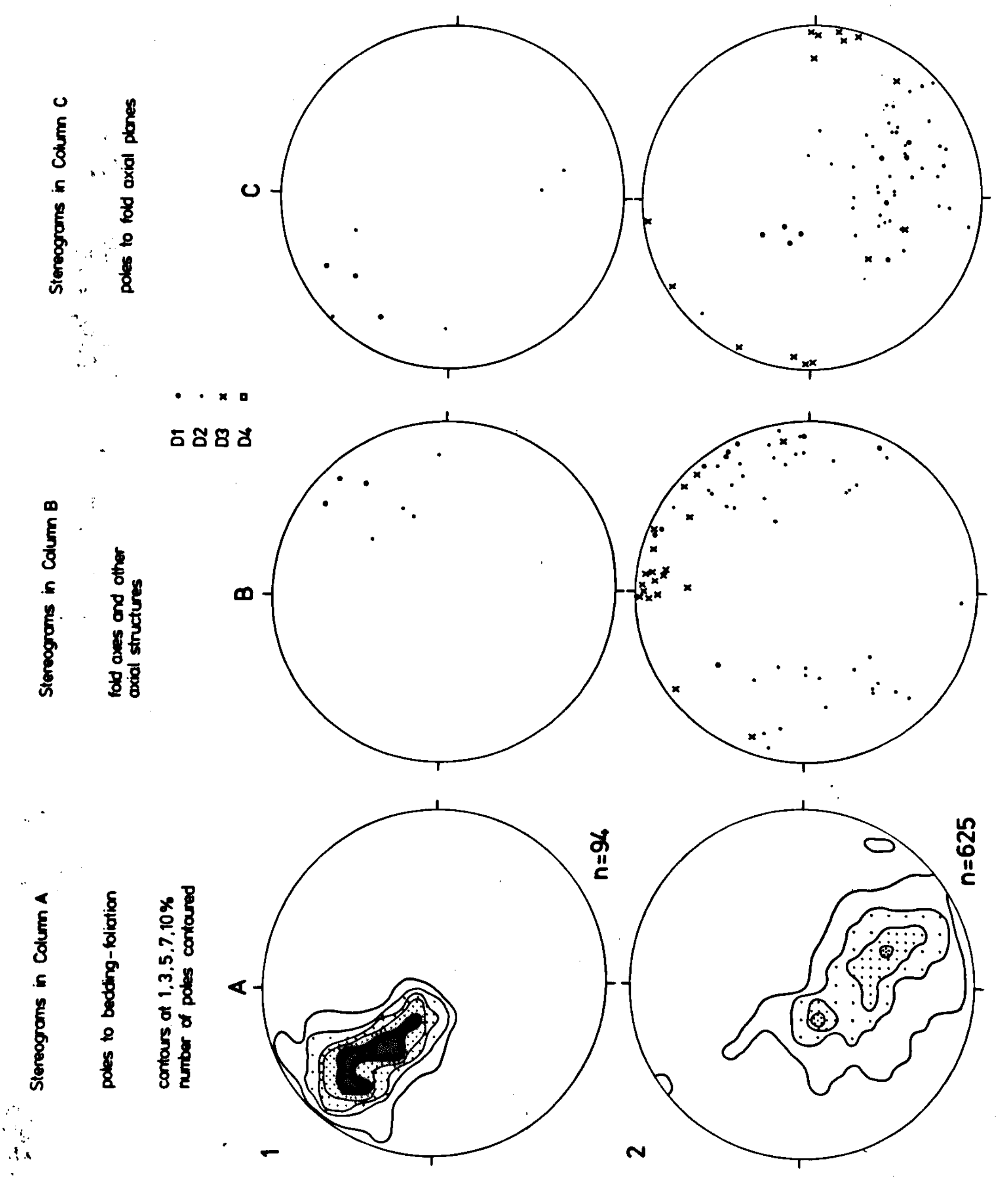


Figure 7: Structural analysis: sub-areas 1 and 2.

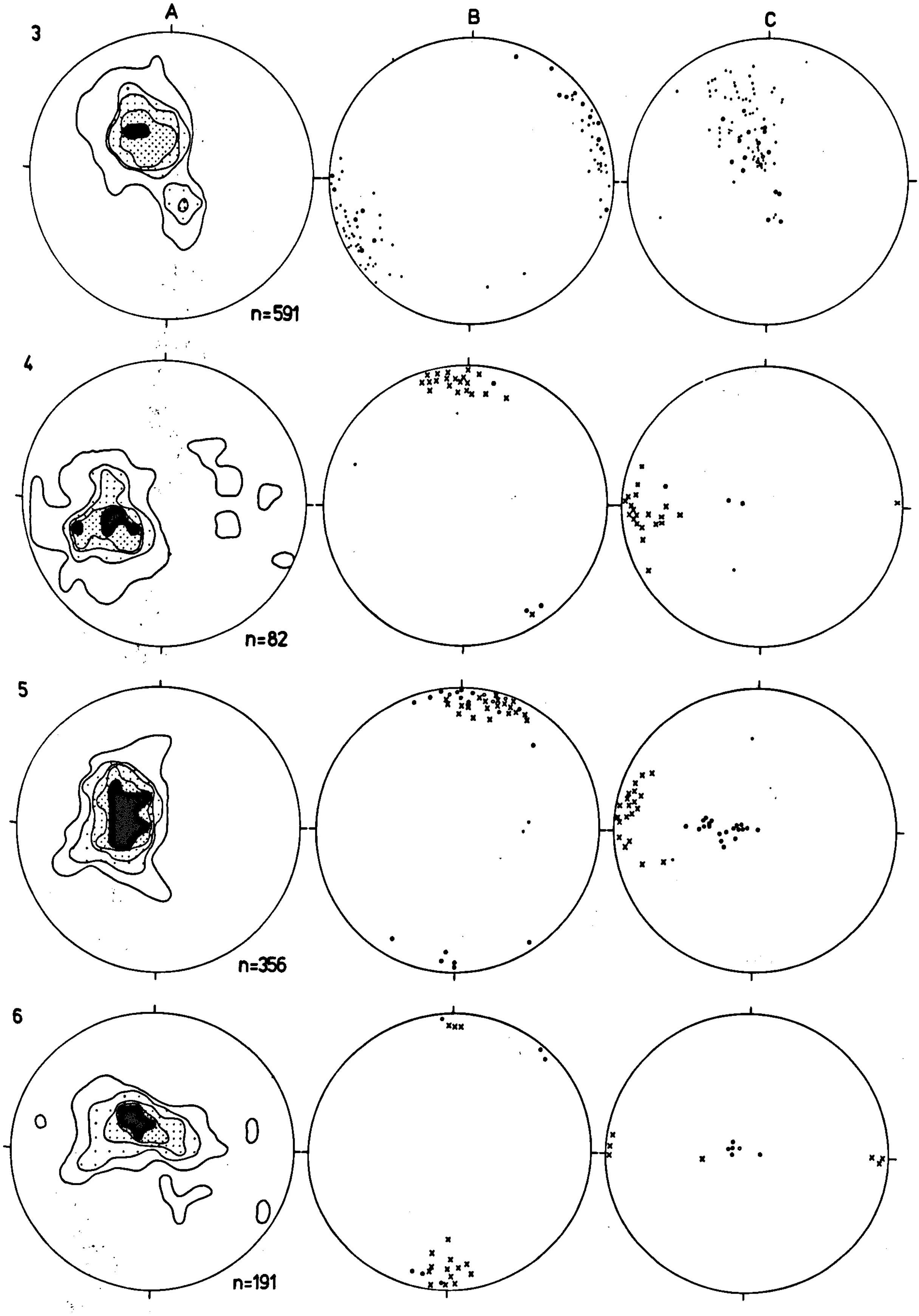


Figure 7: Structural analysis: sub-areas 3-6.

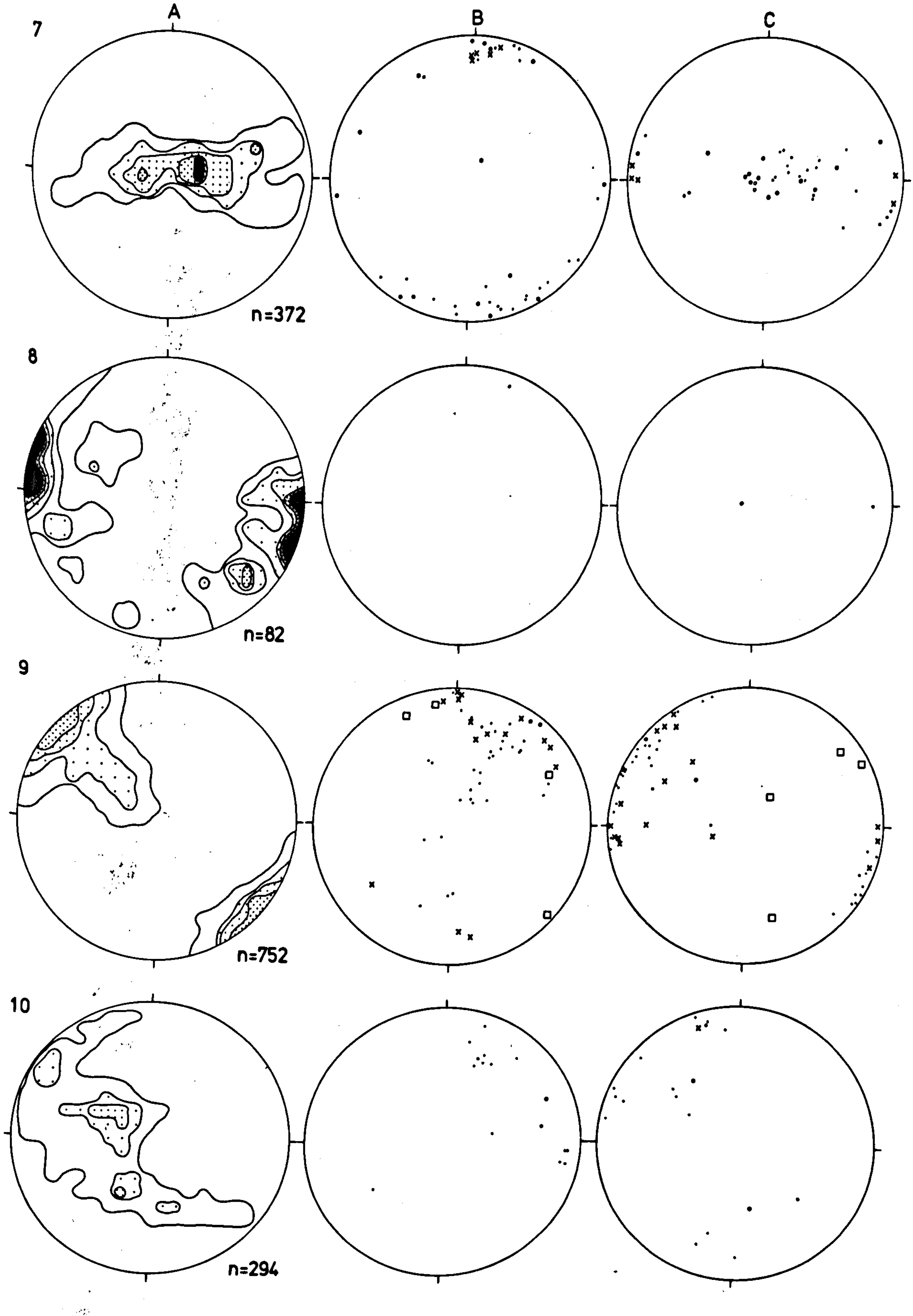


Figure 7: Structural analysis: sub-areas 7-10.

Plate 25: Asymmetric recumbent D1 fold on the W limb of the D3 Loch Eil synform. Sense of vergence to the left (W). (Glen Garvan Psammite, NM 98357885).

Plate 26: Detail of Plate 25 (to right of hammer) showing axial planar S1 mica fabric oblique to S0 in the hinge zone.

sub-parallel to original bedding (S0) except in the hinge zones of D1 folds (Plate 26). S1 is penetrative in all lithologies and is defined by the alignment of biotite and muscovite laths. It is therefore well-defined in semi-psammitic, semi-pelitic and pelitic lithologies, but rather less obvious in psammites and quartzites. A faint S0/S1 intersection lineation is occasionally present near fold hinges, to which it is normally parallel.

D1 structures have been refolded during D2-D4 and it is therefore difficult to ascertain their original attitudes and orientations. However, assuming S0 to have been broadly sub-horizontal prior to D1, and given that S1 is normally parallel to S0, it is reasonable to assume that D1 folds were originally recumbent in attitude. It is considered likely that D1 folds approximate to their original attitudes and orientations in the area immediately N of Loch Eil to the W of the axial plane trace of the D3 Loch Eil synform. This area has been relatively unaffected by either D2 or D3 folding, and only underwent gentle warping during D4 (see page 93). Here, D1 folds have recumbent to gently-inclined axial planes, and sub-horizontal axes which trend approximately N-S. They are commonly asymmetric and display a westerly sense of vergence.

4.2.1.2. Tectonic slides

A series of inter-related tectonic slides, considered to be D1 in age, are present in the W of the area (Fig. 8). Each slide or slide zone will be described and discussed in turn.

(a) Glas Bheinn slide. Between Cona River and Glen Dubh Lighe the line of the slide is marked by the junction of the Druim Na Saille

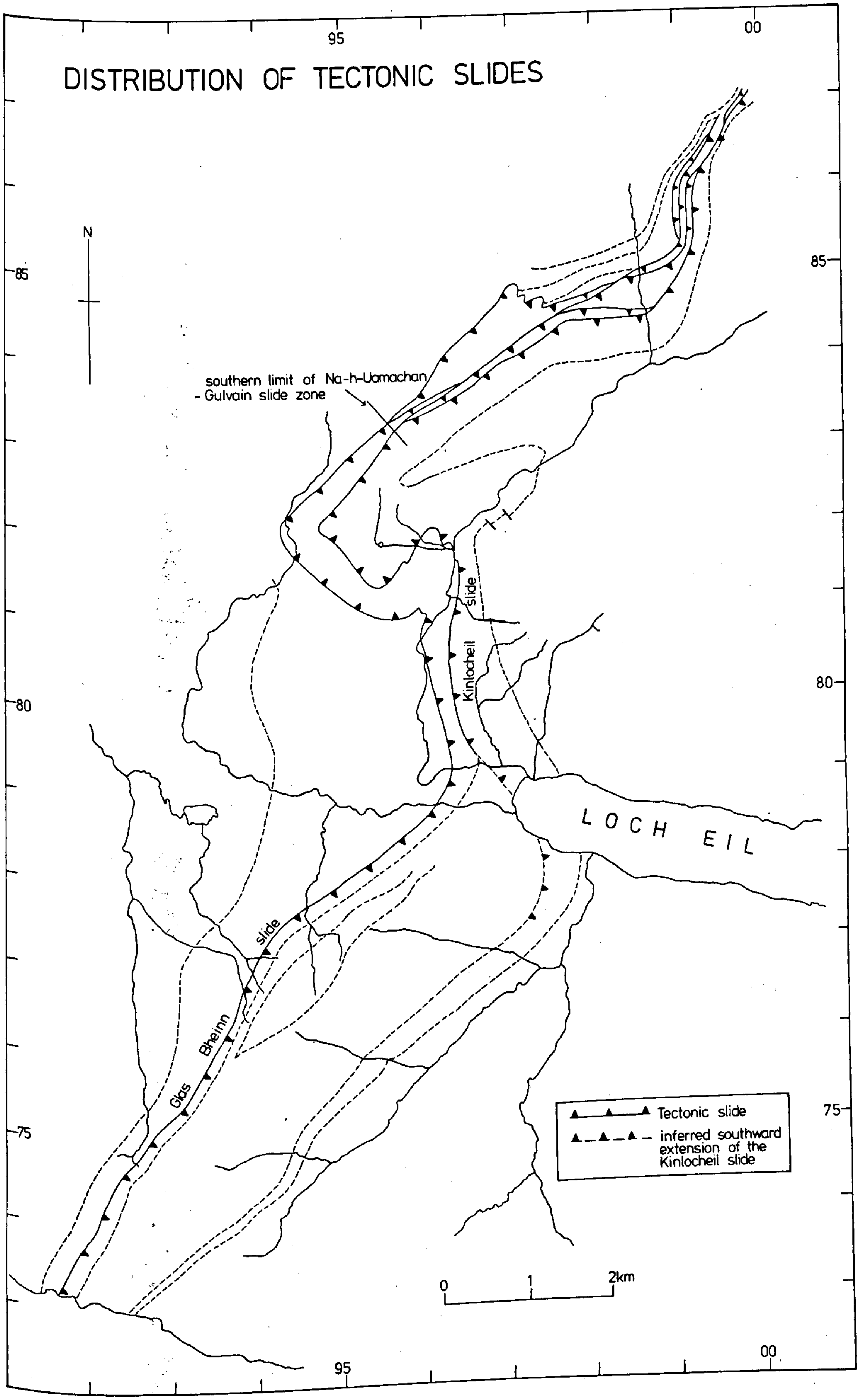

DISTRIBUTION OF TECTONIC SLIDES
95
00
N
85
80
75
southern limit of Na-h-Uamachan
- Gulvain slide zone
Kinlocheil
slide
LOCH EIL
Glas Bheinn
slide
Tectonic slide
inferred southward extension of the Kinlocheil slide
0
1
2km

Figure 8

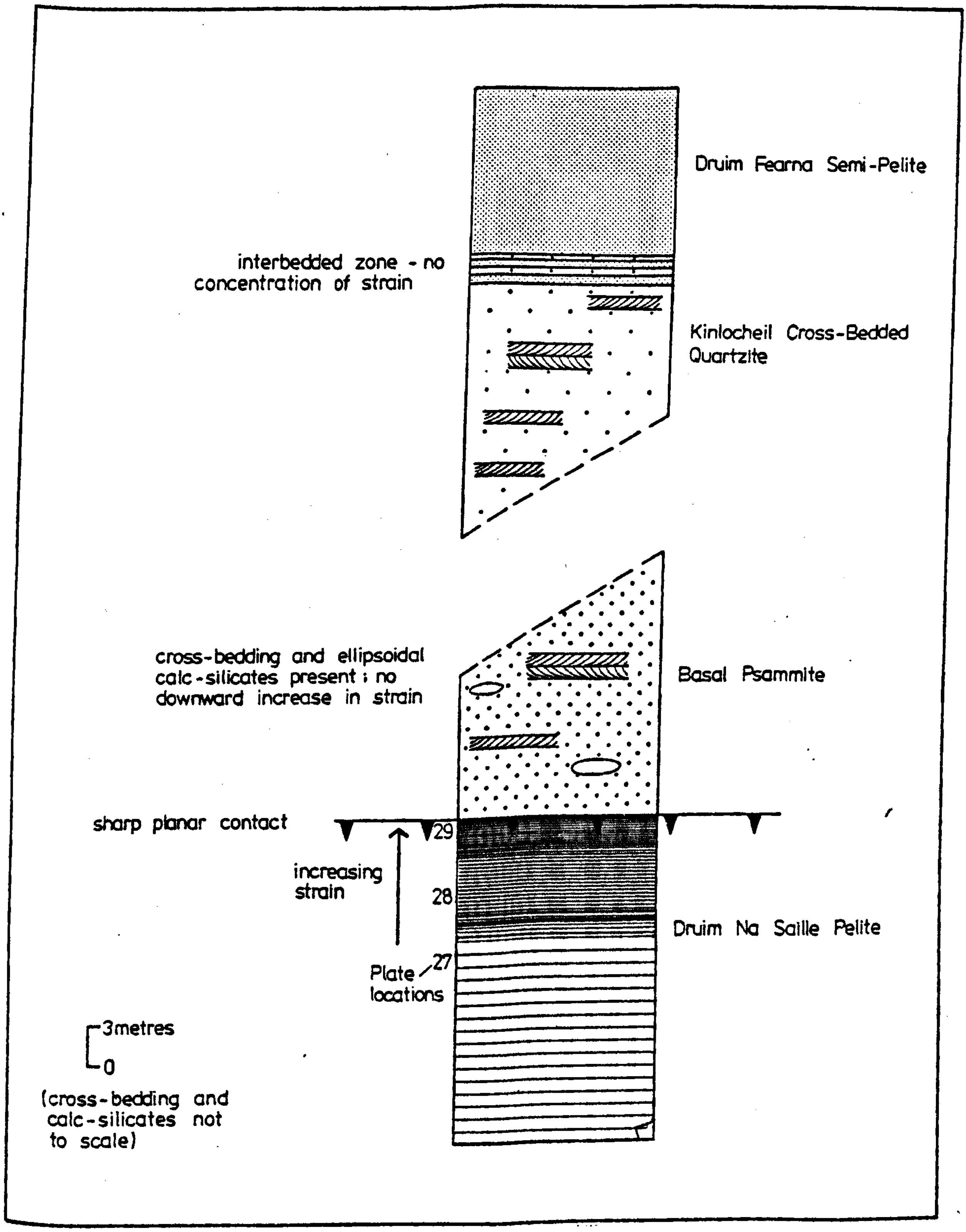


Figure 9: Features associated with the Glas Bheinn slide.

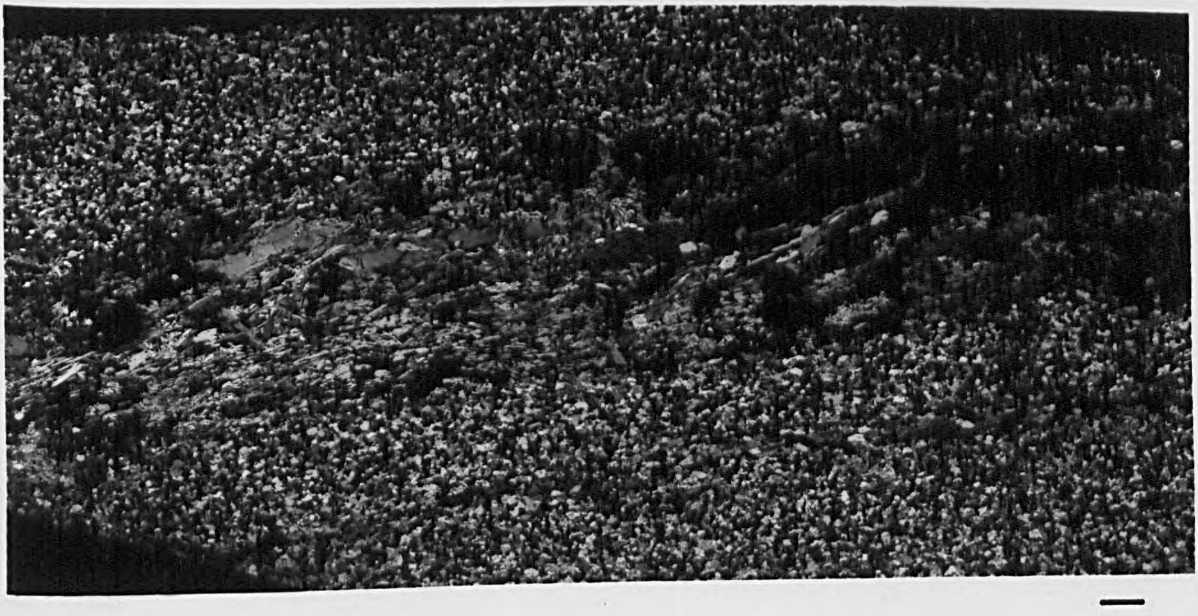
Textural changes which occur within the Druim Na Saille Pelite as the Glas Bheinn slide is approached

Plate 27: 'Normal' Fabric 10 metres below slide: mica-rich bands are c. 2 millimetres apart, and quartz grain size is c. 1 millimetre.

Plate 28: 'Sheared' Fabric 5 metres below slide: the spacing between mica-rich bands is reduced to c.1 millimetre to result in a strongly schistose fabric (crinkled by D3 microfolds on left). Quartz grains show a tendency to elongation.

Plate 29: Highly sheared 'platy' schist adjacent to slide: micas and quartzo-feldspathic components have been segregated into bands, and quartz grain size has been reduced to c.0.2-0.3 millimetres.

Scale bar represents 1mm.



Pelite on the W, and the Basal Psammite on the E. The contact of the units is well-exposed on the western slopes of Glas Bheinn (NM 937763) and the main features associated with the contact in the field are summarized in Fig. 9. The following textural changes occur within the Druim Na Saille Pelites as the contact is approached (Plates 27, 28 and 29).

(i) Planar fabrics intensify: micaceous and quartzo-feldspathic components are progressively segregated into thin parallel bands, and the spacing between mica-rich bands may be considerably reduced to result in highly foliated 'platy' schists. This is interpreted to be a result of mechanical metamorphic differentiation during shearing (Higgins 1971, p.62).

(ii) Quartz grains diminish in size from c. 1 millimetre to c. 0.2-0.3 millimetres. This reduction in grain-size is similarly consistent with an increase in shearing (Higgins op cit. p.60).

These features are clearly indicative of a progressive increase in shear strain towards the contact, and are consistent with the presence of a tectonic break along this lithological junction. It is important to emphasise that there are no signs of 'brittle' deformation along the contact, and no indication that shearing was accompanied by retrogressive metamorphism. This suggests that shearing was broadly syn-metamorphic and deformation was ductile in nature. None of the features associated with this contact have been recorded from the nearby contact on Glas Bheinn between the Kinlocheil Cross-Bedded Quartzite and Druim Fearna Semi-Pelite (Fig. 9).

Addendum to 4.2.1.2.(b):

A sedimentary explanation for the absence of the Kinlocheil Cross-Bedded Quartzites and the Druim Fearna Semi-Pelite N. of Loch Eil is rejected for several reasons:

(i) The Basal Psammites, Kinlocheil Banded Quartzites and the Glen Garvan Psammites all maintain a relatively uniform thickness across the Loch Eil area, and there are no systematic lithological variations within any of these units with respect to the unexposed ground between Druim Fearna and Kinlocheil. Similarly, the Kinlocheil Cross-Bedded Quartzites maintain their dominantly quartzitic character throughout their mapped extent S. of Loch Eil. There is not, therefore, any indication that lateral facies variations are responsible for the observed dispostion of lithostratigraphic units.

(ii) There are no traces of the large-scale soft-sediment deformation which might be expected to accompany syn-sedimentary faulting of the type which causes a rapid thinning of the Middle Dalradian Jura Quartzite (Anderton 1979), and this mechanism is therefore also rejected as a possible explanation for the rapid disappearance of the Kinlocheil Cross-Bedded Quartzites.

(b) Kinlocheil slide. Between the N shore of Loch Eil and the southern slopes of Na h-Uamachan (NM 950830) the slide is marked by the junction of the Basal Psammite on the W, and the Kinlocheil Banded Quartzite on the E. The existence of the slide is suggested by an appreciation of stratigraphic relationships S. of Loch Eil. On the SW slopes of Druim Fearna the Kinlocheil Banded Quartzite overlies the Kinlocheil Cross-Bedded Quartzite and the Druim Fearna Semi-Pelite: these two units have a total thickness of approximately 1450 metres, all of which is absent N. of Loch Eil. The total disappearance of this succession within 1.5 kilometres is too rapid to be attributed to any sedimentological process, and is most likely to be tectonic in origin. Accordingly it is suggested that the contact between the Basal Psammite and the Kinlocheil Banded Quartzite N of Loch Eil represents a tectonic break.

This contact is well-exposed on crags at Cala na Creige, 1.5 kilometres N of the W end of Loch Eil, and a generalised vertical section across the contact is depicted in Fig. 10a. There is little evidence of any progressive increase in strain as the contact is approached. However, the presence of localised 'flaggy' zones marked by the sharp differentiation of psammitic and pelitic stripes on a scale of 1-2 centimetres suggests that shear strains may have been preferentially concentrated along semi-pelitic bands, resulting in the mechanical metamorphic differentiation of micaceous and quartzo-feldspathic components (cf. Piasecki 1980, p.52). The occurrence of these flaggy zones in the Basal Psammite is restricted to its outcrop N of Loch Eil, within 15 metres of the contact with the Kinlocheil Banded Quartzite, and it therefore seems reasonable to relate these to the presence of a tectonic break along this contact.

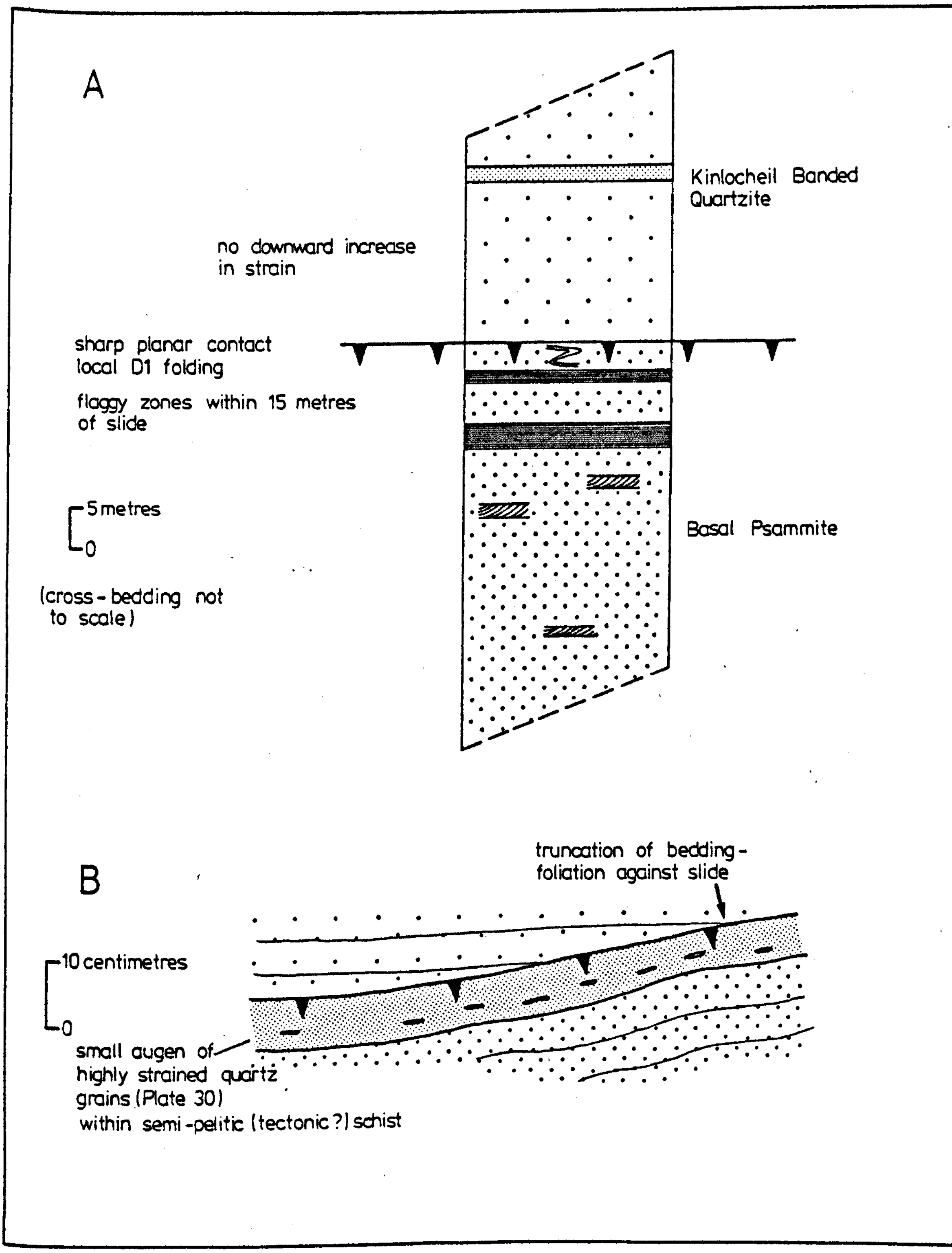


Figure 10: Features associated with the Kinlocheil slide.

Plate 30: Strained quartz plate within a muscovite-quartz semi-pelitic (tectonic?) schist adjacent to the Kinlocheil slide (Cala na Creige, NM 962804).

Scale bar represents 1mm.

Bedding is locally truncated along the contact (Fig. 10b), which may also be marked by the occurrence of a muscovite-quartz semi-pelitic (tectonic?) schist which commonly contains small augen of highly-strained quartz grains (Fig. 10b, Plate 30).

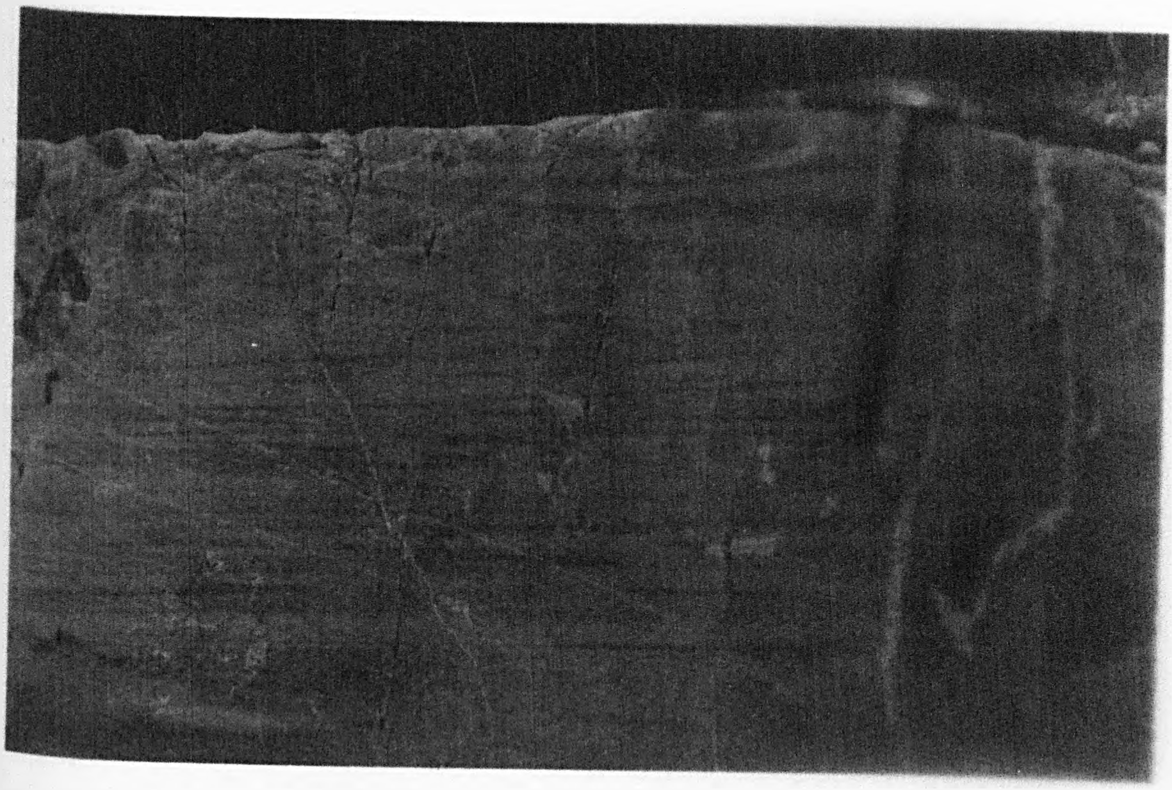
It is also possible to demonstrate a concentration of shear strain in the vicinity of the contact elsewhere. Highly deformed Kinlocheil Banded Quartzite may be examined at a roadside locality adjacent to the A830 road at Kinlocheil (NM 970793). The locality is approximately 50 metres long, and the foliation within the quartzite dips gently to the E at 3^{o}-7^{o}. There are two features worthy of note:

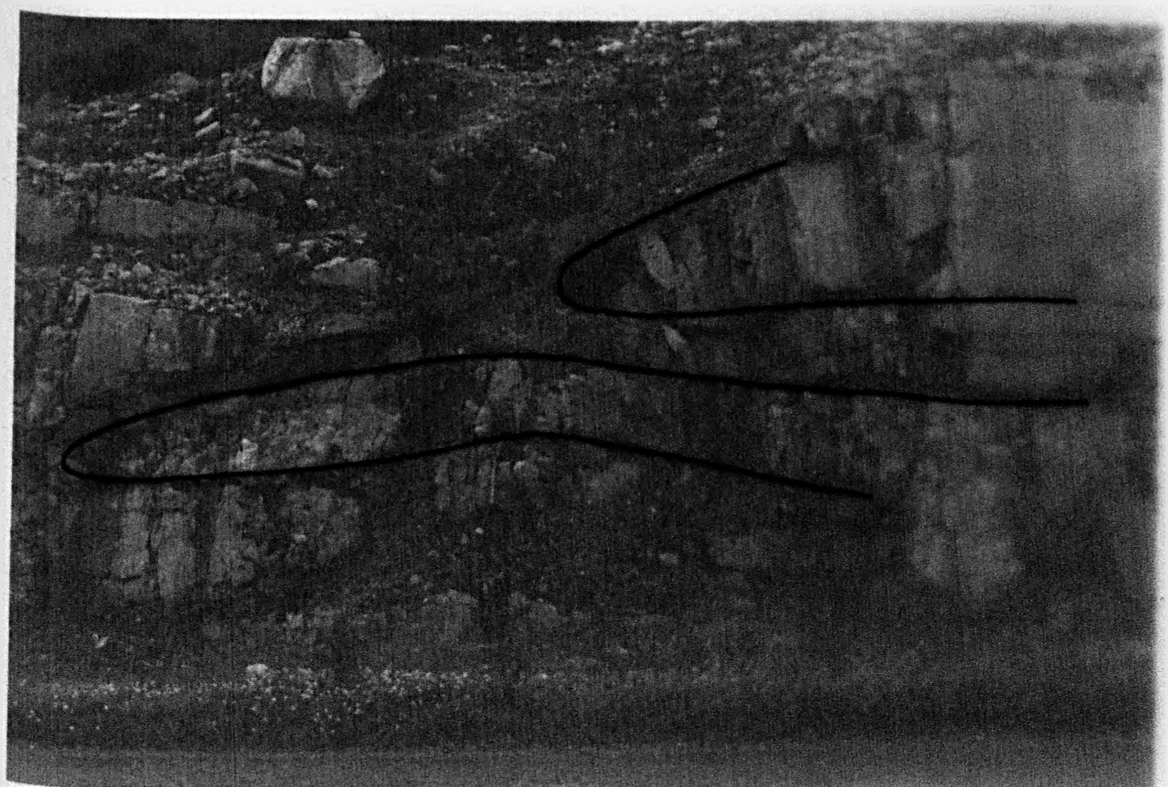
(i) At the W end of the locality the lithological banding within the quartzites takes the form of discontinuous streaks (Plate 31). This may be contrasted with the more normal appearance of the Banded Quartzite (Plate 5) as exposed at the E end of the locality. Although much detail in the mid-portion of the locality is obscured by folding and 'late' granitic sheets, it is possible to demonstrate that the banding in the quartzites becomes progressively thinned and discontinuous in a westerly direction. This is interpreted in terms of increase in shearing and consequent attenuation of lithological banding as the contact with the underlying Basal Psammite is approached. Considerable post-tectonic annealing appears to have obliterated any signs of deformation in thin-section.

(ii) D1 folds at the locality are symmetrical and isoclinal in style with highly attenuated limbs (Plate 32). Two folds may be identified, both of which close to the west; the complementary eastward-closing structure is not visible, even though the eastward limit of exposure is not encountered for 25 metres. Given that the

Plate 31: Highly attenuated lithological banding within the Kinlocheil Banded Quartzite, adjacent to the Kinlocheil slide. (NM 970793).

Plate 32: D1 isoclinal folds adjacent to the Kinlocheil slide. (Kinlocheil Banded Quartzite, NM 970793).





majority of D1 folds are asymmetric and close in style (e.g. Plate 25), the nature of the folding at this locality may be taken to indicate an abnormally high degree of strain.

(e) Na h-Uamachan-Gulvain slide zone. This is formed of an anastomosing series of slides which includes the presumed northward extensions of the Glas Bheinn and Kinlocheil slides. A detailed map of the area is presented in Enclosure 5. The existence of the slide zone depends essentially upon an appreciation of stratigraphic relationships. The sequence

Glen Garvan Psammite

Kinlocheil Banded Quartzite

Basal Psammite

Druim Na Saille Pelite

which has been identified between the N shore of Loch Eil and the southern slopes of Na h-Uamachan, is also present in the extreme N of the area on Gulvain. The geology of the intervening area is more complex and the following features are important:

(i) A lenticular unit of psammitic gneiss in association with thin bands of semi-pelitic gneiss crops out to the NW of the Kinlocheil Banded Quartzite on Na h-Uamachan. These gneisses are lithologically and structurally identical to the nearby Gulvain Psammitic Gneiss of the Glenfinnan Division, and bear no resemblence to any rocks assigned to the Loch Eil Division in the area. These gneisses are therefore allocated to the Glenfinnan Division and tentatively correlated with the Gulvain Psammitic Gneiss.

(ii) The Basal Psammite progressively thins northeastwards on Na.h-Uamachan and is absent for a distance of 1.5 kilometres along strike NE of (NM 964867). It reappears on the eastern slopes of Na-h-Uamachan & is well-exposed in the Allt a Choire Reidh. On the W slopes of Gulvain the Basal Psammite thins again and is absent for 700 metres along strike, reappearing in the extreme N of the area.

(iii) On Na-h-Uamachan a lenticular unit of banded quartzite is in direct contact with the Druim Na Saille Pelite on its NW margin; along its SE margin it is in contact with both Basal Psammite and psammitic gneiss. The banded quartzite attains a maximum thickness of 400 metres and thins rapidly to the NE and SW. A smaller body of banded quartzite underlies the Druim Na Saille Pelite on the W slopes of Gulvain. These banded quartzites are lithologically identical to the Kinlocheil Banded Quartzite, and are distinguishable from Glenfinnan Division quartzites which are locally developed within the Gulvain Psammitic Gneiss but lack the distinctive banding of the Kinlocheil Banded Quartzite. It is therefore suggested that the two lenticular units of banded quartzite should be assigned to the Loch Eil Division and tentatively correlated with the Kinlocheil Banded Quartzite.

(iv) The main unit of Kinlocheil Banded Quartzite is approximately 200 metres thick in the Allt a Choire Reidh and progressively thins northeastwards until it is only 40 metres thick on the west slopes of Gulvain.

In summary, the geology of the Na h-Uamachan-Gulvain area therefore appears to involve the thinning, excission and repetition of stratigraphic units. This is suggestive of the existence of a series of tectonic breaks localised at lithological boundaries (Fig. 8). Close examination of these contacts shows that they display many of the features already described from the Glas Bheinn and Kinlocheil slides. All contacts are sharp and planar (Plate 33) and frequently display features indicative of the localisation of shear strains (Fig. 11). The sharp nature of these contacts may be contrasted with the gradational contacts which link the Kinlocheil Banded Quartzite and Glen Garvan Psammite of the Loch Eil Division, and the Druim Na Saille Pelite and Gulvain Psammitic Gneiss of the Glenfinnan Division. Both are gradational over several metres and are inferred to represent original conformable sedimentary junctions. Although there is never seen to be any discordance of foliation across any of the tectonic contacts in the area, the NW margin of the banded quartzite on Na h-Uamachan clearly transgresses the stratigraphy of the Glenfinnan Division. The tectonic contacts may be locally marked by thin amphibolite bands (e.g. NM 980843), and biotite schists which may be analagous to tectonically-formed biotites recorded from Moine-Lewisian contacts in the Fannich area. (Winchester 1970).

The tectonic breaks which have been described from the Loch Eil area share the following features:

(i) They are localised at lithological boundaries, and are sharp planar contacts.

(ii) They are associated with features consistent with ductile deformation, such as attenuation of banding, and would appear to be syn-metamorphic breaks.

Plate 33: Sharp planar tectonic contact between the Kinlocheil Banded Quartzite and pelitic gneiss (NM 962835).

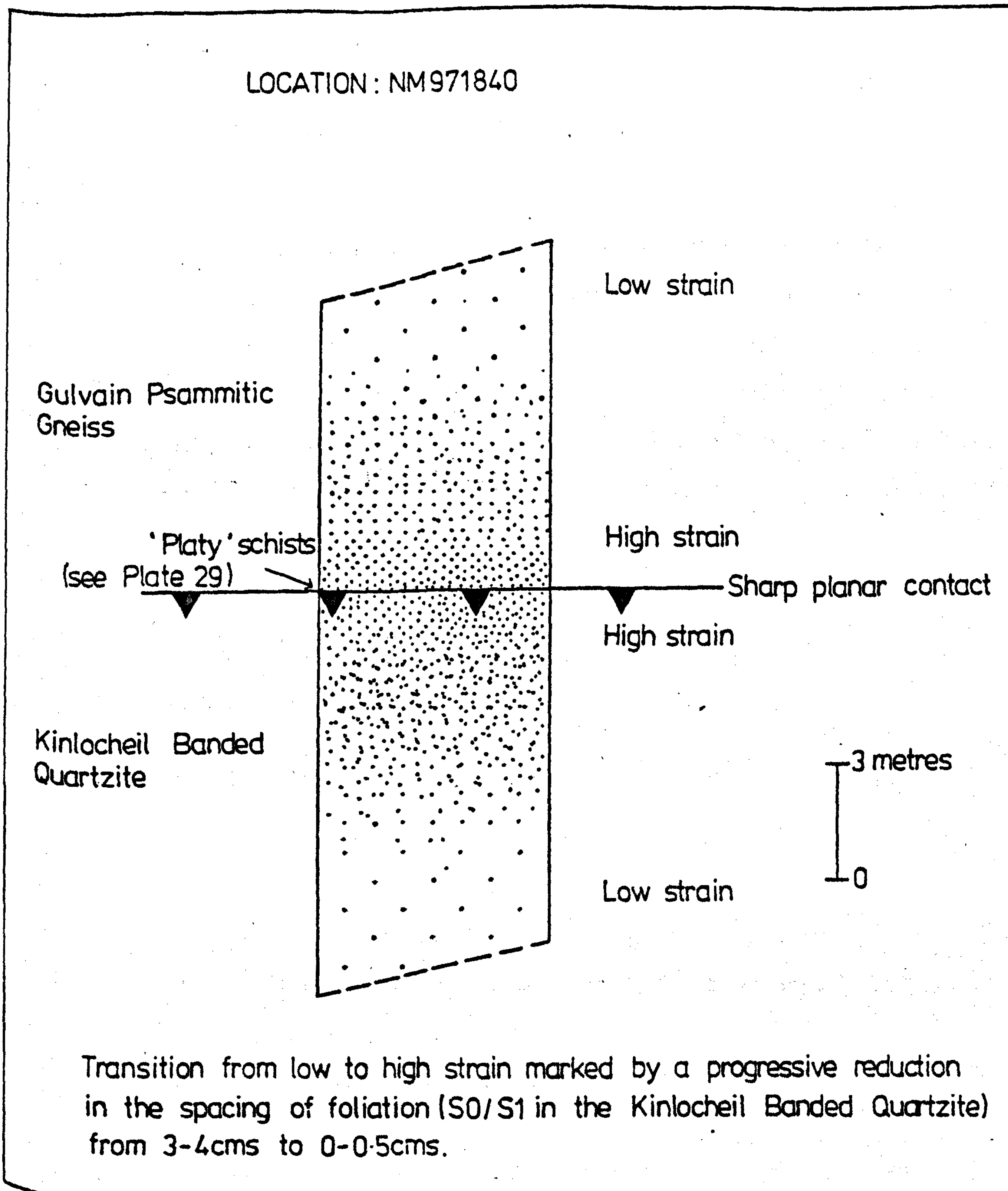


Figure 11: Features associated with a tectonic slide on Na h-Uamachan

They therefore share several of the features associated with <u>tectonic slides</u>, defined by Hutton (1981) as:

"..... faults which form in metamorphic rocks prior to, or during, a metamorphic event. They occur within zones of coeval penetrative (i.e. microscopic) deformation that represent an intensification of a more widespread, often regionally developed deformation phase. Within this zone of high strain slides may lie along, and be sub-parallel to (although they will cross-cut on a larger scale) the boundaries of lithological, tectonic and tectono-metamorphic units".

and this justifies their description as such.

The following observations are relevant in a consideration of the age of the slides:

(i) They are folded by D2 major folds in Glen Fionne Lighe and Glen Dubh Lighe, and by D2 minor folds on Na h-Uamachan (Enclosure 5).

(ii) Where Loch Eil Division rocks are affected by ductile deformation associated with the slides, this is manifest in an intensification of the S0/S1 foliation.

(iii) Slides may be locally marked by an intensification of D1 folding.

These observations suggest that the slides are D1 in age and that movement along them was broadly contemporaneous with D1 folding.

4.2.1.3. Dl strain variation

It has been demonstrated on a qualitative basis that the level of Dl strain increases in the immediate vicinity of tectonic slides. However, these are restricted to the extreme W of the area, and it is clearly desirable to attempt to quantify the levels of Dl strain over the area as a whole. It might then be possible to, firstly, assess whether Dl strain was homogeneous or heterogeneous on a regional scale, and secondly, to compare Dl strains with those characteristic of subsequent deformational episodes. Dl strain has been quantitatively analysed by means of the analysis of fold style:

(a) Method: fold style may be analysed using the techniques described by Ramsay (op cit) and Hudleston (1973). Two of the most useful ways of describing the geometry of folded layers are by the study of dip isogons, and the use of thickness parameters. Tracings of folds were obtained from field photographs and dip isogons were constructed on the folds at 10^{0} intervals. The patterns of the isogons enabled a preliminary classification of the folds into one, or combinations of, classes 1A, 1B, 1C, 2 or 3 (Ramsay, op cit, Fig. 7.24). Orthogonal thicknesses (t_α) of folded layers were measured between tangents to the bounding surfaces of the particular layers at apparent dips (α). The parameter $\emptyset$ was also measured and is defined as the angle between an isogon and the normal to the parallel tangents of the folded surfaces of a layer. The parameters t_α and $\emptyset$ are diagramatically defined in Fig. 13a. A further parameter, t'_α, is defined as the orthogonal thickness at dip α divided by the thickness at the fold hinge. Ramsay's fold classes occupy specific fields or lines on graphs of t'_α against α (Fig. 12a) and $\emptyset$ against α (Fig. 12b).

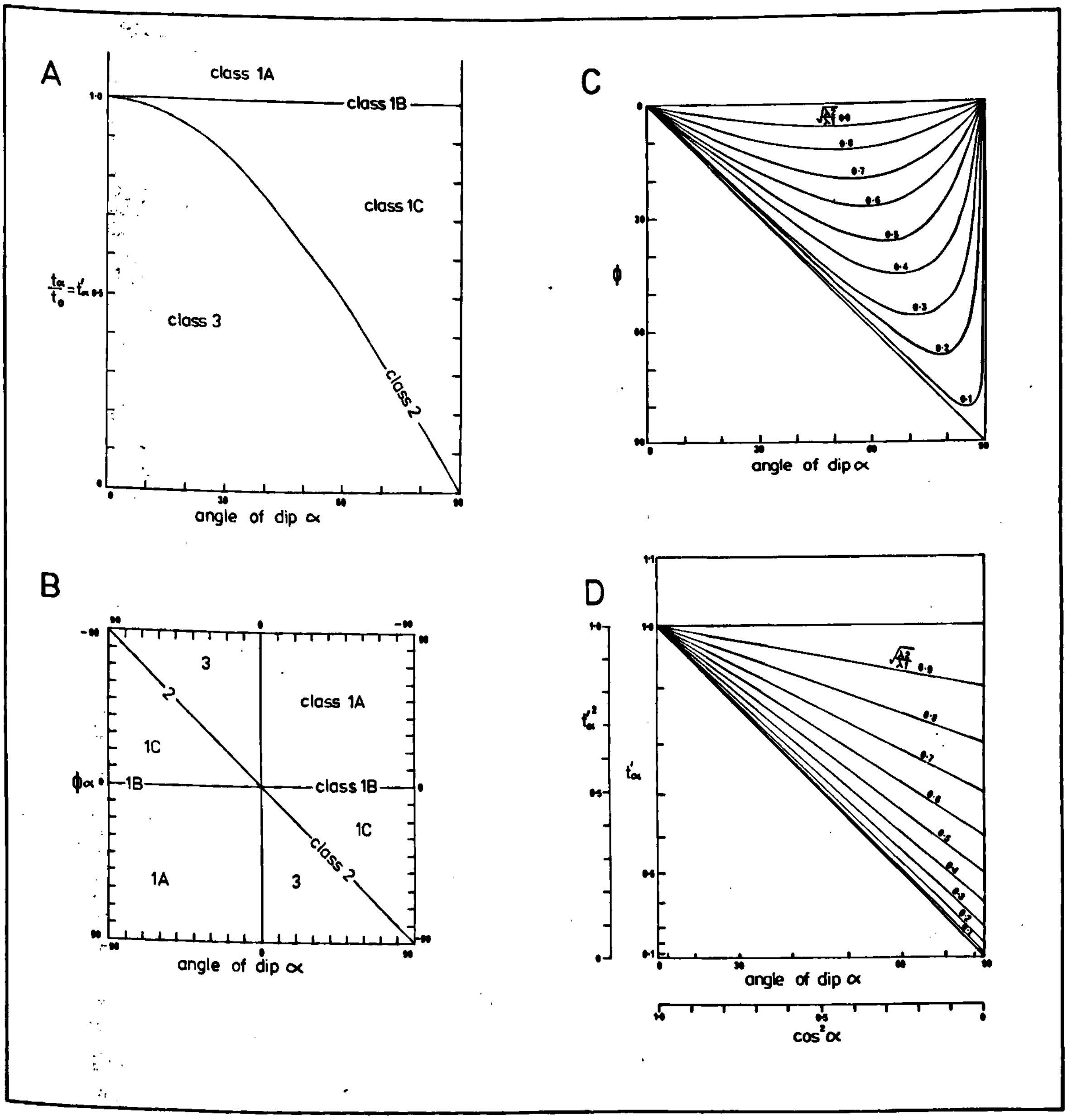


Figure 12: Positions of the fold classes of Ramsay (1967), in the analysis of fold styles, with curves for the various values of flattening in terms of the quadratic elongation λ_2 and $\lambda_1 = \sqrt{\lambda_2 / \lambda_1}$.

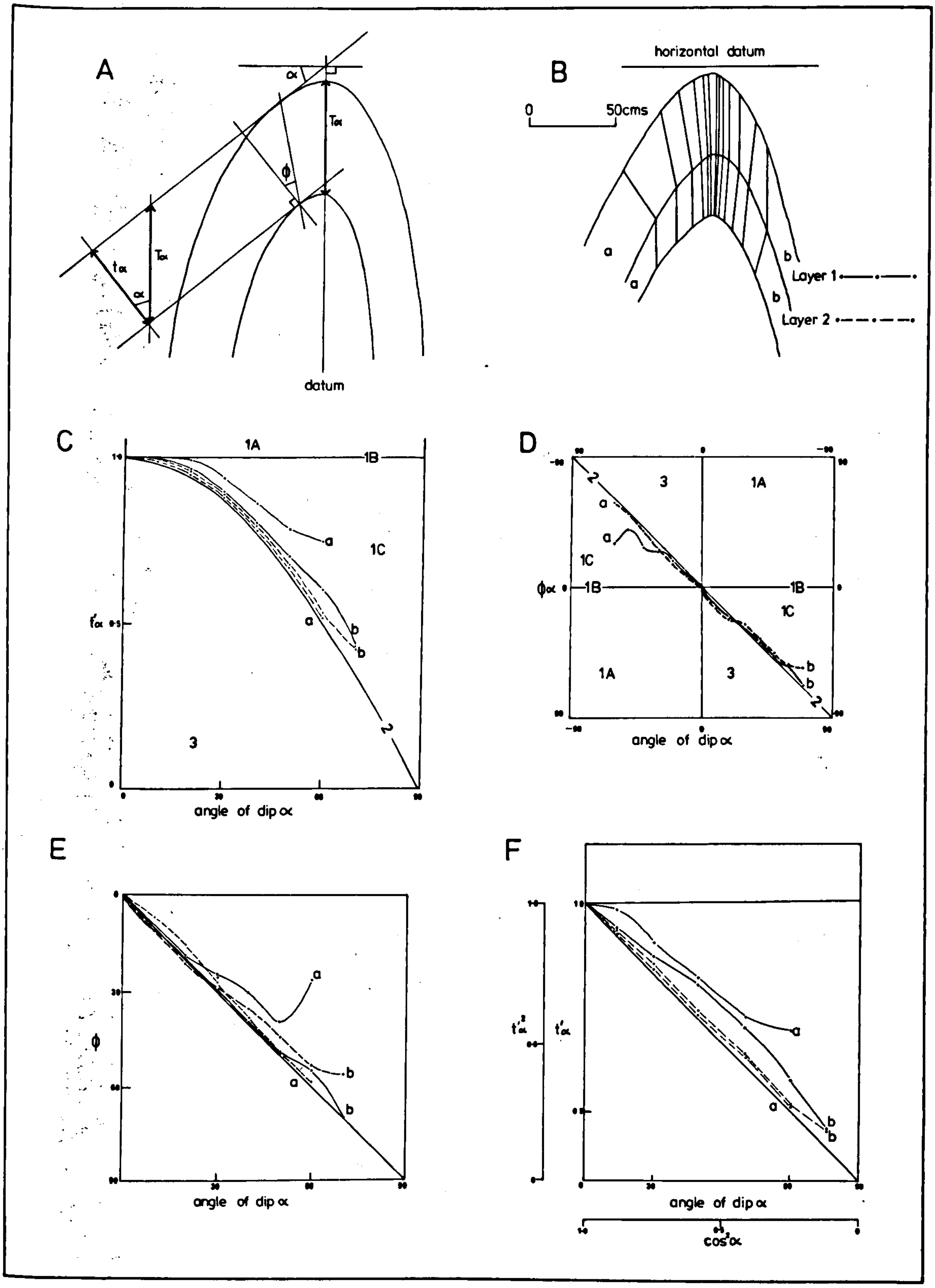


Figure 13: Definition of parameters, and analysis of specimen fold.

Fig. 13b illustrates a specimen fold on which dip isogons have been constructed, and Figs 13c and 13d represent the data derived from the specimen fold which appears to be almost entirely of class 1C. Folds which possess class 1C geometry are assumed to represent initially class 1B 'parallel' folds which have been modified by a superposed finite homogeneous strain (referred to here loosely as a 'flattening'). Provided that the fold axis is a principal direction of strain it is possible to determine the amount of flattening strain by plotting $\emptyset$ against α (Fig.12c) and $t'^2\alpha$ against $\cos^2\alpha$ (Fig.12d). The flattening strains, $\sqrt{\lambda_2/\lambda_1}$ are expressed as an apparent strain ratio, R, which ranges from 0 to 1.0. Figs. 13e and 13f represent the flattening strains involved in the formation of the specimen fold.

(b) <u>Results</u>. A total of 15 folds, comprising 36 individual layers were analysed using the techniques outlined above. The results of the analysis are presented in Table 8 and Fig. 14 . Dip isogons drawn on the folds were, in most cases, only slightly divergent and concentrated in the hinge zones. A preliminary classification of fold class solely on the basis of isogon patterns indicates that most folds are class 1C, closely approximating to class 2. This is confirmed when parameters $t'\alpha$ and $\emptyset$ are measured and plotted against α . There is, in general, a good correspondence between the fold classes obtained from these contrasting plots. Very few folds fall solely into one class on either plot and most are combinations of classes 1C and 2, or 1C, 2 and 3. One fold, layer (b) of fold 8, displays a complete range in fold class. Where the $t'\alpha/\alpha$ and $\emptyset/\alpha$ plots are not in complete agreement as to the fold class of a particular layer, an 'overall' class has been derived based on these plots and a re-examination of isogon patterns.

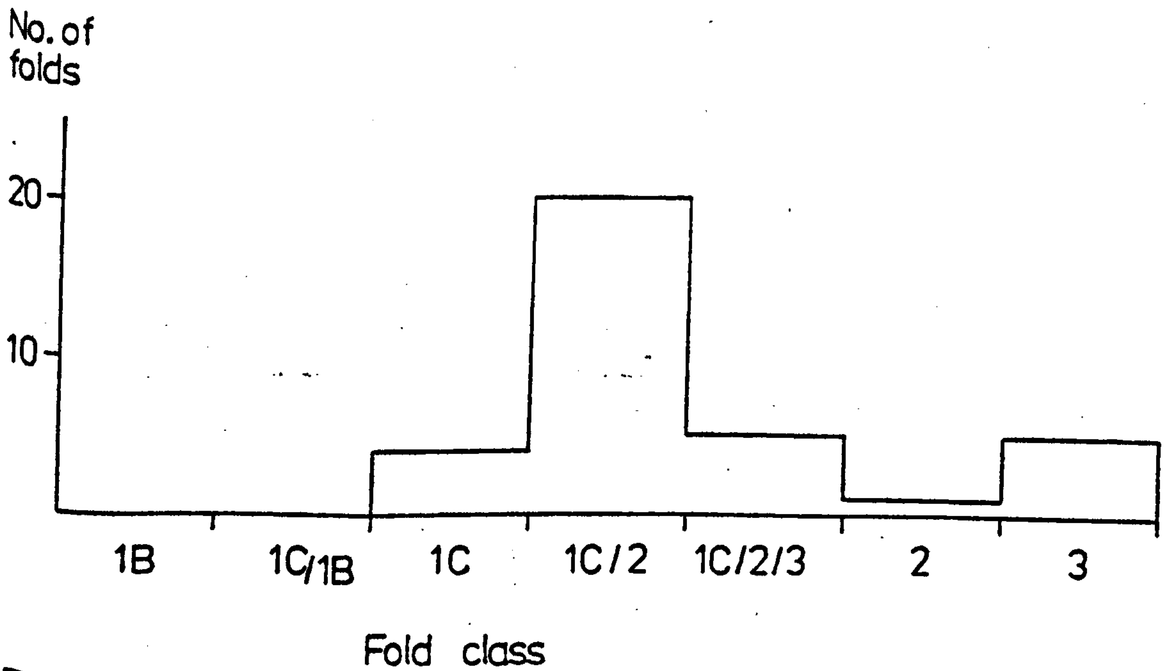
Table 3: D1 fold profile analyses

Fold number	Location and stratigraphic position	Lithology	Fold class from t'_α v. α	Fold class from ϕ v α	'Flattening' strain ratios, $\sqrt{\lambda 2/\lambda 1}$ from t'^2_α v. $\cos^2\alpha$, and ϕ v. α.
1	NN 046784 Cona Glen Psammite	(a) Ps (b) Sp (c) Ps	1C 3 1C-2	1C-2 3 1C-2	0.2 - 0.2
2	NM 98357885 Glen Garvan Psammite	(a) Ps (b) Sp (c) Ps	1C 1C-2-3 1C-2	1C-2 1C-2-3 1C-2	0.2 0.2 0.3
3	NN 046784 Cona Glen Psammite	Ps	1C-2	1C-2	0.1
4	NN 07557755 Cona Glen Psammite	(a) Ps (b) Ps (c) Ps	2 1C 1C-2	2 1C-2 1C-2	- 0.1 0.2
5	NN 083824 Druim Fada Quartzite	(a) Sp (b) Ps	3 1C-2-3	3 1C	- 0.4
6	NN 083824 Druim Fada Quartzite	(a) Q (b) Ps	1C-2 1C-2-3	1C-2-3 1C-2-3	0.4 0.3
7	NN 081825 Druim Fada Quartzite	(a) Q (b) Ps	1C-2 1C	1C-2 1C-2	0.1 0.1
8	NN 081830 Glen Garvan Psammite	(a) Q (b) Pe (c) Ps	1C-2 1A-1B-1C-2 1C	1C-2-3 1A-1B-1C-2-3 1C	0.3 - 0.4
9	NN 081830 Glen Garvan Psammite	(a) Ps (b) Pe (c) Sp	1C-2 3 1C-2-3	1C-2 3 1C-2-3	0.2 - 0.2
10	NN 070821 Druim Fada Quartzite	(a) Ps (b) Ps	1C-2 1C	1C 1C	0.4 0.3
11	NN 083846 Glen Garvan Psammite	(a) Pe (b) Ps	1C-2-3 1C	1C-2-3 1C-2	0.2 0.3
12	NN 018834 Glen Suileag Banded Psammite	(a) Q (b) Ps (c) Ps	1C-2 1C 1C	1C-2 1C 1C-2	0.2 0.4 0.3
13	NN 008822 Glen Garvan Psammite	(a) Sp (b) Ps	3 1C	2-3 1C-2	- 0.1
14	NM 961745 Glen Garvan Psammite	(a) Ps (b) Ps	1C-2 1C	1C-2-3 1C	0.1 0.5
15	NM 985798 Glen Garvan Psammite	(a) Q (b) Sp (c) Q	1C 3 1C-2	1C-2 3 1C-2	0.2 - 0.3

Key to lithologies: Q - Quartzite. Ps - Psammite. Sp - Semi-Pelite. Pe - Pelite.

A

Fold classes of individual layers



B

Flattening strains for folds which carry a large component of class 1C

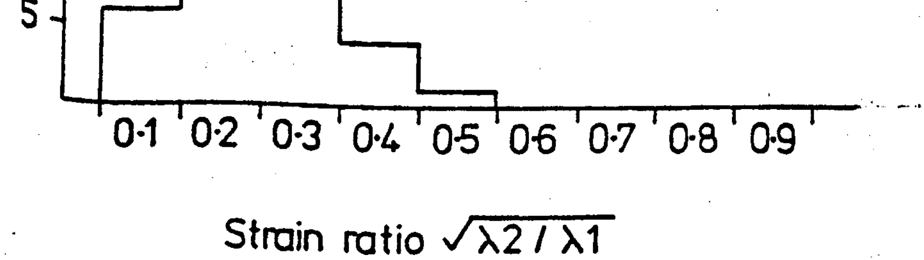


Figure 14: Results of D1 fold profile analysis.

Each individual layer is therefore assigned a class, and this information has been summarised in histogram form in Fig.14a 20 of the layers have been classified as combinations of classes 1C and 2; a further 5 plot predominantly in the class 1C field, but deviate at intervals to cross the class 2 line into the class 3 field. A total of 29 of the layers are therefore either wholly class 1C or have a strong component of class 1C. Strain ratios from these class 1C folds have been calculated and are presented in histogram form in Fig. 14b. 23 of the layers have undergone a minimum of 70% flattening. Flattening values were not obtained from layer (b) of fold 8 which is abberrant; the variable form displayed by this layer is attributed either to heterogeneous shear parallel to the axial surface, or to tangential longitudinal strain, leading to abnormal thickening.

Layer composition has clearly affected the fold class of individual layers. Where high competency contrasts exist between layers the folds conform to the predictions of Ramberg (1963, 1964), the more competent layers taking up a class 1 form and the incompetent layers a class 3 form. The geometry of folds 1, 5, 9, 13 and 15 is thus easily explicable by this process: in each case pelitic or semi-pelitic layers are in direct contact with more competent quartzitic or psammitic layers. The remainder and majority of folds are developed in wholly quartzitic or psammitic lithologies, and these are generally characterized by class 1C or 1C and 2 geometry. These folds might be expected to have comparatively low viscosity contrasts between individual layers, and could therefore have been developed by a simultaneous process of buckling and flattening (Hudleston op cit). A substantial amount of layer parallel shortening may have preceded buckling.

(c) Interpretation. The comparatively uniform nature of the lithologies in the study area suggests that variations in fold style may be used as an approximate indicator of variations in finite strain. The folds analysed are widely distributed throughout the area north of Loch Eil, although only one example has been analysed from the area south of Loch Eil. The foregoing fold analysis indicates that the level of D1 finite strain is relatively uniform across the area. A probable combination of layer-parallel shortening and buckling produced a series of folds, most of which have a strong component of class 1C geometry and underwent at least 70% flattening during their formation.

.2.1.4. A model for the development of D1 structures

(a) Recumbent folds. Major recumbent fold nappes analagous to those which dominate higher tectonic levels of the orogen, E of the Great Glen, have not yet been identified from the NW Highlands (Harris and Rathbone 1979), and the present study provides no evidence of any major D1 fold structure within the Loch Eil Division. It seems likely that at the deeper tectonic levels represented by the Moine (sensu stricto) recumbent folds of the type which developed within the Loch Eil Division during D1 formed in response to large-scale simple shear operating at relatively low angles to sedimentary layering (Fig. 15, adapted from Rhodes and Gayer, 1977).

(b) Tectonic slides. At the base of the Loch Eil Division D1 shortening was accommodated by a series of syn-metamorphic dislocations (tectonic slides) which were broadly contemporaneous with D1 folding (p. 64). The sense of overturning of D1 folds in the western part of the Loch Eil Division suggests that movement along these slides was from E to W.

The structurally lowest slide, the Glas Bheinn slide, is interpreted to be the result of relatively local displacement between the Druim Na Saille Pelite and the Basal Psammite. Overthrust translation of the rocks of the Loch Eil Division along the slide was preceded and accompanied by ductile shearing of the pelitic gneisses underlying the slide, giving rise to the features described earlier (p.61). It is important to emphasise that the scale of the deformation associated with the slide suggests that the amount of differential movement across it has been relatively small, and it is therefore unlikely to constitute a major tectonic dislocation analagous to, for instance, the Sgurr Beag Slide which separates the Morar and Glenfinnan Divisions of the Moine Succession (Rathbone 1980; Powell et al. 1981).

The geometry of the Kinlocheil slide is more complex: during westerly-directed sliding within an upward-facing succession, 'younger' rocks have been thrust over 'older' with consequent removal of the intervening stratigraphic units. To account for this apparent contradiction to the 'normal' rules of thrust belt geometry, it is necessary for the slide to have cut across strata which were inclined at an angle greater than that of the slide. Evidence that inclination of the bedding-foliation occurred before the formation of the Kinlocheil slide is forthcoming from a study of cross-sections drawn across Druim Fearna (Fig. 16a) and Glen Fionne Lighe (Fig. 16b). S. of Loch Eil the bedding-foliation is gently-inclined to the SE in the W. of the cross-section, and rapidly steepens into the vertical plane on Druim Fearna, levelling out again in the E of the section near Garvan. This section reveals the presence of a 1700-metre wide 'steep belt' which extends from the northern slopes of Druim Fearna southwards to Cona

Glen. This feature disappears abruptly N of Druim Fearna since the bedding-foliation immediately N of Loch Eil is sub-horizontal or gently-inclined to the E (Fig. 16b). There is no indication that this feature is directly related to any D2 and D3 major fold, and the style, orientation and intensity of D2 and D3 minor folds within the steep belt are identical with those of adjoining areas. The sudden disappearance of the steep belt N of Loch Eil suggests that the feature existed before sliding and constituted a localised steep belt formed within broadly sub-horizontal rocks. Diagrammatic sections (Fig. 16c and 16d) drawn W-E along Loch Eil present a model for the formation of the Kinlocheil slide, given that the steep belt was probably inclined at 30^{o}-40^{o} prior to further steepening during D2 and D3.

There would appear to be three alternatives with respect to the origin of the steep belt (Fig. 17):

(i) It formed before D1 as a result of extensional tectonics within underlying Moine (and Lewisian?) rocks (Fig. 17a), in a similar manner to that described by Litherland (1982) with reference to Dalradian rocks of the Loch Creran area. This alternative seems unlikely however, since S0 and S1 are subparallel in both the steep belt and adjacent flat belts, which indicates that the former was initiated after the formation of S1.

(ii) The steep belt originated during D1 as a simple monoclinal fold (Fig. 17b): this is hardly compatible, however, with the nature and level of D1 strains.

(iii) The steep belt constitutes part of a fold culmination to a major ramp structure situated at a deeper structural level within underlying rocks (Fig. 17c). This seems to be the most feasible

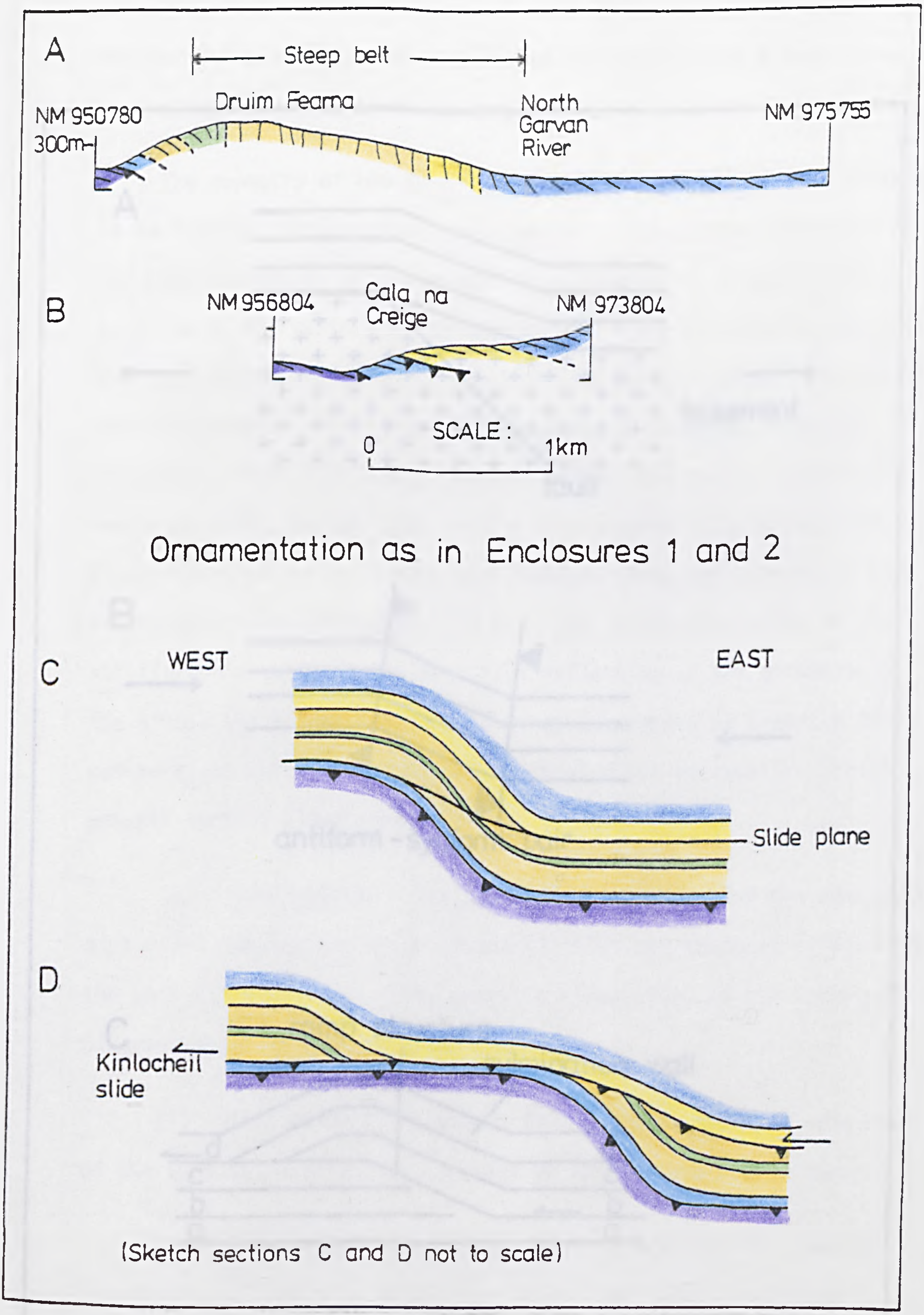


Figure 16: Cross-sections A and B illustrate the structure of the areas immediately to the S and N of Loch Eil. Diagrammatic sections C and D illustrate a model for the formation of the Kinlocheil slide.

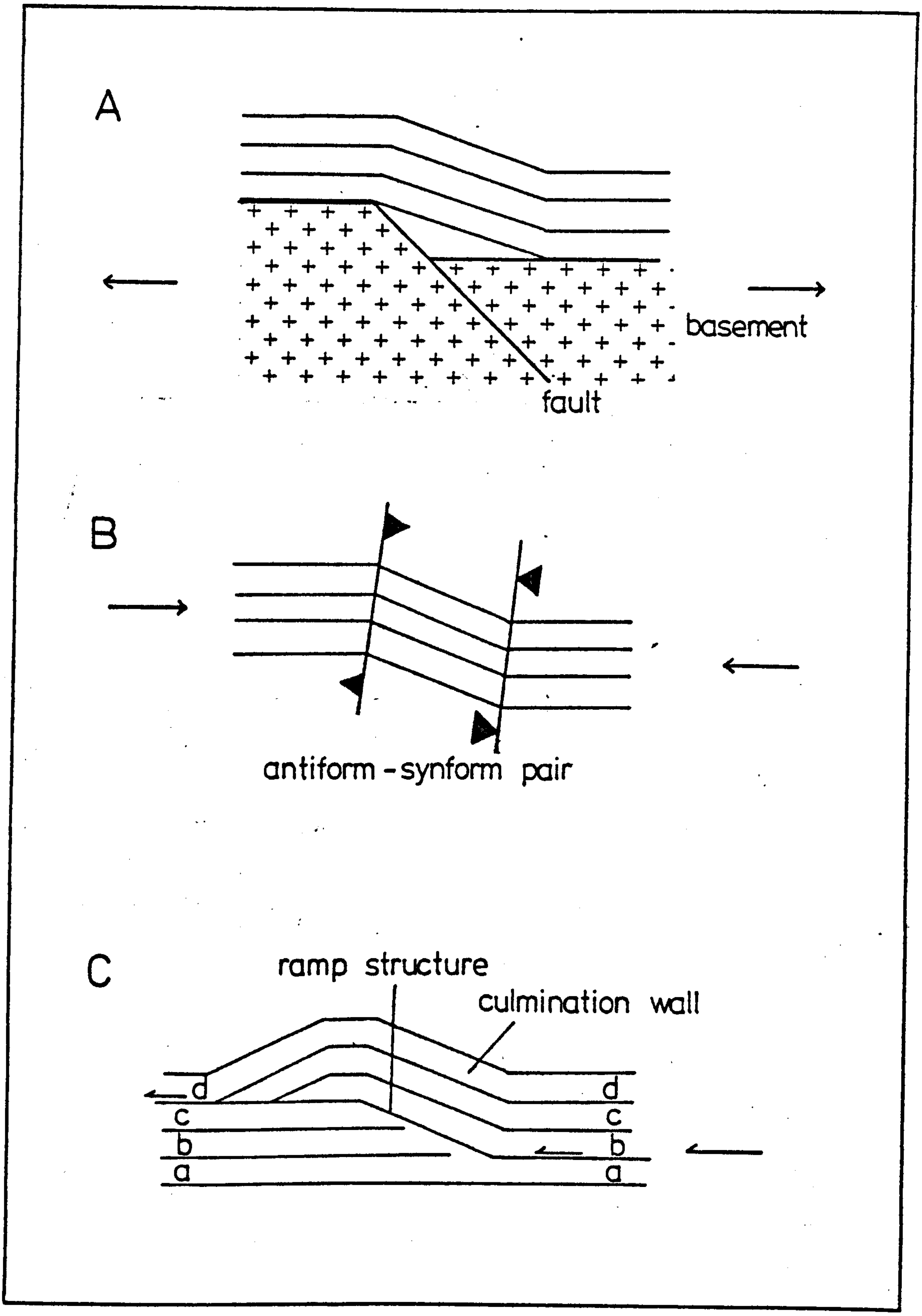


Figure 17: Alternative models for the formation of the steep belt

explanation available and is entirely consistent with a structural regime involving recumbent folding and tectonic sliding.

The geometry of the Na-h-Uamachan-Gulvain slide zone is inferred to be broadly similar, but more complex. The present inversion of the stratigraphy on Na-h-Uamachan is related to D2 folding, and prior to D2 the various slide-bounded units are presumed to have been sub-horizontal or gently-inclined to the E as on Gulvain and at Cala na Creige. It is therefore apparent that during repeated thrusting within this zone, 'younger' rocks were thrust over 'older' and vice versa, and it seems likely that sliding in this area was also influenced by the presence of fold culminations similar to that which controlled sliding further S. The lenticular nature of the stratigraphic units in the area is a reflection of the geometry of the slides which take the form in three dimensions of a series of sub-parallel intersecting planes, each of which changes its stratigraphic horizon along strike.

(c) Conclusions. The above discussion enables the construction of a model for the evolution of the D1 folds and tectonic slides within the Loch Eil Division. This model is illustrated by the series of diagrams shown in Fig. 18 , and comprises:

(i) Initiation of recumbent folding, and sliding at the base of the Loch Eil Division as a result of large-scale simple shear.

(ii) Localised sliding within rocks underlying the Loch Eil Division N. of Loch Eil, producing fold culminations. Repeated sliding thrusts 'younger' rocks over 'older' and vice versa, interleaving rocks of the Glenfinnan and Loch Eil Divisions to give rise to the Na-h-Uamachan-Gulvain slide zone. Displacement within this zone

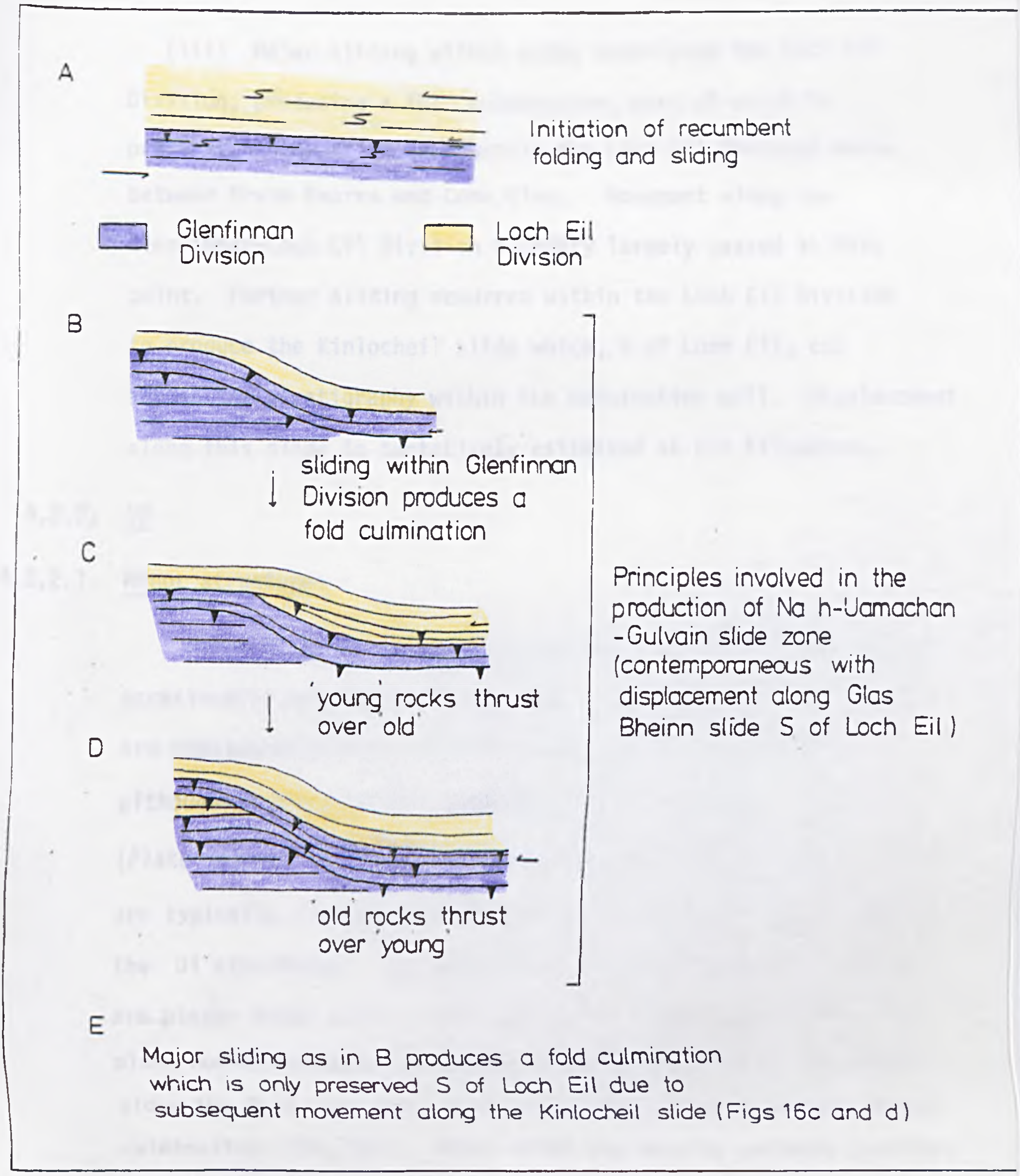


Figure 18: A sequential model for the development of tectonic slides in the Loch Eil area.

is considered to have been contemporaneous with displacement along the Glenfinnan-Loch Eil Division boundary S of Na h-Uamachan.

(iii) Major sliding within rocks underlying the Loch Eil Division, producing a fold culmination, part of which is preserved in modified form within the Loch Eil Division rocks between Druim Fearna and Cona Glen. Movement along the Glenfinnan-Loch Eil Division boundary largely ceased at this point. Further sliding occurred within the Loch Eil Division to produce the Kinlocheil slide which, N of Loch Eil, cut across the stratigraphy within the culmination wall. Displacement along this slide is tentatively estimated at 2-3 kilometres.

4.2.2. D2

4.2.2.1. Minor structures

Minor D2 folds are observed to fold both S0 and S1, and may occasionally develop an axial planar schistosity (S2). D2 folds are considerably more variable in style than D1 structures: although D2 minor folds are commonly open to close (ILA 90°-60°) (Plate 34), they locally vary from open to tight (Plate 35). They are typically asymmetric, but have noticably lower λ/A ratios than the D1 structures. The majority of D2 outcrop-scale structures are planar folds with cylindrical axes. Some, however, are non-plane non-cylindrical structures with marked reversals of plunge along the fold axes (Fig. 19a) which may generate elongate plunge culminations (Fig 19b). Other folds may display variable profiles on a small scale (Fig 19c).

Plate 34: D_2 asymmetric open fold. (Basal Psammite, NM 95658325).

Plate 35: Complex steeply-plunging D2 folds which vary in style from open to tight. (Basal Psammite, NM 930751).

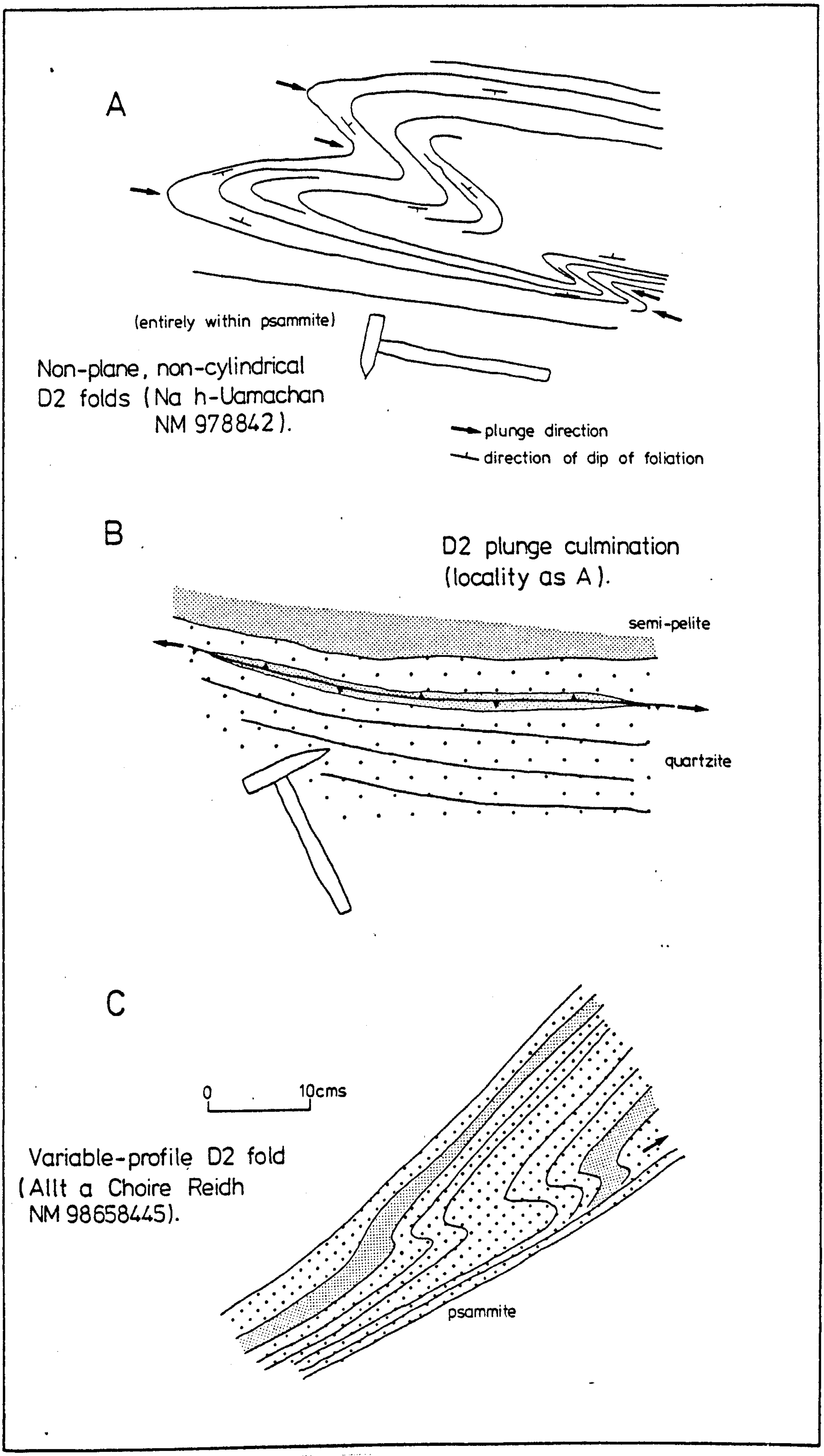

A
(entirely within psammite)
Non-plane, non-cylindrical
D2 folds (Na h-Uamachan
NM 978842).
plunge direction
direction of dip of foliation
B
D2 plunge culmination
(locality as A).
semi-pelite
quartzite
C
0
10cms
Variable-profile D2 fold
(Allt a Choire Reidh
NM 98658445).
psammite

Figure 19

Plate 36: Close D2 fold, accompanied by a strong axial planar S2 mica fabric. (Kinlocheil Banded Quartzite, NM 978842).

S2, when developed, is thoroughly penetrative in semi-pelitic and pelitic bands, where it is defined by the alignment of biotite and muscovite laths (Plate 36). S2 is not, however, developed within psammitic and quartzitic bands. The intersection of S0/S1 with S2 is defined by the alignment of quartz and feldspar aggregates, and may be measured as a linear structure parallel to the axes of minor D2 folds.

4.2.2.2. Major structures

The existence of twelve major D2 folds has been established with reference to the sense of vergence of D2 minor folds, the mapping of the S0/S1 foliation surface and 'younging' directions indicated by sedimentary structures. The distribution of these major structures is indicated in Fig. 20, and the geometry and nature of each of these folds will be discused in turn.

(a) Glen Garvan synform and Meall an Feidh antiform. It is convenient to discuss these two complementary folds together. Their presence is indicated by the mapping of the S0/S1 foliation surface, the younging directions indicated by sedimentary structures and the closure of quartzite units in the cores of the folds on Sron an-t Sluichd and Meall an Feidh. The Glen Garvan synform is an open to close structure (ILA: 120^{o}-35^{o}) with a non-plane subvertical axial surface which trends at approximately 070°. The northwestern limb of the fold dips at 30^{o}-80^{o} to the ESE, and the common limb to both structures dips at 40^{o}-70^{o} to the NW. The Meall an Feidh antiform is a uniformly close fold (ILA: 60^{o}-40^{o}). Its axial surface, which trends at approximately 085°, is subvertical in attitude in the area

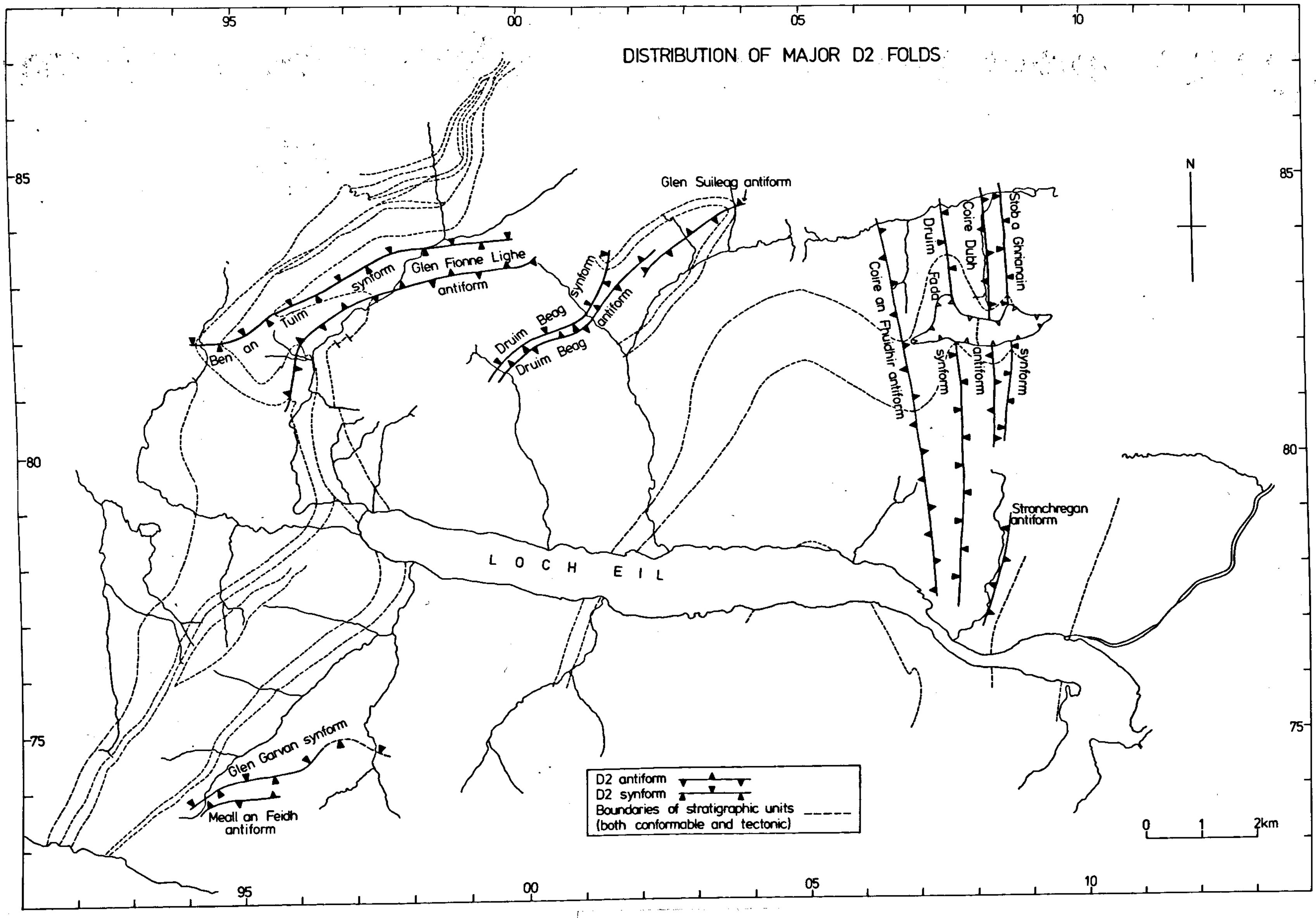
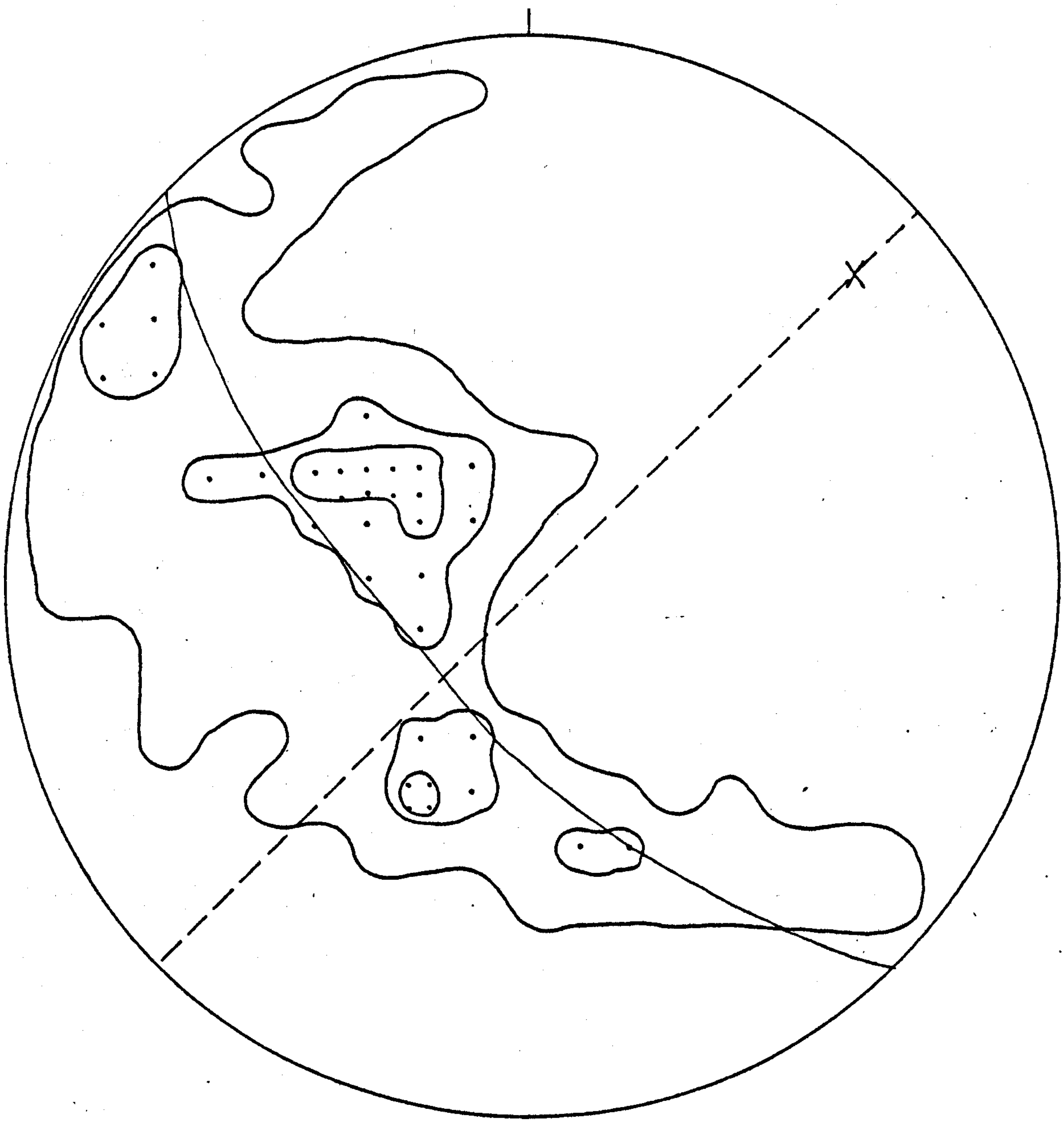

DISTRIBUTION OF MAJOR D2 FOLDS
Glen Suileag antiform
Stob a Ghriangain
Coire Dubh
Druim Fada
Coire an Fhuidhir antiform
synform
antiform
synform
Stronchregan antiform
Glen Fionne Lighe antiform
Ben an Tuim synform
Druim Beag
Druim Beag
synform
antiform
LOCH EIL
Glen Garvan synform
Meall an Feidh antiform
D2 antiform
D2 synform
Boundaries of stratigraphic units
(both conformable and tectonic)
N
0
1
2km
95
00
05
10
85
80
75

Figure 20

immediately to the E of the North Garvan River, gradually shallowing to dip at approximately 65^{o} to the N on Sron an-t Sluichd. The southern limb of the fold is subvertical in attitude on the northern slopes of Meall an Feidh, shallowing southwestwards to dip at approximately 65^{o}-70^{o} to the SE. Poles to the S0/S1 surface in sub-area 10 fall in a well-defined girdle about an average axis of D2 folding (Fig. 21). The study of this girdle suggests that D2 structures plunge at approximately 18° to the NE . Detailed consideration of the S0/S1 surface indicates, however, that the axes of both D2 major folds are markedly non-cylindrical. Their axes plunge steeply at 70^{o}-80^{o} to the NE at the head of the North Garvan River, steadily decreasing in plunge northeastwards such that both plunge gently at 10^{o}-20^{o} on Sron an-t Sluichd. This variation in axial plunge is not, however, reflected in the attitude of associated D2 minor folds, which maintain a relatively uniform plunge of approximately 35^{o} to the NE (Fig.7.10).

(b) Ben An Tuim synform. The presence of this fold is revealed primarily by the closure of stratigraphic units in its core in Glen Dubh Lighe and on the southwestern slopes of Na h-Uamachan. On the southeastern slopes of Na h-Uamachan, where the stratigraphy is in part inverted, the axial surface of the fold may be located with reference to the sense of movement of D2 minor folds. In Glen Dubh Lighe and on Na h-Uamachan the structure is a tight fold (ILA: 10^{o}-30^{o}), which progressively changes in style to the ENE into an open structure (ILA: 70^{o}-90^{o}). The axial surface of the fold is non-plane and dips at approximately 80^{o} to the N in Glen Dubh Lighe, gradually changing in attitude and orientation to dip at 40^{o}-60^{o} to the NW on Na h-Uamachan. On the western slopes of Meall Onfaidh the axial surface is subvertical in attitude and trends E-W. The



X Pole to great circle defined by poles to foliation (sub-area 10)

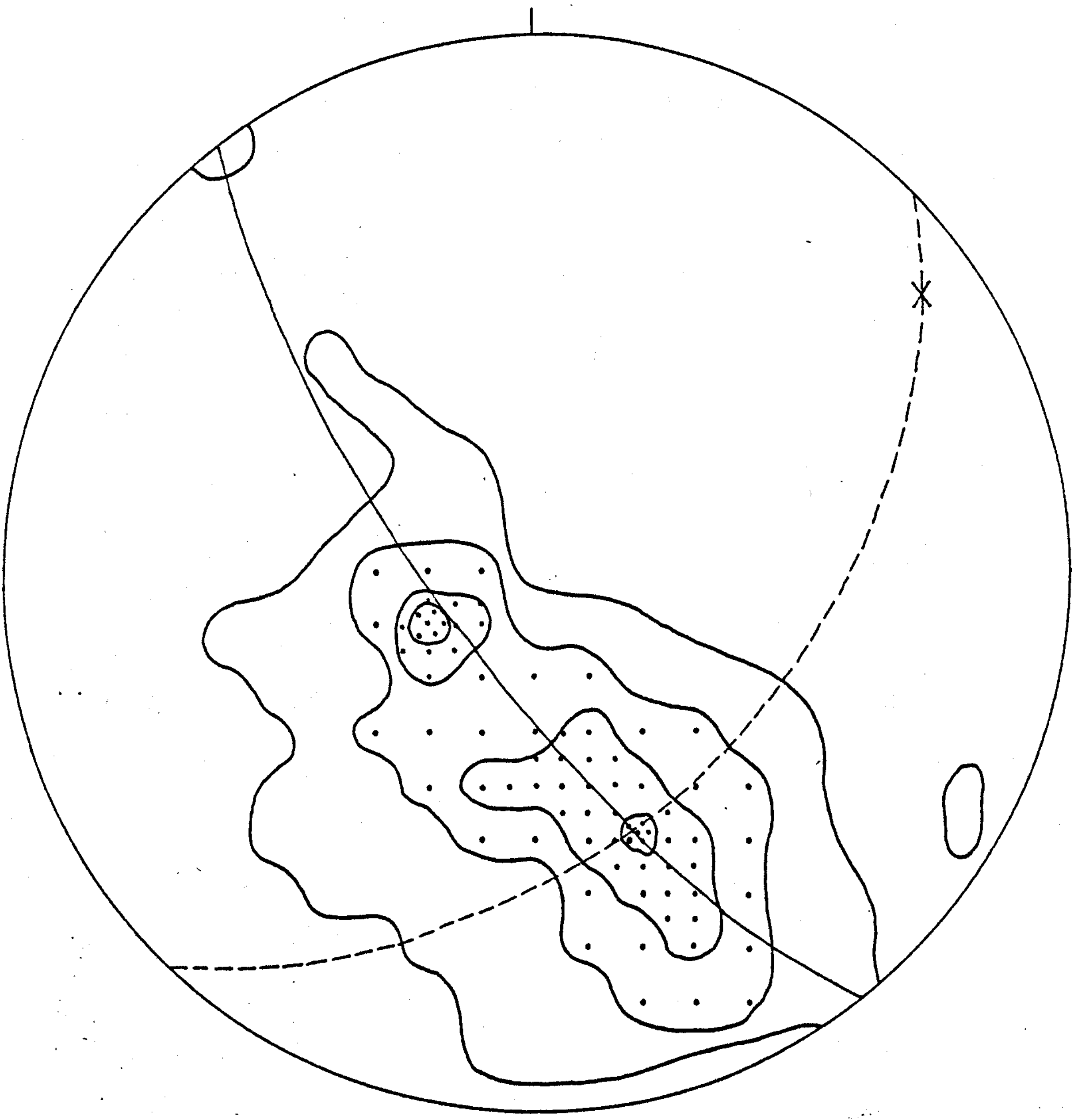
---- 'Average' axial plane of D2 major folds

Figure 21

northwestern limb of the fold is largely inverted and dips at 30^{o}-90^{o} to the NW and N; the southeastern limb has a more uniform dip of 30^{o}-50^{o} towards the NW and N.

The "best-fit" girdle which may be drawn through poles to the S0/S1 surface in sub-area 2 reflects the general northeasterly plunge of the major D2 fold (Fig. 22). In Glen Dubh Lighe the fold axis plunges at approximately 35^{o} to the E, steepening to a plunge of 80^{o} to the NE on Na-h-Uamachan at (NM 95658260). Further to the NE, between the southwestern slopes of Na-h-Uamachan and Meall Onfaidh the axis is subhorizontal or plunges gently at 10^{o}-15^{o} to the NE and E. The axis of the Ben an Tuim synform therefore maintains a relatively constant direction of plunge, although its attitude varies considerably. Associated D2 folds are clearly incongruous with respect to the major structure as they plunge at 10^{o}-50^{o} both to the ENE and WSW (Fig. 7.2).

(c) <u>Glen Fionne Lighe antiform</u>. The axial surface of this fold may be accurately located by the mapping of the S0/S1 surface, and the closure of stratigraphic units in its core in Glen Fionne Lighe. There are comparatively few minor structures associated with this fold. The structure is a gentle fold (ILA: 160^{o}) at its southwestern-most extent; ILA progressively decreases northeastwards such that the fold is open in style (ILA: 80^{o}-110^{o}) in Glen Fionne Lighe, and close (ILA: 45^{o}-50^{o}) on Druim Beag. The axial surface of the fold is non-plane and sub-vertical: it trends at 015° NW of Cala na Creige,



X Pole to great circle defined by poles to foliation (sub-area 2)

---- Axial plane D2 Ben An Tuim synform

Figure 22

progressively changing in orientation northeastwards to trend at 070° on Druim Beag. The fold axis plunges at 30°-40° to the NNE near Cala na Creige and in Glen Fionne Lighe, gradually changing in attitude northeastwards such that it is subhorizontal on Druim Beag. Both limbs of the fold display a considerable range in S0/S1 dips from 10°-70°.

(d) <u>Druim Beag synform and antiform</u>. The axial surfaces of these complementary folds may be located by the mapping of the S0/S1 surface, the sense of movement of D2 minor folds on Druim Beag and the closure of the Glen Suileag Banded Psammite in the core of the Druim Beag synform on Meall Onfaidh. Both structures are open to gentle in style at both their southwestern and northeasternmost extent (ILA: 115°-142°), and vary in style from close to open (ILA: 35°-115°) in the intervening ground on Druim Beag. This variation in style coincides with a change both in the attitude and orientation of the folds' axial surfaces. To the SW of Druim Beag and on Meall Onfaidh they are steeply-inclined at 70°-80° to the NW; on the northeastern slopes of Druim Beag they are steeply-inclined at 60°-70° to SE. The axial surfaces trend at 040° to the SW of Druim Beag, gradually changing in orientation to trend at 070° on the northeastern slopes of Druim Beag. NE of the Leth Allt they diverge, and the synform trends at 010°, and the antiform at 050°. Both folds have sub-horizontal axes which plunge at 2°-10° to the NE.

Associated minor D2 folds are broadly congruous and plunge at 5°-12° either to the NE or SW (Fig. 7.3). The Glen Fionne Lighe antiform and the Druim Beag folds are separated by a series of minor D2 folds with sub-horizontal or gently-plunging axes, and axial surfaces which are moderately to steeply-inclined at 40°-70° to the SE. The attitude and close to tight style of these minor folds is reflected in the concentration of poles to S0/S1 in the NW quadrant of Fig. 7.3 .

(e) Glen Suileag antiform. The presence of this fold is indicated by the mapping of the S0/S1 surface, younging directions provided by sedimentary structures, and the closure of the Glen Suileag Banded Psammite in its core in the Allt Choire nan Laogh. There are few associated minor structures. The axial surface trends at 055° and is markedly non-plane. On the southeastern slopes of Meall Onfeidh the fold is a gentle structure (1LA: 120°-140°) with limb dips of 20°-30° to the NNW and SSE. The fold axis is sub-horizontal and the axial surface sub-vertical. The 1LA decreases northeastwards and in the stream section at (NN 03008385) the structure is a close fold (1LA: 50°) with an axial surface which is moderately-inclined to the NNW at 45°. The overturned nature of the SE limb of the fold is demonstrated by the abundant downward-facing sedimentary structures in the southern part of the Allt Choire nan Laogh (e.g. NN 03758390). Further to the NNE in the Allt Choire nan Laogh the fold is again close in style, with a sub-vertical axial surface. Consideration of the S0/S1 surface suggests that the attitude of the fold axis changes rapidly between (NN 02158330), where it is subhorizontal and the Allt Choire nan Laogh where it plunges steeply to the E at 70°-75°.

(f) Coire an Fhuidhir antiform
Druim Fada synform
Coire Dubh antiform
Stob a Ghrianain synform. It is convenient to discuss these four complementary structures together. In Glen Loy their presence is indicated by the mapping of the S0/S1 surface, younging directions

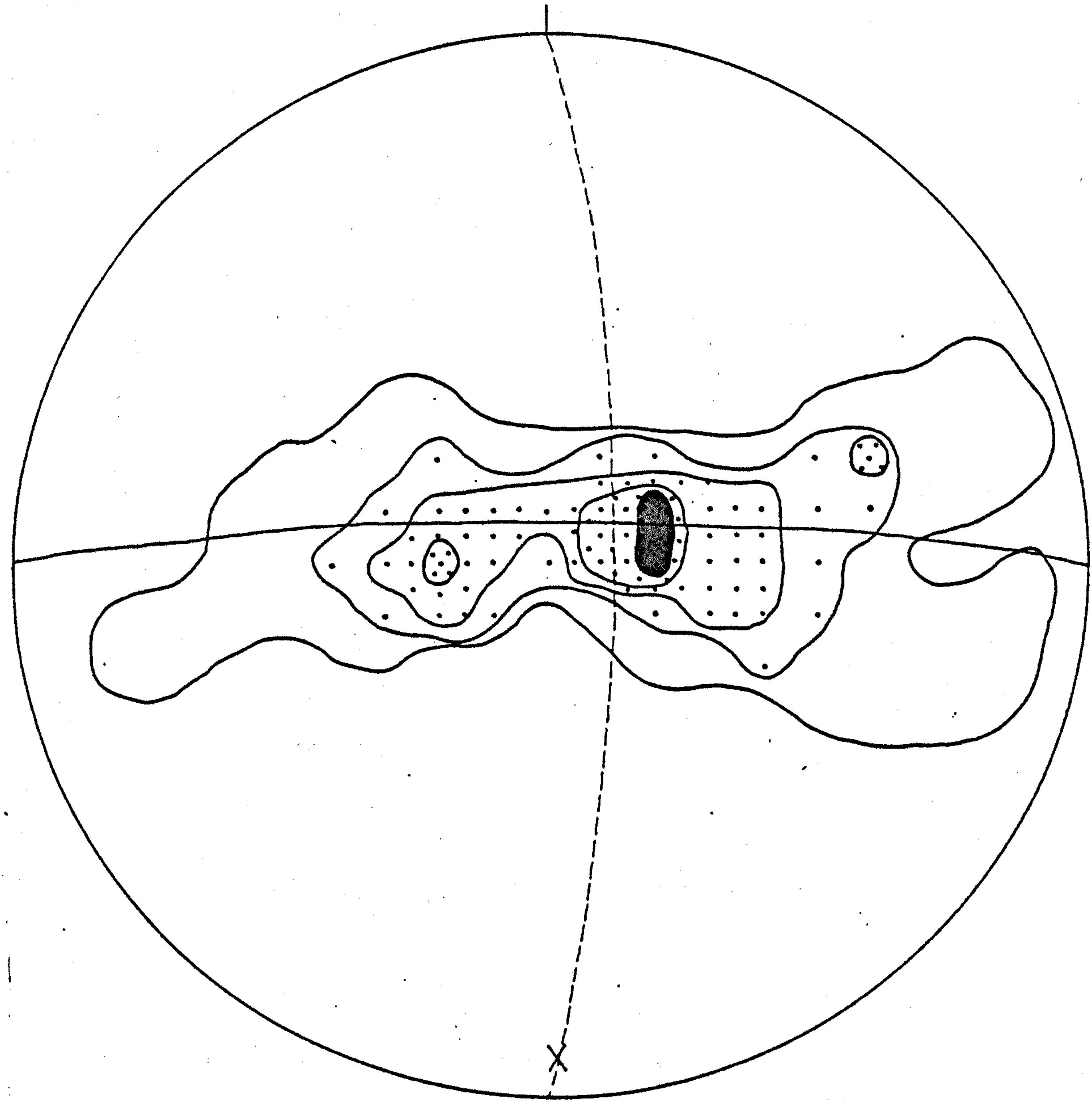
provided by sedimentary structures, and the closure of the Druim Fada Quartzite in their cores. The Coire an Fhuidhir antiform and the Stob a Ghrianain synform are both open in style (1LA: 80^{o}-120^{o}), whereas the Druim Fada synform and the Coire Dubh antiform are both close folds (1LA: 40^{o}-50^{o}). All four structures maintain a relatively constant style between the River Loy and northing 80. The axial surfaces of the structures are all subvertical, almost planar, and trend at 170-180. The fold axes plunge uniformly to the south at 10^{o}-20^{o}. Associated minor structures are broadly congruous with subvertical to steeply-inclined axial planes, and subhorizontal axes which plunge at 4^{o}-10^{o} either to the N or S. The Coire an Fhuidhir antiform is accompanied, in the area between the River Loy and the outcrop of the Druim Fada Quartzite, by six complementary minor D2 folds, which may be traced for distances of up to 1750 metres. At no point, however, do these folds deform the Druim Fada Quartzite, which appears to have acted as a more competent envelope overlying the Glen Garvan Psammite.

The Coire an Fhuidhir antiform and the Druim Fada synform have been traced as far south as the A830 road. Their presence on the southern slopes of Druim Fada is indicated by the mapping of the S0/S1 surface. South of northing 80, however, their axial surfaces may only be located with reference to the younging directions provided by sedimentary structures, and the sense of movement of D2 minor folds. The 1LA of both structures decrease progressively southwards, and south of northing 80, the Coire an Fhuidhir antiform is tight in style (1LA: 27^{o}) and the Druim Fada synform is a close fold (1LA: 35^{o}). The axial surfaces of both structures are moderately to steeply-inclined at 55^{o}-70^{o} to the W. The eastern limb of the Druim Fada synform dips at 25^{o}-35^{o} to the W; the common limb to both folds is downward-facing and is either sub-vertical or steeply-inclined at 70^{o}-80^{o} to the W.

The western limb of the Coire an Fhuidhir antiform is moderately to steeply-inclined at 60°-80° to the W. The axial surfaces of the associated minor D2 folds are moderately to steeply-inclined to the W and are therefore broadly congruous with those of the major structures. The axes of the minor structures, and their associated intersection lineations, are subhorizontal or gently-plunging to the N at 10°-30°, and are therefore slightly incongruous to those of the major folds which would appear, from a study of the S0/S1 surface, to be subhorizontal.

Poles to the S0/S1 surface in sub-area 7 (Fig. 7.7) are widely distributed, reflecting the broadly open to close style of the major folds, and fall in a well-defined girdle about an average axis of D2 folding (Fig. 23). The study of this girdle confirms the observation that the major structures plunge gently to the south at c. 10°.

(g) <u>Stronchreggan antiform</u>. This structure is the direct northerly continuation of the 'Stronchreggan antiform' described by Stoker (1980) from the area immediately to the S of Loch Eil. The presence of the fold in the area to the N of Loch Eil is indicated by the mapping of the S0/S1 surface in the Allt Dogha, and by the sense of movement of minor D2 folds. The structure is a close fold (ILA: 56°), the axial surface of which trends at 195 and is steeply-inclined at 80° to the WNW. The fold axis is inferred to be subhorizontal: associated minor D2 folds plunge at 5°-8° to the N.



X Pole to great circle defined by poles to foliation (sub-area 7)

---- 'Average' axial plane of D2 major folds

Figure 23

4.2.2.3. Relationships between D1 and D2 structures

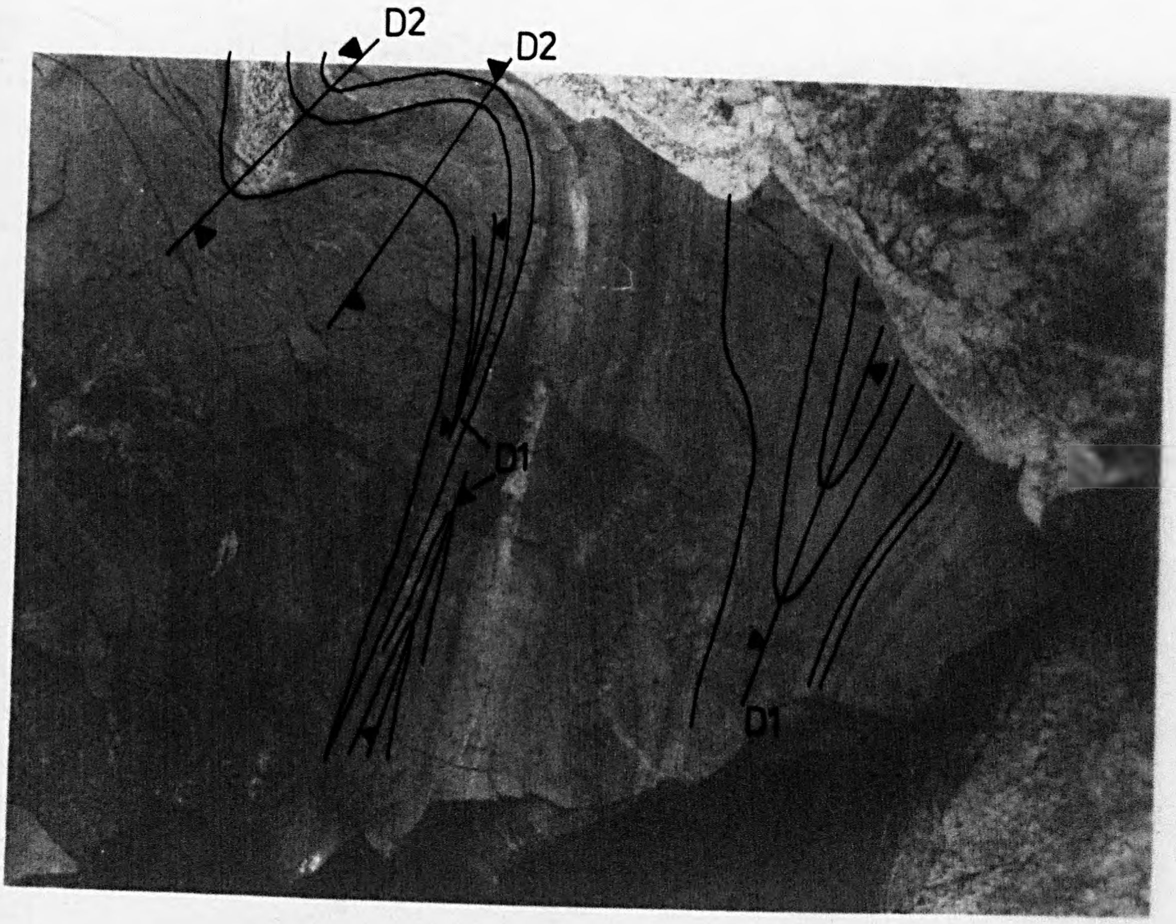
D2 structures were imposed upon a generally sub-horizontal S0/S1 surface (page 60). Axes of D1 folds on Beinn an-t Sneachda (NM 98658230) and in Coire an Fhuidhir (NN 07258220) intersect those of nearby D2 major folds at high angles (25^{o}-60^{o}), whereas those in Coire Dubh (NN 08358250), and on Druim Beag (NN 00655255) and Meall Onfaidh (NN 01858345) are broadly coaxial with local D2 structures. This geometric variation in the orientations of the axes of the two fold systems may be ascribed to one, or a combination of, the following:

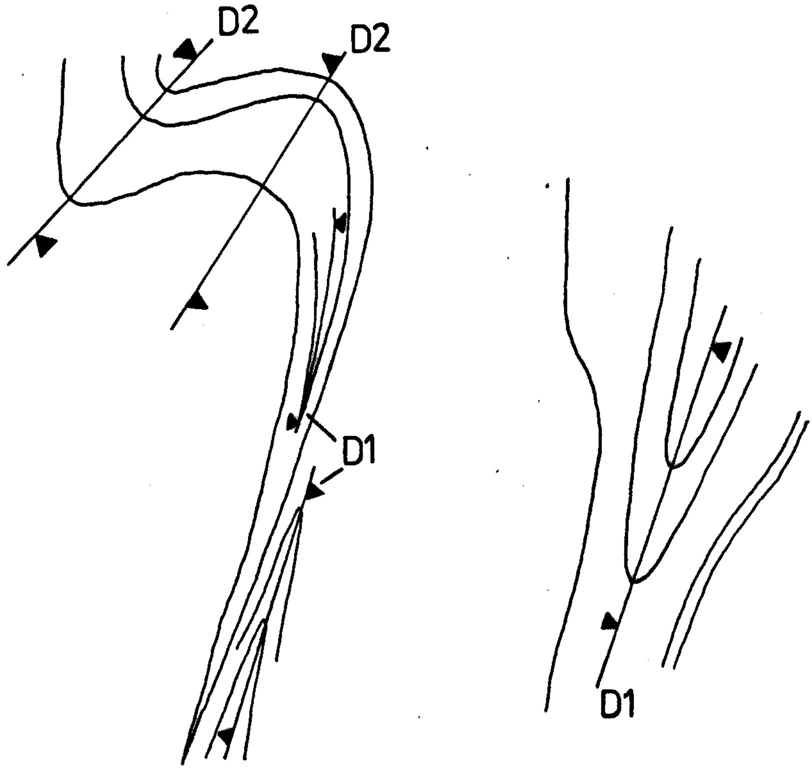
(a) Local variations in the amount of simple shear operative during D1, resulting in non-cylindrical and variably-oriented D1 fold axes.

(b) Heterogeneous deformation during D2 and the production of non-plane, non-cylindrical folds.

The refolding of recumbent D1 folds by steeply-inclined and upright D2 structures leads to the production of Type 3 interference structures (Ramsay 1967, p.531). These are well-exposed at a small quarry adjacent to the A830 road, 1 kilometre W of Corpach (NN 075774). At this locality, D2 folds which are moderately-inclined at 60^{o} to the W and plunge at 28^{o} to the N, refold tight to isoclinal D1 structures (Plate 37). Such structures are also present in Coire Dubh where upright and open D2 folds with gently-plunging axes refold recumbent and tight D1 structures.

Plate 37: Type 3 interference structure produced by the refolding of D1 folds during D2. (Cona Glen Psammite, NN 075774).


D2
D2
D1
D1


D2
D2
D1
D1

4.2.2.4. D2 strain variation

The widespread development of D2 minor and major folds means that it is possible to analyse the lack of D2 strain with reference to these structures.

16 minor D2 folds, comprising 30 individual layers, were analysed using the techniques outlined on p. 68 , and the results of this analysis are presented in Table 9 and Fig. 24 . There is, in general, a good correspondence between the fold classes obtained from t'_α/α and $\emptyset/\alpha$ plots. The majority of folded layers fall quite distinctly into either class 1B or class 1C on these plots. 20 of the folded layers are classified as wholly class 1C, and a further 5, although they are combinations of two classes, are predominantly class 1C. Strain ratios have been calculated from these class 1C folds, and are presented in histogram form in Fig. 24b. Few folds exhibit any great lithological contrast between individual layers, and, as with the D1 folds, they may have developed by a simultaneous process of buckling and flattening.

Given the comparatively uniform nature of the lithologies in the study area, it is again possible to use variaitions in D2 fold style as an approximate indicator of variations in finite strain. A broad assessment of finite strain may therefore be obtained from the shape of the major D2 folds in cross-sectional profile (Enclosure 4) and from the analyses of the minor folds. Those minor folds analysed are widely distributed through the Loch Eil area, and although they are relatively consistent in terms of fold class, the strain ratios exhibited by the class 1C folds are extremely variable. There does not, therefore, appear to be

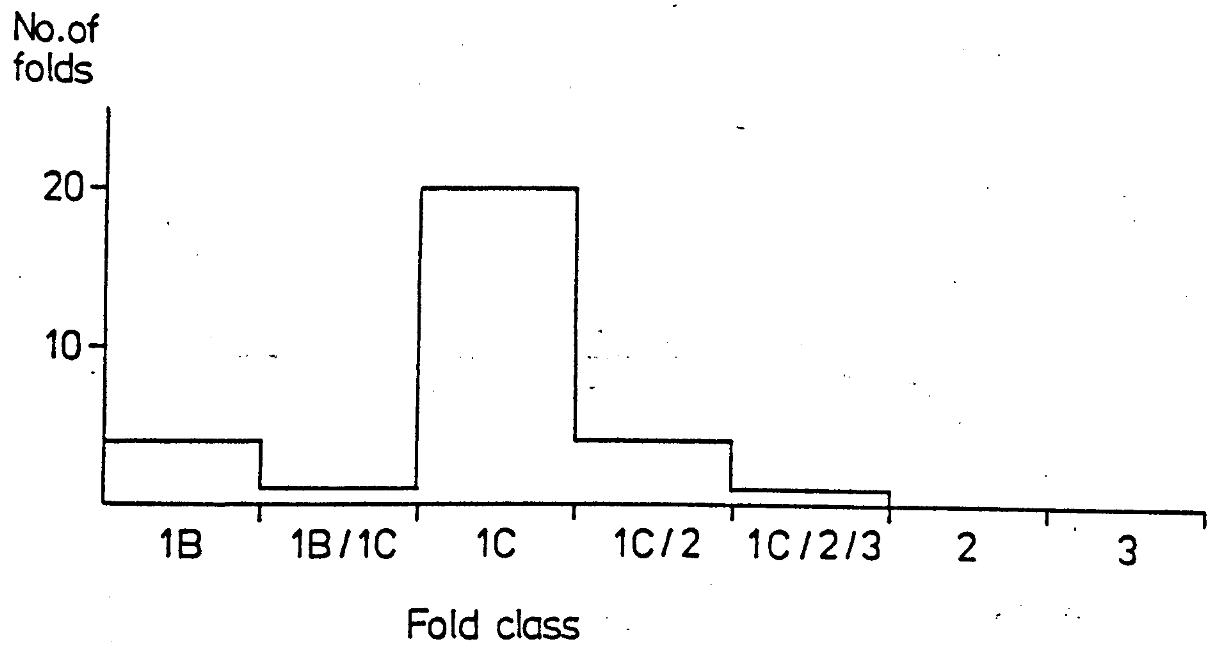
Table 9: D2 fold profile analyses

Fold Number	Location and stratigraphic position	Lithology	Fold class from t'_α v. α	Fold class from ϕ v. α	'Flattening' strain ratios, $\sqrt{\lambda 2/\lambda 1}$ from $\cos^2\alpha$ v. $t'^2\alpha$ and ϕ v. α.
1	NM 748939 Kinlocheil Cross-Bedded Quartzite	Q	1C	1C	0.6
2	NM 851986 Gulvain Psammitic Gneiss	(a) Q (b) Ps (c) Ps	1C 1C 1C	1C 3 1B-1C	0.45 0.25 0.8
3	NM 872955 Druim Fearna Semi-Pelite	Sp	1C	1C	0.45
4	NM 836913 Gulvain Psammitic Gneiss	(a) Ps (b) Ps (c) Ps	1B-1C 1B-1C-2-3 1C	1C 1C 1C	0.75 0.35 0.25
5	NN 82250080 Glen Garvan Psammite	(a) Ps (b) Ps	1B 1B-1C	1B-1C 1B-1C	- 0.90
6	NM 842977 Gulvain Psammitic Gneiss	(a) Q (b) Sp	1C-2-3 1C	1C-2 1C-2	0.1 0.15
7	NM 749928 Basal Psammite	(a) Ps (b) Ps	1B-1C 1B-1C	1C 1B	0.75 -
8	NN 77250760 Cona Glen Psammite	(a) Sp (b) Ps	1C 1C-2	1C-2 1C-2	0.25 0.2
9	NN 770079 Cona Glen Psammite	Q	1B-1C	1B	-
10	NM 834910 Gulvain Psammitic Gneiss	(a) Q (b) Ps	1C 1C-2	1C-2 1C-2-3	0.35 0.2
11	NM 736920 Basal Psammite	(a) Sp (b) Ps (c) Ps	1C 1C 1C-2	1C 1C-2 1C-2	0.4 0.3 0.4
12	NM 826994 Glen Garvan Psammite	(a) Ps (b) Ps	1C 1C	1C 1C	0.5 0.6
13	NM 748960 Glen Garvan Psammite	Ps	1B-1C	1B	-
14	NM 833975 Glen Garvan Psammite	(a) Ps (b) Sp	1C-2 1C	1C 1C	0.7 0.5
15	NN 825002 Glen Garvan Psammite	(a) Ps (b) Ps	1C-2-3 1C	1C-2-3 1C-2	- 0.35
16	NM 834913 Kinlocheil Banded Quartzite	Q	1C	1C	0.5

Key to lithologies: Q - Quartzite. Ps - Psammite. Sp - Semi-Pelite. Pe - Pelite.

A

Fold classes of individual layers



B

Flattening strains for folds which carry a large component of class 1C

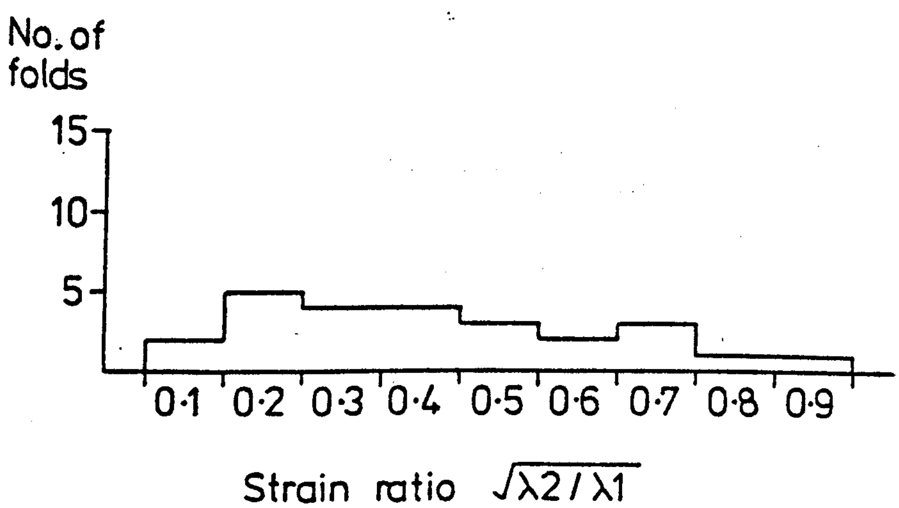


Figure 24: Results of D2 fold profile analysis.

any obvious systematic variation in the intensity of D2 strain as expressed by the style of minor D2 folds. Furthermore, there is no obvious areal variation in the shape of major D2 folds in cross-sectional profile, and this reinforces the impression that D2 strain is clearly heterogeneous.

4.2.2.5. A model for the development of D2 structures

The main features of the D2 deformation may be summarized thus:

(a) Minor D2 folds display a great variation in style and degree of flattening, and vary from relatively simple plane cylindrical folds to more complex non-plane non-cylindrical structures. They are frequently incongruous with respect to major D2 structures.

(b) Major D2 folds similarly show considerable variation in style, and are all non-cylindrical and non-plane to some degree.

(c) There is not, however, any systematic variation to the style of major and minor D2 folds, although, on a purely qualitative basis, the degree of non-cylindrism and non-planarity would appear to be greatest in the western part of the area, W of the axial plane trace of the D3 Loch Eil synform. The regional D2 strain pattern is thus heterogenous.

(d) Despite the heterogeneous deformation, lithostratigraphic units are laterally continuous, and S1 remains the dominant foliation.

D2 folds are subsequently refolded on a regional scale during D3 (p. 91), and some variation in the orientation of the axial surfaces of D2 structures may be ascribed to D3 refolding. An example of this is the refolding of the D2 Glen Fionne Lighe antiform by the D3 Druim Na Saille synform, which causes a change in trend of the D2 structure from 070° to 015°. However, the following considerations suggest that the heterogeneous form of D2 structures is largely a result of D2 deformation and not D3:

(a) Ramsay (1967, Figs. 8-15, 16, 17, 22, 23) demonstrates a systematic relationship between earlier and later linear structures, e.g. the earlier linear structures undergo marked changes in orientation at the hinges of later folds. However, within the present study area the degree of non-cylindrism of D2 folds does not vary systematically with respect to the proximity of D3 fold axes.

(b) The degree of non-planarity of D2 major folds similarly shows no obvious relationship to D3 folding, and in one case the study of the direction of plunge of D3 linear structures strongly suggests that a nearby D2 structure was markedly non-planar prior to D3 folding (p. 91).

(c) If the heterogeneous nature of D2 folds was entirely a product of D3 deformation, then D3 structures might also be expected to show variable forms. However, the regional D3 strain pattern is relatively uniform, and D3 folds are plane structures (p. 92).

Since the heterogeneous nature of D2 folds would appear to have originated during the D2 deformation, it is pertinent at this point to consider the means by which such variable structures may be produced. Voll (1960) proposed four main mechanisms to explain the origin of non-cylindrical structures:

(a) Unequal stretching along the strike of the layering (internal rotation).

(b) Thinning of limbs and subsequent detachment of hinges within the plane of the schistosity (see also Knill and Knill 1958).

(c) Buckling of layers prior to formation of the schistosity so that the layering schistosity lineation produces a curvilinear trace.

(d) Layering planes intersected by schistosity planes of different attitudes.

Since lithologies are laterally continuous along strike, and D2 folding is rarely accompanied by the formation of S2, mechanisms (b), (c) and (d) may be rejected. Consequently, mechanism (a) involving non-uniform flow parallel to the axial surface may be the primary mechanism for the formation of the D2 non-cylindrical folds. Non-uniform compression normal to the axial surface as figured by Ramsay (Fig. 25a) will, however, only produce planar non-cylindrical folds and clearly this model needs modification to produce non-planar structures. The presence of such non-planar folds implies the existence of inhomogenous strains produced by variations in the amount of movement normal to the axial surface (Fig. 25b), or by variations in the orientation of stresses (Fig. 25c), both of which would generate non-planar structures. Flattening superimposed upon existing folds would also have the effect of deforming early-formed axial planes into non-planarity (Ramsay and Sturt 1973).

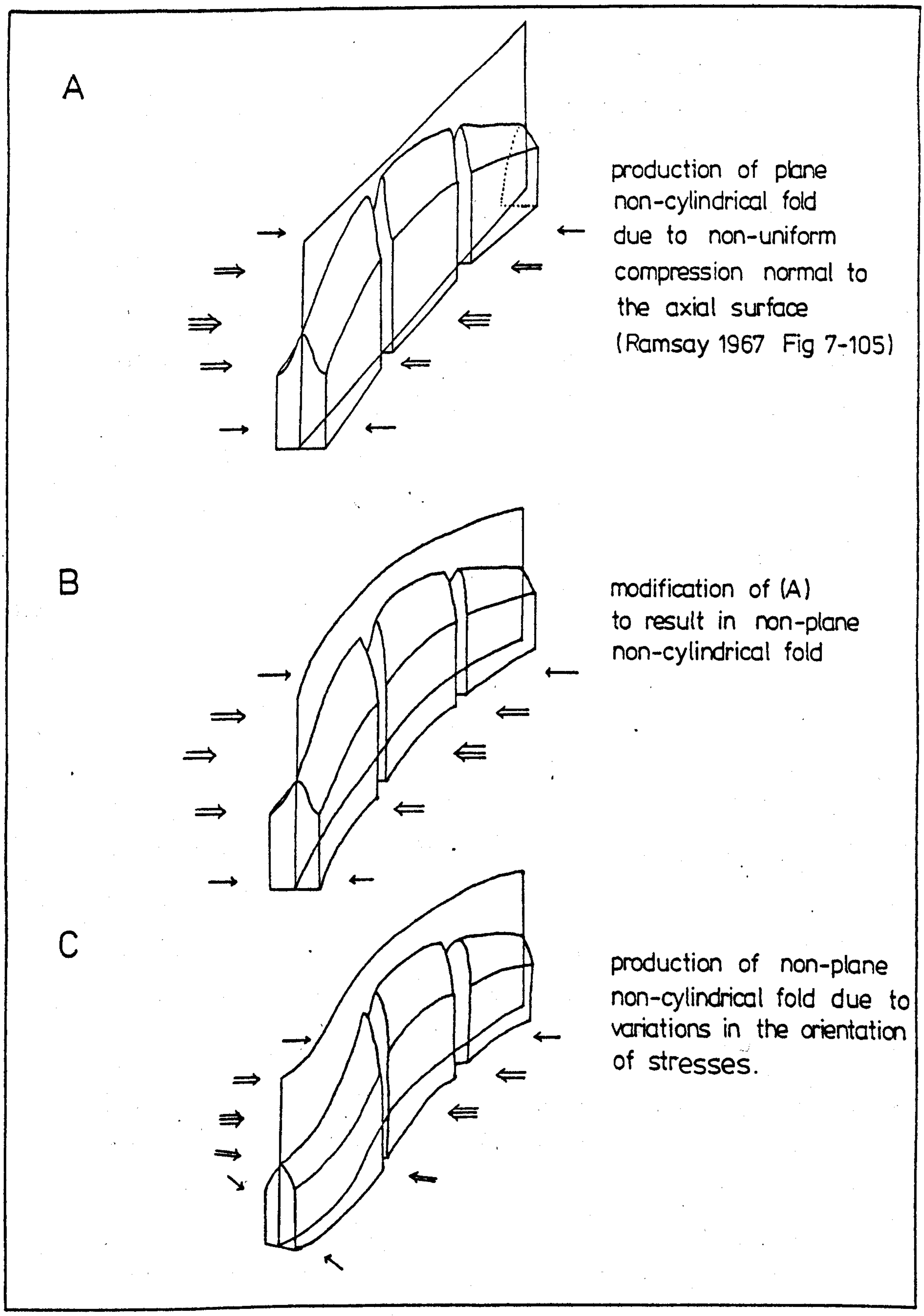


Figure 25: Models for the development of non-cylindrical and non-plane folds.

It still remains to explain the incongruous nature of the minor D2 folds with respect to the major structures. Ramsay and Sturt (op cit) suggest that incongruous folds are an inevitable consequence of tight folding and subsequent flattening, involving layer thinning and extension on the fold limbs. The increase in layer parallel strains on the fold limbs leads to rotation of the hinges of parasitic folds and their consequent low axial stability. Given that the majority of D2 folds are flattened concentric folds it seems likely, therefore, that the incongruous parasitic folds are a result of the style of D2 deformation.

4.2.3. D3

4.2.3.1. Minor Structures

Minor D3 folds are present throughout the Loch Eil Division rocks of the area, although they are less common than either D1 or D2 structures. D3 folds deform S0, S1 and S2, and develop axial-planar crenulation fabrics (S3) within semi-pelitic bands. D3 minor folds within psammites and quartzites are typically gentle in style (1LA: 160°-120°), with upright axial surfaces and sub-horizontal to gently-plunging axes. Fold axes are usually cylindrical where exposed. Where developed within the less competent semi-pelitic bands, D3 folds are normally close to tight in style (1LA: 60°-30°).

S3 fabrics result from the crenulation of S1 (Plate 38) and, more rarely, S2. Micas are rarely observed to recrystallise parallel to the axial surfaces of the D3 folds, and thus no new S-surface is generated during D3. S3 crenulations are close to tight in style (1LA: 60°-30°). The interaction of S3 with S0/S1, and occasionally S2, may be measured as a linear structure parallel to the axes of the D3 folds.

Plate 38: S3 crenulation fabric. (Glen Garvan Psammite, NM 954740).


PENTAX

4.2.3.2. Major structures

The existence of two major D3 folds has been established, and the existence of a further two inferred, with reference to the mapping of the S0/S1 foliation surface, 'younging' directions indicated by sedimentary structures and variations in the orientation and trend of D2 linear and planar structures. The distribution of these major structures is indicated in Fig.26 , and the geometry and nature of each of these folds will be discussed in turn.

(a) Loch Eil synform. The presence of this fold is indicated by the mapping of the S0/S1 surface and the closure of the Druim Fada Quartzite in its core on Druim Fada. The style of the fold varies from open (ILA: 110^{o}-120^{o}) in the area N of the River Loy, to gentle (ILA: 120^{o}-160^{o}) in the area between the River Loy and Loch Eil. The limbs of the fold dip at 0-30^{o}. The axial plane of the fold is subvertical for its entire mapped extent and trends at 180^{o}. The fold axis is non-cylindrical: on the northern slopes of Glen Loy the synform plunges at 50^{o}-55^{o} to the S; plunge is progressively reduced to 15^{o} to the S on Druim Fada and to 0-10^{o} to the S on the N shore of Loch Eil.

Associated minor D3 folds have subvertical axial planes, and subhorizontal axes which plunge either to the N or S at 0-10^{o} (Fig. 7.6). They are therefore broadly congruous with the major structure. Poles to the S0/S1 surface in sub-area 6 (Fig. 7.6) fall in a girdle about an axis of D3 folding (Fig. 27). The position of the girdle reflects the gently-plunging attitude of the major fold.

(b) Druim Na Saille synform. This structure is recognized by the mapping of the S0/S1 foliation, and the closure of the Basal Psammite and Kinlocheil Banded Quartzite in its core. The synform

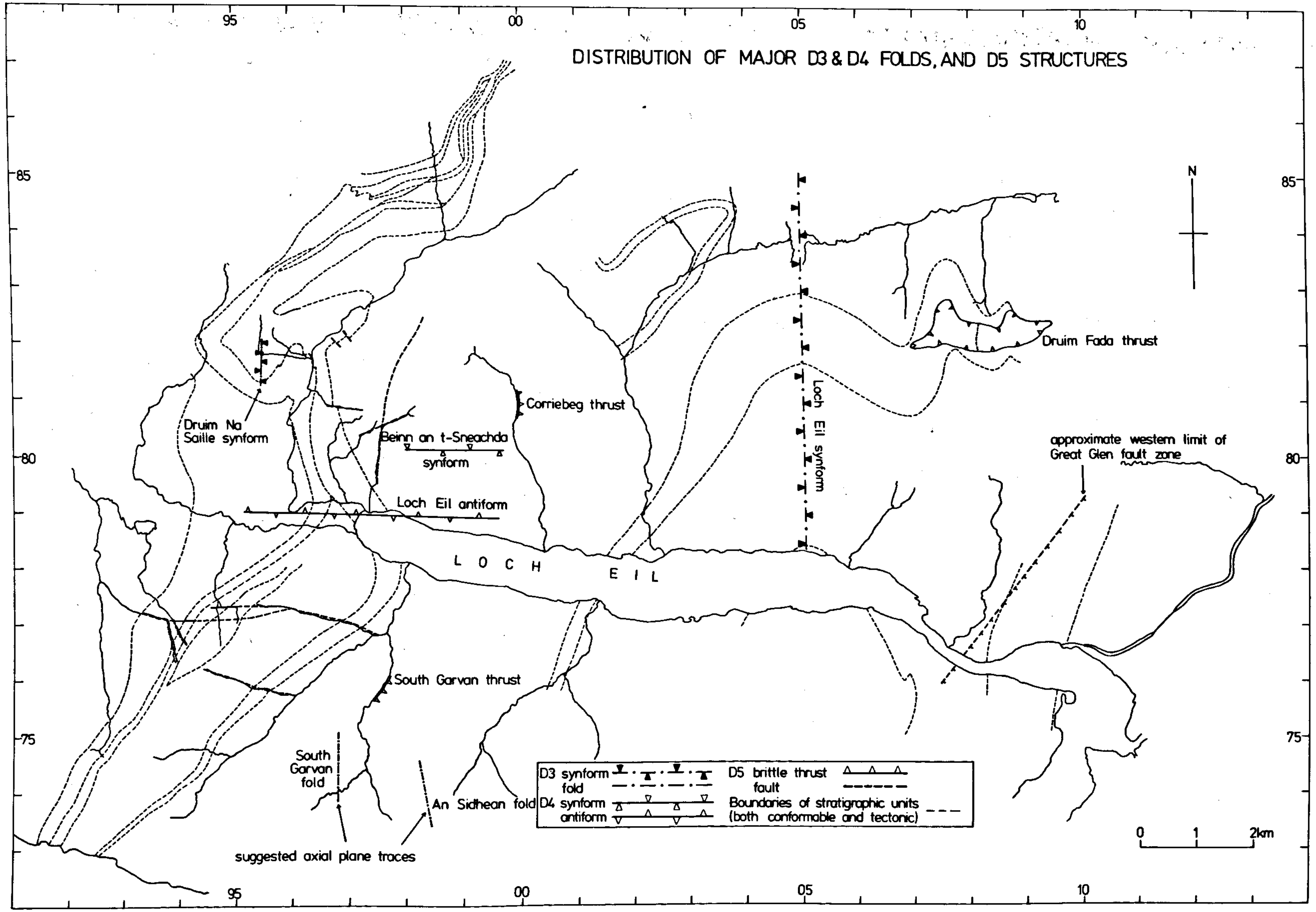
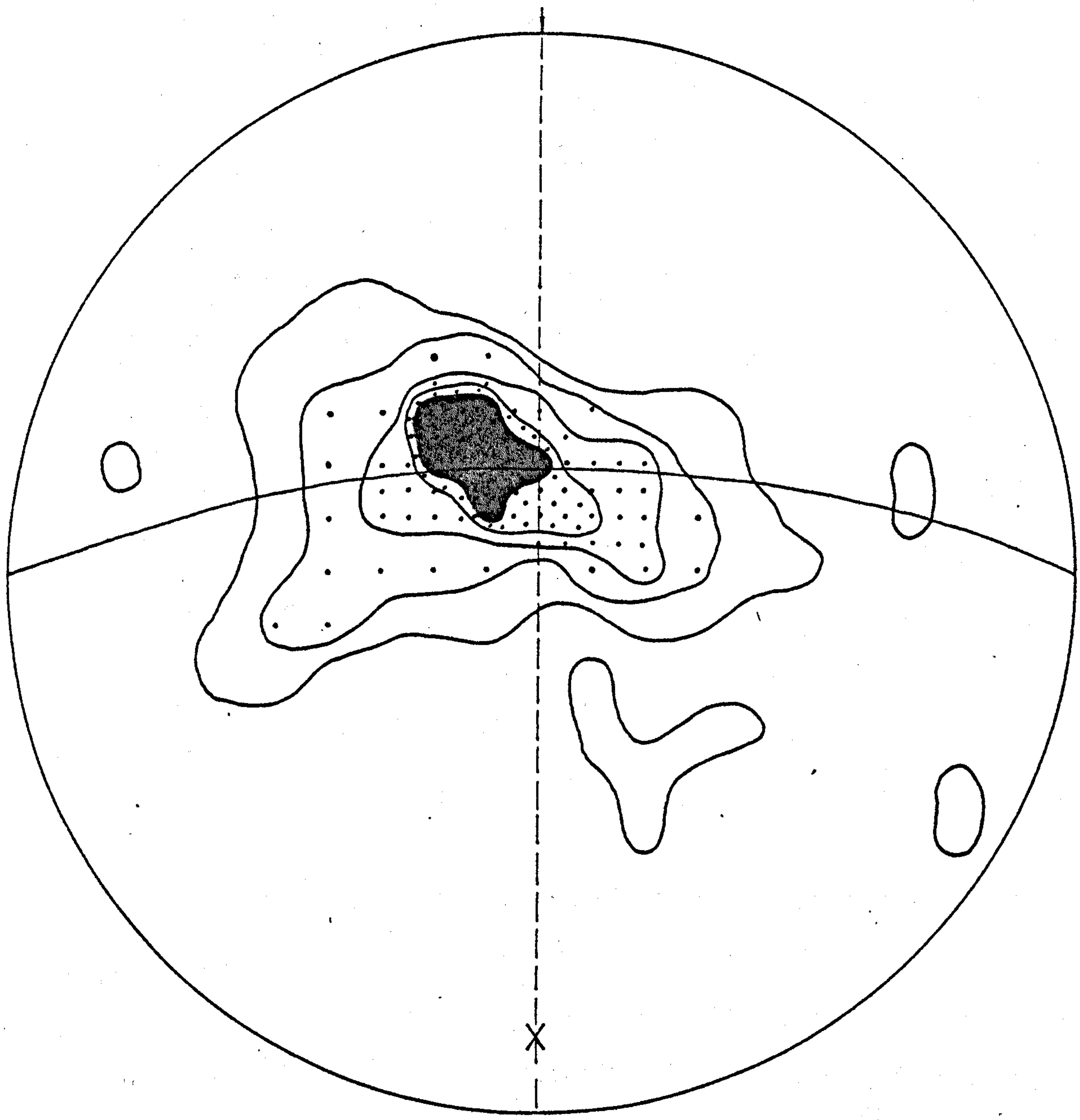

DISTRIBUTION OF MAJOR D3 & D4 FOLDS, AND D5 STRUCTURES
95
00
05
10
85
80
75
N
Druim Fada thrust
Corriebeg thrust
Druim Na Saille synform
Beinn an t-Sneachda synform
Loch Eil antiform
Loch Eil synform
L O C H E I L
approximate western limit of Great Glen fault zone
South Garvan thrust
South Garvan fold
An Sidhean fold
suggested axial plane traces
D3 synform fold
D4 synform antiform
D5 brittle thrust fault
Boundaries of stratigraphic units (both conformable and tectonic)
0 1 2km

Figure 26



X Pole to great circle defined by poles to foliation (sub-area 6)

---- Axial plane D3 Loch Eil synform

Figure 27

is open in style (ILA: 80°-120°) with a subvertical axial plane which trends at 180°. The E and W limbs of the structure dip at 30°-50° to the NW and NE respectively. The axis of the fold is slightly non-cylindrical and plunges to the N at 20°-35°. Associated minor structures have subvertical or steeply-inclined (to the E) axial planes, and plunge gently to the N (Fig. 7.4), and are thus congruous with the major fold.

(c) South Garvan fold

An Sidhean Fold. The existence of these two folds is indicated by the marked changes in the trend of the S0/S1 surface between Sron an-t-Sluichd, the South Garvan River and the Dubh Uisqe. It appears likely that these variations are paralleled by changes in the orientation of D2 folds, since the S0/S1 surface in the South Garvan River indicates the presence of a D2 synform, trending at 110°, and inferred to be the refolded extension of the Glen Garvan synform. The suggested axial plane traces of the two structures responsible for this change in the trend of both the D2 fold and the S0/S1 surface are sub-parallel to proven D3 major and minor structures, and markedly oblique to proven D4 folds. On this basis, therefore, the South Garvan and An Sidhean folds are assigned to D3. From a study of the S0/S1 surface in the area it is thought likely that the axial planes of the structures are subvertical or steeply-inclined in attitude. Since they deform an already folded S0/S1 surface their axes are likely to be non-cylindrical.

4.2.3.3. Relationships between D3 and D1-D2 structures

The axes of D2 and D3 major folds are sub-parallel in the eastern part of the area, but are highly oblique elsewhere. It seems likely that the D2 structures are refolded about the axis of the D3 Loch Eil synform, thus creating a major fold interference pattern of regional dimensions. Unfortunately, partly due to a lack of exposure, it has not proved possible to trace individual D2 structures across the axial plane trace of the Loch Eil synform, and it is clear that further mapping needs to be undertaken in the area to the N of Glen Loy.

The heterogeneous nature of the pre-D3 foliation surface clearly exerted a strong influence on both the attitude and direction of plunge of D3 major and minor fold axes. Thus the southward plunge of the Loch Eil synform is a reflection of the refolding of the southward-dipping limbs of D2 antiforms. The structure attains its maximum plunge in Glen Loy where it refolds the steeply-inclined S limb of an upright D2 antiform; further S it refolds the gently-dipping to subhorizontal limbs of D2 folds, and consequently the amount of plunge decreases. Similarly, the northward plunge of the Druim Na Saille synform is a consequence of the refolding of the northwestward-dipping limb of the Glen Fionne Lighe antiform. The observation that D3 fold axes plunge uniformly to the N throughout sub-area 2 (Fig. 7.2) leads to the conclusion that the NW limb of the Ben An Tuim synform was inverted during D2 folding and not D3.

4.2.3.4. D3 strain variation

D3 fold style has not been quantitatively analysed, partly because of the difficulties in obtaining a quorum of suitable samples. However, on a purely qualitative basis there are no systematic variations in D3 fold style within the area, apart from those related to local lithological control. Accordingly, it seems likely that the level of D3 strain was approximately equal across the area, and was almost certainly considerably less than that which prevailed during either D1 or D2. The relative homogeneity of D3 strain is further reflected in the plane nature of D3 major folds.

4.2.4. D4

4.2.4.1. Minor structures

Minor folds of undoubted D4 age are rare and have only been observed in the western part of the area (e.g. Druim Fearna, NM 95857790, and Glas Bheinn, NM 94207630). D4 minor folds developed within psammites and quartzites tend to be open in style (ILA: 100°-120°), and close to tight (ILA: 25°-65°) within semi-pelites. Their axial planes vary in attitude from subvertical to gently-inclined and axes are typically gently-plunging at 10°-30°. D4 minor folds deform S0, S1, S2 and S3, but do not develop any separate axial-planar schistosity.

4.2.4.2. Major structures

The existence of two major D4 folds has been established with reference to the mapping of the S0/S1 surface, and variations in the trend of D3 linear structures:

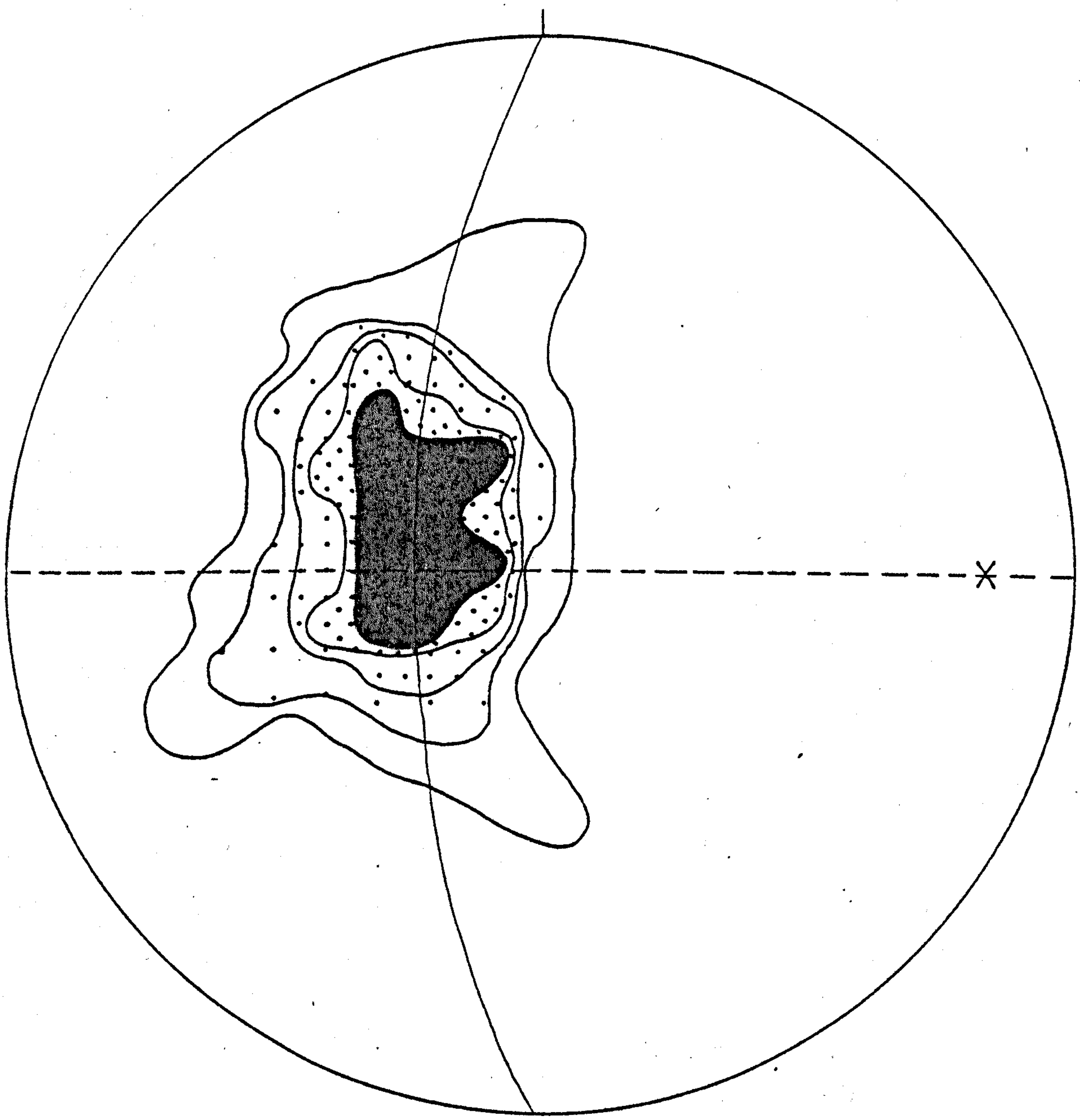
Beinn an-t Sneachda synform
Loch Eil antiform

The location of these two folds is indicated in Fig. 26, and it is convenient to discuss their geometry and nature together. They are not attended by a related suite of minor structures and their presence is largely revealed by large-scale warping of the S0/S1 surface. The Beinn an-t Sneachda synform is open to gentle in style (ILA: 100^{o}-160^{o}) with a subvertical axial plane. The fold limbs dip at 10^{o}-40^{o}, although there is considerable local variation in dip. The axial trace of the fold trends at 090° and the fold axis is slightly non-cylindrical, plunging to the E at 15^{o}-30^{o}. The existence of the Loch Eil antiform is suggested by changes in the trend of S0/S1 1 kilometre W of Corriebeg (NM 988788), and the upper and lower boundaries of the Basal Psammite immediately to the W of Loch Eil. Since this fold occurs in an area of poor exposure, the precise location of the axial plane trace is uncertain. However, it is suggested that the geometry and attitude of the Loch Eil antiform is broadly similar to that of the Beinn an-t Sneachda synform, and that their axial traces are sub-parallel.

Poles to the S0/S1 surface in sub-area 5 (Fig.7.5) fall in a girdle about an average axis of D4 folding (Fig. 28); the study of this girdle confirms the gentle-plunge of the D4 structures.

4.2.4.3. Relationship between D4 and D1-D3 structures

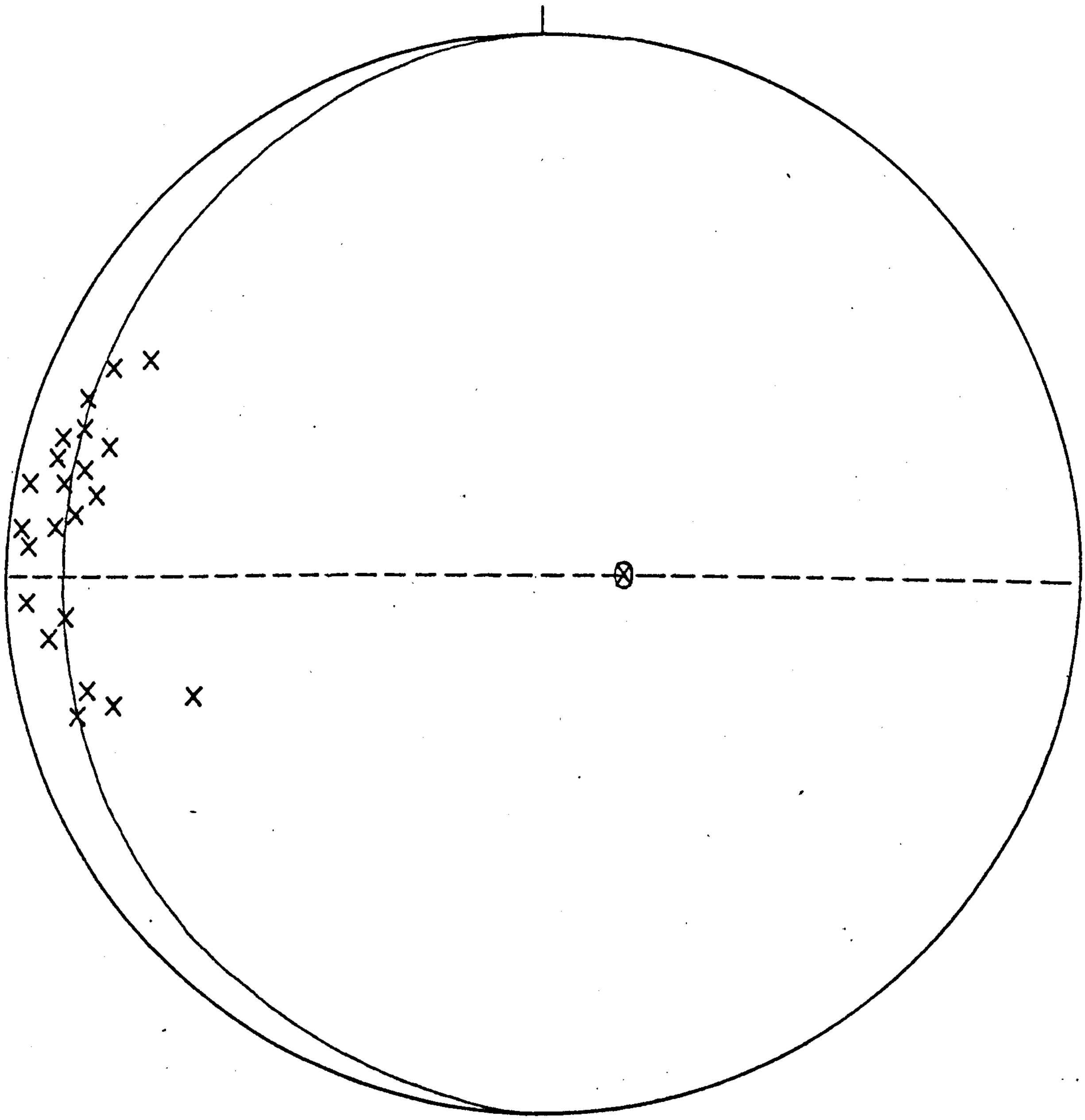
The almost cylindrical form and gently-plunging attitude of the D4 fold axes is primarily a result of the refolding of an S0/S1 surface which was probably sub-horizontal or gently-inclined to the SE after D2 and D3. The post-D3 age of the D4 folds is demonstrated by a study of the orientations of D3 linear structures in sub-area 5. Elsewhere in the study area these tend to plunge either to the N or S; here, however, they plunge to the NNE (Fig. 7.5). A girdle linking these falls about an average axis of D4 folding (Fig. 29).



X Pole to great circle defined by poles to foliation (sub-area 5)

---- 'Average' axial plane of D4 major folds

Figure 28



⊗ Pole to great circle defined by poles to axial planes of D3 minor folds (sub-area 5)

---- 'Average' axial plane of D4 major folds

Figure 29

4.2.5. D5

This phase of deformation comprises a series of faults and fault zones indicated in Fig.26 . None of the faults are observed to be affected by any of the deformational events already described. This, together with the manifestly "brittle" nature of the deformation which accompanied their formation, leads to the conclusion that they are the products of the last major deformational episode to affect the rocks of the area. The majority of the faults are developed in two areas, namely near the W end of Loch Eil, and adjacent to the Great Glen Fault (Fig. 26). The D5 structures in these areas are characteristically sub-vertical to steeply-inclined in attitude, and contrast sharply with the sub-horizontal to gently-inclined attitude of the faults mapped at Corriebeg, South Garvan and on Druim Fada (Fig. 26). These three structures were mapped by the Institute of Geological Sciences as 'thrusts', and this is the term by which they are loosely referred to in this study.

4.2.5.1. Faults near the W end of Loch Eil

All are mainly located in stream sections on Beinn an-t Sneachda, Glas Bheinn and Druim Fearna, and form distinct topographic features. None of these causes any major displacement of stratigraphic boundaries but they may be marked by local changes in the orientation and inclination of the S0/S1 surface. The faults are narrow zones of deformation, 4-5 metres wide, within which the Moine rocks have been thoroughly shattered and reduced to a coarse fault breccia. Thin bands, only a few millimetres thick, of diaphthoritic chlorite are ubiquitous, and the faults are commonly marked by intense granite-veining. Thin-section analysis of rocks along and near the faults demonstrates that these rocks are often extensively sericitised.

4.2.5.2. Great Glen Fault Zone

This comprises a zone of deformation within which certain structures are developed, rather than a series of separate mappable faults. The D5 structures within this zone are identical to those developed elsewhere in association with the Great Glen Fault (Eyles and MacGregor, 1952) and are therefore inferred to relate entirely to movement along this structure. Exposures in Banavie Quarry best demonstrate the nature of the D5 deformation. Here the vertically-foliated psammites are cut by a series of closely-spaced ramifying faults which are usually sub-vertical in attitude, although exceptionally they may be sub-horizontal. Many faults are marked by bands of diaphthoritic chlorite. Few faults have been accompanied by any significant degree of differential movement. The entire zone is extensively granite-veined.

4.2.5.3. Thrusts

The most important of these, the Druim Fada thrust, is a well-defined structure which is sub-horizontal in attitude and located at the 650 metre contour on Druim Fada. It is well exposed in Coire Dubh, where it is seen to be a clear cut planar structure which is accompanied by a 2-3 metre thickness of fault breccia. The breccia is composed of angular fragments of psammite and quartzite set in a green chloritic matrix. The rocks immediately above the thrust plane are often highly jointed for a thickness of 2 metres. The rocks above the thrust are composed of quartzites, in the W, which are overlain by psammites in the E. The quartzites are inferred to be equivalent to the Druim Fada Quartzite; since these are invariably upward facing elsewhere, the overlying psammites are thought to be equivalents of the Cona Glen Psammite. This correlation suggests that movement along the thrust was directed towards the W; it is not possible, however to estimate the amount of horizontal displacement without further mapping to the E of Druim Fada.

The Corriebeg and South Garvan thrusts are comparatively minor structures. The field relations are most clearly demonstrated in the case of the Corriebeg thrust; the thrust plane is sub-parallel to the gently-inclined S0/S1 surface and overlies a 30 centimetre thick layer of pale green fault gouge. There is some accompanying brecciation of the psammites. The geometry of the South Garvan thrust would appear to be broadly similar, although it is less well exposed. It has not proved possible to determine the amount and direction of displacement across either of these structures.

All three structures are accompanied by granite veining. None of the veins display any oriented internal fabrics, but many have undergone some degree of shattering and brecciation.

4.3. STRUCTURAL HISTORY OF THE GLENFINNAN DIVISION

This may be conveniently divided into those structural elements which are inferred to have been either wholly or partly formed before the main phase of D1 folding and sliding within the Loch Eil Division, and those which may be directly related to the sequence D1-D5.

4.3.1. Pre-D1 structural elements

Pre-D1 deformation may be subdivided into two phases.

4.3.1.1. Phase 1

Phase 1 structures comprise a series of small-scale intrafolial isoclinal folds which have as their axial planar fabric the main foliation within the Glenfinnan Division. Phase 1 folds have only been identified at three localities, e.g. Fionn Lighe (NM 95958000) and Druim Na Saille (NM 95608065): all examples have thickened hinges and attenuated limbs, and are only visible due to minor lithological variations within the Druim Na Saille Pelite. It is considered that these folds were originally recumbent in attitude; it was not possible, however, to determine the original orientation of the axes of the phase 1 folds.

The main foliation within the Glenfinnan Division is penetrative in all lithologies. In the Druim Na Saille Pelite it is defined by the alignment of biotite and muscovite laths, and may be enhanced by the presence of concordant migmatitic segregations (Plate 17). Within the Gulvain Psammitic Gneiss the foliation is primarily expressed as a well-developed gneissose banding (Plate 3) to which the mica fabric in pelitic bands is sub-parallel. The foliation is parallel to all lithological variation (Plate 2); since such variations are inferred to relate, at least in part, to original sedimentary layering, the foliation is referred to loosely as a 'bedding-foliation'. The foliation is sub-parallel to S0/S1 within the overlying Loch Eil Division; however, it is suggested that the formation of foliation within the Glenfinnan Division preceded either wholly, or in part, D1 sliding and folding (sections 4.3.1.2. and 4.3.2.1.).

4.3.1.2. Phase 2

Phase 2 structures comprise a series of long-limbed tight to isoclinal minor folds which are confined in their occurrence to the Gulvain Psammitic Gneiss (both allochthonous and autochthonous units). They are abundantly developed at certain localities (Enclosure 5: NM 978845 and NM 98558515) and clearly deform the main foliation within the Gulvain Psammitic Gneiss (Plates 39 and 40), but rarely develop any additional axial planar fabric. Phase 2 structures are also inferred to have originally been recumbent in attitude. Folds of comparable style and axial orientation are completely absent from the Loch Eil Division rocks on Na-h-Uamachan and Gulvain, and it is suggested that the Gulvain Psammitic Gneiss was already deformed by phase 2 structures prior to the tectonic interleaving of the two Divisions during D1 sliding. The observation that the phase 2 structures deform the gneissose fabric within the allochthonous unit of Gulvain Psammitic Gneiss further suggests that this unit was already gneissose (i.e. had undergone phase 1 deformation) prior to its tectonic emplacement.

4.3.2. Deformation during D1-D5

4.3.2.1. D1

Folds which are inferred to be the representatives of the D1 deformational phase within the Glenfinnan Division are only found at two localities. However, at both they deform the main foliation within the Druim Na Saille Pelite (Plates 41 and 42). These folds are similar in style, attitude and axial direction, and display the same sense of vergence, to D1 folds developed in the same structural setting within the Loch Eil Division 1-3 kilometres to the E (Fig.30). The

Plate 39: Gneissose banding deformed by a tight phase 2 fold. (Gulvain Psammitic Gneiss, NM 978845).

Plate 40: Gneissose banding deformed by a steeply-plunging isoclinal phase 2 fold. (Gulvain Psammitic Gneiss, NM 98558515).

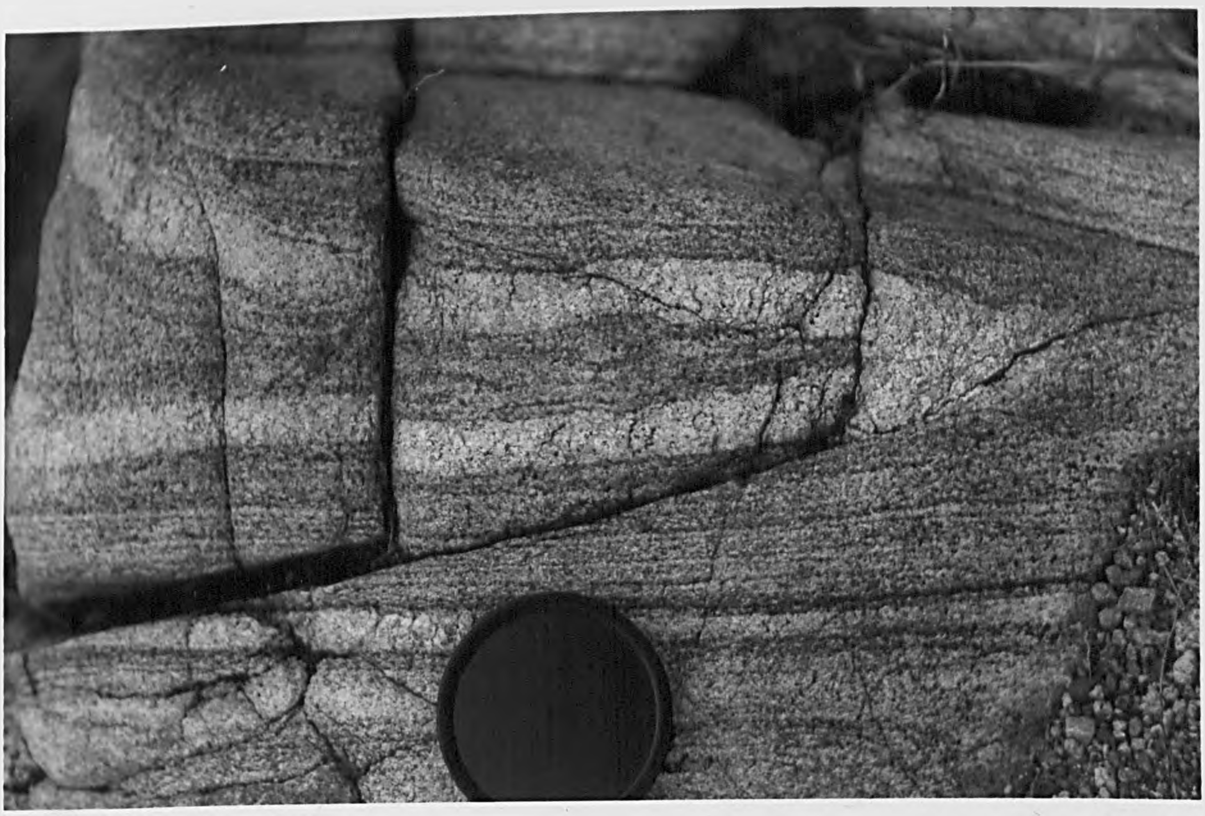
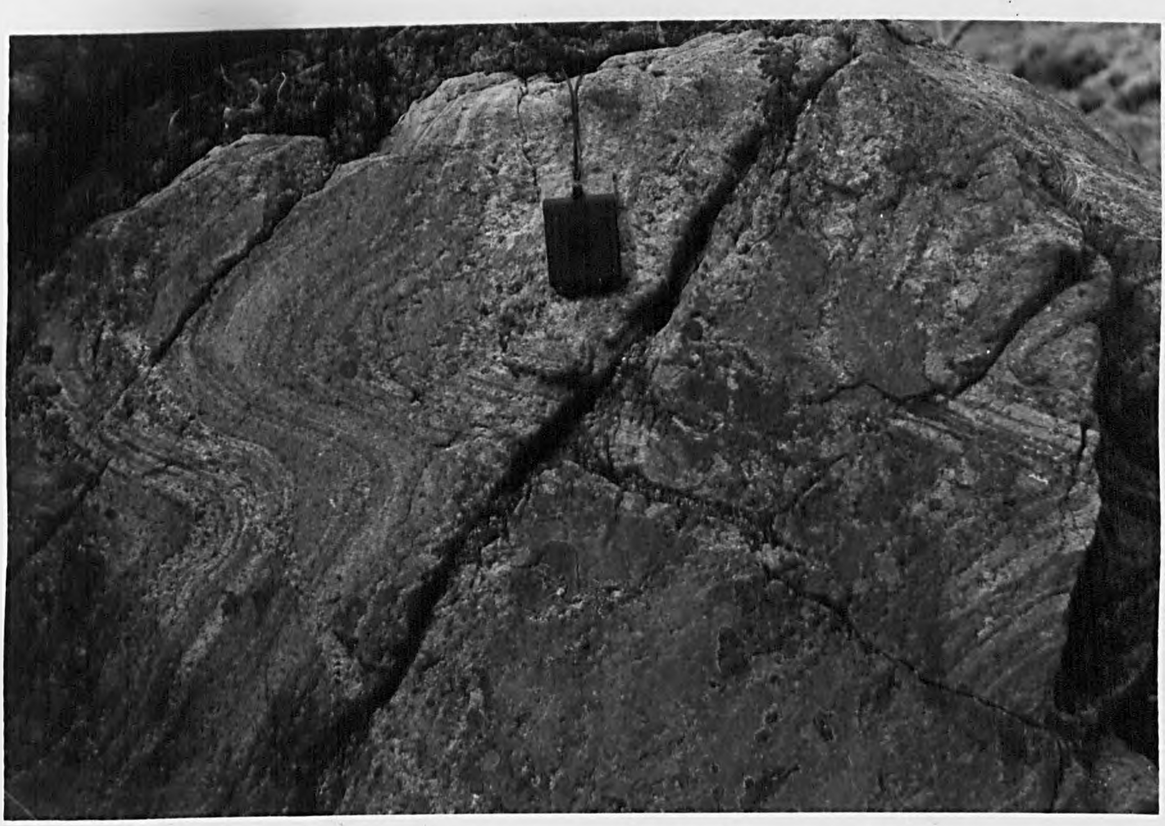


Plate 41: Folding of the foliation within the Druim Na Saille Pelite by a D1 fold (NM 95157910).

Plate 42: Folding of the foliation within the Druim Na Saille Pelite by tight D1 structures. (NM 95007955).

Plate 43: Gneissose banding deformed by asymmetric D2 folds. (Gulvain Psammitic Gneiss, NM 98558515).



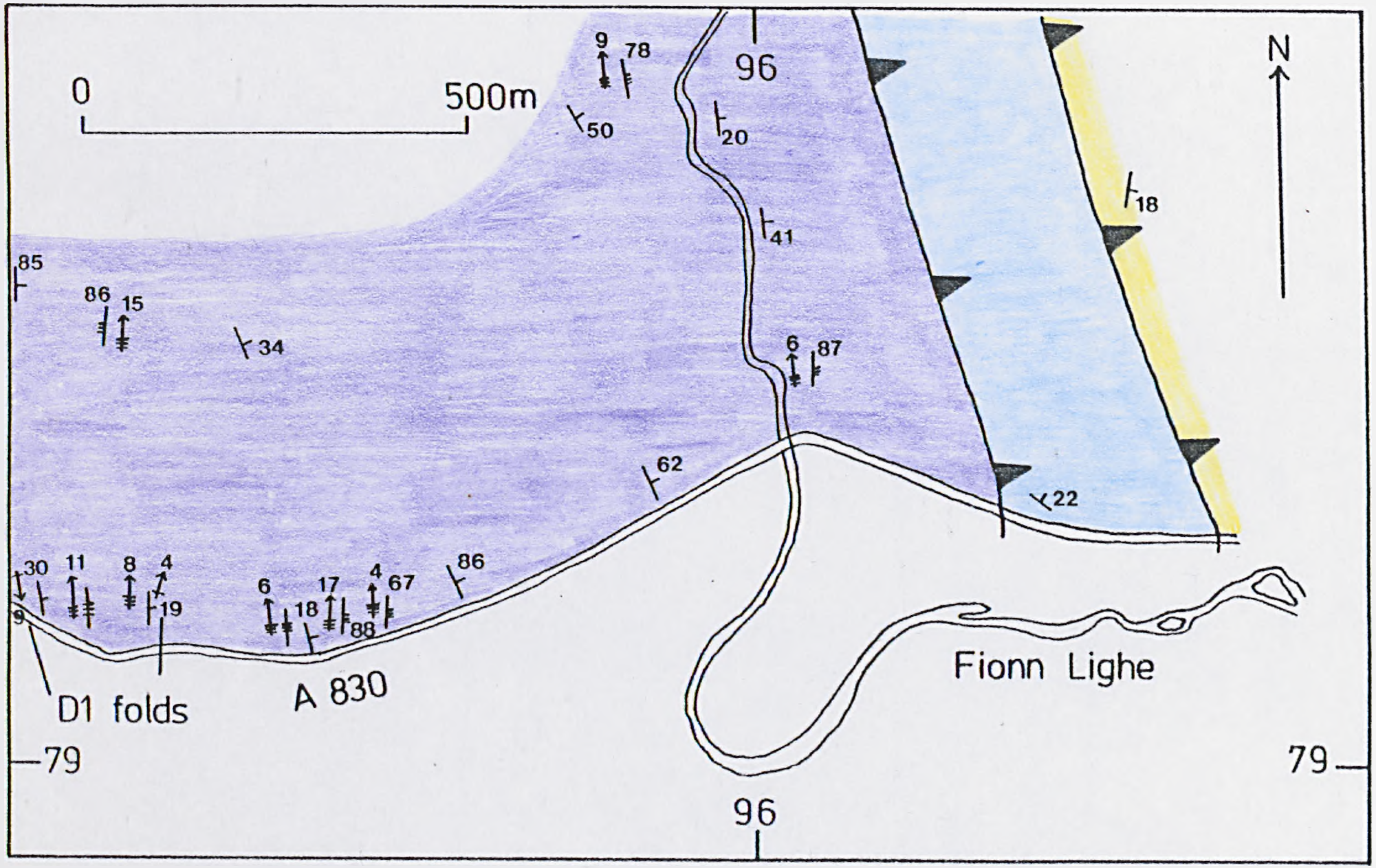


Figure 30: Structural geology of the area W of Loch Eil (ornamentation as in Enclosures 2 and 3).

observation that the foliation is not axial planar to these folds, but is deformed by them, clearly suggests that the formation of the foliation, and by inference Phase 1 folding, at least in part pre-dated D1 folding. The foliation is also deformed adjacent to D1 tectonic slides in the manner described on p. 61.

4.3.2.2. D2

The main foliation within the Druim Na Saille Pelite is clearly folded around the hinge of the major D2 Ben An Tuim synform in Glen Dubh Lighe, and is also folded by associated minor D2 folds at numerous localities on Na h-Uamachan, e.g. (NM 972847). These minor structures have the same style, attitude, axial direction and sense of vergence as nearby D2 folds within the Loch Eil Division, and are undoubtedly of the same age. D2 minor folds similarly deform the foliation within the Gulvain Psammitic Gneiss (Plate 43). Further S, near the Cona River, (Fig. 31) minor folds congruous with D2 folds within the Basal Psammite also fold thoroughly migmatised Druim Na Saille Pelite (Plates 1 and 52). Recrystallisation of micas parallel to the axial surfaces of the D2 folds is rare: the main foliation within the Glenfinnan Division always remains dominant, and thus the observations described unequivocally indicate that the formation of the foliation preceded D2 folding.

D3

4.3.2.3. The foliation within the Druim Na Saille Pelite may be traced around the hinge of the D3 Druim Na Saille synform, and is widely crenulated by associated minor folds. Tight N-S trending minor folds with associated axial planar crenulations are common on the NE slopes of Na h-Uamachan (Enclosure 5) and the northern slopes

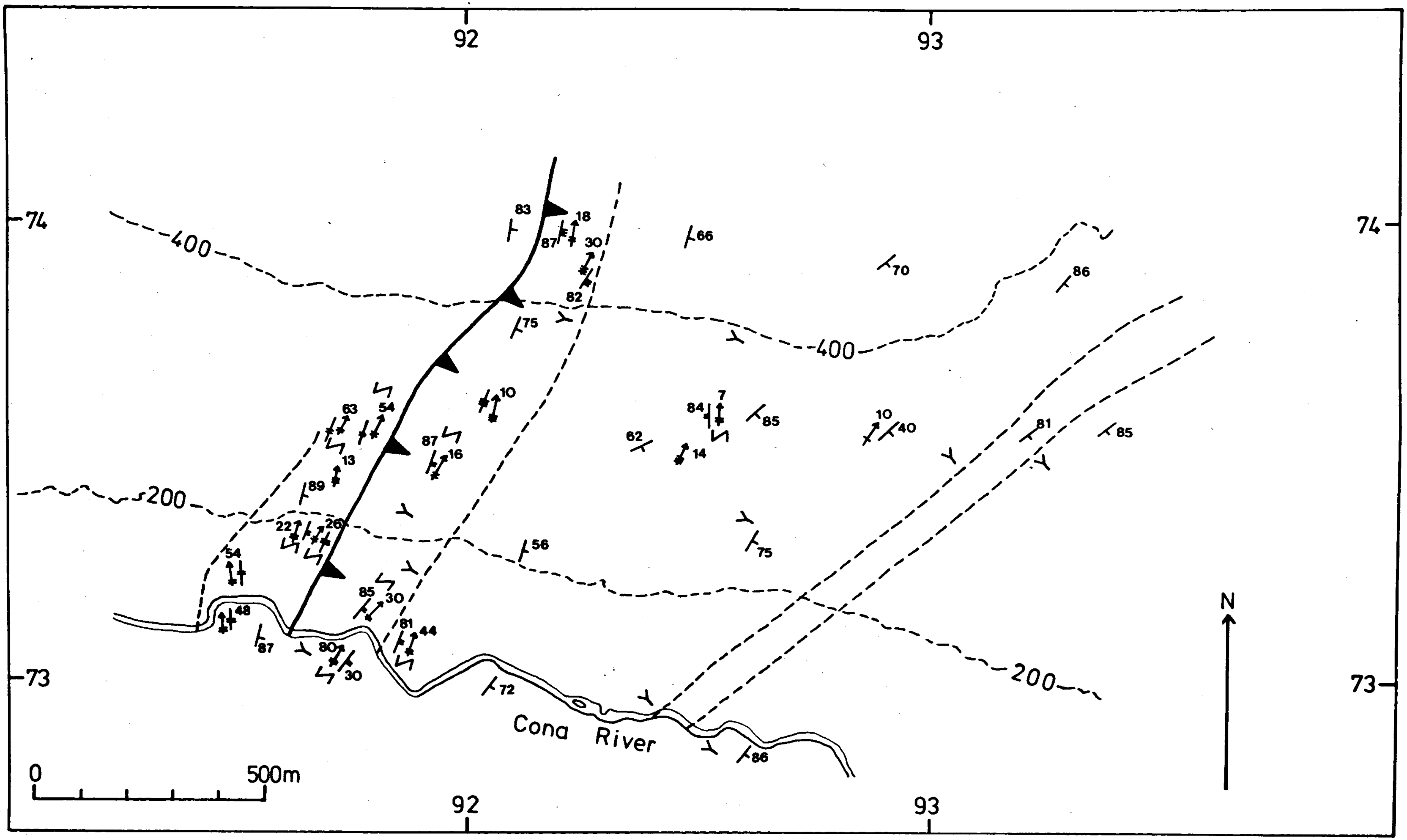


Figure 31: Structural geology of the area adjacent to the Cona River (ornamentation as in Enclosures 2 and 3).

of Cona Glen (Fig. 31), and are inferred to be of the same age as broadly congruous D3 structures within the Loch Eil Division. Adjacent to the A830 road the Druim Na Saille Pelite is folded by open to gentle folds which trend N-S and are probably also D3 in age (Fig. 30).

4.3.2.4. D4

The only evidence of D4 deformation within the Glenfinnan Division is seen in the folding of the contact of the Druim Na Saille Pelite and Basal Psammite in the core of the D4 Loch Eil antiform.

4.3.2.5. D5

Several of the subvertical D5 faults mapped within the Loch Eil Division on the western slopes of Druim Fearna extend westwards into the Druim Na Saille Pelite, where they are similarly marked by thin zones of brecciation, diaphthoritic chlorite and granite-veining.

4.4. CORRELATION WITH PREVIOUS WORK

Previous work within the Loch Eil Division, carried out along the western margin of the area (Dalziel 1966), suggested a structural history comprising four main fold phases. The products of each of these can be directly related to the sequence D1-D4 established within this study and extended throughout the Loch Eil Division.

The deformational sequence established by Stoker (1980) working S of Loch Eil (Fig. 4) comprised an early series of minor isoclinal folds (D1) which were followed by two phases of major folding (D2 and D3). These would appear to be equivalent to the sequence D1-D3 established in this study, and the stratigraphic and structural unity between the areas investigated by Stoker and the present author are illustrated in Fig. 32. The D4 phase of folding recognized in this study does not, however, appear to be represented in the area mapped by Stoker, since the products of the fourth phase of deformation recognized by him comprise a series of brittle thrusts, apparently related to movement along the Great Glen. These are likely to be broadly equivalent to the D5 structures described within the present study.

There is thus a broad measure of agreement between successive workers concerning the number, style and sequence of deformational events represented within the Loch Eil Division. The present study does not, however, uphold the contention of Dalziel (1966) and Brown *et al*. (1970) that both the Glenfinnan and Loch Eil Divisions have undergone a common structural history.

4.5. CONCLUSIONS

These may be summarised thus:

(a) Five deformational events (D1-D5) have been recognized within the Loch Eil Division. Recumbent folding and westerly-directed tectonic sliding occurred during D1, and resulted in the interleaving of the rocks of the Glenfinnan and Loch Eil Divisions. Major folds were produced during D2-D4 and the disposition of the D2 and D3 folds suggests that the regional structure is dominated by the interference of these two fold systems. 'Brittle' faults and thrusts are the characteristic features of the last deformational episode, D5.

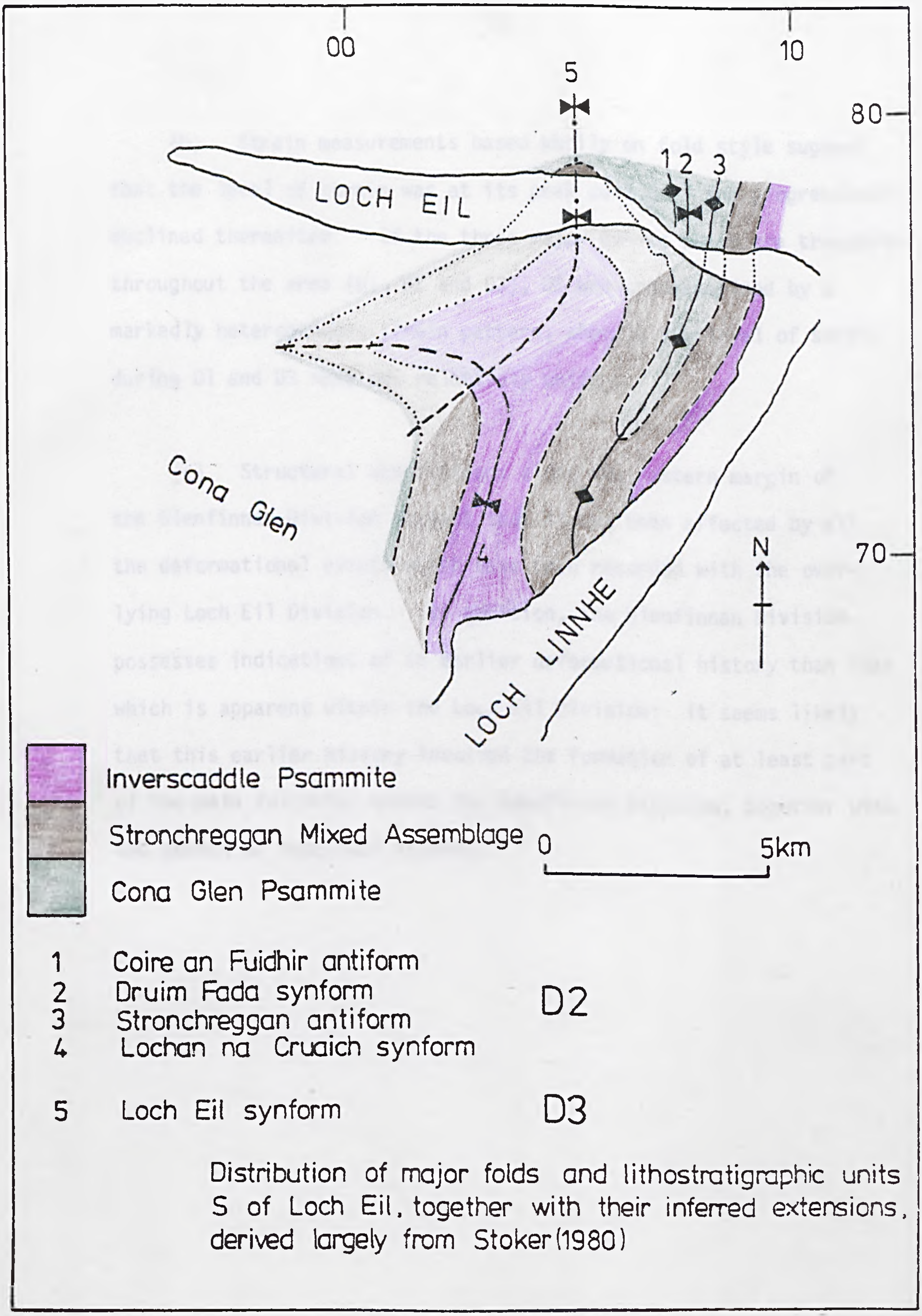


Figure 32: Stratigraphic and structural unity between parts of the areas mapped by Stoker (1980) and the present author.

(b) Strain measurements based wholly on fold style suggest that the level of strain was at its peak during D1 and progressively declined thereafter. Of the three major events which are traceable throughout the area (D1, D2 and D3), D2 was characterised by a markedly heterogeneous strain pattern, whereas the level of strain during D1 and D3 remained relatively uniform.

(c) Structural observations along the eastern margin of the Glenfinnan Division suggest that it has been affected by all the deformational events which have been recorded with the overlying Loch Eil Division. In addition, the Glenfinnan Division possesses indications of an earlier deformational history than that which is apparent within the Loch Eil Division: it seems likely that this earlier history involved the formation of at least part of the main foliation within the Glenfinnan Division, together with two phases of isoclinal folding.