REPT.BK.NO. 76/14

GEOLOGICAL EXCURSION TO LATE PRECAMBRIAN ROCKS IN BRITAIN, SEPTEMBER, 1975

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BIOSTRAT.REPT.BK.2/76

DEPARTMENT OF MINES
SOUTH AUSTRALIA

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by

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Palaeobotany Section

11th February, 1976

Rept.Bk.No. 76/14
G.S. No. 5691
D.M. No. 197/75
Biostrat.Rept.No. 2/76

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ABSTRACT

A thirteen day excursion to Britain during September 1975 provided the opportunity to visit briefly the major outcrops of late Precambrian rocks of England, Scotland and Wales. These included (1) a fossiliferous vulcano-sedimentary sequence at Charnwood Forest, (2) the Dalradian Supergroup of the Scottish Highlands, including very late Precambrian stromatolites and tillites, (3) the Moine succession that underlies the Dalradian, (4) the late Precambrian Stoer and Torridon Groups of redbed clastics that unconformably overlie Lewisian basement metamorphics west of the Moine Thrust, (5) the latest Precambrian eugeosynclinal Monian Supergroup of Anglesey, including a melange containing stromatolitic limestone and (6) the ?latest Precambrian or Cambrian Longmyndian succession of shallow water clastics and volcaniclastics.

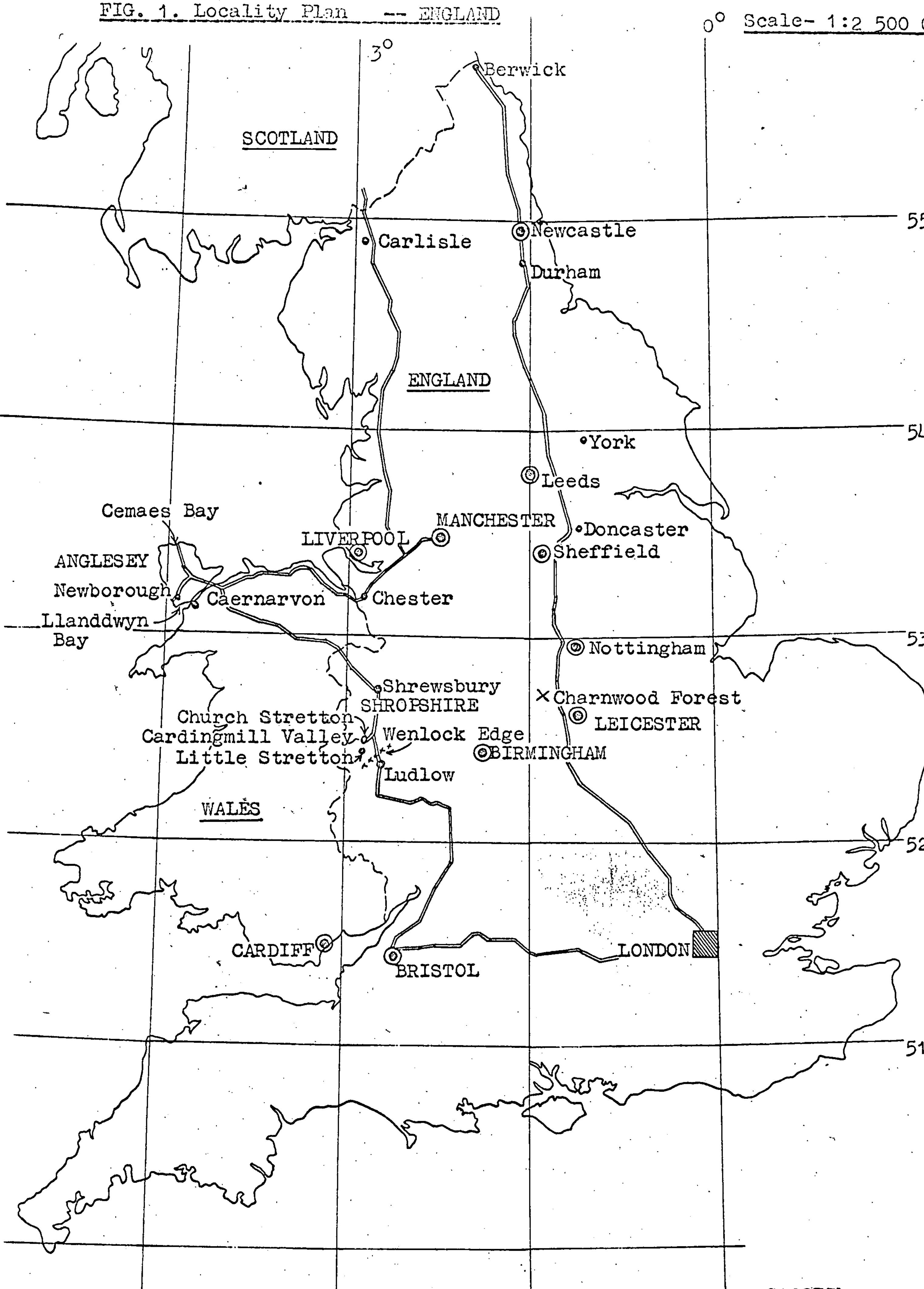
Research in Precambrian and early Palaeozoic acritarchs in the Torridon and Stoer Groups and the Dalradian Supergroup indicates the potential for similar studies to be carried out in the Adelaide Geosyncline.

INTRODUCTION

Upon receipt of an invitation to attend and contribute to a symposium on Precambrian correlations in Moscow, September 1975, it was decided that a conference on Fossil Algae in Erlangen, West Germany, in October, should also be attended. Dr. Marjorie Muir of Imperial College, London, while on a visit to Australia in May, offered to conduct Dr. M.R. Walter (Bureau of Mineral Resources) and myself ~~to conduct us~~ on an informal excursion to areas of Precambrian outcrop in England and Scotland during the time between the two major conferences we both attended. The

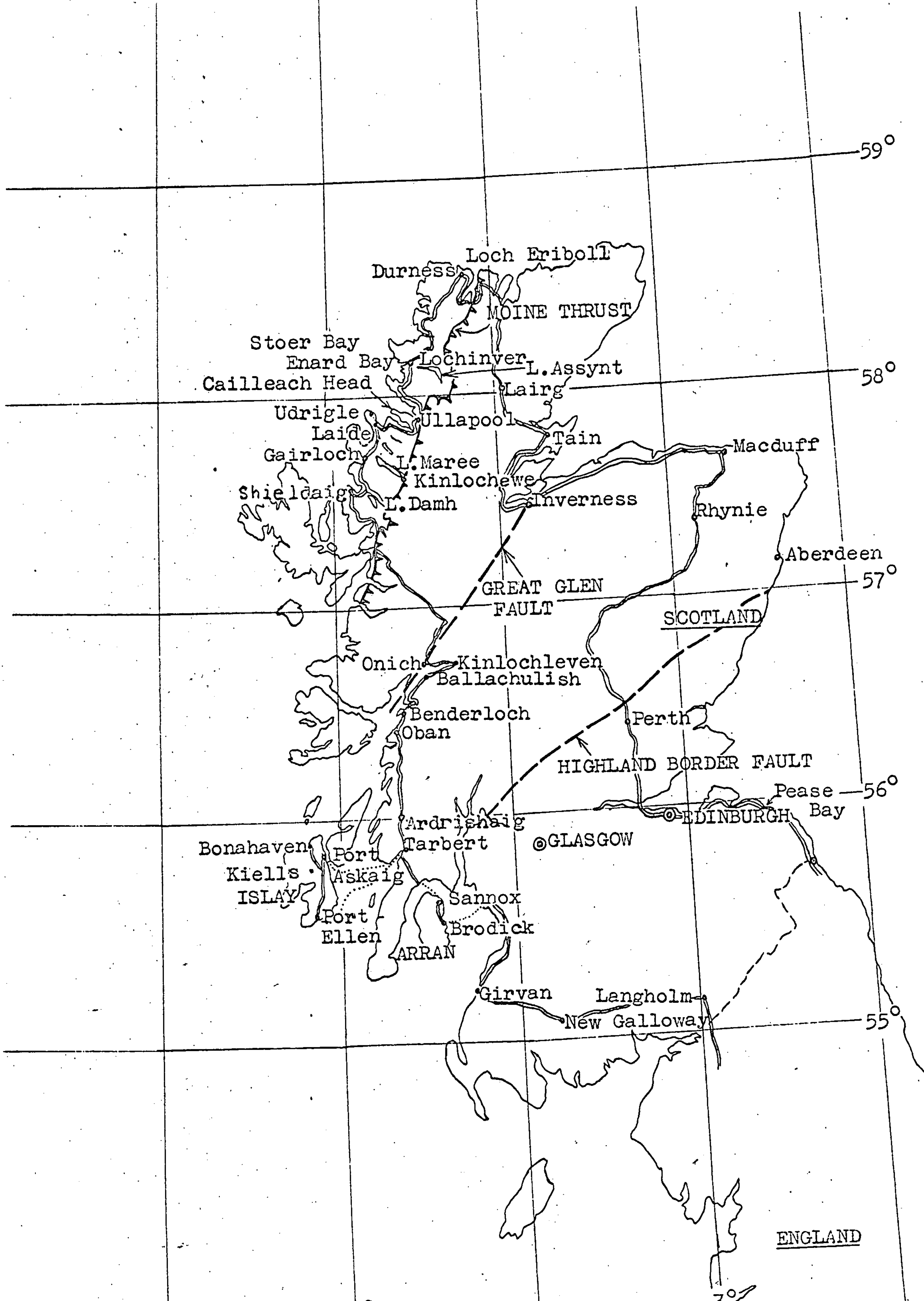
FIG. 1. Locality Plan -- ENGLAND

Scale- 1:2 500 0



S12073b.

FIG. 2. Locality Plan -- SCOTLAND Scale- 1:2 500 000



S12073a.

excursion involved thirteen days of field work (September 17 to 29). This report summarises the geology of areas visited, with special reference to the stratigraphic relations of major sedimentational sequences, and Precambrian palaeontology (acritarch and stromatolite studies).

The excursion will be described in terms of the localities visited. These are indicated on the general locality plans, Fig. 1 and Fig. 2.

ACKNOWLEDGEMENTS

The organisation of the excursion by Dr. M. Muir and Mr. Paul Grant is gratefully acknowledged. These and the remaining participants from Imperial College (Dr. W. Diver, Mr. G. Bliss and Dr. Shukla Sengupta) all contributed by acting as guides in areas they were individually most familiar with. I wish to express my gratitude to these people for their extremely valuable participation, and also to Drs. Trevor Ford and Roy Macgregor who guided us at Charnwood Forest and on Islay respectively.

THE PRECAMBRIAN OF CHARNWOOD FOREST (Guide: Dr. Trevor Ford)

The geology of this area, a small inlier of Precambrian northwest of Leicester (Fig. 1), is described by Dunning (1975). Three major stratigraphic units occur in a south-east plunging anticline, totalling a thickness of 2600 m:-

youngest:	Brand Group (300 m)	Swithland Slates Trachose Grit and Quartzite Hanging Rocks Conglomerate
	Maplewell Group (1400 m)	Woodhouse and Bradgate Formation Slate Agglomerate Beacon Hill Formation Felsitic Agglomerate

oldest: Blackbrook Formation
(900 m)

The Blackbrook Formation consists of banded tuffs, distal turbidites and mudstones. The Felsitic Agglomerate has pink feldspathic rock fragments in a welded tuff matrix. It is very variable in feldspar content and in degree of welding.

The Beacon Hill Formation consists of distal waterlaid pyroclastics, passing northwestwards to coarse boulder beds in which the porphyritic dacite boulders were rounded by attrition in a volcanic vent.

The Slate Agglomerate consists of poorly welded coarse ash with large angular slabby fragments of tuffaceous siltstone (Fig. 3).

The Brand Group is mainly sedimentary with conglomerates, quartzitic sandstones and slates.

Intrusives include markfieldite (micrographic diorite) laccoliths and dacitic and rhyodacitic porphyries, all predating the Charnian cleavage. Dr. Ford quoted an age of about 560 m.y. (K-Ar). In the north, finer grained diorites are younger and were intruded along reverse faults. Similar rocks occur some 15 km away in boulders in Cambrian basal conglomerates resting unconformably on the parent rock. At nearby Bardon Hill, a microdiorite-dacite apparently intrudes all the Charnwood rocks but is thought to belong to the same volcanic suite. Meneisy and Miller (1963) conducted a geochronological study of the igneous rocks of the area (all K-Ar); the Bardon Hill samples are the only ones that gave Precambrian ages (684 ± 29 and 595 ± 26 m.y.). 680 m.y. has generally been accepted as the age of intrusion and as a minimum age for the volcanic and sedimentary rocks at Charnwood Forest.

Fig. 3. The Slate Agglomerate, Maplewell Group, Charnwood Forest, consisting of large angular slabs of tuffaceous siltstone in a poorly welded coarse ash matrix.

Neg. No. 27082.

Fig. 4. The bedding plane that contains impressions of the late Precambrian metazoan fossil *Charniodiscus*, Woodhouse and Bradgate Formation, Maplewell Group, Charnwood Forest.

Neg. No. 27083.

Fig. 5. The circular impression of *Charniodiscus* on the same bedding plane. The lithology is a green slaty siltstone. Scale graduated in centimetres.

Neg. No. 27084.

Fig. 6. Another outcrop with *Charniodiscus* on a bedding plane at the Outwoods, near Charnwood Forest. Diameter lens cap 5.3 cm.

Neg. No. 27085.


Fig. 3


Fig. 4

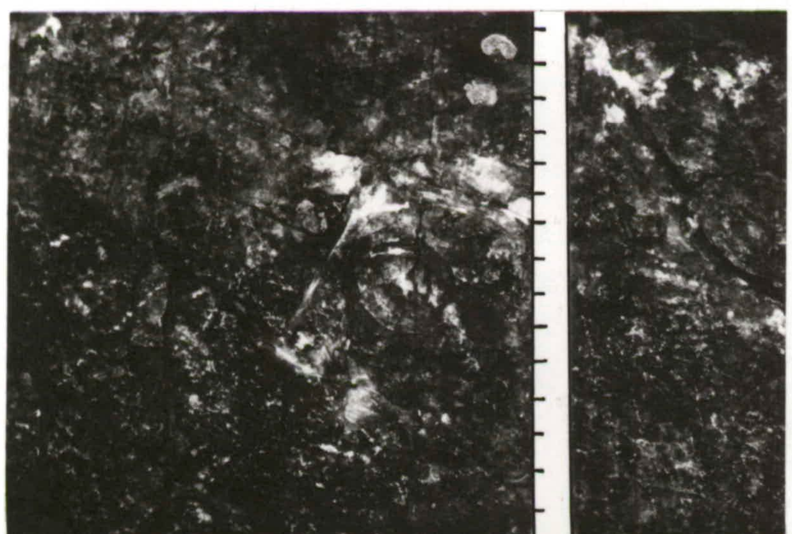


Fig. 5

Fig. 6

The bedding plane containing impressions of soft-bodied metazoa was demonstrated to us (Fig. 4). It occurs in a green slaty siltstone of the Woodhouse and Bradgate Formation, directly overlying the Slate Agglomerate. The circular impression of *Charniodiscus concentricus Ford* (Fig. 5) is thought to represent a medusoid, possibly related to the sea pen *Charnia masoni* Ford, to which it may have been joined by a stalk. No unquestionable fossil to prove this has been found, however, (Glaessner & Wade, 1966). A second outcrop with *Charniodiscus* (Fig. 6) was demonstrated at the Outwoods, near Charnwood Forest.

PALAEOZOIC ROCKS OF SOUTH-EAST SCOTLAND

On leaving Charnwood Forest we travelled north through Yorkshire, where we briefly observed white flaggy, wavy bedded Permian dolomites near Doncaster (Fig. 7). North of our first stopover at Berwick-upon-Tweed, we saw Silurian greywackes with 20 cm graded beds and 10 cm thick slate interbeds, and flute casts on the base of some sandy beds. At Pease Bay (Fig. 2) there are coastal exposures of Carboniferous red to red-brown slightly calcareous sandstones with channel cross-bedding, and pebbly bands. In places channels are exposed on bedding planes; some beds have extremely steep foresets (Fig. 8). There are thin interbeds of black oil shale. One of many coal interbeds was observed, here in fault contact with a sandstone (Fig. 9). One sandstone outcrop contained fossil roots of *Stigmaria* (Fig. 10). At Rhynie, the famous locality of Devonian black cherts containing abundant plant microfossils, there is now little outcrop, and we found only scattered float of chert and laminated sandy, tuffaceous sediments, in places silicified. Small black chert samples collected are potentially fossiliferous.

Fig. 7. White flaggy, wavy bedded Permian dolomites near Doncaster, Yorkshire.

Neg. No. 27086.

Fig. 8. Carboniferous red-brown sandstones with high angle cross-bedding, exposed in wave-cut platform at Pease Bay, South-east Scotland.

Neg. No. 27087.

Fig. 9. A coal interbed in fault contact with a sandstone, (Carboniferous), at Pease Bay, South-East Scotland.

Neg. No. 27088.

Fig. 10. Carboniferous sandstone containing the fossil root *Stigmaria*, Pease Bay, South-East Scotland. Scale graduated in 10 cm intervals.

Neg. No. 27089.


Fig. 7


Fig. 8


Fig. 9


Fig. 10

THE DALRADIAN SUPERGROUP: A LATE PRECAMBRIAN AND EARLY PALAEOZOIC SEQUENCE OF THE SCOTTISH HIGHLANDS

The Dalradian Supergroup is described by Harris and Pitcher (1975) as "a lithologically diverse supergroup ..... of metasedimentary and meta-igneous rocks of late Precambrian - Cambrian age which crop out in Ireland and Scotland (including Shetland) and which are younger than, and on a regional scale overlie the lithologically more monotonous Moine rocks". The Supergroup is exposed in the Scottish Highlands between the Highland Border Fault and the Great Glen Fault (Fig. 2), but does not occur to the west of the Moine Thrust, where unmetamorphosed late Precambrian ("Torridonian") and early Palaeozoic sediments overlie metamorphic basement ("Lewisian"). The Dalradian sequence is very thick (of the order of 20 km) and was deposited "in a complex trough elongated N.E.-S.W. Because the trough margins are tectonically broken away from its forelands, direct correlations with the appropriate shelf deposits is not possible" (Harris & Pitcher, 1975, p.52). The authors propose a three-fold division of the Dalradian: the (upper) Southern Highland Group is Cambrian to possibly Ordovician, the (middle) Argyll Group is latest Precambrian to Cambrian, and the (lower) Appin Group is late Precambrian. The sequence as examined by us is summarised in the generalised stratigraphic table (Table 1).

Southern Highland Group

The first outcrop examined is of Macduff Slate of the Southern Highland Group in coastal exposures at Macduff (Fig. 2). This area is being studied by Mr. G. Bliss, who has succeeded in extracting microfossils (acritarchs) from metamorphosed clastic sediments by HF maceration.

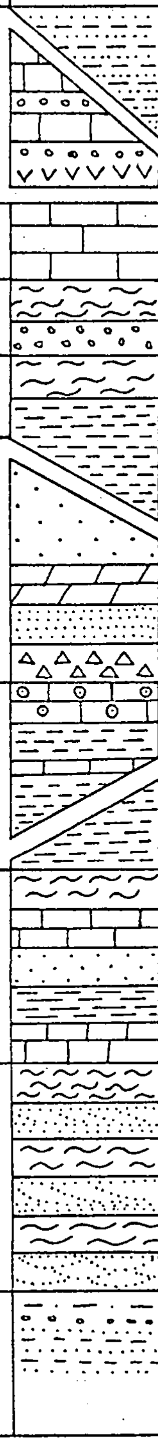
AGE	GROUP	SUB GROUP	LITHO	FORMATION
?Transition to Ordovician	SOUTHERN HIGHLAND GROUP (Upper Dalradian)			Macduff Slate Volcanics, grits Leny Limestone
Cambrian	ARGYLL GROUP (Middle Dalradian)	Tayvallich		Tayvallich Limestone
		Crinan		Stonefield Schist Crinan Grits
?		Easdale		Craignish Phyllite Easdale Slate
?Vendian		Islay		Jura Quartzite Bonahaven Dolomite Quartzite Port Askaig Tillite
Riphean	APPIN GROUP (Lower Dalradian)	Blair Athol		Islay Limestone Slates, phyllites, limestones Cuil Bay Slate
		Ballachulish		Appin Phyllite Appin Limestone Appin Quartzite Ballachulish Slate Ballachulish Limestone
		Lochaber		Leven Schist Glencoe Quartzite Binnein Schist Binnein Quartzite Eilde Schist Eilde Quartzite
				Eilde Flags (?Moine)

TABLE I. Generalized stratigraphy of the Dalradian Supergroup in Scotland (based on Harris & Pitcher, 1975).

Fig. 11. Pull-apart breccia of silty fragments in a metasandstone matrix, part of turbidite sequence of the Macduff Slate (upper Dalradian), in coastal exposures at Macduff, Scotland.

Neg. No. 27090.

Fig. 12. A one-metre thick bed of graded metasandstone, with sharp base, overlying metasiltstone at the top of the previous cycle. Macduff Slate (upper Dalradian), in coastal exposures at Macduff, Scotland.

Neg. No. 27091.

Fig. 13. Granule-filled erosional channels in thickly bedded feldspathic grits. Macduff Slate (upper Dalradian), in coastal exposures at Macduff, Scotland.

Neg. No. 27092.

Fig. 14. Thin graded beds in metasiltstone, Macduff Slate, (upper Dalradian), in coastal exposures at Macduff, Scotland.

Neg. No. 27093.

The pen in each photograph is 14 cm long.

Fig. 11

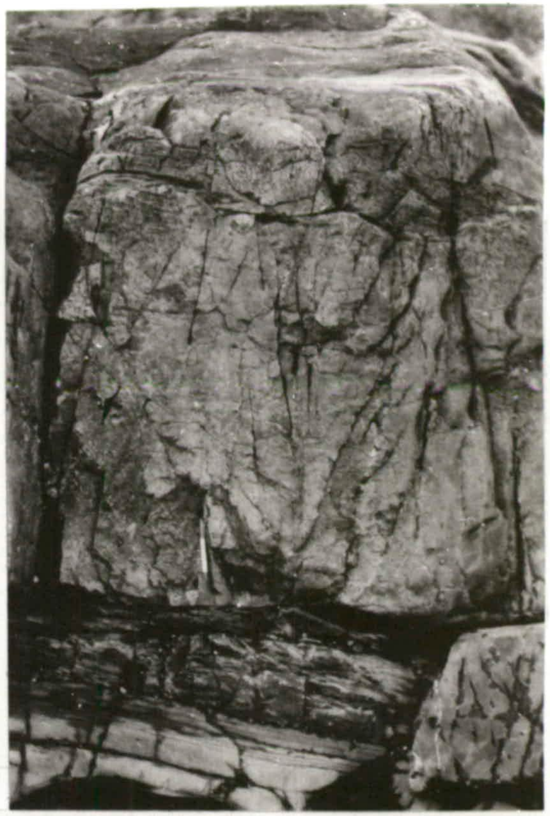


Fig. 12

Fig. 13

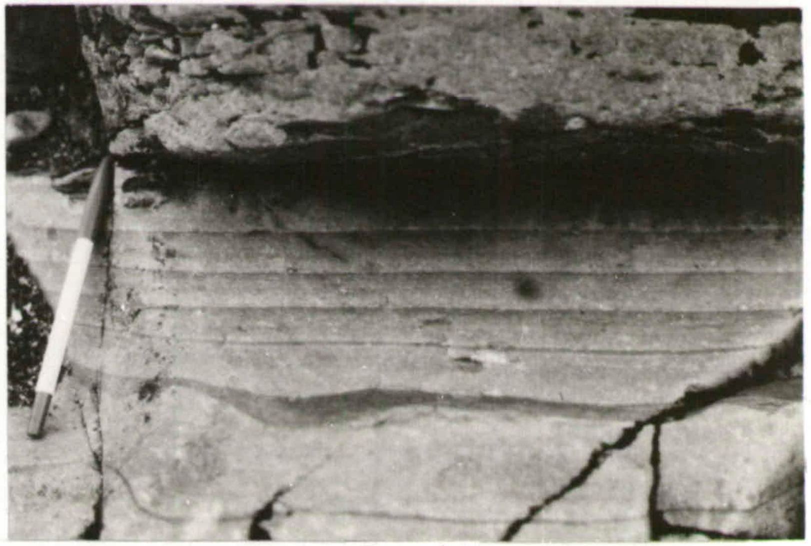


Fig. 14

That microfossils are preserved in such highly deformed and metamorphosed rocks is remarkable, and indicates the potential of similar studies in the far less altered rocks of the Adelaide Geosyncline. The Macduff Group, interpreted as a turbidite sequence, consists of meta-sandstones, sometimes graded (Fig. 12) with interbedded meta-siltstone. Grain size grades up from very coarse sand at the base to medium sand at the top, with a bed thickness of up to one metre. Isoclinal folds are generally confined to the argillaceous beds. Pull-apart breccia, consisting of irregular siltstone fragments in a greywacke matrix (Fig. 11) was probably formed by slumping. There are also thin graded beds only 2-3 cm thick, mainly in siltstone (Fig. 14), but broadly laminated, non-graded siltstone is more common. Ripple marks with internal cross-lamination occur in finer sandstone beds. The sequence here appears to dip and face uniformly to the west at about 30°, but there may be reversals of facing further west, where dark metasiltstones, then coarse, angular feldspathic grits appear. The latter form very massive, crudely graded beds, with small channels filled with coarser granules, (Fig. 13) possibly facing east. Fig. 15 illustrates a greywacke bed with flame structures and siltstone breccia.

The Moine succession (older than the Dalradian)

Leaving Macduff we travelled through Inverness and Tain to Lairg (Fig. 2). Near here we briefly inspected outcrops of gneisses belonging to the Moine succession (Fig. 16). Although the Moine in some areas contains metasandstones displaying cross-bedding (Williams, 1966), in this outcrop there was no evidence of the preservation of bedding or any other sedimentary structures. The rocks are medium grained quartzo-feldspathic gneisses with black micaceous laminations (Fig. 17). They gave the impression of a much higher grade of metamorphism than the

Fig. 15. Flame structures in coarse metagreywacke bed, involving the underlying siltstone. The metagreywacke also contains angular siltstone clasts. Macduff Slate (upper Dalradian) in coastal exposures near Macduff, Scotland. Pen for scale is 14 cm long.

Neg. No. 27094.

Fig. 16. Outcrop of quartzofeldspathic gneisses of the Moine succession, in the vicinity of Lairg, Scotland.

Neg. No. 27095.

Fig. 17. Alternating micaceous and quartzofeldspathic bands in medium grained gneisses of the Moine succession, in the vicinity of Lairg, Scotland. Pen for scale is 14 cm long.

Neg. No. 27096.

Fig. 18. Alternating bands of metasandstone and phyllite in the Moine succession at Coulin Lodge, near Kinlochewe, Scotland. The bands are lenticular and appear to result from the transposition of bedding. Pen for scale is 14 cm long.

Neg. No. 27097.


Fig. 15


Fig. 16

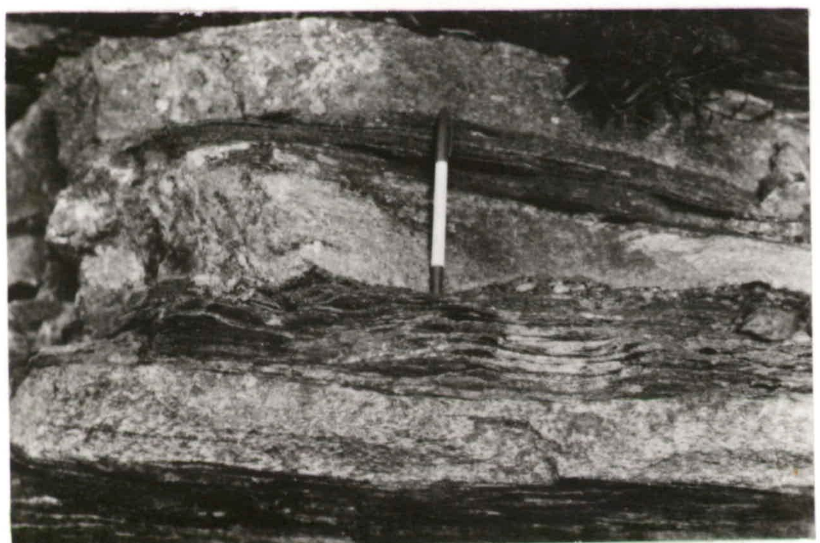


Fig. 17


Fig. 18

Fig. 19. Flaggy, pale brown weathering dolomite with silty limestone interbeds, ("tiger rock"), Appin Limestone, Appin Group (lower Dalradian) in coastal exposures at Onich, Scotland.

Neg. No. 27098.

Fig. 20. Strongly cleaved phyllite with well preserved bedding lamination, Appin Phyllite, Appin Group (lower Dalradian), in coastal exposures at Onich, Scotland.

Neg. No. 27099.

Fig. 21. Interbed of flat pebble breccia limestone in Appin Phyllite, Appin Group, (lower Dalradian) in coastal exposures at Onich, Scotland.

Neg. No. 27100.

Pen for scale is 14 cm long.

Fig. 22. Dolerite dyke intruding white quartzite interbed in Appin Phyllite, Appin Group (lower Dalradian), in coastal exposures at Onich, Scotland.

Neg. No. 27101.


Fig. 19

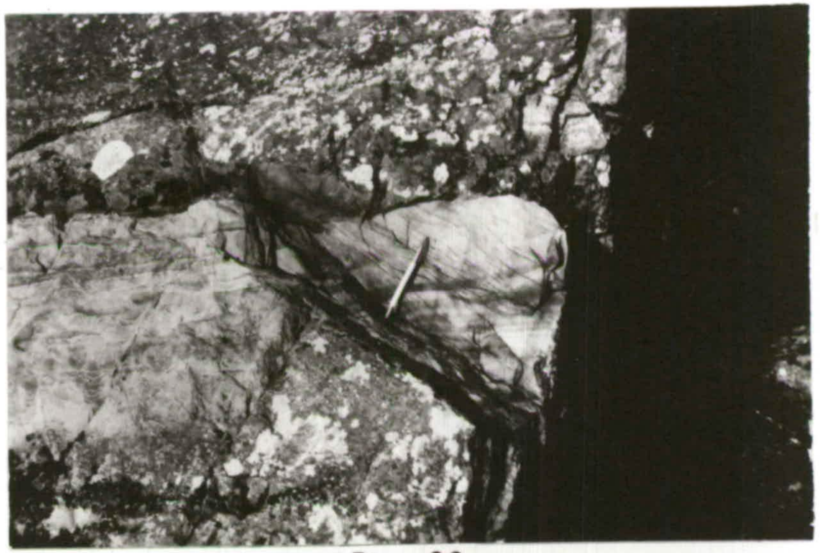


Fig. 20

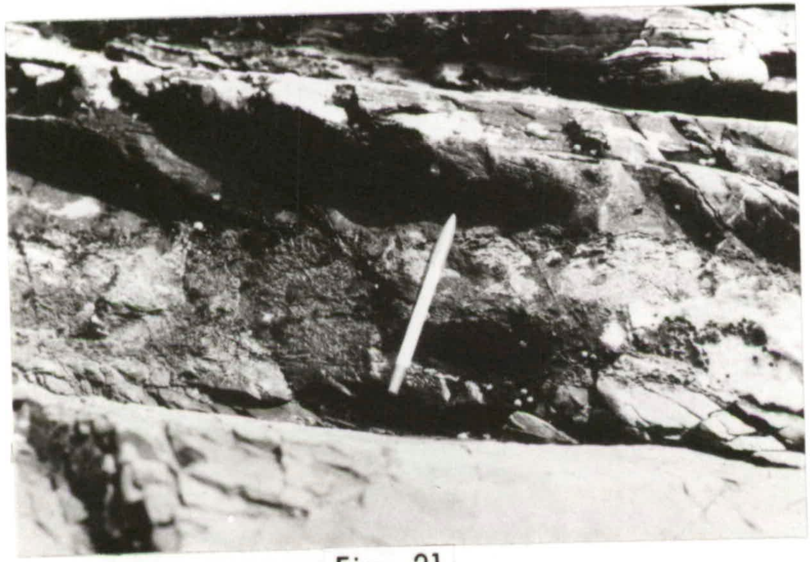


Fig. 21


Fig. 22

Fig. 23. White medium grained quartzite with trough cross-bedding, Appin Quartzite, Appin Group, (lower Dalradian) in coastal exposures at Onich, Scotland. Pen for scale is 14 cm long.

Neg. No. 27102.

Fig. 24. Outcrops of massive white Eilde Quartzite in the Leven River, near Kinlochleven, Appin Group (lower Dalradian), Scotland.

Neg. No. 27103.

Fig. 25. Pebbly interbed in the Eilde Quartzite (near its base), Appin Group, (lower Dalradian), exposed in the Leven River, near Kinlochleven, Scotland. Pen for scale is 14 cm long.

Neg. No. 27104.

Fig. 26. Section in the Leven River spanning the contact between the lower Dalradian Eilde Quartzite (at right) and the Eilde Flags (at left), regarded by some as belonging to the Moine succession, near Kinlochleven, Scotland.

Neg. No. 27015.


Fig. 23

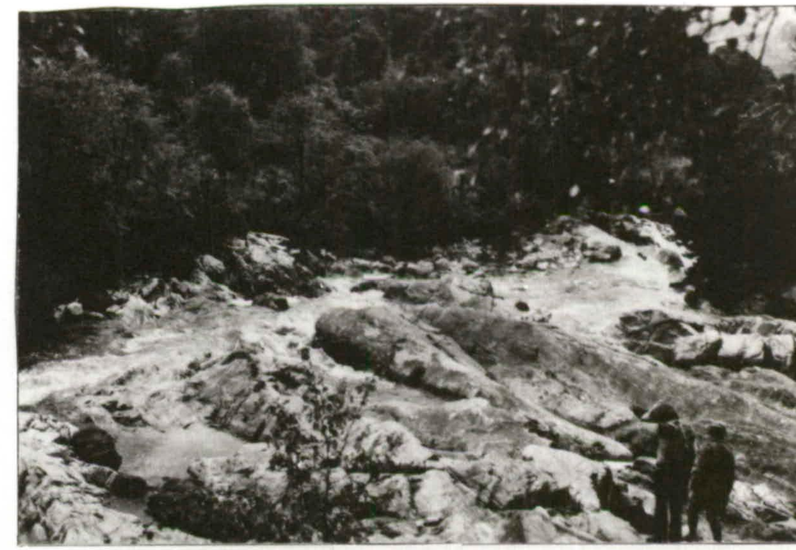


Fig. 24


Fig. 25


Fig. 26

Dalradian. Some days later we briefly saw more of the Moine Succession at Corrieshalloch Gorge near Ullapool (Fig. 2), here consisting of gently dipping but considerably recrystallized metasandstone. Again at Coulin Lodge, near Kinlochewe (Fig. 2) outcrops of Moine metasediments show evidence of complete destruction of sedimentary structures by deformation. Here lenticular bands of coarse feldspathic metasandstone alternate with dark, phyllitic metasiltstones, 1-5 cm thick. The lenses are probably remnants of transposed beds, now aligned parallel to the schistosity (Fig. 18).

The Appin Group

The lower Dalradian Appin Group was examined in some detail in coastal exposures in the vicinity of Onich (Fig. 2). Unlike the upper Dalradian turbidites of the Macduff Slate, the Appin Group consists mainly of shallow water sediments - metamorphosed siltstones, dolomites and pure quartzites. Our section commenced in the generally east dipping but west facing Appin Phyllites, a highly deformed sequence of dark grey, massive to poorly bedded metasiltstones, with interbeds of phyllitic siltstone and metasandstone. These pass down into calcareous siltstones with thin brown weathering dolomite and quartzite interbeds, sometimes with slump structures, and then into pale grey flaggy limestone (Appin Limestone) with silty interbeds. This sequence contains tight isoclinal folds, and in places pods of dark grey silty limestone in phyllitic siltstone. It was not certain if this was a sedimentary feature or due to transposition of bedding. The "tiger rock" (Fig. 19) is a flaggy, pale brown weathering dolomite with silty limestone interbeds, again with isoclinal minor folds. Underlying phyllitic siltstones are highly cleaved but have well preserved bedding laminations (Fig. 20), dipping steeply west. Small cut-and-fill structures and graded bands indicate a west facing. Dolomitic interbeds are tightly folded and boudinaged. White, medium grained quartzite interbeds have west-facing cross-laminations. There are thin interbeds of flat-pebble breccia limestone (Fig. 21) and sandy cross-bedded limestone; facings change on the limbs of isoclinal folds, as indicated by trough cross-bedding, ripple marks, and erosional channels filled with flat pebble breccia dolomite. Dolerite dykes with ophitic texture intrude the sequence, both at this point and also in the underlying quartzites (Fig. 22).

The underlying Appin Quartzite is a pale pink, medium grained clean quartzite with repeated thin interbeds of cream dolomite, cut by several small bodies of acid porphyry. The dolomitic sequence continues downwards to a sheared contact with very massive white clean quartzite with west-facing cross-laminations, again cut by dolerite. Sedimentary structures include trough cross-bedding, slumps and channels (Fig. 23).

The phyllitic, pyritic, crenulated black Ballachulish Slate underlies the quartzite, followed by the Ballachulish Limestone, here consisting of micaceous and calcareous schist with interbeds of dolomite. On the east limb of a syncline, the quartzite is directly in contact with the Leven Schist of the underlying Lochaber Supgroup; the intervening Ballachulish Limestone and Slate were faulted out by the Ballachulish Slide, prior to folding.

The lowest beds of the Dalradian (Lochaber Subgroup) were examined in the Leven River near Kinlochleven, on the west limb of the Blackwater Synform. The structural geology of this area is described in some detail by Treagus, (1974). Our section commenced just east of

Kinlochleven, in the Binnein Quartzite, a clean, white, blocky quartzite with well preserved cross-lamination. There is a transition into the underlying Eilde Schist, a dark, graphitic mica schist, then into the Eilde Quartzite (Fig. 24), consisting of massive to blocky, well bedded, medium grained white to pink quartzite with well preserved bedding laminations and trough cross-bedding. The facings observed were consistently to the north-west. Some foresets were oversteepened by slumping. Lower in the sequence the beds become vertical, and are intruded by basic dykes. The underlying more flaggy, quartzites with interbedded schists (Fig. 26) (Eilde Flags) are considered by many workers to belong to the Moine succession, the base of the Dalradian coinciding with the base of the Eilde Quartzite (Harris & Pitcher, p.58). A pebbly lens, with granules up to 2 cm of quartz and feldspar (Fig. 25), occurs near what is taken as the base of the Eilde Quartzite. The beds above and below this pebbly lens are all concordant, and cross-bedding indicates identical facings. The contact between the Eilde Quartzite and Eilde Flags appears quite conformable, and indeed arbitrary to pick. I therefore find it hard to accept that the Eilde Flags below it should be assigned to the Moine, especially as certain pegmatites intruding the Moine elsewhere are over 700 m.y. old (Van Breemen, Pidgeon and Johnson, 1974). Dunning (1972) discussed evidence that at least part of the Moine is older than 800 m.y. and it may have been metamorphosed prior to the deposition of the Dalradian. An unconformable relationship between the Moine and Dalradian might therefore have been expected, but most of the contacts are tectonic.

The Ballachulish Slate was further examined in the slate quarry of that name. It is a very dark grey banded or laminated, in part massive, phyllitic slate with abundant pyrite. An irregular isolated fragment of

Fig. 27. Lenticular block of dolomite in black Ballachulish Slate, Appin Group, in Ballachulish Slate Quarry, Ballachulish, Scotland. Pen for scale is 14 cm long.

Neg. No. 27106

Fig. 28. Conglomerate of probable mudflow origin in Easdale Slate, Argyll Group (middle Dalradian), in wave-cut platform at Ardnamucknish Bay near BEnderloch, Scotland.

Neg. No. 27107.

Fig. 29. Another outcrop of the same conglomerate, here containing reworked angular fragments of grit, slate and conglomerate.

Neg. No. 27108.

Fig. 30. Laterally-linked stromatolites grown over an erosional surface in trough cross-bedded dolomites, Bonahaven Dolomite, Argyll Group (middle Dalradian), Bonahaven, Islay, Scotland. Pen for scale is 14 cm long.

Fig. 27

Fig. 28

Fig. 29

Fig. 30

dolomite within the slate (Fig. 27) proved enigmatic; possibly it slumped into the basin during deposition.

The Cuil Bay Slate, of the Blair Atholl Subgroup seen at Cuil Bay is the youngest unit exposed in the Appin Syncline. It consists of black slates with occasional limestone marble interbeds. Bedding laminations are only locally visible in these highly cleaved and crenulated rocks. On the north shore of the bay, the underlying Appin Quartzite and dolomitic limestones are exposed.

The Argyll Group

The Easdale Slate, possibly of Early Cambrian age, exposed at Ardnamucknish Bay near Benderloch (Fig. 2), consists of black slates with grey limy lenses. Fine bedding laminations, often sandy, are tightly folded. The slates show a crenulation cleavage as well as slaty cleavage. Gritty and pebbly interbeds contain blue and purple quartz. A conglomerate contains rounded pebbles up to 30 cm in diameter (Fig. 28), and redeposited clasts of grit or conglomerate (Fig. 29). This sediment is described and interpreted as a slump breccia by Litherland (1975), who also recorded oncolites and catagraphia in limestone clasts.

The overlying Craignish Phyllite, a green chloritic phyllite with irregular strings of quartz along the cleavage occurs at Ardrishaig (Fig. 2). The Crinan Grits here comprise isoclinally folded quartzite interbeds in schist.

Islay (Guide: Dr. Roy Macgregor)

From Tarbert, we travelled by ferry to Port Ellen on the island of Islay (Fig. 2), on which we examined parts of the ?latest Precambrian Islay Subgroup. The Bonahaven Dolomite at Bonahaven is largely stromatolitic, and was sampled by M.R. Walter and myself. The stromatolites

Fig. 31. Margin of a stromatolitic bioherm, with flat bedded dolomite lapping on to it, in Bonahaven Dolomite, Argyll Group (middle Dalradian), Bonahaven, Islay, Scotland. Scale graduated in cm.

Neg. No. 27110.

Fig. 32. Stromatolitic dolomite with closely spaced pseudocolumns and columns (calcitic) and with dolomitic interspaces. Bonahaven Dolomite, Argyll Group (middle Dalradian), Bonahaven, Islay, Scotland. The pen for scale is 14 cm long.

Neg. No. 27111.

Fig. 33. A bed of tuberous, divergently branching columnar stromatolites with even lamination in a higher stratigraphic position in the Bonahaven Dolomite, Argyll Group (middle Dalradian), Bonahaven, Islay, Scotland. The pen for scale is 14 cm long.

Neg. No. 27112.

Fig. 34. Margin of a small stromatolitic bioherm of inclined columns and pseudocolumns, surrounded by oolitic dolomite, Bonahaven Dolomite, Argyll Group (middle Dalradian), Bonahaven, Islay, Scotland. The pen for scale is 14 cm long.

Neg. No. 27113.

Fig. 31

Fig. 32

Fig. 33

Fig. 34

were first described by Hackman & Knill (1962) then by Spencer & Spencer (1972). A typical growth sequence observed at Bonahaven commences as laterally-linked mounds over small-scale trough cross-bedded dolomite; the contact is an erosional surface (Fig. 30). The overlying bed contains small bioherms of closely spaced columnar stromatolites, the columns varying from 2 to 7 cm in diameter, and having steeply domed laminations. Columns are frequently calcitic, with dolomitic interspaces (some laminations are also dolomitic) (Fig. 32). A somewhat larger bioherm containing pseudocolumnar stromatolites (Fig. 31) is lapped on to at its margin by flat bedded carbonates. An upper stromatolitic dolomite contains markedly divergently branching, well defined columns with an even, almost banded, lamination (Fig. 33). Other forms include bioherms with inclined columns resting upon and surrounded by cross-bedded oolitic dolomite (Fig. 34). A lower member of the Bonahaven Dolomite contains black slates, which were sampled for acritarch studies.

At Kiells, the Islay Limestone of the Blair Atholl Subgroup, which underlies the Port Askaig Tillite, is a black oolitic limestone grading down into silty black limestone.

The boulder beds of the Port Askaig Tillite were observed near Kiells and at Port Askaig. Near Kiells, a thin, sandy, dolomitic boulder bed contains abundant clasts of buff-weathering dolomite, apparently derived from the underlying dolomite bed; and is structurally repeated in a complex outcrop pattern by faulting. In places, an erosional surface is visible between the boulder bed and the underlying dolomites (top part of the Islay Limestone). The dolomite locally contains intraformational flat-pebble breccia, and one 20 cm wide

Fig. 35. A broad stromatolite column in dolomite of the Islay Limestone, Appin Group, (lower Dalradian), immediately underlying the boulder beds of the Port Askaig Tillite. Exposure near Kiells, Islay, Scotland. The pen for scale is 14 cm long.

Neg. No. 27114.

Fig. 36. Massive dolomitic, sandy boulder beds at the base of the Port Askaig Tillite; many of the carbonate pebbles derived from the underlying Islay Limestone have been weathered out. Argyll Group (middle Dalradian), in exposure near Kiells, Islay, Scotland.

Neg. No. 27115.

Fig. 37. Dolomitic grit and pebble beds, with a thin ironstone band (dark band just below pen) with cleaved diamictite at the top. Port Askaig Tillite, Argyll Group (middle Dalradian), in exposure near Kiells, Islay, Scotland. The pen for scale is 14 cm long.

Neg. No. 27116.

Fig. 38. Quartzite (below) interbedded in the Port Askaig Tillite, Argyll Group (middle Dalradian), at the Port Askaig pier, Islay, Scotland. Bedded diamictite appears higher in the sequence (above the telegraph pole), while massive diamictite is seen in surrounding coastal exposures.

Neg. No. 27117.

Fig. 35

Fig. 36

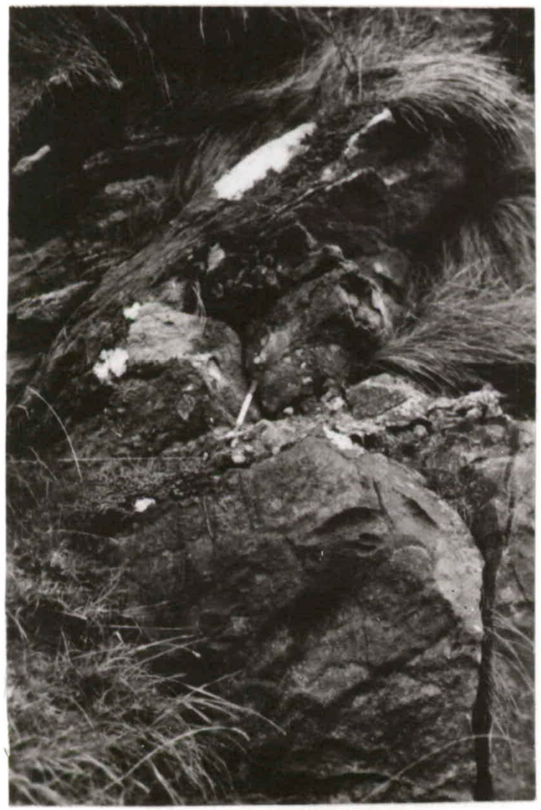


Fig. 37

Fig. 38

Fig. 39. Cleaved massive diamictite containing scattered pebbles and boulders of pink granite (with little mica), Port Askaig Tillite, Argyll Group (middle Dalradian), in coastal exposure near Port Askaig, Islay, Scotland. The scale is graduated in cm.

Neg. No. 27118.

Fig. 40. Imbricated thrust slices of bedded Durness Limestone, within part of the Moine Thrust zone, Loch Eriboll, Scotland. The exposure illustrated is about 2 m high.

Neg. No. 27119.

Fig. 41. Exposure of much less deformed Cambro-Ordovician shelf sediments, immediately west of and below the Moine Thrust zone, Loch Eriboll, Scotland. At the top, some 5 m of Durness limestone are visible, overlying ½ m gritty sandstone, then cleaved siltstone. Massive white quartzite with worm burrows occurs at the base.

Neg. No. 27120.

Fig. 42. Part of a road cutting exposure of Cambrian "pipe rock" - a white and reddish quartzite with vertical worm burrows, flared at the top. Skiag Bridge, Loch Assynt, Scotland. The pen for scale is 14 cm long.

Neg. No. 27121.

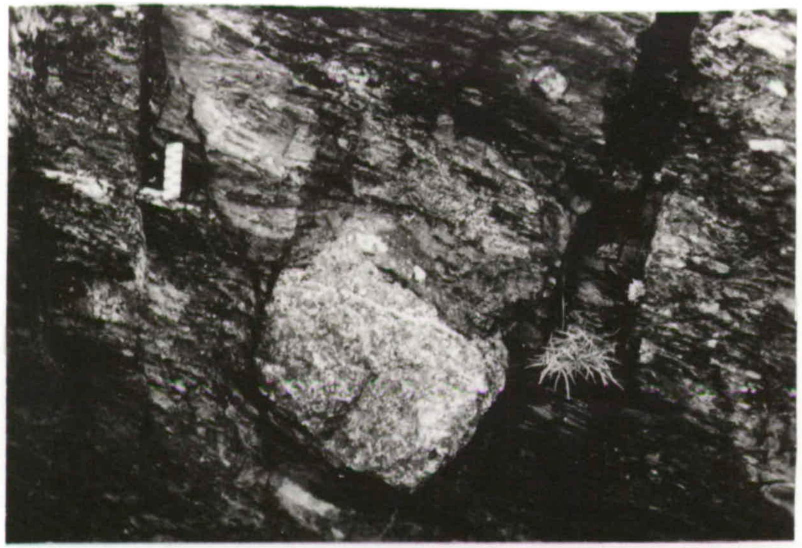


Fig. 39


Fig. 40

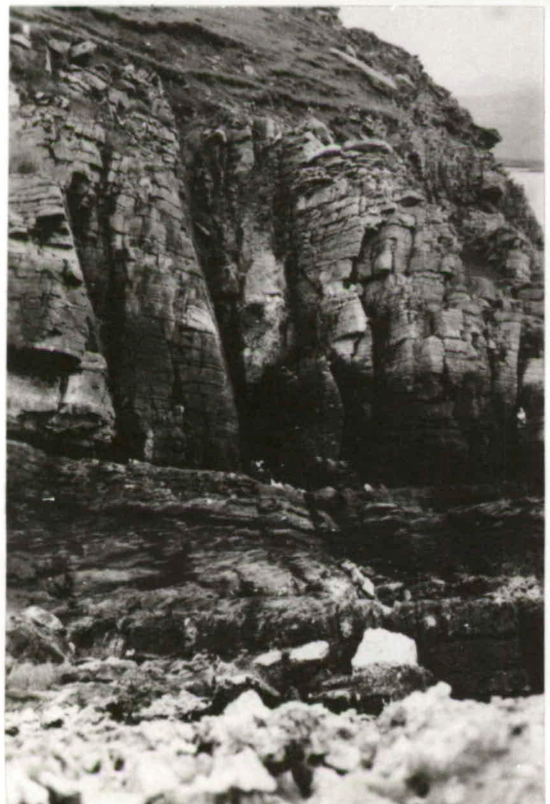


Fig. 41

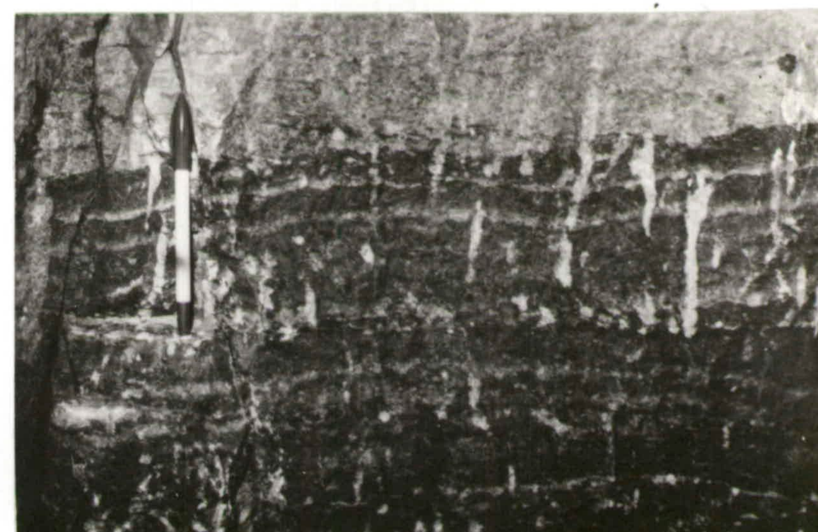


Fig. 42

stromatolite column was observed (Fig. 35). The basal dolomitic boulder bed has a gritty, sandy matrix and contains angular dolomite clasts (Fig. 36). It is overlain by a pebbly dolomite, including an impersistent 3 cm thick ironstone band, followed by a pebbly diamictite with a cleaved, slaty matrix. The uppermost bed is again a dolomitic grit with reworked dolomite clasts (Fig. 37). At Port Askaig a cleaved, unbedded diamictite contains scattered granite boulders in a schistose matrix (Fig. 39). Just above the Port Askaig pier, a medium to fine grained blocky quartzite underlies the diamictite, with a discordant (erosional or faulted) contact (Fig. 38).

After leaving Islay, we travelled by ferry to the island of Arran (Fig. 2), where we briefly observed part of the Southern Highland Group, here consisting of 30 cm thick beds of impure dark grey sandstone interbedded with 10 cm thick dark grey micaceous siltstones, exposed about 1 km west of Sannox. These beds are approximate equivalents of the Macduff Slate.

THE TORRIDON AND STOER GROUPS AND THE LOWER PALAEOZOIC SEQUENCE WEST OF THE MOINE THRUST

Durness Area (Fig. 2).

Geologic relations at Loch Eriboll near Durness were briefly examined. Here thrusting in an imbricate zone (part of the Moine Thrust Zone) has involved Moine rocks (which outcrop predominantly to the east of the thrust), and the Cambrian shelf sediments which are relatively undeformed west of the thrust. The Durness Limestone is here a flaggy pale grey limestone with stylolitic partings, recrystallized and highly veined with calcite. West-vergent recumbent folds and thrust slices are visible in the imbricate zone (Fig. 40); structurally below this the

Fig. 43. View of transverse sections of worm burrows on bedding plane. Cambrian "Pipe Rock", near Skiag Bridge, Loch Assynt, Scotland.

Neg. No. 27122.

Fig. 44. Cambrian Fucoid Beds - brown fine grained bioturbated sandstones with black shaly films, near Skiag Bridge, Loch Assynt, Scotland. The pen for scale is 14 cm long.

Neg. No. 27123.

Fig. 45. Tight isoclinal folds in Lewisian gneisses exposed in wavecut platforms at Stoer Bay, Scotland.

Neg. No. 27124.

Fig. 46. Wavecut platform exposure of the basal unconformity of the Stoer Group (breccia of coarse gneiss fragments at left) on Lewisian gneisses (at right). There is considerable relief on the eroded basement surface. Stoer Bay, Scotland.

Neg. No. 27125.


Fig. 43

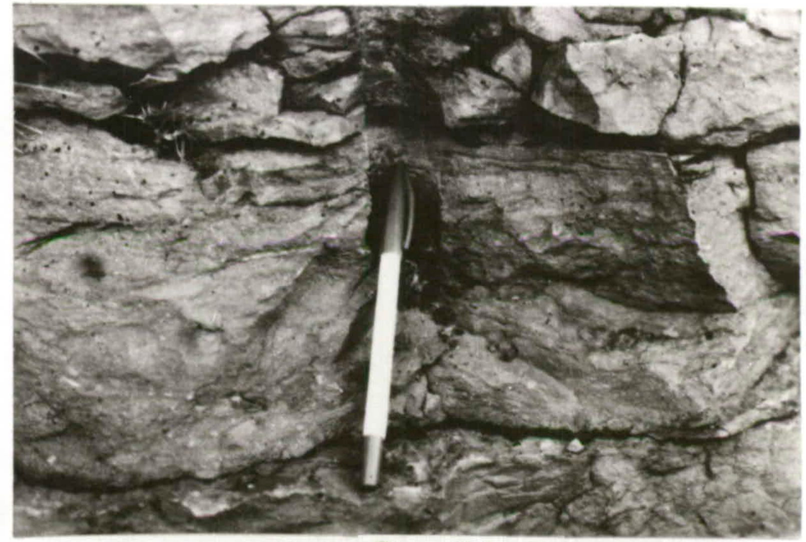


Fig. 44

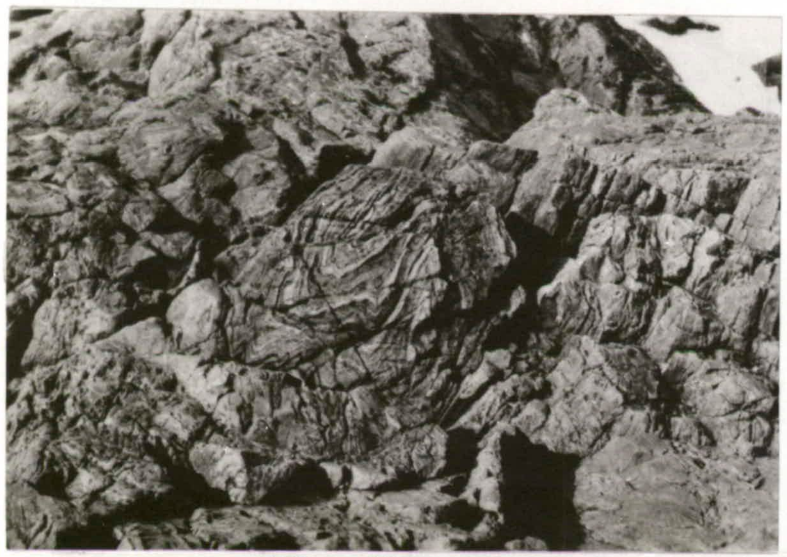


Fig. 45


Fig. 46

beds are less deformed, though siltstone interbeds are still highly cleaved, and the limestone dips consistently west at about 30°, overlying Cambrian beds. The following section was observed, seen partly in Fig. 41.

Top:	*Durness Limestone* (Ordovician)	Pale grey flaggy limestone, including beds with cryptalgal lamination, intraformational breccia, and low domed stromatolites.
		Limestone with irregular 2-5mm diameter burrows and with the Hyolithid *Salterella*.
(Cambrian)	"*Serpulite Grit*"	Gritty sandstone, ½ m.
	and *Fucoid Beds*"	Olive grey slaty siltstone, 2 m.
	"*Pipe Rock*"	Massive clean white quartzite with vertical worm burrows. Very large scale cross-bedding.

At Skiag Bridge near Loch Assynt (Fig. 2), the "Pipe Rock" was again examined. Some of the worm burrows in the quartzite are trumpet-shaped, with flared openings at the top (Figs. 42, 43). Some have reddened iron oxide-rich linings. The overlying "Fucoid Beds" are brown fine grained bioturbated sandstones with black shaly films, originally thought to be of algal origin. (Fig. 44).

<u>Stoer Bay</u> (Fig. 2)

West of the Moine Thrust, two major unmetamorphosed late Precambrian redbed sequences rest unconformably on the older Precambrian (Lewisian) gneisses. The lower of these, the Stoer Group, examined in its type area at Clachtoll, Stoer Bay (Fig. 2), "consists of over 2 km of unmetamorphosed red beds", resting "on a fossil land surface with relief of up to 400 m in Lewisian gneiss" (Stewart, 1975). The basal unconformity with a breccia of angular gneiss fragments, lying on an irregular basement surface, is well exposed on wave-cut platforms (Figs. 46, 47). The

Fig. 47. Basal breccia of the Stoer Group resting unconformably on eroded Lewisian gneisses in wavecut platform at Stoer Bay, Scotland. The pen for scale is 14 cm long, and marks the unconformity.

Neg. No. 27126.

Fig. 48. Small irregular ?stromatolitic mounds in thin limy intercalations in fine grained red silty sandstones, Stoer Group, Stoer Bay, Scotland. The pen for scale is 14 cm long.

Neg. No. 27127.

Fig. 49. Mudcrack polygons in well bedded red silty fine grained sandstones, Stoer Group, Stoer Bay, Scotland. The scale is graduated in cm.

Neg. No. 27128.

Fig. 50. Very large mudcrack polygons in well bedded red silty fine grained sandstones, Stoer Group, Stoer Bay, Scotland.

Neg. No. 27129.

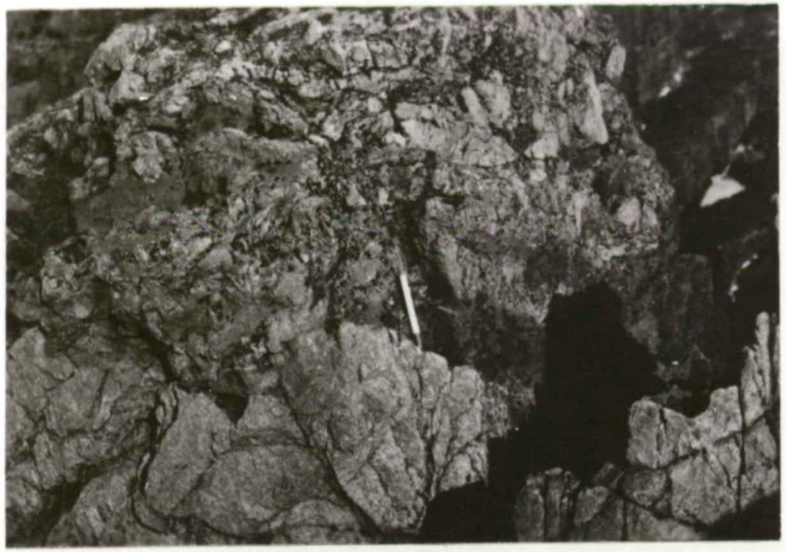


Fig. 47

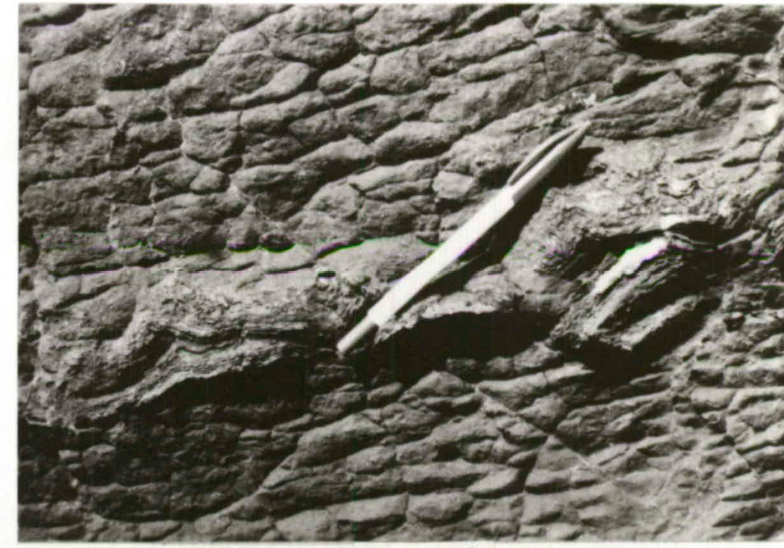


Fig. 48

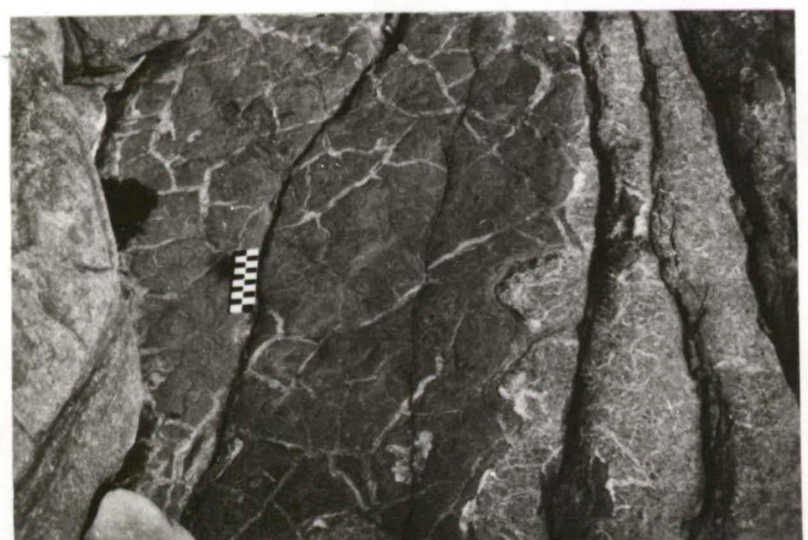


Fig. 49


Fig. 50

Fig. 51. The Stac Fada Member, a volcanic mudflow breccia (dark on the photograph) overlying and partly intruding flaggy red sandstones of the Stoer Group, Stoer Bay, Scotland. An intrusive tongue of the breccia at left wedges out between sandstone beds.

Neg. No. 27130.

Fig. 52. A sequence of intercalated flaggy red sandstones and siltstones of the Stoer Group, Stoer Bay, Scotland.

Neg. No. 27131.

Fig. 53. A thin interbed of cyptalgalaminated limestone from which microfossils are known, in red sandstones of the Stoer Group, Stoer Bay, Scotland. The wispy red lamination is reminiscent of the stratiform stromatolite *Malginella* seen in the Urals. The pen for scale is 14 cm long.

Neg. No. 27132.

Fig. 54. Gritty and pebbly sandstone near the base of the Stoer Group, lapping against large rounded boulders of Lewisian gneiss, in wavecut platform exposure at Enard Bay, Scotland.

Neg. No. 27133.

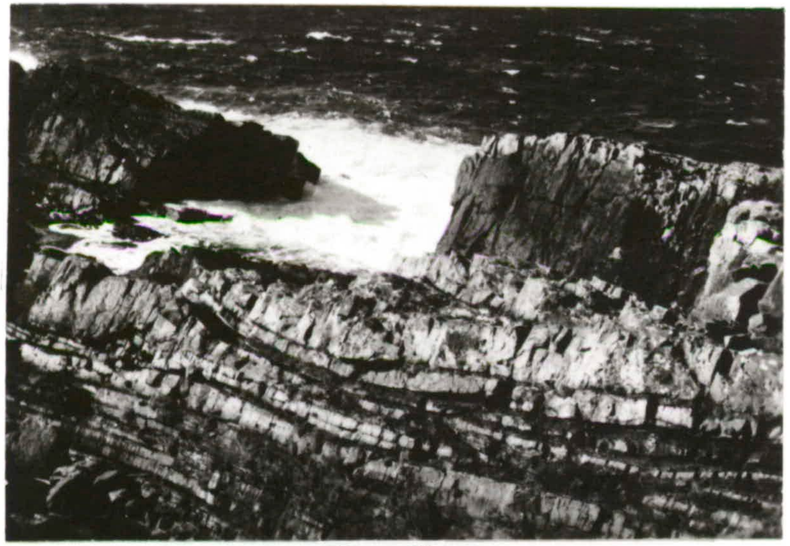


Fig. 51


Fig. 52


Fig. 53


Fig. 54

underlying Lewisian gneisses are tightly folded (Fig. 45). The breccia is overlain by red sandstone, including thin, lenticular limy bands (less than 2 cm thick) with cryptalgal lamination and very low stromatolitic bumps (Fig. 48). The sandstones are silty, fine grained, poorly sorted, red-brown in colour, and well bedded. Red silts and fine sands persist upward, and large, complex mudcracks become prominent (Figs. 49, 50). This unit is overlain by red, cross-bedded sandstones of fluviatile origin, containing pebbles up to 10 cm. Beds 0.2 to 1.0 m thick display trough cross-bedding with pebbly layers.

The Stac Fada Member, a marker horizon within this sequence, is interpreted as a volcanic mudflow. It is a fine sandy, hematitic, ill-sorted red-brown volcaniclastic sediment containing rock fragments, lapilli, and glass shards. Pink feldspar grains give the weathered surface a honeycomb texture. Sandstone beds below the mudflow are partially disrupted, as wedges of it were driven into its substrate (Fig. 51).

The overlying red sandstone-siltstone sequence (Fig. 52) includes a thin grey shale which has yielded microfossils, perhaps marine phytoplankton (Cloud & Germs, 1971). A thinly laminated (?cryptalgal) limestone interbed a few centimetres thick also yielded a microflora (Downie, 1962). The wispy thin red laminae of this limestone (Fig. 53) were highly reminiscent of *Malginella malgica*, a stratiform stromatolite, seen in the Ural Mountains of the USSR.

Moorbath (1969), obtained a Rb/Sr whole rock isochron from a red shale within the Stoer Group with an age of 935 ± 24 m.y. and initial ratio 0.7086 ± 0.0016 (λ = 1.47 x 10 yrs.).

Fig. 55. Very large scale cross-beds in feldspathic sandstones of the Stoer Group, Enard Bay, Scotland.

Neg. No. 27134.

Fig. 56. Red feldspathic sandstones of the Aultbea Formation, Torridon Group, unconformably overlain by calcareous breccia of the Triassic New Red Sandstone sequence, in coastal exposure near Udrigle, Scotland.

Neg. No. 27135.

Fig. 57. Large slump rolls (up to 2 m thick) in reddish feldspathic sandstone of the Aultbea Formation, Torridon Group, in coastal exposure near Udrigle, Scotland.

Neg. No. 27136.

Fig. 58. Basal breccia of the Diabaig Formation, Torridon Group, at Gairloch, Scotland. The scale is graduated in cm.

Neg. No. 27137.


Fig. 55

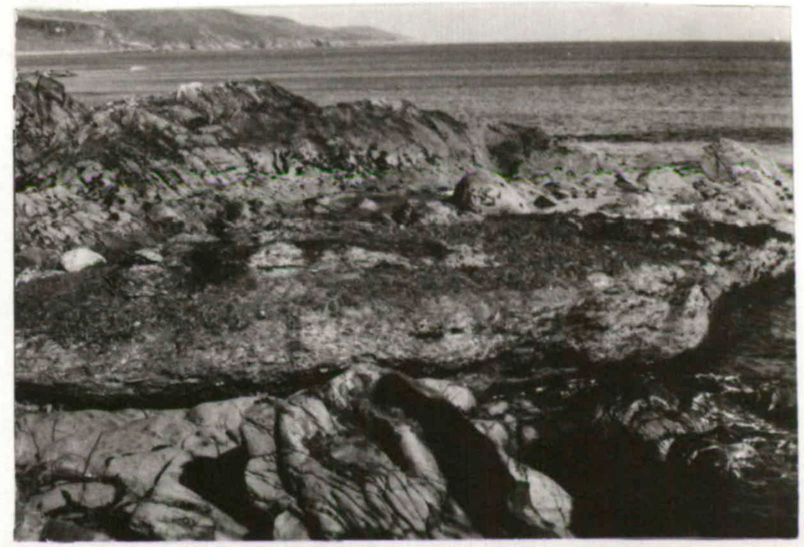


Fig. 56


Fig. 57


Fig. 58

Enard Bay (Fig. 2)

Part of the Stoer Group exposed at the southern end of Enard Bay consists of massive red sandstone beds with steep foresets some 2 m high (Fig. 55). At the base of the succession, gritty sandstone is seen to lap against large, rounded boulders of Lewisian gneiss (Fig. 54). In places, the gneiss boulders are concentrically draped with red laminated limestone; possible interpretations for this include fossil calcrete crusts or stromatolitic mats coating the boulders. A horizontal section of a fossil cliff talus, exposed in the wave-cut platform, consists of large disoriented boulders set in a matrix of smaller cobbles. This occurs again on the north side of a headland, but is here underlain by the Stac Fada Member volcanic breccia with laminated lapilli. The Member is lenticular here, owing to the relief on the basement surface.

The Torridon Group, which disconformably overlies the Stoer Group is subdivided into the following four formations:

Top: Cailleach Head Formation
Aultbea Formation
Applecross Formation
Base: Diabaig Formation

The stratigraphy, sedimentology and relations of these units are discussed by Williams (1966) and Stewart (1975). Small outcrops seen a few kilometres inland from Enard Bay include gritty, pebbly feldspathic sandstone with red granules (either Diabaig or basal Applecross).

Laide - Udrigle Area (Fig. 2)

Here the Aultbea Formation is well exposed in wave-cut platforms, and consists of well laminated deep pink feldspathic, medium grained quartzitic sandstones. In places the bedding is outlined by black heavy mineral bands. Some beds are strongly contorted by slumping, (Fig. 57), affecting beds up to 2 m thick, and overlain by flat unaffected beds. A calcareous cemented breccia of angular sandstone fragments unconformably overlies the tilted beds of the Torridon Group; the breccia is part of the local Triassic New Red Sandstone sequence (Fig. 56).

Gairloch Area

Coastal exposures at Gairloch (Fig. 2) include massive fine grained sandstone with interbeds of dark grey, micaceous coarse siltstone (Diabaig). The basal unit of the Diabaig Formation, exposed just onshore at Gairloch, is a breccia consisting of very angular fragments of quartz, schist, gneiss and jasper in a sandy, silty matrix (Fig. 58).

Pink coarse grained arkose with red fresh feldspar granules up to 2 mm, and heavy mineral laminated cross-bedded medium-grained sandstone seen near Loch Maree (Fig. 61) belong to the Applecross Formation (Fig. 59). Dark greenish-grey sandstones containing fresh hornblende and feldspar and coarse medium-grey siltstones are interbedded. Moorbath (1969) obtained a Rb/Sr isochron of 751 ± 24 m.y. for red shales of the Applecross and Cailleach Head Formations, with initial Sr^{87}/Sr^{86} ratio of 0.7216 ± 0.0019 ($\lambda = 1.47 \times 10^{-11}$ years).

Loch Damh Area (Fig. 2)

At Balgy Bridge over Loch Damh, there are exposures of coarse basal sandstone of the Diabaig Formation, with minor pebbles of quartz, red jasper, feldspar and red sandstone resting unconformably on Lewisian gneisses. A coastal section shows the same basal Diabaig grits abutting against a steep erosional surface on the basement. Away from the unconformity, the sandstone becomes flat-bedded with finer and fewer pebbles. Graded bedding is probably due to sheet flooding on a river flood plain. The overlying sediments are greenish and dark grey platy

Fig. 59. Coarse grained arkose of the Applecross Formation, Torridon Group, near Loch Maree, Scotland. The pen for scale is 14 cm long.

Neg. No. 27138.

Fig. 60. Dark grey siltstone interbed in the Diabaig Formation, Torridon Group, including a thin phosphorite lens (weathered in relief ,centre of photograph), near Balgy Bridge over Loch Damh, Scotland. The pen for scale is 14 cm long.

Neg. No. 27139.

Fig. 61. View across Loch Maree to Mount Slioch, Scotland, showing a capping of the Torridon Group rocks over Lewisian basement.

Neg. No. 27140.

Fig. 62. Pleistocene boulder clay exposed in road cut near New Galloway, Scotland.

Neg. No. 27141.

Fig. 59

Fig. 60

Fig. 61

Fig. 62

Fig. 63. Quarry exposure of the Caradocian (Ordovician) Stinchar Limestone near Girvan, Scotland. The limestone occurs in beds dipping to the right at the right of the photograph; it is faulted against a graded greywacke sequence at left, in turn faulted against serpentinite.

Neg. No. 27142.

Fig. 64. Ovoid *Girvanella* oncolites in shelly bioclastic limestone, Caradocian Stinchar Limestone, in quarry near Girvan, Scotland. The pen for scale is 14 cm long.

Neg. No. 27143.

Fig. 65. Shelly and partly oolitic bioclastic limestone, Caradocian Stinchar Limestone, in quarry near Girvan, Scotland. Lens cap for scale 5.3 cm in diameter.

Neg. No. 27144.

Fig. 66. Graded bedding in greywacke exposed in limestone quarry near Girvan, Scotland. The pen for scale is 14 cm long.

Neg. No. 27145.

Fig. 63

Fig. 64

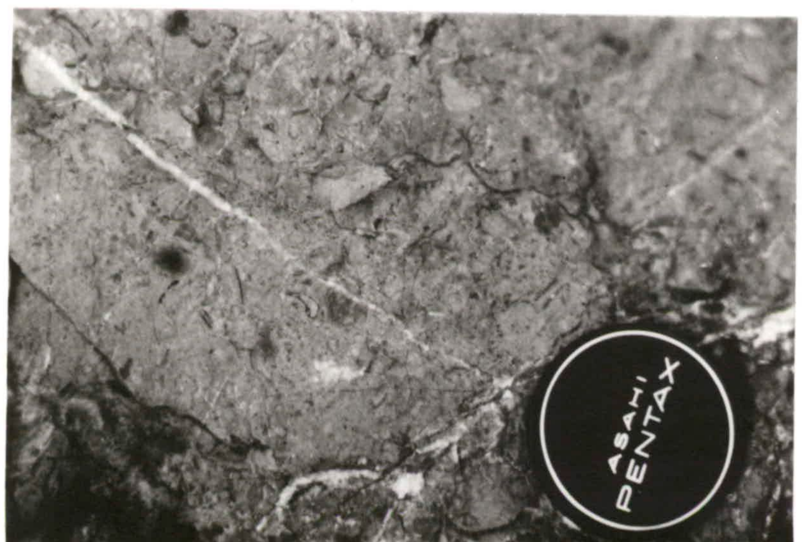


Fig. 65

Fig. 66

fine grained sandstone and coarse micaceous siltstone. A lens of black phosphorite, ½ to 1 cm thick (Fig. 60) was sampled for microfossils. The basal part of the overlying Applecross Formation, a coarse red feldspathic sandstone with trough cross-bedding, is exposed nearby.

PALAEOZOIC CARBONATE ROCKS OF SOUTH-WEST SCOTLAND

Girvan (Fig. 2)

The Caradocian (Ordovician) Stinchar Limestone is exposed in a quarry near Girvan, together with fault wedges of greywacke and serpentinite (Fig. 63). The limestone contains an abundant shelly fauna (Fig. 65) together with oolites and scattered *Girvanella* oncolites (Fig. 64), which tend to be of irregular outline rather than circular. The limestone is faulted against a graded greywacke sequence (Fig. 66), in turn in fault contact with a serpentinite.

In the vicinity of New Galloway (Fig. 2), one of many exposures of Pleistocene till was photographed. It is a gritty boulder clay with numerous facetted and striated pebbles and cobbles (Fig. 62).

Langholm Area (Fig. 2)

Early Carboniferous carbonates are poorly exposed in stream beds at Blackburn near Langholm. A pale brown weathering limestone contains columnar branching stromatolites 5 to 7 cm in diameter, seen in transverse section. Some bedding planes contain probable gypsum pseudo morphs . At arras Water, 8 km south of Langholm, a sequence of dark grey flaggy dolomites and interbedded shales is exposed (Fig. 67). These sediments all belong to the Lower Border Group (Leeder, 1975), formerly referred to as the Cementstone Group. Leeder (1975) described the morphology and palaeoecology of the stromatolites.

Fig. 67. Flaggy dolomites with interbedded black shales of the Cementstone Group (Lower Border Group), Upper Visean, Tarras Water, 8 km south of Langholm, Scotland.

Neg. No. 27146.

Fig. 68. Pillow lavas of the Llanddwyn Spilitic Formation, exposed on beach at Llanddwyn Bay, Anglesey, Wales. The pillows indicate a south-east facing (to the right).

Neg. No. 27147.

Fig. 69. Cherts between pillow structures in the Llanddwyn Spilitic Formation, Llanddwyn Bay, Anglesey, Wales. The pen for scale is 14 cm long.

Neg. No. 27148.

Fig. 70. Lenticular oolitic red chert interbed in highly cleaved limestone (?Gwna Limestone), Anglesey, Wales. The pen for scale is 14 cm long.

Neg. No. 27149.

Fig. 67

Fig. 68

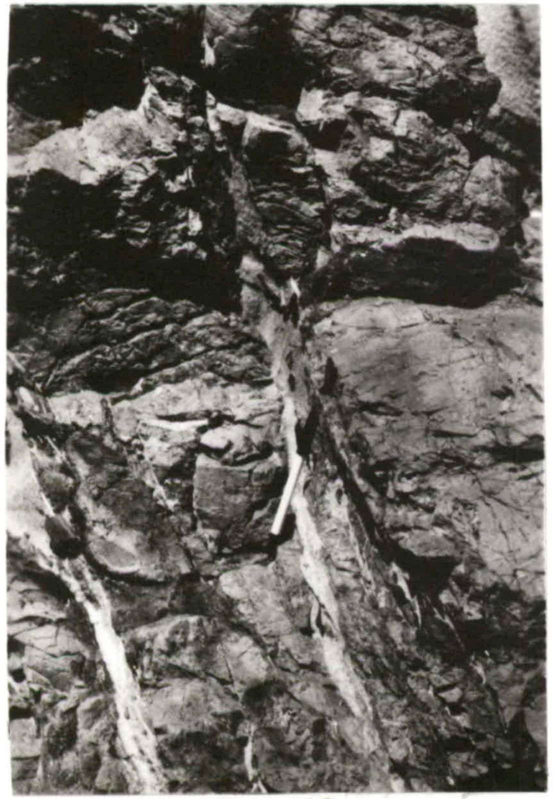


Fig. 69

Fig. 70

PRECAMBRIAN ROCKS OF WALES AND THE WELSH BORDERLANDS

Anglesey

A late Precambrian eugeosynclinal complex, the Monian Supergroup (Shackleton, 1975) wasexamined in coastal exposures on Anglesey. Shackleton, (p.77) records the following succession on Anglesey:-

Fydlyn Felsitic Formation (50 m)

GWNA GROUP (3 000 m)
Tyfry Formation (purple grits)
Gwna Melange Formation (breccia with orthoquartzites, limestone, pillow lava)
Ceinwen and Llanddwyn Spilitic Formation (300 m)
Pelitic beds
Engan Spilitic Formation (500 m)
Pelitic beds
Triple "Group" Formation (limestone, graphitic pelite and orthoquartzite)

SKERRIES GROUP (500 m)
includes Church Bay Tuff Formation and Skerries Formation.

NEW HARBOUR GROUP (2 000 m)
(pelites and semipelites with pillow lavas).

Rhoscolyn Formation (700 m) (turbidites)
Holyhead Quartzite (500 m) (orthoquartzites)
South Stack Formation (250 m) (turbidites)

The Llanddwyn Spilitic Formation is exposed on a sandy beach and low cliffs at Llanddwyn Bay near Newborough. Fine grained green soda-rich basalts contain well developed, south-east facing pillow structures (Fig. 68). Thin bands of red jasper and rare lenses of black chert occur between the pillows (Fig. 69). The latter were sampled by Dr. Muir for microfossil study. A sequence exposed in low cliffs contains conglomerates of green basalt fragments up to 5 cm long, partly angular, set in a matrix of volcanic detritus, possibly tuffaceous. These are followed by green slates with interbedded greywackes with much volcanic detritus and some thick graded beds. Steeply plunging folds have an axial plane slaty cleavage. A red spherulitic chert occurs in lenses in a highly cleaved greenish-grey limestone and purple ?tuffaceous siltstones (Fig. 70). Similar limestone is exposed nearby interbedded with silty limestone and pure white limestone, all considerably sheared and recrystallised (Gwna Limestone).

At Cemaes Bay, on the northern shore of Anglesey, the Gwna Melange is well exposed in coastal cliffs. It is interpreted as a submarine slide breccia or olistostrome (Shackleton, 1975) and contains large masses of white orthoquartzite and carbonates in a foliated matrix of sheared and comminuted fine grained, silty, micaceous lithic sandstone (Fig. 73). Contacts of the quartzite blocks with the matrix involve shattering of the quartzite and shearing of the matrix (Fig. 72). Lenticular quartzite boudins are incorporated in this sheared matrix. Some smaller quartzite pebbles are rounded, others are elongated, both parallel and perpendicular to the shearing direction. Tensional quartz veins are perpendicular to the foliation (Fig. 71). These features suggest that the structure of the melange has been considerably modified tectonically, though the original slump origin is evident from the unsorted rock fragments involved in the matrix. Irregular fragments of brown dolomite appear to have been partly remobilized either

Fig. 71. Breccia containing angular fragments of quartzite in sheared silty matrix, Gwna Melange Formation, Cemaes Bay, Anglesey, Wales. Tensional quartz veins are perpendicular to the foliation. Pen for scale is 14 cm long.

Neg. No. 27150.

Fig. 72. Very large block of white orthoquartzite incorporated in breccia of the Gwna Melange Formation, Cemaes Bay, Anglesey, Wales. The contacts of the block with the matrix are considerably sheared, fractured and slickensided.

Neg. No. 27151.

Fig. 73. Large orthoquartzite blocks in sheared breccia of the Gwna Melange Formation, Cemaes Bay, Anglesey, Wales.

Neg. No. 27152.

Fig. 74. Partly mobilized clasts of dolomite in sheared breccia matrix, Gwna Melange Formation, Cemaes Bay, Anglesey, Wales. The pen for scale is 14 cm long.

Neg. No. 27153.

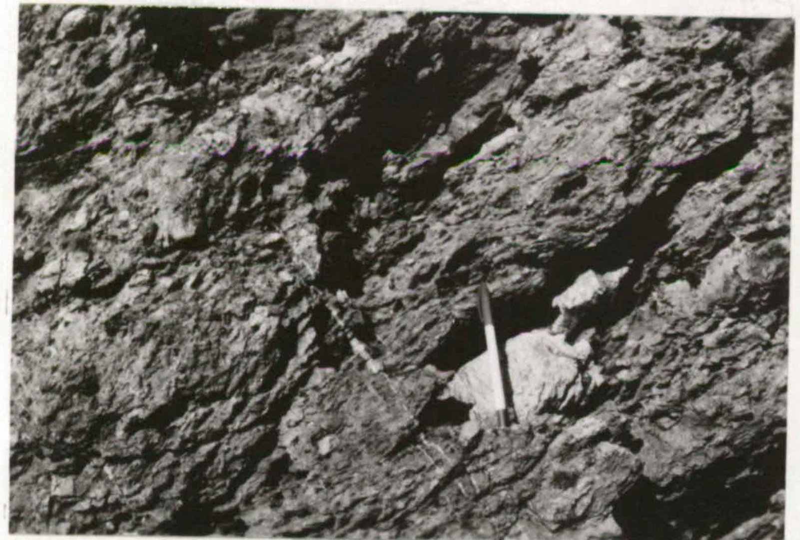


Fig. 71

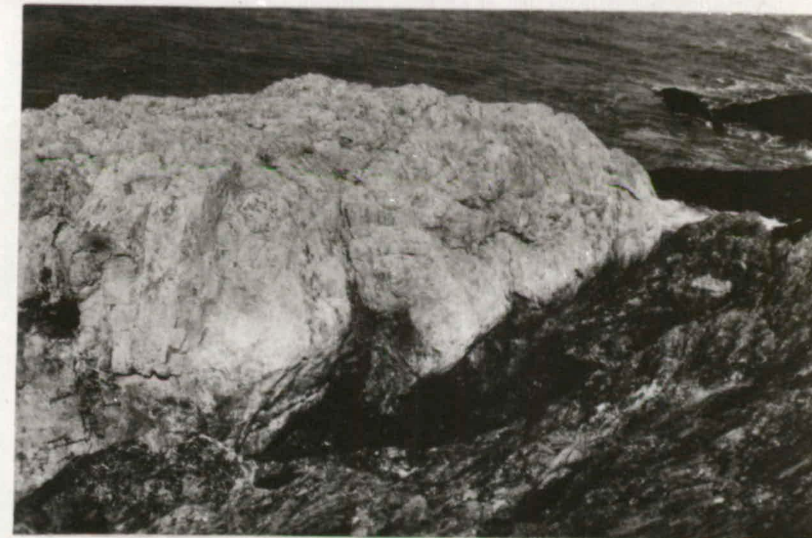


Fig. 72

Fig. 73

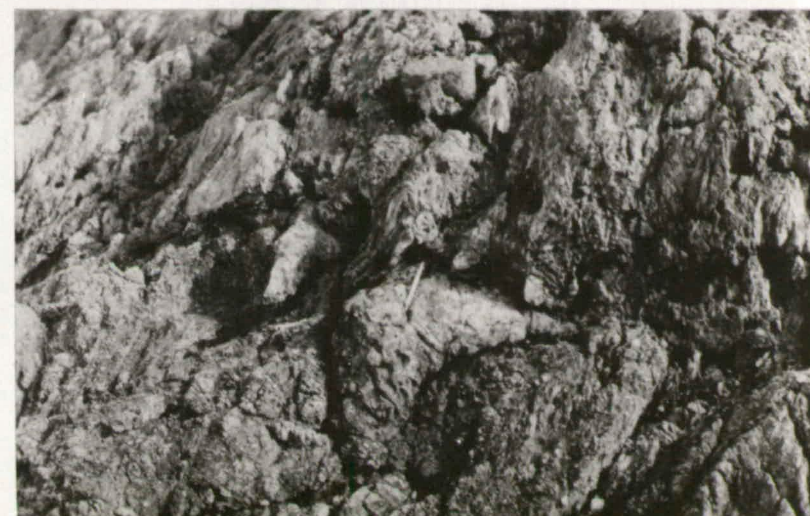


Fig. 74

during slumping or subsequent deformation (Fig. 74). Larger contorted blocks of blue-grey dolomite, weathering brown and partly well-bedded, are in contact with fragmented quartzites and thinly bedded brown sandstones. Tensional features are again perpendicular to the shearing direction.

A very large block of massive, medium grey limestone contains stromatolites with tuberous inclined and vertical columns (Fig. 76). Interspaces are filled with flat-pebble breccias. Flat and rounded intraclast breccias overlie the stromatolitic bed (Fig. 75). Samples were collected for further study.

<u>Church Stretton</u> (Fig. 2)

The Longmyndian succession of Shropshire, some 8 km thick, is folded into an overturned isoclinal syncline, and is subdivided as follows (Dunning, 1975):

<u>Wentnor Group</u>: 3 700 m	<u>Bridges Formation</u> (mainly purple mudstones, siltstones, sandstones). <u>Bayston-Oakswood Formation</u> (mainly coarse purple sandstones and grits, minor mudstones and conglomerates).
	- unconformity -
<u>Stretton Group</u>:	<u>Portway Formation</u> (purple and greenish-grey shaly mudstones and siltstones with sandstone bands. <u>Lightspout Formation</u> (flaggy greenish-grey and purple siltstones with sandstone bands, massive near the base. <u>Synalds Formation</u> (purple shaly mudstones with subordinate sandstone). Includes <u>Batch Volcanics</u> (epidotic crystal - lithic tuff).

Fig. 75. Stromatolitic interbed in a large limestone block in the Gwna Melange Formation, Cemaes Bay, Anglesey, Wales. The pen for scale is 14 cm long.

Neg. No. 27154.

Fig. 76. Tuberous columnar stromatolites in large limestone block in the Gwna Melange Formation, Cemaes Bay, Anglesey, Wales. The pen for scale is 14 cm long.

Neg. No. 27155.

Fig. 77. Purple lithic sandstone and siltstone of the Synalds Formation, Stretton Group of the Longmyndian succession, Cardingmill Valley, Church Stretton, Shropshire, England. The pen for scale is 14 cm long.

Neg. No. 27156.

Fig. 78. Nodular bedded limestone passing laterally into massive biohermal limestone (Silurian), in disused quarry on the scarp of Wenlock Edge, England.

Neg. No. 27157.


Fig. 75


Fig. 76


Fig. 77


Fig. 78

Burway Formation (flaggy greenish-grey laminated siltstones with sandstone layers; dust-tuff at base).

Stretton Shale Formation (greenish-grey mudstones, lithic tuff).

Both groups of the Longmyndian are older than the Uriconian Volcanics which unconformably overlie the Wentnor Group (James, 1956).

A conglomerate of the Wentnor Group is poorly exposed on a hillside near Church Stretton. It consists of 1-8 cm diameter rounded pebbles of quartz, quartzite and sandstone in a gritty matrix.

The Stretton Group was examined in the Cardingmill Valley, where steeply dipping purple and greyish siltstones with purple shaly partings (Fig. 77), belonging to the Synalds Formation, are overlain by siltstones with rare interbeds of lithic purplish-grey sandstone and grit. Current lineations and flute casts occur on the soles of some beds. The overlying Lightspout Formation consists here of purple siltstone and coarse, greenish lithic sandstone. The Stretton Shale Formation was observed at Ashies Hollow Cottage, Little Stretton; it consists of dark greenish splintery, silty shales with minor interbeds of lithic sandstone. The shales have a poorly developed vertical slaty cleavage. Bath (1974) concludes from Rb/Sr whole rock isochrons obtained (529 ± 6 m.y. for the Burway Formation, 452 ± 31 m.y. for the Synalds Formation and 529 ± 23 m.y. for the Lightspout Formation) "that the Longmyndian sediments were deposited no earlier than *c.* 600 m.y. i.e. in the Cambrian or the very late Precambrian".

Wenlock Edge (Fig. 2)

A nodular bedded limestone passing laterally into massive biohermal limestone (Silurian) was observed in a disused quarry (Lilles Quarry), 2 km

SW of Presthope on the scarp of Wenlock Edge (Fig. 78). The flanking nodular limestone is marly and very fossiliferous (chiefly corals, brachiopods) while the biohermal limestone s frequently contain stromatoporoids. A brief search was made for stromatolites but was not successful.

CONCLUSIONS AND DISCUSSION

Late Precambrian rocks in England and Scotland include sediments and volcanics representing a variety of continental, shallow marine and deep sea environments. The chronological and palaeogeographic relations between the various tectono-sedimentary units are still open to discussion. In the Scottish Highlands, for example, the Moine Thrust represents a junction of two quite separate tectonic regimes. To the west, the "Lewisian" basement, showing an early Precambrian high grade metamorphism (Scourian) and mid-Precambrian remobilisation (Laxfordian), is unconformably overlain by two late Precambrian sequences of fluviatile redbed clastics, which are unmetamorphosed and deformed only by tilting (Stoer and Torridon Groups). Cambrian and Ordovician shelf sediments overlie these sequences with a low angle unconformity. To the east of the Thrust lies the Caledonian orogenic belt, in which presumed Lewisian basement occurs only in minor inliers and thrust slices, and in which two major sequences of metasediments are intensely deformed. The older of these successions, the Moine, consists of metasandstones, schists and gneisses, whose age and relations are as yet uncertain. The younger sequence, the Dalradian Supergroup, commences somewhere in the late Precambrian and spans the Precambrian-Cambrian boundary. Early Palaeozoic metamorphism and deformation affected both these sequences, but there is a strong probability that at least part of the Moine was already metamorphic before Dalradian deposition commenced since some intrusive pegmatites and granitic gneisses in the Moine have yielded Precambrian ages. There is little reason to accept that the Eilde Flags should be assigned to the Moine rather than to the overlying Dalradian sequence with which they are perfectly conformable. It may be that the Moine represents a metamorphic basement to the Dalradian, although all the exposed contacts between them are tectonic.

The sandy metasediments of the Moine have frequently been correlated with the Stoer and/or Torridon Groups which have now been dated. Williams (1966) showed what might have been a palaeogeographic relationship between them, using current direction data, if they are correlative. However, the two sequences *may* have accumulated on quite separate crustal blocks (if the Moine Thrust is a major suture) and there would then be no compelling reason to correlate them. There is also no outcrop of Dalradian rocks west of the Moine Thrust, where partial age equivalents (Durness Limestone etc.) are of different facies and have not been affected by the Caledonian folding.

Specimens collected from stromatolitic dolomite (Bonahaven Dolomite) on Islay, and from limestone in the Gwna Melange Formation, Anglesey, are being studied by three-dimensional reconstruction from serial sections and thin sections. It is hoped that this will enable at least a tentative identification, although time in the field did not permit adequate determination of the mode of occurrence and range of variability of the stromatolites at either locality. Stromatolite biostratigraphy has not yet been seriously attempted in Britain, but a comparison of these with forms described from the USSR and Australia may provide some age constraints for the Bonahaven Dolomite and for the source of the stromatolitic boulders in the Gwna Melange.

The maceration of fine grained clastics from late Precambrian and early Palaeozoic sequences in Britain has yielded significant microfossils. Some preliminary results have been published (e.g. Downie et al., 1971, Cloud and Germs, 1971) but the work is still in its initial stages, and the full potential of Precambrian acritarchs remains to be evaluated; considerable success has been claimed for acritarch biostratigraphy in the latest Precambrian and early Palaeozoic in the USSR (e.g. Volkova, 1973). What is particularly encouraging is the fact that acritarchs can be preserved even in moderately metamorphosed sediments such as slates and phyllites, so that good results should be expected from the much less deformed and metamorphosed sediments of the Flinders Ranges.

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12th February, 1976

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PALAEOBOTANY SECTION

REFERENCES

Bath, A.H., 1974. New isotopic data on rocks from the Long Mynd, Shropshire. *J. geol. Soc. Lond.* 130, 567-574.

Cloud, P. & Germs, A., 1971. New Pre-Palaeozoic nannofossils from the Stoer Formation (Torridonian), northwest Scotland. *Bull. geol. Soc. Am.* 82, 3469-3474.

Downie, C., 1962. So-called spores from the Torridonian. *Proc. geol. Soc. Lond.* 1600, 127-128.

Downie, C., Lister, T.R., Harris, A.L. & Fettes, J., 1971. A palynological investigation of the Dalradian rocks of Scotland. *Institute of Geological Sciences*, Rept.No. 71/9, 1-29.

Dunning, F.W., 1972. Dating events in the Metamorphic Caledonides: impressions of the symposium held in Edinburgh, September, 1971. *Scott. J. Geol.* 8, 179-192.

Dunning, F.W., 1975. Precambrian craton of central England and the Welsh Borders. *Geol. Soc. Lond.* Sp. Rept. No. 6, 83-95.

Glaessner, M.F. & Wade, M., 1966. The late Precambrian fossils from Edacara, South Australia. *Palaeontology*, 9, 599-628

Hackman, B.D. & Knill, J.L., 1962. Calcareous algal from the Dalradian of Islay. *Palaeontology*, 5, 268-271.

Harris, A.L. & Pitcher, W.S., 1975. The Dalradian Supergroup. *Geol. Soc. Lond.* Sp. Rept. No. 6, 52-75.

James, J.H., 1956. The structure and stratigraphy of part of the Precambrian outcrop between Church Stretton and Linley, Shropshire. *Q. J. geol. Soc. Lond.* 112, 315-337.

Leeder, M., 1975. Lower Border Group (Tournaisian) stromatolites from the Northumberland Basin. *Scott. J. geol.* 11, 207-226.

Litherland, M., 1975. Organic remains and traces from the Dalradian of Benderloch, Argyll. *Scott. J. Geol.* 11, 47-50.

Meneisy, M.Y. & Miller, J.A., 1963. A geochronological study of the crystalline rocks of Charnwood Forest, England. *Geol. Mag.* 100, 507-253.

Moorbath, S., 1969. Evidence for the age of deposition of the Torridonian sediments of northwest Scotland. *Scott. J. Geol.* 5, 154-170.

Muir, M.D. & Sutton, J., 1970. Some fossiliferous chert pebbles within the Torridonian of Britain. *Nature*, 226, 443-445.

Shackleton, R.M., 1975. Precambrian rocks of Wales. *Geol. Soc. Lond.* Spec. Rept. No. 6, 76-82.

Spencer, A.M. & Spencer, M.O., 1972. The late Precambrian/Lower Cambrian Bonahaven Dolomite of Islay and its stromatolites. *Scott. J. Geol.* 8, 269-282.

Stewart, A.D., 1975. "Torridonian" rocks of western Scotland. *Geol. Soc. Lond.* Spec. Rept. No. 6, 43-51.

Treagus, J.E., 1974. A structural cross-section of the Moine and Dalradian rocks of the Kinlochleven area, Scotland. *J. geol. Soc. Lond.* 130, 525-544.

Van Breemen, O., Pidgeon, R.T. & Johnson, M.R.W., 1974. Precambrian and Palaeozoic pegmatites in the Moines of northern Scotland. *J. geol. Soc. Lond.* 130, 493-507.

Volkova, N.A., 1973. Akritarkhi i korrelyatsiya venda: kembriya zapadnoy chasti Russkoy platformy. (Acritarchs and the correlation of the Cambrian of the western part of the Russian Platform). *Sov. Geol.* , 1973, 1/6. 48-62.

Williams, G.E., 1966. Palaeogeography of the Torridonian Applecross Group. *Nature*, 209, 1303-1306.

Wood, M. & Nicholls, G.D., 1973. Precambrian stromatolite limestones from northern Anglesey. *Nature*, 241, 65.