# AMPHIBOLITE CONTACT ZONES, AMPHIBOLITE XENOLITHS, AND BLUESCHISTS ASSOCIATED WITH SERPENTINITE IN THE GIRVAN-BALLANTRAE COMPLEX, SOUTHWEST SCOTLAND

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ABSTRACT

Brown amphibole (garnet) amphibolites and flasered granulitic gabbros and dolerites occur in narrow discontinuous contact aureoles adjacent to, and as dismembered tectonic inclusions within, ultramafic rocks, which form part of an Ordovician ophiolite complex. The amphibolites are evidence of high temperature emplacement of the ultramafic magma now mainly represented by serpentinite. The metamorphic rocks were affected by later hydrothermal and metasomatic activity associated with serpentinization and are often rodingitized. Blueschists occur as tectonic inclusions in the Knockormal serpentinite and as pebbles in Middle Arenig sedimentary rocks. They may be middle Dalradian like other Caledonian crossite-bearing blueschists in Britain and Ireland.

## INTRODUCTION

The Girvan-Ballantrae area, southwest Scotland, comprises an ophiolitic complex which includes Middle Arenig shales, basaltic pillow lavas, gabbros, dolerites, various ultramafic rocks and trondhjemite (Balsillie, 1932; Bloxam, 1980). The alpine-type peridodites include harzburgite, lherzolite, wehrlite and other pyroxenites, together with their variously serpentinized representatives.

Although almost all contacts between ultramafic and adjacent rocks are high angle faults, a pyroxenite dyke cuts pillow lavas near Breaker Hill (NX 182 895) indicating that ultramafic emplacement at this tectonic level post-dates the lavas.

Pillow lavas and gabbros throughout the complex display a weak regional metamorphism (prehnite-pumpellyite) which may be the result of early sub-seafloor

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metamorphism. Although extensive crushing and shearing is common in association with faults and serpentinite contacts, there is no pervasive cleavage. Steeply dipping, but otherwise undeformed shales, frequently yield Middle Arenig graptolites and brachiopods.

## METAMORPHIC ROCKS

In contrast to the rocks just described are various metamorphic rocks which occur as: *A*. abundant tectonic inclusions within serpentinized ultramafic rocks, and *B*. form narrow tectonized zones along the margins of some ultramafic bodies.

### A. Tectonic inclusions

(i) *Amphibolites*. These rocks occur as abundant inclusions within the southern belt of serpentinite and are mainly amphibolites, together with some greenschists (see Bloxam, 1955 for description and map). Almost all exhibit relict igneous textures and near Millenderdale (NX 177 905) form numerous ovoid crags 50 m or more in diameter, which rise above the surrounding serpentinite (Peach and Horne, 1899, p. 477).

The central parts are composed of coarse, often pegmatitic, gabbro, which is in various stages of recrystallization. Large patches of schillered diallagic pyroxene are replaced by new colourless clinopyroxene ($Ca_{45}Mg_{44}Fe_{11}$), while original plagioclase is also recrystallized to granular plagioclase of about the same composition ($Ab_{52}$). However, in many cases all plagioclase is replaced by saussurite, prehnite, and hydrogarnet (Bloxam, 1954; 1964; 1968).

Towards their margins the metagabbros become increasingly flasered and recrystallized and form coarse banded and gneissose textural varieties which become finer and more strongly schistose as the serpentinite is approached, foliation lying parallel to the margins. This is accompanied by increasing amounts of brown amphibole which replaces pyroxene and also develops independantly. The amphibole is kaersutitic, containing over 3% $TiO_2$. Most of these rocks may be described as granulitic flasered gabbros and dolerites, or beerbachites (Bloxam, 1955).

In some cases the foliated rocks grade into granulitic patches with essentially non-foliated fine grained texture in which all traces of original igneous textures have disappeared. Some of these fine grained granulitic rocks have been sufficiently mobilized to form veins which cut the flasered and foliated parts of the rock.

At their extreme margins the amphibolites develop pink garnet and occasional hypersthene. The rarely exposed contacts between these rocks and the serpentinite are usually tectonic along which the latter is extensively sheared. Amphibolite in contact with serpentinite is often altered to a hard, dense, white rodingite, and is veined with carbonate, prehnite and serpentine.

Rodingitization is widespread at serpentinite contacts and is a metasomatic event (at elevated water pressures) which accompanied, or was responsible for, serpentinization. It has the effect of overprinting the earlier higher temperature metamorphism and obscures original contact relationships.

In addition to the large crag-like masses of amphibolite, there are an enormous number of smaller outcrops down to the size of small boulders. Most are flasered and foliated, the random orientation of which indicates that they have been dismembered and variously dispersed within their serpentinite host.

(ii) *Blueschists.* Blueschists and greenschists occur as tectonic inclusions in serpentinite near Knockormal (NX 138 890) and have been described by Balsillie (1937) and Bloxam and Allen (1960). These rocks form part of a mélange of disoriented blocks in sheared serpentinite, carbonated serpentinite, and serpentinite breccia. Faults separate the serpentinite from pillow lavas, pillow breccias, and black shales. The origin of these blueschists is quite different from that of the brown hornblende amphibolites.

The blueschists are all metabasites, some with relict gabbroidal textures, and their mineralogy is typically crossite-(pargasite/barroisite)-epidote-albite. Sphene is also abundant but garnet is rare and the rocks vary from coarse foliated to fine grained schistose. The crossite frequently forms optically continuous zones around an olive or blue-green amphibole related to pargasite or barroisite (Bloxam and Allen, 1960).

Deep-brown, tough, hornfelsic granulitic dolerites also occur as tectonic inclusions in the Knockormal serpentinite. They belong to the same group of metabasites described under A (i).

(iii) *Garnet peridotite and ariegite.* Part of the serpentinite body at Knockormal comprises banded pyroxenites, wehrlite, and garnet peridotite. The latter rock contains varying proportions of olivine, clinopyroxene (var. fassaite), aluminous amphibole, garnet, and green spinel (ceylonite) (Bloxam and Allen, 1960). Similar rocks also occur in association with banded serpentinite-pyroxenite in the area between Cairn Hill and Laigh Knocklaugh.

The garnet peridotites are considered to represent high pressure phases of the layered peridotite and pyroxenite, and formed in the upper mantle. They are comparable to the rocks described by Kornprobst (1969), Church and Stevens (1971) and Lensch (1976) from other ophiolitic belts.

## B. Contact metamorphic zones adjacent to ultramafic rocks

A group of amphibolites derived from mafic igneous rocks form a semi-continuous faulted and disrupted zone up to about 60 m wide interposed between ultramafic rocks and adjacent lavas, tuffs, shales and arenites. This zone extends from Carleton

Hill on the coast northeastwards through Straid Bridge to beyond Loch Lochton, a distance of about 6 km (Figs. 1 and 2).

These amphibolites are identical to the metabasites found as tectonic inclusions in serpentinite which were described in A (i). Almost all show relict gabbroidal or

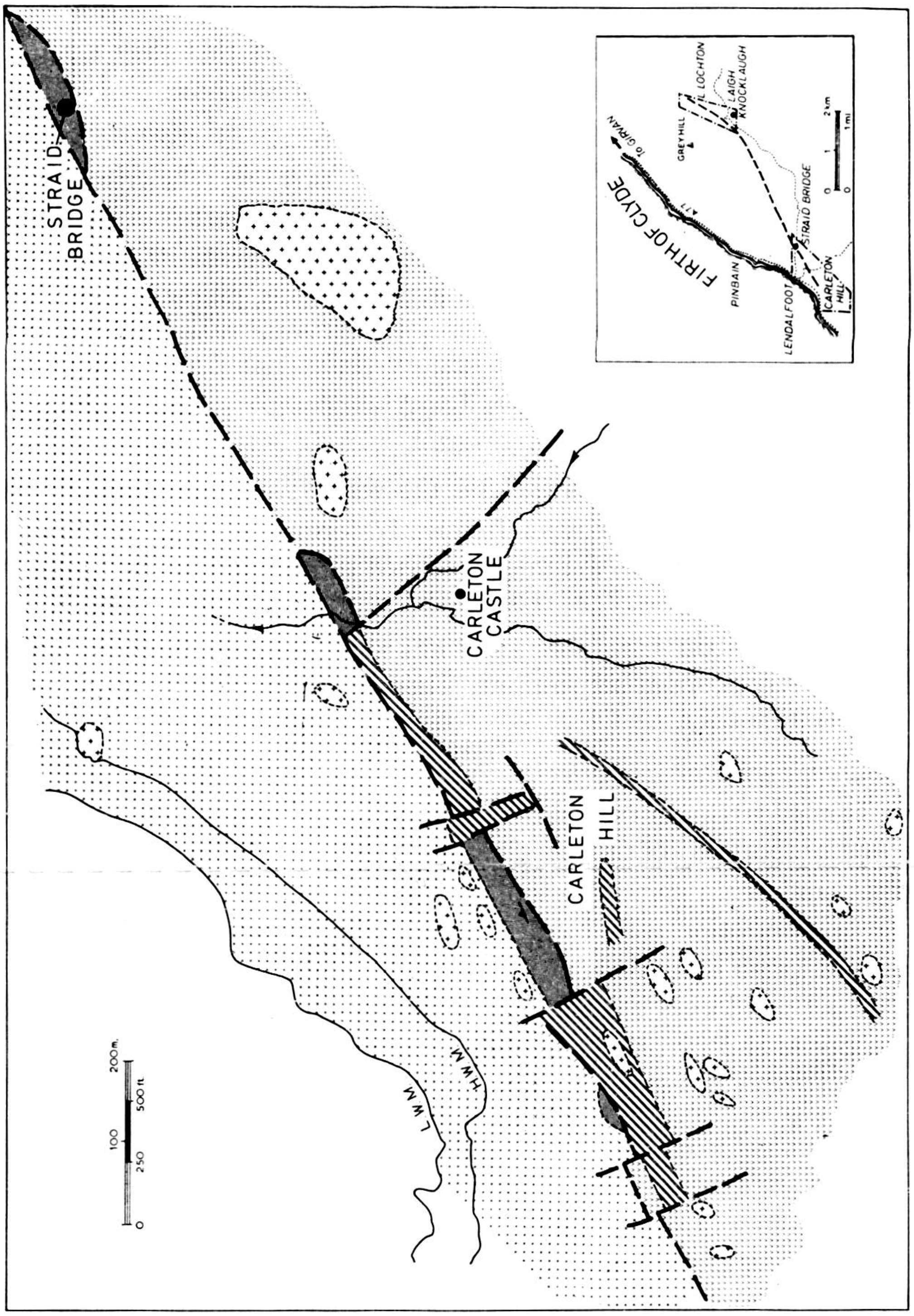


FIG. 1. — Sketch-map of metamorphic and associated rocks in the area between Carleton Hill and Straid Bridge (see Fig. 2 for key).

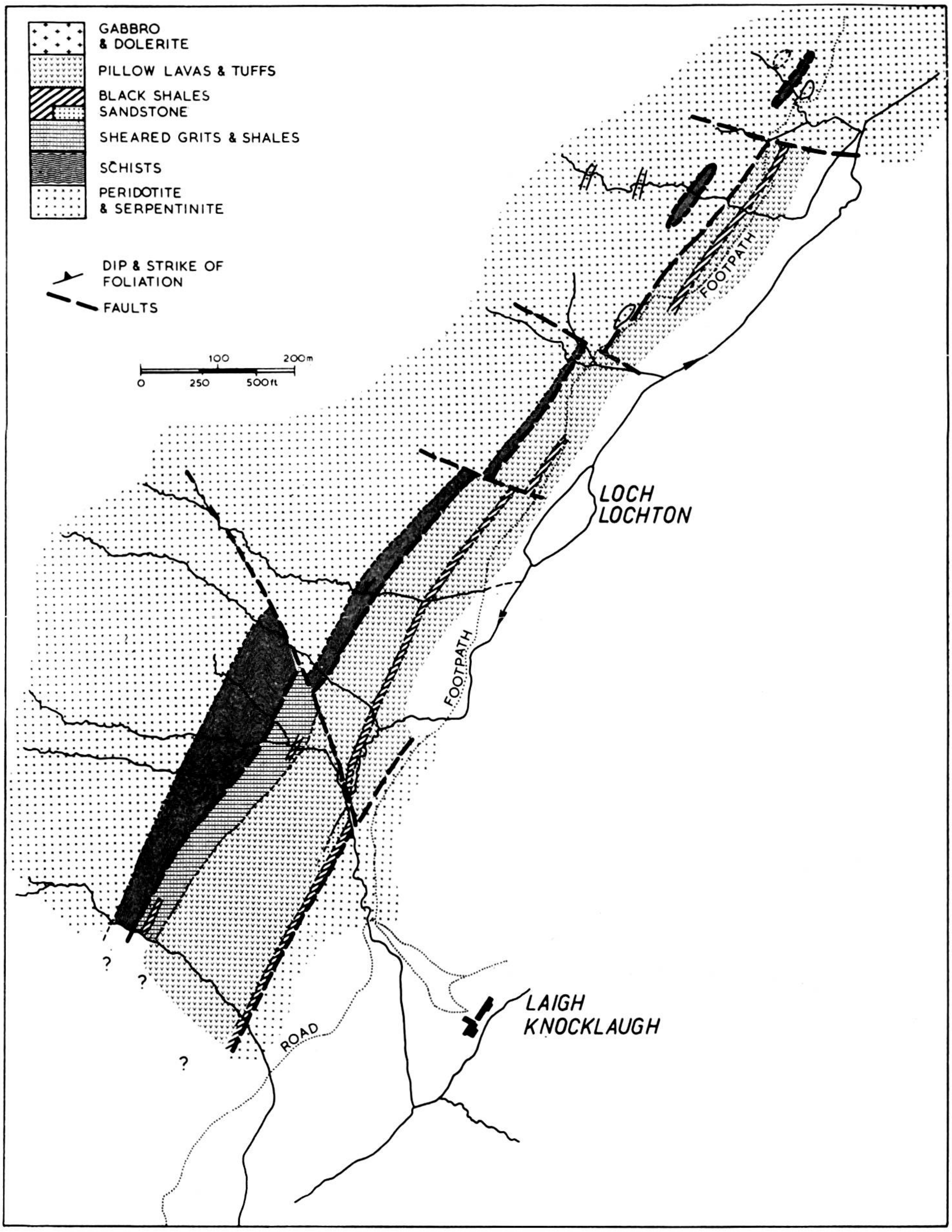


FIG. 2. — Sketch-map of metamorphic and associated rocks in the area between Laigh Knocklaugh and Loch Lochton.

doleritic textures, with metamorphic fabrics ranging from coarse foliated or flasered to fine grained schistose and granulitic. They were noted by Peach and Horne (1899, p. 456) who concluded that they were gabbros and dolerites "... modified by dynamic action...", many resembling flasered gabbros. Anderson (1936) also examined these rocks and regarded them as the products of "... high temperature dynamic metamorphism...", probably associated with the intrusion of the ultramafic magma.

The metamorphic zone has been disrupted by later movements and in places presents the aspect of a mélange consisting of serpentinite, amphibolite, greenschists, lavas, black shales, and associated sedimentary rocks.

Although not all are represented at each outcrop of the metamorphic zone, the following mineral assemblages are typical:

(a) Brown amphibole-clinopyroxene-plagioclase ($\pm$ garnet and hypersthene)

(b) Brown-green amphibole-plagioclase ($\pm$ clinopyroxene)

(c) Green amphibole-plagioclase ($\pm$ clinopyroxene)

(d) Greenschist: albite-chlorite-schist ($\pm$ epidote)

Amphibolites exposed on the northern slopes of Carleton Hill include assemblages (a) and (b). Contacts against adjacent rocks are not exposed and the amphibolites are cut by several non-foliated uralitic dolerites. In places only a few metres separate amphibolites from relatively unaltered black shales and lavas so that the contact is probably a fault. The boundary between amphibolite and serpentinite may also be tectonic since the latter is extensively sheared and slickensided. Bent and fractured minerals, together with cataclastic zones and shear planes in the amphibolites are evidence that they have also been affected by these post-metamorphic movements.

In the stream section around Straid Bridge (Fig. 1) the amphibolites are associated with greenschists (chlorite-albite) which are confined to the eastern side near lavas and black shales. Exposures are poor and the rocks have been extensively disturbed and sheared by later movements. It is not clear whether the greenschists are contemporary with the amphibolite or have been derived from amphibolite and/or marginal tuffs and sediments by the later deformation. However, the uniformly fine grained nature of the greenschists suggests derivation from tuffs or sediments rather than amphibolite.

Similar relationships are found in the Laigh Knocklaugh and Loch Lochton area (Fig. 2). Fractured pillow lavas, pillow breccias, shales, grits and siltstones become increasingly sheared towards the fault zone and form local bands of greenschist near contacts with the similarly sheared margin of the amphibolite.

Although outcrops are discontinuous, the amphibolites appear to be zoned, changing from green amphibole-bearing (c), through variegated green-brown amphibole-bearing (b), to brown amphibole-bearing with garnet (a) as the serpentinite is approached. Plagioclase (igneous and metamorphic) is represented almost entirely by saussurite, accompanied by original (igneous) clinopyroxene and recrystallized granulitic clinopyroxene as described in A (i).

Later deformation and metasomatism overprint the higher temperature event with shear zones, often containing prehnite, calcite, zoisite and hydrogarnet (rodingitization).

As noted by Peach and Horne (1899, p. 458), some lenticular strips of amphibolite north of Loch Lochton (Fig. 2) are enclosed within the serpentinite near its margins. The isolation of these amphibolite bodies may have resulted from secondary mobilization of the ultramafic rocks during serpentinization, as well as by tectonic action. Indeed, these particular amphibolites could be classed as tectonic inclusions under heading A (i).

## DISCUSSION AND CONCLUSIONS

Amphibolites in the Girvan-Ballantrae complex are found only in association with ultramafic rocks. Foliation and flaser planes run parallel to the ultramafic rock boundaries and the highest metamorphic facies (garnet amphibolite) occurs near ultramafic contacts. It is concluded that emplacement of high temperature peridotitic magma was responsible for this metamorphism (Anderson, 1936; Bloxam, 1955; 1980). Contact metamorphic aureoles with precisely the same mineralogical development have been described from the Red Hills of New Zealand (Challis, 1965; Lauder, 1974), the Lizard, Cornwall (Green, 1964), and elsewhere. Brown hornblende-rich granulitic gabbros have been recovered from the Mid-Atlantic ridge and also represent high temperature contact zones resulting from the emplacement of peridotite (Miyashiro, *et al*, 1971).

All amphibolites in the present area were originally gabbros or dolerites from which it is concluded that the ultramafic magma ascended along channels occupied by these mafic rocks. Indeed, the gabbros may represent an early partial melt phase of the peridotite which was subsequently invaded and metamorphosed by residual peridotitic magma. Later tectonic events, together with serpentinization and associated metasomatism, dismembered the metamorphic aureole, obscuring or eliminating original contact relationships. The Ti content of the kaersutitic brown amphibole suggests a temperature of about 900 to 1000° C (Bloxam, 1955; 1980; Helz, 1973). The pressure ($P_{H_2O}$) was probably in the range 1.5 to 5kb (LeMaitre, 1969).

The blueschists bear no imprint of this high temperature event and are found as tectonic inclusions in the Knockormal serpentinite mélange. The presence of identical clasts of blueschists in Middle Arenig sediments exposed on the shore at Pinbain (Bailey and McCallien, 1952; Lewis and Bloxam, 1980) raises the problem of the age of these metamorphic rocks. In particular, it revives the original suggestion of Balsillie (1937) that they are Precambrian rather than Arenig or upper Cambrian (Dewey, 1969; 1971; 1974). The recent discovery of middle Dalradian crossite schists from Claggan (Co. Mayo, Ireland) (Gray and Yardley, 1979), together with their clasts in middle Ordovician sediments (Sanders and Morris, 1978) presents a striking similarity to Ballantrae. The crossite schists of Anglesey are also considered to be of middle Dalradian age (Shackleton, 1969).

Hence, the petrological and geological (stratigraphical) relationships at Claggan, Anglesey, and Ballantrae are the same and provide grounds for postulating a middle Dalradian age for them all.

The Ballantrae blueschists are considered to be samples of Precambrian crust dismembered and caught-up in the serpentinite during its cold diapiric rise and tectonic emplacement. By the Middle Arenig this mélange had been exhumed and was supplying blueschists detritus to the seafloor.

## REFERENCES


Anderson, J. G. C. (1936). Age of the Girvan-Ballantrae serpentine. *Geol. Mag.*, 73, 535-545.

Bailey, E. B. and W. J. McCallien (1952). Ballantrae igneous problems. *Trans. Edinburgh Geol. Soc.*, 15 (Campbell vol.), 14-38.

Balsillie, D. (1932). The Ballantrae igneous complex, South Ayrshire. *Geol. Mag.*, 69, 107-131.

—— (1937). Further observations on the Ballantrae igneous complex, South Ayrshire. *Geol. Mag.*, 74, 20-33.

Bloxam, T. W. (1954). Rodingite from the Girvan-Ballantrae complex, Ayrshire. *Min. Mag.*, 30, 525-528.

—— (1955). Origin of the Girvan-Ballantrae beerbachites. *Geol. Mag.*, 92, 329-337.

—— (1964). Hydrogrossular from the Girvan-Ballantrae complex, Ayrshire. *Min. Mag.*, 33, 814-815.

—— (1968). Petrology of Byne Hill, Ayrshire. *Trans. Roy. Soc. Edinburgh*, 68, 105-122.

—— (1980). Ordovician volcanism in Scotland. In: Sutherland. D. editor. *Igneous rocks of the British Isles*. John Wiley, London (in press).

Bloxam, T. W. and J. B. Allen (1960). Glaucophane schist, eclogite, and associated rocks from Knockormal in the Girvan-Ballantrae complex, South Ayrshire. *Trans. Roy. Soc. Edinburgh*, 64, 1-27.

Challis, G. A. (1965). High-temperature contact metamorphism at the Red Hills ultramafic intrusion — Wairau Valley — New Zealand. *Jl. Petrol.*, 6, 395-419.

Church, W. R. and R. K. Stevens (1971). Early Palaeozoic ophiolite complexes of the Newfoundland Appalachians as mantle-oceanic crust sequences. *Jl. Geophys. Res.*, 76, 1460-1466.

Dewey, J. F. (1969). Evolution of the Appalachian/Caledonian orogen. *Nature*, 222, 124-129.

—— (1971). A model for the Lower Palaeozoic evolution of the southern margin of the early Caledonides of Scotland and Ireland. *Scott. Jl. Geol.*, 7, 219-240.

—— (1974). Continental margins and ophiolite obduction: Appalachian Caledonian system. In: Burke, C. A. and C. L. Drake, editors. *Geology of continental margins*. Springer-Verlag, Berlin, 933-950.

Gray, J. R. and B. W. D. Yardley (1979). A Caledonian blueschist from the Irish Dalradian. *Nature*, 278, 736-737.

Green, D. H. (1964). The metamorphic aureole of the peridotite at the Lizard, Cornwall. *Jl. Geol.*, 72, 543-563.

Helz, R. T. (1973). Phase relations of basalts in their melting range at $P_{H_2O}$ = 5kb as a function of oxygen fugacity. Part 1. Mafic phases. *Jl. Petrol.*, 14, 249-302.

KORNPROBST, J. (1969). Le massif ultrabasique des Beni Bouchera (Rif Interne, Maroc): Etude des péridotites de haute température et de haute pression, et des pyroxénolites, à grenat ou sans grenat, qui leur sont associées. *Contr. Mineral. Petrol.*, 23, 283-322.

LAUDER, W. R. (1974). The geology of some New Zealand ultramafic rocks and associated sediments and volcanics. *Pacific Geol.*, 7, 97-130.

LE MAITRE, R. W. (1969). Kaersutite-bearing plutonic xenoliths from Tristan da Cunha, South Atlantic. *Min. Mag.*, 37, 185-197.

LENSCH, G. (1976). Ariegites and websterites in the lherzolite of Balmuccia. *N. Jb. Miner. Abh.*, 128, 189-208.

LEWIS, A. D. and T. W. BLOXAM (1980). Basaltic macadam-breccias in the Girvan-Ballantrae complex, Ayrshire. *Scott. Jl. Geol.* (in press).

MIYASHIRO, A., F. SHIDO and M. EWING (1971). Metamorphism in the Mid-Atlantic ridge near 24° and 30° N. *Phil. Trans. Roy. Soc. Lond.* A. 268, 589-603.

PEACH, B. N. and J. HORNE (1899). *The Silurian rocks of Britain, vol. 1, Scotland.* Mem. Geol. Surv. G.B. (HMSO).

SANDERS, I. S. and J. H. MORRIS (1978). Evidence for Caledonian subduction from greywacke detritus in the Longford-Down inlier. *Jl. Earth Sci. Roy. Dublin Soc.*, 1, 53-62.

SHACKLETON, R. M. (1969). The Pre-Cambrian of North Wales. In: A. Wood, editor. *The Pre-Cambrian and Lower Palaeozoic rocks of Wales.* Univ. Wales Press, Cardiff, 1-22.