The Dalradian rocks of the Shetland Islands, Scotland

D. Flinn, P. Stone and D. Stephenson

Derek Flinn (deceased) formerly The Jane Herdman Laboratories of Geology, University of Liverpool.
Phillip Stone British Geological Survey, Murchison House, West Mains Road, Edinburgh EH9 3LA.
* *David Stephenson* British Geological Survey, Murchison House, West Mains Road, Edinburgh EH9 3LA.
dst@bgs.ac.uk
0131 650 0323

* Corresponding author

Keywords:
Geological Conservation Review
Shetland Islands
Dalradian Supergroup
Lithostratigraphy
Structural geology
Metamorphism

ABSTRACT

Metasedimentary and metavolcanic rocks to the east of the Walls Boundary Fault on Shetland have lithological similarities to those of the Dalradian Supergroup of the Scottish mainland. In particular, the middle part of the succession, termed the Whiteness Group, includes numerous metalimestones and associated pelites in a shallow-marine succession that recalls the upper parts of the Appin Group and the Argyll Group of mainland Scotland. Metavolcanic rocks within the deeper water turbiditic sequence of the succeeding Clift Hills Group might be broadly coeval with those of the Southern Highland Group of Scotland. Beyond that, correlations with the established Dalradian succession are tenuous and are not possible at formation level. A local succession immediately west of the Walls Boundary Fault is of even more-dubious Dalradian affinity.

The dominant structure is the regional-scale, downward- and east-facing East Mainland Mega-monocline. This has a vertical western limb, which youngs to the east, and an eastern top limb that dips to the north-west at 20-30°. Strata on the eastern limb are inverted on Mainland, Whalsay and Out Skerries but are right way up on the west side of Unst, having been folded around the tight Valla Field Anticline. The Shetland Ophiolite-complex has been thrust over the inverted limb of the Valla Field Anticline on the east side of Unst. The regional monocline folds earlier small- to

medium-scale, tight to isoclinal folds with associated planar and linear structures, which are all assigned to a single 'Main Deformation'. It also post-dates the regional metamorphism, which ranges from chlorite to garnet grade, with localized development of staurolite-kyanite, gneissose fabrics, and the emplacement of schistose granitic sheets in the Colla Firth Permeation Belt.

The GCR sites have been selected mainly to be representative of the East Mainland Succession with its associated structures and metamorphism. Highlights include well-preserved sedimentary structures, high-grade gneisses permeated by granitic material, basaltic pillow lavas and serpentinized ultramafic rocks. Some of the latter contain enigmatic skeletal pseudomorphs after olivine and have been interpreted as former high-magnesium lavas.

1 INTRODUCTION

D. Flinn, P. Stone and D. Stephenson

The Shetland Islands lie about 165 km north-east of the Scottish mainland, and are almost half way between Scotland and Norway. The islands comprise an inlier of Caledonian and pre-Caledonian metamorphic rocks, which is completely surrounded by Devonian (Old Red Sandstone) and younger rocks (Figure 1). Correlation of the metamorphic rocks with those of the Scottish mainland has been based on lithological similarities, aided by some radiometric dating. For general summaries of the geology see Mykura (1976) and Flinn (1985).

The Walls Boundary Fault, a likely northward continuation from the Scottish mainland of the Great Glen Fault (Flinn, 1961) (Figure 1) divides the metamorphic rocks of Shetland into two mutually uncorrelatable successions associated with two distinct sets of post-metamorphic granites.

1.1 West of the Walls Boundary Fault

To the west of the Walls Boundary Fault, the overall tectonic arrangement is a series of structural slices, separated by thrusts and shear-zones that interleave pre-Caledonian basement gneisses with metasedimentary cover sequences (Flinn *et al.*, 1979; Flinn, 1985). Many of the component slices exhibit similarities to parts of the Lewisian, Moine and Dalradian sequences of the Scottish mainland and Western Isles. Quartzofeldspathic orthogneisses contain hornblende gneisses that have yielded radiometric ages up to *c*. 2900 Ma and have been correlated with the Lewisian Gneiss Complex. The orthogneisses are in contact to the east with a belt of predominantly schistose psammites containing zones of coarse hornblende gneisses, which are locally blastomylonitized. The psammites have been tentatively correlated with the Morar Group of the Moine Supergroup, whereas the hornblende gneisses might correspond to the inliers of Lewisianiod rocks that are common in the Morar Group. A blastomylonite shear-zone, which separates the Moine-like rocks from the orthogneisses has been correlated with the Moine Thrust. GCR sites to represent these units are described in the *Lewisian, Moine and Torridonian rocks of Scotland* GCR volume (Mendum *et al.*, 2009). The Moine-like rocks, with their Lewisianoid inliers, are limited to the east by the Virdibreck Shear-zone, along which low-grade phyllitic to schistose metasedimentary and metavolcanic rocks of possible Dalradian affinity (the Queyfirth Group) have been thrust westwards.

1.2 East of the Walls Boundary Fault

On the mainland of Shetland, to the east of the Walls Boundary Fault, a dominantly metasedimentary sequence has been correlated with the Moine and Dalradian successions of the Scottish mainland and is referred to as the East Mainland Succession. This succession has been split into four major, lithostratigraphically distinct 'divisions', now formally defined as groups (Figures 1 and 2; Flinn *et al.*, 1972).

The oldest part of the East Mainland Succession, the Yell Sound Group, crops out in the west, where it has been truncated obliquely by the Walls Boundary Fault. It has a maximum exposed width of 10 km and possibly half as much again allowing for sea cover. It is composed of variably gneissose quartzofeldspathic psammites, alternating with major lenses of mica schist and quartzite. It also contains layers of garnet-studded hornblende schist together with half a dozen Lewisianoid inliers. This lithological assemblage distinguishes the Yell Sound Group from the rest of the East Mainland Succession and has allowed it to be correlated with the Loch Eil and Glenfinnan groups of the Moine Supergroup in Scotland (Flinn, 1967, 1992).

The Yell Sound Group is separated from rocks to the east by the 70 km-long and *c*. 1 km-wide Boundary Zone that extends across the islands of Mainland, Yell and Unst. The western margin of the Boundary Zone is marked by occurrences of a microcline-megacryst augen gneiss, the Valayre Gneiss (Flinn 1992, Flinn in Mendum *et al.*, 2009), and its eastern margin by the Skella Dale Burn Gneiss. Between these two augen gneisses the Boundary Zone contains lenses of locally blastomylonitized Lewisianoid hornblende gneisses, basic metavolcanic rocks and a variety of other gneissose psammites and semipelites together with a metalimestone.

To the east of the Boundary Zone, the rocks of the East Mainland Succession have very general lithological similarities with the Dalradian succession of mainland Scotland and are the subject of this paper. They extend the length of Shetland from north to south and have been divided into three groups. From west to east and older to younger these are the Scatsta, Whiteness and Clift Hills groups.

Along part of the south-east coast of the Mainland, the Dalradian rocks have been overthrust, from the east, by a tectonic nappe containing gneisses and various metasedimentary lithologies. The nappe overlies an imbricate zone, containing some serpentinite that was termed a tectonic mélange by Flinn (1967). Some of the constituent rock types are similar to Dalradian lithologies seen farther west within the East Mainland Succession (e.g. in the *Scalloway* GCR site) but, despite these similarities, the tectonic style is distinct and this south-eastern fringe is recognized as the separate Quarff Nappe Succession. The emplacement of the 'Quarff Nappe' probably took place late in the Caledonian Orogeny, during the Scandian Event. Farther north, part of an Early Palaeozoic ophiolite crops out on the islands of Unst and Fetlar (Figure 1). This, the Shetland Ophiolite-complex, was tectonically emplaced at about 500 Ma above rocks of likely Dalradian affinity; its geology has been summarized by Flinn (2001, in press) and its GCR sites are described in the *Caledonian Igneous Rocks of Great Britain* GCR volume (Stephenson *et al.*, 1999). Elsewhere, across much of the east and south of Shetland's Mainland, the Dalradian rocks are unconformably overlain by sedimentary and volcanic rocks of the Old Red Sandstone Supergroup and are intruded by late-Caledonian granites.

1.3 The Dalradian of Shetland

Dalradian rocks crop out over an area of more than 400 km^2 on the Mainland of Shetland, but also form smaller islands to the east of the Mainland and parts of Unst and Fetlar (Figure 1). Their lithostratigraphy, structure, metamorphism and tectonic implications have been the subject of a comprehensive review by Flinn (2007). On most of the Mainland, the succession is continuous, with a total thickness of 10–12 km, is unfolded except for minor folds, dips vertically and strikes north–south. To the south of Scalloway, the western parts of the succession (Scatsta Group) are increasingly hidden by the sea. To the north of Scalloway the Scatsta Group crops out along strike for 30 km but the eastern parts of the succession (Clift Hills Group) pass eastward beneath the sea.

The *Scatsta Group* is between 1 and 2.5 km wide. It is dominantly composed of quartzites and impure quartzites, planar laminated by muscovite partings and with lensoid layers of schistose kyanite- and staurolite-bearing aluminium-rich pelites (chloritoid-bearing at lower grade). There is evidence of soft-sediment slumping.

The *Whiteness Group* is 6-7 km thick and is composed dominantly of planar laminated psammites with some granofelsic psammites and micaceous psammites, all of biotite grade. It contains four major metalimestones, up to 500 m thick, and several thinner beds. It also contains a 1 km-thick unit of gneisses, comprising the Colla Firth Permeation Belt, which extends the length of Shetland (see the *Scalloway* GCR site report).

The *Clift Hills Group* is 3–4 km thick and is the infill of an extensional basin containing turbiditic quartzites, mafic and ultramafic metavolcanic rocks, metagreywackes, phyllitic chloritoid pelites and metalimestones (see the *Hawks Ness* and *Cunningsburgh* GCR site reports).

This continuous succession is laid out to view across the middle of Mainland Shetland (Figure 2). It is assumed that the overall younging is from west to east, although this cannot be proved and intrafolial isoclinal folding precludes any general inference from sedimentary younging evidence. However, the regional metamorphism shows a progressive decrease from kyanite-, staurolite- and garnet-grade in the west to chlorite-grade in the east and the uninterrupted sedimentary succession shows a progression in the same direction from shallow- to deep-water deposition and eventual rifting.

There is an overall similarity to the Scottish mainland Dalradian succession and the following correlations were suggested tentatively (by J.L. Roberts and J.E. Treagus *in* Flinn *et al.*, 1972):

Scatsta Group = the lower part of the Appin Group;
Whiteness Group = the upper part of the Appin Group and lower part of the Argyll Group;
Clift Hills Group = the upper part of the Argyll Group and the Southern Highland Group.

However a comparison with tables of the Scottish mainland Dalradian succession (Harris *et al.*, 1994; Stephenson and Gould, 1995; Strachan *et al.*, 2002) reveals no possibility of unequivocal correlation at formation level. The Asta Spilitic Formation at the base of the Clift Hills Group was originally matched with volcanic formations in the Easdale Subgroup, and the younger Dunrossness Spilitic Formation was therefore correlated with the Tayvallich volcanic rocks (i.e. by Flinn *et al.*, 1972 as followed by Harris and Pitcher, 1975 and Johnson, 1991). However, more recently it has been suggested that the Asta Spilite and Laxfirth Limestone pair could be correlated with the lithologically similar Tayvallich Slate and Limestone Formation and Tayvallich Volcanic Formation, so that the Dunrossness Spilitic Formation would be equivalent to later volcanic events within the Southern Highland group, such as the Loch Avich lavas and the Green Beds (D. Flinn, personal communication in Harris *et al.*, 1994; Flinn, 2007). On a broader basis it does seem reasonable to label the Clift Hills Group as equal to the topmost part of the Argyll Group and the Southern Highland Group, but the Whiteness Group lacks the deepening cycles of the Argyll Group and there is no tillite or any kind of 'boulder bed' to indicate a possible Appin–Argyll group boundary.

The correlations suggested by Flinn *et al.* (1972) have been indicated on Geological Survey maps, but should be regarded with caution. Current suggestions (in part after Flinn, 2007), also highly tentative but adopted in this paper, are indicated in Table 1. However, a more-radical overall interpretation by Prave *et al*. (2009a), based on C-isotope chemostratigraphy of metacarbonate rocks, has implied that the Dalradian volcanism on Shetland is younger than any on mainland Scotland or Ireland, being significantly later than 600 Ma and possibly post-550 Ma. This would cast doubt upon all previous correlations.

All three of the Dalradian GCR sites in Shetland lie within the outcrop of the East Mainland Succession, in the southern part of Mainland Shetland (Figure 2). Together they demonstrate the relatively rapid transformation of the long continuing Scatsta–Whiteness shallow depositional basin into the well-developed turbidite–volcanic Clift Hills deep extensional basin. The *Scalloway* GCR site demonstrates the regionally metamorphosed, locally gneissose and tectonized state of the sandstones and subordinate limestone of probable shallow-marine facies in the Colla Firth Formation in the central part of the Whiteness Group. The *Hawks Ness* GCR site, father east, demonstrates the sudden deepening of the basin, following the deposition of the Laxfirth Limestone, with the immediate influx into the basin of the volcaniclastic Asta Spilitic Formation, followed by turbiditic quartzites, graded siltstones and greywackes of the Clift Hills Phyllitic Formation. The *Cunningsburgh* GCR site represents the top of the Clift Hills extensional basin in the south of Shetland, in an area of major eruptive magmatism involving ultramafic lava-breccias and locally pillowed mafic lavas.

1.4 Tectonics and Metamorphism

Only one period of intense deformation, referred to by Flinn (1967) as the Main Deformation, has been recognized as affecting the East Mainland Succession. It resulted in the formation of a tectonic fabric ranging from dominantly planar to dominantly linear. Small- to medium-scale, tight to isoclinal, intrafolial folds with wavelengths no more than a few metres are widespread, but there is little preserved structural or stratigraphical evidence for large-scale folds. The principal planar fabric is a schistosity defined mainly by micas that is parallel to any compositional layering, bedding or lamination traces that might still be evident. It is well defined in the more-micaceous, finer grained rocks, but is less precisely defined in the coarser grained gneisses, in which it encloses lenticular resistant relics. There has been widespread boudinage of rock layers that had a marked ductility contrast to their neighbours; hornblende schists (perhaps originally intrusive mafic igneous rocks) within phyllitic sequences have been particularly susceptible.

The north–south-striking, eastward-younging, vertical beds described in the previous section extend from the Walls Boundary Fault to the east coast of the Mainland. However, on the offshore islands to the north of Bressay the whole succession is upside down, dipping at 20–30° to the north-west, and farther south the rocks of the Clift Hills Group to the east of the Cunningsburgh CGR site are overturned and dip to the west at *c.* 20° (Figure 2).

The overall structure of the Dalradian on and around Mainland Shetland therefore takes the form of a north–south-striking, 10 km-thick vertical limb younging east, with an eastern limb of similar thickness inclined at 20–30° to the north-west and younging downwards. The hinge region is accessible in the Cunningsburgh CGR site and is well exposed in the cliffs south of Stava Ness. In between, it is hidden by the overlying Old Red Sandstone succession and the Quarff Nappe. The fabric lineation in the vertical limb plunges gently to the south at 10–20°, while the much more poorly developed lineation in the westerly inclined limb has a near-horizontal north-easterly trend. If the westerly inclined limb could be rotated into a vertical east-facing attitude about a fold axis plunging about 20° to the north, then approximate matching of both stratigraphy and lineation would take place. Hence, the implied structure is a very large-scale, downward-facing monocline, referred to as the East Mainland Mega-monocline (Figure 3). However, apart from that monocline and a large-scale swing in strike south of Stava Ness, deformation subsequent to the Main Deformation on Mainland Shetland was limited to cataclasis, faulting and the production of kink folds. The formation of the East Mainland Mega-monocline post-dates the main regional metamorphism and deformation, currently dated, albeit with poor precision, at *c.* 530 Ma (see below), and is considered to have occurred in an extensional regime accompanying rifting on the passive margin of Laurentia (Flinn, 2007). However, it pre-dates the obduction of the Shetland Ophiolite-complex at *c.* 498 Ma (Flinn *et al.*, 1991), the emplacement of the Quarff Nappe, the deposition of the Old Red Sandstone and the truncation of the East Mainland Succession to the west by the post-Devonian Walls Boundary Fault.

On Unst and Fetlar, structural relations are altogether different due to the emplacement of the Shetland Ophiolite-complex on top of inverted, shallow-dipping Scatsta Group rocks (Flinn, in press). On the west coast of Unst (the Valla Field Block) the Scatsta Group rocks have been folded back around the Valla Field Anticline to dip east at about 45° and are right way up (Figure 3), whilst in the north-east of Unst, a large tectonic lens of the Clift Hills Group (the Saxa Vord Block) has been inserted between the Scatsta Group rocks and the ophiolite.

The main regional metamorphism in the Dalradian of Mainland Shetland was coincident with the Main Deformation (Flinn, 1967) but preceded the formation of the East Mainland Mega-monocline and has been attributed to burial metamorphism within the depositional basin (Flinn, 2007). As a result of this metamorphic episode, the Whiteness and Scatsta group rocks range generally from biotite grade in the former to garnet grade in the latter. The rocks are all well crystallized, with the platy and elongate minerals defining the dominant regional schistose foliation and linear fabric. This was followed, whilst thermal gradients were still high, by the localized imposition of gneissose fabrics on the metasedimentary rocks to form the Colla Firth Permeation Belt and by the emplacement of a series of schistose granitic veins and sheets. In a slightly different interpretation of the evidence May (1970) compressed the tectonometamorphic history, suggesting that the fabrics in the granitic veins and those affecting the regionally metamorphosed rocks had formed at the same time, coincident with intrusion of the veins. From either viewpoint, the age of the granitic veins is critical, as it is much closer to a minimum age for the main deformation and metamorphism than the *c.* 498 Ma provided by the obduction age of the Shetland Ophiolite-complex (see above). A Rb-Sr whole-rock date of 530 ± 25 Ma from one of the veins (Flinn and Pringle, 1976), although imprecise and possibly inaccurate by modern standards, did seem to indicate that the metamorphic peak in Shetland might have occurred earlier than in the Dalradian of mainland Scotland, where the peak of Caledonian deformation and metamorphism occurred at about 470 Ma during the intense but relatively short-lived Grampian Event (e.g. Soper *et al.*, 1999). However, U-Pb monazite ages from pelites beneath the Shetland Ophiolite-complex range from 462–451 Ma and have been interpreted as confirming that both the obduction and the regional metamorphism on Shetland were broadly synchronous with the Grampian Event (Cutts *et* al., 2011). The *Scalloway* GCR site is therefore of particular importance in establishing regional tectonometamorphic relationships and dating there by modern radiometric methods is an obvious need.

Patches of staurolite-kyanite-grade pelitic rocks occur locally within the Colla Firth Permeation Belt. Flinn (1954) interpreted these as ‘hot spots’ within the gneiss, whereas May (1970) interpreted them as relics of an early, relatively high-grade metamorphic event.

Somewhat later, development of porphyroblasts such as biotite, chlorite, staurolite, kyanite, chloritoid and garnet occurred, overprinting the tectonic fabrics in the less strongly tectonized rocks of the Clift Hills Group. In the Dalradian rocks beneath the Shetland Ophiolite-complex on Unst and Fetlar, there is evidence of a later retrograde regional metamorphic event, chiefly involving chloritoid but not easily related to emplacement of the ophiolite (this is the 'second metamorphism' of Read, 1934).

The final metamorphic effect observed in the Dalradian rocks was the formation of thermal aureoles around the post-tectonic Spiggie, Channerwick and Cunningsburgh granite intrusions at about 400 Ma. In pelitic rocks this involved the development of such minerals as staurolite, chloritoid, andalusite, kyanite, sillimanite, garnet and muscovite.

2 SCALLOWAY (HU 396 389–HU 389 408)

D. Flinn and P. Stone

2.1 Introduction

The sea cliffs and rocky foreshore west from Scalloway, around Point of the Pund and northwards into Bur Wick, provide a continuously exposed and accessible traverse across the gneissose Colla Firth Permeation Belt and the non-gneissose rocks on either side. The belt of gneisses has developed within the psammitic Colla Firth Formation of the Whiteness Group and extends from Colsay (north of Fitful Head), northwards for 20 km to Scalloway and then for another 30 km north to Delting where it is cut off by the Nesting Fault. The belt varies between one and two kilometres wide, while the outcrop of the Whiteness Group is about 6 km wide. The layering throughout the outcrop is approximately vertical and strikes north-north-east. The gneisses and their adjacent areas are very variably intruded by granitic sheets, which are characteristically less than a metre thick but in several places they form substantial bodies.

The importance of the Scalloway GCR site is that it provides the only complete traverse across the Colla Firth Permeation Belt and illustrates its relationship with the non-gneissose rocks of the Whiteness Group to either side. The relative timing of gneiss development and intrusion of the granitic sheets is of great importance in assessing the wider tectonometamorphic history of the Shetland Dalradian and the radiometric age of the granitic sheets was investigated by Flinn and Pringle (1976). A detailed account of the geology of this area was given by May (1970) and it is included within the Geological Survey's one-inch Sheet 126 (Southern Shetland, 1978). Other parts of the Colla Firth Permeation Belt, included within the Geological Survey's one-inch sheet 128 (Central Shetland, 1981), have been described by Flinn (1954, 1967).

2.2 Description

The easily accessible coastal section to the west of Scalloway, exposes about 1.5 km of strata, part of the Colla Firth Formation of the Whiteness Group, much of which has been rendered gneissose during the development of the Colla Firth Permeation Belt (Figure 4). Throughout the section, granitic sheets are intruded into both the gneissose and non-gneissose rocks, and they merge into a more-substantial foliated granitic mass at the eastern margin of the gneiss belt.

Between the edge of the built-up area of Scalloway and the headland of Maa Ness, the first *c*. 100 m of section is composed of rather flaggy or laminated and lineated, fine-grained semipelitic rocks alternating with sheets of pinkish or white aplitic microgranite that have both a clear schistose foliation and a lineation. The sheets are up to a metre thick and are mostly conformable with or obliquely cross-cut the metasedimentary layering. They are accompanied by pegmatitic streaks. A 300 m-wide outcrop of granite follows, in which there are only very minor semipelitic screens. Granitic sheets occur the length of the gneiss belt, both within it and for up to 100 m or more on either side. Exposure is poor inland, but elsewhere they seem to be very unevenly distributed, very rarely as closely packed as here and generally less than a metre thick.

Gneissose development is first seen on the east side of Maa Ness, to the west of the large granite sheet. It takes the form of a coarsening of the grain size resulting in a loss of sharpness of the schistosity, the lineation and the muscovitic laminations of the flaggy semipelites. The rocks are also homogenized, so that all evidence of bedding is lost and minor compositional differences are destroyed. The transformation is very patchy and generally partial in the east, but by the Point of the Pund the rock is a magnificent example of the homogenous granoblastic gneiss that is characteristic of the permeation belt as a whole (Figure 5). However, even here it is just possible to find ghostly patches of gneiss that retain traces of their original semipelitic character. Such 'semigneiss' relics serve to distinguish this paragneiss from orthogneiss, which it closely resembles.

North of Point of the Pund, granitic sheets and pegmatitic veins cut both the gneisses and relics of psammite and semipelite and also cut across small folds associated with local shears. Beds and lenses of metalimestone and calcsilicate rock become more common, together with bands of fine-grained hornblende schist. The gneiss formation has had no apparent effect on the non-psammitic rocks, although pelitic beds, which become more common to the north and west, tend to develop an array of small quartzofeldspathic leucosomes. Where the coast turns west at Burwick, areas of non-gneissose semipelite and of semipelite with only streaks and areas of partial recrystallization ('semigneiss') become increasingly common. The western edge of the island of Burwick Holm and the rock supporting the Burwick Broch (HU 3880 4058) are barely affected by the recrystallization. The western edge of the gneiss belt is just offshore to the west of the Ness of Burwick, and intersects the coast a kilometre or so to the north of Burwick.

The first deformation episode to affect the rocks (the so-called 'Main Deformation') resulted in the formation of minor folds and a strong fabric, which ranges from planar to linear (Flinn, 1967). Small, tight to isoclinal, intrafolial folds of bedding are common but no larger scale folds are seen. The foliation of the rock is determined by the schistosity, which is parallel to lithological banding and lamination (bedding). The foliation encloses lenses of hornblende schist. Most of the rocks display a prominent rodding or mineral lineation that plunges to the south-south-west at about 40° in the area of the GCR site but at lesser angles to the north and south.

The development of the gneissose fabric in the permeation belt was controlled locally by the nature of the protolith, which was generally banded and laminated with layers of mica-rich pelite and mica-poor semipelite and psammite. Pelitic layers have been almost entirely converted to gneisses by the segregation of diffuse quartzofeldspathic leucosomes and the development of a strong schistose fabric enclosing microaugen of large andesine crystals, 1-3 mm across. An inclusion of deformed kyanite in one of these microaugen was suggested by May (1970) to be evidence for an early phase of metamorphism prior to the development of gneisses (see below). By contrast, in the dominant more-psammitic lithologies the coarsening of the texture weakens the preferred orientation of the mica flakes and hence weakens the schistosity, so that the rocks are generally transformed into homogeneous granofelsic gneisses; quartzofeldspathic leucosomes locally give a *lit-par-lit* appearance and tend to merge with the cross-cutting granitic sheets in places.

Important features of the Colla Firth Permeation Belt that are not immediately obvious from field inspection are the mineralogical effects of the gneiss formation. These have been described by May (1970) for the area of the Scalloway GCR site and by Flinn (1954, 1967) for areas to the north and south. Microscope examination has shown that, although minerals of higher grade than biotite, blue-green amphibole, epidote etc are extremely rare in the Whiteness Group of the Scalloway area, microcline and diopside occur in calcsilicate bands and metalimestones within and adjacent to the permeation belt. May (1970) has also found a kyanite-staurolite-bearing rock within the belt to the south of Scalloway, and both Flinn (1954) and May (1970) have reported fibrolite and garnet as present within the belt, in particular in Delting and also in a small area some 10 km south of Scalloway. It is apparent that the formation of the gneisses took place at a higher temperature than the metamorphism in the adjoining parts of the Whiteness Group. Late-stage, retrogressive effects include sericitization of feldspar and chloritization of biotite.

The most widespread effect of deformation subsequent to the main phase is cataclastic faulting and locally prominent kink folding. Rare lamprophyre dykes are entirely post tectonic and post metamorphic.

2.3 Interpretation

The original sedimentary protoliths to the now-metamorphosed Scalloway succession were sandstones, mudstones and subordinate limestones of probable shallow marine facies. No definitive examples of sedimentary structure are preserved but the micaceous partings, regularly spaced at intervals of a few millimetres through some psammite units, and the regular division of the rocks into bed-like units, commonly of slightly different composition, are probably original sedimentary features. Mineralogically the psammites and pelites now consist of varying proportions of biotite, muscovite, quartz and plagioclase; garnet, kyanite and staurolite are accessories. These minerals and others mentioned above all developed during prograde metamorphism.

Three stages have been recognized in the formation of the Colla Firth Permeation Belt. May (1970) recognized an earlier stage in which kyanite and staurolite were formed, but since the kyanite and staurolite occur only within the permeation belt they, like the garnet and sillimanite elsewhere, might have formed during the gneiss development. The first undisputed stage recognized in the metamorphism of the area as a whole is the regional metamorphism with coincident tectonizing deformation. In the second stage some of the rocks within the area of the permeation belt were partially or completely transformed into gneiss (Figure 5). The presence of partially transformed rocks ('semigneisses') and even unaltered rocks among the gneisses proves that their formation followed regional metamorphism. The third stage involved the emplacement of granitic and pegmatitic sheets into the folded gneisses of the permeation belt and the adjacent rocks on either side.

The three stages are closely connected by having similar fabrics; foliations, schistosities and lineations are all parallel where they exist, although some of the granitic sheets are structureless. There have been slight differences in the detailed interpretation of this evidence. In the opinion of May (1970), the textural evidence preserved within this GCR site confirms that the granitic sheets were intruded as the gneissose fabric formed; the constituent minerals in the granite have been granulated and recrystallized to produce a fabric continuous with that in both the gneissose and non-gneissose country rocks. May therefore considered that the regional metamorphism, the gneiss development and the emplacement of the granitic sheets were all 'syn-tectonic and broadly synchronous'. In contrast, Flinn (1954, 1967) considered that the gneisses formed in a distinct event immediately after the regional metamorphism, while the thermal and stress structure was still in place. The two events could however have overlapped and the granitic sheets were probably emplaced very soon afterwards. The radiometric (Rb-Sr) date of 530 ± 25 Ma, obtained by Flinn and Pringle (1976) for the granitic sheets should therefore indicate a minimum age for the main deformation and peak metamorphism of the Shetland Dalradian. However, it is neither precise nor accurate by modern standards and needs to be repeated using modern techniques.

The possible causes and/or mechanisms of gneiss development have been discussed by Flinn (1954, 1967, 1995). The metamorphic minerals and grades involved are so low (below garnet grade in the Scalloway area) that there can be no question of the gneisses having formed by partial melting. He considered that the gneisses are most likely the result of recrystallization in which their grain size was doubled or trebled. This was brought about with little or no change of composition by the percolation (permeation) through the rocks of hot watery solutions from below, controlled by the pre-existing vertical layering and schistosity in the Whiteness Group. The water initiated the grain growth by grain-boundary migration and also supplied the heat for the diopside thermal aureole that occurs along the length of the belt. The granitic sheets are of S-type and probably formed by melting of the crust at depth. It is possible that they supplied some heat but it is notable that the aureole is continuous and is entirely confined to the gneisses, whereas the granitic sheets are irregularly distributed and extend beyond the aureole. May (1970), however, attributed the presence of diopside porphyroblasts in calcsilicate rocks to a late period of post-tectonic static metamorphism that is represented by the growth of various porphyroblasts elsewhere in Mainland Shetland (Flinn, 1967; see the *Hawks Ness* GCR site report).

2.4 Conclusions

The Scalloway GCR site provides a well-exposed and instructive section through part of the Colla Firth Permeation Belt, which is of national and possibly international significance. At the GCR site, this gneissose zone is developed within a sequence of semipelitic to psammitic metasedimentary rocks forming part of the Colla Firth Formation in the Whiteness Group of the Shetland Dalradian. The psammites and pelites have been recrystallized to a homogeneous granoblastic gneiss with a fabric parallel to that in the adjacent rocks outside the belt, which have been regionally metamorphosed and deformed but are not gneissose. Numerous granitic sheets and veins were intruded into both the gneiss belt and the adjacent non-gneissose rocks and these too have a schistose fabric.

Textural evidence preserved within the rocks of this GCR site confirms that the regional metamorphism and gneiss formation, although possibly originating from distinct events, were both broadly coincident with the principal deformation and that all of these events only shortly preceded or overlapped with the intrusion of granitic sheets. The age of the granitic sheets is therefore of great national importance as an indicator of the minimum age of deformation and peak metamorphism in the Shetland Dalradian. A radiometric, Rb-Sr date of 530 ± 25 Ma is imprecise, probably inaccurate and dating by a modern, more-precise method is clearly desirable. However, the date does suggest that the deformation might be radically different in timing to the deformation affecting the Dalradian sequence elsewhere (e.g. peaking at *c*. 470 Ma in the Grampian Highlands). It follows that an understanding of these tectonometamorphic relationships is crucial for the wider interpretation of the Dalradian succession both in Shetland and in the Scottish mainland.

3 HAWKS NESS (HU 447 477–HU 458 491–HU 458 473)

P. Stone and D. Flinn

3.1 Introduction

The sea cliffs and rocky foreshore around the promontory of Hawks Ness provide extensive exposure through a metasedimentary sequence extending from the top of the Whiteness Group through the lower part of the Clift Hills Group of the Shetland Dalradian. The lithologies present range from metacarbonate rocks of probable shallow-water origin, to metavolcanic rocks and deep-water turbidites. Sedimentary structures preserved in the turbiditic strata show locally opposed younging directions which, together with the exposure of fold closures, confirm the presence of isoclinal folds. Deformation has also produced a pervasive foliation, a linear fabric and a recrystallized, phyllitic mineral assemblage. Post-tectonic regional metamorphism led to the subsequent growth of staurolite and garnet porphyroblasts.

The regional importance of the Hawks Ness GCR site lies in the unusually wide range of sedimentary, tectonic and metamorphic features preserved in a succession that was deposited in an extensional basin setting. An understanding of the processes and sequence of events involved allows for a more-informed regional interpretation of an otherwise poorly known part of Scottish geology. A detailed account of the geology was given by Flinn (1967) whilst an overview of the regional geological setting was provided by Flinn and May (in Mykura, 1976); the GCR site area is included in the Geological Survey's one-inch Sheet 128 (Central Shetland, 1981).

3.2 Description

Around the promontory that culminates in Hawks Ness, steeply inclined strata strike north-north-east. The stratigraphical sequence commences with the Laxfirth Limestone (the top of the Whiteness Group) on the west side of the promontory, and proceeds upwards and eastwards through the Asta Spilitic Formation and Clift

Hills Phyllitic Formation (the lower part of the Clift Hills Group) (Figure 6). The Asta Spilitic Formation has been correlated with the Easdale Subgroup in the Dalradian succession of the Scottish mainland (Flinn *et al.*, 1972) but more-recently a possible correlation with the Tayvallich volcanic rocks, at the top of the Argyll Group, has found more favour (Harris *et al.*, 1994; Flinn, 2007).

The Laxfirth Limestone crops out as a thin strip along the strike-parallel eastern coast of Lax Firth, although the full outcrop extends to the western side of the firth and the thickness probably exceeds 500 m. It is a crystalline, calcite metacarbonate rock containing scattered coarse grains of quartz, and with small quantities of epidote, zoisite, white mica and pyrite concentrated into fairly continuous laminae. On a larger scale, there is a faint, millimetre- to centimetre-scale colour banding through shades of pale grey and pale pink. Overall, the Laxfirth Limestone is relatively fine grained compared to some other Dalradian metalimestones. At its eastern boundary, it is intimately associated with conformable sheets of hornblende schist up to about a metre thick.

Conformably above the metalimestone is the Asta Spilitic Formation, which crops out along the north-west coast of Hawks Ness in a narrow zone no more than a few tens of metres wide. These largely pyroclastic rocks range from phyllitic fine-metatuffs to pyroclastic metabreccias and are generally thinly interbanded with feldspar-phyric hornblende schists and phyllitic pelites. Adjacent to the Laxfirth Limestone, and corresponding with the pyroclastic rocks, a narrow positive ground-magnetic anomaly of about 1000 nT can be traced continuously, southward to the sea at Scalloway and to the north-east almost as far as the Out Skerries. The pyroclastic rocks are succeeded by a zone, 10–20 m wide, in which beds of turbiditic gritty quartzite alternate with thin beds of laminated and graded, dark semipelite. Some hornblende schists commonly form boudinaged pods.

The north-east coast of Hawks Ness presents a continuous section through more than 300 m of the Clift Hills Phyllitic Formation. This unit contains phyllitic metagreywackes, thin beds of gritty quartzite, phyllitic gritty psammite, pelite, calcsilicate rock and sporadic lenses of hornblendic schist similar to those seen in the underlying Asta Spilitic Formation. The phyllitic rocks are laminated on a millimetre scale, the darker, more-micaceous laminae representing metamorphosed mudstone, while the paler laminae are probably derived from sandstones and siltstones. It is possible to detect small-scale cross-bedding in places, usually with the appearance of low-amplitude ripples (Figure 7). They have a strong foliation and are pervasively recrystallized to fine-grained quartz, feldspar and muscovite, together with biotite and/or chlorite; some are graphitic. Staurolite, biotite and chlorite porphyroblasts post-date the imposition of the tectonic foliation (Flinn, 1967). Inland, in the southern part of the Hawks Ness promontory, are large intrusions of hornblende metagabbro, containing ophitic blue-green hornblende and recrystallized primary albite. Smaller lenticular bodies of hornblende schist containing relict phenocrysts of plagioclase also attest to an igneous protolith.

On the south-east side of the Hawks Ness promontory, the top part of the Clift Hills Phyllitic Formation is the Dales Voe Grit Member, which comprises 1.5 km of turbiditic gritty quartzites. Excellent exposures are provided by the rocky headlands of Brim Ness and Fora Ness. In this well-layered sequence, units of impure quartzite, with bed thickness ranging from several centimetres up to several metres, alternate with subordinate units of thinly bedded laminated and graded semipelite. At Brim Ness there is a thin, conformable interbed of granular calcsilicate rock, whilst thin metalimestones and lenses of Asta Spilite-like rock occur sporadically. Within the quartzite units, many individual beds show normal, upwards grading from coarse, locally pebbly bases, through coarse-grained, gritty quartzite to finely laminated semipelite. Cross-bedding is seen in the upper parts of many beds, whilst evidence of channelling and current scour is preserved on basal bedding planes. This abundance of sedimentary younging evidence demonstrates local reversals that can be attributed to tight folding; many hinges are spectacularly preserved (Figure 8a). These are dominantly single-bed intrafolial isoclinal folds most of which face eastwards and upwards, but a minority face westwards and downwards.

On the eastern side of the Dales Voe Grit, on the opposite side of Dales Voe, there is an upward transition from the gritty metasandstone back into chloritic phyllites. These then continue eastwards, and stratigraphically upwards until, farther south, they are seen to underlie the pelitic Dunrossness Phyllitic Formation, which in turn underlies the volcanic Dunrossness Spilitic Formation, part of which crops out in the *Cunningsburgh* GCR site.

Post-tectonic lamprophyre dykes, one of which can be seen to the south of Brim Ness, are probably of Early- to Mid-Devonian age.

3.3 Interpretation

At the base of the succession within the GCR site, the thick metacarbonate unit of the Laxfirth Limestone suggests sedimentation in relatively shallow water. The subsequent volcanicity recorded in the Asta Spilitic Formation, and the closely associated turbiditic metasedimentary rocks of the Clift Hills Phyllitic Formation, then suggest a phase of rapid subsidence and the establishment of a deep-water depositional environment. The following Dales Voe Grit beds have all the characteristics of deep-water turbidites. The individual beds are graded in their lower parts, passing up into a laminated and sporadically cross-bedded upper sector that is either abruptly overlain by the coarse base of the succeeding bed or passes up into a unit of thinly bedded, graded siltstones. The thicker, sandstone beds were deposited from large-volume and high-density turbidity flows, whereas the sequences of more thinly bedded, graded siltstones derive from a series of smaller, low-density flows. The bases of the thicker beds commonly carry flute and groove casts from which Flinn (1967) was able to calculate an original current flow from the north.

The array of sedimentary features that are preserved also allows the local sedimentary younging direction to be established. Throughout the GCR site area, the beds strike 030° and, in general, they dip steeply to the north-west in the west and to the south-east in the east. The overall stratigraphical trend is for successively younger units to crop out sequentially towards the south-east. This situation is confirmed by some of the localized sedimentary younging evidence but is contradicted in places by unequivocal examples of younging towards the north-west (Figure 7). Flinn (1967) recognized this phenomenon and related it to short wave-length isoclinal folding, which is shown by individual beds (Figure 8a). This was linked to the main tectonic deformation, which produced a steep schistosity and a lineation plunging at *c*. 20° to the south (Figure 8b); a similar fabric and orientation to that in the rocks of the *Scalloway* GCR site to the south-west. However, while the fabric lineation plunges at 20° or so to the south, the axes of the folded turbidite beds plunge at 20–30° to the north (Figure 6, inset).

The local syn-tectonic metamorphic mineral assemblage is dominated by muscovite, biotite, chlorite, quartz and plagioclase. Post-tectonic regional metamorphism has led to the porphyroblastic growth of staurolite, garnet, biotite and chlorite.

3.4 Conclusions

The Hawks Ness GCR site provides a well-exposed and instructive representative section through a metasedimentary sequence extending from the top of the Whiteness Group (the Laxfirth Limestone) through the lower part of the Clift Hills Group (the Asta Spilitic Formation and the Clift Hills Phyllitic Formation) in the Dalradian succession of Shetland. These units are currently thought to be broadly equivalent to the Tayvallich Subgroup of the Scottish mainland succession. The sequence demonstrates deposition in a progressively deepening marine environment with sub-marine volcanism marking the onset of rapid subsidence.

Structural and metamorphic features within the GCR site make a significant contribution to interpretation of the deformational and metamorphic history of the Shetland Dalradian. Deep-water turbiditic strata (in the Dales Voe Grit) preserve sedimentary structures from which opposing stratigraphical younging can be deduced, confirming that the sequence has been affected by short-wavelength, isoclinal folding, which is commonly shown by individual beds. A phyllitic mineral assemblage (muscovite-biotite-chlorite-quartz-plagioclase) formed during deformation-related metamorphism and staurolite, garnet, biotite and chlorite were produced during post-tectonic, regional metamorphism.

4 CUNNINGSBURGH (HU 439 280–HU 421 274–HU 432 264)

D. Flinn, P. Stone and D. Stephenson

4.1 Introduction

This GCR site is named after the collection of hamlets on the south-east coast of Mainland Shetland, some 13 km south-south-west of Lerwick, that is generally known as Cunningsburgh (Figure 9). There, despite relatively intense metamorphism, an unusual and regionally important geological assemblage can be recognized. The east–west foreshore between South Voxter and Mail provides sections through the uppermost part of the Dunrossness Spilitic Formation, at the top of the Clift Hills Group. The rocks are dominantly sub-marine, basic pillow lavas with interbedded volcaniclastic material and intrusive bodies of hornblende metagabbro. To the south of Mail the north–south trending sea cliffs and the hillside between the cliffs and the road are composed of metalavas alternating with layers of metavolcaniclastic material and beds of metasedimentary rock. The rocks are pervasively foliated and are difficult to interpret in the field due to the intensity of metamorphism and their general dark-coloured and fine-grained nature. Inland from the north–south cliff section, the hillside drained by the Burn of Catpund is underlain by a large body of variably altered serpentinite, notable for its local development of highly unusual and controversial spinifex-like texture, which could be of considerable international interest (Figure 10). Along its western margin the serpentinite is in direct contact with a sequence of phyllitic chloritoid-kyanite-chlorite pelites, known as the Dunrossness Phyllitic Formation. These stratigraphically overlie the Clift Hills Phyllitic Formation that is displayed so comprehensively in the *Hawks Ness* GCR site. The Dunrossness Phyllitic Formation is seen to overlie the serpentinite structurally at the southern end of the GCR site, although it underlies it stratigraphically in the accepted order of Shetland succession.

This assemblage of rocks, following on from the sequence seen in the *Hawks Ness* GCR site, provides an illustration of the final stages in the development of a late-Dalradian extensional basin, when crustal disruption culminated in deep-seated intracontinental to oceanic magmatism. An understanding of the processes and sequence of events involved allows for a more-informed regional interpretation of an otherwise poorly known sector of the Scottish Dalradian. Detailed accounts of the local geology were given by Flinn (1967), Flinn and Moffat (1985) and Moffat (1987) and the area is covered by the Geological Survey's one-inch Sheet 126 (Southern Shetland, 1978). The rock assemblage was discussed in its regional context by Flinn (1985, 1999).

An additional feature of this GCR site stems from its considerable archaeological interest. Areas of very soft talc-magnesite schist (steatite), arising from low-temperature hydrothermal alteration of the serpentinite, were exploited in Norse times to be worked-up into various artefacts. Numerous tool-marked recesses have been left behind by the Norse workings and it has been suggested by archaeologists that there was considerable trade in steatite products from these and from other such quarries in Shetland.

4.2 Description

The Dunrossness Spilitic Formation forms the stratigraphically highest part of the Dalradian succession exposed in Shetland (Flinn *et al.*, 1972). It is almost entirely composed of mafic and ultramafic, lavas and volcaniclastic rocks formed in a sub-marine environment. The formation has been correlated broadly with either the lavas and tuffs of the Tayvallich Subgroup at the top of the Argyll Group (Flinn *et al.*, 1972), or possibly with part of the slightly later Southern Highland Group (Harris *et al.*, 1994; Flinn, 2007).

The formation dips consistently to the west at between 25° and 45°. There is no local way-up evidence but, accepting that the overall younging of the Shetland Dalradian succession is to the east, as discussed in the *Introduction* to this paper, the sequence here must be overturned. The outcrop width and dip suggest a formation thickness of about 1 km, with the ultramafic component, a large body of serpentinite, occupying upwards of one half of that, in the topographically highest but stratigraphically lowest part in the west. For the most part, the sequence is thinly foliated with some thicker and more-massive, less well-foliated units that are probably relics of the original bedding. The metamorphic foliation is generally parallel to the igneous and sedimentary layering. Folding is rare but locally the layering and foliation are intensely deformed by a series of small, strongly asymmetrical, tight to isoclinal folds. Fold hinges are subhorizontal but show a range of orientations, possibly in association with minor faulting, which complicates the structure locally. Garnet appears to have grown in two phases of metamorphism, before and after imposition of the foliation. Overall, the rocks stratigraphically above the serpentinite have been metamorphosed to lower to medium amphibolite facies. This is a significantly higher grade than is seen in the rocks of the Clift Hills and Whiteness groups to the west (see the *Hawks Ness* GCR site report).

The serpentinite occupies most of the hillside above the road to the west of the coastal sections. Its basal contact with the metasedimentary, chloritoid-bearing Dunrossness Phyllites is exposed only in the sea cliffs at the southern end of the GCR site, immediately north of Lamba Taing. There, despite the complication of minor but complex faulting, the contact appears to lie parallel to the bedding traces and dominant foliation in the phyllites; there is no evidence for a significant tectonic break. A major lens of serpentinite, separate from the main body, crosses the road and intersects the coast in the middle of the GCR site and wedges out on the hillside south of the Burn of Catpund. This large lens of serpentinite also lies parallel to the foliation in the spilitic and volcaniclastic rocks.

The serpentinite has been variably steatitized and veined by talc. From several hundred metres north of the Burn of Catpund to the south end of the GCR site, the steatitization is sufficiently intense for a quarry to have been opened recently in the expectation of exploitation. The surrounding hillside is scarred by small pits opened during the Norse occupation of Shetland, a thousand years ago, for the manufacture of utensils. Some Norse pits along the Burn of Catpund have been re-excavated by the burn and one has been opened by archeologists for display purposes.

The steatite rock is about half talc and half magnesite. Where the steatitization is not too intensively developed, the rock is seen to be a clast-supported breccia composed of blocks up to about 30 cm in diameter, thoroughly cemented by the serpentinization. Broken blocks within the breccia that have been little affected by steatitization, have in places been weathered and etched to reveal that they are composed of a mass of needle-like, parallel to subparallel crystal pseudomorphs forming a distinctive spinifex-like texture (Figure 10). The 'spinifex' textured rocks can be traced intermittently from about 300 m north of the Burn of Catpund as far as the Burn of Mail, in a zone a hundred metres or so west of the contact of the serpentinite body with the spilitic rocks (Figure 9). Thin sections show that the pseudomorphs have the characteristic crystal terminations of spinifex-textured olivines, but that they are serpentinized or steatitized, as is the matrix that contains them. As is discussed below, the recognition of the spinifex-like texture provides crucial support for the interpretation of the serpentinite as an original quickly chilled, ultramafic lava, possibly a komatiite.

Also present within the serpentinite outcrop are several major lenticular layers of fine-grained non-serpentinite rocks that possibly separate individual ultramafic lavas. These are mainly metavolcaniclastic rocks, best seen on the beach at Mail and in the nearby road cutting. They also include interlayered lenses of metasedimentary rocks including very fine-grained, often graphitic gritty psammites, quartzites and pelites; one such lens crops out on the coast about 200 m south of Sands of Mail. The minerals present include biotite, garnet, chlorite, chloritoid and hornblende. The quartzites might be recrystallized cherts and there is at least one 2 m-thick bed with a melange-like texture showing tectonic stretching of the clasts within the plane of the foliation (Figure 11).

Sporadically distributed through the serpentinite are many near-spherical to sublenticular bodies of hornblende gabbro, 10–20 m across and forming prominent smoothly rounded knolls. Also widely scattered in this area are intrusive veins and lenses, centimetres to several metres in width, of a white to greyish rock with a siliceous patina. The rock is composed of minute aligned crystals of albite with sparse accessory hornblende and biotite. It contains 10% Na_2O and 0.5% K_2O and has been interpreted as a sodic 'keratophyre' (an albite felsite). It also contains abundant micron-sized zircons and an analysis shows 1000 ppm Zr, but it has not as yet been dated and relationships with the host serpentinite cannot be determined.

To the east of the serpentinite, between the road and the sea, are metamorphosed basic lavas alternating with volcaniclastic rocks. In thin section the lavas are seen to be composed dominantly of blue-green hornblende with epidote. Some are aphyric, others contain relict phenocrysts of plagioclase (now corroded albite), and many are amygdaloidal. The rocks are variably tectonized with phenocrysts broken and displaced in some examples and acting as microaugen within the foliation in others. They are tholeiitic Mid-Ocean-Ridge-Basalt (MORB), probably derived from a relatively enriched mantle source (Fettes *et al.*, 2011). The volcaniclastic rocks are black and commonly very fine grained. Their nature is largely indeterminable in the field except where they have been polished by sand along the Mail coast; identification has been assisted greatly by thin-section examination (Flinn, 1967).

Eastwards along the coast from the Sands of Mail, the rocks are exceedingly difficult to interpret. Most are black and fine grained, but in thin section they prove to be basic metavolcaniclastic rocks. Some weathered exposures reveal faint cross-sections of pillow structures (e.g. at HU 441 282) and the sequence might be largely composed of fragmented pillow lavas. Also present, especially adjacent to the Old Red Sandstone to the east of Aith Voe, are exposures of graphitic quartzite and phyllitic pelite. Inland there are a number of hornblende gabbro bosses with the same appearance as those seen to the west within the serpentinite; although here some are schistose and boudinaged, Flinn (1967) reported the preservation of an ophitic texture. An unusually large example crops out on the coast at The Pows (HU 437 278). They might have originated as intrusions into the volcanic sequence.

4.3 Interpretation

The interpretation of the origin of the serpentinite is crucial in any assessment of the wider geological significance of the Cunningsburgh GCR site in relation to the late history of the Dalradian basin in Shetland. When it was first mapped in the late 1950s, the serpentinite was interpreted as comprising one or more sub-marine, ultramafic lava flows (Flinn, 1967). However, this interpretation was regarded as petrologically impossible at the time and was not published until the recognition of the spinifex-like texture by Flinn and Moffat (1985) suggested the possibility of a komatiitic protolith for the serpentinite.

The term ‘komatiite’ was introduced by Viljoen and Viljoen (1969) to describe ultramafic lavas from the Baberton Mountain Land, South Africa. They are now known to be fairly widespread in Archaean greenstone belts but are rare in younger geological assemblages; for an overall review see Arndt and Nisbet, (1982). The high concentration of magnesium (up to 32% MgO) and related elements in komatiitic lavas indicates a high temperature (*c*. 1600°C), a high degree of melting of mantle material and consequently an unusually high heat flow and/or the tapping of an exceptionally deep and hot mantle source. Hence the presence of the ultramafic lava within the Shetland Dalradian has potentially profound implications for the tectonic development of the depositional basin.

Apart from the high MgO values, the most distinctive feature of komatiitic lavas is the common primary crystallization of olivine as long intermeshed crystals in a glass matrix, to produce what is known as ‘spinifex texture’ (after the spiny intermeshed leaves of Australian Spinifex grass). However, the spinifex nature of the texture in the Cunningsburgh rocks was disputed by Nesbitt and Hartman (1986) who thought it more likely to be an example of the well-documented ‘pseudo-spinifex’ or ‘jackstraw’ texture that develops through the regrowth of olivine during prograde metamorphism of serpentinite (Collerson *et al.*, 1976). The distinction between this pseudo-spinifex and true spinifex texture is best based on examination of thin sections of fresh samples. However, the Cunningsburgh rocks are both serpentinized and steatitized, destroying these distinctive thin-section features. The distinction in this case has to be based on the study of the textural patterns revealed on suitably weathered rock surfaces (Figure 10).

Nesbitt and Hartmann (1986) presented various arguments against the presence of komatiitic lavas at Cunningsburgh and elsewhere in the Caledonian–Appalachian Orogen, possibly infuenced by the fact that occurrences in post-Archaean rocks were at that time regarded as exceedingly rare or non-existent. Proterozoic and Phanerozoic komatiitic occurrences are no longer regarded as quite so rare, but it is difficult to reach any conclusions about original magmatic liquid compositions from rocks that are as altered as the Cunningsburgh serpentinites, and the origin of the spinifex-like texture remains somewhat enigmatic. However, even if the Cunningsburgh rocks were not originally komatiites, it is still possible that they originated as basaltic lavas, in which Mg concentrations even higher than those of typical komatiites can arise by olivine fractionation and accumulation (see the *Ardwell Bridge* GCR site report).

In a robust defence of their original interpretation, Flinn and Moffat (1986) pointed out that the complex metamorphic history implied by the Nesbitt and Hartmann interpretation of the origin of the spinifex-like texture does not fit the known geology of the Cunningsburgh area. In particular, there is no evidence in Shetland for a high-grade metamorphic event (of at least upper amphibolite facies) that would have been necessary to produce prograde olivine growth after one episode of serpentinization but before the brecciation and the final serpentinization and steatitization. They re-iterated their belief that a volcanic origin for the serpentinite in the top of an extensional basin requires the fewest assumptions, creates the fewest problems and fits the observed structural and metamorphic history most simply.

Consequently, the Dunrossness Spilitic Formation, including the serpentinite, is regarded as the final volcanic infill to the late-Dalradian extensional basin that is still preserved in Shetland. Following the deposition of the Laxfirth Limestone, early sedimentation in the basin was interrupted by a series of relatively minor volcanic eruptions giving rise to the Asta Spilitic Formation (see the *Hawks Ness* GCR site report). But the later volcanism that created the Dunrossness Spilitic Formation was an event on an altogether different scale. Not only is the formation a kilometre or more thick, but it commenced suddenly with the eruption of a thick sequence of ultramafic lavas. This unusual event is most readily explained by a rapid acceleration of crustal rifting beneath the extending basin, causing adiabatic melting in the mantle immediately below with generation and emplacement of high-temperature, magnesium-rich magmas (Flinn, 2007). The spinifex-like texture, the brecciation and the serpentinization could all be due, in part at least, to sub-marine emplacement of the ultramafic magma; certainly they are all early-formed features. The emplacement of the ultramafic magma was followed by the more-usual eruption of basaltic magma of tholeiitic Mid-Ocean Ridge affinities in the form of lavas, volcaniclastic material and eventually pillow lavas. Their higher grade of metamorphism than any of the rocks in the Clift Hills and Whiteness groups to the west might have been caused, at least in part, by residual heat associated with the ultramafic magmas. The intrusion of small globular masses of the same magma in the form of hornblende gabbro would seem to require special conditions or circumstances that are not fully resolved.

Apart from the sub-marine lavas and volcaniclastic deposits, the original protoliths for the sedimentary components of the Dunrossness Spilitic Formation were interbedded mudstones and sandstones of deep-marine, probable turbiditic facies. Accessory lithologies present possibly included chert and a melange-type rock that might have originated by sedimentary slumping before being tectonized.

The onshore outcrop of the Dunrossness Spilitic Formation is given additional importance by a substantial offshore extension beneath Old Red Sandstone strata, as indicated by major coincident gravity and aeromagnetic anomalies. These anomalies continue as far north as the island of Unst, suggesting that the extensional basin eventually developed into an intracontinental rift on the edge of Laurentia at the time of the opening of the Iapetus Ocean (Flinn, 2007). It has even been suggested by Flinn (2001) that the Shetland Ophiolite could have been obducted from this basin at about 500 Ma.

A possible ophiolitic association of the serpentinite and pillow lava sequence in the Cunningsburgh area was noted by Garson and Plant (1973) and was further hinted at by Nesbitt and Hartmann (1986). This interpretation invoked limited sea-floor spreading during basin extension, but also invited consideration of cold serpentinite diapirism into growing oceanic fracture zones. However, apart from the presence in the Cunningsburgh area of serpentinite and pillow lavas, no convincing evidence has been adduced which in any way suggests the presence of an ophiolite-complex. At the time that these suggestions were made it was still common for all serpentinite occurrences to be interpreted automatically as ophiolites.

4.4 Conclusions

The coast to the east and south of Mail and the hillside inland from the coast at the Cunningsburgh GCR site, provide excellent exposures of the Dunrossness Spilitic Formation, the youngest Dalradian unit present in Shetland. It is largely metavolcanic in origin and comprises sub-marine lavas and various volcaniclastic rocks, interbedded with minor metasedimentary lithologies of deep-water facies. The volcanic succession has been intruded by comagmatic hornblende gabbro and by albite felsite (‘sodic keratophyre’) of unknown affinity. All of the rocks have been deformed and metamorphosed, up to middle amphibolite facies in places; some of the finer grained rocks have a phyllitic texture.

The metavolcanic rocks include basaltic pillow lavas and brecciated ultramafic rocks that are interpreted as high-magnesium lavas. Clasts within the latter have spectacular and highly distinctive elongate pseudomorphs after crystals of olivine, which have been likened to the spinifex texture characteristic of unusual high-temperature lavas known as komatiites. Unfortunately later serpentinization has obliterated details of the texture and its origin has been the subject of debate, but the presence of komatiites in post-Archaean rocks is rather unusual, and the possibility of their presence in Shetland is highly significant and of international interest.

The rock assemblage illustrates the final phase in the development of the Dalradian extensional basin in the Shetland area. An abrupt increase in the rate and depth of extensional faulting is considered to have caused generation of the highly unusual ultramafic lavas, followed by eruption of more-typical, within-plate basaltic lavas. A considerable thickness of the basaltic lavas and associated volcaniclastic rocks built up as the basin filled; since many of the lavas are pillowed, sub-marine eruption is confirmed. The volcanic sequence can be traced offshore by geophysical methods as far north as the island of Unst, and it might have formed the floor of an intracontinental basin on the edge of Laurentia from which the Shetland Ophiolite was obducted. Hence, the geological features preserved within the Cunningsburgh GCR site have profound implications for the wider interpretation of the Dalradian succession both in Shetland and in the Scottish mainland.

ACKNOWLEDGEMENTS

This paper has been compiled by D. Flinn and edited by D. Stephenson. Sadly, Derek Flinn died whilst it was being prepared for publication. His lifelong contribution to all aspects of the geology of Shetland can never be surpassed. The GCR editor was P.H. Banham and the referee was M.R.W. Johnson, who also provided valuable editorial suggestions. The project was cofunded by the Joint Nature Conservation Committee (JNCC) and the British Geological Survey (BGS) and has been managed by N.V. Ellis for JNCC and D.J. Fettes and M. Smith for BGS.

Since the initial site selection and site documentation for the Dalradian block of the Geological Conservation Review, additional sites to represent the Dalradian of Shetland were suggested by D. Flinn and F. May. The necessary amendments to the GCR documentation were greatly facilitated by R. Wignall (for Scottish Natural Heritage).

Diagrams were drafted for publication by S.C. White (JS Publications, Newmarket) and photographs were scanned and prepared by B.M. McIntyre (BGS, Edinburgh). Photographs from the BGS collection are reproduced by kind permission of the Director, BGS © Natural Environment Research Council; all rights reserved (PR/23–27).

The first complete draft of the Dalradian GCR was submitted to the JNCC in June 2009. In 2010, the JNCC terminated its involvement in Earth Science conservation and abandoned its contractual agreements to publish the remaining GCR volumes. So, the authors are greatly indebted to Diarmad Campbell, Chief Geologist Scotland for the BGS, for funding the drafting of remaining figures and to the Geologists' Association and Elsevier, for ensuring that this volume is published as a Special Issue of their Proceedings. We are particularly grateful to Neil Ellis of the JNCC for his efforts to secure a new publisher and to Professor James Rose, Editor in Chief of the PGA, for making it all happen.

Finally, on behalf of all of the site authors, we would like to record our thanks to the owners and managers of land and quarries who have allowed access to the sites, either during previous work or specifically for the GCR exercise.

REFERENCES

Agrell, S. O. (1942) 1. A petrological investigation of the adinoles at Dinas Head, Cornwall. 2. A petrofabric study of the Ben Vuroch granite and the adjacent schists in Perthshire. Unpublished PhD thesis, University of Cambridge.

Ahmed-Said Y. and Tanner P. W. G. (2000) P-T **conditions** during emplacement, and D2 regional metamorphism, of the Ben Vuirich Granite, Perthshire, Scotland. *Mineralogical Magazine,* **64**, 737–53.

Ague, J.J. & Baxter, E.F., 2007. Brief thermal pulses during mountain building recorded by Sr diffusion in apatite and multicomponent diffusion in garnet. Earth and Planetary Science Letters, 261, 500-516.

Allen, J. R. L. 1963. The classification of cross stratified units with notes on their origin. *Sedimentology*, **2**, pp. 93-114.

Allison, A. (1933) The Dalradian succession in Islay and Jura. *Quarterly Journal of the Geological Society, London*, **89**, 125–44.

Allison, A. 1941. Loch Awe succession and tectonics-Kilmartin-Tayvallich-Danna. *Quarterly Journal of the Geological Society, London*, **96**, 423–49.

Allison, I., May, F and Strachan, R.A. (1988) *An Excursion guide to the Moine Geology of the Scottish Highlands*. Scottish Academic Press for Edinburgh Geological Society and Geological Society of Glasgow.

Alsop, G.I. and Hutton, D.H.W. (1990) A review and revision of Dalradian stratigraphy in central and southern Donegal, Ireland. *Irish Journal of Earth Sciences*, **10**, 181–98.

Alsop, G.I., Prave, A.R., Condon, D.J. and Phillips, C.A. (2000) Cleaved clasts in Dalradian conglomerates: possible evidence for Neoproterozoic compressional tectonism in Scotland and Ireland? *Geological Journal*, **35**, 87–98.

Amos, B.J. (1960). The geology of the Bowmore district, Islay. Unpublished PhD thesis, University of London, Imperial College.

Anderson, E M. (1923). The geology of the schists of the Schiehallion district. *Quarterly Journal of the Geological Society of London*, **79**, 423–45.

Anderson, E M. (1951) *The Dynamics of Faulting*. (Second edition). (Edinburgh: Oliver and Boyd.)

Anderson, J. G. C., (1942) The stratigraphical order of the Dalradian schists near the Highland Border in Angus and Kincardineshire. *Transactions of the Geological Society of Glasgow*, **20**, 223–37.

Anderson, J.G.C. (1947a) The geology of the Highland Border, Stonehaven to Arran. *Transactions of the Royal Society of Edinburgh*, **61**, 479–515.

Anderson, J.G.C. (1947b) The Kinlochlaggan Syncline, southern Inverness-shire. *Transactions of the Geological Society of Glasgow*, **21**, 97–115.

Anderson, J.G.C. (1948) Stratigraphic nomenclature of Scottish metamorphic rocks. *Geological Magazine*, **85**, 89–96.

Anderson, J.G.C (1956). The Moinian and Dalradian rocks between Glen Roy and the Monadhliath Mountains, Inverness-shire. *Transactions of the Royal Society of Edinburgh*, **63**, 15–36.

Anderton, R. (1974) Middle Dalradian sedimentation in Argyll, with particular reference to the Jura quartzite, Scarba conglomerate and Craignish phyllites. Unpublished PhD thesis, University of Reading.

Anderton, R. (1975) Tidal flat and shallow marine sediments from the Craignish Phyllites, Middle Dalradian, Argyll, Scotland. *Geological Magazine*, **112**, 337–40.

Anderton, R. (1976) Tidal-shelf sedimentation: an example from the Scottish Dalradian. *Sedimentology*, **23**, 429–58.

Anderton, R. (1977) The Dalradian rocks of Jura. *Scottish Journal of Geology*, **13**, 135–42.

Anderton, R. (1979) Slopes, submarine fans and syn-depositional sedimentology of parts of the Middle and Upper Dalradian in the S.W. Highlands of Scotland. In *The British Caledonides - Reviewed* (eds. Harris, A. L., Holland, C. H. and Leake, B. E.), Geological Society, London, Special Publications, **8**.

Anderton, R. (1980). Distinctive pebbles as indicators of Dalradian provenance. *Scottish Journal of Geology,* **16**, 143–52.

Anderton, R. (1982) Dalradian deposition and the late Precambrian - Cambrian history of the N Atlantic region: a review of the early evolution of the Iapetus Ocean. *Journal of the Geological Society of London*, **139**, 421–31.

Anderton, R. (1985) Sedimentation and tectonics in the Scottish Dalradian. *Scottish Journal of Geology*, **21**, 407–36.

Anderton, R. (1988) Dalradian slides and basin development: a radical interpretation of stratigraphy and structure in the SW and Central Highlands of Scotland. *Journal of the Geological Society of London*, **145**, 669–78.

Arndt, N.T. and Nisbet, E.G. (editors) (1982) *Komatiites*. George Allen and Unwin, London.

Ashcroft W.A., Kneller B.C., Leslie, A.G. and Munro M. (1984) Major shear zones and autochthonous Dalradian in the northeast Scottish Caledonides. *Nature, London* **310**, 760–2.

Ashworth, J.R. (1972) Migmatites of the Huntly-Portsoy area, north-east Scotland. Unpublished PhD thesis, University of Cambridge.

Ashworth, J.R. (1975) The sillimanite zones of the Huntly–Portsoy area in the north-east Dalradian, Scotland. *Geological Magazine*, **112**, 113–224.

Ashworth, J.R. (1976) Petrogenesis of migmatites in the Huntly–Portsoy area, north-east Scotland. *Mineralogical Magazine*, **40**, 661–82.
Ashworth, J.R. (1979) Comparative petrography of deformed and undeformed migmatites from the Grampian Highlands of Scotland. *Geological Magazine*, **116**, 445–56.
Astin, T.R. and Rogers, D.A. (1991) 'Subaqueous shrinkage cracks' in the Devonian of Scotland re-interpreted. *Journal of Sedimentary Petrology*, **61**, 850–9.
Atherton, M.P. (1977) The metamorphism of the Dalradian rocks of Scotland. *Scottish Journal of Geology*, **13**, 331–70.
Atherton, M.P., and Brotherton, M.S. (1972) The composition of some kyanite-bearing regionally-metamorphosed rocks from the Dalradian. *Scottish Journal of Geology*, **8**, 203–13.
Atherton, M.P. and Ghani, A.A. (2002) Slab breakoff: a model for Caledonian, Late Granite syn-collisional magmatism in the ortho-tectonic (metamorphic) zone of Scotland and Donegal. *Lithos*, **62**, 65–85.

Bailey, E.B. (1910) Recumbent folds in the schists of the Scottish Highlands. *Quarterly Journal of the Geological Society of London*, **66**, 586–620.
Bailey, E. B. 1913. The Loch Awe Syncline (Argyllshire). *Quarterly Journal of the Geological Society of London*, **69**, 280–307.
Bailey, E.B. (1917) The Islay anticline (Inner Hebrides). *Quarterly Journal of the Geological Society of London*, **72**, 132–64.
Bailey, E.B. (1922) The structure of the South West Highlands of Scotland. *Quarterly Journal of the Geological Society of London*, **78**, 82–131.
Bailey, E.B. (1925) Perthshire tectonics: Loch Tummel, Blair Atholl and Glen Shee. *Transactions of the Royal Society of Edinburgh*, **53**, 671–98.
Bailey, E.B. (1930) New Light on Sedimentation and Tectonics. *Geological Magazine*, **67**, 77.
Bailey, E.B. (1934) West Highland tectonics: Loch Leven to Glen Roy. *Quarterly Journal of the Geological Society of London*, **90**, 462–523.
Bailey, E.B. (1938) Eddies in mountain structure. *Quarterly Journal of the Geological Society of London*, **94**, 607–25.
Bailey, E B. (1953). Facies changes versus sliding: Loch Leven, Argyll. *Geological Magazine*, **90**, 111–13.
Bailey, E.B. (1960) The geology of Ben Nevis and Glencoe and the surrounding country. (2nd edition). Memoir of the Geological Survey of Great Britain, Sheet 53 (Scotland).
Bailey, E.B., and McCallien, W. (1937). Perthshire tectonics: Schiehallion to Glen Lyon. *Transactions of the Royal Society of Edinburgh*, **59**, 79–118.
Bailey, E B, and MacGregor, M. 1912. The Glen Orchy Anticline, Argyllshire. *Quarterly Journal of the Geological Society of London*, Vol. 68, 164–179.
Bailey, E.B., and Maufe, H.B. (1916) The geology of Ben Nevis and Glen Coe and the surrounding country. (1st edition). Memoir of the Geological Survey of Great Britain, Sheet 53 (Scotland).
Bain, J.A., Briggs, D.A. and May, F. (1971) Geology and mineralogical appraisal of an extensive talc-magnesite deposit in the Shetlands. *Transactions of the Institute of Mining and Metallurgy*, **80**, B77–B84.

Baker, A.J. (1985) Pressures and temperatures of metamorphism in the eastern Dalradian. *Journal of the Geological Society of London,* **142**, 137–48.
Baker, A.J. (1987) Models for the tectonothermal evolution of the eastern Dalradian of Scotland. *Journal of Metamorphic Geology*, **5**, 101–18.
Baker, A.J., and Droop, G.T.R. (1983) Grampian metamorphic conditions deduced from mafic granulites and sillimanite-K-feldspar gneisses in the Dalradian of Glen Muick, Scotland. *Journal of the Geological Society of London,* **140**, 489–97.
Baldwin, C.T. and Johnson, H.D. (1977) The Dalradian rocks of Lunga, Luing and Shuna. *Scottish Journal of Geology*, **13**, 143–54.
Banks, C. J. (2005). Neoproterozoic Basin Analysis: a combined sedimentological and provenance study in the Grampian Group, Central Highlands, Scotland. Unpublished PhD Thesis, University of Keele.
Banks, C.J. (2007) Exceptional preservation of sedimentary structures in metamorphic rocks: an example from the upper Grampian Group, Creag Stalcair, Perthshire. *Scottish Journal of Geology*, **43**, 9–14.
Banks, C.J. and J.A. Winchester (2004). Sedimentology and stratigraphic affinities of Neoproterozoic coarse clastic successions, Glenshirra Group, Inverness-shire Scotland. *Scottish Journal of Geology* **40**, 159–174.
Banks, C.J., Smith, M., Winchester, J.A., Horstwood, M.S.A., Noble, S.R. and Ottley, C.J. (2007) Provenance of intra-Rodinian basin-fills: the lower Dalradian Supergroup, Scotland. *Precambrian Research*, **153**, 46-64.
Barreiro, B.A. (1998) U-Pb systematics on zircon from the Keith and Portsoy granites, Grampian Highlands, Scotland. *NERC Isotope Geosciences Laboratory Report Series* No. **132.**
Barrow, G. (1893) On an intrusion of muscovite-biotite gneiss in the south-east Highlands of Scotland, and its accompanying metamorphism. *Quarterly Journal of the Geological Society of London,* **49**, 330–58.
Barrow, G. (1904) Moine gneisses of the east central Highlands and their position in the Highland sequence. *Quarterly Journal of the Geological Society of London*, **60**, 400–44.
Barrow, G. (1912) On the geology of Lower Deeside and the southern Highland border. *Proceedings of the Geologists' Association*, **23**, 274–90.
Barrow G. and Cunningham Craig E.H. (1912) The geology of the districts of Braemar, Ballater and Glen Clova. *Memoir of the Geological Survey of Great Britain*, Sheet 65 (Scotland).
Barrow, G, Grant Wilson, J S, and Cunningham Craig, E H. (1905). The geology of the country around Blair Atholl, Pitlochry and Aberfeldy. Memoir of the Geological Survey of Great Britain, Sheet 55 (Scotland).
Basahel, A.N. (1971) The Dalradian stratigraphy and structure of southern Islay, Argyll. Unpublished PhD thesis. University of Liverpool.
Batchelor, R.A. (2011) Geochemistry of Torridonian tuffs and contemporary phosphorites; potential for correlation of Torridonian sequences in NW Scotland. *Scottish Journal of Geology*, **47**, 133-142.
Baxter, E.F., Ague, J.J. and Depaolo, D.J. (2002) Prograde temperature-time evolution in the Barrovian type-locality

constrained by Sm/Nd garnet ages from Glen Clova, Scotland. *Journal of the Geological Society, London*, **159**, 71–82.

Beddoe-Stephens B. (1990) Pressures and temperatures of Dalradian metamorphism and the andalusite-kyanite transformation in the northeast Grampians. *Scottish Journal of Geology* **26**, 3–14.

Bell, A. M. (1981) Vergence: an evaluation. *Journal of Structural Geology*, Volume 3, 197–202.

Bendall, C.A. (1995). A geochronological, structural and metamorphic study of rocks from the central and SW Dalradian of Scotland. Unpublished PhD thesis, University of Manchester

Bentley, M.R. (1986) The tectonics of Colonsay, Scotland. Unpublished PhD thesis, University of Wales, Aberystwyth.

Bentley, M.R. (1988). The Colonsay Group. *In* Winchester, J.A (ed.) *Later Proterozoic stratigraphy of the Northern Altlantic Regions.* Blackie and Son Ltd., London, 119–30.

Bentley, M.R., Maltman, A.J., and Fitches, W.R. (1988) Colonsay and Islay: a suspect terrane within the Scottish Caledonides. *Geology*, **16**, 26–8.

Bingen B., Demaiffe D. and van Breemen O. (1998) The 616 Ma old Egersund basaltic dyke swarm, SW Norway, and late Neoproterozoic opening of the Iapetus Ocean. *Journal of Geology,* **106**, 565–74.

Bingen, B., Griffin, W.L. Torsvik, T.H. and Saeed, A. (2005) Timing of late Neoproterozoic glaciation on Baltica constrained by detrital zircon geochronology in the Hedmark Group, south-east Norway. *Terra Nova*, **17**, 250–58.

Bliss, G.M. (1977) The micropalaeontology of the Dalradian. Unpublished PhD thesis, University of London, Imperial College.

Bluck, B.J. (1983) Role of the Midland Valley of Scotland in the Caledonian Orogeny. *Transactions of the Royal Society of Edinburgh: Earth Sciences,* **74**, 119 –136.

Bluck, B.J. (1984) Pre-Carboniferous history of the Midland Valley of Scotland. *Transactions of the Royal Society of Edinburgh: Earth Sciences*, **75**, 275–95.

Bluck, B.J. (2000) 'Where ignorance is bliss 'tis a folly to be wise' (Thomas Gray 1716–1761) – controversy in the basement blocks of Scotland. *Scottish Journal of Geology*, **36**, 97–101.

Bluck, B.J. (2001) Caledonian and related events in Scotland. *Transactions of the Royal Society of Edinburgh: Earth Sciences,* **91**, 375–404.

Bluck, B.J. (2002) The Midland Valley Terrane. *In:* Trewin, N.H. (ed.) *The Geology of Scotland.* The Geological Society, London, 149–66.

Bluck, B.J. (2010) The Highland Boundary Fault and the Highland Boundary Complex. *Scottish Journal of Geology*, **46**, 113-124.

Bluck B.J. and Dempster T.J. (1991) Exotic metamorphic terranes in the Caledonides: tectonic history of the Dalradian block, Scotland. *Geology,* **19**, 1133–6.

Bluck B.J., Dempster T.J., and Rogers G. (1997) Allochthonous metamorphic blocks on the Hebridean passive margin, Scotland. *Journal of the Geological Society of London* **154**, 921–4.

Bluck, B.J., Gibbons, W. and Ingham, J.K. (1992). Terranes. 1–4 in Atlas of palaeogeography and lithofacies. Cope, J.C.W., Ingham, J.K., and Rawson, P.F. (editors). Geological Society of London Memoir, No. 13.

Bluck B.J., Halliday A. N., Aftalion M., and Macintyre R.M. (1980) Age and origin of the Ballantrae ophiolite and its significance to the Caledonian orogeny and Ordovician time scale. *Geology* **8**, 492–95.

Bluck, B.J. and Ingham, J.K. (1997) The Highland Border controversy: a discussion of "New evidence that the Lower Cambrian Leny Limestone at Callander, Perthshire belongs to the Dalradian Supergroup, and a reassessment of the 'exotic' status of the Highland Border Complex". *Geological Magazine*, **134**, 563–70.

Bluck B.J., Ingham J.K., Curry G.B., and Williams A. (1984) The significance of a reliable age from some Highland Border rocks in Central Scotland. *Journal of the Geological Society of London* **139**, 451–4.

Boersma, J.R. (1969) Internal structures of some tidal megaripples on a shoal in the Westerschelde estuary, the Netherlands. *Geologie on Mijnbouw*, **48**, 409–14.

Booth, J.E. (1984) Structural, stratigraphic and metamorphic studies in the SE Dalradian Highlands. Unpublished PhD thesis. University of Edinburgh.

Borradaile, G.J. (1970) The west limb of the Loch Awe syncline and the associated cleavage fan. *Geological Magazine*, **107**, 459–467.

Borradaile, G.J. (1972a) The structural and stratigraphic history of the Dalradian rocks of the Northern Loch Awe syncline, Argyllshire. Unpublished PhD thesis, University of Liverpool.

Borradaile, G.J. (1972b) Variably oriented co-planar primary folds. *Geological Magazine*, **190**, 89–98.

Borradaile, G. J. (1973) Dalradian structure and stratigraphy of the northern Loch Awe district, Argyllshire. *Transactions of the Royal Society of Edinburgh*, **69**, 1–21.

Borradaile, G.J. (1974). Bulk finite strain estimates from the deformation of Neptunian dykes. *Tectonophysics,* **22**, 127–39.

Borradaile, G.J. (1977) The Dalradian rocks of the northern Loch Awe district. *Scottish Journal of Geology*, **13**, 155–64.

Borradaile, G.J. (1979). Pre-tectonic reconstruction of the Islay anticline: implications for the depositional history of Dalradian rocks in the SW Highlands. In *The Caledonides of the British Isles–reviewed*. Harris, A L, Holland, C H, and Leake, B E (editors). Special Publication of the Geological Society of London, No. 8, pp. 229–38.

Borradaile, G.J. and Johnson, H.D. (1973) Finite strain estimates from the Dalradian Dolomitic Formation, Islay, Argyll, Scotland. *Tectonophysics*, **18**, 249–59.

Boué, A. (1820) *Essai Géologique sur l'Écosse*. Ve Courcier, Paris.

Bouma, A. H. (1962). *Sedimentology of some Flysch Deposits, a Graphic Approach to Facies Interpretation.* Elsevier Co. Amsterdam, 168 pp.

Bowden, A.J. (2007) Book review: MacCulloch's 1840 Geological Map of Scotland. *Scottish Journal of Geology*, **43**, 181–4.

Bowes, D.R. and Convery, H.J.E. (1966) The composition of some Ben Ledi grits and its bearing on the origin of albite schists in the south-west Highlands. *Scottish Journal of Geology*, **2**, 67–75.

Bowes, D.R. and Wright, A.E. (1967) The explosion breccia pipes near Kentallen, Scotland and their geological setting. *Transactions of the Royal Society of Edinburgh*, **67**, 109–43.

Bowes, D.R. and Wright, A.E. (1973) Early phases of Caledonian deformation in the Dalradian of the Ballachulish district, Argyll. *Geological Journal*, **8**, 333–44.

Bowring, S., Myrow, P., Landing, E., Ramezani, J. and Grotzinger, J. (2003) Geochronological constraints on Terminal Neoproterozoic

events and the rise of metazoans. *Geophysical Research Abstracts* **5**, p13219.
Bradbury, H.J. (1978) Stratigraphic, structural, igneous and metamorphic history of the Dalradian rocks of the Ben Vrackie-Ben Vuirich district, Tayside, Scotland. Unpublished PhD thesis, University of Liverpool.
Bradbury, H.J. (1979) Migmatization, deformation and porphyroblast growth in the Dalradian of Tayside, Scotland. In *The Caledonides of the British Isles — Reviewed* Harris, A.L., Holland, C.H. and Leake, B.E. (eds). Geological Society, London, Special Publications, **8**, 351–6.
Bradbury, H.J. (1985) The Caledonian metamorphic core: an Alpine model. *Journal of the Geological Society of London*, **142**, 129–36.
Bradbury, H.J., and Harris, A.L. (1982) Low grade Dalradian sediments carrying spaced cleavage; Polyphase deformation of spaced cleavage. In *Atlas of deformational and metamorphic rock fabrics*. Borradaile, G J, Bayly, M B, and Powell, C McA (editors). Springer Verlag, Berlin, pp. 100–9.
Bradbury, H.J., Harris, A.L. and Smith, R.A. (1979). Geometry and emplacement of nappes in the Central Scottish Highlands. In *The Caledonides of the British Isles - reviewed*. (eds. Harris, A.L., Holland, C.H. and Leake, B.E.*), Special Publication of the Geological Society of London*, **8**, 213–20.
Bradbury H.J., Smith R.A. and Harris A.L. (1976) 'Older' granites as time-markers in Dalradian evolution. *Journal of the Geological Society, London,* **132**, 677–84.
Brasier, M.D., Ingham, J.K. and Rushton, A.W.A. (1992) Cambrian. 13–18 in Atlas of Palaeogeography and Lithofacies. Cope, J.C.W., Ingham, J.K. and Rawson, P. F. (editors). *Memoirs of the Geological Society, London,* **13**.
Brasier, M.D. and Mcilroy, D. (1998) Neonereites uniserialis from c. 600 Ma year old rocks in western Scotland and the emergence of animals. *Journal of the Geological Society, London*, **155**, 5–12.
Brasier, M.D. and Shields, G. (2000) Neoproterozoic chemostratigraphy and correlation of the Port Askaig glaciation, Dalradian Supergroup of Scotland. *Journal of the Geological Society, London*, **157**, 909–14.
Brasier, M.D., McCarron, G., Tucker, R., Leather, J., Allen, P. and Shields, G. (2000) New U-Pb zircon dates for the Neoproterozoic Ghubrah glacaiation and for the top of the Huqf Supergroup, Oman. *Geology,* **28**, 175–8.
Briden, J.C., Turnell, H.B. and Watts, D.R. (1984) British palaeomagnetism, Iapetus Ocean and the Great Glen Fault. *Geology* **12**, 136–9.
Burgess J.G, Graham, C.M. and Harte, B. (1981). Kyanite and chloritoid phyllites from the chlorite zone of the Scottish Highlands. *Journal of the Geological Society of London,* **138**, p. 634 (abstract).
Burt, C.E. (2002) Sedimentary environments and basin evolution of the upper Dalradian: Tayvallich Subgroup and Southern Highland Group. Unpublished PhD thesis, Kingston University.
Burton, C.J., Hocken, C., MacCallum, D. and Young, M.E. 1983. Chitinozoa and the age of the Margie Limestone of the North Esk. *Proceedings of the Geological Society of Glasgow* Vol. **124–125**, 27–32.

Cannat M. (1989) Late Caledonian northeastward ophiolite thrusting in the Shetland Islands, U.K. *Tectonophysics* **169**, 257–70.

Canning J.C., Henney P.J., Morrison M.A. and Gaskarth J.W. (1996) Geochemistry of late Caledonian minettes from northern Britain: implications for the Caledonian sub-continental lithospheric mantle. *Mineralogical Magazine* **60**, 221–36.

Canning, J.C., Henney, P.J., Morrison, M.A., Van Calsteren, P.W.C., Gaskarth, J.W. and Swarbrick, A. (1998) The Great Glen Fault: a major vertical lithospheric boundary. *Journal of the Geological Society, London*, **155**, 425–8.

Carty, J.P. (2001) Deformation, metamorphism, magmatism and fluid-flow in the Portsoy Shear Zone, N.E. Scotland. Unpublished PhD thesis, University of Derby.

Cawood, P.A., McCausland, P.J.A. and Dunning, G.R. (2001) Opening Iapetus: constraints from the Laurentian margin in Newfoundland. *Geological Society of America Bulletin*, **113**, 443–53.

Cawood, P.A., Nemchin, A.A., Smith, M. and Loewy, S. (2003). Source of the Dalradian Supergroup constrained by U-Pb dating of detrital zircon and implications for the East Laurentian margin. *Journal of the Geological Society of London* **160**, 231–46.

Cawood, P.A., Nemchin, A.A., Strachan, R.A., Prave, A.R. and Krabbendam, M. (2007) Sedimentary basin and detrital zircon record along East Laurentia and Baltica during assembly and breakup of Rodinia. *Journal of the Geological Society, London,* **164**, 257–75.

Chew, D.M. (2001) Basement protrusion origin of serpentinite in the Dalradian. *Irish Journal of Earth Science*, **19**, 23-35.

Chew, D.M., Daly, J.S., Magna, T., Page, L.M., Kirkland, C.L., Whitehouse, M.J. and Lam, R. (2010) Timing of ophiolite obduction in the Grampian orogen. *Geological Society of America Bulletin*, **122**, 1787-1799.

Chew, D.M., Fallon, N., Kennelly, C., Crowley, Q. and Pointon, (2009) Basic volcanism contemporaneous with the Sturtian glacial episode in NE Scotland. *Earth and Environmental Science Transactions of the Royal Society of Edinburgh*, **100**, 399-415

Chew, D.M., Graham, J.R. and Whitehouse, M.J. (2007) U-Pb zircon geochronology of plagiogranites from the Lough Nafooey (= Midland Valley) arc in western Ireland: constraints on the onset of the Grampian orogeny. *Journal of the Geological Society, London* Vol. **164**, 747–50.

Chinner, G.A. (1957) The metamorphic history of the Glen Clova district, Angus. Unpublished PhD Thesis, University of Cambridge.

Chinner, G.A. (1960) Pelitic gneisses with varying ferrous/ferric ratios from Glen Clova, Angus, Scotland. *Journal of Petrology*, **1**, 178–217.

Chinner, G.A. (1961) The origin of sillimanite in Glen Clova, Angus. *Journal of Petrology* Vol. **2**, 312–23.

Chinner, G.A. (1966) The distribution of pressure and temperature during Dalradian metamorphism. *Quarterly Journal of the Geological Society of London,* **122**, 159–86.

Chinner, G.A. (1978) Metamorphic zones and fault displacement in the Scottish Highlands. *Geological Magazine*, Vol. 115, 37–45.

Chinner, G.A. and Heseltine, F.J. (1979) The Grampian andalusite/kyanite isograd. *Scottish Journal of Geology*, Vol. 15, 117–127.

Coats, J.S., Pease, S.F. and Gallagher, M.J. (1984) Exploration of the Scottish Dalradian. 21–34 in *Prospecting in areas of glaciated terrain*. (London: Institution of Mining and Metallurgy.)

Coats, J.S., Smith, C.G., Gallagher, M.J., May, F., Fortey, N.J. and Parker, M.E. (1978) Stratabound barium-zinc mineralisation in Dalradian schist near Aberfeldy, Scotland: preliminary report. *Institute of Geological Sciences, Mineral Reconnaisance Programme Report* No. **26**.

Coats, J.S., Smith, C.G., Fortey, N.J., Gallagher, M.J., May, F. and McCourt, W.J. (1980) Stratabound barium-zinc mineralization in Dalradian schist near Aberfeldy. *Transactions of the Institution of Mining and Metallurgy (Section B: Applied Earth Science)*, **89**, 110–22.

Coats, J.S., Smith, C.G., Gallagher, M.J., May, F., McCourt, W.J., Parker, M.E. and Fortey, N.J. (1981) Stratabound barium-zinc mineralisation in Dalradian schist near Aberfeldy, Scotland: final report. *Institute of Geological Sciences, Mineral Reconnaissance Programme Report* No. **40**.

Collerson, K.D., Jesseau, C.W. and Bridgewater, D. (1976). Contrasting types of bladed olivine in ultramafic rocks from the Archaean of Labrador. *Canadian Journal of Earth Sciences*, **13**, 442–50.

Collinson, J. (1994). Sedimentary deformational structures. pp. 95–125 *In* Maltman, A. (ed.). *The geological deformation of sediments.* Chapman and Hall.

Collinson, J.D. and Thompson, D.B. 1988. Sedimentary Structures. George Allen and Unwin, London. 207 pp.

Condon, D.J. and Prave, A.R. (2000). Two from Donegal: Neoproterozoic glacial episodes on the northeast margin of Laurentia. *Geology*, **28**, 951–4.

Cooper, M.R. and Johnston, T.P. (2004) Central Highlands (Grampian) Terrane. 9–24, in: Mitchell, W.I. (editor), *The Geology of Northern Ireland–Our Natural Foundation* (2nd edition). Geological Survey of Northern Ireland, Belfast.

Coward, M.P. (1983) The thrust and shear zones of the Moine Thrust Zone of NW Scotland. *Journal of the Geological Society of London* **140**, 795–811.

Coward, M.P. (1990) The Precambrian, Caledonian and Variscan framework to NW Europe. In *Tectonic Events Responsible for Britain's Oil and Gas Reserves*. Hardman, R.F.P. and Brooks, J. (eds) Geological Society, London, Special Publications, **55**, 1–34.

Craig G. Y., McIntyre D. B., and Waterston C. D. (1978) *James Hutton's Theory of the Earth: the lost drawings*. Scottish Academic Press, Edinburgh.

Crane A., Goodman S., Krabbendam M., Leslie A. G., Paterson I. B., Robertson S. And Rollin K. E. (2002) *Geology of the Glen Shee District.* Memoir of the British Geological Survey. Sheet 56W with parts of sheets 55E, 65W and 64E (Scotland).

Cummins, W.A. and Shackleton, R.M. (1955) The Ben Lui recumbent syncline. *Geological Magazine*, **92**, 353–62.

Cunningham Craig, E.H. (1904) Metamorphism in the Loch-Lomond District. *Quarterly Journal of the Geological Society, London*, **60**, 10–31.

Cunningham Craig, E.H. (2000) (written 1901). Explanation of Sheet 38 (Loch Lomond). Selected documents from the BGS Archives No 3. *British Geological Survey Technical Report* No. **WO/00/05**.

Cunningham Craig, E.H., Wright, W.B. and Bailey, E.B. (1911) The Geology of Colonsay and Oronsay with parts of Ross of Mull. *Memoir of the Geological Survey of Scotland*, Sheet 35 (Scotland).

Curry, G.B., Bluck, B.J., Burton, C.J., Ingham, J.K., Siveter, D.J. And Williams, A. (1984) Age, evolution and tectonic history of the Highland Border Complex, Scotland. *Transactions of the Royal Society of Edinburgh: Earth Sciences*, **75**, 113–33.

Cutts, K.A., Hand, M., Kelsey, D.E. and Strachan, R.A. (2011) P–T constraints and timing of Barrovian metamorphism in the Shetland Islands, Scottish Caledonides: implications for the structural setting of the Unst ophiolite. *Journal of the Geological Society*, **168**, 1265-1284.

Dallmeyer, R.D., Strachan, R.A., Rogers, G., Watt, G.R. and Friend, C.R.L. (2001) Dating deformation and cooling in the Caledonian thrust nappes of north Sutherland, Scotland: insights from 40Ar/39Ar and Rb–Sr chronology. *Journal of the Geological Society of London* **158**, 501–12.

Daly, J.S., Muir, R.J. and Cliff, R.A. (1991) A precise U-Pb zircon age for the Inishtrahull syenitic gneiss, County Donegal, Ireland. *Journal of the Geological Society, London,* **148**, 639–42.

Dalziel, I.W.D. (1994) Precambrian Scotland as a Laurentia–Gondwana link: Origin and significance of cratonic promontories. *Geology*, **22**, 589–92.

Dalziel, I.W.D. (1997) Neoproterozoic–Paleozoic geography and tectonics; review, hypothesis, environmental speculation. *Geological Society of America Bulletin* **109**(1), 16–42.

Davidek, K., Landing, E., Bowring, S.A., Westrop, S.R., Rushton, S.A., Fortey, R.A. And Adrain, J. (1998) New Uppermost Cambrian U-Pb date from Avalonian Wales and age of the Cambrian-Ordovician boundary. *Geological Magazine*, **135**, 303–09.

Deer, W.A., Howie, R.A. and Zussman, J. (1992). *An Introduction to the Rock Forming Minerals,* 2nd ed. Longman Scientific and Technical, London.

Dempster, T.J. (1983) Studies of orogenic evolution in the Scottish Dalradian. Unpublished PhD thesis, University of Edinburgh.

Dempster, T.J. (1985a) Uplift patterns and orogenic evolution in the Scottish Dalradian. *Journal of the Geological Society of London,* **142**, 111–128.

Dempster, T.J. (1985b) Garnet zoning and metamorphism of the Barrovian type. *Contributions to Mineralogy and Petrology,* **89**, 30–8.

Dempster T.J. and Bluck B.J. (1991) The age and tectonic significance of the Bute amphibolite, Highland Border Complex, Scotland. *Geological Magazine* **128**, 77–80.

Dempster, T.J. and Harte, B. (1986) Polymetamorphism in the Dalradian of the Central Scottish Highlands. *Geological Magazine*, Vol. 123, 95–104.

Dempster, T.J., Hudson, N.F. and Rogers, G. (1995). Metamorphism and cooling of the NE Dalradian. *Journal of the Geological Society, London,* **152**, 383–90.

Dempster, T.J., Rogers, G., Tanner, P.W.G., Bluck, B.J., Muir, R.J., Redwood, S.D., Ireland, T.R. and Paterson, B.A. (2002) Timing of deposition, orogenesis and glaciation within the Dalradian rocks of Scotland: constraints from U-Pb zircon ages. *Journal of the Geological Society, London*, **159**, 83–94.

Dewey, H. and Flett, J.S. (1911) On some British pillow lavas and the rocks associated with them. *Geological Magazine*, **8**, 202–9, 240–8.

Dewey J. F. (1969) Evolution of the Appalchian/Caledonian orogen. *Nature, London* **222**, 124–9.

Dewey, J.F. (2005) Orogeny can be very short. *Proceedings of the National Academy of Sciences, USA* Vol. **102**, 15286–93.

Dewey, J.F. and Mange, M. (1999) Petrography of Ordovician and Silurian sediments in the western Irish Caledonides: tracers of a short-lived Ordovician continent-arc collision orogeny and the evolution of the Laurentian Appalachian-Caledonian margin. In: *Continental Tectonics* (edited by MacNiocaill, C. and Ryan, P. D.). *Geological Society, London, Special Publication*, **164**, 55–107.

Dewey, J.F. and Pankhurst, R.J. (1970) The evolution of the Scottish Caledonides in relation to their radiometric age pattern. *Transactions of the Royal Society of Edinburgh,* **68**, 361–89.

Dewey, J.F. and Ryan, P.D. (1990) The Ordovician evolution of the South Mayo Trough, Western Ireland. *Tectonics*, **9**, 887–903.

Dewey J.F. and Shackleton R.M. (1984) A model for the evolution of the Grampian tract in the early Caledonides and Appalachians. *Nature, London* **312**, 115–21.

Dewey, J.F. and Strachan, R.A. (2003) Changing Silurian-Devonian relative plate motion in the Caledonides; sinistral transpression to sinistral transtension. *Journal of the Geological Society, London*, **160**, 219–229.

Dickin, A.P. (1992). Evidence for an Early Proterozoic crustal province in the North Atlantic region. *Journal of the Geological Society, London*, **149**, 483–6.

Dickin, A.P., and Bowes, D.R. (1991) Isotopic evidence for the extent of the early Proterozoic basement of Scotland and northwest Ireland. *Geological Magazine*, **128**, 385–8.

Droop, G.T.R. (1987). A general equation for estimating Fe^{3+} concentrations in ferromagnesian silicates or oxides from microprobe analysis using stoichiometric criteria. *Mineralogical Magazine,* **51**, 431–55.

Droop G.T.R. and Charnley N. (1985) Comparative geobarometry of pelitic hornfelses associated with the Newer Gabbros: a preliminary study. *Journal of the Geological Society of London* **142**, 53–62.

Droop, G.T.R., Clemens, J.D. and Dalrymple, D.J. (2003) Processes and conditions during contact anatexis, melt escape and restite formation: the Huntley Gabbro complex, NE Scotland. *Journal of Petrology* Vol. **44**, 995–1029.

Donovan, R.N. and Foster, R.J. (1972). Subaqueous shrinkage cracks from the Caithness Flagstone Series (Middle Devonian) of north-east Scotland. *Journal of Sedimentary Petrology*, **42**, 309–17.

Downie, C. (1975) The Precambrian of the British Isles: Palaeontology. In *A Correlation of Precambrian Rocks in the British Isles* (eds. Harris, A.L., Shackleton, R.M., Watson, J.V., Downie, C., Harland, W.B. and Moorbath, S.). Special Report of the Geological Society of London, No. 6. Pp. 113–15

Downie, C. (1984) Acritarchs in British stratigraphy. Special Report of the Geological Society of London, No. **17**.

Downie, C., Lister, T.R., Harris, A.L. and Fettes, D.J. (1971) A palynological investigation of the Dalradian rocks of Scotland. *Report of the Institute of Geological Sciences*, No. 71/9.

Dymoke, P.L. (1989) Geochronological and petrological studies of the thermal evolution of the Dalradian, South-west Scottish Highlands. Unpublished PhD thesis, University of Edinburgh.

Eby G. N. (1992) Chemical subdivision of the A-type granitoids: petrogenetic and tectonic implications. *Geology,* 20, 641–4.
Edwards, M.B. (1986) Glacial Environments. 416–436 in: *Sedimentary Environments and facies* (Editor: H.G. Reading). Blackwell Scientific
Publications.
Elles, G.L. (1926) The geological structure of Ben Lawers and Meall Corranaich (Perthshire). *Quarterly Journal of the Geological Society of London*, **82**, 304–31.
Elles, G.L. (1931) Notes on the Portsoy coastal district. *Geological Magazine*, **68**, 24–34.
Elles, G.L. (1935) The Loch na Cille Boulder Bed and its place in the Highland succession. *Quarterly Journal of the Geological Society of London*, **91**, 111–49.
Elles, G.L. and Tilley, C.E. (1930) Metamorphism in relation to structure in the Scottish Highlands. *Transactions of the Royal Society of Edinburgh*, **56**, 621–46.
Ellis, D.J. and Green, D.H. (1979) An experimental study of the effect of Ca upon garnet-clinopyroxene Fe-Mg exchange equilibria. *Contributions to Mineralogy and Petrology,* **71**, 13–22.
Ellis, N.V., Bowen, D.Q., Campbell, S., Knill, J.L., McKirdy, A.P., Prosser, C.D., Vincent, M.A. and Wilson, R.C.L. (1996) *An Introduction to the Geological Conservation Review*. Joint Nature Conservation Committee, Peterborough.
Emery, M. (2005) Polyorogenic history of the Moine rocks of Glen Urquhart, Inverness-shire. Unpublished PhD thesis, University of Portsmouth.
Evans, J.A., Fitches, W.R. and Muir, R.J. (1998) Laurentian Clasts in a Neoproterozic Tillite in Scotland. *Journal of Geology*, **106**, 361–9.
Evans, J.A, and Soper, N.J. (1997) Discussion on metamorphism and cooling of the NE Dalradian and U-Pb and Rb-Sr geochronology of magmatism and metamorphism in the Dalradian of Connemara, western Ireland. *Journal of the Geological Society, London*, **154**, 357–60.
Evans, R.H.S. and Tanner, P.W.G. (1996). A late Vendian age for the Kinlochlaggan Boulder Bed (Dalradian)? *Journal of the Geological Society, London*, **153**, 823–6.
Evans, R.H.S. and Tanner, P.W.G. (1997). Discussion on a late Vendian age for the Kinlochlaggan Boulder Bed (Dalradian): reply. *Journal of the Geological Society, London*, **154**, 917–19.
Eyles, C.H. (1988) Glacially - and tidally - influenced shallow marine sedimentation of the Late Precambrian Port Askaig Formation, Scotland. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **68**, 1–25.
Eyles, C.H. and Eyles, N. (1983) Glaciomarine model for upper Precambrian diamictiles of the Port Askaig Formation, Scotland. *Geology*, **11**, 692–6.
Eyles, N. and Clark, M. (1985) Gravity-induced soft-sediment deformation in glaciomarine sequences of the upper Proterozoic Port Askaig Formation, Scotland. *Sedimentology*, **32**, 789–814.

Fairchild, I.J. (1977) Phengite spherules from the Dalradian Bonnahaven Formation, Islay, Scotland: Glauconitized microfossils. *Geological Magazine*, **114**, 355–64.

Fairchild, I.F. (1980a) Sedimentation and origin of a Late Precambrian "dolomite" from Scotland. *Journal of Sedimentary Petrology*, **50**, 423–46.
Fairchild, I.J. (1980b) Stages in a Precambrian dolomitization, Scotland: Cementing versus replacement textures. *Sedimentology*, **27**, 631–50.
Fairchild, I.J. (1980c) The structure of NE Islay. *Scottish Journal of Geology*, **16**, 189–97.
Fairchild, I.J. (1985) Comment on 'Glaciomarine model for Upper Precambrian diamictiles of the Port Askaig Formation, Scotland'. *Geology*, **13**, 89–90.
Fairchild, I.J. (1985) Petrography and carbonate chemistry of some Dalradian dolomitic metasediments: preservation of diagenetic textures. *Journal of the Geological Society, London*, **142**, 167–85.
Fairchild, I.J. (1989) Dolomitic stromatolite-bearing units with storm deposits from the Vendian of East Greenland and Scotland: a case of facies equivalence. In *Caledonian and related Geology of Scandinavia* (ed. Gayer, R. A.), pp. Graham and Trotman, London, pp. 275–283.
Fairchild, I.J. (1991) Itinerary II: Topmost Islay Limestone (Appin Group), Port Askaig and Bonahaven Formations (Argyll Group) Port Askaig area, Islay. In *The Late Precambrian geology of the Scottish Highlands and Islands* (ed. Lister, C.J.) Geologists' Association Guide No. **44**, pp. 33–41.
Fairchild, I.J. (1993) Balmy shores and icy wastes: the paradox of carbonates associated with glacial deposits in Neoproterozoic times. *Sedimentology Review*, **1**, 1–16.
Ferry, J.M. and Spear, F.S. (1978) Experimental calibration of the partitioning of Fe and Mg between biotite and garnet. *Contributions to Mineralogy and Petrology,* **66**, 113–17.
Fettes, D.J., (1968). Metamorphic structures of Dalradian rocks in North East Scotland. Unpublished PhD thesis, University of Edinburgh.
Fettes, D.J. (1970) The structural and metamorphic state of the Dalradian rocks and their bearing on the age of emplacement of the basic sheet. *Scottish Journal of Geology*, Vol. 6, 108–118.
Fettes, D.J. (1971) Relation of cleavage and metamorphism in the Macduff Slates. *Scottish Journal of Geology*, **7**, 248–53.
Fettes, D.J. (1979) A metamorphic map of the British and Irish Caledonides. *In*: Harris, A.L., Holland, C.H. and Leake, B.E. (eds) *The Caledonides of the British Isles–Reviewed*. Geological Society, London, Special Publications, **8**, 307–21.
Fettes, D.J. and Desmons, J. (editors) (2007) *Metamorphic Rocks: a Classification and Glossary of Terms. Recommendations of the International Union of Geological Sciences Subcommission on the Systematics of Metamorphic Rocks*. Cambridge University Press, Cambridge
Fettes, D.J., Graham, C.M., Harte, B., and Plant, J.A. (1986a) Lineaments and basement domains; an alternative view of Dalradian evolution. *Journal of the Geological Society of London*, **143**, 453–64.
Fettes, D.J., Graham, C.M., Sassi, F.P., and Scolari, A. (1976) The lateral spacing of potassic white micas and facies series variations across the Caledonides. *Scottish Journal of Geology*, **12**, 227–36.
Fettes, D.J., Harris, A.L. and Hall, L.M. (1986b) The Caledonian geology of the Scottish Highlands. In *Synthesis of the*

Caledonian rocks of Britain. Proceedings of the NATO Advanced Study Institute. Fettes, D J, and Harris, A L (editors). Reidel Dordrecht, pp. 303–34.
Fettes, D.J., Leslie A.G., Stephenson D., and Kimbell S.F. (1991) Disruption of Dalradian stratigraphy along the Portsoy Lineament from new geological and magnetic surveys. *Scottish Journal of Geology* **27**, 57–73.
Fettes, D.J., Long, C.B., Bevins, R.E., Max, M.D., Oliver, G.J.H., Primmer, T.J., Thomas, L.J. and Yardley, B.W.D., 1985. Grade and time of metamorphism in the Caledonide Orogen of Britain and Ireland. . 5 In, Harris, A.L.(ed), The Nature and Timing of Orogenic Activity in the Caledonian Rocks of the British Isles. Memoir of the Geological Society, London, 9.
Fettes, D.J., Macdonald, R., Fitton, J.G., Stephenson, D. and Cooper, M.R. (2011) Geochemical evolution of Dalradian metavolcanic rocks: implications for the break-up of the Rodinia supercontinent. *Journal of the Geological Society*, **168**, 1133-1146.
Fisk, S. (1986) An oxygen isotope study of siliceous rocks associated with stratabound mineralisation in Scotland and Ireland. Unpublished PhD thesis, University of Strathclyde.
Fitches, W. R. And Maltman, A. J. (1984) Tectonic development and stratigraphy of the western margin of the Caledonides: Islay and Colonsay, Scotland. *Transactions of the Royal Society of Edinburgh*, **75**, 365–82.
Fitches, W.R., Muir, R.J., Maltman, A.J. and Bentley, M.R. (1990) Is the Colonsay-west Islay block of SW Scotland an allochthonous terrane? Evidence from Dalradian tillite clasts. *Journal of the Geological Society, London*, **147**, 417–20.
Fitches, W.R., Pearce, J.A., Evans, J.A. and Muir, R.J. (1996) Provenance of the late Proterozoic Dalradian tillite clasts, Inner Hebrides, Scotland. In *Precambrian Crustal Evolution in the North Atlantic Region* (ed. Brewer, T. S.), pp. 367–77.
Flinn, D., (1953) Regional metamorphism and migmatisation in Delting, Shetland. Unpublished PhD thesis, University of London, Imperial College.
Flinn, D. (1954) On the time relations between regional metamorphism amd permeation in Delting, Shetland. *Quarterly Journal of the Geological Society of London*, **110**, 177–99.
Flinn, D. (1961) Continuation of the Great Glen Fault beyond the Moray Firth. *Nature, London*, **191**, 589–91.
Flinn, D. (1967) The metamorphic rocks of the southern part of the Mainland of Shetland. *Geological Journal*, **5**, 251–90.
Flinn, D. (1985) The Caledonides of Shetland. *In* Gee, D. G. and Sturt, B. A. (editors) *The Caledonide Orogen–Scandinavia and Related Areas*. John Wiley and Sons, Chichester. 1161–72.
Flinn, D. (1995) Formation of gneisses of migmatite and diatexite appearance in Yell, Shetland by solid-state grain growth recrystallisation. *Geological Journal*, **30**, 415–22.
Flinn, D. (1999) The Shetland Ophiolite. 31–33, 36–58 *In* Stephenson *et al*. (editors) *Caledonian Igneous Rocks of Great Britain*. Geological Conservation Review Series, No. **17**. Joint Nature Conservation Committee, Peterborough, UK.
Flinn, D. (2001) The basic rocks of the Shetland Ophiolite Complex and their bearing on its genesis. *Scottish Journal of Geology*, **37**, 79–96.

Flinn, D. (2007) The Dalradian rocks of Shetland and their implications for the plate tectonics of the northern Iapetus. *Scottish Journal of Geology*, Vol. **43**, 125-42.
Flinn, D. in press. Geology of Unst and Fetlar in Shetland. Memoir of the British Geological Survey, Sheet 131 (Scotland).
Flinn, D. and Moffat, D. T. 1985. A peridotitic komatiite from the Dalradian of Shetland. *Geological Journal*, **20**, 287-292.
Flinn, D. and Moffat, D.T. (1986) A reply to R. W. Nesbitt and L. A. Hartmann. *Geological Journal*, **21**, 207-9.
Flinn, D. and Pringle, I.R. (1976). Age of migmatisation in the Dalradian of Shetland. *Nature, London*, **259**, 299-300.
Flinn, D., Frank, P.L., Brook, M. and Pringle, I.R. (1979) Basement-cover relations in Shetland. In *The Caledonides of the British Isles-reviewed*. Harris, A.L., Holland, C.H. and Leake, B.E. (eds), Geological Society of London Special Publication No. 8, 109-15.
Flinn, D., May, F., Roberts, J.L. and Treagus, J.E. (1972). A revision of the stratigraphic succession of the East Mainland of Shetland. *Scottish Journal of Geology*, **8**, 335-343.
Flinn, D., Miller, J.A. and Roddam, D. (1991) The age of the Norwick hornblendic schists of Unst and Fetlar and the obduction of the Shetland ophiolite. *Scottish Journal of Geology* **27**, 11-19.
Flinn, D. and Oglethorpe, R.J.D. (2005). A history of the Shetland Ophiolite Complex. *Scottish Journal of Geology*, **41**, 141-8.
Fortey, N.J., Coats, J.S., Gallagher, M.J., Greenwood, P.G. and Smith, C.G. (1993) Dalradian stratabound baryte and base metals near Braemar, NE Scotland. *Transactions of the Institution of Mining and Metallurgy (Section B: Applied Earth Science)*, Vol. 102, B55-64.
Fortey, N.J. and Smith, C.G. (1986). Stratabound mineralisation in Dalradian rocks near Tyndrum, Perthshire. *Scottish Journal of Geology*, **22**, 377-93.
France, D.S. (1971) Structure and metamorphism of Moine and Dalradian rocks in the Grampians of Scotland near Beinn Dorain between Tyndrum and Moor of Rannoch. Unpublished PhD thesis, University of Liverpool.
Francis, E.H. (1982). Magma and sediment-1: Emplacement mechanisms of late Carboniferous tholeiitic sills in Northern Britain. *Journal of the Geological Society, London,* **139**, 1-20.
Friedrich, A.M, Hodges, K.V., Bowring, S.A. and Martin, M.W. (1999) Geochronological constraints on the magmatic, metamorphic and thermal evolution of the Connemara Caledonides, western Ireland. *Journal of the Geological Society, London*, **156**, 1217-30.
Friend, C.R.L., Kinny, P.D., Rogers, G., Strachan, R.A. and Patterson, B.A. (1997) U-Pb zircon geochronological evidence for Neoproterozoic events in the Glenfinnan Group (Moine Supergroup): the formation of the Ardgour granite gneiss, north-west Scotland. *Contributions to Mineralogy and Petrology* **128**, 101-13.
Friend, C.R.L., Strachan, R.A., Kinny, P.D. and Watt, G.R. (2003) Provenance of the Moine Supergroup of NW Scotland; evidence from geochronology of detrital and inherited zircons from (meta)sedimentary rocks, granites and migmatites. *Journal of the Geological Society, London* **160**, 247-57.

Gallagher, M.J., Smith, C.G., Coats, J.S., Greenwood, P.G., Chacksfield, B.C., Fortey, N.J. and Nancarrow, P.H.A. (1989) Stratabound barium and base-metal mineralisation in Middle

Dalradian metasediments near Braemar, Scotland. *British Geological Survey, Mineral Reconnaisance Programme Report*, No. 104.

Ganguly, J. (1979) Garnet and clinopyroxene solid solutions, and geothermometry based on Fe-Mg distribution coefficient. *Geochemica and Cosmochemica Acta* **43**, 1021–9.

Garson, M.S, and Plant, J. (1973) Alpine Type Ultramafic Rocks and Episodic Mountain Building in the Scottish Highlands. *Nature Physical Science*, **242**, 34–8.

Geikie, A. (1865) *The scenery of Scotland viewed in connection with its physical geology (with a geological map by Sir Roderick I. Murchison and Archibald Geikie)*. Macmillan, London and Cambridge.

Geikie, A. (1897) Annual report of the Geological Survey of the United Kingdom and of the Museum of Practical Geology for the year ending December 31, 1896. In Appendix E from the 44th Report of the Department of Science and Art. (London: Her Majesty's Stationery Office.)

Gibbons, W. And Harris, A.L. (1994) A Revised Correlation of Precambrian rocks in the British Isles. *Special Reports, Geological Society, London, 22*.

Gillen, C. (1987) Huntly, Elgin and Lossiemouth. 149–160 in *Excursion Guide to the Geology of the Aberdeen area.* (editors N.H.Trewin, B.C. Kneller, and C. Gillen,). (Edinburgh: Scottish Academic press for Geological Society of Aberdeen).

Gillespie, M.R. and Styles, M.T. (1999). BGS rock classification scheme, Volume 1: Classification of igneous rocks, 2nd edition. *British Geological Survey Research Report*, **RR/99/6**

Glover, B.W. (1989). The sedimentology and basin evolution of the Grampian Group. Unpublished PhD Thesis. University of Keele.

Glover, B.W. (1993). The sedimentology of the Neoproterozoic Grampian Group and the significance of the Fort William Slide between Spean Bridge and Rubha Cuilcheanna, Inverness-shire. *Scottish Journal of Geology*, **29**, 29–43.

Glover, B.W. (1998). Sedimentology and lateral extent of the Glenshirra succession, Monadhliath Mountains, Scotland. *British Geological Survey Technical Report*, WA/98/23.

Glover B.W., Key, R.M., May, F., Clark, G.C., Phillips, E.R. and Chacksfield, B.C. (1995). A Neoproterozoic multi-phase rift sequence: the Grampian and Appin groups of the southwestern Monadhliath Mountains of Scotland. *Journal of the Geological Society of London*, **152**, 391–406.

Glover B.W. and McKie, T. (1996). A sequence stratigraphical approach to the understanding of basin history in orogenic Neoproterozoic successions: an example from the central Highlands of Scotland. In: *Sequence stratigraphy in British Geology* (eds. Hesselbo, S.P. and Parkinson, D.N.). *Geological Society of London*, Special Publication, **103**, 257–69.

Glover, B.W. and Winchester, J.A. (1989) The Grampian Group: a major Late Proterozoic clastic sequence in the central Highlands of Scotland. *Journal of the Geological Society, London*, **146**, 85–97.

Goodman, S (1991) The Pannanich Hill Complex and the origin of the Crinan Subgroup migmatites in the North-eastern and Central Highlands. *Scottish Journal of Geology,* **27**, 147–56.

Goodman, S. (1994) The Portsoy-Duchray Hill Lineament; a review of the evidence. *Geological Magazine* **131**, 407–15.

Goodman, S., Crane, A., Krabbendam, M. and Leslie, A.G. (1997) Correlation of lithostratigraphic sequences in a structurally

complex area: Gleann Fearnach to Glen Shee, Scotland. *Transactions of the Royal Society of Edinburgh,* **87**, 503–13.
Goodman, S, and Lappin, M.A. (1996) The thermal aureole of the Lochnagar Complex: mineral reactions and implications from thermal modelling. *Scottish Journal of Geology,* 27, 159–72.
Goodman, S., Leslie, A.G., Ashcroft, W.A. and Crane, A. (1990) The geology of the central part of Sheet 65E (Ballater); contribution to the memoir. *British Geological Survey Technical Report* No. **WA/90/59**.
Goodman, S. and Winchester, J.A. (1993) Geochemical variations within metavolcanic rocks of the Dalradian Farragon Beds and adjacent formations. *Scottish Journal of Geology*, **29**, 131–41.
Gorokhov, M., Siedlecka, A., Roberts, D., Melnikov, N.N. and Turchenko, T.L. (2001) Rb–Sr dating of diagenetic illite in Neoproterozoic shales, Varanger Peninsula, northern Norway. *Geological Magazine*, **138**, 541–62.
Gould, D. (1997) The geology of the country around Inverurie and Alford. *Memoir of the British Geological Survey,* Sheets 76E and 76W (Scotland).
Gould, D. (2001) Geology of the Aboyne district. *Memoir of the British Geological Survey,* Sheet 66W (Scotland).
Gower, P.J. (1973) The Middle–Upper Dalradian Boundary with special reference to the Loch Tay Limestone. Unpublished PhD thesis, University of Liverpool.
Gower, P.J. (1977) The Dalradian rocks of the west coast of the Tayvallich peninsula. *Scottish Journal of Geology*, **13**, 125–33.
Gradstein, F.M., Ogg, J.G., and Smith, A.G., Agterberg, F.P., Bleeker, W., Cooper, R.A., Davydov, V., Gibbard, P., Hinnov, L.A., House, M.R., Lourens, L., Luterbacher, H.P., McArthur, J., Melchin, M.J., Robb, L.J., Shergold, J., Villeneuve, M., Wardlaw, B.R., Ali, J., Brinkhuis, H., Hilgen, F.J., Hooker, J., Howarth, R.J., Knoll, A.H., Laskar, J., Monechi, S., Plumb, K.A., Powell, J., Raffi, I., Röhl, U., Sadler, P., Sanfilippo, A., Schmitz, B., Shackleton, N.J., Shields, G.A., Strauss, H., Van Dam, J., van Kolfschoten, T., Veizer, J., and Wilson, D. (2004) *A Geologic Time Scale 2004. Cambridge University Press,* 589 pp.
Graham, C.M. (1976) Petrochemistry and tectonic significance of Dalradian metabasaltic rocks of the SW Scottish Highlands. *Journal of the Geological Society, London*, **132**, 61–84.
Graham, C.M. (1983). High-pressure greenschist to epidote-amphibolite facies metamorphism of the Dalradian rocks of the SW Scottish Highlands. *Geological Society Newsletter*, **12**, No. 4, 19.
Graham, C.M. (1986) The role of the Cruachan Lineament during Dalradian evolution. *Scottish Journal of Geology*, **22**, 257–70.
Graham, C.M. and Borradaile, G.J. (1984). The petrology and structure of Dalradian metabasic dykes of Jura: implications for Dalradian evolution. *Scottish Journal of Geology,* **20**, 257–70. *Same page range as previous ref?*
Graham, C.M. and Bradbury, H.J. (1981) Cambrian and late Precambrian basaltic igneous activity in the Scottish Dalradian: a review. Geological Magazine, **118**, 27–37.
Graham, C.M., Greig, K.M., Sheppard, S.M.F. and Turi, B. (1983) Genesis and mobility of the H_2O-CO_2 fluid phase during regional greenschist and epidote amphibolite facies metamorphism: a petrological and stable isotope study in the Scottish Dalradian. *Journal of the Geological Society, London*, **140**, 577–599.

Graham, C.M. and Harte, B. (1985) Conditions of Dalradian metamorphism. *Journal of the Geological Society, London,* **142**, 1–3.
Grant Wilson, J.S. (1882) Explanation of Sheet 97. Northern Aberdeenshire, Eastern Banffshire. *Memoir of the Geological Survey, Scotland*.
Grant Wilson, J.S. (1886) Explanation of Sheet 87, North-east Aberdeenshire and detached portions of Banffshire. Memoir of the Geological Survey, Scotland.
Grant Wilson, J.S., and Hinxman, L.W. (1890) Geology of central Aberdeenshire. *Memoir of the Geological Survey of Scotland,* Sheet 76 (Scotland).
Green, J.F.N. (1924) The structure of the Bowmore–Portaskaig District of Islay. *Quarterly Journal of the Geological Society, London*, **80**, 72 –105.
Green, J.F.N. (1931) The South-west Highland Sequence. *Quarterly Journal of the Geological Society of London* **87**, 513–550.
Gregory, J.W. (1910) Work for Glasgow geologists–the problems of the South-western Highlands. *Transactions of the Geological Society of Glasgow* **14**, 1–29.
Gregory, J.W. (1916) Pre-Cambrian of Scotland. *Handbuch der Regionaler Geologie*, III, Part I, 34–42.
Gregory, J.W. (1928) The geology of Loch Lomond. *Transactions of the Geological Society of Glasgow* **18**, 301–23.
Gregory, J.W. (1929) The Pre-Cambrian or Pre-Palaeozoic of Scotland. 28–42 in Evans, J. W. and Stubblefield, C. J. (editors) *Handbook of the geology of Great Britain*. Murby.
Gregory, J.W. (1930) The sequence in Islay and Jura. *Transactions of the Geological Society of Glasgow* Vol. **18**, 420–441.
Gregory, J.W. (1931) *Dalradian Geology: The Dalradian Rocks of Scotland and their Equivalents in other Countries*. Methuen, London.
Greig, K.M., (1987) Metamorphosed carbonates and fluid behaviour in the Dalradian of S.W. Argyll, Scotland. Unpublished PhD thesis, University of Edinburgh
Grieve, A. (1996) Ruskin and Millais at Glenfinlas. *The Burlington Magazine*, **138**, 228–234.
Gunn, A.G., Styles, M.T., Stephenson, D., Shaw, M.H. and Rollin, K. (1990) Platinum-group elements in ultramafic rocks of the Upper Deveron Valley, near Huntly, Aberdeenshire. *Mineral Reconnaissance Programme Report, British Geological Survey*, No. 115.
Gunn, W., Clough, C.T. and Hill, J.B. (1897) *The Geology of Cowal, including the part of Argyllshire between the Clyde and Loch Fyne*. Memoirs of the Geological Survey of Scotland, Sheets 29, 37 and 38.

Hackman, B.D. and Knill, J.L. (1962) Calcareous algae from the Dalradian of Islay. *Palaeontology*, **5**, 268–71.
Hall, A.J. (1993) Stratiform mineralisation in the Dalradian of Scotland. In *Mineralisation in the British Isles*. Pattrick, R.A.D., and Polya, D.A. (editors). Chapman and Hall, London, pp. 38–101.
Hall, J., Brewer, J.A., Matthews, D.H. and Warner, M. (1984) Crustal structure across the Caledonides from the WINCH seismic reflection profile: Influences on the evolution of the Midland Valley of Scotland. *Transactions of the Royal Society of Edinburgh: Earth Sciences,* **75**, 97–109.

Halliday, A.N., Graham, C.M., Aftalion, M. and Dymoke, P. (1989) The depositional age of the Dalradian Supergroup: U-Pb and Sm-Nd isotopic studies of the Tayvallich Volcanics, Scotland. *Journal of the Geological Society, London*, **146**, 3–6.
Hambrey, M.J. (1983) Correlation of the Late Proterozoic tillites in the North Atlantic region and Europe. *Geological Magazine*, **120**, 209–32.
Hambrey, M.J. and Harland, W.B. (editors). (1981) *Earth's pre-Pleistocene glacial record*. Cambridge University Press, Cambridge.
Hambrey, M.J. and Harland, W.B. (1985) The Late Proterozoic glacial era. *Palaeogeography, Palaeoclimatology and Palaeoecology*, **51**, 255–72.
Hambrey, M.J. and Waddams, P. (1981) Glaciogenic boulder-bearing deposits in the Upper Dalradian Macduff Slates, northeastern Scotland. In *Earth's pre-Pleistocene glacial record*. Hambrey, M.J. and Harland, W.B. (editors). Cambridge University Press, Cambridge, pp. 571–5.
Harkness, R. (1861) On the rocks of the portions of the Highlands of Scotland south of the Caledonian Canal; and on their equivalents in the north of Ireland. *Quarterly Journal of the Geological Society of London* **17**, 256–71.
Harris, A.L. (1960) Dalradian geology of an area between Pitlochry and Blair Atholl. Unpublished PhD thesis, University of Wales, Aberystwyth.
Harris, A.L. (1962) Dalradian geology of the Highland Border, near Callander. *Bulletin of the Geological Survey of Great Britain*, **19**, 1–15.
Harris, A.L. (1963). Structural investigations in the Dalradian rocks between Pitlochry and Blair Atholl. *Transactions of the Edinburgh Geological Society*, **19**, 256–278.
Harris, A.L. (1969) The relationships of the Leny Limestone to the Dalradian. *Scottish Journal of Geology*, **5**, 187–90.
Harris, A.L. (1972) The Dalradian rocks at Dunkeld, Perthshire. *Bulletin of the Geological Survey of Great Britain*, **38**, 1–10.
Harris, A.L. (1995) Nature and timing of orogenesis in the Scottish Highlands and the role of the Great Glen Fault. In *Current perspectives in the Appalachian–Caledonian Orogen*, Hibbard, J., van Stall, C.R. and Cawood, P.A. (editors) *Geological Association of Canada, Special Paper* **41**, 65–79.
Harris, A.L., Baldwin, C.T., Bradbury, H.J., Johnson, H.D. and Smith, R.A. (1978) Ensialic basin sedimentation: the Dalradian Supergroup. In *Crustal evolution in northwestern Britain,* Bowes, D R, and Leake, B E (editors)Special Issue of the Geological Journal No. 10 . Seel House Press, Liverpool, pp. 115–38
Harris, A.L., and Bradbury, H.J. (1977) Discussion of 'The evolution and transport of the Tay Nappe'. *Scottish Journal of Geology*, **13**, 81–3.
Harris, A.L., Bradbury, H.J. and McGonigal, N.H. (1976) The evolution and transport of the Tay Nappe. *Scottish Journal of Geology*, **12**, 103–13.
Harris, A.L. And Fettes, D.J. (1972) Stratigraphy and structure of Upper Dalradian rocks at the Highland Border. *Scottish Journal of Geology*, **8**, 253–64.
Harris, A.L., Fettes, D.J. And Soper, N.J. (1998a) Age of the Grampian event: a Discussion of "New evidence that the Lower Cambrian Leny Limestone at Callander, Perthshire, belongs to the

Dalradian Supergroup, and a re-assessment of the "exotic" status of the Highland Border Complex". *Geological Magazine*, **135**, 575.

Harris, A.L., Haselock, P.J., Kennedy, M.J., Mendum, J.R., Long, J.A., Winchester, J.A. and Tanner, P.W.G. (1994). The Dalradian Supergroup in Scotland, Shetland, and Ireland, *In A Revised Correlation of the Precambrian Rocks of the British Isles* (eds. W. Gibbons and A.L. Harris), Geological Society, London, Special Report No. **22**, 33–53.

Harris, A.L., Parson, L.M., Highton, A.J. and Smith, D.I. 1981. New/Old Moine relationships between Fort Augustus and Inverness (Abstract). *Journal of Structural Geology*, **3**, 187–88.

Harris, A.L. and Pitcher, W.S. (1975) The Dalradian Supergroup. In *A Correlation of Precambrian Rocks in the British Isles.* (eds. Harris, A. L., Shackleton, R. M., Watson, J.V., Downie, C., Harland, W. B. and Moorbath, S.), Special Reports of the Geological Society, London, 6, pp. 52–75.

Harte, B. (1966) Stratigraphy, structure and metamorphism in the south-eastern Grampian Highlands of Scotland. Unpublished PhD thesis, University of Cambridge.

Harte, B., (1975) Determination of a pelite petrogenetic grid for the eastern Scottish Dalradian. *Yearbook of the Carnegie Institute, Washington*, **74**, 438–446.

Harte, B. (1979) The Tarfside succession and the structure and stratigraphy of the eastern Scottish Dalradian rocks. In *Special Publications, Geological Society, London, 8* (eds. Harris, A. L., Holland, C. H. and Leake, B. E.), pp. 221–28.

Harte, B. (1987) Glen Esk Dalradian, Barrovian metamorphic zones. In *Excursion Guide to the Geology of the Aberdeen area.* (editors N.H.Trewin, B.C. Kneller, and C. Gillen,). Scottish Academic press for Geological Society of Aberdeen, Edinburgh, p 193–210.

Harte, B. (1988) Lower Palaeozoic metamorphism in the Moine–Dalradian belt of the British Isles. In *The Caledonian–Appalachian Orogen*. Harris, A L, and Fettes, D J (editors). Special Publication of the Geological Society of London, No. 38, pp. 123–34.

Harte, B., Booth, J.E., Dempster, T.J., Fettes, D.J., Mendum, J.R. and Watts, D. (1984) Aspects of the post-depositional evolution of Dalradian and Highland Border Complex rocks in the Southern Highlands of Scotland. *Transactions of the Royal Society of Edinburgh*, **75**, 151–63.

Harte, B., Booth, J.E. and Fettes, D.J., (1987) Stonehaven to Findon: Dalradian Structure and Metamorphism. In *Excursion Guide to the Geology of the Aberdeen Area* (eds Trewin, N. H., Kneller, B. C. and Gillen, C.). Scottish Academic Press for Geological Society of Aberdeen, Edinburgh, pp. 211–26

Harte, B. and Dempster, T.J. (1987) Regional metamorphic zones: tectonic controls. *Philosophical Transactions of the Royal Society of London* Vol. **321**, 105–27.

Harte, B, and Hudson, N.F.C. (1979) Pelite facies series and the temperatures and pressures of Dalradian metamorphism in E Scotland. in The Caledonides of the British Isles–Reviewed. (eds. A.L. Harris, C.H. Holland, and B.E. Leake,) *Geological Society of London Special Publication*, **8**, pp 323–37.

Harte, B, and Johnson, M.R.W. (1969) Metamorphic history of Dalradian rocks in Glens Clova, Esk and Lethnot, Angus, Scotland. *Scottish Journal of Geology*, **5**, 54–80.

Haselock, P.J. (1982) The geology of the Corrieyairack Pass area, Inverness-shire. Unpublished PhD thesis, University of Keele.

Haselock, P.J. (1984) The systematic geochemical variation between two tectonically separate successions in the southern Monadhliaths, Inverness-shire. *Scottish Journal of Geology*. **20**, 191–205.

Haselock, P.J. and Gibbons, W. (1990). The Central Highland controversy: a traverse through the Precambrian metasediments of the Central Highlands of Scotland. *Episodes* **13**, 113–15.

Haselock, P.J. and Leslie, A.G. (1992). Polyphase deformation in Grampian Group rocks of the Monadhliath defined by a group magnetic survey. *Scottish Journal of Geology* **28**, 81–7.

Haselock, P.J., Winchester, J.A. and Whittles, K.H. (1982). The stratigraphy and structure of the southern Monadhliath Mountains between Loch Killin and upper Glen Roy. *Scottish Journal of Geology*, **18**, 275–90.

Heddle, M.F. (1878) Chapters on the mineralogy of Scotland. Chapter fourth - augite, hornblende and serpentinous change. *Transactions of the Royal Society of Edinburgh* **28**, 453–555.

Heddle M. F. (1901) *The mineralogy of Scotland*. D. Douglas, Edinburgh.

Henderson, S.M.K. (1938) The Dalradian Succession of the Southern Highlands. *Report of the meeting of the British Association for the Advancement of Science, Cambridge, 1938*, 424.

Henderson, W.G. and Robertson, A.H.F. (1982). The Highland Border rocks and their relation to marginal basin development in the Scottish Caledonides. *Journal of the Geological Society of London*, **139**, 433–50.

Henderson, W.G., Tanner, P.W.G. and Strachan, R.A. (2009) The Highland Border Ophiolite of Scotland: observations from the Highland Workshop field excursion of April 2008. *Scottish Journal of Geology*, **45**, 13–18.

Hibbert, S. (1822) *A Description of the Shetland Islands: comprising an account of their geology, scenary, antiquities and superstitions.* Constable and Co., Edinburgh.

Hickman, A.H. (1975) The stratigraphy of late Precambrian metasediments between Glen Roy and Lismore. *Scottish Journal of Geology*, **11**, 117–42.

Hickman, A H. (1978) Recumbent folds between Glen Roy and Lismore. *Scottish Journal of Geology*, **14**, 191–212.

Hickman, A.H. and Roberts, J.L. (1977). Discussion of the North Ballachulish Dalradian. *Journal of the Geological Society of London*, **133**, Part 3, 277–79.

Hickman, A.H. and Wright, A.E. (1983) Geochemistry and chemostratigraphical correlation of slates, marbles and quartzites of the Appin Group, Argyll, Scotland. *Transactions of the Royal Society of Edinburgh: Earth Sciences*, **73**, 251–78.

Highton, A.J. (1986). Caledonian and pre-Caledonian events in the Moine south of the Great Glen Fault, Unpublished PhD thesis, University of Liverpool.

Highton, A.J. (1992). The tectonostratigraphical significance of pre-750 Ma metagabbros within the northern Central Highlands, Inverness-shire. *Scottish Journal of Geology* **28**, 71–6.

Highton, A.J. (1999). Solid Geology of the Aviemore District. *Memoir of the British Geological Survey,* Sheet 74E (Scotland).

Highton, A.J., Hyslop, E.K. and Noble, S.R. (1999).U-Pb zircon geochronology of migmatization in the northern Central Highlands:

evidence for pre-Caledonian (Neoproterozoic) tectonmetamorphism in the Grampian Block, Scotland. *Journal of the Geological Society, London*, **156**, 1195–204.
Hill, J.B. (1899) On the progressive metamorphism of some Dalradian sediments in the region of Loch Awe. *Quarterly Journal of the Geological Society, London*, **40**, 470–93.
Hill, J.B. (1905) *The geology of mid-Argyll*. Memoirs of the Geological Survey, Scotland. Explanation of Sheet 37.
Hill, J. and Buist, D. (1994) A Geological Field Guide to the Island of Bute, Scotland. (editor Greensmith, J. T.) *Geologists' Association Guide,* No. **51**, 95 pp. Warwick Press.
Hinxman, L.W. (1896). Explanation of Sheet 75. West Aberdeenshire, Banffshire, parts of Elgin and Inverness. Memoir of the Geological Survey, Scotland.
Hinxman, L. W. and Anderson, E. M. (1915). The geology of Mid-Strathspey and Strathdearn, including the country between Kingussie and Grantown, Scotland. *Memoir of the Geological Survey, Scotland,* Sheet 74 (Scotland).
Hinxman, L. W., Carruthers, R. G. and Macgregor, M. (1923). The geology of Corrour and the Moor of Rannoch. *Memoir of the Geological Survey, Scotland,* Sheet 54 (Scotland).
Hinxman, L.W. and Grant Wilson, J.S. (1902) The geology of Lower Strathspey. Memoir of the Geological Survey, Scotland, Sheet 85 (Scotland).
Hoffmann, P.F., Condon, D.J., Bowring, S.A. and Crowley, J.L. (2004) U-Pb zircon date from the Neoproterozoic Ghaub Formation, Namibia: Constraints on Marinoan glaciation. *Geology*, **32**, 817–20.
Holdsworth, R.E., Woodcock, N. and Strachan, R. (2000) Geological Framework of Britain and Ireland. In *Geological History of Britain and Ireland* (edited by Woodcock, N. and Strachan, R.) Blackwell Science, Oxford.
Holland, C.H. and Sanders, I.S. (editors) 2009. *The Geology of Ireland* (2nd edition). Dunedin Academic Press, Edinburgh. 576 pp.
Howarth, R.J. and Leake, B.E. (2002) *The Life of Frank Coles Phillips (1902–1982) and the Structural Geology of the Moine Petrofabric Controversy*. Memoir of the Geological Society, London, **23**, 95pp.
Hudson, N.F.C. (1976) Mineral facies in pelitic rocks, with particular reference to the Buchan type metamorphism of north-eastern Scotland. Unpublished PhD thesis, University of Edinburgh.
Hudson, N.F.C. (1980) Regional metamorphism of some Dalradian pelites in the Buchan area, NE Scotland. *Contributions to Mineralogy and Petrology,* **73**, 39–51.
Hudson, N.F.C. (1985) Conditions of Dalradian metamorphism in the Buchan area. *Journal of the Geological Society of London*, **142**, 63–76.
Hutchison, A.R. and Oliver, G.J.H. (1998) Garnet provenance studies, juxtaposition of Laurentian marginal terranes and timing of the Grampian Orogeny in Scotland. *Journal of the Geological Society, London*, **155**, 541–50.
Hutton D.H.W. (1987) Strike slip terranes and a model for the evolution of the British and Irish Caledonides. *Geological Magazine* **124**, 405–425.
Hutton, D.H.W. and Alsop, G.I. (2004) Evidence for a major Neoproterozoic orogenic unconformity within the Dalradian Supergroup of NW Ireland. *Journal of the Geological Society, London*, **161**, 629–40.

Hutton, D.H.W. and Alsop, G.I. (2005) Discussion on evidence for a major Neoproterozoic orogenic unconformity within the Dalradian Supergroup of NW Ireland. *Journal of the Geological Society, London*, **162**, 221–4.

Hutton J. (1788) Theory of the Earth; or an Investigation of the Laws observable in the Composition, Dissolution, and Restoration of the Land upon the Globe. *Transactions of the Royal Society of Edinburgh* **1**, 209–304.

Hyslop, E. K. (1992). Strain-induced metamorphism and pegmatite development in the Moine rocks of Scotland. Unpublished PhD thesis, University of Hull.

Hyslop, E.K. and Piasecki, M.A.J. (1999). Mineralogy, geochemistry and the development of ductile shear zones in the Grampian Slide Zone of the Scottish Central Highlands. *Journal of the Geological Society, London*, **156**, 577–90.

Hyslop, E.K. and Pickett, E.A. (1999) Stratigraphy and magmatism in the uppermost Dalradian of the SW Scottish Highlands: A field excursion to Tayvallich, Loch Avich and Tarbert (Loch Fyne). *BGS Technical Report* **WA/99/73**.

Indares, A. and Dunning, G.R. (1997) Coronitic metagabbro and eclogite from the Grenville Province of western Quebec; interpretation of U-Pb geochronology and metamorphism. *Canadian Journal of Earth Sciences* **34**, 891–901.

Jacques J.M. and Reavy R.J. (1994) Caledonian plutonism and major lineaments in the SW Scottish Highlands. *Journal of the Geological Society, London*, **151**, 955–69.

Jamieson, T.F. (1861) On the structure of the south-west Highlands of Scotland. *Quarterly Journal of the Geological Society of London*, **17**, 133–45.

Jehu, T.J. and Campbell, R. (1917) The Highland Border rocks of the Aberfoyle District. *Transactions of the Royal Society of Edinburgh*, **52**, 175–212.

Johnson, M.R.W. (1962) Relations of movement and metamorphism in the Dalradians of Banffshire. *Transactions of the Edinburgh Geological Society*, **19**, 29–64.

Johnson, M.R.W. (1963) Some time relations of movement and metamorphism in the Scottish Highlands. *Geologie en Mijnbouw*, **42**, 121–42.

Johnson, M.R.W. (1965) Dalradian. In *The Geology of Scotland* (1st edition). Craig, G. Y. (ed.) Oliver and Boyd, Edinburgh. 117–60.

Johnson, M.R.W. (1983) Dalradian. In *Geology of Scotland* (2nd edition), Craig, G. Y. (ed.), Scottish Academic Press, Edinburgh, pp. 77–104.

Johnson, M.R.W. (1991) Dalradian. In *Geology of Scotland* (3rd edition). Craig, G. Y. (ed.) The Geological Society, London, pp. 125–60.

Johnson, M.R.W. and Harris, A.L. (1967) Dalradian–?Arenig relations in part of the Highland Border, Scotland, and their significance in the chronology of the Caledonian orogeny. *Scottish Journal of Geology*, **3**, 1–16.

Johnson, M.R.W. and Stewart, F.H. (1960) On Dalradian structures in north-east Scotland. *Transactions of the Edinburgh Geological Society*, **18**, 94–103.

Johnson T.E. (1999) Partial melting in Dalradian pelitic migmatites from the Fraserburgh–Inzie Head area of Buchan, northeast Scotland. Unpublished PhD thesis, University of Derby.

Johnson T.E., Hudson N.F.C. and Droop G.T.R. (2001a) Partial melting in the Inzie Head gneisses: the role of water and a petrogenetic grid in KFMASH applicable to anatectic pelitic migmatites. *Journal of Metamorphic Geology*, **19**, 99–118.

Johnson T.E., Hudson N.F.C. and Droop, G.T.R (2001b) Melt segregation structures within the Inzie Head gneisses of the northeastern Dalradian. *Scottish Journal of Geology*, **37**, 59–72.

Johnson T.E., Hudson N.F.C. and Droop G.T.R. (2003) Evidence for a genetic granite-migmatite link in the Dalradian of NE Scotland. *Journal of the Geological Society, London*, **160**, 447- 57.

Johnstone, G.S. (1966) British regional geology: the Grampian Highlands (3rd edition). HMSO, Edinburgh for Geological Survey and Museum.

Johnstone, G.S. (1975) The Moine Succession. In *A Correlation of Precambrian Rocks in the British Isles* (eds. Harris, A. L., Shackleton, R. M., Watson, J.V., Downie, C., Harland, W. B. and Moorbath, S.) *Geological Society, London, Special Report*, **6**, 30–42.

Johnstone, G.S. and Smith, D.I. (1965) Geological observations concerning the Breadalbane Hydroelectric Project, Perthshire. *Bulletin of the Geological Survey of Great Britain*, **22**, 1–52.

Johnstone, G.S. and Wright, J.E. (1957) The Geology of the tunnels of the Loch Sloy hydroelectric scheme. *Bulletin of the Geological Survey of Great Britain*, **12**, 1–17.

Jones, K.A. (1959) The tectonic and metamorphic history of the Ben More—Am Binnein area, Western Perthshire. Unpublished PhD thesis, University of Wales, Swansea.

Kearns, S. (1989) Metamorphism of calc-silicate and related rocks from the Dalradian of N.E. Scotland. Unpublished PhD thesis, Derbyshire College of Higher Education.

Kennedy, M.J. (1975) The Fleur de Lys Supergroup: stratigraphic comparison of Moine and Dalradian equivalents in Newfoundland with the British Caledonides. *Journal of the Geological Society, London,* **131**, 305–10.

Kennedy W.Q. (1946) The Great Glen Fault. *Quarterly Journal of the Geological Society of London*, **102**, 41–76.

Kennedy, W.Q. (1948) On the significance of thermal structure in the Scottish Highlands. *Geological Magazine*, **85**, 229–34.

Kessler, L.G. and Gollop, I.G. (1988) Inner shelf/shoreface-intertidal transition, Upper Precambrian, Port Askaig Tillite, Isle of Islay, Argyll, Scotland. In *Tide Influenced Sedimentology, Environments and Facies* (eds. de Boer, P. L., van Gelder, A. and Nio, S. D.), Reidal, Dohdrecht, pp. 341–58.

Key, R.M., Clark, G.C., May, F., Phillips, E.R., Chacksfield, B.C. and Peacock, J.D. (1997). Geology of the Glen Roy district. *Memoir of the British Geological Survey*, Sheet 63W (Scotland).

Kilburn, C., Pitcher, W.S. and Shackleton, R.M. (1965) The stratigraphy and origin of the Portaskaig Boulder Bed series (Dalradian). *Geological Journal*, **4**, 343–60.

Kinny, P.D., Friend, C.R.L., Strachan, R.A., Watt, G.R. and Burns, I.M. (1999) U-Pb geochronology of regional migmatites in East Sutherland, Scotland; evidence for crustal melting during the

Caledonian Orogeny. *Journal of the Geological Society, London*, **156**, 1143–52.
Kinny, P.D., Strachan, R.A., Friend, C.R.L., Kocks, H., Rogers, G. and Paterson, B.A. (2003a) U-Pb geochronology of deformed metagranites in central Sutherland, Scotland; evidence for widespread late Silurian metamorphism and ductile deformation of the Moine Supergroup during the Caledonian orogeny. *Journal of the Geological Society of London,* **160**, 259–69.
Kinny, P.D., Strachan, R.A., Kocks, H. and Friend, C.R.L. (2003b) U-Pb geochronology of late Neoproterozoic augen granites in the Moine Supergroup, NW Scotland: dating of rift-related, felsic magmatism during supercontinent break-up? *Journal of the Geological Society of London,* **160**, 925–34.
Klein, G.D.V. (1970) Tidal origin of a Precambrian quartzite – the Lower Fine-grained Quartzite (Middle Dalradian) of Islay, Scotland. *Journal of Sedimentary Petrology*, **40**, 973–85.
Klein, G.D.V. (1971) Tidal origin of a Precambrian quartzite – the Lower Fine-grained Quartzite (Middle Dalradian) of Islay, Scotland: Reply. *Journal of Sedimentary Petrology*, **41**, 886–9.
Kneller, B.C. (1985) Dalradian basin evolution and metamorphism. *Journal of the Geological Society of London*, **142**, 4 (abstract).
Kneller, B.C. (1987) A geological history of NE Scotland. 1–50. In *Excursion guide to the geology of the Aberdeen area*. Trewin, H.N., Kneller, B.C. and Gillen, C. (editors). Scottish Academic Press for Geological Society of Aberdeen, Edinburgh.
Kneller, B.C. (1988) The geology of part of Buchan. Unpublished PhD thesis, University of Aberdeen.
Kneller, B.C. and Aftalion M. (1987) The isotopic and structural age of the Aberdeen Granite. *Journal of the Geological Society of London* **144**, 717–21.
Kneller, B.C. and Leslie, A.G. (1984) Amphibolite facies metamorphism in shear zones in the Buchan area of NE Scotland. *Journal of Metamorphic Geology* **2**, 83–94.
Knill, J.L. (1959) Palaeocurrents and sedimentary facies of the Dalradian metasediments of the Craignish-Kilmelfort district. *Proceedings of the Geologists' Association*, **70**, 273–84.
Knill, J.L. (1960) The tectonc pattern in the Dalradian of the Craignish-Kilmelfort District, Argyllshire. *Quarterly Journal of the Geological Society of London*, **115**, 339–64.
Knill, J.L. (1963) A sedimentary history of the Dalradian Series. In *The British Caledonides.* (eds Johnson, M.R.W. and Stewart, F.H.). Oliver and Boyd, Edinburgh, pp. 99–121.
Krabbendam, M. and Leslie, A.G. (1996) Folds with vergence opposite to the sense of shear. *Journal of Structural Geology*, **18**, 777–81.
Krabbendam, M., Leslie, A.G., Crane, A. and Goodman, S. (1997) Generation of the Tay Nappe, Scotland, by large-scale SE-directed shearing. *Journal of the Geological Society, London*, **154**, 15–24.
Krabbendam, M., Prave, A.R. and Cheer, D.A. (2008) A fluvial origin for the Neoproterozoic Morar Group, NW Scotland; implications for Torridon-Morar Group correlation and the Grenville Orogen foreland basin. *Journal of the Geological Society, London,* **165**, 379–94.
Kruhl, J. and Voll, G. (1975) Large scale pre-metamorphic and pre-cleavage inversion at Loch Leven, Scottish Highlands. *Neues Jahrbuch für Mineralogie*, **2**, 71–8.

Kynaston, H. and Hill J.B. (1908) *The Geology of the country near Oban and Dalmally*. Memoir of the Geological Survey, Sheet 45 (Scotland).

Lambert, R.St. J. (1975) Discussion of Moine-Dalradian relationships in the River Leven. *Journal of the Geological Society of London,* **131**, 327-8.

Lambert, R.St.J., Holland, J.G. and Winchester, J.A. (1982) A geochemical comparison of the Dalradian Leven Schists and the Grampian Division Monadhliath Schists of Scotland. *Journal of the Geological Society of London*, **139**, 71-84.

Lambert, R.St.J. and McKerrow, W.S. (1976) The Grampian Orogeny. *Scottish Journal of Geology*, **12**, 271-92.

Lambert, R.St.J, Winchester, J.A. and Holland, J.G. (1981) Comparative geochemistry of pelites from the Moinian and Appin Group (Dalradian) of Scotland. *Geological Magazine*, **118**, 477-90.

Lawson, J. D. and Weedon, D. S. (editors) (1992) *Geological Excursions around Glasgow and Girvan*. Geological Society of Glasgow, Glasgow.

Leake, B.E. (1982) Volcanism in the Dalradian. In *Igneous rocks of the British Isles*. Sutherland, D. S. (editor). John Wiley and Sons, Chichester, pp. 45-50.

Leake, B.E. and Tanner, P.W.G. (1994) *The Geology of the Dalradian and Associated Rocks of Connemara, Western Ireland: a report to accompany the 1:63360 geological map and cross sections.* Royal Irish Academy, Dublin.

Lee, G.W. and Bailey, E.B. (1925) The pre-Tertiary geology of Mull, Loch Aline and Oban. Memoir of the Geological Survey of Great Britain, Sheet 44 (Scotland).

Leggo, P.J., Tanner, P.W.G. and Leake, B.E. (1969) Isochron study of Donegal Granite and certain Dalradian rocks of Britain. In *North Atlantic-geology and Continental Drift, a symposium* (ed. M. Kay), Memoir of the American Association of Petroleum Geologists, 12, pp. 354-62.

Le Maitre, R.W (editor) (2002). *Igneous Rocks: a Classification and Glossary of Terms; Recommendations of the International Union of Geological Sciences Subcommission on the Systematics of Igneous Rocks*. Cambridge University Press, Cambridge, 236 pp.

Leslie, A.G., Chacksfield, B.C., Smith, M. and Smith, R.A. (1999). The Geophysical signature of a major shear zone in the Central Highlands of Scotland. *British Geological Survey Technical Report* No. **WA/99/32R**.

Leslie, A.G., Krabbendam, M. and Smith, R.A. (2006) The Gaick Fold Complex: large-scale recumbent folds and their implications for Caledonian structural architecture in the Central Grampian Highlands. *Scottish Journal of Geology*, **42**, 149-60.

Leslie, A.G., Smith, M. and Soper, N.J. (2008) Laurentian margin evolution and the Caledonian orogeny-a template for Scotland and East Greenland. In *The Greenland Caledonides: Evolution of the Northeast Margin of Laurentia.* Higgins, A.K., Gilotti, J.A. and Smith, M.P. (editors), Geological Society of America Memoir, **202**, 307-43.

Lindsay, N.G. (1988) Contrasts in Caledonian tectonics of the Northern and Central Highlands. Unpublished PhD thesis, University of Liverpool.

Lindsay, N.G., Haselock, P.J. and Harris, A.L. (1989). The extent of Grampian orogenic activity in the Scottish Highlands. *Journal of the Geological Society of London*, **146**, 733–5.

Litherland, M. (1970) The stratigraphy and structure of the Dalradian rocks around Loch Creran, Argyll. Unpublished PhD thesis, University of Liverpool.

Litherland, M. (1975) Organic remains and traces from the Dalradian of Benderloch, Argyll. *Scottish Journal of Geology*, **11**, 47–50.

Litherland, M. (1980) The stratigraphy of the Dalradian rocks around Loch Creran, Argyll. *Scottish Journal of Geology*, **16**, 105–23.

Litherland, M. (1982) The structure of the Loch Creran Dalradian and a new model for the SW Highlands. *Scottish Journal of Geology*, **18**, 205–25.

Loudon, T.V. (1963) The sedimentation and structure in the Macduff District of North Banffshire and Aberdeenshire. Unpublished PhD thesis, University of Edinburgh.

Lowe, D. R. 1976. Subaqueous liquified and fluidised sediment flows and their deposits. *Sedimentology*, **23**, pp. 285-308.

Lyubetskaya, T. and Ague, J.J., 2010. Modeling metamorphism in collisional orogens intruded by magmas: fluid flow and implications for Barrovian and Buchan metamorphism, Scotland. American Journal of Science, 310, 459-491.

McAteer, C.A., Daly, J.S., Flowerdew, M.J., Connelly, J.N., Housh, T.B. and Whitehouse, M.J. (2010) Detrital zircon, detrital titanite and igneous clast U-Pb geochronology and basement-cover relationships of the Colonsay Group, SW Scotland: Laurentian provenance and correlation with the Neoproterozoic Dalradian Supergroup. *Precambrian Research*, **181**, 21-42.

McCallien, W.J. (1925) Notes on the Geology of the Tarbet district of Loch Fyne. *Transactions of the Geological Society of Glasgow*, **17**, 233–63.

McCallien, W.J. (1926) The structure of South Knapdale (Argyll). *Transactions of the Geological Society of Glasgow*, **17**, 377–94.

McCallien, W.J. (1929) The metamorphic rocks of Kintyre. *Transactions of the Royal Society of Edinburgh*, **56**, 409–36.

Mccallien, W.J. (1938) The Geology of Bute. *Transactions of the Buteshire Natural History Society*, **12**, 84–112.

McCay, G.A., Prave, A.R., Alsop, G.I. and Fallick, A.E. (2006) Glacial trinity: Neoproterozoic Earth history within the British-Irish Caledonides. *Geology,* **34**, 909–12.

McClay, K.R. (1987) *The Mapping of Geological Structures*. Geological Society of London Handbook, Open University Press, Milton Keynes, 161 pp.

McClay K.R., Norton M.G., Cony P. and Davis G.H. (1986) Collapse of the Caledonian Orogen and the Old Red Sandstone. *Nature, London* **323**, 147–9.

MacCulloch, J. (1814) Remarks on several parts of Scotland which exhibit quartz rock, and on the nature and connexions of this rock in general. *Transactions of the Geological Society,* **2**, 450–87.

MacCulloch, J. (1819) *A description of the western islands of Scotland including the Isle of Man: comprising an account of their geological structure; with remarks on their agriculture, scenary and antiquities*. 3 volumes. Constable, London.

MacDonald, J.G. and Herriot, A. (1983) *Macgregor's excursion guide to the geology of Arran*. (3rd edition). Geological Society of Glasgow and University of Glasgow, Glasgow.

Macdonald, R. and Fettes, D.J. (2007) The tectonomagmatic evolution of Scotland. *Transactions of the Royal Society of Edinburgh: Earth Sciences*, **97**, 213–95.

Macdonald, R., Fettes, D.J., Stephenson, D. and Graham, C.M. (2005) Basic and ultrabasic volcanic rocks from the Argyll Group (Dalradian) of NE Scotland. *Scottish Journal of Geology*, **41**, 159–74.

MacGregor, A.G. (1948) British regional geology: the Grampian Highlands (2nd edition), HMSO for Geological Survey and Museum, Edinburgh.

MacGregor, A.R. (1996) Edzell and Glen Esk. 93–108 in *Fife and Angus Geology, an excursion guide* (3rd edition) by A.R. MacGregor, Pentland Press, Durham.

MacGregor, S.M.A. and Roberts, J.L. (1963) Dalradian pillow lavas, Ardwell Bridge, Banffshire. *Geological Magazine*, **100**, 17–23.

McIntyre, D.B. (1950) Lineation, boudinage and recumbent folding in the Struan Flags (Moine), near Dalnacardoch, Perthshire. *Geological Magazine*, **87**, 205–25.

McIntyre, D.B. (1951) The tectonics of the area between Grantown and Tomintoul (mid-Strathspey). *Quarterly Journal of the Geological Society of London*, **107**, 1-22.

McKenzie, D.P. and Bickle, M.J. (1988). The volume and composition of melt generated by the extension of the lithosphere. *Journal of Petrology*, **29**, 625–79.

McKie, T. (1990) Tidal and storm-influenced sedimentation from a Cambrian transgressive passive margin sequence. *Journal of the Geological Society, London*, **147**, 785–94.

Mackie, W. (1908) Evidence of contemporaneous volcanic action in the Banffshire schists. *Transactions of the Edinburgh Geological Society*, **9**, 93–101.

McLellan, E.L. (1983) Barrovian migmatites and the thermal history of the south-eastern Grampians. Unpublished PhD thesis, University of Cambridge.

McLellan, E.L., 1985. Metamorphic reactions in the kyanite and sillimanite zones of the Barrovian type area, Journal of Petrology, 26, 789-818.

Macnair, P. (1896) The altered clastic rocks of the Southern Highlands: their structure and succession. *Geological Magazine*, Decade 4, **3**, 167–174, 211–217.

Macnair, P. (1906) On the development of the great axial lines of folding in the Highland schists. *Proceedings of the Royal Philosophical Society of Glasgow* Vol. **37**, 129–xxx.

Macnair, P. (1908) *The Geology and Scenery of the Grampians and the Valley of Strathmore,* James MacLehose and Sons, Glasgow, 2 volumes, 256 pp.

Marcantonio, F., Dickin, A.P., McNutt, R.H. and Heaman, L.M. (1988). A 1880-million year old Proterozoic gneiss terrane in Islay with implications for crustal evolution of Britain. *Nature,* **335**, 62–64.

Mather, J.D. (1968) A geochemical, mineralogical and petrological study of rocks of lower greenschist facies from the Dalradian of Scotland. Unpublished PhD thesis, University of Liverpool.

May, F. (1970) Movement, metamorphism and migmatization in the Scalloway region of Shetland. *Bulletin of the Geological Survey of Great Britain*, **31**, 205–26.

May, F. and Highton, A.J. (1997) Geology of the Invermoriston district. *Memoir of the British Geological Survey*. Sheet 73W (Scotland).

Melezhik, V.A., Gorokhov, I.M., Kuznetsov, A.B. and Fallick, A.E. (2001). Chemostratigraphy of Neoproterozoic carbonates: implications for 'blind dating'. *Terra Nova*, **13**, 1–11.

Mendum, J.R. 1987. Dalradian of the Collieston coast section. 161–172 in *Excursion guide to the geology of the Aberdeen area*. Trewin, N H, Kneller, B C, and Gillen, C (editors). (Edinburgh: Scottish Academic Press for Geological Society of Aberdeen.)

Mendum, J.R., Barber, A.J., Butler, R.W.H., Flinn, D., Goodenough, K.M., Krabbendam, M., Park, R.G. and Stewart, A.D. (2009) *Lewisian, Torridonian and Moine rocks of Scotland*, Geological Conservation Review Series, No. **34**, Joint Nature Conservation Committee, Peterborough, 722 pp.

Mendum, J.R. and Fettes, D.J. (1985) The Tay nappe and associated folding in the Ben Ledi–Loch Lomond area. *Scottish Journal of Geology*, **21**, 41–56.

Mendum, J.R. and Noble, S.R. (2010) Mid-Devonian sinistral transpression on the Great Glen Fault: the rise of the Rosemarkie Inlier and the Acadian Event in Scotland. In *Continental tectonics and mountain building: the legacy of Peach and Horne*. (eds R.D. Law, R.W.H. Butler, R.E. Holdsworth, M. Krabbendam and R.A. Strachan), *Geological Society, London, Special Publication*, No. **335**, pp. 161-187.

Mendum, J.R. and Thomas, C.W. (1997) Discussion on the generation of the Tay Nappe, Scotland, by large-scale SE-directed shearing. *Journal of the Geological Society, London*, **154**, 581–3.

Miall, A. D. 1985. Architectural-element analysis: a new method of facies analysis applied to fluvial deposits. *Earth Science Reviews*, **22**, pp. 261-308.

Miall, A. D. 1992. Alluvial Deposits. In: Walker, R. G. & James, N. P. (eds), Facies models – response to sea level changes. Geoscience Canada, pp. 119-1992.

Millar, I.L. (1999) Neoproterozoic extensional basic magmatism associated with the West Highland granite gneiss in the Moine Supergroup of NW Scotland. *Journal of the Geological Society, London* **156**, 1153–62.

Moffat, D.T. (1987) The serpentinized ultramafites of the Shetland Caledonides. Unpublished PhD thesis, University of Liverpool.

Moig, N.A.W. (1986) A structural study of the Dalradian rocks of the Banff coastal transect, NE Scotland. Unpublished PhD thesis, University of Dundee.

Moles, N.R. (1985a) Geology, geochemistry and petrology of the Foss stratiform baryte–base metal deposit and adjacent Dalradian metasediments, near Aberfeldy. Unpublished PhD thesis, University of Edinburgh.

Moles, N.R. (1985b) Metamorphic conditions and uplift history in central Perthshire: evidence from mineral equilibria in the Foss celsian-barite-sulphide deposit, Aberfeldy. *Journal of the Geological Society of London*, **142**, 39–52.

Möller, C. (1998) Decompressed eclogites in the Sveconorwegian (Grenvillian) Orogen of SW Sweden; petrology and tectonic implications. *Journal of Metamorphic Geology*, **16**, 641–56.
Molyneux, S.G. 1998. An upper Dalradian microfossil reassessed. *Journal of the Geological Society, London*, **155**, 740–743.
Morgan, W.C. (1966) The metamorphic history of the Dalradian rocks between Tomintoul and Loch Builg, Banfshire. Unpublished Ph D thesis, University of Aberdeen.
Morris, G.A. and Hutton, D.H.W. (1993) Evidence for sinistral shear associated with the emplacement of the early Devonian Etive dyke swarm. *Scottish Journal of Geology*, **29**, 69–72.
Mould, D.D.C.P. (1946) The geology of the Foyers 'granite' and the surrounding country. *Geological Magazine*, **83**, 249–65.
Muir, R.J. (1990) The Precambrian basement and related rocks of the southern Inner Hebrides, Scotland. Unpublished PhD thesis, University of Wales, Aberystwyth.
Muir, R.J., Fitches, W.R. and Maltman, A.J. (1989) An Early Proterozoic link between Greenland and Scandinavia in the Inner Hebrides of Scotland. *Terra Abstract*, **1**, 5.
Muir, R.J., Fitches, W.R. and Maltman, A.J. (1992). Rhinns Complex: a missing link in the Proterozoic basement of the North Atlantic region. *Geology*, **20**, 1043–6.
Muir, R.J., Fitches, W.R. and Maltman, A.J. (1994a). The Rhinns Complex: Proterozoic basement on Islay and Colonsay, Inner Hebrides, Scotland, and on Inishtrahull, NW Ireland. *Transactions of the Royal Society of Edinburgh: Earth Sciences*, **85**, 77–90.
Muir, R.J., Fitches, W.R., Maltman, A.J. and Bentley, M.R. (1994b) Precambrian rocks of the southern Inner Hebrides–Malin Sea region: Colonsay, west Islay, Inishtrahull and Iona. *In*: Gibbons, W. and Harris, A.L. (eds) *A revised correlation of Precambrian rocks in the British Isles*. Geological Society, London, Special Report **22**, 54–58.
Muir, R.J., Fitches, W.R. and Maltman, A.J. (1995). The Colonsay Group and basement-cover relationship on the Rhinns of Islay, Inner Hebrides. *Scottish Journal of Geology*, **31**, 125–30.
Munro, M. (1986) Geology of the country around Aberdeen. *Memoir of the British Geological Survey*, Sheet 77 (Scotland).
Munro, M. and Gallagher, J W. (1984) Disruption of the 'Younger Basic' masses in the Huntly-Portsoy area, Grampian Region. *Scottish Journal of Geology*, **20**, 361–82.
Murchison, R.I. (1851) On the Silurian rocks of the south of Scotland. *Quarterly Journal of the Geological Society of London*, **7**, 139–78.
Murchison, R.I. (1859) *Siluria: the History of the Oldest Known Rocks Containing Organic Remains, With a Brief Sketch of the Distribution of Gold Over the Earth*. 3rd edition. John Murray, London.
Murchison, R.I. and Geikie, A. (1861) On the altered rocks of the Western Islands of Scotland and the North-Western and Central Highlands. *Quarterly Journal of the Geological Society of London* **17**, 171– ??.
Mutti, E. and Normark, W.R. (1987) Comparing examples of modern and ancient turbidite systems: problems and concepts. In *Marine Clastic Sedimentology* (eds. Legget, J.K and Zuffa, G.G.), Graham and Trotman, pp.1–38.
Mykura, W. (1976) *British Regional Geology: Orkney and Shetland*. HMSO, Edinburgh for the Institute of Geological Sciences.

Nell, P.A.R. (1984) The geology of lower Glen Lyon. Unpublished PhD thesis, University of Manchester.

Nell, P.A.R. (1986) Discussion on the Caledonian metamorphic core: an Alpine model. *Journal of the Geological Society of London*, **143**, 723–8.

Nesbitt, R.W. and Hartmann, L.A. (1986) Comments on 'A peridotitic komatiite from the Dalradian of Shetland' by D. Flinn and D.T. Moffat. *Geological Journal*, **21**, 201–5.

Nicol, J. (1844) *Guide to the geology of Scotland: Containing an Account of the Character, Distribution and More Interesting Appearances of its Rocks and Minerals*. Oliver and Boyd, Edinburgh.

Nicol, J. (1852) On the geology of the southern portion of the peninsula of Cantyre, Argyllshire. *Quarterly Journal of the Geological Society of London*, **8**, 406–25.

Nicol J. (1863) On the geological structure of the Southern Grampians. *Quarterly Journal of the Geological Society of London* **19**, 180–209.

Noble, S.R., Hyslop, E.K. and Highton, A.J. (1996). High-precision U-Pb monazite geochronology of the *c.* 806 Ma Grampian Shear Zone and the implications for evolution of the Central Highlands of Scotland. *Journal of the Geological Society, London*, **153**, 511–14.

Okonkwo, C.T. (1985). The geology and geochemistry of the metasedimentary rocks of the Loch Laggan–Upper Strathspey area, Inverness-shire. Unpublished PhD thesis, University of Keele.

Okonkwo, C.T. (1988). The stratigraphy and structure of the metasedimentary rocks of the Loch Laggan–Upper Strathspey area, Inverness-shire. *Scottish Journal of Geology*, **24**, 21–34.

Oldroyd, D.R. and Hamilton, B.M. (2002) Themes in the early history of Scottish geology. In: Trewin N. H. (ed.) *The Geology of Scotland*. The Geological Society, London, pp. 27–43.

Oliver, G.J.H. (2001) Reconstruction of the Grampian episode in Scotland: its place in the Caledonian Orogeny. *Tectonophysics*, **332**, 23–49.

Oliver, G.J.H. (2002) Chronology and terrane assembly, new and old controversies. In *The Geology of Scotland* (edited by Trewin, N. H.) The Geological Society, London, 201–11.

Oliver, G.J.H., Chen, F., Buchwald, R. and Hegner, E. (2000) Fast tectonometamorphism and exhumation in the type area of the Barrovian and Buchan zones. *Geology*, **28**, 459–62.

Oliver, G.J.H., Simon, A.W., Wan, Y., 2008. Geochronology and geodynamics of Scottish granitoids from the late Neoproterozoic break-up of Rodinia to Palaeozoic collision. Journal of the Geological Society, London, 165, 661-674.

Pankhurst, R.J. (1970) The geochronology of the basic igneous complexes. *Scottish Journal of Geology*, **6**, 83–107.

Pankhurst, R.J. and Pidgeon, R.T. (1976) Inherted isotope systems and the source region prehistory of the early Caledonian granites in the Dalradian Series of Scotland. *Earth and Planetary Science Letters*, **31**, 58-66.

Pantin, H.M. (1952) Part 1: The petrology and structure of the Ben Vrackie epidiorite. Part 2: Some new observations on Dalradian stratigraphy and tectonics. Unpublished PhD thesis, University of Cambridge.

Pantin H.M. (1961) The stratigraphy and structure of the Blair Atholl–Ben a' Gloe area, Perthshire, Scotland. *Transactions of the Royal Society of New Zealand,* **88**, 597-622.
Park, R.G. (1992) Plate kinematic history of Baltica during the Middle to Late Proterozoic: a model. *Geology* **20**, 725–8.
Park, R.G. (1994) Early Proterozoic tectonic overview of the northern British Isles and neighbouring terrains in Laurentia and Baltica. *Precambrian Research,* **68**, 65–79.
Parson, L M. (1982) The Precambrian and Caledonian geology of the ground near Fort Augustus, Inverness-shire. Unpublished PhD thesis, University of Liverpool.
Paterson, I.B., Hall, I.H.S. and Stephenson, D. (1990) Geology of the Greenock district. Memoir of the British Geological Survey, Sheet 30W and part of Sheet 29E (Scotland).
Pattrick, R.A. and Treagus, J.E. (1996) Economic geology of the Schiehallion district, central highlands of Scotland. *British Geological Survey Technical Report* No. **WA/96/89.**
Peach, B.N. (1904) *Summary of Progress of the Geological Survey of the United Kingdom for 1903*, 69.
Peach, B.N. and Horne, J. (1930) *Chapters on the Geology of Scotland,* Oxford University Press, London.
Peach, B.N., Kynaston, B.A. and Muff, H.B. (1909) The geology of the seaboard of mid Argyll including the islands of Luing, Scarba, the Garvellachs, and the Lesser Isles, together with the northern part of Jura and a small portion of Mull. Memoirs of the Geological Survey of Scotland, Sheet 36.
Peach, B.N., Wilson, J.G.S., Hill, J.B., Bailey, E.B. and Grabham, G.W. (1911) The Geology of Knapdale, Jura and North Kintyre. Memoirs of the Geological Survey of Scotland, Sheet 28.
Peach, B.N. and Horne, J. (1930) *Chapters on the Geology of Scotland,* Oxford University Press, Oxford.
Peacock, J.D., Berridge, N.G., Harris, A.L. and May, F. (1968) The geology of the Elgin district. Memoir of the Geological Survey of Scotland, Sheet 95 (Scotland).
Phillips, E.R. (1996) The mineralogy and petrology of the igneous and metamorphic rocks exposed in the Macduff district (Sheet 96E), Northeast Scotland. British Geological Survey, Mineralogy and Petrology Technical Report, **WG/96/26.**
Phillips, E.R. and Auton, C.A. (1997) Ductile fault rocks and metamorphic zonation in the Dalradian of the Highland Border SW of Stonehaven, Kincardineshire. *Scottish Journal of Geology*, **33**, 83–93.
Phillips, E.R., Clark, G.C. and Smith, D.I. (1993) Mineralogy, petrology, and microfabric analysis of the Eilrig Shear Zone, Fort Augustus, Scotland. *Scottish Journal of Geology*, **29**, 143–58.
Phillips, E.R., Hyslop, E.K., Highton, A.J and Smith, M. (1999). The timing and P-T conditions of regional metamorphism in the Central Highlands. *Journal of the Geological Society, London,* **156**, 1183–93.
Phillips, F.C. (1930) Some mineralogical and chemical changes induced by progressive metamorphism in the Green Bed group of the Scottish Dalradian. *Journal of the Mineralogical Society*, **22**, 240–256.
Phillips, F.C. (1954) *The Use of Stereographic Projection in Structural Geology,* Arnold, London.

Phillips, W.E.A., Stillman, C.J. and Murphy, T. (1976) A Caledonian plate tectonic model. *Journal of the Geological Society of London*, **132**, 579–609.

Piasecki M.A.J. (1975) Tectonic and metamorphic history of the Upper Findhorn, Inverness-shire, Scotland. *Scottish Journal of Geology,* **11**, 87–115.

Piasecki, M.A.J. (1980). New light on the Moine rocks of the Central Highlands of Scotland. *Journal of the Geological Society of London,* **137**, 41–59.

Piasecki, M.A.J. and van Breemen, O. (1979a) A Morarian age for the "younger Moines" of central and western Scotland. *Nature, London*, **278**, 734–6.

Piasecki, M.A.J. and van Breemen, O. (1979b). The 'Central Highland Granulites': cover-basement tectonics in the Moine. In *The Caledonides of the British Isles - reviewed.* (editors. Harris, A.L., Holland, C.H. and Leake, B.E.*), The Geological Society of London*, Special Publications, **8**, 139–44.

Piasecki, M.A.J. and van Breemen, O. (1983) Field and isotopic evidence for a c. 750 Ma tectonothermal event in Moine rocks in the Central Highland region of the Scottish Caledonides. *Transactions of the Royal Society of Edinburgh: Earth Sciences*, **73**, 119–34.

Piasecki, M.A.J., van Breemen, O. and Wright, A.E. (1981) Late Precambrian geology of Scotland, England and Wales. In *Geology of the North Atlantic Borderlands,* Kerr, J.W. and Fergusson, A.J. (eds). Memoir of the Canadian Society of Petroleum Geologists, **7**, 57–94.

Piasecki, M.A.J. and Temperley, S. (1988a). The Central Highland Division. *In*: Winchester, J.A. (ed) *Later Proterozoic stratigraphy of the Northern Atlantic regions*. Blackie, Glasgow and London, 46–53.

Piasecki, M.A.J. and Temperley, S. (1988b). The northern sector of the central Highlands. 51-68 in *An excursion guide to the Moine geology of the Scottish Highlands*. Allison, I, May, F, and Strachan, R A (editors). (Edinburgh: Scottish Academic Press for Edinburgh Geological Society and Geological Society of Glasgow.)

Pickering K.T., Bassett M.G., and Siveter D.J. (1988) Late Ordovician–early Silurian destruction of the Iapetus Ocean: Newfoundland, British Isles and Scandinavia: A discusion. *Transactions of the Royal Society of Edinburgh: Earth Sciences,* **79**, 361–82.

Pickett, E.A. (1997) An introduction to the Green Beds of the Southern Highland Group: previous research and an account of preliminary work carried out in 1997. *British Geological Survey Technical Report* WA/97/92.

Pickett, E.A., Hyslop, E.K. and Petterson, M.G. (2006) The Green Beds of the SW Highlands: deposition and origin of a basic igneous-rich sedimentary sequence in the Dalradian Supergroup of Scotland. *Scottish Journal of Geology*, **42**, 43–57.

Pidgeon R.T. and Compston W. (1992) A Shrimp ion microprobe study of inherited and magmatic zircon from Scottish Caledonian granites. *Transactions of the Royal Society, Edinburgh: Earth Sciences,* **83**, 473–83.

Pitcher, W.S. and Berger, A.R. (1972) *The Geology of Donegal: a study of granite emplacement and unroofing*. Wiley-Interscience, New York, 435 pp.

Plant, J.A., Stone, P. and Mendum, J.R. (1999) Regional geochemistry, terrane analysis and metallogeny in the British Caledonides. In *Continental Tectonics*. MacNiocaill, C and Ryan, P.D. (editors), Geological Society, London, Special Publication No **164**, 109–26.

Plant, J.A., Watson, J.V. and Green, P.M. (1984) Moine–Dalradian relationships and their palaeotectonic significance. *Proceedings of the Royal Society*, **395a**, 185–202.

Powell, R. and Evans, J.A. (1983). A new geobarometer for the assemblage biotite-muscovite-chlorite-quartz. *Journal of Metamorphic Geology*, **1**, 331–6.

Power, M.R. and Pirrie, D. (2000) Platinum-group mineralization within ultramafic rocks at Corrycharmaig, Perthshire: implications for the origin of the complex. *Scottish Journal of Geology*, **36**, 143–50.

Prave, A.R. (1999) The Neoproterozoic Dalradian Supergroup of Scotland: an alternative hypothesis. *Geological Magazine*, **136**, 609–17.

Prave, A.R., Fallick, A.E., Thomas, C.W. and Graham, C.M. (2009a) A composite C-isotope profile for the Neoproterozoic Dalradian Supergroup of Scotland and Ireland. *Journal of the Geological Society*, **166**, 845-857.

Prave, A.R., Strachan, R.A. and Fallick, A.E. (2009b) Global C cycle perturbations recorded in marbles: a record of Neoproterozoic Earth history within the Dalradian succession of the Shetland Islands, Scotland. *Journal of the Geological Society*, **166**, 129-135.

Pringle, I.R. (1972) Rb-Sr age determinations on shales associated with the Varanger Ice Age. *Geological Magazine*, **109**, 465–72.

Pringle, J. (1940) The discovery of Cambrian trilobites in the Highland Border rocks near Callander, Perthshire (Scotland). *British Association for the Advancement of Science: Annual Report for 1939–40*, **1**, 252.

Pumpelly, R., Wolff, J.E. and Dale, T.N. (1894) Geology of the Green Mountains. *United States Geological Survey Memoir*, **23**, 1–157.

Rainbird, R.H., Hamilton, M.A. and Young, G.M. (2001) Detrital zircon geochronology and provenance of the Torridonian, NW Scotland. *Journal of the Geological Society, London,* **158**, 15–27.

Ramsay, D.M. (1959) Structure and metamorphism of Glen Lyon. Unpublished PhD thesis, University of Glasgow.

Ramsay, D.M. and Sturt, B.A. (1979) The status of the Banff Nappe. In *The Caledonides of the British Isles—reviewed*. Harris, A L, Holland, C H and Leake, B E (editors). Special Publication of the Geological Society of London, No. 8. 145–151

Ramsay, J.G. (1958) Moine—Lewisian relations at Glenelg, Inverness-shire. *Quarterly Journal of the Geological Society of London* **113**, 487–523.

Rast, N. (1956) Tectonics of Central Perthshire. Unpublished PhD thesis, University of Glasgow.

Rast, N. (1958) Metamorphic history of the Schiehallion complex, Perthshire. *Transactions of the Royal Society of Edinburgh*, **64**, 413–31.

Rast, N. (1963). Structure and metamorphism of the Dalradian rocks of Scotland. In *The British Caledonides.* (editors. Johnson, M.R.W. and Stewart, F.H.). Oliver and Boyd, Edinburgh, 123–42.
Rast, N. and Litherland, M. (1970) The correlation of the Ballachulish and Perthshire (Islay) successions. *Geological Magazine*, **107**, 259–72.
Read, H.H. (1919) The two magmas of Strathbogie and Lower Banffshire. *Geological Magazine* **56**, 364–71.
Read, H.H. (1923) The geology of the country around Banff, Huntly, and Turriff, Lower Banffshire and north-west Aberdeenshire. *Memoir of the Geological Survey, Scotland.* Sheets 86 and 96 (Scotland).
Read, H.H. (1927) The igneous and metamorphic history of Cromar, Deeside. *Transactions of the Royal Society of Edinburgh,* **55**, 317–53.
Read, H.H. (1928) The Highland Schists of middle Deeside and east Glen Muick. *Transactions of the Royal Society of Edinburgh,* **55**, 755–72.
Read, H.H. (1933). On quartz-kyanite rocks in Unst, Shetland Islands, and their bearing on metamorphic differentiation. *Mineralogical Magazine,* **23**, 317–28.
Read, H.H. (1934) The metamorphic geology of Unst in the Shetland Islands. *Quarterly Journal of the Geological Society of London* **90**, 637–88.
Read, H.H. (1935) *British Regional Geology: the Grampian Highlands* (1st edition). HMSO for Geological Survey and Museum, Edinburgh.
Read, H.H. (1936) The stratigraphical order of the Dalradian rocks of the Banffshire coast. *Geological Magazine*, **73**, 468–75.
Read, H.H. (1937) Metamorphic correlation in the polymetamorphic rocks of the Valla Field Block, Unst, Shetland Islands. *Transactions of the Royal Society of Edinburgh,* **59**, 195–221.
Read, H.H. (1952) Metamorphism and migmatisation in the Ythan Valley, Aberdeenshire. *Transactions of the Edinburgh Geological Society*, **15**, 265–79.
Read, H.H. (1955) The Banff nappe: an interpretation of the structure of the Dalradian rocks of north-east Scotland. *Proceedings of the Geologists' Association,* **66**, 1–29.
Read, H.H. (1960) North-east Scotland: the Dalradian. Geologists' Association Guide, **31**. Benham and Co., Colchester.
Read, H.H. and Farquhar, O.C. (1956) The Buchan Anticline of the Banff Nappe of Dalradian rocks in north-east Scotland. *Quarterly Journal of the Geological Society of London*, 112, 131–56.
Richardson, S.W. and Powell, R. (1976) Thermal causes of the Dalradian metamorphism in the Central Highlands of Scotland. *Scottish Journal of Geology*, **12**, 237–68.
Ritchie, J.D. and Hitchen, K. (1993) Discussion on the location and history of the Walls Boundary fault and Moine thrust north and south of Shetland. *Journal of the Geological Society, London,* **150**, 1003–8.
Roberts, J.L. (1959) Fold Structures in the Dalradian Rocks of Knapdale, Argyllshire. *Geological Magazine*, **94**, 221–9.
Roberts, J.L. (1963) The Dalradian of the southwest highlands of Scotland. Unpublished PhD thesis, University of Liverpool.
Roberts, J.L. (1966a) Sedimentary affiliations and stratigraphic correlation of the Dalradian rocks in the South-west Highlands of Scotland. *Scottish Journal of Geology*, **2**, 200–23.
Roberts, J.L. (1966b) The formation of similar folds by inhomogeneous plastic strain, with reference to the fourth phase

of deformation affecting the Dalradian rocks in the southwest Highlands of Scotland. *Journal of Geology*, **74**, 831–55.

Roberts, J.L. (1974) The structure of the Dalradian rocks in the SW Highlands of Scotland. *Journal of the Geological Society of London*, **130**, 93–124.

Roberts, J.L. (1976) The structure of the Dalradian rocks in the north Ballachulish district of Scotland. *Journal of the Geological Society of London*, **132**, 139–54.

Roberts, J.L. (1977a) The evolution and transport of the Tay Nappe: Discussion. *Scottish Journal of Geology*, **13**, 79–80.

Roberts, J.L. (1977b) The Dalradian rocks of Rosneath and South-east Cowal. *Scottish Journal of Geology*, **13**, 101–11.

Roberts, J.L. (1977c) The Dalradian rocks of Knapdale and North Kintyre. *Scottish Journal of Geology*, **13**, 113–124.

Roberts, J.L. and Sanderson, D.J. (1974) Oblique fold axes in the Dalradian rocks of the Southwest Highlands. *Scottish Journal of Geology*, **9**, 281–96.

Roberts, J.L. and Treagus, J.E. (1964) A reinterpretation of the Ben Lui Fold. *Geological Magazine*, **101**, 512–16.

Roberts, J.L, and Treagus, J.E. (1975) The structure of the Moine and Dalradian rocks in the Dalmally district of Argyllshire, Scotland. *Geological Journal*, **10**, 59–74.

Roberts, J.L, and Treagus, J.E. (1977a) The Dalradian rocks of the South-west Highlands–Introduction. *Scottish Journal of Geology*, Vol. 13, 87–99.

Roberts, J.L. and Treagus, J.E. (1977b) The Dalradian rocks of the Loch Leven area. *Scottish Journal of Geology*, **13**, 165–184.

Roberts, J.L. and Treagus, J.E. (1977c) Polyphase generation of nappe structures in the Dalradian rocks of the Southwest Highlands of Scotland. *Scottish Journal of Geology*. **13**, 237–254.

Roberts, J.L, and Treagus, J.E. (1979) Stratigraphical and structural correlation between the Dalradian rocks of the SW and Central Highlands of Scotland. 199–204 in The Caledonides of the British Isles–reviewed. Harris, A.L., Holland, C.H., and Leake, B.E.(editors). Special Publication of the Geological Society of London. 8.

Roberts, J.L, and Treagus, J E. (1980) The structural interpretation of the Loch Leven area. *Scottish Journal of Geology*, **16**, 73–5.

Robertson, S. (1991) Older granites in the south-eastern Scottish Highlands. *Scottish Journal of Geology*, **27**, 21–6.

Robertson, S. (1994) Timing of Barrovian metamorphism and 'Older Granite' emplacement in relation to Dalradian deformation. *Journal of the Geological Society of London*, **151**, 5–8.

Robertson, S. (1999) BGS Rock Classification Scheme Volume 2: Classification of metamorphic rocks. *British Geological Survey Research Report*, **RR 99–02**.

Robertson, S. and Smith, M. (1999) The significance of the Geal charn–Ossian Steep Belt in basin development in the Central Scottish Highlands. *Journal of the Geological Society, London*, **156**, 1175–82.

Rock, N.M.S. (1985) A compilation of analytical data for metamorphic limestones from the Scottish Highlands and Islands, with lists of BGS registered samples, and comments on the reproducibility and accuracy of limestone analyses by different analytical techniques. *Mineralogical and Petrological Report British Geological Survey*, No. 85/5.

Rock, N.M.S. (1986) Chemistry of the Dalradian (Vendian–Cambrian) metalimestones, British Isles. *Chemical Geology*, **56**, 289–311.
Rock, N.M.S., Macdonald, R. and Bower, J. (1986) The comparative geochemistry of some Highland pelites (Anomalous local limestone-pelite successions within the Moine outcrop; II). *Scottish Journal of Geology*, **22**, 107–26.
Rogers, G., Dempster, T.J., Bluck, B.J. and Tanner, P.W.G. (1989) A high precision U-Pb age for the Ben Vuirich Granite: implications for the evolution of the Scottish Dalradian Supergroup. *Journal of the Geological Society, London*, **146**, 789–98.
Rogers, G., Hyslop, E.K., Strachan, R.A., Paterson, B.A. and Holdsworth, R.A. (1998) The structural setting and U-Pb geochronology of the Knoydartian pegmatites of W Inverness-shire: evidence for Neoproterozoic tectonothermal events in the Moine of NW Scotland. *Journal of the Geological Society, London,* **155**, 685–96.
Rogers, G., Kinny, P.D., Strachan, R.A., Friend, C.R.L. and Patterson, B.A. (2001) U-Pb geochronology of the Fort Augustus granite gneiss, constraints on the timing of Neoproterozoic and Paleozoic tectonothermal events in the NW Highlands of Scotland. *Journal of the Geological Society, London,* **158**, 7–14.
Rogers, G. and Pankhurst, R.J. (1993) Unravelling dates through the ages: geochronology of the Scottish metamorphic complexes. *Journal of the Geological Society, London*, **150**, 447–64.
Rollin, K.E. (1994) Geophysical correlation of Precambrian rocks in northern Britain. In *A Revised Correlation of Precambrian Rocks in the British Isles.* Gibbons, W. and Harris, A.L. (eds.) Geological Society, London, Special Report, **22**, 65–74.
Rooney, A.D., Chew, D.M. and Selby, D. (2011) Re – Os geochronology of the Neoproterozoic – Cambrian Dalradian Supergroup of Scotland and Ireland: implications for Neoproterozoic stratigraphy, glaciations and Re – Os systematics. *Precambrian Research*,
Rose, P.T.S. (1989) The emplacement of the Tay Nappe Scotland. Unpublished PhD thesis, University of Liverpool.
Rose, P.T.S. and Harris, A.L. (2000) Evidence for the lower Palaeozoic age of the Tay Nappe; the timing and nature of Grampian events in the Scottish Highland sector of the Laurentian margin. *Journal of the Geological Society, London*, **157**, 789–98.
Rushton, A.W.A., Owen, A.W., Owens, R.M. and Prigmore, J.K. (1999) British Cambrian and Ordovician stratigraphy, Geological Conservation Review Series No. **18**, Joint Nature Conservation Committee, Peterborough.
Russell, M.J., Hall, A.J., Willan, R.C.R., Allison, I., Anderton, R., and Bowes, G. (1984) On the origin of the Aberfeldy celsian+barite+base metals deposits, Scotland. In *Prospecting in areas of glaciated terrain*, 1984. Institution of Mining and Metallurgy, London, pp. 159–170.
Ryan, P.D. and Soper, N.J. (2001) Modelling anatexis in intra-cratonic basins: an example from the Neoproterozoic rocks of the Scottish Highlands. *Geological Magazine*, **138**, 577–588.
Ryan, P.D., Soper, N.J., Snyder, D.B., England, R.W. and Hutton, D.H.W. (1995) The Antrim – Galway Line: a resolution of the Highland Border Fault enigma of the Caledonides of Britain and Ireland. *Geological Magazine*, **132**, 171–184.

Saha, D. (1989) The Caledonian Loch Skerrols Thrust, SW Scotland: Microstructure and Strain. *Journal of Structural Geology*, **11**, 553-568.

Schermerhorn, L.J.G. (1974) Late Precambrian mixtites: glacial and/or non-glacial? *American Journal of Science*, **274**, 673–824.

Schermerhorn, L.J.G. (1975) Tectonic framework of Late Precambrian supposed glacials. In *Ice Ages: Ancient and Modern* (eds. Wright, A.E. and Moseley, F.), proceedings of the Inter-University Geological Congress (University of Birmingham) (1974), *Geological Journal* special issue No. 6, 242–247.

Scott, R.A. (1987) Lithostratigraphy, structure and mineralization of the Argyll Group Dalradian near Tyndrum, Scotland. Unpublished PhD thesis, University of Manchester.

Scott, R.A., Pattrick, R.A.D., and Polya, D.A. (1991) Origin of sulphur in metamorphosed stratabound mineralization from the Argyll Group Dalradian of Scotland. *Transactions of the Royal Society of Edinburgh: Earth Sciences*, Vol. 82, 91–98.

Scott, R.A., Polya, D.A., and Pattrick, R.A.D. (1988) Proximal Cu + Zn exhalites in the Argyll Group Dalradian, Creag Bhocan, Perthshire. *Scottish Journal of Geology*, Vol. 24, 97–112.

Seranne, M. (1992) Devonian extensional tectonics versus Carboniferous inversion in the northern Orcadian basin. *Journal of the Geological Society, London*, **149**, 27–37.

Shackleton, R. M. 1958. Downward-facing structures of the Highland Border. *Quarterly Journal of the Geological Society, London*, **113**, 361–392.

Shackleton, R.M. (1979) The British Caledonides: comments and summary. 299–304 in The Caledonides of the British Isles—reviewed. Harris, A L, Holland, C H, and Leake, B E (editors). Special Publication of the Geological Society of London, No. 8.

Shearman, D.J. and Smith, A.J. (1985) Ikaite, the parent mineral of jarrowite-type pseudomorphs. *Proceedings of the Geologists' Association*, **96**, 305–314.

Sibson, R.H. (1977) Fault rocks and fault mechanisms. *Journal of the Geological Society, London*, Vol 133, 191–213.

Simpson, A. and Wedden, D. (1974) Downward-facing structures in the Dalradian Leny Grits on Bute. *Scottish Journal of Geology*, **10**, 257–267.

Skelton, A.D.L. (1993) Petrological, geochemical and field studies of fluid infiltration during regional metamorphism of the Dalradian of the SW Scottish Highlands. Unpublished PhD thesis, University of Edinburgh.

Skelton, A.D.L., Bickle, M.J. and Graham, C.M. (1997) Fluid-flux and reaction rate from advective-diffusive carbonation of mafic sill margins in the Dalradian, southwest Scottish Highlands. *Earth and Planetary Science Letters*, **146**, 527–539

Skelton, A.D.L., Graham, C.M. and Bickle, M.J. (1995) Lithological and structural constraints on regional 3-D fluid flow patterns during greenschist facies metamorphism of the Dalradian of the SW Highlands. *Journal of Petrology*, **36**, 563–586.

Skevington, D. (1971) Palaeontological evidence bearing on the age of the Dalradian deformation and metamorphism in Ireland and Scotland. *Scottish Journal of Geology*, Vol. **7**, 285–288.

Smallwood, J.R. (2007) Maskelyne's 1774 Schiehallion experiment revisited. *Scottish Journal of Geology*, Vol. **43**, 15–31.

Smith, A.J. and Rast, N. (1958) Sedimentary dykes in the Dalradian of Scotland. *Geological Magazine* **95**, 234 –240.

Smith, C.G., Gallagher, M.J., Coats, J.S. and Parker, M.E. (1984) Detection and general characteristics of stratabound mineralization in the Dalradian of Scotland. *Transactions of the Institution of Mining and Metallurgy (Section B: Applied Earth Science)*, Vol. 93, B125-133.

Smith, C.G., Gallagher, M.J., Grout, A., Coats, J.S., Vickers, B.P., Peachey, D., Pease, S.F., Parker, M.E. and Fortey, N.J. (1988) Stratabound base-metal materialisation in Dalradian rocks near Tyndrum, Scotland. *Mineral Reconnaissance Programme Report, British Geological Survey*, No. **93**.

Smith, C.G., Goodman, S. and Robertson, S. (2002) Geology of the Ballater district. Memoir of the British Geological Survey, Sheet 65E (Scotland).

Smith, M., Robertson, S. and Rollin, K.E. (1999) Rift basin architecture and stratigraphical implications for basement-cover relationships in the Neoproterozoic Grampian Group of the Scottish Caledonides. *Journal of the Geological Society, London,* **156**, 1163-1173.

Smith, R.A. (1980) The Geology of the Dalradian rocks around Blair Atholl, Central Perthshire, Scotland. Unpublished PhD thesis, University of Liverpool.

Smith, R.A. and Harris, A,L. (1976) The Ballachulish rocks of the Blair Atholl District. *Scottish Journal of Geology*, Vol. 12, 153-157.

Smith, T.E. (1968) Tectonics in Upper Strathspey, Inverness-shire. *Scottish Journal of Geology*, **4**, 68-84.

Snyder, D.B. and Flack, C.A. (1990) A Caledonian age for reflectors within the mantle lithosphere north and west of Scotland. *Tectonics*, **9**, 903-922.

Soper N.J. (1994) Was Scotland a Vendian RRR junction? *Journal of the Geological Society, London,* 151, 579-582.

Soper N.J. (1994) Neoproterozoic sedimentation on the northeast margin of Laurentia and the opening of Iapetus. *Geological Magazine,* 131, 291-299.

Soper, N.J. and Anderton, R. (1984) Did the Dalradian slides originate as extensional faults? *Nature, London*, Vol. 307, 357-360.

Soper, N.J. and England, R.W. (1995) Vendian and Riphean rifting in NW Scotland. *Journal of the Geological Society, London* **152**, 11-14.

Soper, N.J. and Evans, J.A., 1997. Discussion on metamorphism and cooling of the NE Dalradian. Journal of the Geological Society, London. 154, 357-360.

Soper N.J. and Hutton D.H.W. (1984) Late Caledonian sinistral displacements in Britain: Implications for a three-plate collision model. *Tectonics* **3**, 781-794.

Soper, N.J., Ryan, P.D. and Dewey, J.F. (1999) Age of the Grampian Orogeny in Scotland and Ireland. *Journal of the Geological Society, London* **156**, 1231-1236.

Soper N.J., Strachan R.A., Holdsworth R.E., Gayer R.A. and O'Greiling, R.O. (1992) Sinistral transpression and the Silurian closure of Iapetus. *Journal of the Geological Society, London* **149**, 871-880.

Spear, F.S. (1993) *Metamorphic phase equilibria and pressure-temperature-time paths.* Mineralogical Society of America.

Spencer, A.M. (1971) Late Precambrian glaciation in Scotland. Memoir of the Geological Society of London, No. 6.

Spencer, A.M. (1981) The late Precambrian Port Askaig Tillite in Scotland. In Earth's pre-Pleistocene glacial record (eds. Hambrey, M. J. and Harland, W. B.), pp. 632–636. Cambridge University Press, Cambridge.

Spencer, A.M. (1985) Mechanisms and environments of deposition of Late Precambrian geosynclinal tillites: Scotland and East Greenland. *Palaeogeography, Palaeoclimatology and Palaeoecology*, 51, 143–157.

Spencer, A.M. and Pitcher, W.S. (1968) Occurrence of the Port Askaig Tillite in north-east Scotland. *Proceedings of the Geological Society of London*, No. 1650, 195–198.

Spencer, A.M. and Spencer, M. (1972) The Late Precambrian/Lower Cambrian Bonnahaven Dolomite of Islay and its stromatolites. *Scottish Journal of Geology*, 8, 269–282.

Spray J.G. and Dunning G.R. (1991) A U/Pb age for the Shetland Islands oceanic fragment, Scottish Caledonides: evidence from anatectic plagiogranites in "layer 3" shear zones. *Geological Magazine* **128**, 667–671.

Stephenson, D. (1993) Amphiboles from Dalradian metasedimentary rocks of NE Scotland: environmental inferences and distinction from meta-igneous amphibolites. *Mineralogy and Petrology*, Vol. 49, 45–62.

Stephenson, D., Bevins, R.E., Millward, D., Highton, A.J., Parsons, I., Stone, P. and Wadsworth, W.J. (1999) Caledonian Igneous rocks of Great Britain. *Geological Conservation Review Series* No.**17**. Joint Nature Conservation Committee, Peterborough. 648pp.

Stephenson, D. and Gould, D. (1995) *British regional geology: the Grampian Highlands* (4^{th} edition). HMSO for the British Geological Survey, London.

Stewart, A.D. (1960) On the sedimentary and metamorphic history of the Torridonian, and the later igneous intrusions of Colonsay and Oronsay. Unpublished PhD thesis, University of Liverpool.

Stewart, A.D. (1962) On the Torridonian sediments of Colonsay and their relationship to the main outcrop in north-west Scotland. *Liverpool and Manchester Geological Journal* **3**, 121–156.

Stewart, A.D. (1969) Torridonian rocks of Scotland reviewed. *In* Kay, M. (ed.) *North Atlantic-Geology and Continental Drift, a symposium*. Memoir of the American Association of Petroleum Geologists **12**, 595–608.

Stewart, A.D. (1975) 'Torridonian' rocks of western Scotland. In: *A correlation of Precambrian rocks in the British Isles* (eds. Harris, A. L., Shackleton, R. M., Watson, J.V., Downie, C., Harland, W. B. and Moorbath, S.) *Geological Society, London, Special Report*, **6**, 43–51.

Stewart, A.D. and Hackman, B.D. (1973) Precambrian sediments of Islay. *Scottish Journal of Geology,* **9**, 185–201.

Stewart, M., Strachan, R.A. and Holdsworth, R.E. (1999) Structure and early kinematic history of the Great Glen fault zone, Scotland. *Tectonics* **18**, 326–342.

Stewart, M., Strachan, R.A., Martin, M.W. and Holdsworth, R.E. (2001) Constraints on early sinistral displacements along the Great Glen Fault Zone, Scotland; structural setting, U-Pb geochronology and emplacement of the syn-tectonic Clunes Tonalite. *Journal of the Geological Society, London* **158**, 821–830.

Stoker, M.S., Howe, J.A. and Stoker, S.J. (1999) Late Vendian-?Cambrian glacially influenced deep-water sedimentation, Macduff

Slate Formation (Dalradian), NE Scotland. *Journal of the Geological Society, London,* **156**, 55–61.
Stone, M. (1957) The Aberfoyle Anticline, Callander, Perthshire. *Geological Magazine*, **94**, 265–276.
Stone, P., Plant, J.A., Mendum, J.R. and Green, P.M. (1999) A regional geochemical assessment of some terrane relationships in the British Caledonides. *Scottish Journal of Geology,* **35**, 145–156.
Strachan, R.A. (2000) The Grampian Orogeny: Mid-Ordovician arc—continent collision along the Laurentian margin of Iapetus. *In*: Woodcock, N.H. and Strachan, R.A. (eds) *Geological History of Britain and Ireland*. Blackwell Science Ltd, 88–106.
Strachan, R.A., Harris, A.L., Fettes D.J. and Smith, M. (2002) The Northern Highland and Grampian terranes. In: Trewin N. H. (ed.) *The Geology of Scotland*. (4th edition) The Geological Society, London, pp. 81–148.
Strachan, R.A. and Holdsworth, R.E. (2000) Proterozoic sedimentation, orogenesis and magmatism on the Laurentian Craton (2700–750 Ma). In: *Geological history of Great Britain and Ireland* (edited by Woodcock, N. and Strachan, R. A.) Blackwell Science. Oxford, 52–72.
Stringer, P.J. (1957) Polyphase deformation in the Upper Dalradian rocks of the Southern Highlands of Scotland. Unpublished PhD thesis, University of Liverpool.
Stupavsky, M., Symons, D.T.A. and Gravenor, C.P. (1982) Evidence for metamorphic remagnetisation of the upper Precambrian tillite in the Dalradian Supergroup of Scotland. *Transactions of the Royal Society of Edinburgh*, **73**, 59–65.
Sturt, B.A. (1959) Studies in the metamorphic rocks of the Loch Tummel district, Perthshire. Unpublished PhD thesis, University of Wales, Aberystwyth.
Sturt, B.A. (1961) The geological structure of the area south of Loch Tummel. *Quarterly Journal of the Geological Society of London*, Vol. 117, 131–156.
Sturt, B.A. and Harris, A.L. (1961) The metamorphic history of the Loch Tummel area. *Liverpool and Manchester Geological Journal*, Vol. 2, 689–711.
Sturt, B.A., Ramsay, D.M., Pringle, I.R. and Teggin, D.E. (1977) Precambrian gneisses in the Dalradian sequence of NE Scotland. *Journal of the Geological Society of London*, Vol. 134, 41–44.
Sutton, J. and Watson, J.V. (1954) Ice-borne boulders in the Macduff Group of the Dalradian of Banffshire. *Geological Magazine*, Vol. 91, 391–398.
Sutton, J. and Watson, J.V. (1955) The deposition of the Upper Dalradian rocks of the Banffshire coast. *Proceedings of the Geologists' Association*, Vol. 66, 101–133.
Sutton, J. and Watson, J.V. (1956) The Boyndie syncline of the Dalradian of the Banffshire coast. *Quarterly Journal of the Geological Society of London*, Vol. 112, 103–130.

Tanner, P. W. G. 1992. Rosneath Peninsula and Loch Long. In *Geological excursions around Glasgow and Girvan* (eds. Lawson, J. D. and Weedon, D. S.), pp. 159–185. Geological Society of Glasgow.
Tanner, P. W. G. 1995. New evidence that the Lower Cambrian Leny Limestone at Callander, Perthshire, belongs to the Dalradian Supergroup, and a reassessment of the 'exotic' status of the Highland Border Complex. *Geological Magazine*, **132**, 473–483.

Tanner, P. W. G. 1996. Significance of the early fabric in the contact metamorphic aureole of the 590 Ma Ben Vuirich Granite, Perthshire, Scotland. *Geological Magazine*, **133**, 683–695.
Tanner, P. W. G. 1997. The Highland Border controversy: Reply to a Discussion of 'New evidence that the Lower Cambrian Leny Limestone at Callander, Perthshire, belongs to the Dalradian Supergroup, and a reassessment of the 'exotic' status of the Highland Border Complex'. *Geological Magazine*, **134**, 565–570.
Tanner, P. W. G. 1998a. Interstratal dewatering origin for polygonal patterns of sand-filled cracks: a case study from Late Proterozoic metasediments of Islay, Scotland. *Sedimentology*, **45**, 71–89.
Tanner, P W G. 1998b. Age of the Grampian event: Reply to a Discussion of 'New evidence that the Lower Cambrian Leny Limestone at Callander, Perthshire belongs to the Dalradian Supergroup, and a reassessment of the 'exotic' status of the Highland Border Complex'. Geological Magazine, Vol. **135**, 575–579.
Tanner, P. W. G. 2005. Discussion on evidence for a major Neoproterozoic orogenic unconformity within the Dalradian Supergroup of NW Ireland. *Journal of the Geological Society, London*, **162**, 221–224.
Tanner, P.W.G. 2007. The role of the Highland Border Ophiolite in the ~ 470 Ma Grampian Event, Scotland. *Geological Magazine* Vol. **144**, 597–602.
Tanner, P.W.G. 2008. Tectonic significance of the Highland Boundary Fault. *Journal of the Geological Society, London* Vol. **165**, 915–921.
Tanner, P.W.G. and Bluck, B.J. (2011) Discussion of 'The Highland Boundary Fault and the Highland Boundary Complex' by B.J. Bluck *Scottish Journal of Geology* **46**, 113-124. *Scottish Journal of Geolgy*, **47**, 89-93.
Tanner, P. W. G. and BLUCK, B. J. 1999. Current controversies in the Caledonides. *Journal of the Geological Society, London*, **156**, 1137–1141.
Tanner, P. W. G. and Evans, J. A. 2003. Late Precambrian U-Pb titanite age for peak regional metamorphism and deformation (Knoydartian Orogeny) in the western Moine, Scotland. *Journal of the Geological Society, London* **160**, 555–564.
Tanner, P. W. G. and Leslie, A. G. 1994. A pre-D2 age for the 590 Ma Ben Vuirich Granite in the Dalradian of Scotland. *Journal of the Geological Society, London*, **151**, 209–212.
Tanner P. W. G., Leslie A. G. and Gillespie M.R. 2006. Structural setting and petrogenesis of a rift-related intrusion: the Ben Vuirich Granite of the Grampian Highlands, Scotland. *Scottish Journal of Geology,* Vol. **42**, 113–136.
Tanner, P. W. G. and Pringle, M. 1999. Testing for a terrane boundary within Neoproterozoic (Dalradian) to Cambrian siliceous turbidites at Callander, Perthshire, Scotland. *Journal of the Geological Society, London*, **156**, 1205–1216.
Tanner, P.W.G. and Sutherland, S. 2007. The Highland Border Complex, Scotland: a paradox resolved. *Journal of the Geological Society, London*, **164**, 111–116.
Tannner, P.W.G. and Thomas, P.R. (2010) Major nappe-like D2 folds in the Dalradian rocks of the Beinn Udlaidh area, Central Highlands, Scotland. *Earth and Environmental Science Transactions of the Royal Society of Edinburgh*. **100**, 371-389.

Temperley, S. (1990). The Late Proterozoic to Early Palaeozoic geology of the Glen Banchor area in the Monadhliath Mountains of Scotland, with particular reference to deformation in Knoydartian shear zones and the Caledonian Central Highland steep belt. Unpublished PhD thesis, University of Hull.

Thomas, C W. 1989. Application of geochemistry to the stratigraphic correlation of Appin and Argyll Group carbonate rocks from the Dalradian of northeast Scotland. *Journal of the Geological Society of London*, Vol. 146, 631-647.

Thomas, C. W. 1993. Sources of Rare Earth elements in Appin Group limestones, Dalradian, north-east Scotland. *Mineralogy and Petrology* Vol. **49**, 27-44 .

Thomas, C.W. (1995). The geochemistry of metacarbonate rocks from the Monadhliath Project area. *British Geological Survey Technical Report*. WA/95/40/R.

Thomas, C. W. (1999). The isotope Geochemistry and Petrology of Dalradian Metacarbonate Rocks, Unpublished PhD thesis, University of Edinburgh.

Thomas, C.W. and Aitchison (1998). Application of logratios to the statistical analysis of the geochemistry of metamorphosed limestones from the Northeast and Central Highlands of Scotland: the case for Appin Group correlations. *British Geological Survey Technical Report*, WA/98/03.

Thomas, C W, Aitken, A M, Pickett, E P, Mendum, J R, Hyslop, E K, and Petterson, M.P. in press. Geology of the Aberfoyle District. Sheet Description for the British Geological Survey, 1:50 000 Series Sheet 38E (Scotland).

Thomas, C. W., Graham, C. M., Ellam, R.M. and Fallick, A. E. (2004). ^{87}Sr/^{8}6Sr chemostratigraphy of Neoproterozoic Dalradian limestones of Scotland: constraints on depositional ages and timescales. *Journal of the Geological Society, London* **161**, 223-243.

Thomas, C.W., Smith, M. and Robertson, S. (1997). The geochemistry of Dalradian metacarbonate rocks from the Schiehallion District and Blargie, Laggan: implications for stratigraphical correlations in the Geal Charn—Ossian Steep Belt. *British Geological Survey Technical Report,* WA/97/81.

Thomas, P R. 1965. The structure and metamorphism of the Moinian rocks in Glen Garry, Glen Tilt, and adjacent areas of Scotland. Unpublished PhD thesis, University of Liverpool.

Thomas, P R. 1979. New evidence for a Central Highland Root Zone. 205-211 in The Caledonides of the British Isles -Reviewed. Harris, A L, Holland, C H, and Leake, B E (editors). Special Publication of the Geological Society, No. 8.

Thomas, P R. 1980. The stratigraphy and structure of the Moine rocks north of the Schiehallion Complex, Scotland. *Journal of the Geological Society of London*, Vol. 137, 469-482.

Thomas, P R. 1988. A9 road section—Blair Atholl to Newtonmore. 39-50 in *An excursion guide to the Moine geology of the Scottish Highlands*. Allison, I, May, F, and Strachan, R A (editors). (Edinburgh: Scottish Academic Press for Edinburgh Geological Society and Geological Society of Glasgow.)

Thomas, P R, and Treagus, J E. 1968. The stratigraphy and structure of the Glen Orchy area, Argyllshire, Scotland. *Scottish Journal of Geology*, Vol. 4, 121-134.

Thomson, J. 1877. On the geology of the Island of Islay. *Transactions of the Geological Society of Glasgow*, **5**, 200-222.

Tilley, C.E. (1925) A preliminary survey of metamorphic zones in the southern Highlands of Scotland. *Quarterly Journal of the Geological Society of London*, Vol. 81, 100-110.

Tollo R. P., Aleinikoff J. N., Bartholomew M. J. and Rankin D. W. 2004. Neoproterozoic A-type granitoids of the central and southern Appalachians: intraplate magmatism associated with episodic rifting of the Rodinian supercontinent. *Precambrian Research,* 128, 3–38.

Torsvik, T. H., Smethurst, M. A., Meert, J. G., Van der Voo, R., McKerrow, W. S., Brasier, M. D., Sturt, B. A. and Walderhaug, H. J. 1996. Continental break-up and collision in the Neoproterozoic and Palaeozoic—a tale of Baltica and Laurentia. *Earth Science Reviews* **40**, 229–258.

Treagus, J. E. 1964a. The structural and metamorphic history of an area of Moine and Dalradian rocks south of Loch Rannoch, Perthshire. Unpublished PhD thesis, University of Liverpool.

Treagus, J E. 1964b. Notes on the structure of the Ben Lawers Synform. *Geological Magazine*, Vol. 101, 260-270.

Treagus, J.E. (1969). The Kinlochlaggan Boulder Bed. *Proceedings of the Geological Society of London*, **1654**, 55-60.

Treagus, J E. 1974. A structural cross-section of the Moine and Dalradian rocks of the Kinlochleven area, Scotland. *Journal of the Geological Society of London*, Vol. 130, 525-544.

Treagus, J.E. (1981). The Lower Dalradian Kinlochlaggan Boulder Bed, Central Scotland. In: *Earth's pre-Pleistocene glacial record.* (editors. Hambrey, J.M. and Harland, W.B.), Cambridge University Press, 637-639.

Treagus, J E. 1987. The structural evolution of the Dalradian of the Central Highlands of Scotland. *Transactions of the Royal Society of Edinburgh: Earth Sciences*, Vol. 78, 1-15.

Treagus, J E. 1991. Fault displacements in the Dalradian of the Central Highlands. *Scottish Journal of Geology*, Vol. 27, 135-145.

Treagus, J. E. (editor). 1992. *Caledonian Structures in Britain South of the Midland Valley*, Geological Conservation Review Series No. **3**. London: Chapman and Hall.

Treagus, J.E. (1997) Discussion on a late Vendian age for the Kinlochlaggan Boulder bed (Dalradian). *Journal of the Geological Society, London,* **154**, 917-919.

Treagus, J E. 1999. A structural reinterpretation of the Tummel Belt and a transpressional model of evolution of the Tay Nappe in the Central Highlands of Scotland. *Geological Magazine*, Vol. 136, Pt 6, 643-660.

Treagus, J. E. 2000. The Solid Geology of the Schiehallion District. Memoir of the British Geological Survey. Sheet 55W (Scotland).

Treagus, J.E. 2009. The Dalradian of Scotland. *Geologists' Association Guide* No. **67**. 202pp.

Treagus, J E, and King, G. 1978. A complete Lower Dalradian succession in the Schiehallion district, central Perthshire. *Scottish Journal of Geology*, Vol. 14, 157-166.

Treagus, J E, Pattrick, R A D, and Curtis, S F. 1999. Movement and mineralization in the Tyndrum fault zone, Scotland and its regional significance. *Journal of the Geological Society, London*, Vol. 156, 591-604.

Treagus, J E. and Roberts, J L. 1981. The Boyndie Syncline, a D1 structure in the Dalradian of Scotland. *Geological Journal*, Vol. 16, 125-135.

Treagus, J E, Talbot, C J, and Stringer, P. 1972. Downward-facing structures in the Birnam Slates, Dunkeld, Perthshire. *Geological Journal*, Vol. 8, 125–128.

Treagus, J E, and Treagus, S H. 1971. The structures of the Ardsheal peninsula, their age and regional significance. *Geological Journal*, Vol. 7, 335–346.

Treagus, J E, and Treagus, S H. 1981. Folds and the strain ellipsoid; a general model. *Journal of Structural Geology*, Vol. 3, Pt 1, 1–17.

Trewin, N. H. (editor) 2002. *The Geology of Scotland*. (4th edition) The Geological Society, London. 576 pp.

Trewin, N.H., Kneller, B.C. and Gillen, C. (1987) *Excursion Guide to the Geology of the Aberdeen area*. (Edinburgh: Scottish Academic Press, for Geological Society of Aberdeen).

Trewin, N.H. and Rollin, K. 2002. *In:* Trewin, N.H. (ed.) *The geology of Scotland.*(4th edition) The Geological Society, London, 1–25.

Trewin, N.H. and Thirlwall, M.F. 2002. Old Red Sandstone. In: Trewin N. H. (ed.) *The Geology of Scotland*. (4th edition) The Geological Society, London, pp. 213–249.

Tyrrell, G.W. 1921. Some points in petrographic nomenclature. *Geological Magazine* Vol. **58**, 494–502.

Underhill, J.R. 1993. Discussion on the location and history of the Walls Boundary fault and Moine thrust north and south of Shetland. *Journal of the Geological Society, London,* **150**, 1003–1008.

Upton, P.S., 1983. A stratigraphic, structural and metamorphic study of the lower and middle Dalradian, between Braemar and the Spittal of Glenshee, N.E. Scotland. Unpublished PhD thesis, University of Manchester.

Upton, P S. 1986. A structural cross-section of the Moine and Dalradian rocks of the Braemar area. *Report of the British Geological Survey*, Vol. 17, No. 1, 9–19.

Van Breemen, O., Aftalion, M. and Johnson, M. R. 1979. Age of the Loch Borrolan complex, Assynt and late movements along the Moine Thrust Zone. *Journal of the Geological Society of London* **16**, 489–495.

Van de Kamp, P.C. 1968. Origins of para-amphibolites. Unpublished PhD thesis, University of Bristol.

Van de Kamp, P C. 1970. The Green Beds of the Scottish Dalradian Series: geochemistry, origin and metamorphism of mafic sediments. *Journal of Geology*, Vol. 78, 281–303.

Van Staal, C. R., Dewey, J. F., McKerrow, W. S. and MacNiocaill, C. 1998. The Cambrian-Silurian tectonic evolution of the northern Appalachians and British Caledonides: history of a complex, southwest Pacific-type segment of Iapetus. In: *Lyell: the Present is in the Past* (edited by Blundell, D. J. and Scott, A. C.). *Geological Society, London, Special Publication*, **143**, 199–242.

Vance, D., Strachan, R. A. and Jones, K. A. 1998. Extensional versus compressional settings for metamorphism: Garnet chronometry and pressure–temperature–time histories in the Moine Supergroup, northwest Scotland. *Geology* **26**, 927–930.

Viete, D.R., Forster, M.A. and Lister, G.S. (2011) The nature and origin of the Barrovian metamorphism, Scotland: $^{40}Ar/^{39}Ar$ apparent age patterns and the duration of metamorphism in the biotite zone. *Journal of the Geological Society, London*, **168**, 133-146.

Viete, D.R., Hermann, J., Lister, G.S. and Stenhouse, I.R. (2011) The nature and origin of the Barrovian metamorphism, Scotland: diffusion length scales in garnet and inferred thermal time scales. *Journal of the Geological Society, London*, **168**, 115-132.

Viete, D.R., Richards, S.W., Lister, G.S., Oliver, G.J.H. and Banks, G.J. (2010) Lithospheric-scale extension during Grampian orogenesis in Scotland. in Law, R.D., Butler, R.W.H., Holdsworth, R.E., Krabbendam, M. and Strachan, R.A. (editors) *Continental Tectonics and Mountain Building: the Legacy of Peach and Horne*. Geological Society, London, Special Publications, **335**, 121-160.

Viljoen, M. J and Viljoen, R. P. 1969. Evidence for the existence of a mobile extrusive peridotite magma from the Komati Formation of the Onverwacht Group. *Geological Society of South Africa, Special Publication* No. 2, 87–112.

Vogt, T. 1930. On the chronological order of deposition in the Highlands. *Geological Magazine*, **67**, 68–76.

Voll, G. 1960. New work on Petrofabrics. *Liverpool and Manchester Geological Journal*, **2**, 503–567.

Voll, G. 1964. Deckenbau und fazies im Schottischen Dalradian. *Geologische Rundschau*, Vol. 53, 590–612.

Vorhies, S.H. and Ague, J.J. (2011) Pressure – temperature evolution and thermal regimes in the Barrovian zones, Scotland. *Journal of the Geological Society, London*, **168**, 1147-1166.

Wain, A. (1999). The petrography and metamorphic evolution of metabasic rocks from the Lower Dalradian of the Central Highlands area. *British Geological Survey Technical Report* No. **WA/99/13**.

Watkins, K.P. 1982. The structure and metamorphism of the Balquhidder—Crianlarich region of the Scottish Dalradian. Unpublished PhD thesis, University of Cambridge.

Watkins, K P. 1983. Petrogenesis of Dalradian albite porphyroblast schists. *Journal of the Geological Society of London*, Vol. 140, 601–618.

Watkins, K P. 1984. The structure of the Balquhidder–Crianlarich region of the Scottish Dalradian and its relation to the Barrovian garnet isograd surface. *Scottish Journal of Geology*, Vol. 20, 53–64.

Watkins, K.P. 1985. Geothermometry and geobarometry of inverted metamorphic zones in the W. Central Scottish Dalradian. *Journal of the Geological Society of London,* **142**, 157–165.

Watson, J. V. 1984. The ending of the Caledonian Orogeny in Scotland. *Journal of the Geological Society of London* **141**, 193–214.

Weiss, L E, and McIntyre, D B. 1957. Structural geometry of Dalradian rocks at Loch Leven, Scottish Highlands. *Journal of Geology*, Vol. 65, 575–602.

Wells, P. R. A. and Richardson, S. W. 1979. Thermal evolution of metamorphic rocks in the Central Highlands of Scotland. *In* Harris, A. L., Holland, C. H. and Leake, B. E. (editors), *The Caledonides of the British Isles–reviewed*. Geological Society of London Special Publication No. 8, published by Scottish Academic Press, Edinburgh, 339–344.

Whalen J. B., Currie J. L. and Chappell B. W. 1987. A-type granites: geochemical characteristics, discrimination and petrogenesis. *Contributions to Mineralogy and Petrology,* **95**, 407–419.

Whitten, E H T. 1959. A study of two directions of folding; the structural geology of the Monadhliath and mid-Strathspey. *Journal of Geology*, Vol. 67, 14-47.
Whittles, K.H. 1981. The geology and geochemistry of the area west of Loch Killin, Inverness-shire. Unpublished PhD thesis, University of Keele.
Wilkinson, S. B. 1907. The geology of Islay. Memoirs of the Geological Survey of Scotland, Sheets 19 and 27, and parts of 20.
Willan, R. C. R., and Coleman, M L. 1983. Sulphur isotope study of the Aberfeldy barite, zinc, lead deposit and minor sulfide mineralization in the Dalradian metamorphic terrain, Scotland. *Economic Geology*, Vol. 78, 1619–1656.
Williamson, D. H., 1953. Petrology of chloritoid and staurolite rocks north of Stonehaven, Kincardineshire. *Geological Magazine*, 90, 353–361.
Williamson, W O. 1935. The composite gneiss and contaminated granodiorite of Glen Shee, Perthshire. *Quarterly Journal of the Geological Society of London*, Vol. 91, 382–422.
Wilson, J.R. and Leake, B.E. 1972. The petrochemistry of the epidiorites of the Tayvallich Peninsula, North Knapdale, Argyllshire. *Scottish Journal of Geology* **8**, 215–252.
Winchester, J.A. 1974. The zonal pattern of regional metamorphism in the Scottish Caledonides. *Journal of the Geological Society of London,* **130**, 509–24.
Winchester, J.A. and Glover, B.W. (1988). The Grampian Group, Scotland. In: *Later Proterozoic stratigraphy of the Northern Atlantic region.* (editor Winchester, J.A.). Blackie, Glasgow and London, 146–161.
Winchester, J.A. and Glover, B.W. (1991). Grampian Group: Pitlochry—Loch Laggan—Glen Spean. In: *The Late Precambrian Geology of the Scottish Highlands and Islands*. (editors Hambrey, M.J., Fairchild, I.J., Glover, B.W., Stewart, A.D., Treagus, J.E. and Winchester, J.A.). Geologists' Association Guide No. **44**, 66–85.
Wiseman, J D H. 1934. The central and south-west Highland epidiorites: a study in progressive metamorphism. *Quarterly Journal of the Geological Society of London*, Vol. 90, 354–417.
Wood, D.S. 1964. Some structures in the Dalradian pillow lavas of the Tayvallich Peninsula, Argyll. *Geological Magazine,* **101**, 481
Woodcock, N. and Strachan, R. 2000. *Geological History of Britain and Ireland*. Blackwell Science, Oxford.
Wright, A.E. 1976. Alternating subduction direction and the evolution of the Atlantic Caledonides *Nature, London* **264**, 156.
Wright, A. E. 1988. 15. The Appin Group. In *Later Proterozoic Stratigraphy of the Northern Atlantic Regions* (editor Winchester, J. A.), pp. 177–199. Blackie.

Yardley B. W. D. (1989) *An introduction to metamorphic petrology*. Longman, Harlow.
Yardley, B.W.D. and Valley, J.W. 1997. The petrologic case for a dry lower crust. *Journal of Geophysical Research*, **106 B6**, 12173-12185.

Zeh, A. and Millar, I. L. 2001. Metamorphic evolution of garnet-epidote-biotite gneiss from the Moine Supergroup, Scotland, and geotectonic implications. *Journal of Petrology* **42**, 529–554.
Zenk, M. and Schulz, B. 2004. Zoned Ca-amphiboles and related P-T evolution in metabasites from the classical Barrovian metamorphic

zones in Scotland. *Mineralogical Magazine*, **68**, 769-786.

Figure 1 Map of the Shetland Islands showing the outcrops of the Moine and Dalradian 'divisions' and overlying structural units. From Flinn *et al.* (1972) with modifications taken from the BGS 1:50 0000 sheet 131 (Unst and Fetlar, 2002).
Proposed GCR sites: 1 Scalloway, 2 Hawks Ness, 3 Cunningsburgh.
BSF Bluemull Sound Fault, NF Nesting Fault, WBF Walls Boundary Fault.

Figure 2 Map of the 'divisions' of Moine and Dalradian rocks on Mainland Shetland, east of the Walls Boundary Fault (the so-called 'East Mainland Succession'), showing main structural features and the location of the proposed GCR sites: 1 Scalloway, 2 Hawks Ness, 3 Cunningsburgh.
BSF Bluemull Sound Fault, NF Nesting Fault, WBF Walls Boundary Fault.

Figure 3 Schematic cross-section of the East Mainland Mega-monocline and Valla Field Anticline, Shetland (after Flinn, 2007).
EMM East Mainland Mega-monocline axial plane trace.

Figure 4 Map of the area around the Scalloway GCR site.

Figure 5 Typical homogeneous granoblastic gneiss of the Colla Firth Permeation Belt, Whiteness Group, viewed normal to the lineation and parallel to the foliation. Point of the Pund, Scalloway (HU 3873 3889). Hammer shaft is 33 cm long. (Photo: D. Flinn, BGS No. P 574422.)

Figure 6 Map of the area around the Hawks Ness GCR site. Inset is an equal-area stereographic projection showing the relationship between poles to bedding, axes of prominent isoclinal folds in individual quartzite beds and fabric lineations.

Figure 7 Ripple cross-lamination preserved within the Dales Voe Grit Member of the Clift Hills Phyllitic Formation. Brim Ness (HU 4606 4825). Hammer head is 16.5 cm long. (Photo: F. May, BGS No. P 726605.)

Figure 8 Structures in the Clift Hills Phyllitic Formation (see stereoplot inset in Figure 6).
(a) Isoclinal synform in beds of turbiditic psammite of the Dales Voe Grit Member. Houbie (HU 4572 4807).
(b) South-west-plunging lineation caused by tectonic elongation of clastic grains in a bed of coarse, schistose psammite. North-west tip of Hawks Ness (HU 4583 4909). Coin is 30 mm diameter.
(Photos: F. May, BGS Nos. P 726606 and P 726607.)

Figure 9 Map of the area around the Cunningsburgh GCR site.

Figure 10 Spinifex-like texture preserved as pseudomorphs after olivine in a block of brecciated and then serpentinized ultramafic rock. Hillside south-west of Sands of Mail, Cunningsburgh (HU 4261

2744). Coin is 26 mm in diameter. (Photo: D. Flinn, BGS No. P 550134.)

Figure 11 Tectonically stretched clasts within a debris-flow deposit, probably volcaniclastic, interbedded with spilitic lavas of the Dunrossness Spilitic Formation on the coast south-west of Mail, Cunningsburgh (HU 429 278). Hammer shaft is 28 cm long. (Photo: P. Stone, BGS No. P 726608.)

Table 1 The East Mainland Succession of Shetland, showing tentative informal correlations with the Moine and Dalradian supergroups of mainland Scotland. Stratigraphical ranges exhibited by the GCR sites are also shown: 1 Scalloway, 2 Hawks Ness, 3 Cunningsburgh.

Table 7.1

SHETLAND			GCR	SCOTLAND	
group	**formation**	**member**	**site**	**formation**	**group**
Clift Hills	Dunrossness Spilitic		3	Loch Avich Lavas/Green Beds	Southern Highland
	Dunrossness Phyllitic				
	Clift Hills Phyllitic				
		Dales Voe Grit	2		
	Asta Spilitic			Tayvallich Volcanic	Argyll
Whiteness	Laxfirth Limestone			Tayvallich Slate and Limestone	
	Wadbister Ness				
	Girlsta Limestone		1		
	Colla Firth	host rocks of the Colla Firth Permeation and Injection Belt			??????????? / ???????????
		Nesbister Limestone			Appin
		Whiteness Limestone			
	Weisdale Limestone				
Scatsta	Scatsta Quartzitic				Grampian
Boundary Zone	Skella Dale Burn Gneiss				??
	Valayre Gneiss				
Yell Sound					?Loch Eil + Glenfinnan

Table 7.1 The East Mainland Succession of Shetland, showing tentative informal correlations with the Moine and Dalradian supergroups of mainland Scotland.

Stratigraphical ranges exhibited by the GCR sites are also shown: 1 Scalloway, 2 Hawks Ness, 3 Cunningsburgh.

Figure 7.1

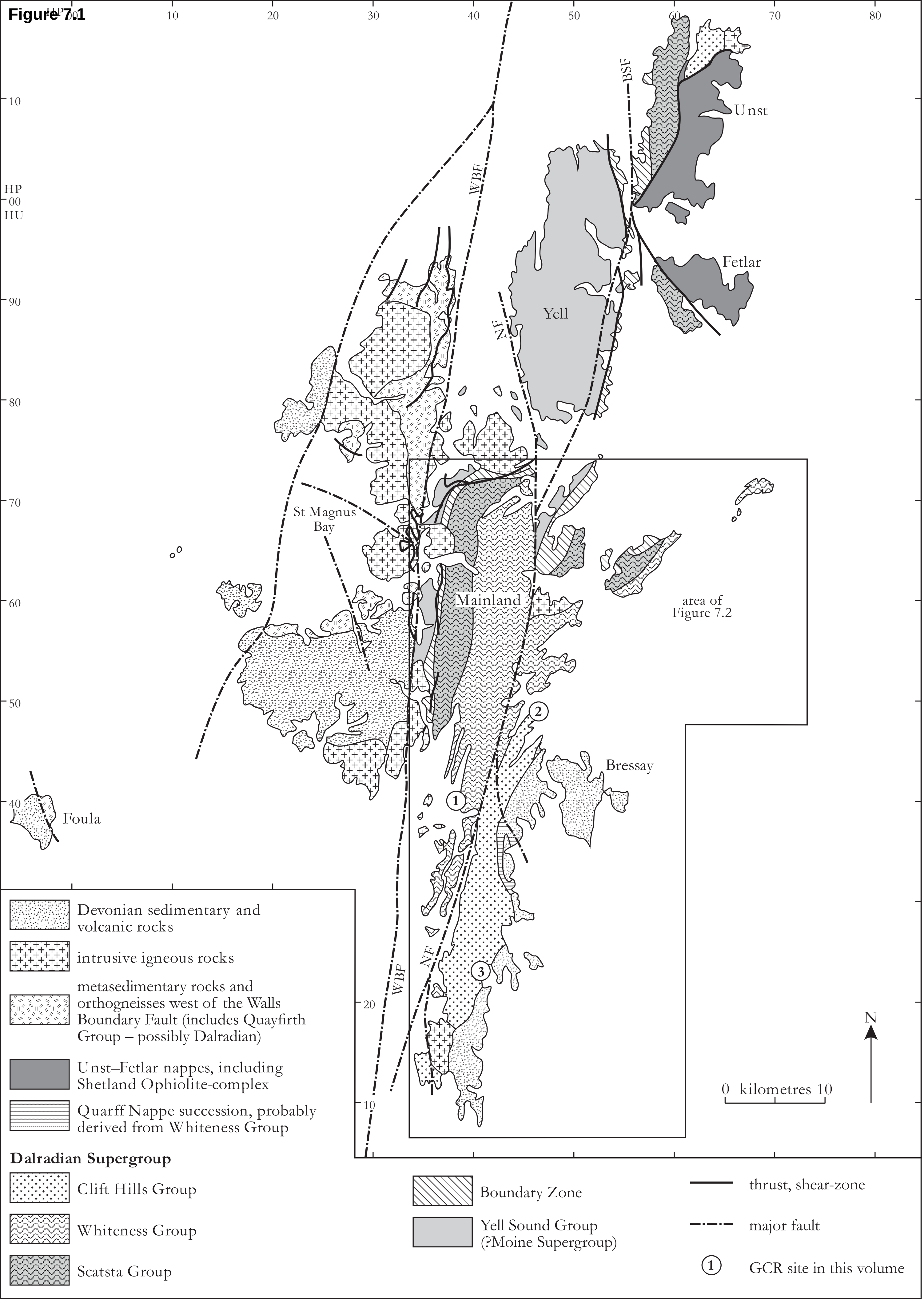
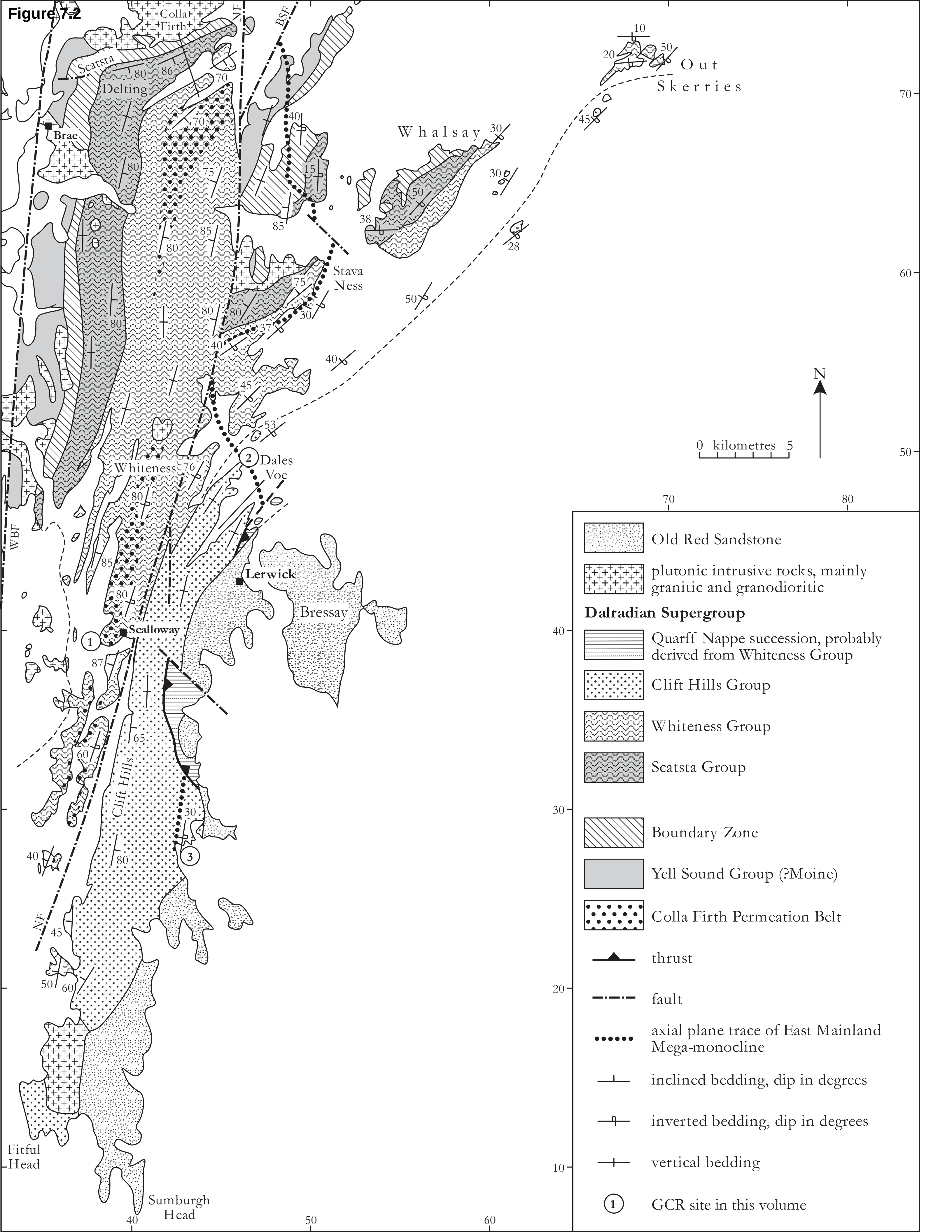
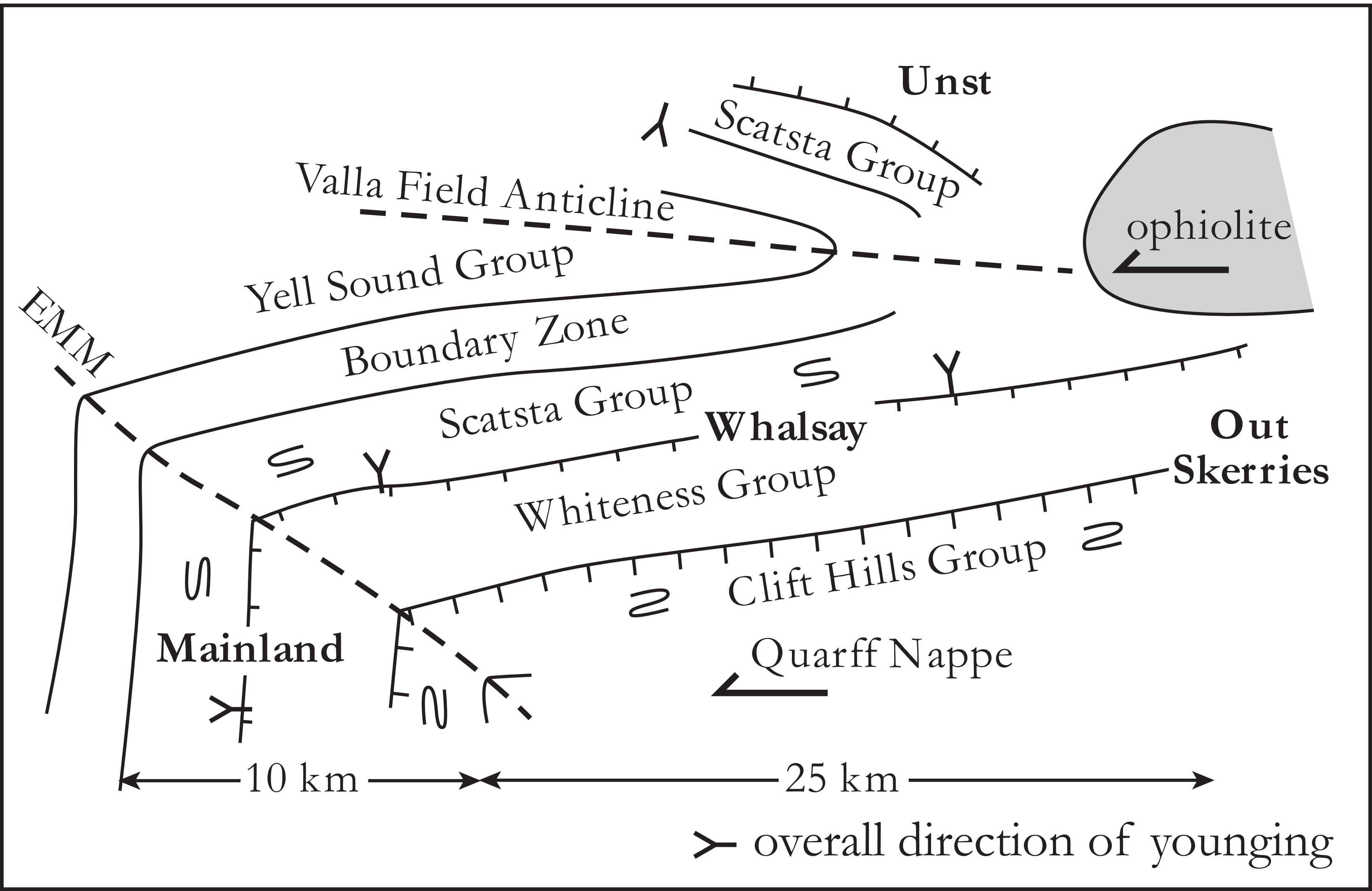

Unst
Fetlar
Yell
Mainland
Bressay
Foula
St Magnus Bay
area of Figure 7.2
WBF
NF
BSF
Devonian sedimentary and volcanic rocks
intrusive igneous rocks
metasedimentary rocks and orthogneisses west of the Walls Boundary Fault (includes Quayfirth Group – possibly Dalradian)
Unst–Fetlar nappes, including Shetland Ophiolite-complex
Quarff Nappe succession, probably derived from Whiteness Group
Dalradian Supergroup
Clift Hills Group
Whiteness Group
Scatsta Group
Boundary Zone
Yell Sound Group (?Moine Supergroup)
thrust, shear-zone
major fault
GCR site in this volume
0 kilometres 10
N
HP 00 HU

Figure 7.2



Colla Firth
Scatsta
Delting
Brae
Whalsay
Out Skerries
Stava Ness
Whiteness
Dales Voe
Lerwick
Bressay
Scalloway
Clift Hills
Fitful Head
Sumburgh Head
WBF
NF
BSF
N
0 kilometres 5
Old Red Sandstone
plutonic intrusive rocks, mainly granitic and granodioritic
Dalradian Supergroup
Quarff Nappe succession, probably derived from Whiteness Group
Clift Hills Group
Whiteness Group
Scatsta Group
Boundary Zone
Yell Sound Group (?Moine)
Colla Firth Permeation Belt
thrust
fault
axial plane trace of East Mainland Mega-monocline
inclined bedding, dip in degrees
inverted bedding, dip in degrees
vertical bedding
GCR site in this volume

Figure 7.3



Unst
Scatsta Group
Valla Field Anticline
ophiolite
Yell Sound Group
EMM
Boundary Zone
Scatsta Group
Whalsay
Out
Skerries
Whiteness Group
Clift Hills Group
Mainland
Quarff Nappe
10 km
25 km
overall direction of younging

Figure 7.4

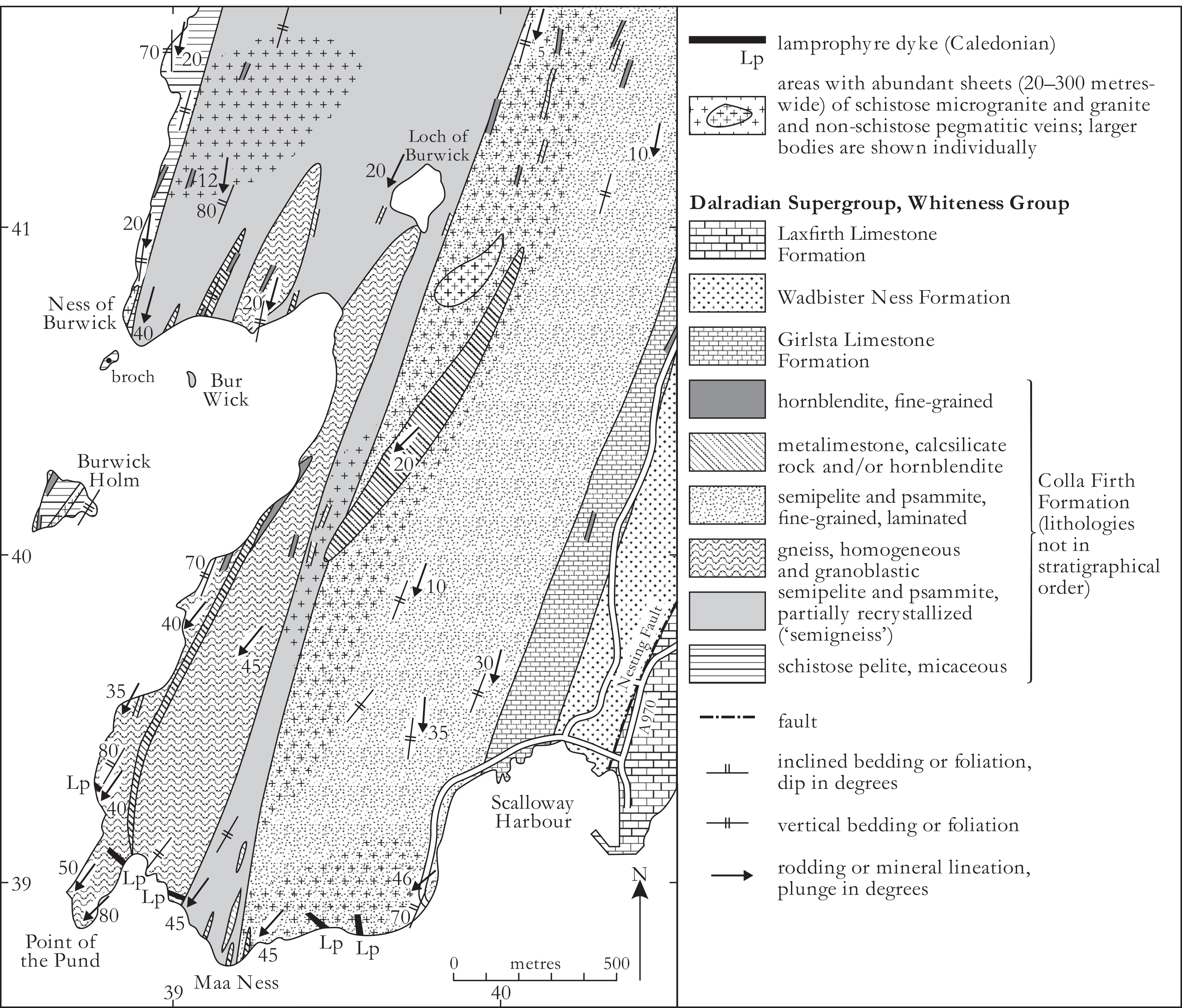

lamprophyre dyke (Caledonian)
Lp
areas with abundant sheets (20–300 metres-wide) of schistose microgranite and granite and non-schistose pegmatitic veins; larger bodies are shown individually
Dalradian Supergroup, Whiteness Group
Laxfirth Limestone Formation
Wadbister Ness Formation
Girlsta Limestone Formation
hornblendite, fine-grained
metalimestone, calcsilicate rock and/or hornblendite
semipelite and psammite, fine-grained, laminated
gneiss, homogeneous and granoblastic
semipelite and psammite, partially recrystallized ('semigneiss')
schistose pelite, micaceous
Colla Firth Formation (lithologies not in stratigraphical order)
fault
inclined bedding or foliation, dip in degrees
vertical bedding or foliation
rodding or mineral lineation, plunge in degrees
Loch of Burwick
Ness of Burwick
broch
Bur Wick
Burwick Holm
Scalloway Harbour
Nesting Fault
A970
Point of the Pund
Maa Ness
N
0
metres
500
39
40
41

Figure 7.6

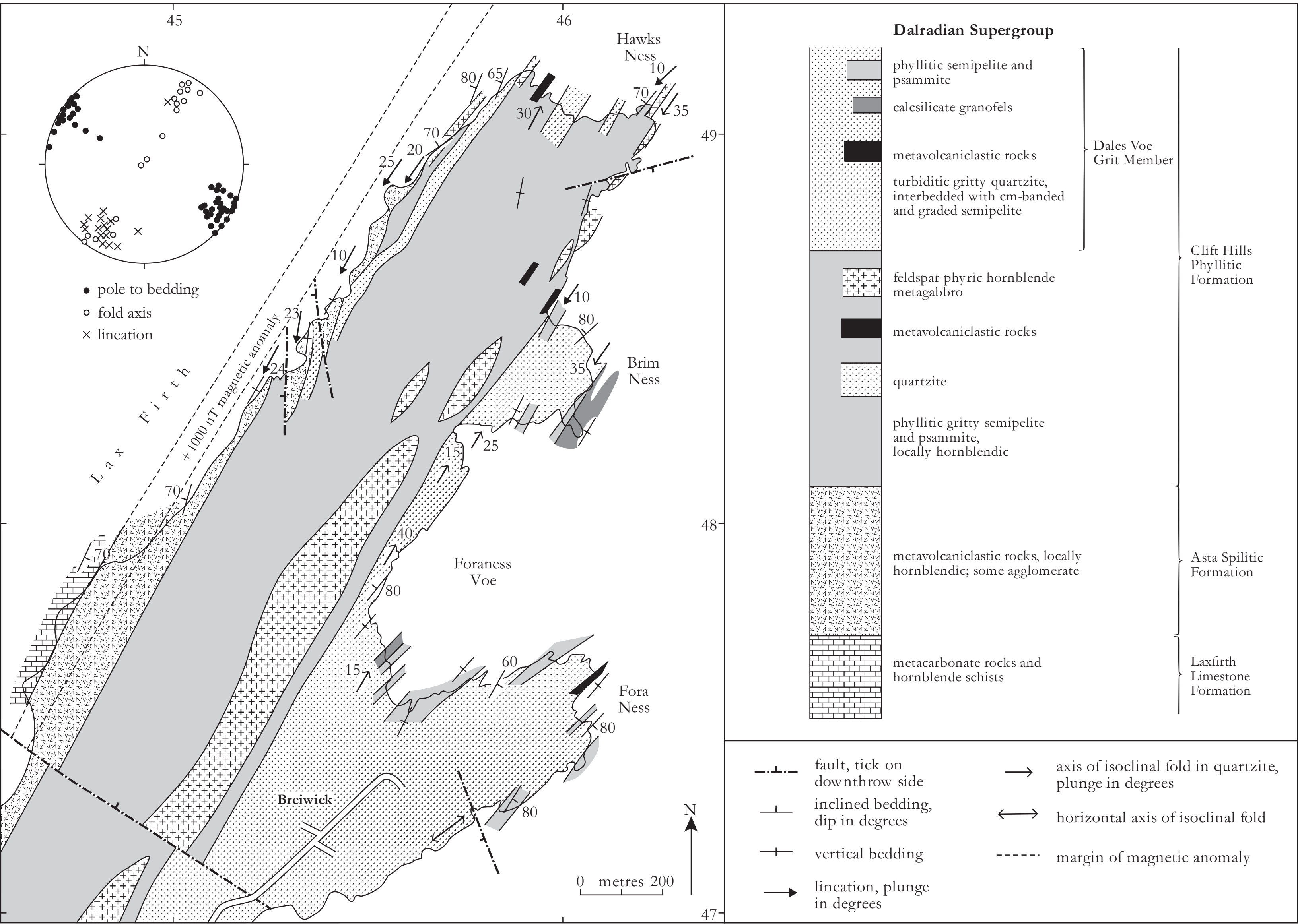

45
46
N
pole to bedding
fold axis
lineation
Hawks
Ness
Lax Firth
+1000 nT magnetic anomaly
Brim
Ness
Foraness
Voe
Fora
Ness
Breiwick
0 metres 200
49
48
47
Dalradian Supergroup
phyllitic semipelite and psammite
calcsilicate granofels
metavolcaniclastic rocks
turbiditic gritty quartzite, interbedded with cm-banded and graded semipelite
Dales Voe Grit Member
feldspar-phyric hornblende metagabbro
metavolcaniclastic rocks
quartzite
phyllitic gritty semipelite and psammite, locally hornblendic
Clift Hills Phyllitic Formation
metavolcaniclastic rocks, locally hornblendic; some agglomerate
Asta Spilitic Formation
metacarbonate rocks and hornblende schists
Laxfirth Limestone Formation
fault, tick on downthrow side
inclined bedding, dip in degrees
vertical bedding
lineation, plunge in degrees
axis of isoclinal fold in quartzite, plunge in degrees
horizontal axis of isoclinal fold
margin of magnetic anomaly

Figure 7.9

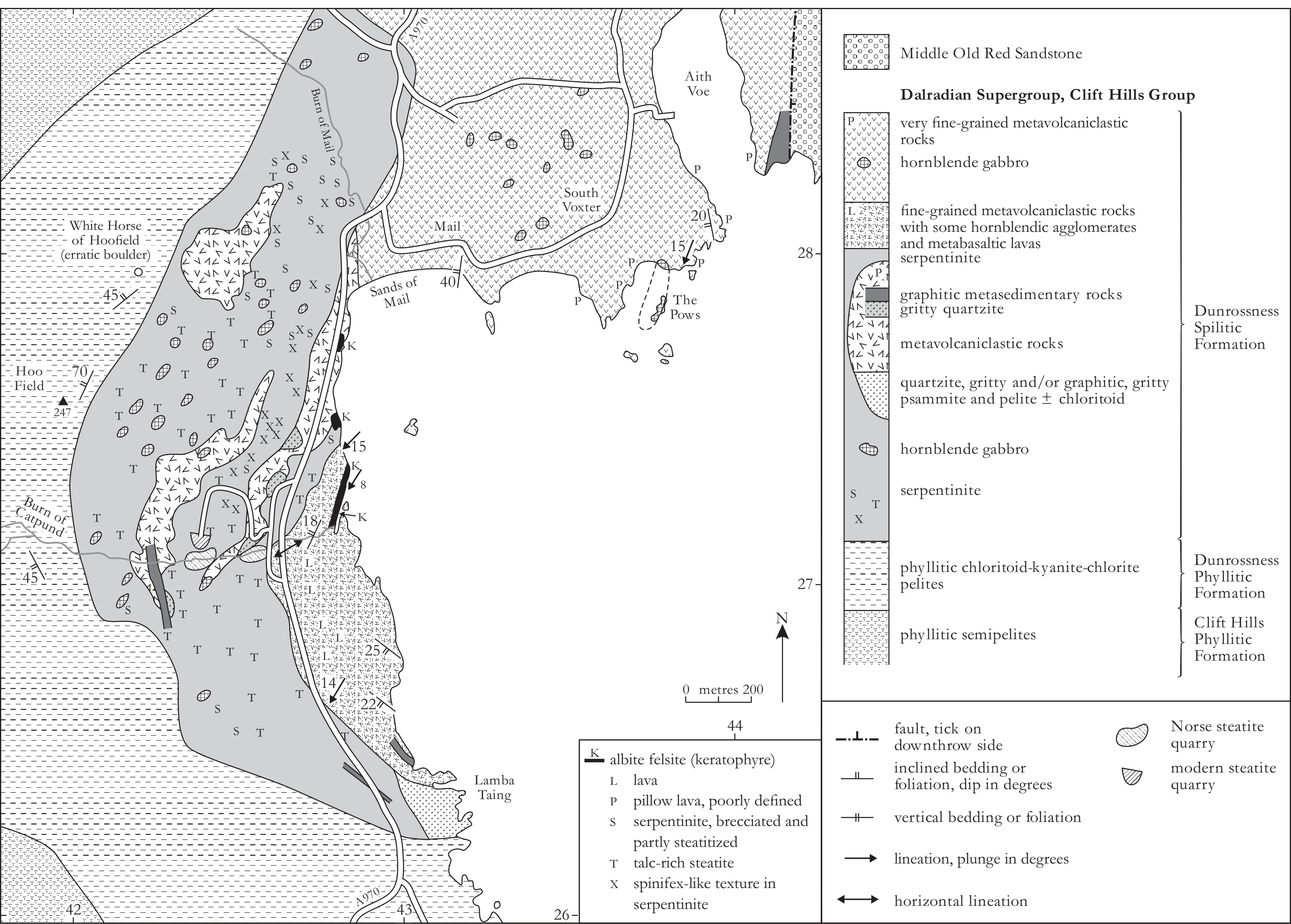

Middle Old Red Sandstone
Dalradian Supergroup, Clift Hills Group
very fine-grained metavolcaniclastic rocks
hornblende gabbro
fine-grained metavolcaniclastic rocks with some hornblendic agglomerates and metabasaltic lavas
serpentinite
graphitic metasedimentary rocks
gritty quartzite
metavolcaniclastic rocks
quartzite, gritty and/or graphitic, gritty psammite and pelite ± chloritoid
hornblende gabbro
serpentinite
Dunrossness Spilitic Formation
phyllitic chloritoid-kyanite-chlorite pelites
Dunrossness Phyllitic Formation
phyllitic semipelites
Clift Hills Phyllitic Formation
fault, tick on downthrow side
inclined bedding or foliation, dip in degrees
vertical bedding or foliation
lineation, plunge in degrees
horizontal lineation
Norse steatite quarry
modern steatite quarry
albite felsite (keratophyre)
lava
pillow lava, poorly defined
serpentinite, brecciated and partly steatitized
talc-rich steatite
spinifex-like texture in serpentinite
White Horse of Hoofield (erratic boulder)
Hoo Field
Burn of Mail
Burn of Catpund
Sands of Mail
Mail
South Voxter
Aith Voe
The Pows
Lamba Taing
A970
0 metres 200
N

Figure 7.5 B&W

Click here to download high resolution image

Figure 7.7 B&W

Click here to download high resolution image

Figure 7.8a B&W
Click here to download high resolution image

Figure 7.8b B&W

Click here to download high resolution image

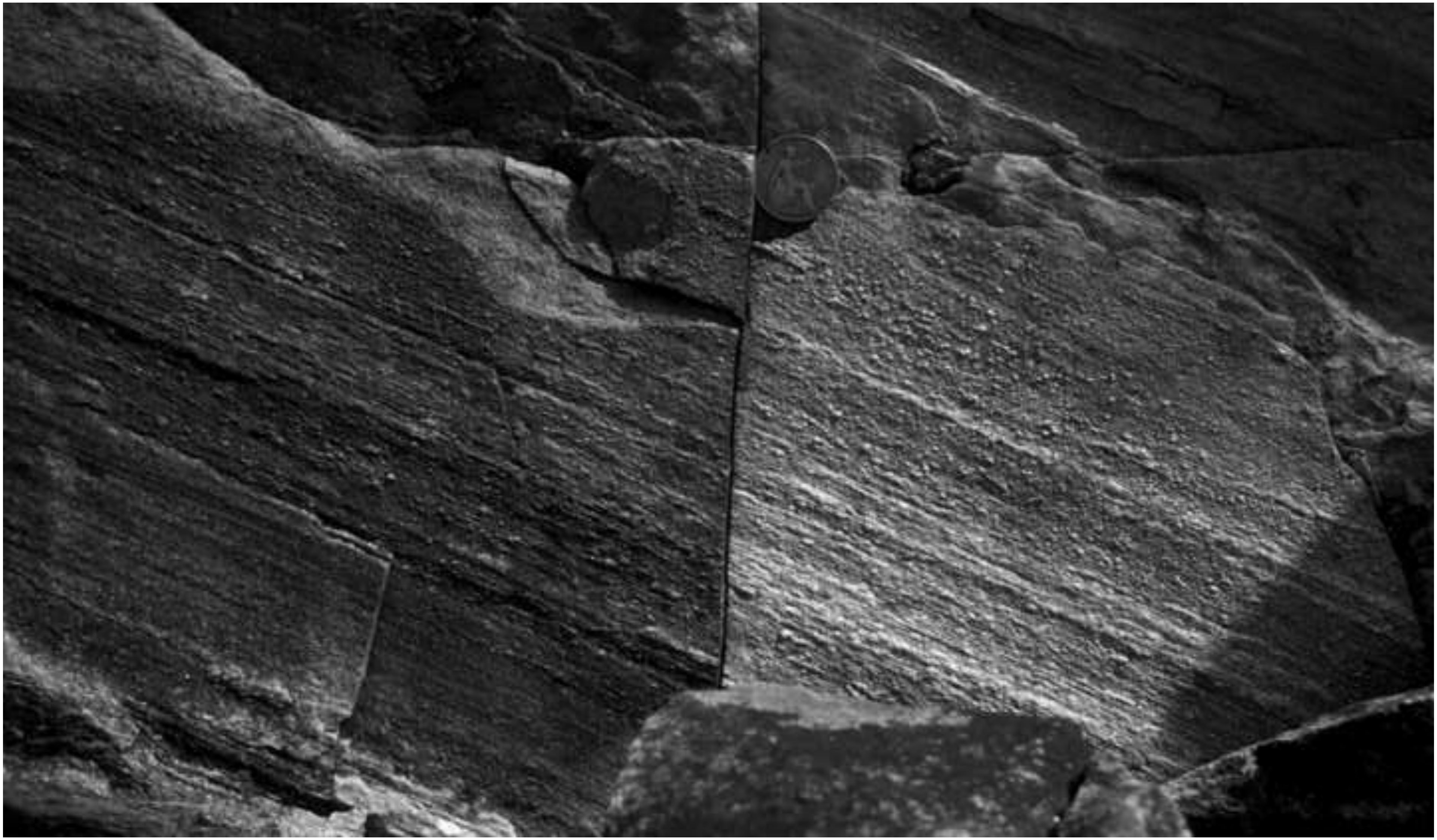


Figure 7.10 B&W

Click here to download high resolution image

Figure 7.11 B&W
Click here to download high resolution image

Figure 7.5 colour
Click here to download high resolution image

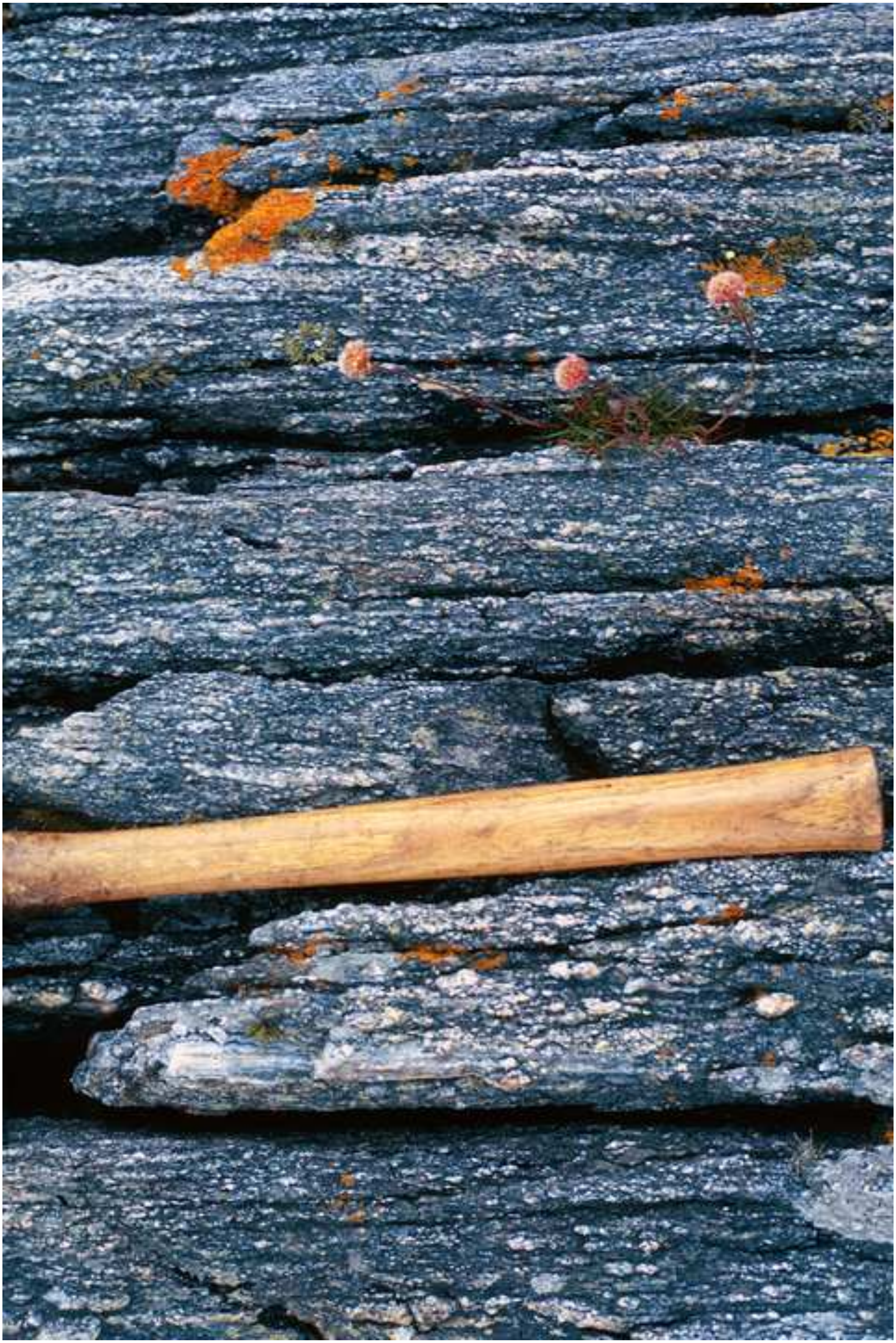


Figure 7.7 colour
Click here to download high resolution image

Figure 7.8a colour

Click here to download high resolution image

Figure 7.8b colour

Click here to download high resolution image

Figure 7.10 colour

Click here to download high resolution image

Figure 7.11 colour
Click here to download high resolution image