The Dalradian rocks of the south-west Grampian Highlands of Scotland

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Abstract

The South-west Grampian Highlands, as defined here, include the Inner Hebridean islands of Islay and Jura, and extend north-east as far as Dalmally at the northern tip of Loch Awe. Due to a favourable combination of excellent coastal exposures and low tectonic strain, the late-Neoproterozoic rocks of the Dalradian Supergroup in this region are ideal for studying sedimentary structures. In addition, the diversity in protolith lithology from carbonate rocks to siliciclastic rocks of all grain sizes and volcanic rocks makes it possible to establish a very detailed lithostratigraphical succession and to recognize lateral facies changes. The stratigraphical range extends from the base of the Appin Group to the base of the Southern Highland Group and the area provides type localities for many regionally extensive formations of the Argyll Group. Rocks forming part of the basement to the Dalradian basins, the Rhinns Complex, are seen on Islay, where they are overlain by the Colonsay Group, a thick metasedimentary siliciclastic sequence of uncertain stratigraphical affinity.

The structure of the Dalradian rocks in the South-west Grampian Highlands is controlled by early (D1) major folds (Islay Anticline, Loch Awe Syncline, and Ardrishaig Anticline), associated with a ubiquitous, penetrative, slaty or spaced cleavage. Most of the Dalradian rocks have been regionally metamorphosed under greenschist-facies conditions and amphibolite-facies (garnet zone) assemblages occur only in a narrow central zone, strongly affected by the D2 deformation.

The area provides GCR sites of international importance for studying Neoproterozoic glacial deposits, splendidly preserved stromatolite bioherms and calcite pseudomorphs after gypsum. Deformed and undeformed sandstone dykes and interstratal dewatering structures are well displayed at several sites. Other features include thick sills of basic meta-igneous rock with unusual minerals such as stilpnomelane, and greenschist-facies rocks containing regional metamorphic kyanite. The area is of historical interest for the first recognition in Scotland, prior to 1910, of sedimentary

way-up structures and pillow lavas in regionally deformed and metamorphosed rocks.

1 Introduction

P.W.G. Tanner

The South-west Grampian Highlands region, as defined in this paper, includes the islands of Islay, Jura, and the Garvellach isles in the north-west. it is bounded to the south-east by the base of the Southern Highland Group, which runs from Campbeltown along the Kintyre peninsula and the south-east side of Loch Fyne, to Ben Lui (Figure 2.1). the north-eastern boundary follows the lower part of Loch Etive and the A85 road to Dalmally and Ben Lui. The region has an extremely long, indented coastline that faces into the prevailing south-west wind, which results in many kilometres of clean, well-scoured, coastal rock exposures being available for detailed study. thus, 19 out of 21 of the GCR sites reported here are on coastal exposures.

The primary survey of the South-west Grampian Highlands was begun in 1880 and culminated in the publication of 'The Geology of the Seaboard of Mid-Argyll' (Peach *et al*., 1909). The Geological Survey memoirs and accompanying geological maps produced during this period remain the sole source of reference to the distribution of rock types, and their petrography, for a considerable part of the region. This work was carried out whilst major advances were being made in structural geology and sedimentology worldwide, but much of this work came too late to help define and resolve some of the more fundamental problems in Highland geology. For example, the stratigraphical sequences established by the early workers such as Green (1924), Hill (1899, 1909) and Wilkinson (1907) were later shown to be wrong, as these geologists did not have the tools to identify way-up, and based their interpretations on Uniformitarian principles, such as the Law of Superposition, and the dip direction. This approach was successful in areas with simple upright, open folds but obviously failed in situations where the rocks had, for example, already been inverted by regional-scale folding. As a result, some parts of the stratigraphical sequence had to be revised when way-up techniques were first applied (Vogt, 1930; Bailey, 1930; Allison, 1933).

Despite the progress made by Pumpelly *et al.* (1894) in interpreting bedding/cleavage relationships in the USA, and by Clough (in Gunn *et al*., 1897) in recognizing the effects of polyphase deformation in the Cowal peninsula, there is no indication from the work published prior to 1909 that these techniques were used in the areas described in this paper. The overall structure of this region was finally established by Bailey (1922); this framework has not been superseded but was progressively modified as modern techniques of structural geology were applied from the late 1950s onwards (i.e. Shackleton, 1958; Knill, 1960; Rast, 1963; Borradaile, 1970, 1973; Roberts, 1974).

The Dalradian rocks of this region, with their great diversity in lithology, relatively simple structure and low-grade regional metamorphism, have played a very important part in establishing the overall stratigraphical sequence in the Grampian Highlands as a whole. All subgroups of the Argyll Group are named after localities in this region, and these encompass a wide range of metamorphosed rock types from tillites to carbonate rocks and basic igneous rocks, and mudrocks to conglomerates. The Argyll Group includes two important marker horizons: the Port Askaig Tillite Formation at the base, and the Loch Tay Limestone Formation at the top (see Stephenson et al., 2013a for discussion) (Figure 2).

The environment in which the Argyll Group was deposited shows increasing tectonic instability with time (Anderton, 1985). Syndepositional basin-bounding faults became increasingly active throughout this period, as witnessed by marked lateral variations in the thickness and facies of both members and formations, together with the incoming and increasing frequency of debris flows and coarse-grained turbidite-facies rocks. Sediments of the Islay Subgroup were deposited in shallow water, some even in the intertidal zone, as indicated by storm deposits in the Jura Quartzite Formation, and pseudomorphs after gypsum in the Craignish Phyllite Formation. Deepening of the basin in Easdale Subgroup times is indicated by the deposition of a considerable thickness of black, euxinic mudrock, which was followed by a thick sequence of coarse-grained quartzofeldspathic turbidites in Crinan Subgroup times. Volcanicity reached a peak during Tayvallich Subgroup times as the now sediment-starved basin subsided further and the underlying lithosphere thinned and finally ruptured.

In view of the possibility that one or more orogenic unconformities is present in the Dalradian rocks of the South-west Grampian Highlands (Dempster *et al*., 2002; Hutton and Alsop 2004; but see Tanner, 2005), emphasis in this paper is placed upon relationships between the various stratigraphical units, and especially on the nature of the contacts between subgroups, including the critical junction between the Jura Quartzite and the Easdale Slate.

The overall structure of the South-west Grampian Highlands is controlled by two upward-facing major folds, the Islay Anticline and the Loch Awe Syncline, both of D1 age. The axial plane of the Islay Anticline dips to the south-east, and the fold faces up to the north-west, whereas the Loch Awe Syncline is an upright, symmetrical structure. The Dalradian rocks are least deformed along the western seaboard and, in areas of particularly low strain such as on Islay and Jura, many of the original sedimentary features are preserved. There it is also possible to examine the earliest tectonic structures in their pristine state. In over 70% of the GCR sites included in this paper, the rocks have been affected by only a single major ductile tectonic event (D1), followed by weak, late-stage deformations. The Dalradian rocks at two of these GCR sites (*Caol Isla* and *Craignish Point*) appear in the field to be almost undeformed, and only two of the remaining sites show the full effects of polyphase deformation (*Black Mill Bay* and *Port Cill Maluaig*). The metamorphic grade throughout the area is generally of greenschist facies, with some garnet-bearing epidote-amphibolite-facies rocks occurring along the south-east margin.

In this paper, the GCR site reports are arranged in stratigraphical sequence with the oldest first, but there are some anomalies where either subject matter or geographical location takes precedence. Of the 21 site reports, three are concerned with contemporaneous igneous activity (dykes and sills); two record the occurrence of minerals not normally found in Dalradian rocks that are unusual for their form (gypsum), or are in some way unique in their particular setting (kyanite and stilpnomelane); two deal largely with water-escape structures and clastic dykes, respectively; and the remaining 14 are focussed on stratigraphical and structural aspects. Examples of innovatory studies in the region include the first uses in the United Kingdom of sedimentary cross-bedding and graded bedding in metasedimentary rocks to determine the younging direction (see the *Kilmory Bay* GCR site report).

1.1 The pre-Dalradian basement and units of uncertain stratigraphical affinity

The Dalradian Supergroup is not seen in contact with its basement anywhere in the South-west Grampian Highlands but the Palaeoproterozoic Rhinns Complex on Islay almost certainly represents at least the local basement. Intervening structurally between the Rhinns Complex and rocks of undoubted Dalradian affinity on Islay are two groups of Dalradian-like rocks, the Colonsay Group and the Bowmore Sandstone Group. Both are rather monotonous sequences of metasandstone and lack any specific characteristics that would help to confirm their Dalradian identity. The Bowmore Sandstone Group, described in the *Bun-an-uilt, Islay* CGR site report, is separated from the Dalradian proper by the Loch Skerrols Thrust and might be equivalent to the Crinan Grit Formation, described below (Fitches and Maltman, 1984). The Colonsay Group has a tectonized, unconformable contact with the Rhinns Complex, exposed in the *Kilchiaran to Ardnave Point* GCR site, but it cannot be correlated directly with the Dalradian sequence; it has been compared to the Grampian Group and possibly the lower part of the Appin Group (Stephenson and Gould, 1995). U-Pb ages on detrital zircons from the Colonsay Group strongly support its correlation with the Grampian Group, and help to confirm that the Rhinns Complex is part of the basement to the Dalradian (McAteer, *et al.*, 2010). See Stephenson et al. (2013a) for more detailed discussions of these units and their possible affinities.

1.2 Dalradian stratigraphy

Appin Group rocks are only exposed in this region on the Isle of Islay, within the core of the Islay Anticline (Rast and Litherland, 1970; Basahel, 1971; Wright, 1988; see also BGS 1:50 000 sheets 19, South Islay, 1998 and 27, North Islay, 1994). Strata of all three subgroups are present, and show a remarkable similarity to the mainland succession, some 80 km to the north-east along strike (see Treagus et al., 2013). However, they are poorly exposed and are not represented by any GCR sites.

The Lochaber Subgroup on Islay is divided into two units. The lower, Maol an Fhithich Quartzite Formation, consists of massive, cross■bedded quartzites with phyllitic metamudstones and pebble beds containing extrabasinal granite clasts. The overlying Glen Egedale Slate Formation is composed of striped greenish, phyllitic or slaty metasiltstones that

become more calcareous upwards. The Ballachulish Subgroup consists of the Kintra Dolostone Formation, Mulindry Bridge Slate Formation, Cnoc Donn Quartzite Formationand theNeriby Formation, and can be matched confidently with the type succession of the Appin–Loch Leven area, with little variation in facies. In the Blair Atholl Subgroup, theBallygrant Formation, consisting of dark grey, slaty and phyllitic graphitic metamudstones, followed by a bluish grey metalimestone, can be equated confidently with the Cuil Bay Slate and Lismore Limestone. Owing to the south■westerly plunge of the major folds in the Appin–Lismore area, any higher beds of the Blair Atholl Subgroup that may have been deposited there lie beneath the Firth of Lorn, but an extended sequence is present on Islay. There, the Ballygrant Formation is overlain by dark grey phyllitic metamudstones with graded metasandstone or calcareous beds, the Mullach Dubh Phyllite Formation, and a distinctive banded unit containing partly ooidal and stromatolitic, thin-bedded metalimestones, the Lossit Limestone Formation (formerly the Islay Limestone, Spencer, 1971), which is overlain unconformably by the Port Askaig Tillite Formation.

The stratigraphical sequence covered by the GCR sites in this paper begins with the Port Askaig Tillite Formation at the base of the Argyll Group, which is magnificently exposed in the *Garvellach Isles* (Spencer, 1971) (Figure 2.2. This GCR site is of international importance as it is the best-preserved example of a Precambrian tillite in the British Isles. The tillite is also instrumental, because of its distinctive character and association with a thick quartzite unit above, and a dolomitic unit below, in forging a stratigraphical correlation between the Dalradian rocks of Scotland and those of Connemara and Donegal (Kilburn *et al*., 1965). Currently, it plays a major role in the search for a continuation of the Dalradian tract prior to the break-up of Rodinia. This is despite the fact that the origin of the formation is still in dispute, the precise age of deposition is not known, and a debate as to whether it represents a ‘Snowball Earth’ situation has ensued (Dempster *et al.,* 2002).

The important features of tillite formation include the ‘Great Breccia’ and the neighbouring ‘Disturbed Beds’, which occur in a well-documented sequence of 47 metadiamictites. Within the metadiamictites there is a change from locally derived stones to an incoming of foreign exotic stones at bed 12. The top of the sequence can be examined north of Port Askaig on Islay, where a transition to the overlying Bonahaven Dolomite Formation can be seen at the *Caol Isla* GCR site. The current interpretation for its origin is that the tillite was deposited sub-aqueously from icebergs, and was then partly reworked by tidal currents.

The Bonahaven Dolomite Formation (Spencer and Spencer, 1972) was interpreted by Fairchild (1993) to be the ‘cap carbonate’ to the Portaskaig Tillite and, apart from the lowest beds, consists almost entirely of orange-yellow, Fe-rich dolomitic rocks. It is divided into four members, the lowest of which is subdivided into five units. The lowermost unit contains isolated boulders and has an affinity with the tillite, and unit 2 consists of well-bedded metasandstones with channel deposits. The metasandstone beds are almost undeformed and contain mud cracks. Sedimentary dykes result from the injection of water-saturated, over-pressured sand and silt as dyke-like bodies into the adjoining sediments. Those at Caol Isla have recently been interpreted as being the result of interstratal dewatering, probably caused by earthquake activity associated with the synsedimentary Bolsa Fault (Tanner, 1998a). The *Caol Isla* GCR site also became famous, briefly, for the reported presence of Neoproterozoic trace fossils by Brasier and McIlroy (1998). However, this identification was withdrawn subsequently by Brasier and Shields (2000).

The upper part of the Bonahaven Dolomite Formation is best exposed along the north coast of Islay at the *Rubha a’ Mhail* GCR site. There, distinctive stratigraphically controlled beds contain stromatolites, which have either spherical or elliptical shapes up to 3 m across, or occur as layer-form sheets. The rocks at this GCR site are more deformed than those at Caol Isla but fine-grained siliciclastic beds still preserve water-escape structures and small clastic dykelets. In addition, there is possible evidence for the former presence of anhydrite, a mineral that, like gypsum, is characteristic of evaporite deposits.

The Jura Quartzite Formation is not represented by a GCR site, as this unit crops out over a large area and is particularly well exposed. It is a clean, locally feldspathic, cross-bedded and cross-laminated quartzite deposited in a wave- and storm-dominated environment (Anderton, 1976). Anderton (1979) suggested that deposition took place in a series of fault-controlled basins as the formation shows extreme lateral thickness changes from 5 km on Jura to approximately 1000 km on Islay to the south-west, and thinning to *c*. 100 m on Lunga to the north-east.

Over a distance of 110 km between Port Ellen, on Islay and Benderloch to the north-east, the contact between the Jura Quartzite and the overlying Scarba Conglomerate Formation at the base of the Easdale Subgroup appears to be conformable, with no evidence of an orogenic unconformity at this level in the Dalradian succession (see the *Camas Nathais* CGR site report for further discussion in Treagus et al., 2013). However, marked lateral changes occur within the rock units immediately above this boundary (Figure 2.2)a. For example, the Jura Slate Member is 60 m thick in the south-west at the *Kilnaughton Bay* GCR site on Islay, reaches a maximum thickness of over 200 m a the *Lussa Bay* site on Jura (Tanner 2005), and is absent from the north-east of Juraat the *Kinuachdrachd* GCR site. The overlying Pebbly Sandstone Member is not as well developed on Jura as in the type area on the Isle of Scarba where individual blocks are on a metre scale (Anderton, 1979). At the *Kinuachdrachd* and *Lussa Bay* GCR sites on Jura the clasts seldom exceed one to two centimetres across and are commonly accompanied by rip-up clasts of mudstone. Individual beds commonly show normal grading in units 1–2 m thick. Cross-lamination is found in the tops of many beds, and slump structures, channelling, bottom structures and erosional bases to beds are common.

The Easdale Slate Formation consists mainly of dark grey to black graphitic slaty metamudstone, generally pyrite-rich, with pods and bands of orange-brown-weathering dolostone, and some layers of metasiltstone and metasandstone. The formation maintains the same monotonous lithology from the island of Kerrera, near Oban, southwards across the whole outcrop. The *Black Mill Bay* GCR site displays examples of all of the main lithologies. In addition, at this site there are black gritty metasandstones and a 4 m-thick debris flow containing strongly elongated sandstone clasts. This latter deposit is of the same type as that found at the *Port Selma* GCR site (Treagus et al., 2013). A clastic dyke sourced by a sandstone bed below the debrite flow was folded and cleaved during D1.

On Islay and Jura, the Kilbride Limestone Member of the Port Ellen Phyllite Formation that occurs above the Easdale Slates (Figure 2.2)a, is equated with the Degnish Limestone Formation and its equivalent, the Shuna Limestone (Figure 2.2)b, on the mainland. These metalimestones are correlated with the Cranford Limestone in Donegal (Pitcher and Berger, 1976), which has recently been taken as marking the plane of an orogenic unconformity within the Dalradian block (Hutton and Alsop, 2004). To date, no evidence has been reported from the South-west Grampian Highlands to support this contention (Tanner, 2005).

The outcrop of the Port Ellen Phyllite Formation on the islands of Islay and Jura lies in strike continuity, and is correlated with the Craignish Phyllite Formation on the mainland (Figure 2.2)b (Hill, 1879). The latter formation is well exposed at the *Craignish Point* and *Fearnach Bay* GCR sites and is characterized by grey-green calcareous phyllites with 1—2 m-thick beds of fine-grained quartzite, and thinner bands of orange-brown-weathering metacarbonate rock. Minor components include foliated sheets of basic meta-igneous rock, generally sills, whose ‘volcanic’ association was first recognized by Peach (1903). Where they are protected from subsequent deformation by thick basic sills, the metasedimentary rocks preserve a unique twinned form of gypsum, now pseudomorphed by calcite (*Craignish Point* GCR site), whose precise palaeoenvironmental significance is not clear at present.

On Islay, the Laphroaig Quartzite Formation (Figure 2.2)a (see the (*Surnaig Farm* GCR site report) marks the top of the Easdale Subgroup. The *Surnaig Farm* GCR site is also an exceptional locality for studying deformed clastic dykes. Over 30 dykes are exposed in a small area; they were originally described by Borradaile (1976) as Neptunian dykes but are re-interpreted here as injected clastic material and could be of interstratal origin. They were both folded and cleaved during D1.

On the east limb of the Loch Awe Syncline, the Ardrishaig Phyllite Formation is well exposed in the *Port Cill Maluaig* and *Strone Point* GCR sites. Despite the higher degree of metamorphism and deformation, the Ardrishaig Phyllites show the same field appearance, and maintain the same range in lithologies, as the Craignish Phyllites at the *Loch Fearnach* GCR site. The Crinan Grit Formation is best exposed in the *Kilmory Bay* GCR site where it has a conglomeratic unit, the Ardnoe Member at the base. The Ardmore Formation represents the base of the Crinan Subgroup on the islands, and is correlated with the Ardnoe Member on the mainland. A local calcareous unit, the Shira Limestone and Slate Formation occurs at the junction between the Easdale and Crinan subgroups (Figure 2.2)a and is seen on the mainland as a dolomitic breccia at the base of the Ardnoe Member. The top part of the Crinan Subgroup is best exposed in the *South Bay, Barmore Island* GCR site were it is represented by the Stonefield Schist Formation, which has a conformable and transitional contact with the Loch Tay Limestone Formation. The latter is 75 m thick in Kintyre at the *South Bay, Barmore*

Island GCR site but is represented in the core of the Loch Awe Syncline by the Tayvallich Slate and Limestone Formation and the Tayvallich Volcanic Formation, which have a combined thickness of 3200 m (of which the metalimestone accounts for *c*. 100 m). At the top of the Tayvallich Slate and Limestone Formation is the Kilchrenan Conglomerate Member, described in the *Kilchrenan Burn and Shore* GCR site report.

The Loch Na Cille Boulder Bed found near the top of the Tayvallich Subgroup (see the *West Tayvallich Peninsula* GCR site report)has been variously interpreted as a tectonic breccia (Peach *et al.,* 1911), a volcaniclastic debris flow (Pickett *et al*., 2006) or a glacial deposit (Elles, 1935; Prave, 1999). In the core of the Loch Awe Syncline the Tayvallich Subgroup passes up into the Loch Avich Grit Formation and Loch Avich Lavas Formation, belonging to the Southern Highland Group (Figure 2.2)b.

1.3 Pre-tectonic igneous dykes and sills

Basic sills that were emplaced before the regional deformation and metamorphism are common in the upper part of the Argyll Group in the South-west Grampian Highlands, and in places they make up more than 50 per cent of the succession. Contact metamorphism adjacent to the thicker sills causes local baking and hardening of the country rocks. As a result these beds are protected from much of the subsequent deformation, so preserving features such as pseudomorphs after gypsum (*Craignish Point* GCR site), and sedimentary structures (*Kilmory Bay* GCR site). Massive sills of this type are reported from the *Ardilistry Bay, Ardbeg, Craignish Point and Kilmory Bay* GCR sites. Those at Ardbeg and Ardilistry Bay are considered to be representative.

Igneous dykes and sills either of unusual composition (i.e. more mafic than normal) or containing unusual minerals, are found at three localities in South Islay, close to the Port Ellen Phyllite–Laphroaig Quartzite contact. At Ardbeg, there is a folded 70 m-thick sill that is unusual for containing large crystals (up to 1 mm long) of the brittle mica, stilpnomelane. At Ardilistry Bay, there is a unique, 12–14 m-thick basic sill containing at the base a 3 m-thick layer of metapyroxenite and a 1 m-thick meta-anorthosite. The clinopyroxene has been altered to actinolite, and the anorthosite to an assemblage containing albite and epidote. At the *Surnaig Farm* GCR site, there is a unique occurrence of a cleaved dyke of metamafic rock.

1.4 Structure

The area has a simple structural geometry controlled by a series of upward-facing F1 major folds. These are (from south-east to north-west) the Ardrishaig Anticline (equivalent to the Tay Nappe), the compound Loch Awe Syncline, and the Islay Anticline (Figure 2.1), (Figure 2.33). The slaty cleavage shared by these structures changes orientation from vertical in the south-east, to dipping south-east at a moderate angle on Islay. The folds are gently curvilinear and the stretching lineation has a regional down-dip orientation. No major tectonic breaks have been recognized.

The Tay Nappe and its relationship with the Ardrishaig Anticline are fully described and discussed by Tanner et al. (2013b). The Loch Awe Syncline, being a more-obvious, open structure, has been known about for much longer and MacCulloch reported a ‘fan structure’ in this region in 1819. Hill (1899) recognized that it is a major fold and he was the first person to correlate the Craignish Phyllites on the north-west limb with the Ardrishaig Phyllites on the south-east limb. Roberts (1974) identified it as a major F1 structure, correcting Bailey’s (1913) interpretation of it as a secondary fold (see the *Kilmory Bay* GCR site report). The Loch Awe Syncline has a tripartite hinge comprising the Tayvallich Syncline, the Loch Sween Anticline and the Kilmory Bay Syncline. The Kilmory Bay Syncline is the more complex of these three structures and its hinge-zone consists of a bundle of at least five mesoscopic fold closures (see the *Kilmory Bay* GCR site report).

The Islay Anticline was first recognized by Peach and Wilkinson (1909) but both the stratigraphy and the structure were completely re-interpreted by Bailey (1917). Part of his map is reproduced here (Figure 2.4), as it is a fine example of the style of map produced during this period, and is accompanied by a dynamic cross-section, which has not been bettered. There was an early dispute over whether this fold is a syncline or an anticline, and this was not resolved conclusively until the work of Allison (1933). The Islay Anticline is poorly exposed; for such a large structure, there is surprisingly little published information on its geometry, and few structural symbols on the BGS 1:50 000 sheets for the area. The fold

trace appears to consist of en-echelon segments displaced by faulting (Figure 2.1). The fold axis plunges gently to the north-east for most of its outcrop on Islay, except at the far north end of the island where it plunges to the south-west (see the *Rubha a' Mhail* GCR site report).

The area also lies on the north-west limb of the F4 Cowal Antiform, a major arch-like structure that folds the early fabrics and the Ardrishaig Anticline/Tay Nappe (see Tanner et al., 2013b). It has a broad hinge-zone represented by the Cowal Flat Belt, the north-west limit of which was designated the Tarbert Monoform by Roberts (1977c). However, although F4 box folds occur locally in the position of the proposed monoform, examination of the Geological Survey map sheets 29 and 37 suggests that there is a gradual change in overall curvature of the strata across this zone, and no evidence of an abrupt increase in regional dip.

In the context of these major structures, the *Rubha a' Mhail* GCR site lies in the core of the Islay Anticline; the *West Tayvallich Peninsula* GCR site contains the hinge-zone of the Tayvallich Syncline;the *Kilmory Bay* GCR site straddles the complex hinge-zone of the Kilmory Bay Syncline; the *Loch Avich* GCR site lies in the core of the Kilchrenan Syncline, a component of the Loch Awe Syncline; and the *Strone Point* GCR site is located a short distance south-east of the hinge of the Ardrishaig Anticline where there is a analogous pair of congruous mesoscopic F1 folds.

Of the remaining sites, 14 lie on the common limb between the Islay Anticline and the Loch Awe Syncline. Bedding dips to the south-east at a moderate angle at all of these sites, except at the *Caol Isla* GCR site, which is affected by its proximity to the hinge-zone of the Islay Anticline. It is everywhere cut by the S1 penetrative to spaced cleavage, which dips more steeply in the same direction. F1 fold hinges generally plunge to the north-east or south-west but are locally strongly curvilinear. There is a weak down-dip L1 stretching lineation at most of these localities. A gently dipping to horizontal crenulation cleavage is sporadically developed throughout this fold limb, and is only associated with mesoscopic folds at the *Black Mill Bay* GCR site. This fabric represents a late deformation, which is of post-D2 age. The effects of the D2 deformation, seen as an intense planar fabric that overprints and almost completely reworks S1, is seen only at the *Port Cill Malluaig* GCR site.

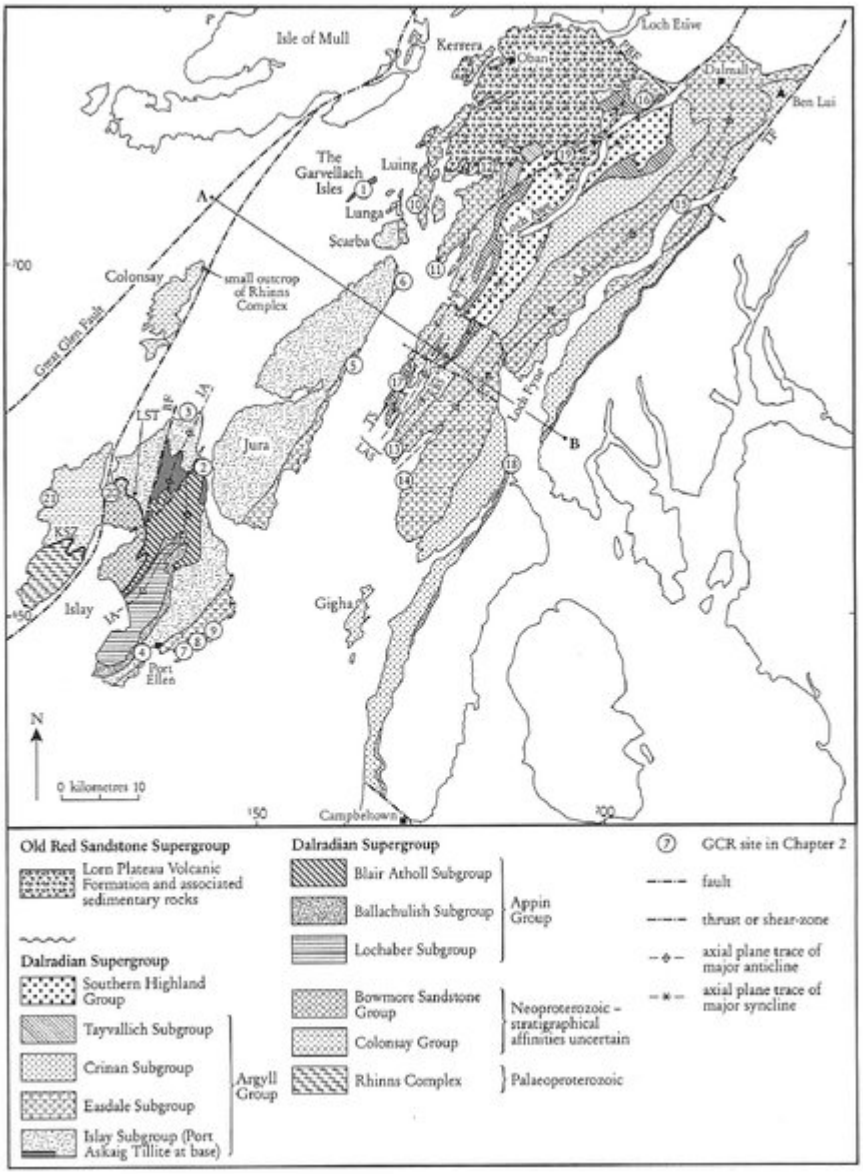
1.5 Regional metamorphism

Metamorphic grade is largely of greenschist facies, except along the south-east margin of the region, where it reaches the garnet zone of the epidote-amphibolite facies at a temperature of over 500°C and a pressure estimated at 10 kbar (Graham *et al*., 1983). A number of studies have been carried out on the regional metamorphism of the concordant basic meta-igneous sheets, and models have been formulated for the regional circulation of metamorphic fluids in these rocks (i.e. Graham *et al.,* 1985; Skelton *et al.,* 1995), with the major antiformal fold closures acting as conduits for the fluids. Apparently anomalous high pressures, calculated using the phengite geobarometer (Graham *et al*., 1983; Dymoke, 1989), are partly substantiated by the local presence of regional metamorphic kyanite in greenschist-facies rocks (see the *Kilnaughton Bay* GCR site report).

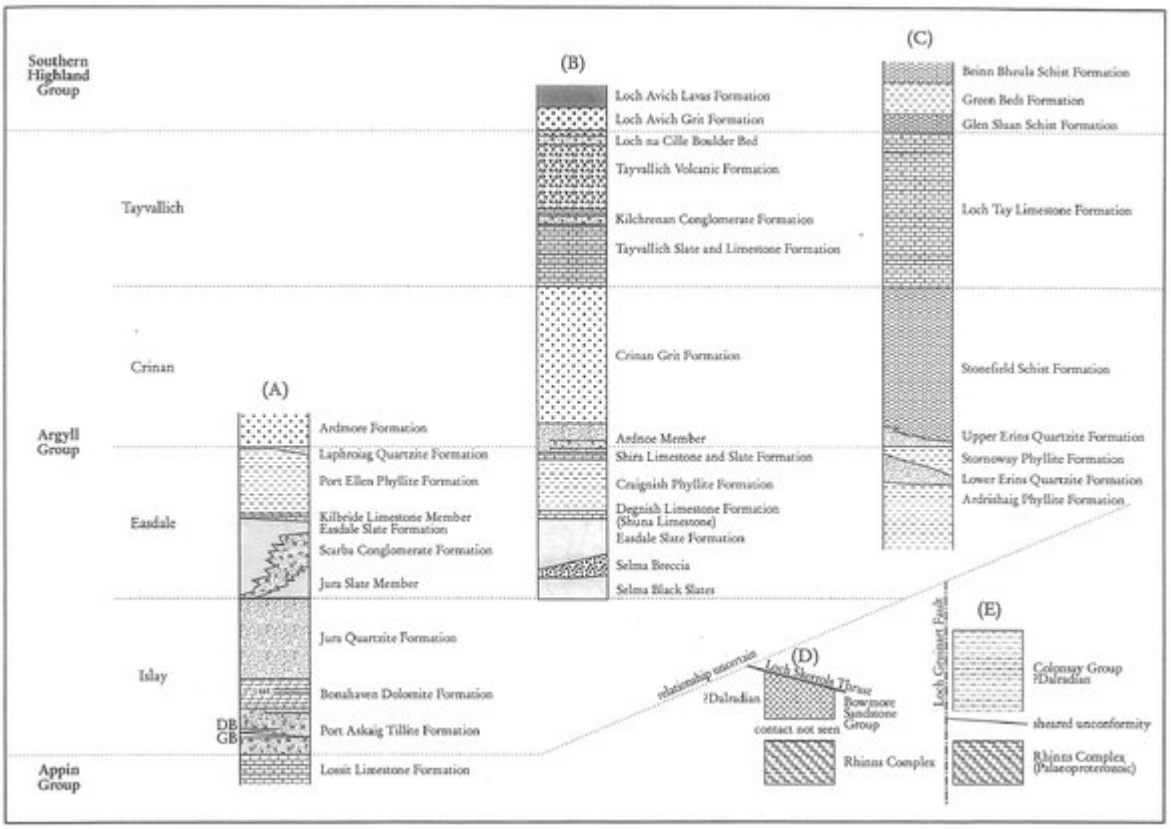
1.6 Features of specialized interest

Topics of particular interest covered in the GCR reports in this paper include:

- Origin of a Neoproterozoic glacial deposit: the Port Askaig Tillite (*Garvellachs Isles* GCR site)
- Extremely well-preserved Neoproterozoic stromatolites (*Rubha a'Mhail* GCR site)
- Water-escape structures and sedimentary or clastic dykes (*Coal Isla* and *Surnaig Farm* GCR sites)
- The unique form of gypsum, and its environmental implications (*Craignish Point* GCR site)
- Pre-tectonic igneous dykes and sills, and some unusual minerals
- The geometry of cylindrical and curvilinear folds (*Strone Point*, *Fearnach Bay* and *Port Cill Maluaig* GCR sites)
- The development of kyanite in greenschist-facies regional metamorphic rocks (*Kilnaughton Bay* GCR site)
- A putative orogenic unconformity in the Dalradian (*Kilnaughton Bay*, *Lussa Bay* and*Kinuachdrachd* GCR sites
- Nature of the Dalradian basement (*Kilchiaran to Ardnave Point* GCR site).

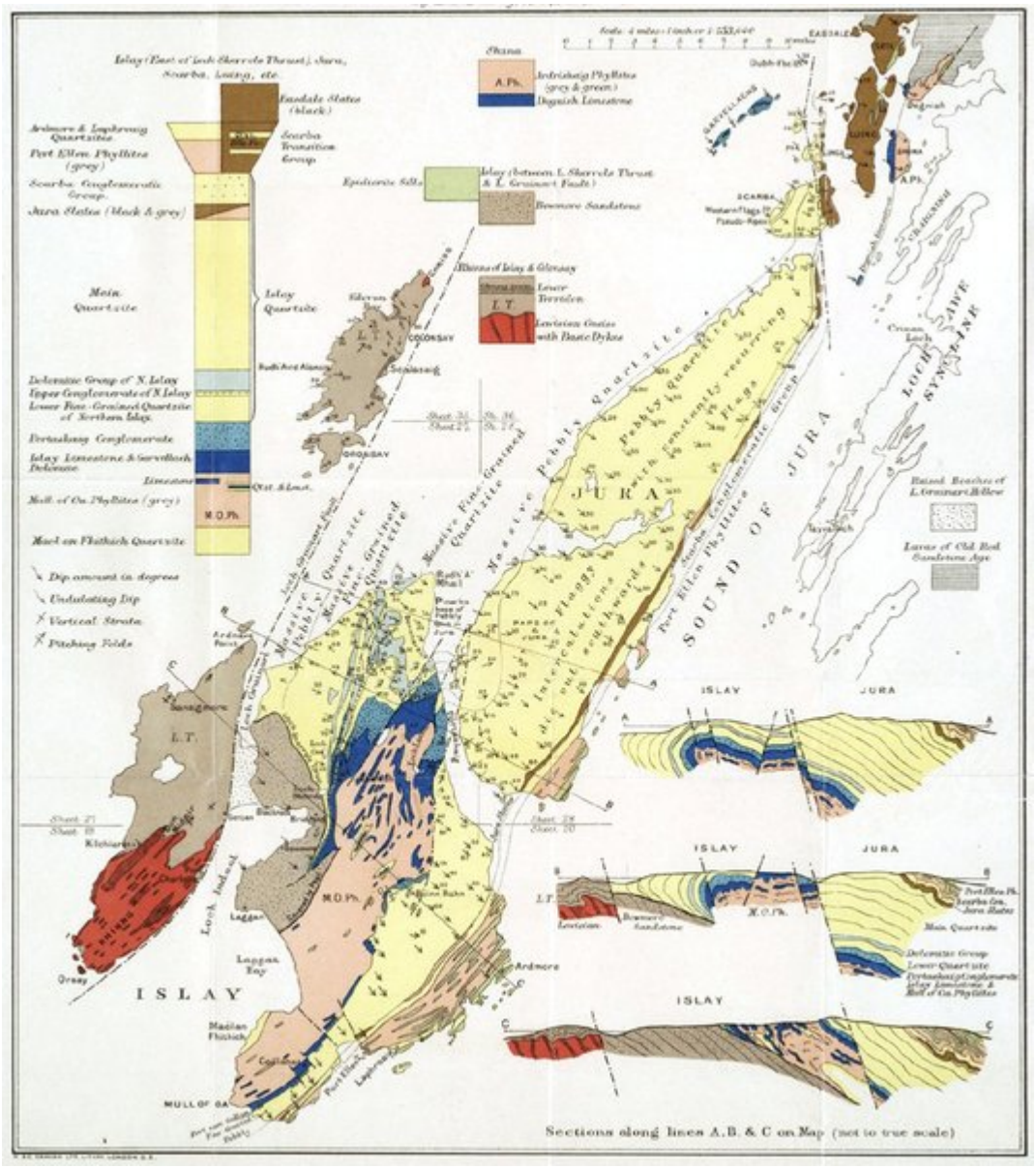


(Figure 2.1) Map of the South-west Grampian Highlands showing subgroups of the Dalradian Supergroup, the axial plane traces of major folds, the line of section A–B on (Figure 2.3) and the locations of the GCR sites included in this chapter. Only areas described in Chapter 2 are ornamented. GCR sites: 1 Garvellach Isles, 2 Caol Isla, Islay, 3 Rubha a'Mhail, Islay, 4 Kilnaughton Bay, Islay, 5 Lussa Bay, Jura, 6 Kinuachdrach, Jura, 7 Surnaig Farm, Islay, 8 Ardbeg, Islay, 9 Ardilistry Bay, Islay, 10 Black Mill Bay, Luing, 11 Craignish Point, 12 Fearnach Bay, 13 Kilmory Bay, 14 Port Cill Maluaig, 15 Strone Point, 16 Kilchrenan burn and shore, 17 West Tayvallich peninsula, 18 South Bay, Barmore Island, 19 Loch Avich, 20 Bun-an-Uillt, Islay, 21 Kilchiaran to Ardnave Point, Islay. Abbreviations: AA Ardrishaig Anticline, BF Bolsa Fault, IA Islay Anticline, KBS Kilmory Bay Syncline, KSZ Kilchiaran Shear-zone, LAS Loch Awe Syncline, LGF Loch Gruinart Fault, LST Loch Skerrols Thrust, PBF Pass of Brander Fault, TF Tyndrum Fault, TS Tayvallich Syncline.



(Figure 2.2) Stratigraphical columns (not to scale) showing lateral correlations between members and formations of the Dalradian Supergroup in the South-west Grampian Highlands. A the islands of Islay, Jura and the Garvellachs, B the Loch Awe Syncline, C the Ardrishaig Anticline, core and south-east limb, D and E rocks of uncertain affinity on Islay and Colonsay, and those forming the basement to the Dalradian Supergroup. GB Great Breccia, DB Disrupted Beds.

(Figure 2.33) En-echelon segmented sedimentary dyke (centre) parallel to spaced axial planar cleavage, Ardrishaig Phyllite, Kilmory Bay [NR 697 728]. (Photo: P.W.G. Tanner.)



(Figure 2.4) Facsimile copy of part of the geological map of Islay published by E.B. Bailey (1917).