2 Garvellach Isles

[NM 633 088]–[NM 683 128]

P.W.G. Tanner

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2.1 Introduction

The Garvellachs ('Isles of the Sea') are an isolated group of uninhabited islands in the Firth of Lorn, which preserve the best-exposed section through a Precambrian glacial deposit to be found in the United Kingdom. This unit, the Port Askaig Tillite Formation, consists of a succession of 'boulder beds' (metadiamictites) and interbedded metasedimentary rocks that, although gently tilted, is largely unaffected by tectonic distortion or faulting. Its relationship with the underlying Lossit (formerly Islay) Limestone Formation may be examined in the Garvellachs, and the top of the tillite sequence can be seen on Islay, 50 km to the south-west, where it passes conformably upwards into rocks of the Bonahaven Dolomite Formation (see the *Caol Isla* GCR site report) (Figure 2.1). The Port Askaig Tillite marks the base of the Argyll Group (Figure 2.2) and has been used as a key lithostratigraphical marker for correlating the Scottish and Irish Dalradian successions (Kilburn *et al*., 1965).

The architecture and internal morphology of the tillite formation are magnificently exposed on the 7.6 m (25 ft) raised rock platform around the islands, and individual beds can be reliably traced across each island due to the excellent exposures. Here the beds preserve a wealth of sedimentological features, which have been largely destroyed in rocks of similar age elsewhere in Scotland and Ireland due to the effects of later intense deformation and metamorphism. The tillite sequence on the Garvellachs consists of numerous boulder beds, which together with the interstratified sedimentary rocks, has an exposed thickness of 578 m (Spencer, 1971, 1981). Together with a further 172 m of beds at the top of the sequence, seen on Islay but not exposed on the Garvellachs, it represents the thickest known development of the Port Askaig Tillite.

Following regional mapping by the Geological Survey (Peach *et al.*, 1907), the first detailed account was by Kilburn *et al.* (1965) who prepared a measured section across the boulder beds as part of a survey of glacial deposits in the Dalradian successions of Scotland and Ireland. Spencer (1971) then published the definitive monograph on the Port Askaig Tillite, which has proved a *vade-mechum* for all future work and interpretation. However, despite the benefit of its excellent state of preservation, the age, origin, and source of the tillite have been hotly disputed. Hypotheses for its formation have ranged from non-glacial causes, such as subaqueous mud or debris flows (Schermerhorn, 1974, 1975), to a glacial origin, either by deposition from grounded glacier ice (Kilburn *et al*., 1965; Spencer, 1971, 1985), or from floating icebergs supplying exotic materials to a tidally-influenced marine basin (Eyles and Eyles, 1983; Eyles and Clark, 1985; Eyles, 1988). Source terrains for the exotic stones have been sought in Sweden and Finland (Spencer, 1981); Labrador and Greenland (Evans*et al*., 1998); and even South America (Dalziel, 1994). An additional problem is its age of deposition. For many years the tillite was assumed to be equivalent to the Varanger Tillites of Scandinavia, Greenland and Svalbard (Hambrey, 1983; Hambrey and Harland, 1985). However, the long-accepted, though imprecise, *c*. 653 Ma age of these tillites has now been revised to 620–590 Ma, which is more comparable with the top of the Argyll Group than the bottom. Hence various alternative suggestions have been made, which correlate the Port Askaig Tillite with either the Marinoan (*c*. 635 Ma) or Sturtian (*c*. 723 Ma) global glacial events (see Stephenson et al., 2013a).

There has been a recent resurgence of interest in the number, age, and causes of the late-Precambrian glaciations and their temporal relationship to the evolution of metazoan life forms in the Cambrian, and the Garvellach Isles GCR site has a key role to play in this work.

2.2 Description

The sequence on the Garvellachs begins with the dolomitized, 70 m-thick, upper part of the Lossit Limestone Formation, which is exposed on the most westerly and accessible of the islands, Garbh Eileach (Figure 2.5). An interesting feature of the metalimestone is that locally it contains arrays of radiating, stellate pseudomorphs a few centimetres long (Spencer, 1971, plate 6), which consist of a quartz-dolomite intergrowth. These pseudomorphs can be examined at [NM 676 127] and are of disputed parentage.

The Lossit Limestone is overlain conformably by the Port Askaig Tillite Formation ('Boulder Bed' or 'Conglomerate' of the early authors). Although the type area of the tillite is at Port Askaig on Islay, it is best seen on the Garvellachs where it consists of 38 individual metadiamictites, from less than 1 m to over 20 m thick, with boulders to 2 m across. The upper dolomitized part of the Lossit Limestone together with the first 12 metadiamictite units are seen only on the Garvellachs, being absent on Islay where Unit 13 lies unconformably upon the metalimestone.

The boulder beds were called 'mixtites' by Spencer (1971), but modern workers prefer the non-genetic term 'diamictite', to describe a rock consisting of a poorly sorted aggregate of mud-, sand-, and gravel-sized detritus. The tillite sequence, which includes considerable thicknesses of tabular bedded sedimentary rocks and breccias, was divided into 5 units by Spencer (1971), and includes two distinctive members, the Great Breccia and the Disrupted Beds. The uppermost part of the tillite is not preserved in the Garvallachs, but is seen in the Port Askaig area of Islay.

The tillite is excellently exposed on the rock platform around the north-east end of Garbh Eilach and is accessible from 200 m north-west of Belach Buidhe [NM 676 127] to Sloc a' Cheatharnaich [NM 675 119]. The field relationships have been described in detail by Fairchild (1991). The sequence begins with metadiamictites 1–12, containing mainly dolostone clasts, passes upwards into the Great Breccia and the Disrupted Beds, and ends with the upper metadiamictites (18–32) which are characterized by their high content of 'exotic', usually granitic, boulders (Figure 2.5). Most features of the succession are well displayed in this section, with the upper metadiamictites being best seen between [NM 675 119] and [NM 670 118], close to the landing stage. These include dropstones, erosion surfaces, sandstone wedges, load structures, slumped horizons, wave-ripples, and varve-like sequences (Kilburn *et al.,* 1965; Spencer, 1971; Eyles and Eyles, 1983; Eyles and Clark, 1985).

The metadiamictites decrease in thickness and frequency upwards, and the whole formation is an upwards-fining sequence that shows a transitional passage into the overlying Bonahaven Dolomite Formation (see the *Caol Isla* GCR site report). The associated interbeds, which occur in units up to 11 m thick, include rippled and cross-bedded white and brown metasandstones, orange-brown metadolostones, and metaconglomerates, are rich in dolomite at the base of the sequence and become less dolomitic and more feldspathic upwards. Most of the metadolostones have been shown to be detrital in origin and derived from the underlying Lossit (formerly Islay) Limestone (Fairchild, 1983, 1985), and therefore have no palaeoclimatical significance.

The clasts in the metadiamictite horizons can be divided into *intrabasinal* stones derived from the local substrate, and *extrabasinal*, or 'exotic,' stones of unknown provenance. The intrabasinal stones consist of abundant, angular, metadolostone fragments, with dolomitic metasiltstone, metaconglomerate and very rare metalimestones; the exotic ones are mainly of pink granite (commonly referred to as being of Rapakivi-type or nordmakite e.g. Spencer, 1971), with some gneiss, schist and quartz clasts. The extrabasinal stones are subrounded and reach 1.5–2.0 m in diameter. The lowest metadiamictites contain locally-derived stones but exotic stones appear above Unit 12 and become common in the upper beds in which a feldspar-rich matrix is also developed. This upward change in provenance is reflected in the whole-rock geochemistry (Panahi and Young, 1997), which distinguishes lower metadiamictites derived by the erosion of sediments, which had already undergone a previous cycle of post-Archaean weathering, from upper metadiamictites derived from a mixed granitic and post-Achaean sedimentary source.

Two distinctive members are thicker and coarser grained than on Islay, and are not seen elsewhere in the tillite outcrop. The Great Breccia is 40 m thick and contains enormous intrabasinal clasts of metadolostone, the largest, occurring at [NM 639 099] on Eileach an Naoimh, being over 70 m long and folded into an antiform. The overlying Disrupted Beds is a unit 29–40 m thick, well exposed at [NM 666 122] on Garbh Eilach, which consists of semicontinuous beds of metadolostone and cross-bedded metasandstone that have been partially boudinaged and pulled-apart.

Special features of the metadiamictites that have provided clues as to their glacial origin, or are of particular interest, include: numerous dropstones in finely bedded or laminated sequences; large polygonal structures on bedding surfaces, illustrated and described in detail by Kilburn *et al*. (1965), Spencer (1971) and Eyles and Clark (1985) and seen at [NM 646 101]; millimetre-thick, varve-like, laminations in metasiltstone beds, some with over 2500 laminae (Spencer, 1981) [NM 675 119]; sedimentary dykes up to 30 cm thick and traceable for several hundred metres [NM 667 124]; and sandstone downfold structures above metadiamictites (Spencer, 1971; Eyles and Clark, 1985), which can be seen at a number of places.

The Port Askaig Tillite on the Garvellachs has a simple structural setting: the entire sequence of beds dips to the south or south-east at around 35°, and forms part of the north-western limb of the Loch Awe Syncline (F1). A single main penetrative cleavage is developed locally, which dips to the south-east more steeply than bedding and appears to belong to the same generation as the major syncline; it can be seen as a spaced cleavage in some of the metasandstones. The early cleavage is crenulated locally, and late kink bands are also seen (Spencer, 1971). The beds are affected by some internal strain, as shown by the deformation of pebbles and by the slight distortion of the polygonal patterns seen on bedding surfaces.

2.3 Interpretation

The mode of origin and source of the tillite have been the subject of lively geological interest since MacCulloch, one of the earliest geological travellers in the region, reported the presence of a conglomerate on the Garvellachs in 1819, and suggested that it might be correlated with similar deposits at Schihallion, and on Islay. However it was Thomson (1877, p. 211) who first suggested a glacial origin for this boulder bed and anticipated the modern, most widely accepted, interpretation for the deposit, writing that 'the entire absence of stratification in one part of the section, which in another shows signs of regular deposition, and the occurrence of far transported rocks of the character already stated, indicate that the mass had been transported and dropped from melting ice in a shallow, tranquil sea, the bottom consisting of mud and sand'.

Spencer (1971) concluded that the tillite was deposited from a grounded ice sheet, an interpretation challenged by Schermerhorn (1974) who interpreted it as a mass-flow deposit, and by Eyles and Eyles (1983) who argued for glacimarine deposition beneath floating icebergs, with much reworking of the sediments by currents. These interpretations are dependent upon understanding not only the overall architecture of the deposit, but the depositional environment of the sedimentary interbeds, and the degree to which the diamictites have been reworked by currents. The interpretation of minor features diagnostic of particular environments, such as polygonal sets of sediment-filled cracks, varves, pseudomorphs etc. also plays a vital role in this work and these features have been much discussed in recent years. For example, large polygonal networks seen on bedding surfaces at [NM 646 101] on Eileach an Naoimh were interpreted as ice-wedge polygons (indicating subareal exposure in a cold climate) by Spencer (1971, plate 8), but as subaqueous soft-sediment dykes whose formation is not dependent upon the presence of ice, by Eyles and Clark (1985). Likewise, the pseudomorphs seen in the Lossit Limestone, which Spencer (1971) speculated may be of glendonite (and hence derived from ikaite, a mineral stable only below 4°C (Shearman and Smith, 1985), and diagnostic of a cold climate), could equally well be secondary after gypsum, and indicative of warm, arid conditions.

On a continental scale, glacial deposits have been used to reconstruct past plate configurations, by determining the direction of transport of the tillite and tracing the origin of the boulders to their source region. U-Pb dating of zircon from two granitic clasts from the Port Askaig Tillite on the Garvellachs and Islay has yielded ages of *c*. 1800 Ma (Evans *et al.,* 1998). These dates, together with Nd model ages (Fitches *et al.,* 1996), show that the material was derived from a Palaeoproterozoic source, with no involvement of Archaean crust. The exotic clasts might have been derived from Palaeoproterozoic (*c*. 1800 Ma) terranes in Labrador, South Greenland or Scandinavia. A Laurentian, rather than Gondwanian, source is favoured. It is unfortunate in this respect that a palaeomagnetic study of the Port Askaig Tillite on Garbh Eileach has shown that the rocks were remagnetized during the Early Ordovician (Stuparsky *et al*., 1982), and hence this technique cannot be used to determine the palaeolatitude at which the tillite was deposited, as had been suggested previously by Tarling (1974).

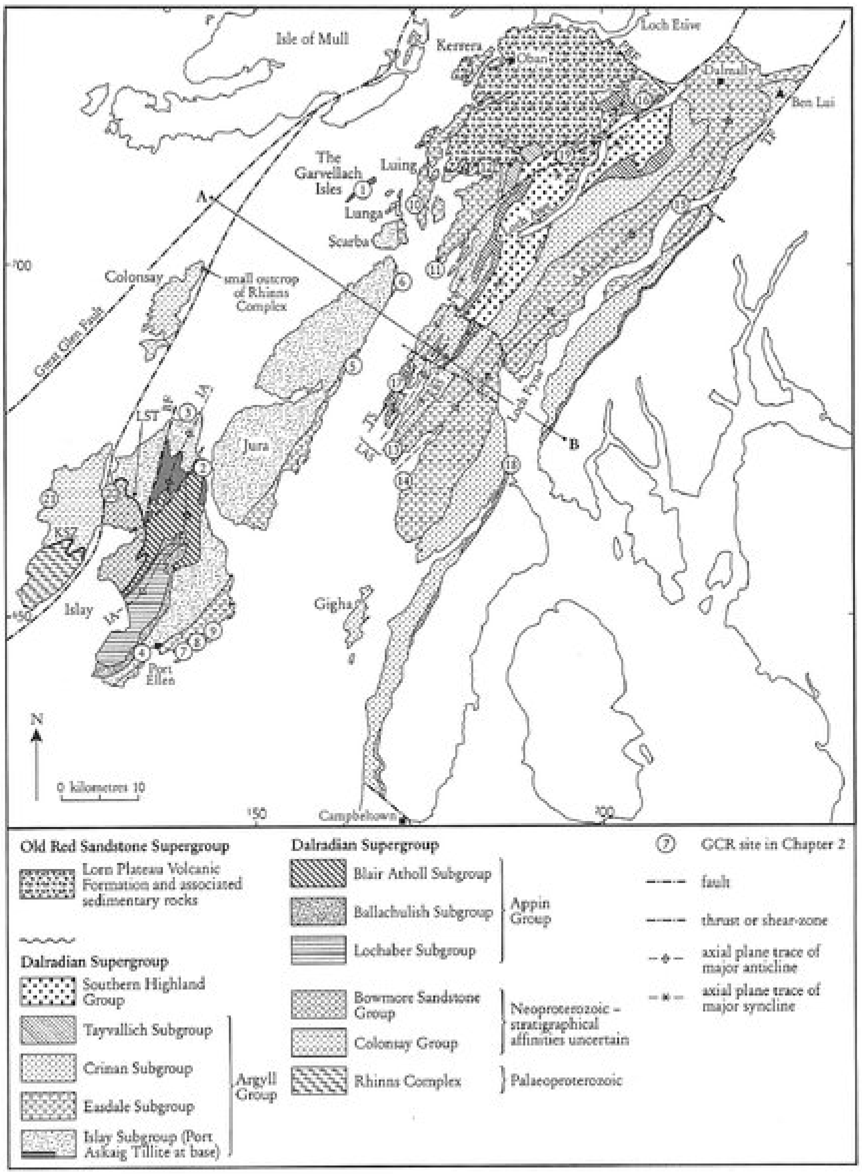
Physical evidence for the direction of movement of the glacial material is also ambiguous. The Great Breccia has been interpreted as either a debris flow (Eyles and Eyles, 1983) or as a grounded-ice till (Fairchild, 1985, 1991). The large fold in the Great Breccia (first figured by Peach *et al.,* 1909) has been much discussed in the literature as it is considered by some workers to be a glacial-push fold (Spencer, 1971), with movement from the south-east, or a soft-sediment slump fold (Eyles and Eyles, 1983), with movement in the opposite direction.

2.4 Conclusions

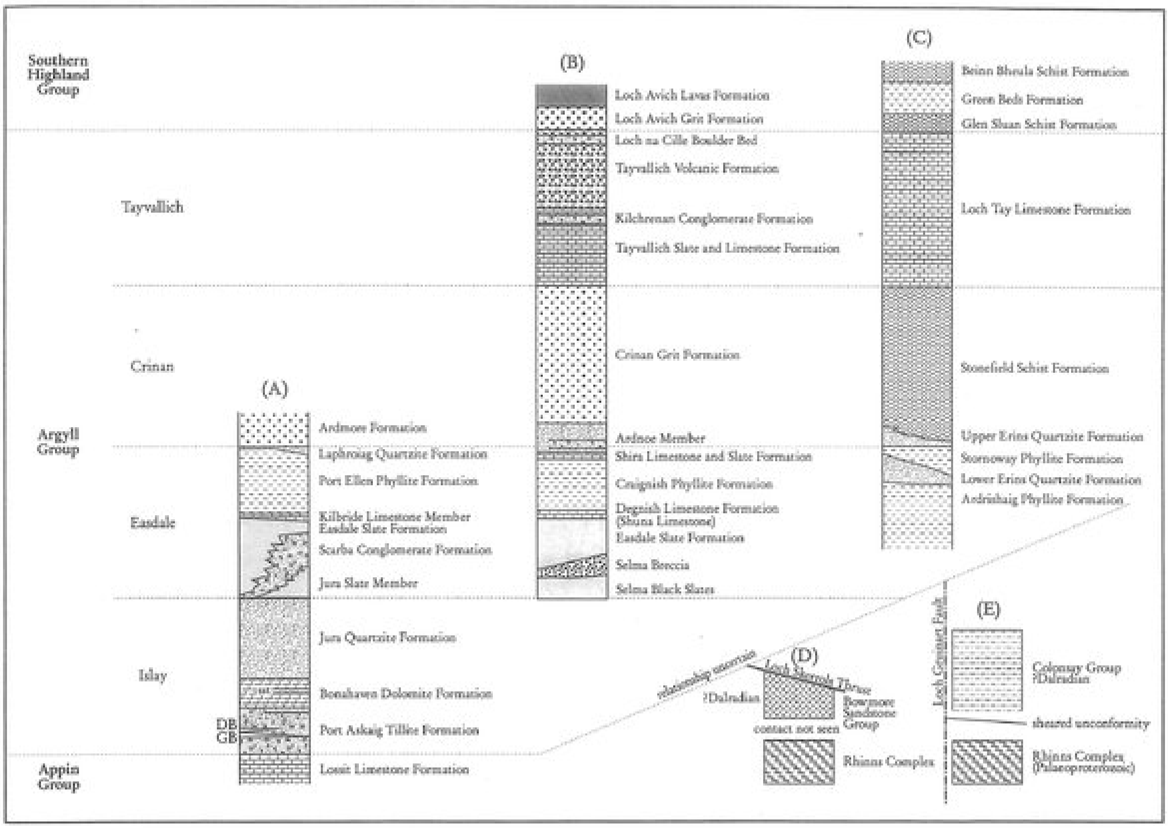
The Garvellach Isles GCR site preserves internationally important exposures of a Precambrian glacial deposit, the Port Askaig Tillite, which is unique in the UK for its excellent state of preservation and wealth of small-scale sedimentary features. This stratigraphical unit has been used as a marker horizon for correlating Dalradian sequences in Scotland and Ireland, and has been proposed as a link for use in global-scale tectonic plate reconstructions. Although its precise environment of deposition is still being debated, it is generally agreed to be of glacial origin, as evidenced by the presence of numerous, large, 'exotic', far-travelled dropstones in finely laminated metasedimentary rock. It was probably formed largely of material dropped from floating icebergs and reworked by tidal currents, and is the thickest deposit of this type in the Dalradian Supergroup. The Port Askaig Tillite is evidence for a major glacial episode having occurred in late-Precambrian times.

This GCR site continues to provide a classical testing ground in which to distinguish between different models for Precambrian tillite formation, and for examining the morphology of a wealth of controversial features such as fossil ice-wedge polygons, soft-sediment deformation structures, varves, exotic boulders of problematical origin, and unusual pseudomorphs. The interpretation of these features is important in understanding the climatic conditions, and hence the latitude, at which these rocks were deposited on the Earth's surface prior to the subsequent break-up and dispersal of the continental blocks in the North Atlantic region. The value of this site is considerably enhanced by the current interest worldwide in the timing, correlation, and causes of Neoproterozoic glaciations.

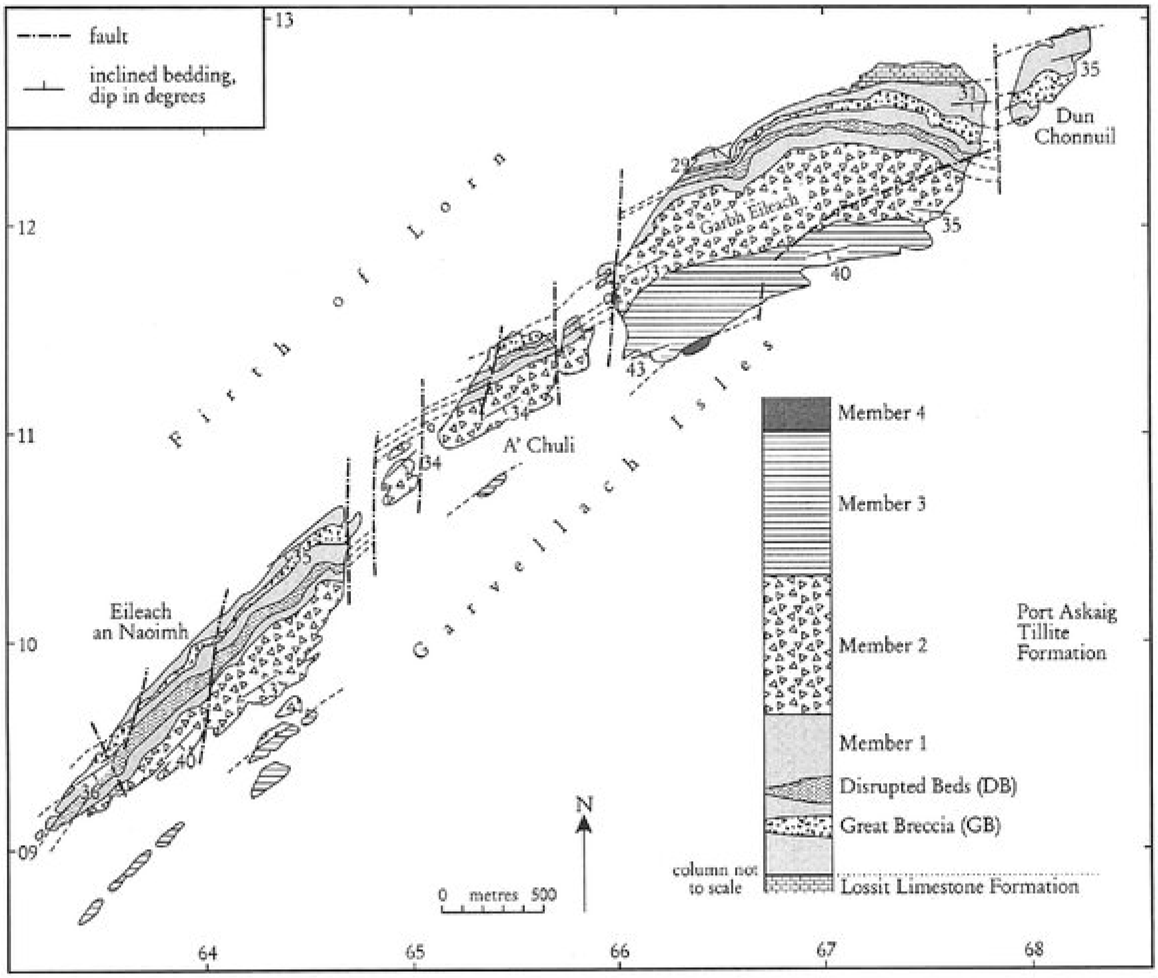
References



(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 2.5) Map of the Garvellach Isles, Firth of Lorn, after Spencer, (1971).