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SHORT PAPER

Is the Colonsay–west Islay block of SW Scotland an allochthonous terrane? Evidence from Dalradian tillite clasts

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In the Scottish Caledonides context, the Colonsay–west Islay terrane has seemed anomalous and therefore likely to be allochthonous. New studies suggest, however, that its basement is not necessarily exotic but represents the missing early Proterozoic link between Greenland and Scandinavia. Recent interpretations of the Scottish mainland deformation history imply that the age of the Grampian events there resembles that of the late Proterozoic deformation previously identified in the Colonsay Group cover succession. Reconnaisance studies of Dalradian tillite provenance suggest that the Colonsay–west Islay basement was a source of Dalradian sediment and perhaps floored that basin. There is, therefore, less reason now to regard the Colonsay–west Islay terrane as allochthonous, and recent hypotheses of its tectonic emplacement being the cause of the Grampian orogeny should be viewed with caution.

The Dalradian Supergroup of Scotland and the Grampian nappes that deform it are entirely Precambrian, according to the interpretations of new isotope data by Rogers *et al.* (1989). Consequently, a major reappraisal of the late Proterozoic history of the Grampian terrane is required. Among their far-reaching interpretations, Rogers *et al.* speculated that the *c.* 600 Ma Grampian deformation in the SW Highlands region was caused largely by the docking of the Colonsay–west Islay terrane against the Grampian terrane (Fig. 1). They suggested that the terranes amalgamated by NW–SE compressional displacement, close to a tectonically active ocean margin, rather than by the strike-slip motion invoked by Bentley *et al.* (1988).

This new interpretation seems to be an attractive explanation of the apparently anomalous lithological and tectonic aspects of the Colonsay–west Islay terrane highlighted by Fitches & Maltman (1984), Bentley (1988) and Bentley *et al.* (1988), and of the Grampian events. However, we see three reasons for urging caution in accepting this model uncritically: early structures and fabrics in the Colonsay–west Islay terrane are not entirely consistent with the NW–SE terrane closure model; the concept of a Colonsay–west Islay terrane that evolved independently of SW Scotland is questioned in the light of recently acquired isotope data and field-based studies in Islay; and there are indications from clasts in Dalradian sedimentary rocks that the basement to the terrane was already near the Dalradian basin during its subsidence history. These three points are treated in turn.

Tectonic displacement directions in the Colonsay Group. Fitches & Maltman (1984) explained the early, flat-lying structures and fabrics in the Colonsay Group of Colonsay as products of NW-directed simple shear, but noted that there are structures in Islay that do not readily conform to that interpretation. Rogers *et al.* (1989) suggested that the early structures were induced by the docking of the Colonsay–west Islay terrane with the Grampian terrane. Bentley (1986), however, has re-interpreted the early tectonic events in Colonsay in terms of sub-horizontal transpression in which the simple shear was directed NNE. In Islay, the recumbent folds, sub-horizontal cleavage and shear-sense indicators recorded in the Colonsay Group and its basement by one of us (R.J.M.) point to SW-directed ductile shear. Defining the senses of displacement during the early deformation of the cover and basement of the Colonsay–west Islay terrane is a subject of our on-going research. On present evidence, however, the displacements are not easily incorporated into a model of NW–SE terrane collision, without resorting to convoluted explanations.

Isotopic ages of basement and cover. The concept of a Colonsay–west Islay exotic terrane has been based on two main criteria. First, there are fundamental contrasts between the basement rocks of that terrane and those of the Lewisian Complex of NW Scotland and the Outer Hebrides (Muir *et al.* 1989). Secondly, the Colonsay Group cover has been deformed by structures shown to be older than *c.* 600 Ma by Bentley (1986), thereby seeming to rule out correlation of that cover with the Dalradian Supergroup which, until recently, was considered to have been deformed for the first time in the Phanerozoic.

The basement contrasts have been fully confirmed by recent field and isotope studies. Marcantonio *et al.* (1989), from their reconnaissance isotope work, suggested that the Islay basement comprises juvenile mantle-derived rocks emplaced *c.* 1800 Ma ago, implying correlation with the Ketilidian province of S. Greenland and the Svecofennian of Scandinavia. Results of a comprehensive isotope study of the Islay basement by one of us (R.J.M.) supports and elaborates on this suggestion. Moreover, his field and petrographic studies have revealed that the basement protolith is an alkalic igneous association of syenite, granodiorite, gabbro, ultrabasic and other rocks. This association has no counterpart in the Lewisian terrane to the north. It is probable that the Colonsay–west Islay basement partly completes the link between the Ketilidian and Svecofennian components of the early Proterozoic mobile belt that fringes the southern margin of the Laurentian craton; there is no longer reason to explain it as an exotic terrane.

The Colonsay Group of sedimentary rocks was deposited unconformably on the plutonic basement of the Colonsay–west Islay terrane, deformed by flat-lying structures, then intruded by alkaline-subalkaline igneous plugs at 600–635 Ma (Bentley 1986; Bentley *et al.* in prep.), and deformed again. This evidence of late Proterozoic deformation seemed to distinguish the Colonsay Group from the Dalradian Supergroup. The recognition of a pre-595 Ma age for the Grampian deformation by Rogers *et al.* (1989), however, begins to remove this distinction. There remain difficulties in structural and stratigraphic correlations between the Colonsay Group and the Dalradian Supergroup, but the need to view terrane as allochthonous is now greatly diminshed. Any model based on docking of the terrane should therefore be regarded with circumspection.

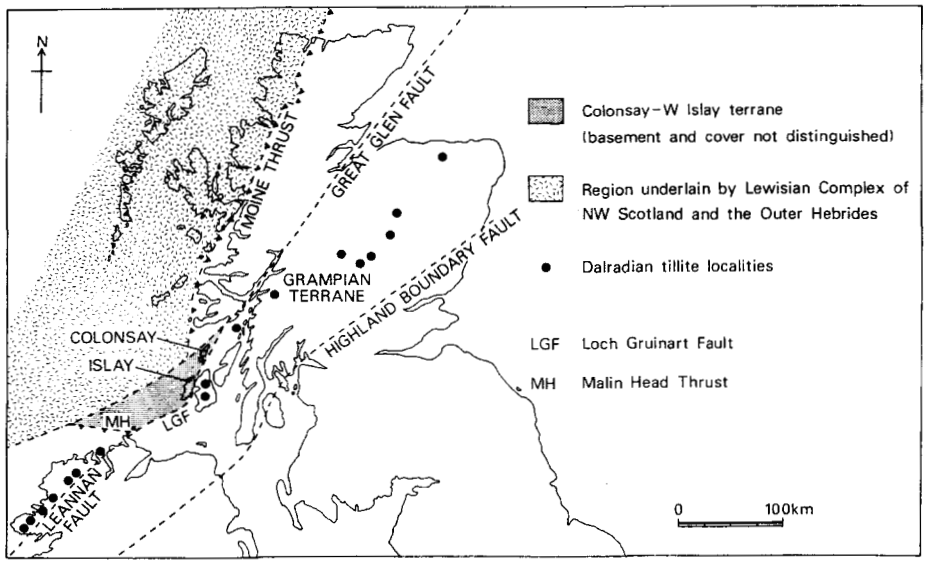

Fig. 1. Geological map of Scotland and NW Ireland (after Dunning 1985) to show the setting of the Colonsay–west Islay terrane and the distribution of late Proterozoic Dalradian tillites. Tillite localities after Harris & Pitcher (1975).

Provenance of Dalradian sediment. Perhaps the main impediment to determining precisely the geological relationships between the Colonsay–west Islay and Grampian terranes is that they are separated by faults or the boundary is submerged. It has become apparent from our recent studies, however, that the Colonsay–west Islay basement could be a source of clasts in parts of the Dalradian Supergroup succession. If so, that basement lay exposed close to the site of Dalradian sedimentation and was not some distant microcontinent that later impinged on the basin as it collided with the Grampian terrane. On this basis, the wedge-shaped mass imaged under the SW Highlands on the WINCH seismic profile (Hall *et al.* 1984), can be envisaged as Colonsay–west Islay basement continuing beneath part of the Dalradian basin as in situ basement, rather than a slab introduced tectonically beneath the basin as suggested by Rogers *et al.*

Our provenance arguments, still at the tentative stage, are based on observations made on clasts in the Port Askaig Tillite (Fig. 1), lying at the base of the Argyll Group ('middle' Dalradian), and to some extent on published information on other Dalradian siliciclastic units.

The Port Askaig Tillite is correlated with the Schiehallion Boulder Beds of the central Highlands of Scotland and the Glencolumkille Boulder Beds of Ireland (Spencer 1969, 1971, 1975), and probably equates approximately with the Varanger Tillites of Norway (Pringle 1972). It is widely exposed on eastern Islay, within 10 km of the Colonsay–west Islay terrane but separated from it by the Loch Gruinart fault. Most stones (using the terminology of those authors concerned with the glacial aspects of the deposits) in the lower part of the succession are dolomite, probably derived from older Dalradian strata. Higher in the succession the stones are predominantly of crystalline rocks. Their compositions have not been thoroughly described in the literature but are said to include: unfoliated granite and minor granitic gneiss (Spencer 1971); granite with Rapikivi-type texture and albitized granite (Spencer 1969, 1975); coarse, pink biotite alkali granite, granophyre, granite porphyry, gneissose granite, granitic gneiss and rare, altered basic igneous rocks (Kilburn *et al.* 1965); alkali granite (Treagus 1969, Kinlochlaggan Boulder Bed); and vein quartz, gneiss, and white, pink and red granite (Howarth *et al.* 1966 and Howarth 1971, Glencolumkille Boulder Bed). Sand-size particles from the tillites, listed by Spencer (1971), comprise a wide range of minerals: quartz, chess-board albite, albite–oligoclase, untwinned plagioclase, microcline, muscovite, biotite, dolomite, magnetite and pyrite, with accessory apatite, green tourmaline, zircon and rutile. Quartz with acicular rutile needles (in our opinion, probably the blue quartz observed in hand specimens), chess-board albite, albite–oligoclase, apatite, zircon and rutile are also components of the crystalline stones.

The crystalline stones and mineral fragments have been described as 'extra-basinal' and 'exotic' by various authors, and their source has been the subject of speculation. The upward change from dolomite-dominated to crystalline-dominated stones has been explained by either a progressive blanketing of the source rocks by the glacial beds (Kilburn *et al.* 1965) or by stripping of a dolomite cover from the source region to expose a granite-metamorphic basement (Spencer 1971). One of the problems in locating the source is that the palaeocurrent indicators in the glacial beds offer no clues on regional sediment transport directions. Spencer (1971, p. 29) concluded that 'a single palaeoslope of regional extent was absent throughout the deposition of the whole formation', and Kilburn *et al.* (1965, p. 358) considered that evidence of transport direction is 'too slight to be seriously discussed'.

Spencer (1969, 1975) favoured derivation from regions southeast of the Dalradian outcrop, partly on the evidence of rare NW-verging glacial push folds in the tillites and, as Kilburn *et al.* (1965) also noted, because of the conspicuous absence of Lewisian-type stones. Spencer (1969, 1975) further pointed out that some stones resemble the Rapikivi granites of Sweden and Finland, and suggested that their source therefore might lie within a southern extension of the 1000 Ma 'Gothides' (Sveconorweigan Province) now hidden beneath the northern European plain. He cited as support for this interpretation a *c.* 1000 Ma Rb/Sr whole rock age obtained from albitized granite stones, which he considered might date a metamorphic event (data of P. Leggo, reported by Spencer 1975).

Spencer (1975) also recorded K/Ar ages of 1807 ± 50 Ma and 1816 ± 40 Ma obtained from muscovite in a 'quartz–muscovite-granulite' boulder from the tillite by S. Moorbath. Here, we cannot comment constructively on the interpretation of these isotope ages, and simply point out that the K/Ar ages resemble those from the Colonsay–west Islay basement using other methods.

It was recognized by Spencer that derivation of stones from a southeasterly direction seems to require some method of transporting immense numbers of stones across the Iapetus Ocean. That problem is alleviated if the Iapetus Ocean opened widely after the glacial event or the source was continental crust lying between the Dalradian basin and that ocean (Anderton 1980). Eyles & Clark (1985) suggested the ocean was already open and was receiving large volumes of glacial debris from a mainland source to the southeast. A close source might best explain the uniformity of stone types, whereas distant sources would supply a much greater diversity (A.Stewart in discussion of Spencer 1969).

In the absence of Lewisian-type stones, a westerly source of stones has been largely discounted, although Llewelyn (in discussion of Spencer 1969) favoured that option. This alternative becomes more credible in the Islay region in the light of Anderton's (1985, 1988) arguments for a linked extensional fault system affecting Dalradian sedimentation patterns in that district. Footwall uplift on half-graben faults and elevation of blocks between transfer faults could have exposed the basement locally, whilst west Islay and other more westerly parts of that terrane perhaps remained emergent.

In our view, the Colonsay–west Islay terrane basement or its extension beneath the SW Highlands Dalradian provides a ready source of the tillite crystalline stones. The basement on Islay has been strongly deformed but the protolith is still recognizable as a suite of mainly syenites and gabbros, with localized granodiorite, together with a wide range of minor intrusions ranging in composition from acidic to ultrabasic. There are close petrographical similarities between several of these rock types and the tillite stones from the Port Askaig area, the deformed and undeformed granitic and syenitic rocks, in particular, appearing to be common to both. Moreover, the nordmarkitic, granitic and porphyritic acidic stones in the tillite point to derivation from a region with alkalic to sub-alkaline affinities; the Islay basement has just these affinities. Virtually all the detrital minerals in the tillites listed by Spencer (1971) can be identified in these basement rocks, which provide in particular an abundance of various feldspars.

It is also relevant to note that Anderton (1980) showed that clasts in the Jura Quartzites and other Dalradian psammites appear to be derived from the northwest. He suggested that the ultimate source may have been an early Proterozoic terrane of the type found in N America but that the more immediate source could have been the Torridonian Supergroup of NW Scotland. The chert, jasper and ferruginous clasts described by Anderton have no known counterparts in the Colonsay–west Islay terrane, but that basement could have supplied the other components, especially the abundant microcline.

Recent isotope data from Ireland are also consistent with a Colonsay–west Islay-type terrane supplying detritus to the southwestern parts of the Dalradian Supergroup. Daly & Menuge (1989) have shown from Sm-Nd data that *c.* 1900 Ma crust was a major contributor to those sedimentary rocks. Moreover, recent studies by one of us (R.J.M.) have shown that the islands of Inishtrahull and Tor Rocks, off Malin Head in Ireland, comprise deformed syenites and gabbros that are petrographically and geochemically indistinguishable from those of the Colonsay–west Islay basement. The ^{39}Ar-^{40}Ar isotope age of 1710 Ma obtained from amphiboles of the Tor Rocks gabbros by Roddick & Max (1983) augments the similarities with west Islay, and supports the hypothesis that Colonsay–west Islay type basement extended from the Inner Hebrides to Ireland and provided a substantial component of the NW margin of the Dalradian basin.

Our observations on the tillite stones are at a preliminary stage and therefore we make no categorical correlations with the west Islay basement. On-going studies of the geochemistry, petrography and isotopic aspects of the stones should enable us to test this hypothesis, and thereby demonstrate whether or not the Colonsay–west Islay igneous association lay close to, and perhaps continued beneath, part of the Dalradian basin. In the meantime, preliminary findings support the hypothesis, prompting caution about invoking collision of a formerly remote Colonsay–west Islay terrane with the Grampian terrane as an explanation of the Grampian deformation in SW Scotland.

Concluding remarks. The hypothesis that the Colonsay–west Islay terrane is exotic was prompted largely by evidence of deformation in the Colonsay Group being older than any tectonic event then dated in the Dalradian Supergroup, the lack of any convincing means of correlating the Colonsay Group with late Proterozoic successions on neighbouring islands and the mainland, and the anomalous petrography of the basement. Since the formulation of that hypothesis, however, the age of the earlier, Grampian deformation of the Dalradian has been revised and shown to be no longer conspicuously different from the earlier tectonic events in the Colonsay Group. The basement of the Colonsay–west Islay terrane has been confirmed as profoundly different from the Lewisian Complex of NW Scotland and the Outer Isles. It readily provides the 'missing link' between the Ketilidian province of S Greenland and the Svecofennian province of Scandinavia, and is therefore not necessarily allochthonous or exotic in its N Atlantic context. Moreover, there are strong indications that rocks of Colonsay–west Islay basement type supplied debris to the late Proterozoic Dalradian tillites and other siliciclastic deposits. If so, that basement was exposed close to the subsiding Dalradian basin and perhaps lay beneath it. In view of these new data and interpretations, any model of Grampian orogeny relying on the tectonic insertion of an exotic Colonsay–west Islay terrane is best regarded cautiously.

The configuration of the Colonsay–west Islay terrane and its relationships with neighbouring Archaean and early Proterozoic regimes have yet to be clarified. Our studies show that the high grade gneisses of Tiree, Coll and Iona, islands to the north of Colonsay, have much in common with the Lewisian of the Outer Hebrides. The boundary, or transition zone, between the Colonsay–west Islay terrane and the Lewisian therefore probably lies between Colonsay and Iona. These islands are separated by the Great Glen Fault, however, so the original junction has probably been

dismembered and perhaps rendered indecipherable. It is considered inadvisable, on present evidence, to speculate on the apparent coincidence of the Great Glen Fault with the junction.

One potential method of assessing the broad configurations of the Archaean and early–mid-Proterozoic crustal components of Scotland and Ireland, now largely hidden by the Upper Proterozoic cover, is to use information offered by the Dalradian tillite formation. Its clasts probably include samples of those older rocks. By this method, under evaluation, a clearer picture of the floor to the northern Caledonides, and particularly the Dalradian basin, may emerge.

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