The Islay Anticline was first recognized by Bailey (1917), who considered it to be a 'secondary' structure. Later workers (Roberts, 1974; Fairchild, 1977) concluded that it is a major primary (D1) structure but it has a number of anomalous features. For example, the structure of its closure at this GCR site, where it is best exposed, is not fully understood. Over most of Islay, the anticline plunges and closes to the north, but at this GCR site the closure plunges south, suggesting that the Bonahaven Dolomite Formation has been brought back to ground level by a plunge culmination in the major structure. However, there is an area (between NR 398 787 and NR 410 788) which has an 'anomalous' cleavage orientation (Fairchild, 1977), suggesting that there may be a cleavage that pre-dates the main cleavage associated with the Islay Anticline. These structural problems clearly warrant further investigation. Another interesting structural aspect of the area is that the Bolsa Fault is inferred, from an abrupt change in thickness of Member 3 across the fault-zone, to have been active during sedimentation (Fairchild, 1980c; Anderton, 1985).

4.4. Conclusions

The Rubha a'Mhail GCR site is of international importance for the excellent state of preservation, in three dimensions, and in their position of growth, of fossil algal bodies (stromatolites). These are amongst the most primitive fossil forms to be preserved in the geological record, and pre-date the evolution of more advanced organisms, the metazoans, which used them as a food source. Stromatolites originated as a microbial slime, which coated the sea floor and, by trapping grains of sediment, enabled a variety of different forms to develop. At this locality, these range from continuous layers to a variety of intriguing spheroidal and elliptical bodies up to 3 m across. The range in morphological types, and excellent state of preservation of these stromatolites is unique in the Precambrian rocks of the British Isles, and they are of value for future study.

Sedimentary structures at this GCR site show that the stromatolites grew within a sequence of rocks that was deposited in a shallow-water, subtidal to intertidal environment. Due to the low degree of metamorphism and deformation, the mode of formation of these organisms, and their relationship to bedding and other sedimentary structures can be examined in detail. Some problematical small-scale structures found only at this site could shed more light on the environment in which the stromatolites thrived. These include possible desiccation cracks and pseudomorphs after anhydrite (calcium sulphate, normally formed by the evaporation of seawater and hence indicating a warm climate).

The dolomitic rocks described from here and the *Caol Isla* GCR site overlie the Port Askaig Tillite, and this site has provided a type section for a detailed comparison with dolostones associated with other late-Precambrian tillites, in particular those in East Greenland (Fairchild, 1989).

5. Kilnaughton Bay, Islay (NR 346441–NR 345450) (C.A. Bendall)

5.1. Introduction

The transition from the Islay Subgroup to the Easdale Subgroup is important in terms of the sedimentary evolution of the Dalradian Supergroup in the south-west Grampian Highlands. It marks the change from shallow-water marine sands to deeper water muds and gravity-flow deposits. An almost complete succession through this transition is exposed on the south-west side of Kilnaughton Bay near Port Ellen in south Islay (Fig. 11). Approximately 550 m of the succession is exposed along the foreshore and in the low cliffs 20–50 m inland. The succession here comprises the Jura Quartzite Formation (Islay Subgroup) and the overlying Scarba

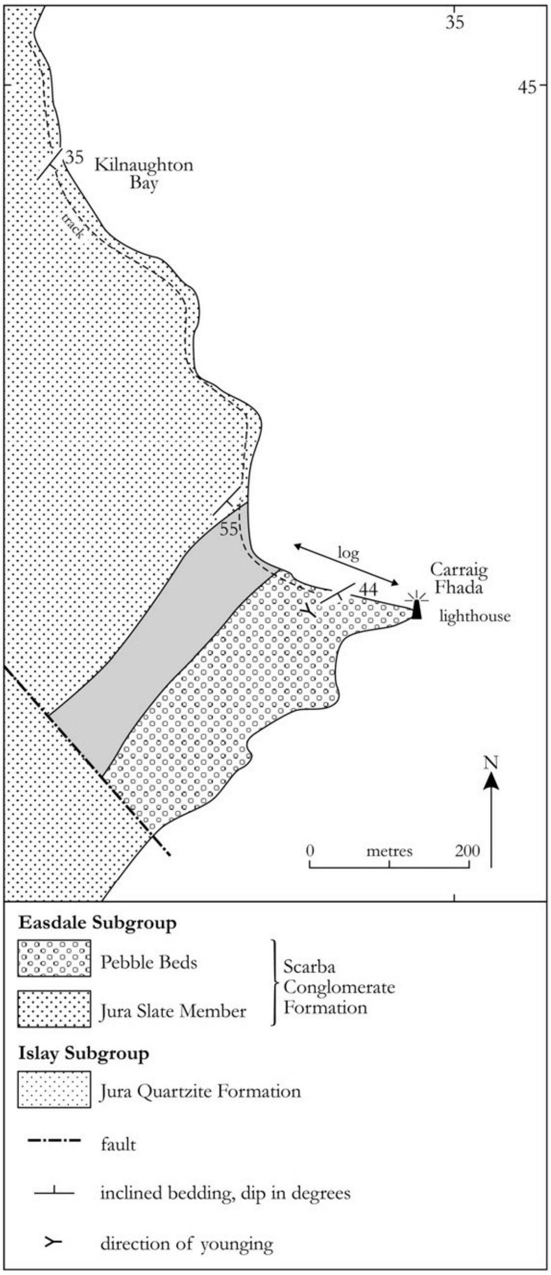

Fig. 11. Map of the area around the Kilnaughton Bay, Islay GCR site, south-east Islay.

Conglomerate Formation (Easdale Subgroup). The latter formation includes the Jura Slate Member at the base and the upper part is referred to here as the Pebble Beds for ease of description. These correlate well with the succession found on Jura (see the *Lussa Bay* and *Kinuachdrachd* GCR site reports). The Pebble Beds are of particular interest here. The beds are generally about a metre thick and consist of rounded pebbles of quartzite between 1 and 2 cm in size. These beds have a well-developed pressure-solution cleavage and the pebbles, although rounded, are distinctively either flattened or ellipsoidal and therefore are potentially good strain indicators. Hence they would enable quantification of the strain associated with the Islay Anticline.

Some white bladed porphyroblasts of highly altered kyanite occur in white-mica-rich rocks belonging to the Jura Quartzite Formation (Fig. 13). Much of the original kyanite has been replaced by fine-grained pyrophyllite and kaolinite (Burgess et al., 1981). The rocks at this locality, which also include chloritoid-bearing assemblages, have undergone greenschist-facies metamorphism and lie within the biotite zone. In the Dalradian it is most unusual to find kyanite in rocks of biotite grade, as kyanite is usually associated with much higher grade (amphibolite-facies) rocks, according to the ideal Barrovian mineral-zone sequence.

5.2. Description

Some 300 m thickness of the Jura Quartzite Formation is exposed along the foreshore (Fig. 11). At its maximum thickness on Jura, the quartzite is of the order of 5000 m thick, whereas on Islay the thickness varies from *c*. 3000 m in the north to 1000 m around Kilnaughton Bay (Anderton, 1985). At Kilnaughton Bay the rocks are predominantly coarse-grained metasandstones, with scattered pebbles ranging up to about 5 mm in size. The thickness of the metasandstone beds ranges from a few centimetres to massive beds some 2.5 m thick. Thin partings of metamudstone are common and there are interbedded metasiltstone–metamudstone units several metres thick. Beds of fine- to medium-grained metasandstone are also quite common. Cross-bedding is ubiquitous throughout the succession and is generally planar. The rocks do not appear to be well sorted and thin-section analysis reveals a bimodal grain-size distribution with the coarser grains supported in a matrix of finer sand grade. Most grains appear to be subangular to subrounded, although the grain shape may have been modified by quartz overgrowth. Although white feldspar can be found, the sandstones are not generally feldspathic.

Conformably overlying this formation are approximately 60 m of the Jura Slate Member, which is not fully exposed on the foreshore but can be seen in a disused quarry just inland (NR 3470 4435). These are fine-grained rocks with a prominent slaty cleavage. Bedding is defined by thin partings of coarser material, and shows that these rocks are folded by minor folds with wavelengths generally less than 1 m.

Conformable above this are the Pebble Beds. This unit consists of a series of pebbly beds that occur within a succession of finer metasandstones and metamudstones whose top is not exposed (see Fig. 12). Individual pebbly beds are usually no more than about a metre thick and fine upwards into metasandstone units; they have sharp erosional bases. The pebbles are of rounded quartzite and range from 1–5 cm in size. The pebbly beds are generally matrix supported, with the matrix being of coarse sand grade. Up to 13 pebbly beds occur between the top of the Jura Slate Member and the lighthouse (NR 3479 4440–NR 3495 4464). The top of the Scarba Conglomerate Formation is not exposed but it grades up into the pelitic Port Ellen Phyllite Formation.

These rocks lie on the south-eastern limb of the Islay Anticline (Figs. 1 and 3) (Bailey, 1917). The quartzites have an anastamosing spaced cleavage defined by cleavage domains of white micas, which appears to be a primary cleavage as no earlier fabric can be seen in the quartz microlithons. The vergence of cleavage on bedding is to the north-west, which is consistent with the cleavage having formed at the same time as the Islay Anticline. The Islay Anticline is believed to have formed during the first phase (D1) of Dalradian regional deformation (Roberts and Treagus, 1977). The cleavage in the Jura Slate is a primary slaty cleavage. At least one crenulation cleavage is also found in the slaty rocks. It dips between 25° and 50° to the south and gives a sense of vergence (on bedding and the primary cleavage) to the south-east. This cleavage, in places, consists of very closely spaced (less than 0.5 mm) planar micaceous surfaces and looks superficially like a slaty cleavage.

There is also a spaced cleavage in the pebbly beds that appears to be primary, and contemporaneous with the formation of the Islay Anticline. The pebbles are generally elliptical with aspect ratios (long axis: short axis) of between 1.5:1 and 3:1, and appear to show a consistent alignment, clearly demonstrating that the rocks have been strained.

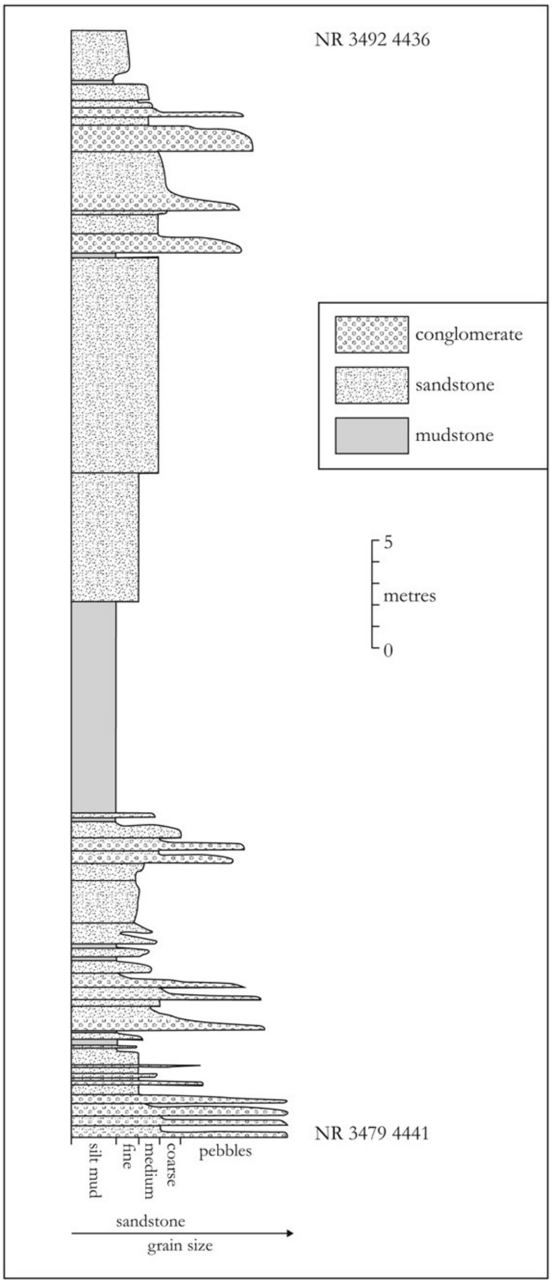

Fig. 12. Stratigraphical log of the pebble beds in the upper part of the Scarba Conglomerate Formation from NR 3479 4440 to NR 3492 4464, on the north side of Carraig Fhada, Kilnaughton Bay, Isle of Islay.

At the top of the Jura Quartzite Formation there is a fine-grained quartzite that contains planar cleavage planes. These cleavage planes are formed by thin partings of white-mica-rich rock, and hence these rocks are likely to be aluminium rich. Lying on the cleavage planes are white bladed grains up to about 1 cm long (Fig. 13). These blades have been interpreted as porphyroblasts of kyanite that have subsequently been retrogressed to a mixture of kaolinite and, more rarely, pyrophyllite (Burgess et al., 1981). The blades lie within the cleavage plane but are randomly orientated within that plane.

Other rocks cropping out on the site reveal little about the grade of metamorphism. However, elsewhere in south-east Islay, intrusions of mafic meta-igneous rocks indicate that the grade of metamorphism reached greenschist facies, and pelitic rock assemblages usually contain biotite as the highest grade index

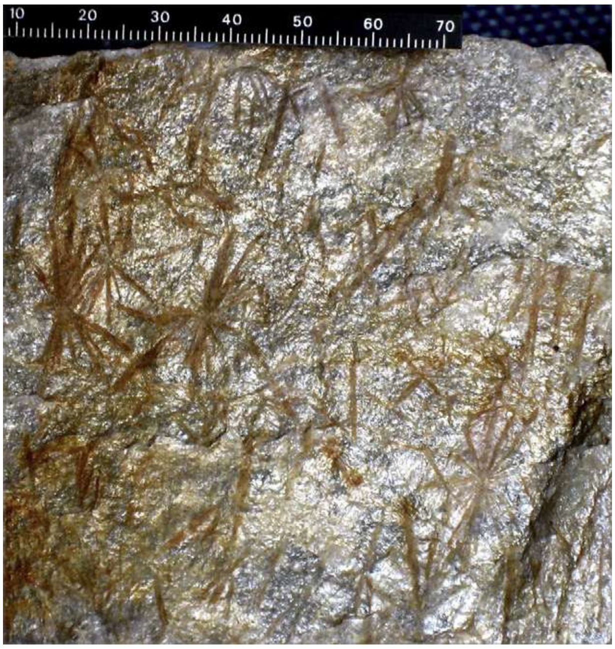

Fig. 13. Rosettes and blades of kyanite, largely pseudomorphed by kaolinite and pyrophyllite (Burgess et al., 1981), lying on a bedding plane at a low angle to the S1 cleavage in the Jura Quartzite at Kilnaughton Bay, Isle of Islay. Scale is in cm/mm (photo: P.W.G. Tanner).

mineral. The rocks therefore lie within the Barrovian biotite zone and the presence of kyanite is anomalous.

5.3. Interpretation

The rocks at this site, together with the GCR sites on Jura, preserve an important episode in Dalradian sedimentation; namely the change from the shallow-marine sandstones of the Jura Quartzite Formation, to the deeper water slump deposits of the Scarba Conglomerate Formation. According to Anderton (1979) this represents a change from a stable tectonic environment to an unstable environment, with rapid subsidence of a basin taking place along syndepositional faults.

At this GCR site the cross-bedded metasandstones, along with the interbedded metasandstones and metamudstones, are typical of shallow tidal-shelf deposits (Anderton, 1976). The Jura Slate Member was originally laid down as mud with thin sand beds, indicating a rapid change in depositional environment to deeper water conditions. The pebbly beds are slump deposits or debris-flow deposits, which were laid down on a deep-water marine slope in a similar fashion to those described from the Scarba Conglomerate on Jura (e.g. Anderton, 1979). This apparent rapid change in depositional environment indicates tectonic instability and rapid subsidence along basin-bounding faults.

The main phase of deformation in the eastern part of Islay was the first, D1 and this resulted in the formation of the Islay Anticline (Roberts and Treagus, 1977). The predominant cleavage in the Dalradian rocks is associated with this phase, while later stages of deformation have been responsible for the development of crenulation cleavages and minor folding. There are no major fold structures associated with these later events, and it is likely that the bulk of the strain that the rocks have experienced occurred during the formation of the Islay Anticline. Pebble beds are useful strain indicators; in this case the pebbles have been flattened rather than stretched, with X:Z ratios (length:height) varying between about 1.5:1 to 3:1. It is possible to discern a stretching direction in these rocks, which appears to plunge approximately east at *c.* 20°. However, more detailed studies are necessary to quantify the strain.

Establishing the temperatures and pressures of metamorphism using geothermometers and geobarometers based on mineral compositions is not straightforward in greenschist-facies rocks, as the rocks do not always attain thermodynamic equilibrium between the constituent mineral phases. Hence it is important to consider other lines of evidence.

Kyanite is very rarely found in low-grade Dalradian rocks, as it can only form in highly aluminous pelitic rocks at this grade. The majority of Dalradian pelites are relatively aluminium poor and are correspondingly richer in iron and magnesium; hence the consistency of the Barrovian Zones across the central Grampian Highlands. This GCR site has the only reported occurrence of kyanite in the greenschist-facies rocks of the Dalradian of the south-west Grampian Highlands. Using the occurrence of kyanite, and its growth at the expense of pyrophyllite, Skelton et al. (1995) have proposed that the peak metamorphic temperature for this area of Islay was in excess of 430 °C. Indeed, this is one of the critical localities for establishing the grade of metamorphism in the south-west Grampian Highlands.

5.4. Conclusions

The Dalradian of the south-west Grampian Highlands has undergone a long convoluted history in terms of sedimentation, deformation, and metamorphism, and the Kilnaughton Bay GCR site provides information on all three of these aspects. The metasedimentary rocks here and in the *Lussa Bay* and *Kinuachdrachd* GCR sites record an episode of rapid sea-level change, which was probably caused by movements along major basin-bounding faults. All three sites lie on the south-east limb of the Islay Anticline but the rocks at Kilnaughton Bay have undergone greater deformation, which can be quantified by measurements of pebbles within the Scarba Conglomerate Formation.

An unusual occurrence of kyanite within the Jura Quartzite indicates that these rocks were heated up to over 430 °C during the metamorphism that accompanied the deformation. Kyanite is normally found in medium- to high-pressure, upper amphibolite-facies assemblages its occurrence here in rocks of lower metamorphic grade is thought to be due to an unusually high aluminium content in the sediments that the rocks were derived from. This might be the only known example of kyanite-bearing low-grade metamorphic rocks in Britain.

6. Lussa Bay, Jura (NR 637 865–NR 648 870) (C.A. Bendall)

6.1. Introduction

Much of the island of Jura consists of rugged hills, which are composed almost entirely of monotonous Jura Quartzite, but along the south-east coast there are excellent exposures of spectacular rocks that reflect the change in the depositional environment from the shallow-water Jura Quartzite Formation to the deeper water Scarba Conglomerate Formation. The transition between these formations is well exposed at Lussa Bay, which is located about half way along the south-east coast of the island. Sedimentary structures are particularly well preserved in the coarser-grained metasedimentary rocks of Jura, and this is superbly demonstrated around Lussa Bay.

The Dalradian rocks of Jura were first described by Peach et al. (1911) and later by Allison (1933). More recent work includes that of Anderton (1976, 1977, 1979, 1980), which is mainly concerned with the sedimentology of the Islay and Easdale subgroups of the Argyll Group. A revised edition of the BGS 1:50 000 Sheet 28 W (South Jura) was published in 1996.