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## Girvan foreshore

[NX 147 931]–[NX 178 961]

### Introduction

The spectacular exposures along the Girvan foreshore provide a wealth of sedimentological, structural and palaeontological information indicative of a tectonically active, deep-water environment and are thus crucial to the understanding of the Midland Valley Terrane in the British Caledonides. The site is the type locality for several Caradoc to lower Ashgill lithostratigraphical units and for some magnificently preserved deep-water trilobite species. The shelly and graptolite faunas in the upper part of the section are important for understanding the international correlation, especially of the base of the Ashgill Series.

The succession between Kennedy's Pass and Craigs Kelly on the outskirts of Girvan, extending for 4.5 km along the foreshore, provides exposures of the lower Caradoc to lower Ashgill cover-sequence above the obducted Ballantrae Complex (Figure 14.8). The site contains the type localities for the Kilranny Conglomerate, the Ardwell Group, the Whitehouse Group (with many of its constituent formations) and the Shalloch Formation. It is also the type locality for a number of deep-water trilobite genera and species. It is thus important nationally, for establishing the depositional and plate-tectonic environment of this segment of the British Caledonides, and internationally, for the understanding of tectonic and palaeobiogeographical processes operating along the Laurentian margin of the Iapetus Ocean. Moreover, the faunas of the Whitehouse Group have provided the best evidence hitherto for the positioning of the graptolite zones in relation to the shelly-based definition of the base of the Ashgill Series (Fortey *et al.*, 1991, 1995).

Dr J.K. Ingham (University of Glasgow) has produced very detailed maps of most of the Girvan Foreshore, and these were published in simplified form in a field guide to the Girvan district (Ingham, 1992b; Bluck and Ingham, 1992a). Ingham has also provided overviews of the succession and its significance (1978, 1992a); in collaboration with Dr D.A.T. Harper, he has also formally subdivided the Whitehouse Group (Harper, 1984). The geology of the area was summarized by Cameron *et al.* (1986), and detailed sedimentological (Hubert, 1966; Bluck, 1983) and faunal (Harper, 1979, 1984–1989; Williams, 1987; Bergström, 1990; J.K. Ingham, in prep.) studies have clarified the palaeoenvironmental and tectonic history of the site.

The base of the cover sequence above the eroded Ballantrae Complex at Girvan is markedly diachronous and becomes progressively younger northwards across a series of syndepositional listric faults. The Girvan Foreshore site lies on the block between the Pinmore and the Girvan Valley faults (Ingham, 1992b, fig. 30.5) (Figure 14.1), in which the base of the succession is marked by the lower Caradoc Benan Conglomerate. The Ordovician succession extends up to the Cautleyan and is overlain by the strongly diachronous base of the local Silurian succession. In the block to the north of the Girvan Valley Fault, exposed in the Craighead Inlier, the lower part of the cover sequence is the Craighead Limestone (see the Craighead Quarry site report), which is equivalent to a level high in the Ardwell Group in the foreshore section (Figure 14.1). The uppermost Caradoc and lower Ashgill in the Craighead taller are cut out by faulting, but the Shalloch Formation can be recognized, and the overlying sequence extends much higher in the Ashgill (see the South Threave site report).

### Description

At the southern end of the site, at Kennedy's Pass, the lower Caradoc Kilranny Conglomerate is in faulted contact with igneous rocks of the Ballantrae Complex and crops out along the foreshore for about 250 m. It is rich in igneous clasts and is underlain by siltstones and fine sandstones (the 'Infra-Kilranny Greywackes' of Williams, 1962), seen in a cleft in the raised cliff near the northern end of the conglomerate outcrop. The Kilranny Conglomerate is overlain at [NX 1490 9330] by siltstones of the Ardwell Group at 'Henderson's unconformity' (Figure 14.9) (see Henderson, 1935), which has been re-identified as the base of a channel cut in the conglomerates (Ingham, 1978, p. 168). The mudstones, siltstones and fine sandstones of the Ardwell Flags crop out for some 1.6 km along the foreshore and display the spectacular folds

(Figure 14.10) for which this part of the Girvan foreshore is famous. Clean, wave-washed surfaces reveal small deformational and sedimentary features in exquisite detail. Structural complexity makes the thickness of the Ardwell Group here very difficult to estimate; Ingham (1978) suggested a thickness in excess of 1200 m, whereas Cameron *et al.* (1986) gave about 750 m, but they agree that the formation thickens to about 1400 m inland. The sandstones and shales of the uppermost part of the group are exposed on the outer part of the foreshore near Ardwell Farm and lie between branches of a dextral wrench fault extending from Kennedy's Pass. The shales contain graptolites of the *Dicranograptus clingani* Zone (Ingham, 1992b), and these beds are thought to be equivalent to the thick Cascade conglomerates, sandstones and shales in Penwhapple Burn, 8 km to the north-east.

The base of the Whitehouse Group is exposed on the northern side of Ardwell Bay, and the group occupies virtually the whole of the Whitehouse foreshore for some 350 m north of this (Figure 14.11), beyond which the overlying Shalloch Formation extends landward to the high-water mark, except on the southern part of the bay, at Port Cardloch [NX 1670 9495], where the upper part of the Whitehouse Group is again exposed. The Upper Whitehouse Group also crops out on the foreshore a further kilometre towards Girvan, in Myoch Bay. The lithologically varied Whitehouse Group is almost vertical and strikes approximately NE–SW, but the outcrop patterns of its constituent formations are disrupted by numerous faults of varying magnitudes. Meticulous mapping of this part of the site by Dr J.K. Ingham has done much to elucidate the succession, and his field guide (Ingham, 1992b) provides a far fuller picture than it is possible to give here and is in itself a succinct summary of this important section.

The South Shore Formation at the base of the Lower Whitehouse Group marks an abrupt change to detrital, sandy limestones ('limestone flysch' of Ingham, 1978 and earlier authors) interbedded with grey and green shales. Well-developed Bouma (1962) sequences can be recognized (Hubert, 1966), with the basal parts of graded beds containing a variety of lithoclasts, including igneous and metamorphic rocks; the lowest bed is rich in clasts of the underlying Ardwell Flags. The formation is about 75 m thick and has yielded conodonts indicative of the *Amorphognathus superbis* conodont zone (Bergström, 1990). It grades up into the Three Mile Formation (Figure 14.11): more than 45 m of alternating grey-green shales and thin but very persistent grey sandstones, with fine-scale sedimentary structures clearly displayed on wave-washed surfaces. A major, strike-parallel reverse fault cuts out the Penwhapple Formation (the upper unit of the Lower Whitehouse Group) from the foreshore area, but it is seen in Penwhapple Burn, where it mostly comprises siltstones, fine sandstones and mudstones, the latter including graptolites of the *Pleurograptus linearis* Zone (Rushton, fig. 11, in Floyd, 1999). Graptolites of this zone are also present in the uppermost part of the group in Myoch Burn near to the northern end of the foreshore site [NX 1780 9550].

The reverse fault on the Whitehouse shore is marked by a distinct gully, to the north of which red and green silty mudstones of the Myoch Formation are exposed. A pebbly sandstone near the base of this lowest formation of the Upper Whitehouse Group is seen near low-water mark and contains cross-bedding indicating currents flowing from the north-west (Hubert, 1966). Red mudstones within the formation locally contain a rich deep-water fauna dominated by atheloptic trilobites and are latest Caradoc to earliest Ashgill in age. There is an abrupt change to the overlying grey and green banded shales of the lower part of the Mill Formation on the Whitehouse Shore, where the lowest horizons indicate the mixing of partly consolidated sediment on an unstable slope. The Mill Formation on the Whitehouse shore comprises a lower shale unit, containing graptolites of the *Dicellograptus complanatus* Zone (Williams, 1987) and transported deep-water trilobites, overlain by a siltstone–sandstone member. The upper Whitehouse Group exposure in Myoch Bay, 1.5 km to the north-east, is structurally complex but is more complete and includes units not seen on the Whitehouse shore (Ingham, 1992b). These include a sandstone–shale channel-fill unit in the Myoch Formation and, in the lower part of the Mill Formation, a coarsening-upwards sequence of shales overlain by calcareous siltstones, succeeded by a channel-fill conglomerate. The shales include a graptolitic horizon indicative of a level close to the *linearis–complanatus* zonal boundary (Williams, 1987). The conglomerate contains a large number of mudclasts, together with more exotic clasts, set in a matrix that also contains shelf brachiopods and trilobites indicative of an early Ashgill age (Thomas *et al.*, 1984, p. 39, Ingham, 1992b, p. 412).

The base of the Shalloch Formation is seen both on the Whitehouse shore and in Myoch Bay and is marked by a lead-grey mudstone, 1 m thick, overlain by over 200 m of alternating sandstone and shale beds, with a few graded limestones. Graptolitic horizons near the base and top of the formation indicate respectively the *complanatus* and *anceps* graptolite zones (Ingham, 1978), and a limestone 117 m above the base of the formation has yielded one of the richer

conodont faunas in the Girvan district, indicative of the *Amorphognathus ordovicicus* conodont zone (Bergström, 1990).

The upper part of the Ordovician succession (upper Cautleyan to Hirnantian) is missing, and the Shalloch Formation is overlain with slight (about 8°) unconformity at Woodland Point [NX 1695 9530] by calcareous sandstones of the lower Llandovery Woodland Formation. These contain brachiopods and graptolites of the *Monograptus cyphus* Zone and are overlain on the headland by the quartz-rich conglomerates of the Scart Formation. There is a substantial gap in exposure, covered by beach sand, between the highest outcrops of the Shalloch Formation in Myoch Bay and at Craigs Kelly, at the northern end of the site, where another Llandovery conglomerate, the Craigs Kelly Conglomerate, crops out. The exposures at Horse Rock, to the immediate north of the site, show that this conglomerate, dominated by acid igneous rocks, overlies the Shalloch Formation and is in turn overlain by the Woodland Formation.

## Interpretation

The succession along the Girvan Foreshore indicates the existence of a deep-water, tectonically active environment of deposition along the southern edge of the Midland Valley Terrane throughout Caradoc and early Ashgill times. Moreover, whilst some of the igneous clasts in the Kilranny Conglomerate were derived from the Ballantrae Complex, others were derived from the unroofing of intrusions not much older than the sedimentary succession that now contains them (Longman *et al.*, 1979; Bluck, 1983). The Girvan succession was therefore considered by Bluck (1983) to represent a proximal fore-arc environment (see also Bluck and Ingham, 1992a).

The 'cascade' folds in the Ardwell Flags are complex (see Williams, 1959; Ramsay, 1976; Williams and Spray, 1979) and were once thought to be tectonic in origin. However, their restriction to this part of the stratigraphy and the recognition of sand-flows in some fold closures (Bluck, in Ingham, 1978, p. 169) suggest that they are syn-sedimentary features reflecting downslope movement from the north-west.

The Bouma sequences of the South Shore Formation indicate deposition by turbidity flows, and the overlying Three Mile Formation is regarded as a more distal turbidite succession ('sandstone flysch') (see Ingham (1978)). Bioclasts in the South Shore Formation include the trinucleid trilobite *Tretaspis ceriodes*, a typical member of latest Caradoc shelf faunas in the Anglo-Welsh area, Scandinavia and even China (Ingham, 1978, 1992b; Owen, 1987). Its occurrence at Girvan provides an indication not only of the age of the South Shore Formation but also of the extent to which the faunal provincialism of the earlier part of the Ordovician had broken down by the late Caradoc. This is also seen in the composition of the deep-water faunas of the upper Whitehouse Group, where the trilobites include an extremely diverse mixture (Thomas *et al.*, 1984, p. 40; Ingham, 1992b, p. 402) of the large-eyed, pelagic species (mostly cyclopygids) and small-eyed or blind benthic taxa, a typical atheloptic assemblage (Fortey and Owens, 1987). This deep-water biofacies was previously restricted to mesopelagic and outer-shelf to upper-slope environments on the margins of Gondwana and Avalonia, except for a brief incursion of two taxa into the Girvan area in the early Caradoc (Ingham and Tripp, 1991; Rushton *et al.*, 1996b). Whittard (1952b) and Owen and Ingham (1996) have described some of the trilobite species of the upper Whitehouse Group, and Dr Ingham (in prep.) is working on several widely distributed taxa. The brachiopod fauna is also of deep-water aspect and is an example of the widespread *Foliomena* fauna (Harper, 1979, 1984).

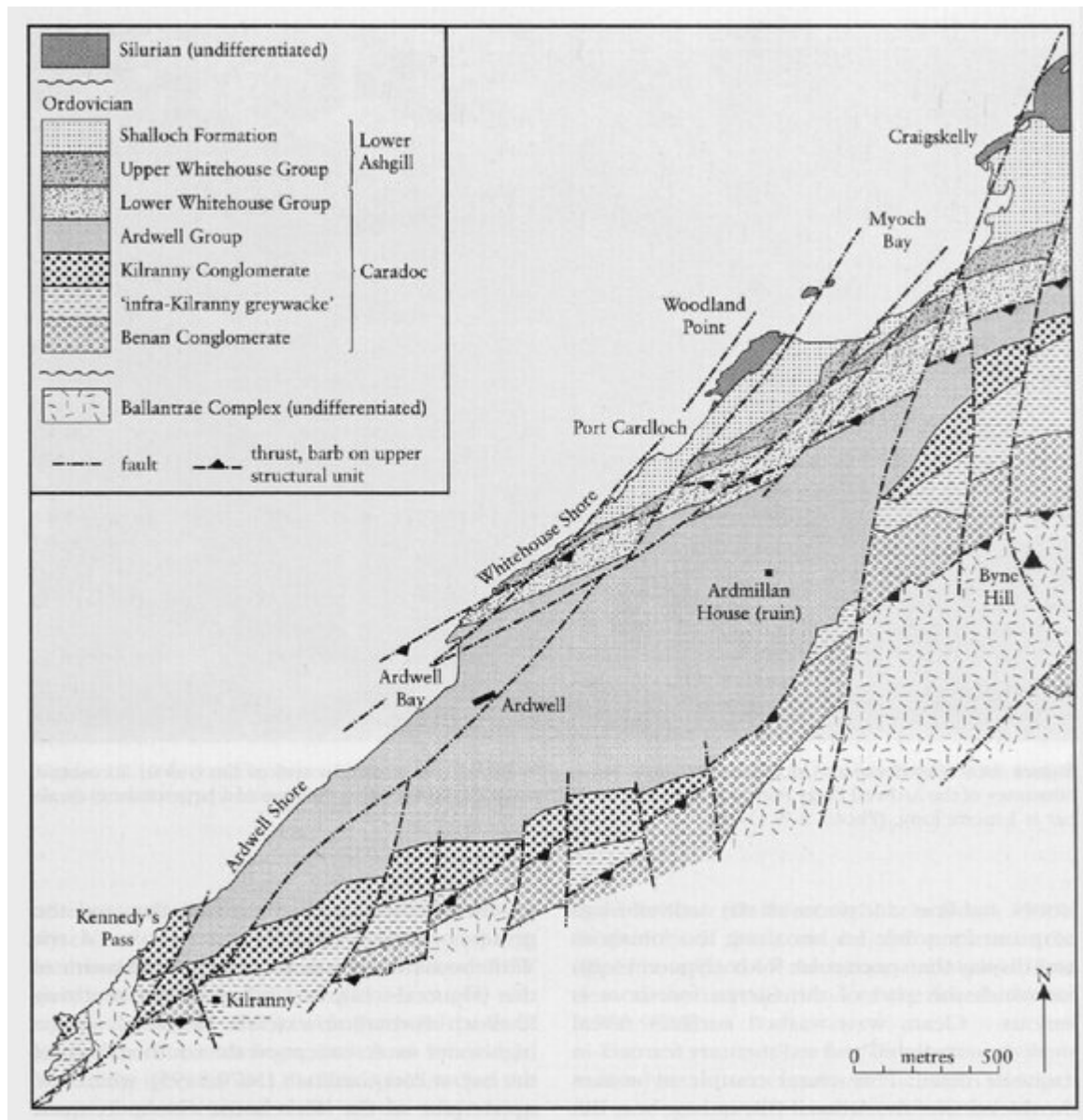
The association of graptolites and early Ashgill shelly faunas in the lower part of the Mill Formation at Myoch Bay is valuable for wider correlation of the base of the Ashgill Series. The absence of the lower part of the Mill Formation on the Whitehouse shore and the mixing of partly consolidated sediment in the lowest horizons of the formation present there are probably the result of local down-slope failure of part of the sediment pile (Ingham, 1992b, fig. 30.2). The channel-fill mudclast conglomerate in Myoch Bay also indicates down-slope transport and the sandstone flysch of the Shalloch Formation indicates a distal environment, well supplied with siliceous sediment. The removal of the upper part of the Ordovician was probably by submarine slope failure or channelling, reflecting continued tectonic instability.

## Conclusions

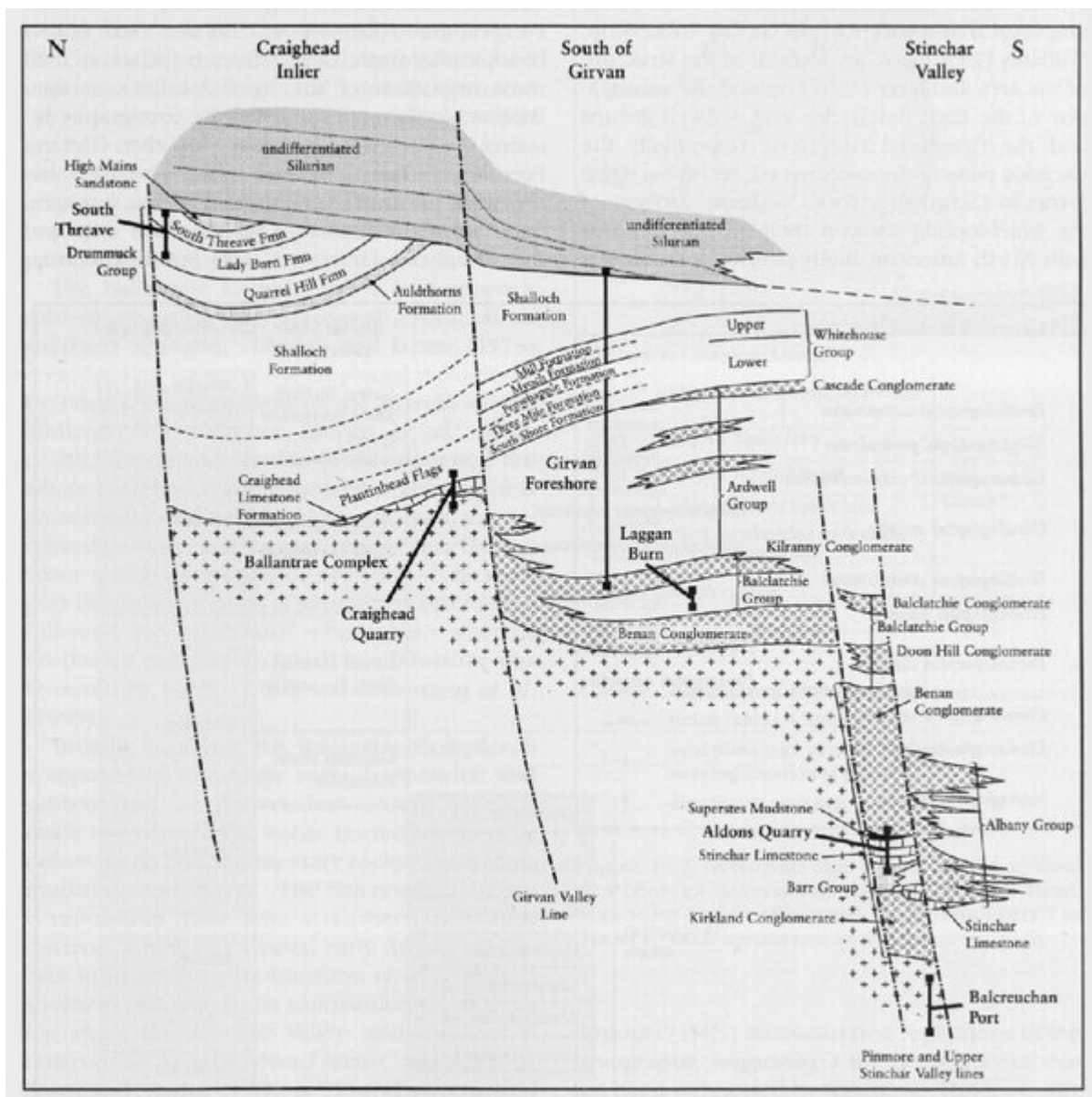
The Girvan Foreshore is a classic site in British geology. It contains spectacular structures and sedimentary features that, together with some magnificently preserved deep-water fossils, indicate an unstable deep-water environment during the

Caradoc and early Ashgill divisions of the Ordovician. This information plays a crucial part in understanding the British segment of the Caledonian-Appalachian mountain belt. Moreover, the relative levels of certain shelly and graptolitic faunas are important in the international understanding of the correlation of the base of the Ashgill Series.

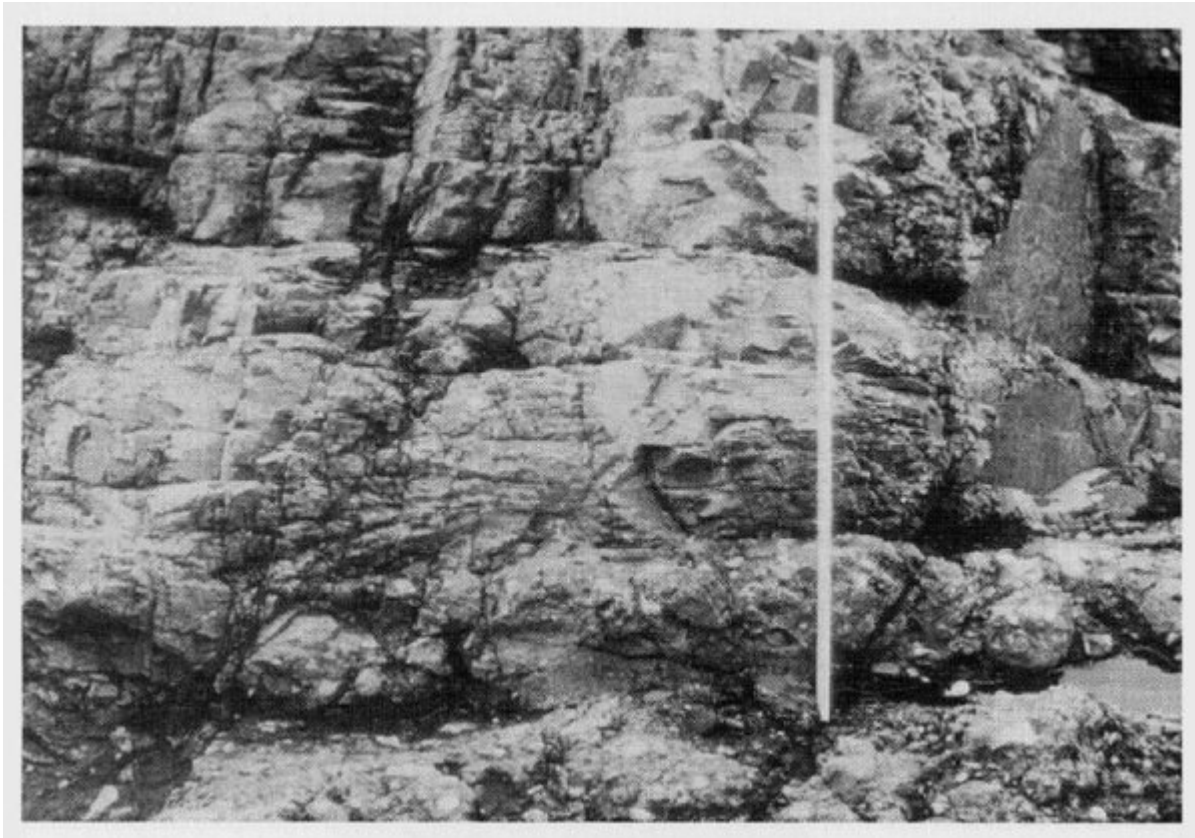
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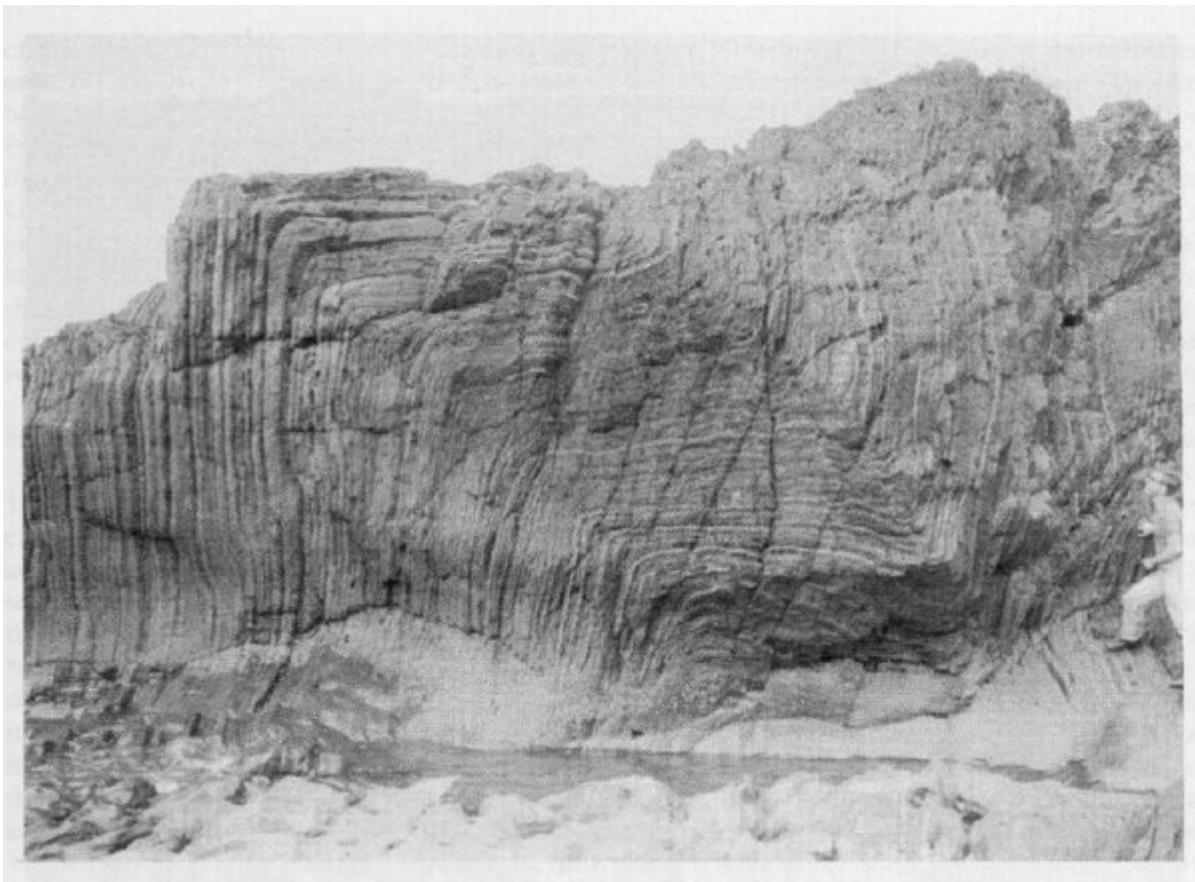
(Figure 14.8) Simplified map of the Ordovician rocks along the Girvan Foreshore and the area immediately inland, after Bluck and Ingham (1992a, fig. 28.1a, b).



(Figure 14.1) Schematic cross-section in the Girvan area to show the stratigraphical and structural relationships across the major south-facing growth faults. The GCR sites are shown in bold type. After Ingham (1992b, fig. 30.5).

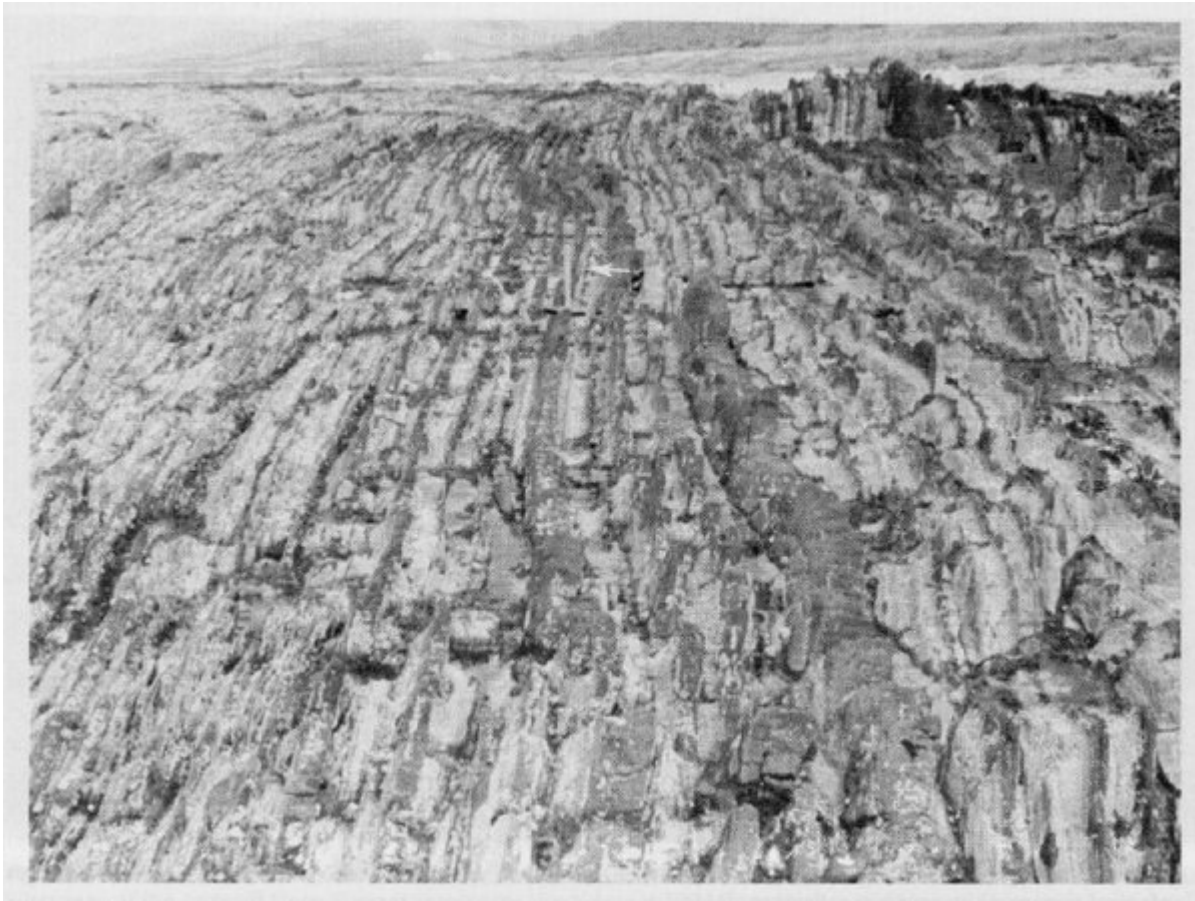


*(Figure 14.9) 'Henderson's Unconformity' near Kennedy's Pass at the southern end of the Girvan Foreshore. Siltstones of the Ardwell Flags Formation overlie the Kilranny Conglomerate at the base of a large channel (scale bar is 1 metre long. (Photo: A.W. Owen.)*



*(Figure 14.10) Girvan foreshore. Box-fold in the Ardwell Formation, north-east of Kennedy's Pass. (Photo: British Geological Survey photographic collection, D1563.)*





*(Figure 14.11) Girvan foreshore west of Ardmillan, looking ENE. Steeply dipping fine-grained turbidites of the Three Mile Formation (Lower Whitehouse Group), younging to the left. Hammer (arrowed) above centre for scale. (Photo: British Geological Survey photographic collection, D3527.)*