The Girvan–Ballantrae Complex

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Introduction

The Girvan–Ballantrae district has always played a key role in our understanding of Scotland's Lower Palaeozoic history. In the past, whatever the prevailing ideas of Scottish geology of that period may have been, reference has always been made to the rocks and fossils of this region. Present day thinking, which sees southern Scotland as part of an erstwhile destructive plate margin, has drawn heavily on these rock and fossil assemblages for evidence of the nature of its margin and the processes taking place along it. Although the older Ballantrae Complex and the younger cover rocks are here described separately, they form an integrated whole; fore-arc basins, of which the Girvan cover sequence appears representative, are commonly founded on fragments of obducted oceanic crust suchas the Ballantrae Complex.

The Ballantrae Complex

The Ballantrae rocks, although having a dark and sometimes forbidding appearance, are amongst the most varied to be found in a small region of Scotland. Not only are there unusual varieties of igneous, sedimentary and metamorphic types, but many of the rocks show evidence of having formed in widely differing regimes. Rocks which were generated at radically differing depths, sometimes as much as 50 km vertical distance apart within the Earth's crust and beneath it, are now to be seen in juxtaposition on the surface and this fact implies substantial tectonic activity.

The reasons for the great variety and varied depth of provenance of this rock assemblage have a great deal to do with the tectonic regime in which it is thought to have formed. The whole complex apparently represents a fragment, or fragments, of oceanic crust and mantle which has been thrust onto a continental margin so that there are present not only rock types which were generated in the oceanic realm, but also rocks which formed during the period of thrusting. As a result of tectonic activity during the generation of the crust, as well as the thickness of the lithospheric slabs involved, we now see rock types from a range of depths.

The oceanic crust, normally the upper 6–7 km of the oceanic lithosphere, forms much of the Ballantrae exposure and is believed to have formed during Arenig times (Early Ordovician, c. 493–470 Ma). There are excellent exposures of pillow lavas, lava conglomerates, cherts and graptoliferous black shales which formed on the sea floor and, although pillow lavas and cherts are usually thought of as deep water sediments, there is abundant evidence for a shallow water origin for at least some of them. Gabbros and trondhjemites which are formed in magma chambers within the crust are also present, the former commonly well foliated, having been deformed as injection took place at an active ocean ridge.

Oceanic mantle is now represented by quite large but poorly exposed tracts of serpentinite, amongst which there are a few exposures of the ultramafic protolith, usually harzburgite. Some of these mantle rocks may have formed at depths in excess of 40 km within the lithosphere. Uplift and serpentinisation clearly took place before intrusion of the gabbro and trondhjemite during Arenig times. Although the radiometric age of the mantle material is unknown, it is assumed to be part of the dated crustal sequence.

The first major phase of obduction took place at c. 480 Ma and, during the obduction, a metamorphic sole was created with mantle rocks being brought up from depths which may be greater than 45 km. Final accretion to the Midland Valley terrane was achieved by the end of Arenig time.

Thus, it is evident that the Ballantrae Complex is compound: it comprises rocks which were not all produced in the same place, either vertically or areally. Some may have been laterally transported by shears: others instigated by major thrusts which detached material from deep levels within the lithosphere. Probably during their tectonic transportation they became rotated, as shown by the palaeomagnetic data of Trench et al. (1988). However, the greatest interpretational difficulty lies with isolated blocks of garnet metapyroxenite which occur in mélange-olistostrome units. They indicate deep burial and metamorphism of ocean type crust at c. 570 Ma (Early Cambrian), a time when Scotland, or rather Hebridean Scotland, is thought of as a passive rather than a destructive Laurentian continental margin. Dempster and Bluck (1991) address this problem.

The Lower Palaeozoic cover sequence

The Ballantrae Complex had been deformed, uplifted and had accreted to the south-eastern margin of the Midland Valley terrane as obducted sheets by Mid Ordovician (Llanvirn) times, for the Mid Ordovician to Early Silurian cover rests unconformably on an irregular, eroded Ballantrae 'basement' and is markedly transgressive northwards or northwestwards. It shows considerable overlap in those directions so that the oldest beds, of Upper Llanvirn age, are exposed in the SE of the district in the Stinchar Valley area, whereas in the Craighead Inlier, to the NW of the district, a sedimentary sequence of Mid Caradoc age rests on the Ballantrae rocks (Figure 25.1), (Figure 25.2) (Ingham 1978). Late Silurian (Caledonian) movements have complicated the picture somewhat by foreshortening the original transgressive distribution pattern but the overall picture is quite clear.

One of the most striking features of the Girvan cover sequence, whether it be of Ordovician or Silurian age, is that it is rich in conglomerates dominated by a volcanic provenance and having accumulated in restricted sedimentary basins. Many of the conglomerates are coarse with large boulders often set in a matrix of volcanogenic and related sediment. Most are derived from the north or NW and have travelled no great distance. A high percentage of the clasts are of obvious local derivation, being either cobbles of Ballantrae rocks or of sedimentary rocks from the cover sequence underlying the conglomerate in question, but some high level acid plutonic clasts have no modern counterpart at outcrop and give radiometric dates which are commonly only marginally older than the conglomerates which contain them (Bluck 1983). They derive largely from a contemporary intrusive and volcanic tract, a presumed magmatic arc 'axis' of the Midland Valley terrane, which probably lay only a few kilometres north of the present Lower Palaeozoic outcrops in the Girvan district. The large regional variations in thickness of the conglomerates, commonly their limited distribution, together with sedimentological details of both the conglomerates and associated sediments, have suggested to many workers (Williams 1962; Ingham 1978; Bluck 1983; Ince 1984; Ingham and Tripp 1991) that the controls on sedimentation were essentially contemporary movements on listric basement faults which produced a sequence of basins marginal to the Midland Valley magmatic arc. It is appears therefore that the Girvan cover sequence consists essentially of a proximal fore-arc succession with regular basement faulting, producing a cyclical stratigraphy in which an initially shallow but rapidly deepening sequence is capped by a thick conglomerate, commonly channelling into the underlying sediments and this is followed by another, similar cycle.

Another important feature of the Girvan cover sequence lies in its palaeontology. Clearly such a varied sedimentary succession, deposited in a wide range of water depths, will be reflected in the fossil content of its rocks. Deeper water, commonly graptolitic assemblages alternate with diverse, shallow water, shelly assemblages and there are other, bizarre facies faunas reflecting special depositional conditions. There is evidence from some parts of the succession for shallower water assemblages having been displaced, together with sediment, downslope into deeper, basinal slope environments. Most importantly, however, the shallower, inshore faunas of the Llanvirn to Late Caradoc epochs are of decidedly North American (Appalachian) aspect, so much so that it is more useful to apply a North American chronostratigraphical standard to these parts of the succession rather than the traditional Anglo-Welsh one, there being virtually nothing in common between the shelly faunas of the two areas (Figure 25.2). Conodonts, however, have permitted a reasonably precise correlation with the Anglo-Welsh standard. This is all obviously a reflection of the Lower Palaeozoic palaeogeographical picture whereby a wide, but closing, Iapetus Ocean separated the Anglo-Welsh area (part of the Avalon terrane, then in the southern hemisphere) from southern Scotland which was peripheral to, and progressively accreting to the Laurentian palaeocontinent at much lower southern latitudes. Overall and local successional details are tabulated in (Figure 25.2).

As mentioned above, the succession was finally disrupted by late, or end Silurian movements, heralded by Late Llandovery red beds. These Caledonian movements, although fairly major, appear largely to have affected only the upper crustal rocks in the Girvan area for the folding and faulting, although locally complex, is unaccompanied by cleavage. The Girvan tract was pushed progressively to the NW and some of the large-scale folds are asymmetrical in this direction with steep, sometimes vertical, NW limbs (e.g., the Byne Hill monocline). There are several major thrusts striking in the same direction as the fold axes, usually cutting the NW-facing anticlinal limbs and similarly translating the rocks north-westwards. Superimposed on this pattern is a plethora of brittle fracture conjugate faults, the dextrals essentially E–W and the sinistrals N–S. Finally, large NE-SW faults of a variety of later ages may have dextral or sinistral displacements as well as vertical throws: some of them are almost certainly rejuvenated basement faults, such as those which controlled the sedimentation patterns in the Lower Palaeozoic cover sequence (Figure 25.1). Following some rapid erosion, a topographically varied surface was produced on which the continental deposits of the Lower Old Red Sandstone were deposited.

One day itineraries: Girvan and Ballantrae

A and B can be combined for a week-end visit.

A. Ballantrae Complex (B.J. Bluck)

The following localities are chosen in sequence from north to south and as they are also chosen to illustrate the origin of the ophiolite, they should be visited in conjunction with reading the introduction to the Ballantrae Complex.

1. Excursion 25, Localities 5–7: Slockenray: Hyaloclastic delta, tuffs intermixing with lavas.
2. Excursion 26, Localities 1–4: Knocklaugh: Thin metamorphic sole to the ophiolite; olistrostrome with greenschists–amphibolites.
3. Excursion 27, Localities 1–4: Bennane Lea: Cherts interfingering with mass-flow comglomerates, tuffs, fossiliferous black shales and thrust contact between cherts and serpentinite.
4. Excursion 27, Locality 6: Downan Point: Beautiful pillow lavas in excellent exposures. Pillowed lava tubes, and many good illustrations of how pillow lavas grow.

B. Lower Palaeozoic cover sequence (J.K. Ingham)

All localities easily accessible by car with only a little walking.

1. Excursion 29, Locality 7: Aldons Quarry: Cover rock (including Benan Conglomerate and Stinchar Limestone) overlying spilites of the Ballantrae Volcanic Complex.
2. Excursion 30, Locality 1: Kennedy 's Pass: Kilranny Conglomerate and Henderson's 'unconformity'.
3. Excursion 30, Locality 2: Ardwell Foreshore: 'Cascade folding'.
4. Excursion 30, Localities 5–7: Whitehouse Shore (centre): flysch deposits, deep-water facies faunas, conjugate folding, slumping, graptolites.
5. Excursion 31, Locality 1: Craighead Quarry: spilites of Ballantrae Complex overlain by late Ordovician limestones and mudstones with shelly fossils.
6. Excursion 31, Locality 7: Rough Neuk Quarry: Lower Silurian shelly fossils.

C. Girvan tour (M.C. Keen)

Involving a walk and including some examples of Ballantrae Complex rocks, Upper Ordovician and Silurian sediments. Drive to Girvan Cemetery [NX 187 956] and park car or bus.

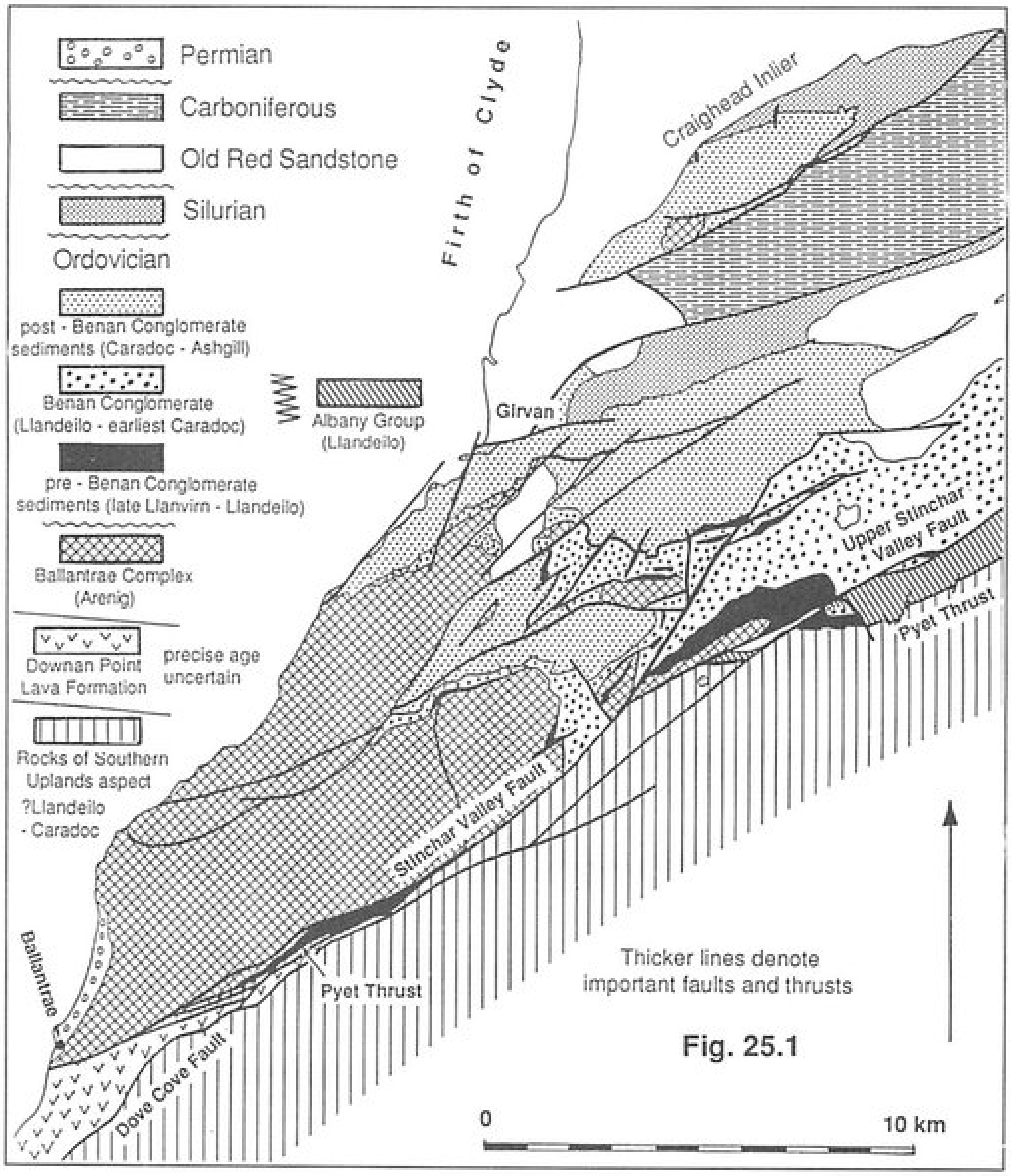
1. Excursion 28, Localities 2, 3 and 4: Byne Hill (summit optional): Serpentinite, gabbro, trondhjemite and Benan Conglomerate. Return to vehicle.
2. Excursion 30, Localities 1, 2 (briefly) , 3, 4 and 6: Kennedy 's Pass to Whitehouse shore: Kilranny conglomerate, Henderson's 'unconformity', 'cascade folding', graptolites and graded limestones.
3. Excursion 30, Localities 9 and 10 (if low tide): Port Cardloch and Woodland Point: sinistral faulting, cross-bedding, unconformity, Silurian brachiopods and graptolites.

4. Excursion 31, Locality 7: Rough Neuk Quarry: Mulloch Hill Sandstone, early Silurian shelly fossils.

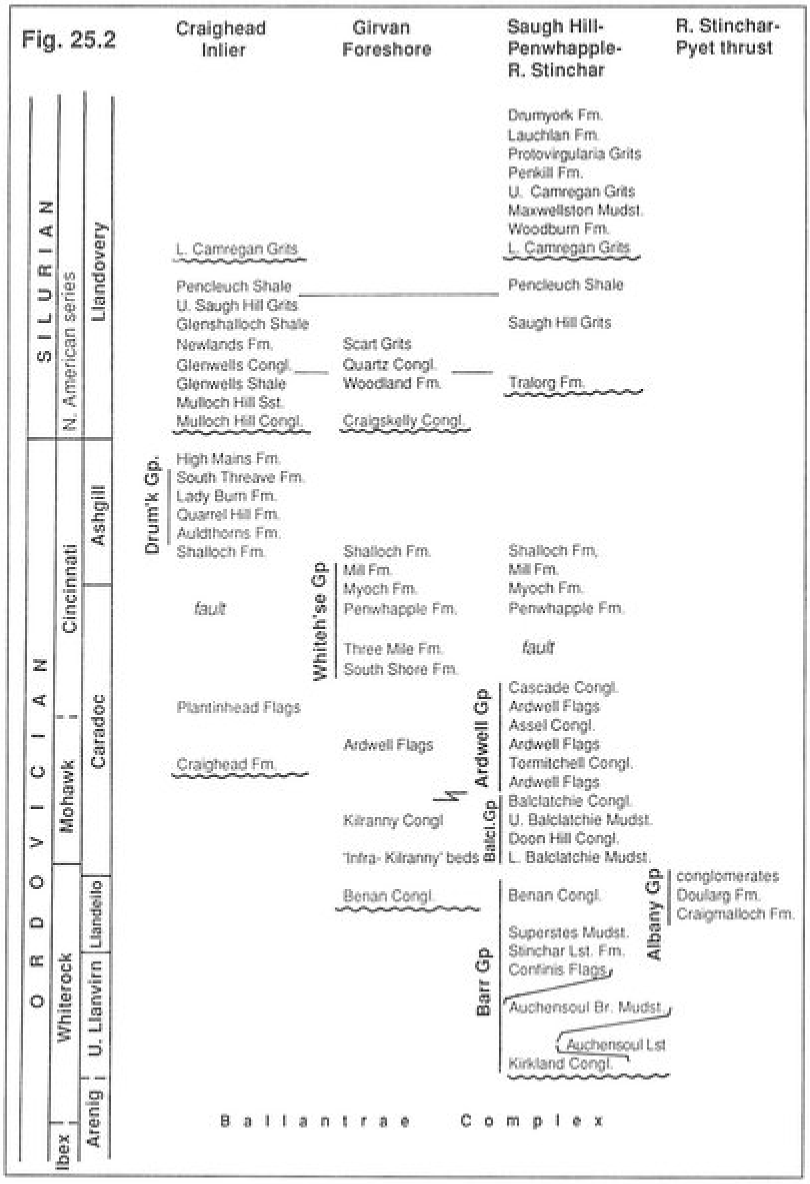
D. Coastal tour (J.D. Lawson)

Mainly by car or coach: a long summer's day: probably need to select and omit according to personal interest.

1. Excursion 27, Locality 6: Downan Point: Pillow lavas.
2. Excursion 27, Localities 1–4: Bennane Lea: Serpentinite, cherts, tuffs, black shales with graptolites, thrust.
3. Excursion 30, Locality 1: Kennedy 's Pass: Kilranny conglomerate and Henderson's ' unconformity'.
4. Excursion 30, Locality 4–6: Whitehouse shore (but close to road): graded limestones: deep-water trilobites etc.
5. Excursion 30, Locality 10 (if tide low): Woodland Point: Unconformity, Silurian brachiopods and graptolites.
6. Excursion 31, Locality 7 (if time permits): Rough Neuk Quarry: Mulloch Hill Sandstone, early Silurian shelly fossils.



(Figure 25.1) Simplified geological map of the Girvan district showing the relationships between the major rock units.



(Figure 25.2) The Lower Palaeozoic successions in the Girvan district and their chronostratigraphical ages.