Excursion 15 Rhins of Galloway: a coastal traverse across the Northern and Central belts of the Southern Uplands

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OS 1:50 000 sheets 76 Girvan and 82 Stranraer; Glen Luce surrounding area

BGS 1:50 000 Sheet 1 and 3 with parts of 7 and 4W The Rhins of Galloway

Route map: (Figure 45)

Main points of interest Ordovician and Silurian structure; turbidite sedimentology (conglomerate, greywacke and shale) and stratigraphy; Caledonian folding and thrusting.

Logistics The itinerary suggested for this relatively remote area can be used as the basis for a 2- or 3-day excursion centred on Portpatrick. Some of the localities in Excursions 17 and 18 can also be visited from here. All the localities are readily accessible to small vehicles, but anything larger than a minibus will not be able to negotiate the narrow roads. All the localities are coastal, so more rock will be seen at low tide. Localities 2, 9 and 10 are the most tide dependent and should be visited out of sequence if necessary. Most of the localities require scrambling over steep rock outcrops which may be wet and slippery; the longest walk required is about 4 km.

Introduction

The coast sections of the 45 km-long Rhins of Galloway peninsula provide an unsurpassed traverse through the Lower Palaeozoic outcrop of south-west Scotland. The sections chosen (Figure 45) build up a complete cross-strike traverse through the imbricate thrust sheet of late Ordovician and early Silurian turbidite strata. Biostratigraphical ages quoted are based largely on recent determinations by A.W.A. Rushton and S.P. Tunnicliff summarised in Stone (1995). The summary of tectonostratigraphy given in (Figure 46) encapsulates the stratigraphical paradox of the Southern Uplands: within each fault-bounded tract the exposed strata become younger towards the NW, though the tracts themselves become sequentially younger towards the SE. The strike faults separating the tracts are therefore thrust faults which originally propagated mostly towards the SE, carrying older beds over younger. Each thrust slice steepened upwards before its sole thrust stuck and was replaced at a lower level by a new thrust. In some interpretations one of the faults is given special importance as a possible terrane boundary along which a large displacement has occurred. This structure, the Orlock Bridge Fault, is examined in Excursion 17. In the Rhins of Galloway traverse described here Localities 1–5 are within the Ordovician Northern Belt of the Southern Uplands and Localities 6–10 are in the Silurian Central Belt to the south.

The introductory section of this guide which deals with the Lower Palaeozoic regional geology is particularly relevant to this excursion. Also of great value is the BGS 1:50 000 Rhins of Galloway map, but note the alternative interpretation at Locality 9. Much of the evidence to be seen is pertinent to the debate over the origin of the Southern Uplands: forearc accretionary prism or backarc to foreland basin thrust belt. The regional palaeocurrent pattern (at least in the Ordovician) and the interdigitating siliceous and volcaniclastic turbidites at locality 4 provide evidence of a volcanic source to the south of a backarc Southern Uplands (Stone et al., 1987); the opposing younging and vergence of D1 thrusting and folding on either side of the Port Logan Fault (Localities *7,* 8 and 9) provide evidence of obduction accretion comparable with that in the Washington—Oregon forearc (McCurry and Anderson, 1989). Descriptions for Localities 1, 2 and 5 have been prepared by P Stone, for Localities 3, 7, 9 and 10 by J McCurry, and for Localities 6 and 8 jointly.

1 Finnarts Bay: Kirkcolm Formation

Finnarts Bay is on the east side of Loch Ryan. If approaching from the east on theA75 turn north on the A751 and follow the A77 through Cairnryan. About 4 km north of Cairnryan a large, disused quarry is seen on the right; shortly after take the left turn signposted for the Fish Farm and at the bottom of the hill turn abruptly left to park on the extensive raised beach [NX 051 725]. If approaching from the north, follow the A77 down the valley of Glen App and, when the road reaches the coast and swings south, turn right towards the Fish Farm. The itinerary (Figure 47) has two sections, a coastal traverse and a nearby road section along the A77. For the latter part there is parking for one or two cars at the entrance to the rough track leading into the old quarry [NX 053 720] or in the lay-by on the opposite (seaward) side of the road. If a larger number of vehicles is involved it is safer to leave them parked on the raised beach and walk back ro the quarry entrance and road section.

Coastal traverseAt the south-west end of the raised beach an extensive rocky area is exposed below the high tide mark. This outcrop consists of very thinly bedded, fine-grained greywacke and siltstone. At low tide and subject to the movement of beach shingle, a low northward extension of the main outcrop shows an intrusive porphyritic dyke (a in (Figure 47)). The dyke is up to 2 m across and contains abundant feldspar phenocrysts set in a fine-grained microdioritic groundmass. It has sharp margins against the host siltstone and contains no trace of tectonic foliation. It was clearly intruded after deformation. The surrounding sedimentary strata, best seen on the larger exposures to the south of the dyke (b in (Figure 47)), form a thinly bedded interval within the Kirkcolm Formation and contain a sparse *gracilis* Biozone graptolite fauna (Figure 46). Seemingly chaotic deformation has affected the siltstone and greywacke, with folding on a variety of scales and styles. Brittle dislocation of the thin beds in both an extensional and a compressional sense is also apparent. The folding may well be poly-genetic, with tectonic deformation superimposed on syndepositional slump-related folding. Within the chaotically folded zones diagenetic carbonate concretions are fairly common, forming disc-shaped bodies up to I m across. These weather brown and may project from the eroded surface of the host strata. Significantly, when such concretions are surrounded by chaotically deformed layers they may preserve internal undisturbed lamination. The concretions are therefore thought to have formed before deformation occurred which suggests that much folding was post-diagenetic.

About 20 m south into the next small bay another felsic dyke is intruded into the laminated siltstone (c). However, in this case the dyke is pervasively foliated with a fabric parallel to, and apparently continuous with, that seen in the surrounding sedimentary strata. If possible, dig out the sand to expose the contact of dyke and siltstone; locally it is quite irregular but, whereas the dyke cuts across the overall bedding trend at an angle of about 10°, the cleavage fabric is continuous across the contact. Clearly the dyke was intruded prior to the imposition of the cleavage. The contrast with the dyke examined earlier, which is of very similar composition, suggests that dyke intrusion spanned the cleavage-forming deformation.

Slightly farther south within the same bay thick greywacke beds up to 1.5 m across appear in the sequence. These are medium-grained quartzofeldspathic representatives of the Kirkcolm Formation. Another thick greywacke bed forms part of the cliff at the south end of the bay, exposed beneath the World War II gun emplacement (Loch Ryan was a convoy assembly point and flying boat base, hence the fortifications). Bedding dip in the cliff section (d) is about 50° SE but sedimentary structures such as ripple crests and shale flames show that the beds are inverted. A well-developed slaty cleavage dips more steeply than the bedding and therefore cannot be a simple axial-planar cleavage. Various explanations are possible. Either the bedding and cleavage have been jointly rotated or the cleavage has been imposed on bedding already tilted out of the horizontal; both situations require at least two deformation episodes. Alternatively a nonaxial-planar cleavage, developed coevally with the folding, could locally give this relationship. Examples of the latter phenomenon are widespread in the southern part of the Rhins of Galloway.

Seaward from the inverted greywacke beds the chaotically deformed siltstone lithology reappears. It is intruded by a porphyritic dyke (feldspar phenocrysts in a microdiorite groundmass) up to 2 m across which runs oblique to bedding and has irregular margins. Examination of the dyke margins shows that the cleavage in the siltstone continues for up to a centimetre into the chilled margins. This dyke was clearly intruded before the end of cleavage-forming deformation.

Continue south along the beach and scramble up the low cliff on to the slightly higher rock platform; this is easiest at the inland end of the cliff: A narrow track leads south but after about 20 m leave it and scramble across the rock outcrops to seaward. The thinly bedded siltstones are here deformed in a slightly more orderly fashion and, if the beds are traced out, a sequence of steeply plunging ‘S’ folds can be established (e). A spaced cleavage can be seen subparallel to the axial plane of the folds. Note the similarity between the attitude of this cleavage and that in the inverted greywacke beds seen previously. The associated steeply plunging 'S' folds may be the result of the late sinistral shear (D3) imposed on this part of the Southern Uplands.

Regain the track and continue south for a short distance and descend into the next small inlet. The most prominent feature here (f) is a 2 m-thick felsic dyke containing abundant feldspar phenocrysts. At first sight the dyke appears compound, with a discrete central zone, but examination of thin sections has proved it to be a homogeneous porphyritic microdiorite. There is no cleavage in the dyke and so, like the first example seen, it is probably post-tectonic.

The less agile should retrace their route to the parking area, but the more sure-footed can scramble over the next two rocky spurs; the distance is only about 50 m but is quite arduous at anything but very low tide. The reward is a magnificent array of flute casts on the base of a greywacke bed, slightly overturned to dip steeply SE (g). The rock face must therefore be viewed looking north. The linear nested flutes indicate a current flow from top right to bottom left. If you imagine the bedding plane restored to the horizontal, an original eroding current flowing from the SE is suggested.

Return to the raised beach at Finnarts Bay. If several vehicles are being used the party should walk back to the A77 and **proceed with care** (the road carries **much heavy traffic** to and from the Irish ferry terminals) to the entrance track for the large disused quarry [NX 053 720]. One or two vehicles can be parked in the rough track entrance or on the hard shoulder area on the opposite (seaward) side of the road. The quarry itself is structurally complex and has loose, dangerous faces. It should not be entered. Fortunately the more accessible cliffs forming the roadside section running south from the quarry (Figure 47) are both secure and instructive.

Roadside traverseThis section is only slightly lower in the sequence than the flute casts viewed earlier at sea level. The entrance to the quarry coincides with an overturned F1 synclinal hinge zone with short limb partly eliminated by faulting (h). Closest to the quarry entrance the greywacke beds are the right way up and dip moderately south whereas, to the south in the roadside section, beds dip steeply south but are slightly overturned and young north. The direction of younging can be readily established from the array of sedimentary structures. The greywacke beds range from about 10 cm to over 1 m in thickness. Many beds are clearly graded and contain weak cross-lamination in places. Bed bases commonly carry small flute casts and more bulbous load casts.

The roadside section continues south becoming progressively lower and more obscured by bushes. Initially the attitude of the greywacke beds remains uniform with steep dip to SE and northwards younging. However, about 100 m SE from the quarry the greywackes are folded about an F1 anticline—syncline pair with both hinge zones broken and faulted (i). The anticline lies to the north of the syncline in a structural pattern characteristic of much folding throughout the Southern Uplands (Types 1 and 2, (Figure 3)). No cleavage is developed in association with these folds and cleavage is in fact absent from the whole roadside section.

The greywackes exposed on the shore and roadside are all in the Kirkcolm Formation (Figure 46). They are quartzo-feldspathic greywackes with a few accessory grains of spilite, schist, garnet and zircon; the quartz content averages about 45 per cent. Full compositional details are provided by Kelling (1962), Floyd and Trench (1989), Evans et al. (1991) and Stone (1995).

2 Lady Bay: Glen App Fault and Corsewall Formation

Leave Finnarts Bay and drive south on the A77 to Stranraer; pass through the town following signs for Leswalt and Kirkcolm and leave on the A718 heading NW. After passing the Stranraer golf course turn right at the Craigencross roundabout, still following the A718 for Kirkcolm. About 3.5 km beyond the roundabout it is worth stopping briefly beside the sea at St Mary's Croft [NX 034 659]. Here, on the foreshore, are exposed the Permian breccias which fill the 1500 m-deep Stranraer basin (Stone, 1988 and references therein). The east side of the basin is formed by a major fault which defines the east coast of Loch Ryan. This contrasts with the west side of the basin, where the Permian (and some Westphalian) strata lie unconformably above the Lower Palaeozoic greywackes; the structure is a classic half-graben (Figure 45). The breccias consist of greywacke pebbles up to about 6 cm across, contained in a matrix of coarse red sand. Thin interbeds of red sandstone and siltstone are also present. The most extensive outcrop is near the low water mark.

Continue north on the A718 through Kirkcolm. About 2 km beyond the village, fork right following signs for Corsewall Point and about 1 km beyond the fork turn right following signs for Lady Bay. The road is metalled as far as Low Portencalzie Farm but thereafter deteriorates into a rough track. Nevertheless continue on down towards the sea where there is a paved parking area with adjacent picnic tables.

It is essential to visit this locality around low tide. The Glen App Fault zone is exposed, subject to the vagaries of shifting sand and shingle, at the north end of the bay [027 718] below high water mark. All the rocks in the vicinity are pervasively reddened, a reminder of the nearby Permian sequence of red sandstone and breccia. A complex array of shear zones and quartz veins cuts through the reddened greywackes defining a fault zone about 5 m across and trending approximately NE towards Finnarts Bay and Glen App on the far side of Loch Ryan. The character and geometry of the structures within the fault zone suggest that ductile deformation occurred with a sinistral sense of shear, followed by small-scale brittle effects with a dextral shear sense.

Thickly bedded greywackes abut the fault zone on its north side and it is well worth scrambling over the cliffs a little way northwards to examine their sedimentary features. A well-trodden track provides a route. The greywackes are all part of the Corsewall Formation and are compositionally immature, with abundant clasts of igneous lithologies including spilite, gabbro and serpentinite probably derived from an ophiolitic source. The quartz content is only about 14 per cent on average. Compositional details are given by Kelling (1962), Evans et al. (1991) and Stone (1995). The lithic composition gives the greywackes a dark appearance which contrasts with the pale grey Kirkcolm Formation greywackes seen at Locality 1.

Immediately north of Lady Bay the Corsewall Formation greywackes are thickly bedded (tip to 1.5 m) graded turbidites. Beds are steeply inclined and the grading, together with the weak cross-lamination in the top part of some beds and the bottom structures on their bases, establishes a consistent direction of younging towards the north. Slightly farther north (up sequence) the thick greywacke beds are separated by thinly bedded intervals of greywacke and siltstone showing classical turbidite structures such as grading, cross-lamination and rippled bed tops. Some of the thick, coarser interbeds have pockets of pebbly greywacke along their bases.

3 Corsewall Point: Corsewall Conglomerate

Return to the parking area in Lady Bay and retrace the route to the KirkcolmCorsewall Point road. Turn right and continue towards the lighthouse. Just over 1 km NW from the Lady Bay road junction be sure to take the right fork; thereafter the route is fairly obvious, though occasionally gated. At Corsewall Point park on the right side of the road by the wildlife information board [NW 982 727]. From there walk NW on to the fault-bounded promontory (3a on (Figure 48)). On this and the two promontories to the east (3b and 3c) the sedimentary features of the conglomeratic member of the Corsewall Formation (late Llandeilo—early Caradoc) can be examined. This site has been mapped and logged in detail by Holroyd (1978) who interprets its rocks as an inner fan channel sequence deposited at the base of a deep-sea slope. The steeply SE-dipping beds are slightly overturned and young north. The sequence consists of extrabasinal conglomerates interbedded with coarse, massive sandstone units. Individual units are up to 4 m thick. Tertiary igneous activity is evidenced by thin cross-cutting dolerite dykes and, offshore to the north, by the microgranitic plug of Ailsa Craig.

The conglomerates are variably clast and matrix supported and consist of well-rounded pebbles and boulders up to 1.5 m in diameter set in a sandy matrix (3aand 3b). Granites and acid volcanic clasts predominate, but spilites, gabbros, greywackes and cherts are also found. Although mostly disorganised, the conglomerates display increased organisation eastwards across the three promontories. Organisation is shown by the alignment of the long axes of clasts parallel to bedding and, in places, by a crude lamination in the matrix. Both normal and reverse grading are present, but rare. Bedding is lenticular and channelised, in places clearly eroding the underlying unit (3c). The massive sandstone units are coarse grained and frequently contain outsize extrabasinal clasts. Rare sole markings indicate palaeoflow from the NW. Further east the boulder conglomerates are less common so that massive and graded sandstone units predominate. At Ochley Point [NW 986 728], about 300 m east of the parking area, fine-grained sandstone, laminated siltstone and mudstone form interbedded units up to 1.5 m thick in an overall fining-and thinning-up sequence (3d). This facies assemblage represents an interchannel environment on a submarine fan.

Work by Elders (1987) on the provenance of the granite clasts has highlighted the tectonic importance of the site. He identified a suite of five granitic clast types within the conglomerate. The most distinctive of these is a weakly foliated, muscovite-bearing biotite granite dated at 1265 Ma. Two of the other granites yielded ages of 600 Ma and 475 Ma. Combining these dates with petrographic and geochemical evidence, Elders identified north-west Newfoundland as the only area with a plutonic and tectonic history to match that of the clasts. The Corsewall conglomerate was obviously deposited close to source and a sinistral strike-slip movement of 1500 km during closure of the Iapetus Ocean would therefore be needed to account for its present position. This controversial conclusion has not been universally accepted; Kelley and Bluck (1989) refute it based on radiometric work of their own from the Southern Uplands (see discussion, Elders, 1990); whilst Owen and Clarkson (1992) argue that faunal evidence supports at most a few hundred kilometres of strike-slip movement along the Southern Upland Fault (but see also McKerrow and Elders, 1989). In view of its importance this locality has been designated a Site of Special Scientific Interest (McCurry, 1994).

4 Killantringan: Portpatrick Formation

From Corsewall Point return via minor roads to the A718 north of Kirkcolm. Drive south through the village to the Craigencross roundabout and proceed straight on along the Glenstockadale road; at the end turn left on to the A764 towards Portpatrick. After about 3 km turn right on to a single-track road signposted for Killantringan Lighthouse. This road forms part of the Southern Upland Way footpath and is marked accordingly. When the road reaches the coast cars should be parked on the right-hand side overlooking Killantringan Bay [NW 982 567]. At low tide a broad sweep of sandy beach allows easy access to the cliffs; when the tide is high the sea reaches the foot of the cliffs and isolates a number of small coves. These may then be accessed via the cliff top path.

Walk north on to the sea cliffs, either at beach level or by way of the cliff path, where thinly bedded greywackes and siltstones of the Portpatrick Formation are extensively exposed (4a in (Figure 49)). Sporadic thicker greywacke beds are also present and isoclinal fold structures can be picked out in places by careful examination. However, the probability of folding is most readily deduced from the sedimentary younging indicators, mostly grading, which show local reversals. Despite these, the dominant younging direction is to the north. Structural complexity is illustrated at one place (4b) where a synclinal hinge is exposed in a section which the sedimentary younging indicators show is broadly anticlinal. A strong slaty cleavage dips moderately to the SE, compatible with the bedding attitude in an axial-planar relationship. A fragmentary graptolite fauna recovered from this vicinity indicates a *linearis* Biozone age (Figure 46).

Return past the parking area and move on to the rocky outcrops around high water mark to the west. A different facies of the Portpatrick Formation is exposed with thicker greywacke beds ranging up to 1 m. Cleavage is still strong but is generally confined to the finer-grained, upper part of the greywacke beds and is markedly curved, refracting through the bed as the grain size varies. Some beds preserve bottom structures on their bases (the south side of the bed so view looking north) including some large flute casts indicating current flow from the SW (4c). The greywackes are dark and immature, and on fresh surfaces it may be possible to discern with a hand lens the abundant detrital mafic minerals, dominantly pyroxene and amphibole. This composition, rich in andesitic debris, is characteristic of the Portpatrick Formation.

Leave the south end of Killantringan Bay and walk south and inland to join the Southern Upland Way. The route skirts the inlet of Portamaggie where the wreck of the Craigantlet may still be visible; the ship ran aground in February, 1982. Continue for about 200 m south from Portamaggie and then drop down on the right-hand sidetowards the coastal rocks and cliff line. Thickly bedded Portpatrick Formation greywackes are well exposed; bedding is uniformly upright and youngs north. Many of the greywacke beds are coarse and gravelly at the base and show marked truncation of the cross-laminated tops of underlying beds. Bed bases also preserve abundant bottom structures, including flute casts which uniformly indicate current flow from the SW (4d). A few tens of metres farther south the cliff section recommences, coincident with a decrease in average bed thickness. Most of the greywackes have the characteristic dark colour of the Portpatrick Formation but thin interbeds (up to 25 cm) of pale grey quartz arenite can be seen (4e). These are correlated with the Glenwhargen Formation which develops as a thick sequence of quartzose greywackes farther east (see Excursion 14). The interbeds illustrate the interfingering of two different turbidite fan systems derived from very different source areas. Portpatrick Formation greywackes contain on average about 15 per cent quartz grains whereas the

Glenwhargen Formation arenite contains about 65 per cent quartz. Full compositional details are given by Stone (1995) and a sedimentological analysis is included in Kelling et al. (1987). Return to the parking area via the Southern Upland Way.

5 Portpatrick: Portpatrick Formation, folding and fault zone

Drive back along the lighthouse road to the A764 and turn right for Portpatrick. After about 4km turn right again into the village. Part of the described route requires a lowish tide and it may be necessary to arrange the sequence of localities to accommodate this. If time allows, a walk south along the cliff path to Dunskey Castle [NX 004 534] is a worthwhile diversion from the geology. The path is reached via steep steps just beyond the SE margin of the main car park on the south side of the harbour. The castle is about 500 in from the top of the steps. It occupies an impressive position on the cliff edge and is built mainly of local greywacke, with dressed corner stones and lintels of Permian red sandstone most probably brought in from Dumfries. It was built around 1510 by Adair of Kilhilt on the site of an earlier stronghold but was in a ruinous condition by 1684 and has remained so.

Folded Portpatrick Formation greywackes are well exposed in and around Portpatrick Harbour and exposure is more or less complete southwards to Morroch Bay. At Morroch Bay the basal beds of the Portpatrick Formation conformably overlie the Moffat Shale Group and are interbedded with shales containing *clingani* Biozone graprolites (Figure 46). Full details are given in Excursion 18.

A spectacular exposure of the greywackes is provided by an old quarry, 250 m SE from the southern harbour car park. The quarry is paved and landscaped. The main face, viewed looking east, exposes a magnificent F1 monoclinal fold. Remember, as you view the fold, that north is to your left. On the left the beds are vertical at ground level but higher in the cliff face assume a more gentle northward dip. The axial plane of the monocline dips moderately south (towards your right) and so the upper, gently dipping limb of the fold descends to ground level in that direction. A fine selection of turbidite features includes gravelly bed bases, shale rip-up clasts and cross-laminated bed tops. These make it easy to confirm the younging directions. In the north of the quarry the bedding at ground level is vertical and youngs north; in the south of the quarry it is the right way up and dips gently northwards.

Continue NW across the intertidal rocks towards Portpatrick Harbour. Bedding dip is variable and by applying younging criteria it can be seen that the beds are right way up and are folded about several open F1 synclines and anticlines. The hinges are mostly replaced by faults or shear zones but one good example of an open syncline is preserved slightly farther north in the back wall of the outer harbour and, at lowish tide, is accessible from the beach. The hinge plunges about 15° NE. A strong slaty cleavage is developed throughout this section, striking NE, and is either vertical or dips steeply SE.

Ascend the steps at the back of the harbour near the synclinal hinge. Turn left at the top and walk to the NW corner of the inner harbour [NW 997 542]. Thence continue west past the paddling pool and the Southern Upland Way start/finish indicator. A rocky gully continues west and the remains of a red sandstone archway at its seaward end marks the outfall of an old (perhaps Victorian) sewer. As you approach the archway **take care on the slippery rocks** and note the abundant quartz veins. The modern sewer follows the same line as its ruined predecessor and this outcrop is occasionally polluted. The gully utilised by the sewer pipes follows a major fault zone, the internal structure of which is exposed at low tide beneath the red sandstone archway. A black shaly siltstone is pervasively sheared and cut by several generations of quartz veins which are themselves sheared and folded. At least some of the deformation appears to have been ductile and the fold style suggests an overall sense of sinistral shear. An important feature of this fault is its separation of two contrasting structural domains. To the south lies the open folding just traversed; to the north the bedding is upright and youngs almost consistently northwards into the Killantringan section (Locality 4). This uniform section extends for almost 3 km, interrupted only sporadically by tight F1 fold pairs.

From Portpatrick Harbour return to the car park, and take the A77 Stranraer road to Ardwell Bay. Time may be available *en route* for diversions to Morroch Bay or Cairngarroch Bay. The former exposes a conformable contact between the Portpatrick Formation and the Moffat Shale Group (Excursion 18, Locality 3). The second locality allows examination of the Orlock Bridge Fault zone (Excursion 17, Locality 1).

6 Ardwell Bay: Gala Group, contrasting fold styles

From Portpatrick travel via the A77 and B7042 to join the A716 at Sandhead. Just south of Sandhead turn right at the signpost for the early Christian site at Kirkmadrine and continue on to the Clachanmore crossroads [NX 084 467]. (If Morroch Bay or Cairngarroch Bay have been visited continue south along minor roads for 10 km or 5 km respectively to Clachanmore crossroads). At the crossroads continue SW for 2 km along the road and then the rough track (which may be gated) to Ardwell Bay. Parking is available in a paved area with a picnic site [NX 071 449]. This journey crosses the major sinistral Orlock Bridge Fault, which separates Ordovician greywackes to the north from Silurian greywackes to the south. Ardwell Bay is on the south (Silurian) side of the fault (Figure 45) and exposes quartz-rich greywackes, the Stinking Bight beds (Gala Group 5) of *gregarius* Biozone age (Figure 46).

At the north end of the sandy bay [NX 071 453], where a fence meets the coast, a series of eight upright F1 folds are exposed over a 25 m section. These tight to open folds are developed in interbedded mudstones and sandstones with beds of less than 50 cm thickness. The folds display characteristic F1 geometry with curvilinear hinges plunging gently to moderately SW and axial surfaces inclined steeply SE. A vertical fault in one synclinal hinge has a minor downthrow to NW. Cleavage fans are centred on the axial surface of the folds and show strong refraction between sandstones and mud-stones in all the hinges. This indicates that the cleavage is contemporaneous with folding, not superimposed later. In the second anticlinal hinge from the south a 'finite neutral point' is particularly well formed in the mudstones. This represents a point of zero stress during fold deformation of the adjacent sandstones, now marked by the bifurcation of the cleavage in the mudstone. Clockwise rotation of the S_1 cleavage by 10–20° out of the axial surface in plan view is particularly well displayed. Bedding/ cleavage intersection lineations are less steep than fold plunge (or have a reversed plunge) on SE-younging limbs and plunge more steeply than the hinge on NW-younging limbs. This has produced downward facing bedding/cleavage relationships on some NW-younging limbs. Clockwise transecting S1 cleavage is common throughout the Silurian rocks of the Rhins and is believed to result from sinistral transpression acting during D1 deformation.

Return south along the beach past the parking area and continue to the south side of Ardwell Bay. The strata here are overturned so that the gently dipping bedding planes are the inverted bases of greywacke turbidite beds. These carry an impressive array of bottom structures and it is worth spending some time examining them under low tide conditions. Thereafter continue south and take the footpath up the slope past the ruined fortification of Doon Castle on Ardwell Point (labelled *Broch* on some OS maps). This path leads round the top of the cliff skirting the Hooies inlet [NX 069 446]. The agile can scramble down to beach level where dark graptolitic shales with pale bentonite layers are apparently interbedded among the Gala Group greywackes. Graptolites may be collected from several of the intertidal outcrops and prove the *gregarius* Biozone (Gala 5; (Figure 46)). If the graptolite localities are visited it is possible, with care, to climb out of the bay on the south side. Otherwise follow the cliff path around the back of the bay and then descend to the promontory on its south side. The bedding on the south side of the Hooies is steeply inclined and youngs to the south but on the headland it is folded about vertical hinges in a sinistral sense. The slaty cleavage developed subparallel to the bedding is also folded about the same hinges whilst maintaining its angular relationship to the bed-cling planes. Two generations of deformation are thus evident here: the main cleavage forming event was probably related to the fold and thrust episode (D1) with subsequent sinistral shear (D3) responsible for the steeply plunging hinges. If the steeply plunging hinge zone is followed seaward as far as possible the final exposure shows bedding, cleavage and fold hinge all cut across by a thin (and definitely post-tectonic) lamprophyre dyke. This instructive outcrop therefore also provides evidence for the local relationship of deformation and intrusion.

From the Hooies return via the cliff path to Ardwell Bay.

7. Drumbreddan Bay: Gala and Moffat Shale groups

Drive back to Clachanmore crossroads, turn right and proceed SE for 1.5 km to a prominent left-hand bend. Turn right at the bend and continue first south and then SW for 2 km to Drumbreddan Farm where permission to park and to visit Drumbreddan Bay should be obtained. Walk west through the farm for 150 m to the track which leads past the cattle sheds [083 439]. Follow this track SW for 600 m to the coast.

part of the Drumbreddan Bay Imbricate Zone and provides remarkable structural and sedimentological exposure across three imbricate thrust slices of Moffat Shale, each overlain by Gala Group greywackes of the Grennan Point Formation (Gala 6, (Figure 46)). The Moffat Shales acted as a decollement during thrusting and so form the lowest beds exposed. A rich graptolite fauna may be recovered from the shales (Excursion 18, Locality 4). Bedding youngs north but is overturned with a steep dip SE. Like most Gala Group lithologies the Grennan Point Formation has a siliceous petrography.

The southernmost imbricate thrust slice is exposed in a 100 m-wide promontory between two bays at the end of the track (7a in (Figure 50)). As the Moffat Shales exposed at the SE edge of the promontory are only visible at low spring ride, proceed NW across the bay to examine the more accessible exposure within the Grennan Bay Site of Special Scientific Interest (Treagus, 1992). Along the NW edge of the bay [NX 077 437] (7b) Birkhill Shales (Moffat Shale Group) of the gregarius and convolutus biozones young into the overlying Grennan Point Formation to the NW. The black fissile Birkhill Shales contain numerous pale bentonite layers (originally volcanic ash), one of which has been dextrally imbricated in response to a minor post-D2 steeply plunging dextral fold. The progradational sedimentary sequence from black shales into coarse well-graded turbidite beds with load, scour and tool (sole) markings, takes place over 8 m. Transitional parallel-laminated, shales and siltstones with rare cross-lamination yield graptolites of convolutus Biozone age. Flute casts indicate flow derivation from the NE, a trend supported by the general NE—SW alignment of groove casts.

The nature of turbidite sedimentation can be examined in more detail at the edge of Grennan Point [NX 076 437] (7c). The coarse- to fine-grained turbidites are well graded and in places display complete Bouma Ta, sequences. Convolute and cross-lamination are present in Tc divisions, and load structures are common on bedding soles. Amalgamation of beds is observed in places. Thickening-upward cycles range from 5 m to 20 m, and 80 m above the base of the formation a 20 m-thick sequence of shales and thin base-absent (Tcde, Tce) turbidites is present. The facies associations at Grennan Point indicate progradation from a basin plain and outer fan into a mid-fan lobe environment. The latter predominates throughout the succession apart from a temporary regression to outer fan deposits marked by the shaly section 80 m above the base.

At the north end of Grennan Point [NX 075 438] an inclined F1 synclinal hinge with a steeply inclined axial surface (7d) is deformed by the fault forming the base of the next imbricate thrust slice (7e). Beyond this fault a 100 m-thick outcrop of Moffat Shale is again overlain by the Grennan Point Formation. The structures associated with major D1 thrusting can be seen in detail. The fault at the base of the slice appears to dip steeply SE and contains brecciated greywacke lenses within a sheared black shale (7e). The S1 cleavage is in places disturbed, so is earlier than at least some of the movement. No conclusive movement indicators are apparent, although the synclinal hinge SE of the fault, and subvertical slickensides within the fault zone, suggest a south-easterly downthrow compatible with the regional stratigraphy. The fault is itself displaced by a series of small post-D2 sinistral wrenches trending NNE.

Within the Moffat Shales beyond the fault a series of neutrally verging F1 folds with wavelengths less than I m plunge gently NE (70. A few steeply plunging folds are also present. At this locality S1 cleavage is axial planar to the folds (cf. Locality 6 Ardwell Bay). About 20 m NW of the fault an antiformal hinge within the Moffat Shales has had its SE limb removed by a subvertical fault (thrust?) developed preferentially along a 12 cm bentonite horizon(7g). The incompetent nature of bentonite relative to black shale is demonstrated by extreme thickening of the bentonites in the fold hinge. In the most north-westerly 25 m of this Moffat Shale outcrop a 12 m-thick structural inlier of black Lower Hartfell Shales and pale grey Barren Mudstones of the Upper Hartfell Shales (both of Ordovician age) are exposed NW of a steep SE-dipping fault (7h). Graptolites collected from the Lower Hartfell Shales indicate a *wilsoni* or *clingani* Biozone age. These beds young north into the Silurian Birkhill Shales thus exposing the Ordovician–Silurian boundary. Graptolites ranging from the persculptus to the *atavus* Biozone have been identified in the Birkhill Shales here. A synform in the Birkhill Shales south of the fault is compatible with the regional stratigraphy in suggesting a downthrow to the SE.

However, local biostratigraphical evidence indicates some, possibly late, movement with downthrow to the NW (cf. Excursion 18, Locality 4).

The boundary between the Moffat Shale sequence and overlying Grennan Point Formation to the NW is a poorly exposed fault (7i). The fault has a steep south-easterly dip and separates black Moffat Shales from grey siltstones. Brecciated lensoid greywackes set in a sheared silty matrix are present for 8 m north of the boundary, beyond which are seen NW-younging brecciated greywackes of the Grennan Point Formation.

8 Port Logan: Gala Group

From Drumbreddan Farm drive along minor roads to join the A716 at Ardwell. Follow this road south for 2.5 km and then take a right turn for Port Logan. This road leads past the renowned Logan Botanical Gardens, which are well worth a visit. At Port Logan drive along the seafront and park by the pier at the SW corner of the bay [NX 095 404]. Beneath the bay, but not exposed, is the Port Logan Fault, a major DI tectonic boundary separating north-younging, SE-verging folds and thrusts to the north, from south-younging, NW-verging fold and thrust structures to the south.

The outcrop extending SW from the car park is formed by well-bedded greywackes of the Port Logan Formation (Gala 8, (Figure 45) and (Figure 46)). These rocks retain a diagenetic mineralogy (Merriman et al., 1991), making the grade of metamorphism here one of the lowest recorded in the Rhins of Galloway area (see Introductory chapter for further discussion). Turbidite features are well developed, both in terms of Bouma divisions and of bottom and top bed-surface structures. A short walk SW along the coast into the next small bay will in addition traverse the following features:

1. A cross-cutting, Tertiary dolerite dyke 2 m thick forms a vertical wall trending NW within a small inlet. Note the unusual honeycomb weathering of the dyke surface.
2. A zone of open folding with one well-preserved open synclinal hinge and evidence of bedding imbrication in the limbs.
3. Sequences of dark, interlaminated siltstone and shale up to 5 m thick interbedded with the greywacke.
4. A spectacular array of ripple marks on large, steeply dipping slabs at the south side of the small bay [NX 091 401].

Retrace the coastal route to Port Logan.

9 Clanyard Bay: Gala and Moffat Shale groups

To reach the next locality, Clanyard Bay, continue SE along the B7065 for 3.5 km to an offset crossroads. Turn right and drive for 800 m to just beyond the point where the road bends sharply south. Branching off to the right is the track to Low Clanyard Farm [NX 107 376]. Park carefully at the road adjacent to the track, or drive to the farm where permission should be obtained to visit Clanyard Bay. This locality provides evidence for the reversed sense of D1 thrusting and allows a comparison with the Drumbreddan Bay Imbricate Zone (Locality 7).

The Moffat Shale outcrops at Clanyard Bay are locally rich in graptolites and the locality is also described in Excursion 18, Locality 5.

One important difference in interpretation is adopted here to that shown on the BGS 1:50 000 Rhins of Galloway geological map and described by Stone (1995). The Cairnharrow Formation shown therein as a part of the Hawick Group is considered by McCurry (1989) to be the most southerly Gala Group unit (Gala 9, (Figure 46)). McCurry places the northern boundary of this unit to the north of Clanyard Bay and thus overlaps with a part of the Gala 8 unit shown on the BGS map. The critical area is examined in this excursion at locality 9 and visitors may judge for themselves.

From Low Clanyard Farm follow the track first NW and then west for 800 m past the derelict mill to Clanyard Bay. Walk to the north end of the bay [NX 101 381] where there is an exposure of Moffat Shale 60 m thick (Figure 51). This forms part of the 1.5 km-wide Clanyard Bay Imbricate Zone within the south-younging sequences south of Port Logan. The Moffat Shale exposure is divided in two by an east-west-trending felsitic dyke 6 m thick. The northern margin of the dyke is formed by a steep SE-dipping fault. South of the dyke the Moffat Shales are folded by a large synformal F1 hinge plunging gently west (9a in (Figure 51)). This hinge folds a faulted contact between intensely sheared Birkhill Shale in the core of the fold and Barren Mudstone (Upper Hartfell Shale) away from the core. The fault is interpreted as an early thrust formed within the Moffat Shale decollement prior to folding. The northern limb of the synform is displaced by a late-D1 fault dipping steeply NW. At the core of the synform the Birkhill Shales range from *atavus* to a possible *gregarius* Biozone age. The surrounding Barren Mudstones are variably red, grey, blue or brown in colour and contain numerous irregularly shaped siderite nodules of diagenetic origin. The red mudstones have been reduced to produce a buff or green reaction rim around each nodule. Both F1 and post-F1 (probable F2) isoclinal folds are present in the Barren Mudstones.

North of the dyke Birkhill Shales are exposed for 30 m and have an anomalous WNW bedding strike. Graptolites indicate an age range spanning the *atavus* to the *sedgwickii* biozones in an overall north-younging sequence. At the northern boundary of the Birkhill Shales two prominent felsitic dykes, each 1 m thick, are spaced about 2 m apart. The shales are intensely sheared and contain brecciated greywacke lenses. This sheared zone continues for about 7 m north of the dykes to a distinct gouge plane with an associated S1 fabric intruded by a thin (10 cm) felsitic dyke (9b). The attitudes of the fabric and breccia zones marginal to the fault indicate a downthrow to the NW. An adjacent large synclinal F1 hinge plunging gently NE has had its SE limb sheared and removed by the fault consistent with NW downthrow. There is therefore evidence for two phases of thrusting associated with the Moffat Shale decollement: the first was probably pre-E1 folding and the second was syn- or post-F1 folding. The NW downthrow is the opposite to that suggested earlier within the Drumbreddan Bay Imbricate Zone (Locality 7) and is atypical of the Southern Uplands generally. It is consistent though with the SE-younging and NW-vergence of D1 structures south of the Port Logan Bay Fault (McCurry and Anderson, 1989).

From the north end of Clanyard Bay [100 382] continue WNW across the southyounging turbidites of the Clanyard Bay Formation (Gala 9, (Figure 45), (Figure 46). Graptolites collected from rare black shale interbeds indicate a *turriculatus* or *crispus* Biozone age. After 30 m an upright F1 anticlinal hinge with a moderate westerly plunge is reached (9c). Some of the irregular joints developed in the hinge contain rare radiating sheaves of haematite. About 5 m north of the anticlinal hinge the beds are once again intensely brecciated in association with a number of moderate to steeply plunging post-F1 folds of wavelength 1–2 m.

Continue WNW for 70 m across a fence and over a prominent grassy ridge to a small bay (9d). On an island in the bay a superbly exposed NW-verging chevron fold pair is developed in overturned south-younging strata. The regular geometry of the fold pair represents in microcosm the structure demonstrated throughout the south-younging sequences south of the Port Logan Fault. The extreme angularity of the hinges and the straightness of the limbs characterise major fold structures, which dramatically increase in wavelength to over 1.5 km away from the boundaries of individual thrust sheets. The overturned bedding on the long limbs of folds is inclined steeply NW whereas the right-way-up flat limbs are inclined gently NW. These flat limbs are often intensely folded.

In the cliff at the north end of the bay another NW-verging F1 fold pair affecting thinly bedded turbidites can be examined in detail. A thrust is developed in the synclinal hinge and progressively excises the short limb westwards. The same style of chevron folding continues north for 400 m to the sole thrust of the sequence just north of Dunbuck [NX 094 382]. Within this zone the south-younging strata are intensely brecciated and disrupted by numerous faults. There are few precise movement indicators on the faults, but fold geometry, younging directions and stratigraphy all suggest downthrow to NW. Note once again the major regional difference in structure between these sections and the north-younging sequences seen further north.

Return to the south end of Clanyard Bay, to about 150 m beyond the mouth of the burn at Clanyard Mill. Here the Moffat Shales are divided in two by an ENE fault which forms a small gully through the exposure (9e). North of the fault gully a complex sequence of Upper Hartfell Barren Mudstones and Birkhill Shales (visible only at low tide) appears to young north despite disruption by a series of strike-parallel faults. To the south of the fault gully Birkhill Shales are isoclinally folded with hinges plunging gently to moderately NE or SW. Some folds display clockwise cleavage transection of up to 8°. Graptolites indicate *typhus* and *convolutus* Biozone ages (Excursion 18, Locality 5). At the south margin of the Moffat Shale outcrop a prominent east—west felsite dyke dips steeply north. Beyond the dyke intensely brecciated south-younging greywackes are present. Beyond the dyke intensely brecciated south-younging greywackes are present.

10 West Tarbet: Hawick Group

From Low Clanyard continue south and then east on the minor road to join the B7041 at Kirkmaiden. Drive south on the B7041 for 3 km and take the left-hand fork for the Mull of Galloway. On reaching the narrow isthmus at West Tarbet (Figure 52) turn right and park at the side of the road next to the track [NX 142 309]. This locality must be visited within three hours either side of low tide.

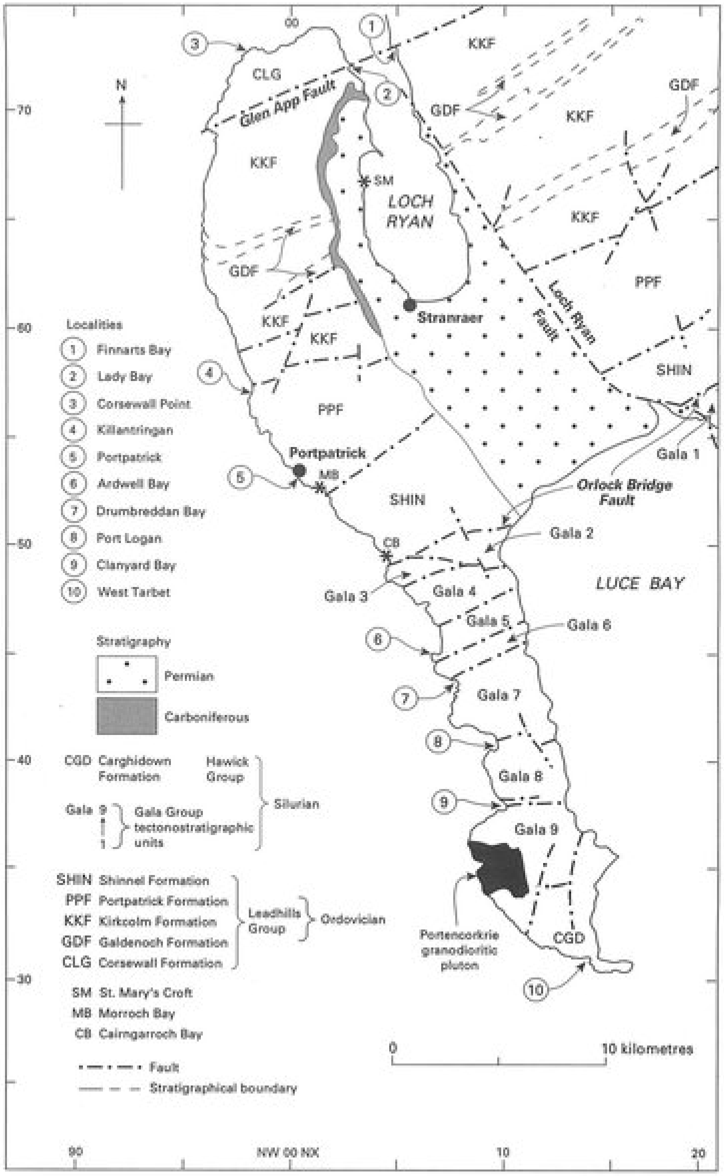
The platform between the bays at East and West Tarbet (10a in (Figure 52)) is covered by a layer of rounded pebbles and may be a late-glacial kame terrace. A small area of raised beach is visible in the bay below. The isthmus has formed by erosion along the major ENE trending Tarbet Fault. From the platform walk down to the northern foreshore of the bay at West Tarbet [NX 140 309]. The position of the fault is indicated by a felsitic mass intruded along it and exposed in the centre of the bay (10B). The pale green Hawick Group lirhologies exposed both north and south of the fault are turbidites, but much finer grained than those of the Gala Group seen at the previous three localities, and with a calcareous matrix. They are part of the Carghidown Formation and north of the fault form the Leucarron Member of McCurry (1989). This is a sequence of fine-grained - $T_{ace,}$ $T_{ade,}$ $T_{ee,}$ and T_{de} turbidites with thick mudstone interbeds intercalated with packets of coarser channelised $T_{ade,}$ T_{ace} turbidites.

For 120 m along the northern shore of the bay the strata are contorted into a series of unusual tight-to-open, post F1 folds (10c). With increased distance from the Tarbet Fault the folds develop a strong sinistral vergence and plunge moderately to steeply SE. They approach a parallel style, with little or no hinge thickening, and have a chevron geometry. Towards the fault they become increasingly brecciated, develop strong coaxial refolding and plunge moderately NE. Although they fold the S1 cleavage, only a few hinges have developed a weak coaxial crenulation cleavage. Examples of this planar crenulation can be seen in folds within the cliffs 30 m east ofthe prominent shallow cave (10d); since the cleavage is axial planar to the folds its orientation varies with the hinge orientation. Commonly both hinge and cleavage are coaxially refolded by later uncleaved folds of the same deformation, showing that this weak cleavage is an early-formed feature. These distinctive folds are probably linked with isomorphic folds seen elsewhere in the southern Rhins which are spatially associated with major late D1 thrusts. The folds at West Tarbet are restricted to a 120 m-wide zone between the Tarbet Fault and a major north–south-trending sinistral wrench fault. The latter structure has been eroded to form the prominent Mull Glen [NX 139 310] within which the folds are spectacularly exposed (10e).

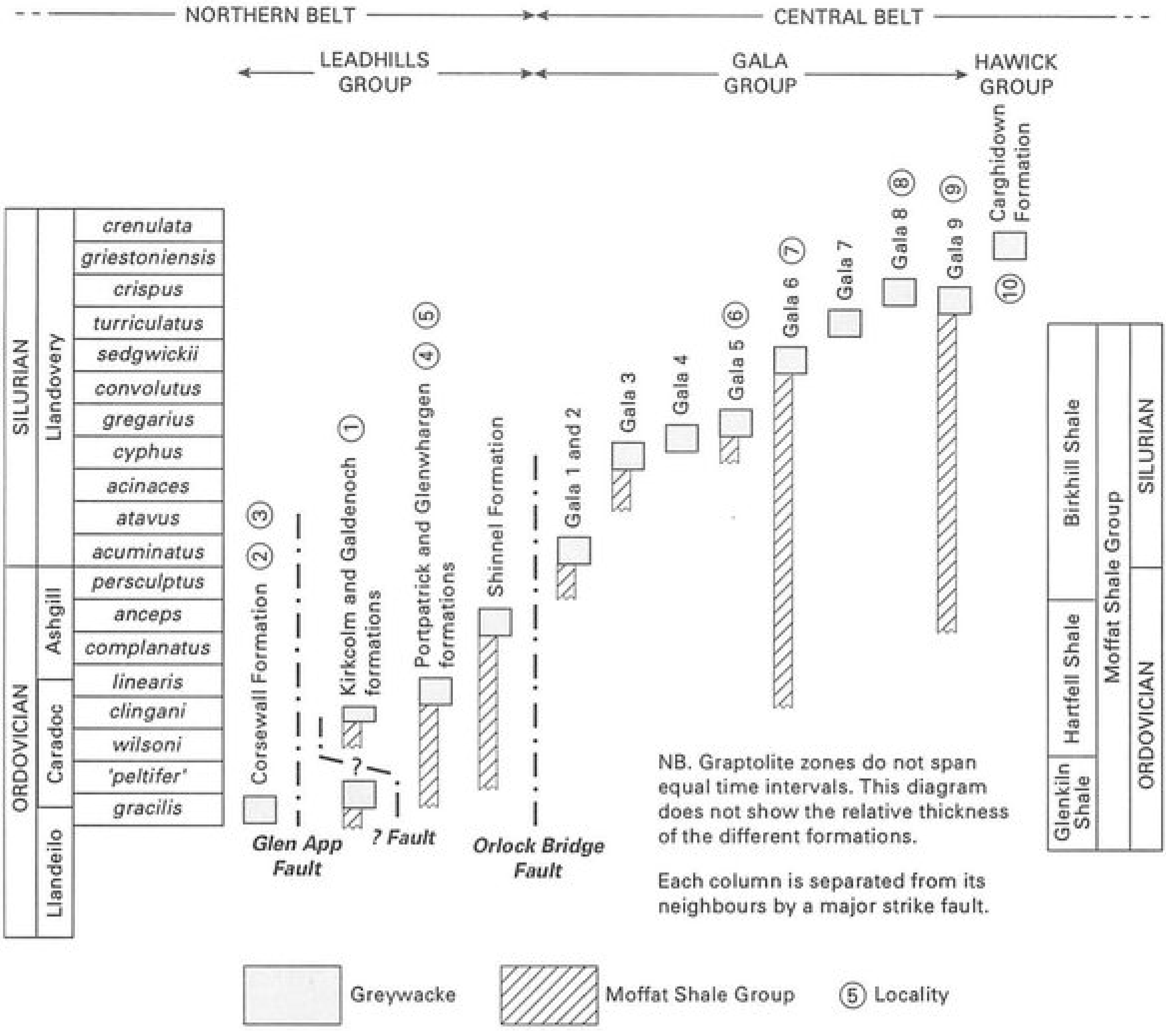
Proceed over the promontory on the west side of the glen, crossing overturned, south-younging beds on the steep limb of a major NW-verging F1 fold pair. On the far side of the promontory, a bedding sole is covered in large well-formed flute casts (10f).Like most sole current structures in the Leucarron Member these indicate palaeoflow from the SE. This contrasts with the NW- and NE-derived currents that typify the Hawick Group elsewhere in the Southern Uplands. Ripples on a bedding surface on the opposite side of a small bay (10g) indicate palaeoflow at a high angle to that of the flute casts. This strong divergence in flow direction between sole markings and ripples is not uncommon.

From West Tarbet visitors may wish to continue to the Mull of Galloway lighthouse. This windswept spot is the most southerly point in Scotland and affords splendid views across to Ireland, the Isle of Man and English Lake District. There are numerous exposures of thinly bedded Carghidown Formation greywackes but the sea cliffs around the headland are high and extremely precipitous and should not be approached too closely.

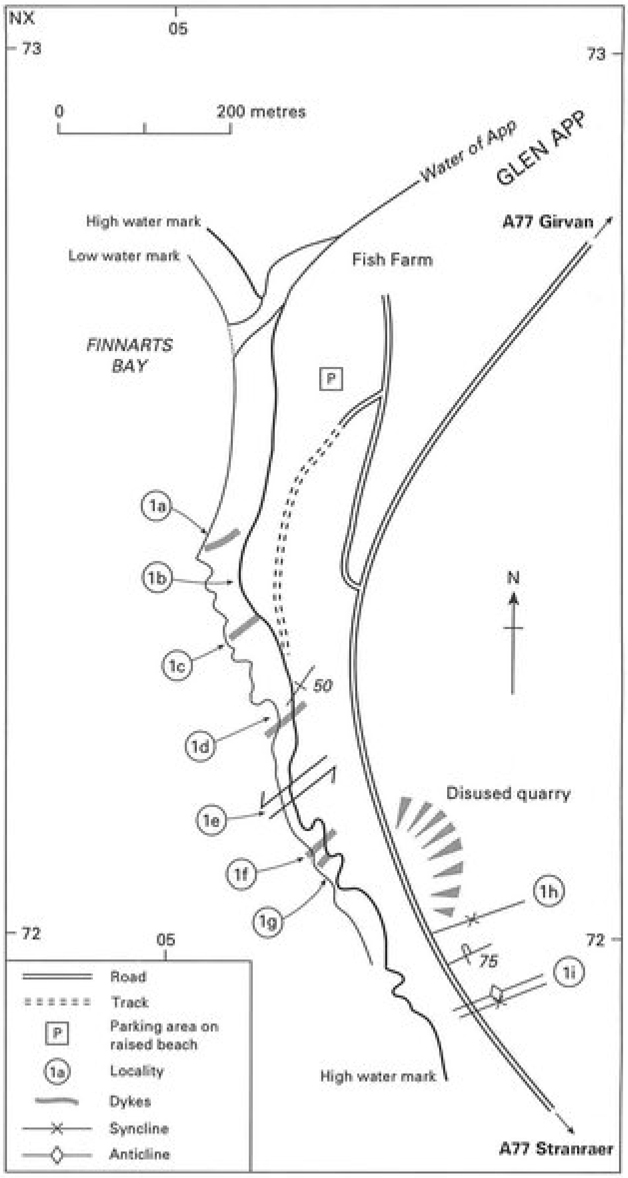
References



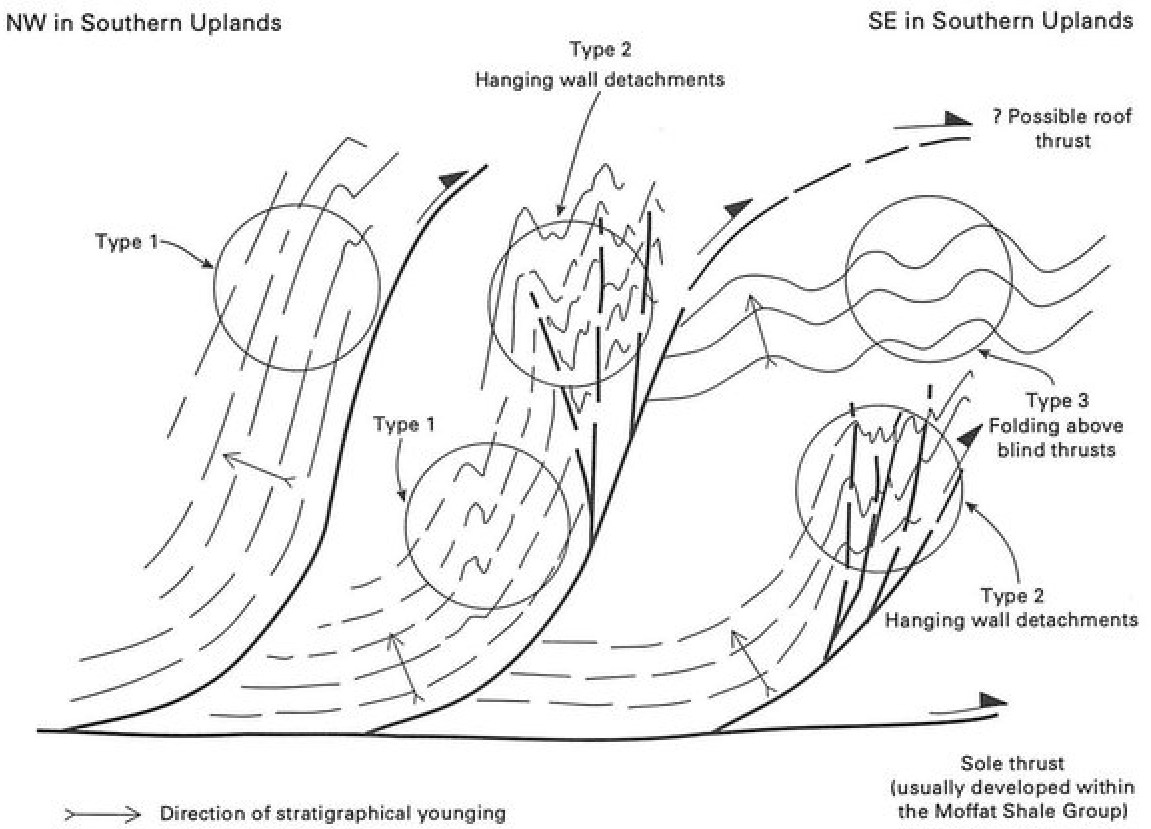
(Figure 45) Outline geology for the Rhins of Galloway 122.



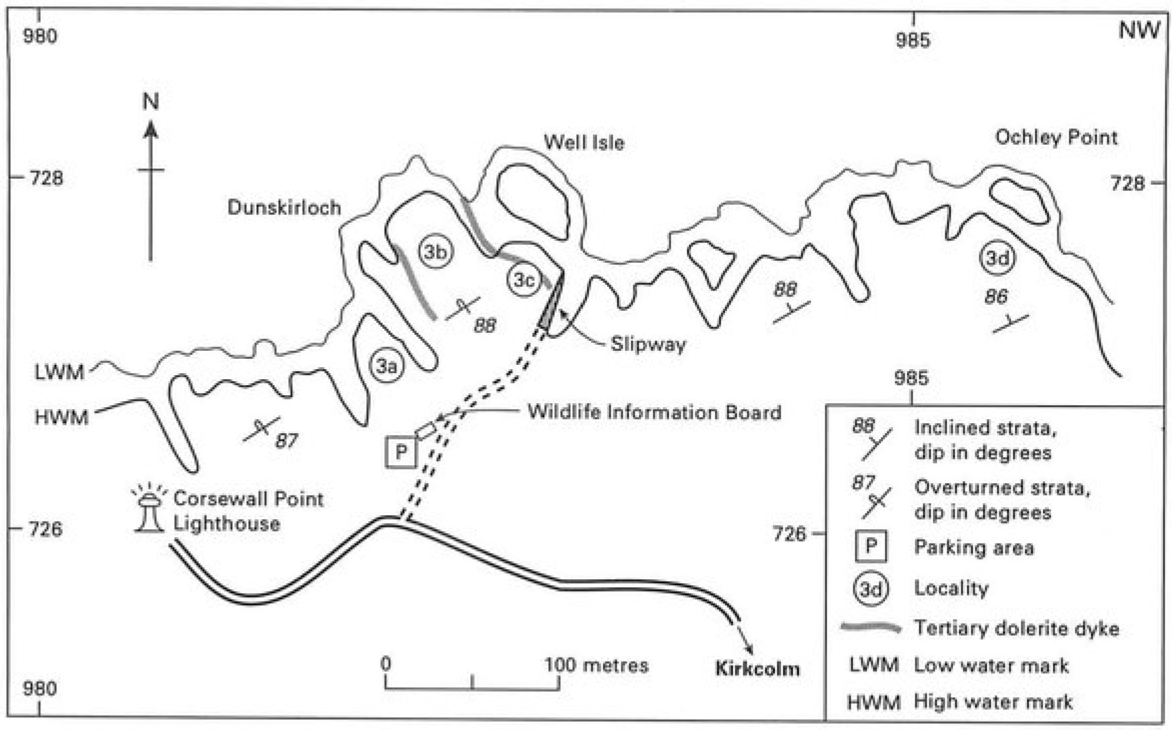
(Figure 46) Summary of Lower Palaeozoic stratigraphy on the Rhins of Galloway.



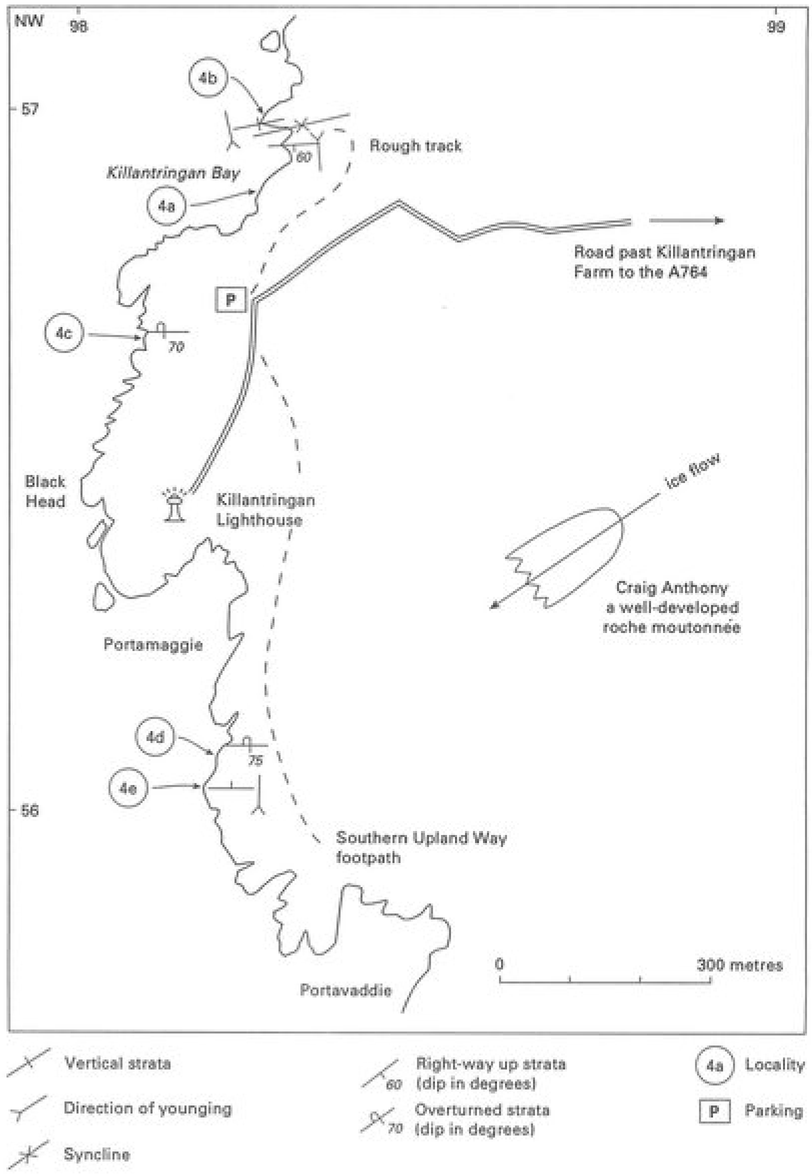
(Figure 47) Locality map and outline geology for the Finnarts Bay area (Locality l).



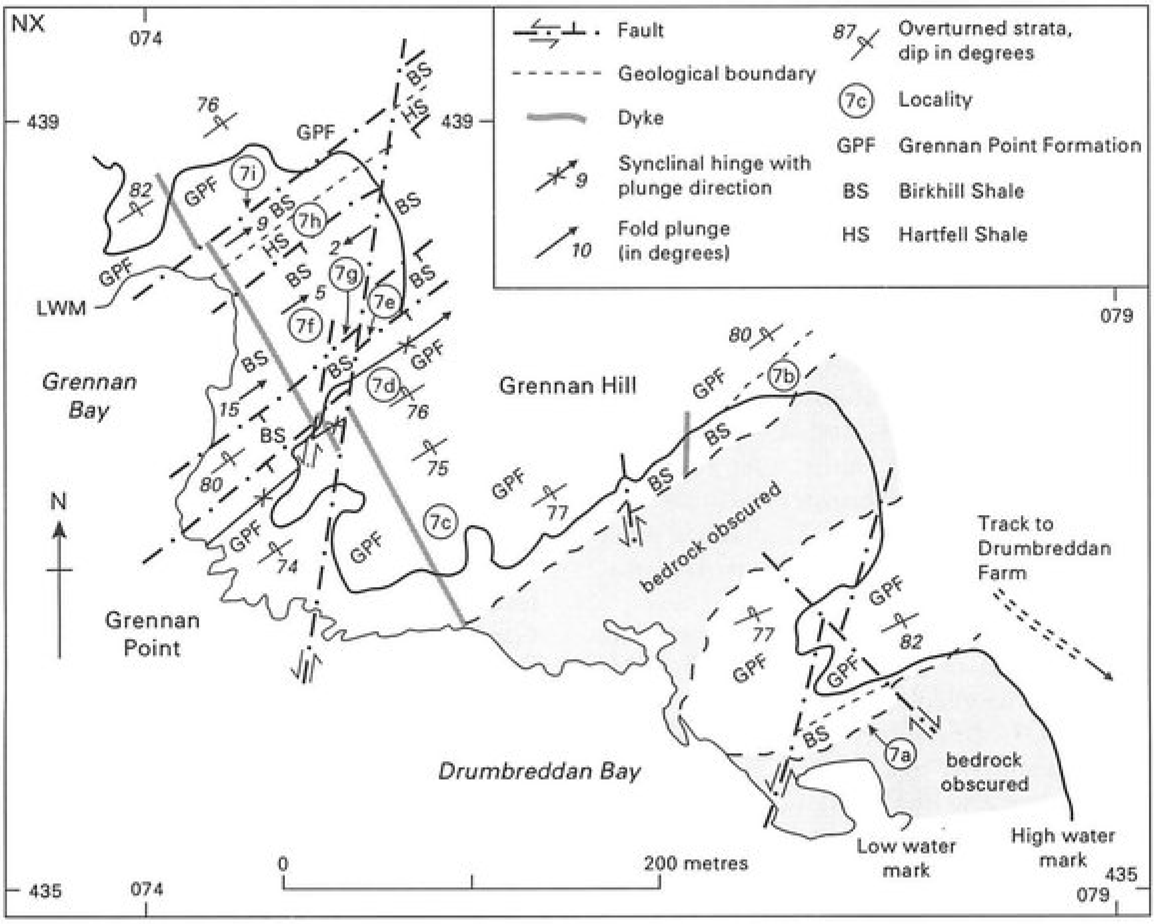
(Figure 3) Variable fold style developed within an idealised thrust sequence: examples are seen in the Southern Uplands.



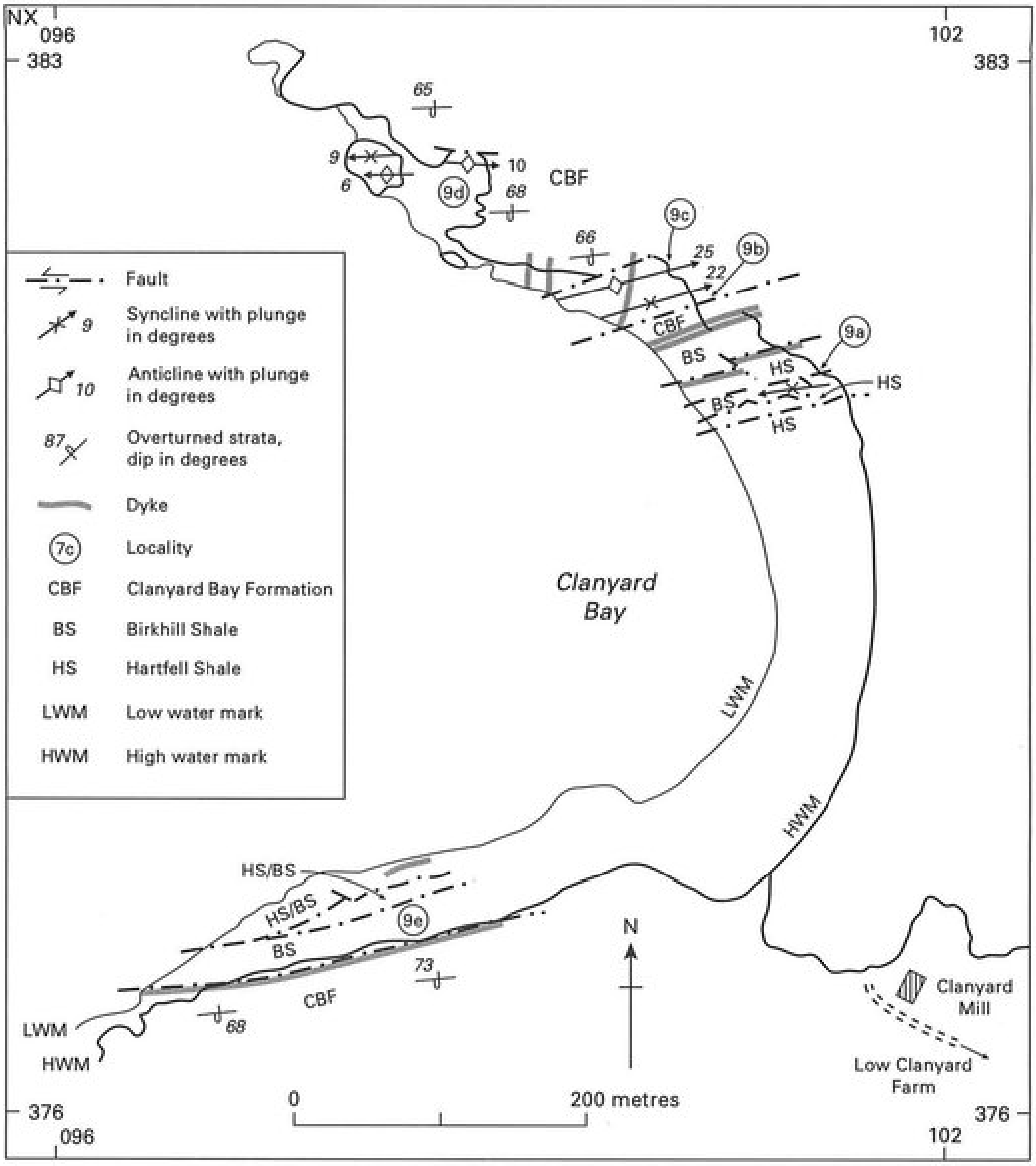
(Figure 48) Locality map and outline geology for the Corsewall Poinr area (Locality 3).



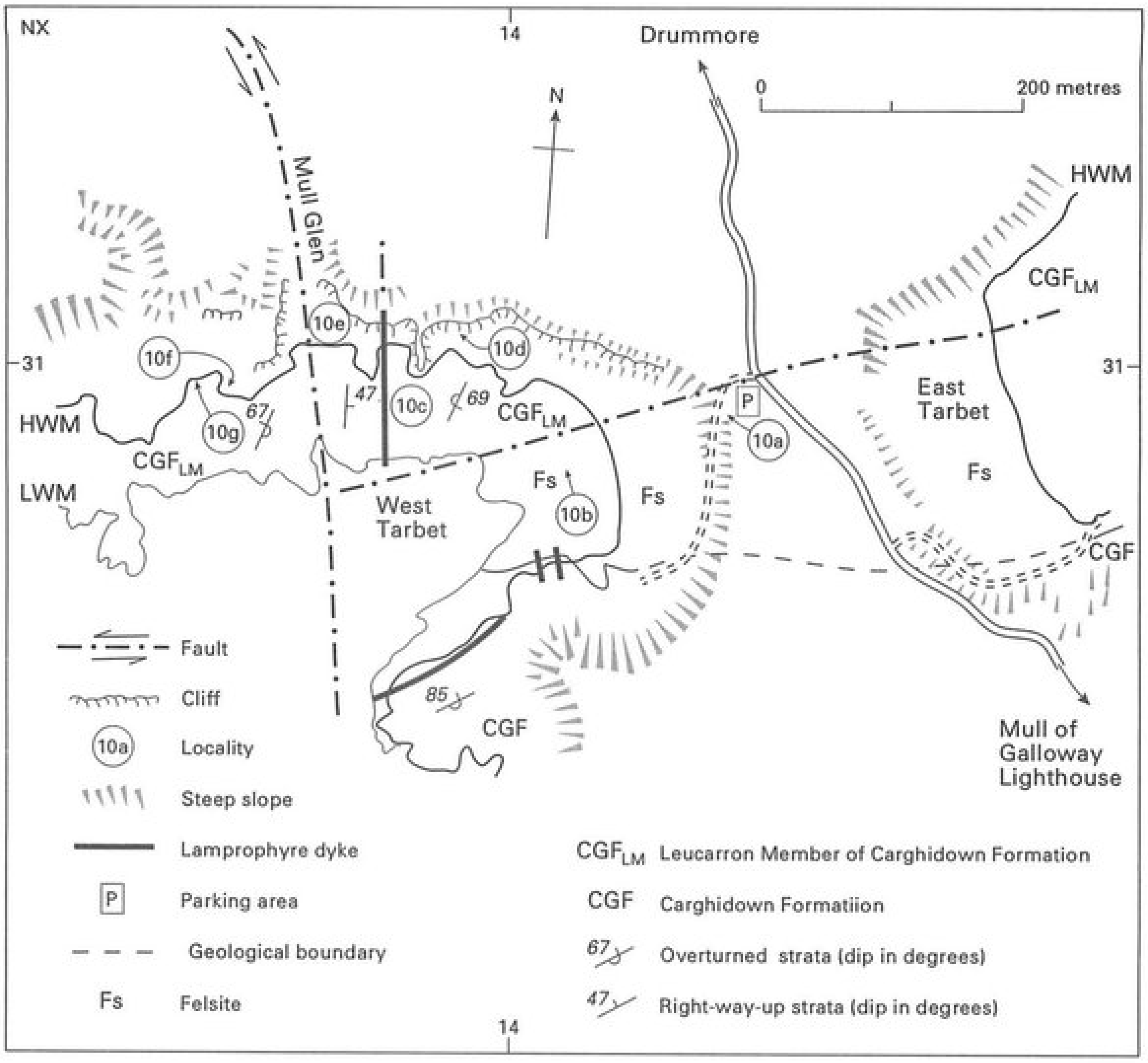
(Figure 49) Locality map and outline geology for the Killantringan area (Locality 4) .



(Figure 50) Locality map and outline geology for the Drumbreddan Bay area (Local iry 7).



(Figure 51) Locality map and outline geology for the Clanyard Bay area (Locality 9).



(Figure 52) Locality map and outline geology for the West Tarbet area (Locality 10).