Excursion 12. Gatehouse Of Fleet: structural complexities of the Hawick Group

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OS 1:50 000 Sheet 83 Newton Stewart & Kirkcudbright

BGS 1:50 000 Sheet 4E Wigtown

Route map: (Figure 39)

Main points of interest Sedimentology and structure in the late Llandovery Hawick Group, polyphase deformation, late Caledonian porphyry and felsite dykes.

Logistics The area may be approached either from Gatehouse in the east or from Creetown in the west via the A75 road and the excursion may be started or curtailed at Ravenshall Point, Mossyard Farm or Low Auchenlarie Farm. Note that account has to be taken of the state of the tide at Auchenlarie, Mossyard and the Newton shore. The likelihood of congestion in the Mossyard Farm car park during the holiday season may also have to be considered. Localities visited are situated along the coast between the Ardwall shore [NX 585 545], on the Fleet estuary 2 km west of Gatehouse, and Ravenshall Point [NX 523 523] on the east side of Wigtown Bay. Exposures are in the wave-cut platform, intertidal skerries and cliffs. Nearby cuttings along the main A75 Carlisle–Dumfries–Stranraer road are informative but are not now recommended for examination due to the hazard of high-speed traffic. On a clear day the A75, which follows the coast a short distance inland, gives good views of the Cumbrian mountains and the Isle of Man.

Introduction

The eastern coastline of Wigtown Bay provides good sections through the Cairnharrow and Kirkmaiden formations of the late Llandovery Hawick Group. The succession consists of greywackes which are typically poorly graded and bedded in units mostly less than 1 m thick. Fine arenite forms up to 90 per cent thickness of each unit and grades upwards into pelite; T_{abde} (Figure 6) cycles predominate. Grading is expressed mainly in the progressive upward intensification of cleavage into the finer-grained intervals. A high quartz content commonly imparts a vitreous lustre to fresh surfaces. Calcareous nodule trails parallel to the bedding are dispersed through many of the thicker arenite intervals, reflecting a general abundance of secondary carbonate within the Hawick Group as a whole. Sole markings are well developed in the Cairnharrow Formation, but are scarce in the Kirkmaiden Formation. They are predominantly non-directional drag marks, with small directional flute casts, longitudinal ridge casts and prod marks. Directional sole markings denote palaeoflow towards the WSW, the prevalent trend within the area and subparallel to the regional fold plunge. Deposition in an intermediate to distal trench, or lateral lobe of a submarine fan, is suggested (Weir, 1974).

The strata have been subjected to a continuity of deformation in which two stages, designated 'main' and late' (cf. Needham, 1993), are prominently developed. An 'early' soft-sediment deformation is sparingly represented. The main-stage folds are of two contrasting styles: NW-facing homoclinal zones of steeply inclined bedding up to 1 km and more wide ('steep belts'), which alternate with comparably wide tracts of dominantly open, upright buckle folds; where asymmetrical these latter structures are SE-verging. Adjacent structurally contrasting belts are separated by strike faults downthrowing SE (Weir, 1968; 1979). Evidence from elsewhere in the outcrop of the Hawick Group suggests that the strike faults, though now steep, originated as thrusts over-riding towards the SE, and were subsequently steepened and back-rotated. Anticlines are commonly faulted along their axial surfaces, suggesting that the folds grew ahead of the developing thrusts, ultimately to be cut by them. The SE-downthrow of the strike faults, in combination with the NW-facing of the steep belts, has led to duplication of the succession, and there are no gross changes in stratigraphical horizon across the 10 km-wide outcrop of the Cairnharrow and Kirkmaiden formations (Craig and Walton, 1959). The main cleavage in the pelite intervals is steep, penetrative and slaty, with development of new sericite; an equally steep but irregular, non-penetrative and spaced cleavage occurs in the arenites. The cleavage is rotated by up to 15° clockwise relative to fold axial surfaces indicating continuous deformation under a sinistral transpressive regime. This also resulted

in the reactivation of at least some of the rotated main strike faults with a sinistral strike-slip displacement (Stringer and Treagus, 1980).

Late-stage structures are more variable. Open folds with wavelengths of a few metres, asymmetrical with respect to dip though symmetrical in relation to limb lengths, verge NW and affect the steep belts. Minor NW-directed thrusts are associated with small recumbent folds which refold the main folds; an associated flat-lying crenulation cleavage displaces the main cleavage. This episode postdates the sinistral transpressive phase and is likely to relate to a period of back-thrusting (Stone et al., 1987). The late crenulation cleavage dips SSE at 45° or less. It is irregularly spaced, planar and weakly penetrative in pelites, and spaced, irregular, non-penetrative and strongly refracted to steeper inclinations in arenites.

A conjugate set of NNE sinistral and ESE dextral wrench faults displaces the main folds and succeeds the thrusting episode. Porphyry dykes of late Caledonian age are especially associated with axes of parasitic main-stage anticlines within the steep belts but also invade at least one late wrench fault.

1 and 2 Ravenshall Point: Cairnharrow Formation

Follow the A75 west from Gatehouse for 10 km to a lay-by on the south side of the road [NX 525 524]. This can accommodate more than one coach. Follow the path to Ravenshall Point, which breaches the wall near the west end of the lay-by and turns sharply west for 300 m.

The Cairnharrow Formation as developed at Ravenshall consists of turbidite units characterised by abundance and variety of sole markings both directional and non-directional. Exposures around high water mark [NX 522 522], across the small bay beyond the western headland (Locality 1), are reached through a natural arch which cuts the headland**.** Bed bases display a comprehensive range of sole markings.

A thick breccia horizon in the western headland may have been formed by slumping of a thick turbidite bed, probably during the late deformation. In such circumstances brecciation may be caused by bed-parallel fluid escape in response to seismic pumping following shear failure on a basement fault (Murphy, 1984). The locality is within a steep belt which has been refolded by late asymmetrical folds. These include a medium-sized monoform in which the upper limb has dips varying around 30° and the lower steep limb is vertical.

On the north (landward) side of an isolated stack (Locality 2) at mid-tide level 100 m east of the eastern headland [NX 524 522], one bedding surface displays current ripple marks denoting a SSE-directed palaeoflow. Another bedding plane exposed on the south side of the stack displays structures which mimic linguoid ripple marks with wavelengths comparable to those already examined. Close examination reveals that these are small monoformal folds cut by minute, evenly spaced thrusts dipping NNW and with top-to-SE displacements. These are late structures, the 'pseudo-ripples' of Craig and Walton (1959).

3 and 4 Auchenlarie shore: Kirkmaiden Formation

Drive east on the A75 for 1.5 km to the caravan site at Low Auchenlarie Farm [NX 536 521]. Transport may be parked by arrangement with the caravan site shop, which may charge a fee. Follow the metalled road on foot southwards to its eastward turn at the cliff top (250 m) and descend the steep gullied track for about 100 m to the shore (Locality 3). These exposures are also described in Excursion 16, Locality I.

Along the Gatehouse coastal section the greywackes of the Kirkmaiden Formation (Rust, 1965) contrast with those of the Cairnharrow Formation in displaying a scarcity of sole markings and internal structures, though grading is more convincingly developed, principally as T_{ae} units. The turbidites of this formation are typified by a large thickness range. Packets of turbidite units reaching upwards of a metre thick, and including one succession of conspicuously thick beds, alternate with sequences of thinly bedded and pelite-dominated units a few metres thick at the most. Some thick packets constitute thinning- and fining-upward cycles, which may terminate in pelite-dominated sequences. The succession here crops out within a buckle fold belt 750 m wide.

Pelite partings, which are well exposed in fault gullies in the western headland of the small bay, carry a well-developed main cleavage which is penetrative with regular spacing and a near-vertical attitude. This cleavage carries crenulations on a scale of a few millimetres, related to a coarse, evenly spaced and weakly penetrative late cleavage with a shallow SSE dip. One conspicuously thick pelite interval near the mouth of the nearest gully clearly displays the intersecting relationship of the late and main cleavages. The crenulations are strongly asymmetrical, with long limbs facing upwards and short limbs facing downwards. This broadly reflects the style of the larger late asymmetrical folds which here have axial surfaces dipping at around 35° SSE. Hinges in the larger folds are rounded with no thickening and the axial traces are nearly horizontal. Limbs are roughly equidimensional, around 5 m in length and with amplitudes of less than 20 per cent of wavelength. Arenites carry a coarse, irregular and irregularly spaced fracture cleavage dipping 45° SSE.

Quartz veins in arenite immediately south of the cliff path carry slickenfibres and the associated pelites a stretching lineation, both of which are aligned parallel to the regional fold hinge plunge. About 100 m east of the cliff path, the most thickly bedded turbidite sequence on the Gatehouse coast displays a series of late folds having uncommonly large wavelengths of around 25 m and amplitudes of up to 15 m. Axial separation of the folds is here controlled by bed thicknesses. A detached exposure to seaward shows an isolated example of back-thrusting, in which the steep limb of a small recumbent fold is displaced by a minor thrust with an indeterminate top-to NW displacement.

The wide and shallow gully (Locality 4) of the Boatdraught [NX 537 518] follows the boundary fault between the Auchenlarie buckle fold belt and a steep belt 1.3 km wide to the SE. This gully, though lacking exposures, is likely to have been eroded out along a disruption zone generated by the fault (Needham, 1993).

A bedding plane 50 m east of Boat-draught is covered with small sand volcanoes related to dewatering during the early, soft-sediment deformation. These structures are around 60 mm long and are elongated parallel to the main cleavage. This denotes axial extension during the main deformation and confirms the evidence of the slickenfibres and the stretching lineation at the previous locality.

5 to 10 Mossyard shore: Kirkmaiden Formation and minor intrusions

Continue east along the A75 for a further 900 m to the junction with the Mossyard farm road [NX 544 525]. Follow this road south for 1 km to the farm. The road beyond the farm is unmetalled and unsuitable for coaches; passengers should disembark at the farm and follow the road to the coast on foot, coaches returning to Auchenlarie to park. A parking charge is levied and to gain permission for access it is advisable to contact Mossyard Farm, Gatehouse of Fleet, Kirkcudbrightshire in advance.

The Kirkmaiden Formation here lies partly within the Auchenlarie–Mossyard steep belt (to the NW) and partly in a buckle fold belt characterised by upright, open to very tight main-stage folds with wavelengths of more than 100 m to less than 1 m. This belt continues past Mossyard at least as far as Gatehouse. From the car park, walk SW along the rocky shore for about 1 km; two parasitic main fold pairs within this steep belt can be examined at Locality 5 [NX 542 515]. The more northerly fold pair has been coaxially refolded into a SE-verging recumbent attitude such that the main cleavage is also nearly horizontal. The main structure, which deforms a more thickly bedded sequence, originated as a tight fold pair with an axial separation of 3 m and a rounded axis with little or no thickening. The core of the anticline is occupied by a pale, pinkish grey porphyry sheet about 1 m thick. This has a dense in-situ growth along each margin consisting of alkali feldspar phenocrysts about 2 cm long with their long axes aligned roughly normal to the dyke margins. The intrusion belongs to the late Caledonian acidic suite and is unsheared; it thus postdates the main folding and was deformed along with the main fold pair during the late folding (Stringer and Treagus, 1981).

The second fold pair is situated 28 m farther south, and affects a pelite-dominated sequence. This fold is upright and very tight with a twofold axial thickening. It is nearly symmetrical with an axial separation of 1 m and a NE plunge of 5°. The main-stage cleavage is strong and rotated by some 15° clockwise relative to the anticlinal axis.

A third main-phase anticline at Locality 6 [NX 543 514] is tight and upright, and has a particularly thick and bright pink, felsitic dyke intruded into the core. This dyke is again unsheared, but also lacks marginal concentrations of aligned feldspar phenocrysts and may be entirely post-tectonic. There is little if any evidence of faulting along the axial surface of

the anticline but it is displaced by a small ESE dextral strike-slip fault, one of only two observed within the area and now eroded to form a prominent gully parallel to the shoreline.

The boundary between the Mossyard steep belt and the Mossyard—Gatehouse buckle fold belt is well exposed on Ringdoo Point at Locality 7 [NX 545 513] and takes the form of an axially faulted anticline. Each limb is nearly vertical and the fault plane is marked by a narrow, quartz-filled crush zone. Poorly developed grading and occasional bottom structures (mainly drag marks) indicate southerly facing seaward of the fault and northerly facing to landward. Strong reddening and ochreous discoloration of the strata in the vicinity of the fault are ascribed to weathering during development of the major Permo-Triassic depositional basin whose present margin lies a short distance offshore.

A low west-facing cliff at Locality 8 [NX 552 516] displays a symmetrical and upright main fold pair with a comprehensive range of minor structures. The syncline is wide and open and the anticline to the south narrow and very tight. There is considerable thickening of the anticline hinge in association with both small-scale disharmonic folding and flat-lying faults with quartz veining. The axial separation is about 25 m, and there is a gentle easterly plunge. Main slaty and late crenulation cleavages are especially well developed and replicate the features observed on the Auchenlarie shore. The relationship of the late cleavage to the crenulations is especially convincing, as is displacement of the main by the late cleavage. There is also a strong development of a steep main fracture cleavage in the arenite beds. The late cleavage in the pelites has a SE dip of 30°, strongly refracted in the arenites to dip 45°. The strata in the syncline constitute a thinning-and fining-upwards greywacke sequence which rests on pelites forming the anticline. This anticline is aligned with the Ringdoo Point anticline (Figure 39) but is unlikely to be an extension of it since the fold styles contrast markedly. There is likely to be a strike-slip fault through the sandy bay to the west of this locality.

Another main fold pair is well exposed in the three Garvellan Rocks (Locality 9). In the eastern rock [NX 552 514] the anticline folds a fine-grained sequence, and the NW limb is slightly overturned. The main cleavage has a southerly dip of 40°–60° and is offset by small SE-facing monoformal folds with a 10 cm scale of wavelength. These folds are closely comparable in style to the late crenulations but are an order of magnitude larger and are associated with a weak crenulation cleavage. This has itself been coaxially refolded into a gentle anticline. A felsitic dyke which traverses the middle rock occupies a late fault trending ESE. Drag folds in the adjacent strata indicate a dextral strike-slip movement though there is no discernible displacement of the anticlinal axis. This is the second of the two dextral faults observed in the area.

Several folds within the Mossyard buckle fold belt crop out on intertidal skerries (Locality 10) between the Garvellan Rocks and the Cardoness shore [NX 570 538]. The traces of these folds are assumed to terminate against faults trending between north and NNE, the prevailing trend of the late sinistral wrench set.

11 Skyreburn Bay: tectonic structures in the Kirkmaiden Formation

Return to the main road and continue east for 3 km, parking in a lay-by on the seaward side [NX 576 545]. Pass through the wicket gate near the eastern end of the lay-by and descend to the shore.

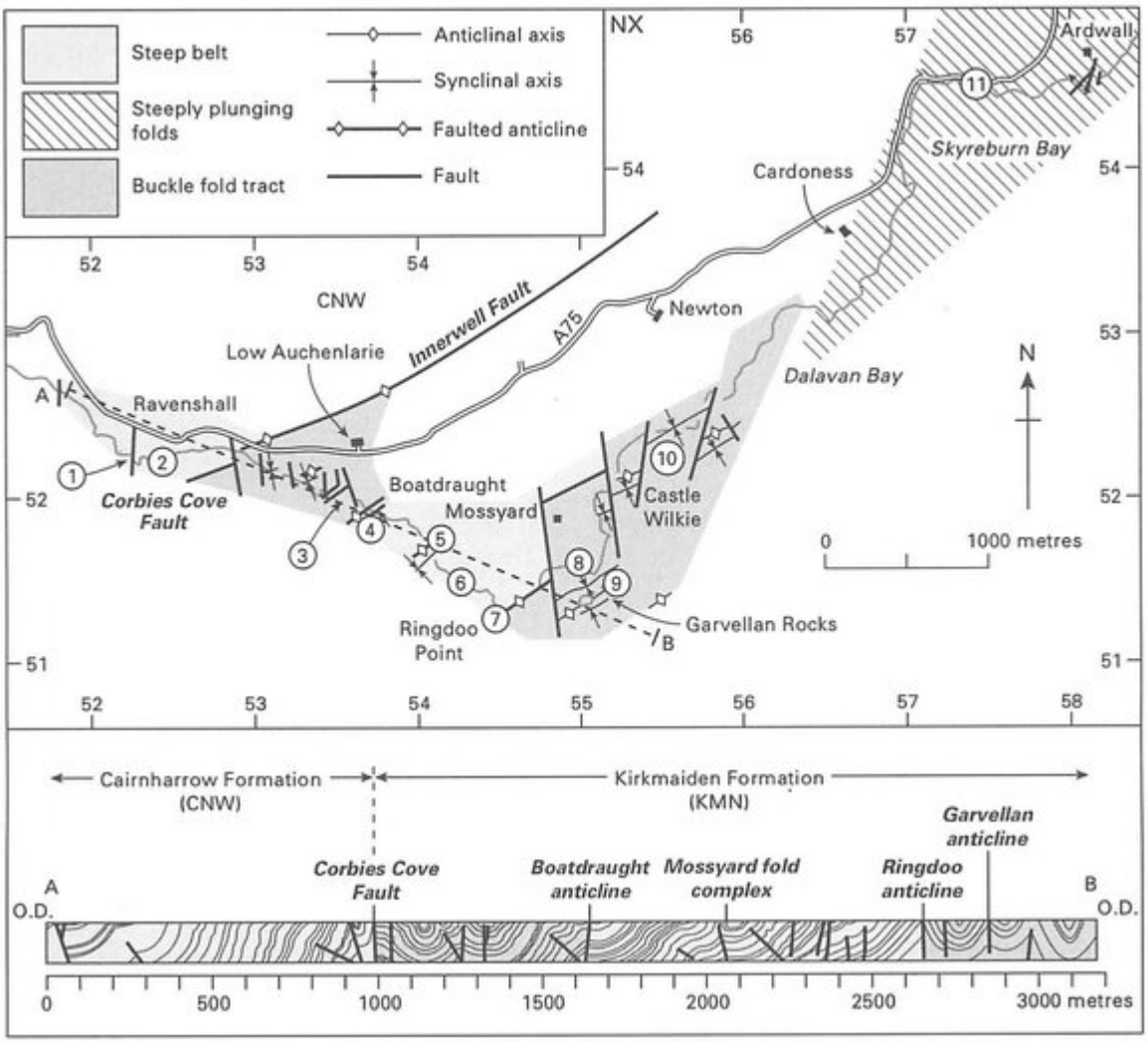
A series of small folds is exposed on the wave-cut platform below the east end of the lay-by. These folds have vertical axial surfaces with a north–south strike and are strongly asymmetrical, with east-facing limbs several centimetres long and west-facing limbs a metre or more in length. They are thus open, sharply angled chevron folds with interlimb angles of around 150° and near-vertical plunges; they represent a late brittle kink-band phase with dextral sense of displacement.

Several medium-sized main-stage folds are exposed above high water mark at this locality. They are symmetrical, have vertical axial surfaces striking ENE, are open with rounded hinges and show no axial thickening. Dips range up to 70° and hinge plunges, which are variable, are mostly steeper than 45° ENE. Wavelengths vary between 10 and 50 m. These moderately to steeply plunging folds occupy a tract 2.5 km long trending WSW between Skyreburn Bay and Cardoness, the plunge lessening progressively south-westwards. Apart from the steep plunges, the style and associated cleavages of these folds correspond with the other main buckle folds, including the clockwise rotation of the main cleavage relative to the axial surfaces. Late crenulations have plunges parallel to those of the main fold axes. Steepening of the plunges

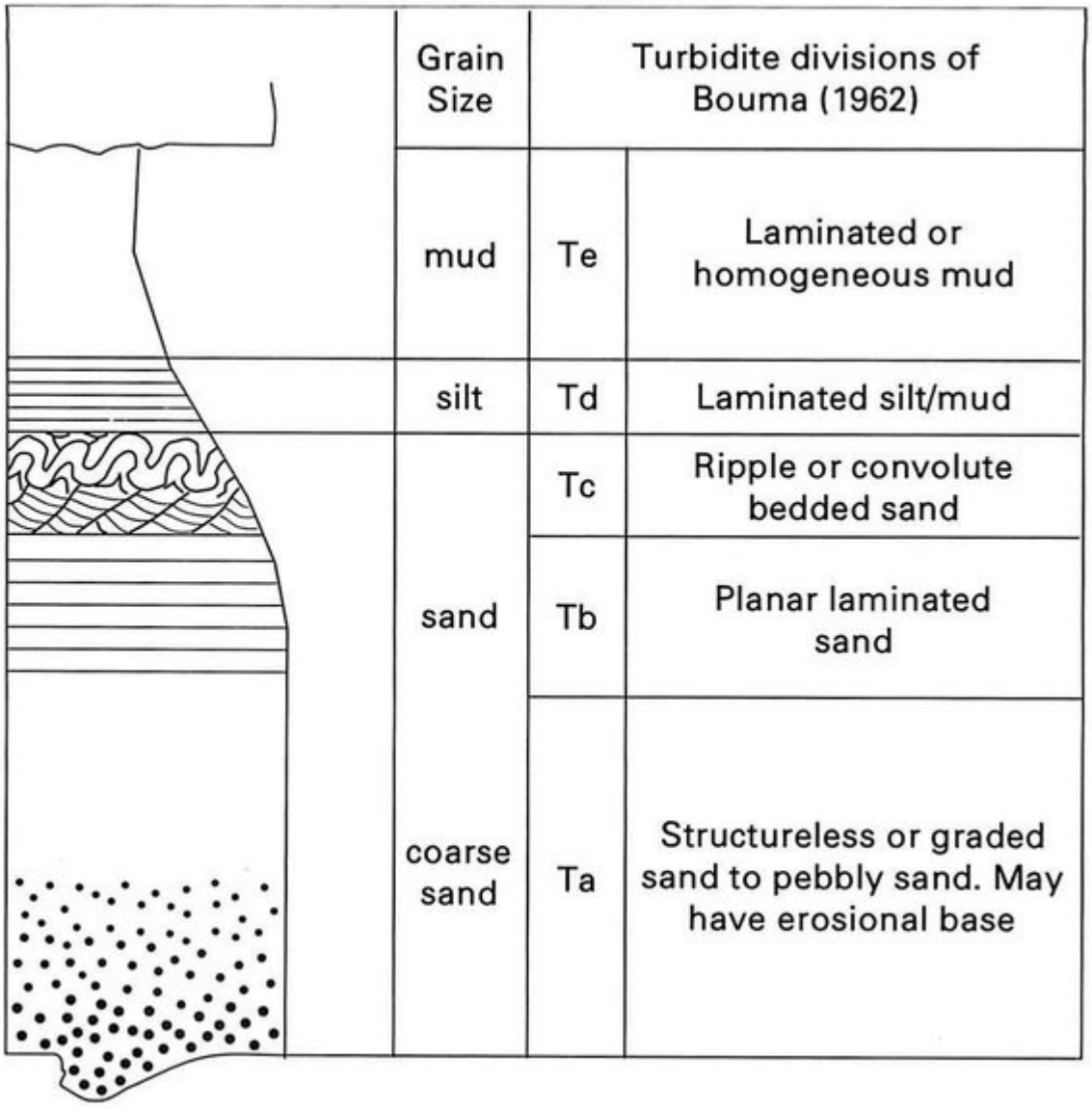
thus postdates the crenulation cleavage, and may relate to fold rotation by a major fault, as yet unproved, following the Fleet valley.

One arenite interval, just above high water mark close to the western limit of exposure displays sigmoidal tension gashes filled with quartz. These indicate a sinistral sense of movement in accordance with the late transpressive episode but contradicting the dextral kink bands which probably represent the latest Caledonian effect.

References



(Figure 39) Locality map and outline geology for the Gatehouse of Fleet excursion.



(Figure 6) Divisions within an idealised turbidite bed after Bouma (1962) and Pickering et al. (1989).