Chapter 9 Walls Sandstone–structure

The sedimentary and volcanic rocks of the Walls and Sandsting formations have been affected by two periods of intense folding (Plate 12). The axes of the earlier folds (F_1) trend in an east to north-easterly direction, while those of the later folds (F_2) have trends which range from N25°E to N20°W. The more intense folding is confined to two intersecting belts, the limits of which are shown in (Figure 12). Both belts contain zones in which the finer-grained sediments exhibit well-developed minor structures, such as cleavage, small-scale folds, and various types of lineation. The geometric relationships of these structures correspond to those of the major folds. In the coast sections along the shores of Gruting Voe and the Voe of Browland the cleavage and lineation associated with the two periods of folding are seen to intersect each other and produce small-scale interference structures.

The minor structures produced by the two periods of folding do not extend into the area in which the beds are indurated or hornfelsed by the Sandsting Granite, and the evidence suggests that granite intrusion preceded the folding. Radiometric determinations give an age of 360 m.y. for the date of emplacement of the granite. This suggests that the folding, which on fossil evidence (p. 117) was certainly later than at least part of the Middle Old Red Sandstone, took place not earlier than late-Middle or early-Upper Old Red Sandstone times.

Structures attributed to the first phase of folding (F1)

The first phase of folding which affected the Walls Sandstone produced an east to east-north-east trending synclinorium with a northern limb in which the strata are consistently steep and only locally flexured, a complex hinge zone containing small, locally isoclinal, folds arranged *en échelon,* and a fairly steep southern limb. Cleavage, lineation and minor folds are confined to the fine-grained sediments in the axial zone and southern limb of the synclinorium.

Structural units of the synclinorium

Northern limb

The northern limb of the synclinorium is formed by the outcrop of the Sandness Formation, and is separated from the hinge zone by the Sulma Water Fault ((Plate 12); (Figure 13)). This fault appears to have acted as a hinge fault and has a considerably greater southward displacement at the western end of its outcrop than in the east.

The dip of the sedimentary and volcanic rocks of the Sandness Formation is, over the greater part of the area, inclined at between 45° and 80° to east-southeast, steepening to vertical and shifting in trend to north-north-east on the island of Papa Little, in the extreme east of the area. In the area between Sandness Hill and the head of West Burra Firth the northern limb of the synclinorium contains a parasitic flexure which forms the Djuba Water Syncline and the complementary Mousavord Loch Anticline (Plate 9). These two folds converge and die out westwards ; in an eastward direction the hinge zone of the Mousavord Loch Anticline passes into a tectonic movement plane.

Within the Sandness Formation cleavage, minor folds and linear structures which can be attributed to the first phase of folding are extremely rare. Poorly developed linear structures and small crinkles which are inclined at 25° to 30° to the south-west are found in the red shales and siltstones associated with the Clousta Volcanic Rocks on the shore of the Voe of Dale, at the extreme western end of the outcrop (pp. 91–92). The minor folds within fine-grained sediments adjoining the volcanic rocks in the Burga Water and Brindister Voe areas all appear, however, to have been formed during the second phase of deformation (pp. 88–89).

Hinge zone

Major structures

The hinge zone of the synclinorium has a width of 1500 to 1650 yd (1400–1500 m) but the belt of intense folding is confined to the southern half of this zone and is only 440 to 880 yd (400–800 m) wide (Plate 12). In the western third of the outcrop of the hinge zone there are a number of second-order folds whose axes plunge in most instances to west-south-west. As is shown in (Figure 14) and (Figure 15) the folds of this order exposed between Ram's Head and The Flaes, just north-west of the Voe of Footabrough, have wavelengths ranging from 120 to 222 yd (110–200 m) and amplitudes of 65 to 165 yd (60–150 m). The interlimb angle of these folds varies from 55° to 110° (i.e. 'close' to 'open' according to the classification of Fleuty (1964, p. 470). Some of the folds are westward plunging monoclines and several have irregular disharmonic folds (third order folds) developed on their steep limbs.

The second order folds described above lie on a more or less horizontal limb section of the hinge zone of the synclinorium which connects the axes of the Scarvister Syncline and the Watsness–Browland Anticline ((Plate 12), (Figure 13)). The style of the first order fold becomes tight and eventually isoclinal in an easterly direction, and the second order folds appear to die out east of the head of the Voe of Footabrough. The Scarvister Syncline dies out eastwards in the area between Braga Ness and Vaila Sound and is replaced *en échelon* by the Walls Syncline, which is the main and most southerly axis of the synclinorium further east (Plate 12). East of Vaila Sound a steep to vertical shear plane appears to be developed along the axial plane of the Walls Syncline. Similar east–west trending movement planes, not usually recognizable on the ground, appear also to be present within the northern limb of the syncline and seem to have cut out considerable portions of the sequence (Plate 12). These faults may be parallel to the limb of the fold. In the area around the Voe of Browland and Gruting Voe the Walls Syncline is isoclinal and its axial plane is inclined at between 65° and 80° to the north, so that part of its northern limb is inverted.

The Watsness–Browland Anticline is also at its tightest at the longitude of the Voe of Browland ((Figure 13), C–C′) where it forms a westward plunging nearmonocline with a gently inclined northern limb and a nearly vertical southern limb. The anticline becomes progressively more open both west and east of this area.

In the west and north-west of the Walls Peninsula all folds plunge to the west or west-south-west, but in the ground between the Voe of Footabrough and Gruting Voe the plunge of the fold axes and concordant small-scale linear structures is in places to the east. This reversal in plunge may be partly due to refolding along the north–south trending second folds (F_2).

The east-north-east trending F_1 folds do not appear to extend into the extreme eastern part of the Walls Peninsula, where exposure is very poor. It is likely that these folds may originally have continued eastward but that they are now difficult to recognize owing to the effects of later north–south trending folding.

Cleavage, jointing and lineation

An axial plane cleavage which locally obscures the bedding is present in many shales and siltstones within the belt of intense F_1 folding and a corresponding refracted fracture cleavage affects the intervening sandstone bands. The trend and inclination of the cleavage is everywhere sub-parallel to the axial surfaces of the folds (Figure 14) and (Figure 15). In most instances the cleavage is a true slaty cleavage, characterized by the parallel alignment of phylloblastic minerals either along the limbs of the minor corrugations (e.g. (S52549) [HU 179 493]) or along the axial planes of the minor folds (e.g. (S52550) [HU 179 493]). In other examples the cleavage planes are less regular and in extreme cases the cleavage surfaces have a phacoidal (lens-shaped) pattern (cf. Elliston 1963, pp. C11–C13).

Many fine-grained sediments, particularly the calcareous beds and the thinly interlaminated shales and sandstones, exhibit intense microcrinkling. This produces a strong lineation (Plate 15A) which is invariably parallel to the plunge of the axes of the major folds. Linear structures are of varying sizes, ranging from very fine striations on bedding surfaces of sandy sediments to the axes of small folds with wavelengths up to 1 cm.

'Convolute' minor folds

There are numerous horizons, particularly in the area between The Flaes and Fidlar Stack, just west of the Voe of Footabrough (Figure 14) and close to Point of the Hus [HU 196 482] on the south-west shore of Braga Ness, at which small-scale 'convolute' folds are developed in silty or inter-laminated shaly and sandy beds. These structures are described and their origin discussed on pp. 105–8 and they are illustrated in (Plate 14A), (Plate 14B), (Plate 14C). They resemble the sedimentary structures known as convolute bedding (Kuenen 1953, pp. 1056–8) or convolute lamination

(Ten Haaf 1956, p. 188), which are characterized by possessing rounded troughs and pointed, or more rarely, mushroom-shaped crests. Seen in three dimensions these fold structures are elongated asymmetric basins with elongation ratios ranging from 5:1 to 10:1 and with long axes invariably parallel to the regional lineation. The axial, planes of the folds are always parallel to the cleavage, even on the steep limbs of the major folds where the cleavage is at an acute angle to the bedding. The vergence of the convolute folds is always in accord with the theoretical vergence of minor folds in the particular limb of the major fold. The shape and style of these folds leaves little doubt that they were formed when the sediment was still in a plastic and probably waterlogged condition (pp. 106–8). The parallelism of the planar and linear elements of the minor folds with those of the major folds and the coincidence of the trend and inclination of their axial planes with that of the regional cleavage, however, strongly suggests that they were formed, or at least strongly modified, by the same stresses as those responsible for the major structures. At one horizon 'convolute' folds can, in fact, be traced laterally into concertina folds of similar amplitude.

The above reasoning could suggest that the major folds, cleavage and lineation of this area were all initiated at a time when the finer-grained sediments were still in a plastic or waterlogged condition. Evidence for the formation of slaty cleavage in unconsolidated waterlogged sediments has been brought forward by Maxwell (1962, pp. 284–302), who, in the Martinsburg Slates of the Delaware Water Gap area of New Jersey and Pennsylvania, has recorded the presence of small sandstone dykes, which branch out from sandstone beds along the cleavage planes of the adjacent slates. Maxwell concluded that the sandstone beds were unconsolidated and waterlogged at the time the cleavage was formed and has shown that in these slates the cleavage is due to the presence of aligned plates of illite, and not sericite or muscovite which are the characteristic platy minerals of slates formed under metamorphic conditions. He suggested that the cleavage in the slates was formed in waterlogged sediments by deformation which produced a series of similar folds under very low-grade or non-metamorphic conditions, at depths probably not exceeding 12 000 ft (3658 m) and at no greatly elevated temperatures. He considered that the slaty cleavage resulted from the upward expulsion of water from the sediments which led to the rotation, upward transport and consequent parallel orientation of the component minerals. Further evidence for the formation of cleavage in unconsolidated sediments has been assembled by Elliston (1963, pp. C11–C13), who in Tennant Creek, Tasmania, has recorded fragments of slate with a strongly developed, often bent or curved cleavage set in a 'quickstone' (intrusive sandstone) breccia, which must have formed when the sandstone beds were still in a plastic state.

More recently Williams and others (1969, pp. 421–5) have recorded a poorly developed axial plane cleavage within small penecontemporaneous folds in the Devonian Bunga Beds exposed on the south coast of New South Wales, Australia. These folds differ from the convolute folds of Western Shetland in that the orientation of their axes and axial planes is very variable and quite unrelated to the major tectonic elements. Though the style of the individual folds is indistinguishable from that of many tectonic folds, the sum of their relationships has convinced Williams and his co-authors that they are convolute laminations formed by load deformation of a semi-fluid sediment, and that the slaty cleavage was formed at the same time as the folds by the rotation of pre-existing inequant mineral grains.

In the present area no work has yet been done to determine the composition of the phylloblastic minerals which impart the slaty cleavage on the fine-grained sediment. It is possible that the cleavage may, as in the Martinsburg Slates and the Bunga Beds of New South Wales, have formed before the sediments were consolidated in a manner similar to that postulated by Maxwell. There are here, however, no sandstone dykes branching from sandstone beds out along the cleavage of the finer sediment, which would have suggested that the sandstones were still 'mobile' when the cleavage was being formed. It is more likely that in this area the close accord of the geometric parameters of the 'plastic folds' with those of the undoubted tectonic structures resulted from a continuous homoaxial deformation which gave rise to a series of stages in the development of the tectonic pattern of the sediments. These stages may be summarized as follows :

1. During and shortly after deposition the environment was unstable and repeated earthquake shocks produced beds with pseudo-nodules and probably also some unaligned convolute laminations.
2. The compressive stresses which eventually led to the formation of the F_1 synclinorium commenced while the finer-grained sediments within the highest part of the Walls Formation, as now exposed, were still plastic and waterlogged. This led to the formation of the aligned 'convolute folds' in certain mixed fine-grained bands and probably also to the regular deformation of previously formed convolute laminations and pseudo-nodules. Sandstones

were apparently no longer plastic at this stage, as no 'liquidized' sandstone dykes occur. Minor folds of convolute type have not been recorded in the lower part of the Walls Formation, suggesting that part of the formation may already have been lithified when the compressive movements commenced.

3. With continued compression all the water was expelled and the fine-grained beds were lithified. After this stage, when the large-scale folds were developing, the same continuing stresses produced the cleavage and lineation in the fine sediments, the small-scale folds in the calcareous shales, limestones and in some mixed sediments, and the complex joint systems in the sandstones.

In many localities within the intensely deformed areas the boundaries between sandstones and fine-grained sediments are shear planes. Movement planes are also developed along or close to the axial planes of folds both in the southwestern coastal areas and to a much greater extent in the areas around Walls and the head of Gruting Voe ((Figure 13), sections B–B′, C–C′). These shear movements may be the latest manifestations of the first (F_1) orogenic phase.

In the most intensely folded part of the hinge zone around Walls and especially at the head of Gruting Voe, lineation, cleavage and intense 'internal folds' within the fine-grained beds are everywhere developed. The style of F_1 minor folding at the head of Gruting Voe is illustrated in (Plate 15B), (Plate 15C). The folds are complex sharp-crested zig-zag folds with several orders of fold size (cf. Ramsay 1967, pp. 354–5) which appear to have formed after the rock was lithified. Folds of the 'convolute' type have not been recognized in this area. The F_1 slaty cleavage in the shales is here very pronounced and is characterized by the complete alignment of all micaceous and elongate minerals ((Plate 13), figs. 6–8). Though the trend of the lineation and the axes of minor folds in this area is more or less parallel to the regional strike of the beds, the amount and direction of their plunge varies greatly with short distances (Figure 12). Although some of the variations could have developed during the F_1 folding, most are thought to be due to the refolding of the F_1 folds by the second (F_2) phase of earth movement.

Southern limb

The southern limb of the F_1 synclinorium is composed of evenly bedded sediments dipping at 40°–90° to between north-east and north. The limb is almost vertical in the area just south of Walls. Fine-grained sediments within the limb are cleaved and lineated. The linear features are either minute straight corrugations or intersections of bedding and cleavage. Small-scale folds are relatively rare and 'convolute folds' have not been recorded east of Vaila Sound.

Neither cleavage nor lineation are seen within the aureole of the Sandsting Granite and the beds which contain these structures farther west become strongly jointed and shattered as they enter the aureole. These features are best seen in the peninsula south of Walls and on the east shore of Gruting Voe. This transition suggests that the fine-grained sediments within the aureole were already hornfelsed when they were subjected to the regional compressive stresses, and were no longer sufficiently plastic to form small-scale folds or crinkles or to take on a cleavage. The presence of small folds and linear structures in granite dykes and scapolite veins outwith the thermal aureole indicates that folding was still in progress after the latest intrusions and veins associated with the Sandsting Complex had formed.

Structures attributed to second phase of folding (F_2)

Major folds

The folds attributed to the second phase of folding have axial trends ranging from north-north-east to north-north-west (Figure 12). The main belt of folding is of limited width and extends from the area between the Voe of Clousta and Brindister Voe south-south-westwards to the Voe of Browland where it abuts against vertical strata, previously folded by the F_1 movements. Folds with the same general trend but with more open styles occur south-west of this belt and extend to Braga Ness. Fairly open north-north-west trending folds are also present in the area between the main fold belt and the Walls Boundary Fault where the strata are generally steeply inclined and have a predominantly north-north-westerly trend. This area has, however, been affected by later movements, possibly associated with the Walls Boundary Fault (p. 236) and because of indifferent exposures it is here not possible to assess the style of the F_2 folds and associated structures.

The north-north-east trending folds within the main F_2 fold belt have inter-limb angles of 60° to 70° and wavelengths from 0.5 to 1.5 miles (800m–24km). The traces of individual fold axes are usually of limited length (1.5 to 4 miles; 2.5–6.5 km) and adjacent folds are arranged *en échelon.* Because of discontinuous exposures and the rarity of exposures in fine-grained sediments it has not been possible to determine the tectonic pattern of this area with any accuracy.

Minor folds, cleavage and lineation

Though the major folds of the main F_2 fold belt are confined to a belt bounded by the Sulma Water Fault in the north and the crest of the Watsness–Browland Anticline in the south, the minor structures produced by this period of folding extend both northwards into the area occupied by the Sandness Formation and southward into the vertical strata exposed on the shores of Gruting Voe.

Small-scale folds and corrugations are developed in the siltstones, shales and interlaminated sandy siltstones associated with the Clousta Volcanic Rocks and they are well seen on the shores of Brindister Voe. They also occur in rare inland sections between Brindister Voe and the Voe of Clousta and westward as far as the shores of Burga Water (Plate 12). The size of individual folds ranges from 4 in (10 cm) wavelength and 2 in (5 cm) amplitude to 10 in (25 cm) wavelength and 8 in (20 cm) amplitude. The interlimb angles range from 70° to 120° and the crests of the folds are predominantly angular. The fold axes plunge in the direction of the regional dip and their plunge is thus invariably steep. The axial planes of the folds are generally perpendicular to the regional strike. Slaty cleavage has not been recognized in the corrugated beds within the Sandness Formation described above but is common in crinkled and lineated fine-grained sediments of this formation farther east, along and close to the east shore of the Loch of Clousta [HU 319 584].

Within the belt of intense folding between the Sulma Water Fault and the Watsness–Browland anticline, exposures of fine sediments are relatively rare and sandstones are generally intensely jointed. Only minute wrinkles have been recorded in the shales of this belt, but all the fine-grained sediments have a cleavage, which is particularly pronounced in the area west and north-west of the Voe of Browland, where the zone of intense F_2 folds intersects the northern margin of tight F_1 folding (Plate 12). Lack of exposures in the fine-grained sediments has, however, not permitted a meaningful analysis of this cleavage.

Within the zone of vertical, inverted and steeply inclined strata exposed on the shores of the Voe of Browland and Scutta Voe, F_2 minor folds, corrugations and cleavages have refolded or cut the generally more pronounced F_1 minor structures. As in the Sandness Formation to the north (p. 88) the F_2 linear structures plunge down the dip of the vertical or steeply inclined regional bedding planes. The plunge of the F_2 fold axes is either vertical or inclined at angles greater than 70° to east or west. The F_2 folds are much more open than the tight F_1 folds and they are usually gentle puckers with wavelengths of 1 to 3 in (2.5–8 cm). Larger open folds with wavelengths up to 3.5 ft (1 m) and rare smaller linear F_2 structures form corrugations with wavelengths of less than 5 mm, and in extreme cases they appear as fine striations on bedding planes. In many instances these have largely obliterated the smallest linear F_1 structures.

The F_2 microcrinkling has produced an incipient cleavage in the fine-grained sediments, and the refolding of the F_1 slaty cleavage is well seen in thin section. In one specimen (S53688) [HU 261 503] the first cleavage, which is sub-parallel to the bedding, has been puckered into asymmetric microfolds and an incipient second cleavage is formed by the alignment of mica flakes along the limbs of the fold. The aligned plates form belts up to 0.02 mm thick and 0.045 mm apart which are parallel to the axial planes of the folds. This new cleavage is a strain slip cleavage and makes an angle of about 44° with the original slaty cleavage ((Plate 13), fig. 8). In the siltstones (S53696) [HU 278 499] the F_1 slaty cleavage, characterized by aligned mica flakes and strongly elongated and aligned quartz grains, has been corrugated into folds of two orders of magnitude. (Major corrugations: λ=6 to 7 mm, minor corrugations : λ=0.15 to 0.2 mm) The microfolds of the lower order have wide rounded hinge zones and very short steeply inclined straight limbs ((Plate 13), fig. 7). The alignment of micas along the short straight limbs has produced an incipient strain slip cleavage. In the sandstone (S51495) [HU 278 498] it has not been possible to differentiate between the effects of the two phases of folding. In some of these the individual quartz (with highly undulose extinction) and feldspar grains now have diamond-shaped outlines and the surrounding fine-grained micaceous matrix is intensely corrugated and imbricated.

An interesting feature of the F_2 fold system in the Walls Sandstone is the varying plunge of the fold axes. In the central sector of the fold belt, between the Sulma Water Fault and the axial plane of the Watsness–Browland Anticline, where the post- F_1 dip of the bedding was more or less horizontal, the axes of the major F_2 folds are roughly horizontal. In the vertical or steeply dipping belts to north and south of this belt, the plunge of the axes of the F_2 minor folds is steeply inclined and more or less parallel to the true dip of the strata. In these areas there are no large F_2 folds. The axial plunges and varying magnitudes of F_2 folds appear to have been determined by the F_1 structure of the area. Thus in the ground where the strata were gently inclined large folds with horizontal axes could form, but in the belts of vertical strata compression parallel to the strike could only produce minor crinkles with steeply plunging axes. It is also likely that during the F_2 phase considerable lateral movement took place along shear planes trending parallel to the axial planes or limbs of the F_1 folds. This would account for the different amounts of crustal shortening in the various sectors (p. 133).

Comparison with other areas of Late-Caledonian folding

The Walls Sandstone is unique among the Lower and Middle Old Red Sandstone sediments of the Northern Isles and Scotland in that it is the only sediment which:

1. may have been laid down in a fresh-water flysch basin, rather than a fluviatile or shallow water lacustrine environment;
2. has a total thickness of over 30 000 ft (9000 m) and
3. has been involved in two periods of intense late-Devonian folding, which also affected the underlying metamorphic basement.

The first of these tectonic phases produced major folds the trend of which is west-south-west. This is virtually at right angles to the Caledonoid trend of the metamorphic rocks in the greater part of eastern Shetland and to the strike of the steeply inclined Middle and Upper Old Red Sandstone sediments of southeast Shetland, which is more or less north–south.

East to east-north-east trending basins of Lower and Middle Devonian sediments occur along the west coast of Norway between Trondheimfjord and Sognefjord (Holtedahl 1960, pp. 285–93; Brynhi 1963; Nilsen 1968). These basins contain great thicknesses of strata, 20 to 25 km having been estimated by Kolderup (1927, p. 41) for the Hornelen basin, though Brynhi (1963, p. 24; 1964, p. 385) considers that the centre of deposition within this basin was displaced progressively eastwards and that the true thickness of sediments at any point in the basin may not exceed 5000 m. Estimated thickness for some of the other basins are as follows: Hasteinen 1000 m+ (Kolderup 1927, p. 28), Solund 5200 m (Nilsen 1968, p. 14). The sediments filling these basins are fluvial deposits, consisting of conglomerate, sandstone and basal breccias. It is believed that the present outcrops are separate depositional basins and that the Nordfjor–Sognefjord area must have undergone vertical tectonic movements during the Devonian period, producing block-faulted areas and east–west trending graben structures with marked intermittent uplift of the adjoining areas (Nilsen 1968, pp. 98–9). The belief that the Old Red Sandstone basins were involved in late-Devonian large-scale thrusting (Holtedahl 1960) has not been substantiated by later research, but evidence obtained from an outcrop of Devonian rocks near Roros in Eastern Norway indicates that in this area Devonian strata have been strongly folded together with the metamorphic basement (Holmsen 1963). The Devonian earth movements in Norway have been attributed to the last phase of the Caledonian Orogeny, which has been termed the Svalbardian Phase by Vogt (1928).

Earth movements of Middle and Upper Devonian date have also affected the Old Red Sandstone sediments of East Greenland (Haller *in* Raasch 1961, pp. 179–85; Butler 1959, pp. 179–81). In the Moskusoksefjord area Butler distinguished five phases of earth movement during the Middle and Upper Devonian. Some of these were essentially differential vertical block movements, but the later phases also involved the thrusting of basement blocks over the Old Red Sandstone sediments and the local folding of the sediments. Haller showed that over a greater part of East Greenland the Devonian earth movements were first tensional, producing an extensive graben-like basin bounded by north-north-west trending step-folds. The fracturing was followed by compressional phases, which gave rise to two fold belts trending respectively north-west and northeast, as well as to associated areas of superficial thrusting. As in Western Shetland, the fold belts are linked with the syntectonic intrusion of granitic magma.

In Norway the late-tectonic earth movements were not of the same intensity as those affecting the Walls Sandstone, but in Greenland there were local belts where the basement rocks were remobilized and rejuvenated by chemical and thermal action (Haller *in* Raasch 1961, p. 180). In the two areas both the tensional and compressional phases of the earth movement appear to have been confined to zones of limited extent. In Shetland the two phases of folding in the Walls Sandstone affected neither the lower Givetian Melby Formation nor the upper Givetian sediments of Eastern Shetland. Though the present near-juxtaposition of the three outcrops of Old Red Sandstone deposits in Shetland may have been brought about by lateral transcurrent movements along the Melby and Walls Boundary faults (p. 266), it must be assumed that the phases of folding recorded in the Walls Sandstone were either of very restricted areal extent or were completed before the deposition of the Melby Sandstone.

It is possible that the motive force for these localized tectonic episodes was provided by the forcible emplacement of the Western Shetland granite-diorite complexes. The extent of the folding within the Walls Sandstone, however, suggests that the folding is not causally connected with the granite emplacement. The folding may have been preceded by differential vertical block movement which was responsible for the formation of a restricted basin in which the great thickness of Walls Sandstone was deposited. A similar history is reported from Greenland, and there is a marked similarity between the Devonian tectonic history of East Greenland, West Norway and West Shetland, all of which record various aspects of the final Svalbardian phase of the Caledonian Orogeny.

References

BRYNHI, I. 1963. Relasjonen mellom senkaledonisk tektoniki og sedimentasjon ved Hornelens og Håsteinens devon. *Norg. geol. Unders.,* 223, 10–25.

BRYNHI, I. 1964. Migrating basins on the Old Red Continent. *Nature, Lond.,* 202, 384–5.

BUTLER, H. 1959. Das Old Red–Gebiet am Moskusoksefjord. *Meddr. Gronland,* 160, Nr. 5, p.188.

ELLISTON, J. 1963. Gravitational sediment movements in the Warramunga Geosyncline *in* WARREN, C. S. (Editor). *Syntaphral Tectonics and Diagenesis: A Symposium.* University of Tasmania, Hobart.

FLEUTY, M. J. 1964. The description of folds. *Proc. geol. Ass.,* 75, 461–92.

HOLTEDAHL, 0. 1960. (Editor). Geology of Norway. *Norg. geol. Unders. Smaskr.,* 208.

HOLMSEN, P. 1963. On the tectonic relations of the Devonian complex of the Røragen area, east-central Norway. *Norg. geol. Unders.,* 223, 127–38.

KOLDERUP, C. F. 1927. Hornelens devonfelt. *Bergens, Mus. Årb.* 1926. *Naturvidensk. Raekke.,* Nr. 6.

KUENEN, PH. H. 1953. Significant features of graded bedding. *Bull. Am. Ass. petrol. Geol.,* 37, 1044–66.

MAXWELL, J. C. 1962. Origin of slaty and fracture cleavage in the Delaware Water Gap Area, New Jersey and Pennsylvania. *Mem. geol. Soc. Am.* (Buddington Volume), 281–311.

NILSEN, T. H. 1968. The Relationship of Sedimentation to tectonics in the Solund Devonian District of south-western Norway. *Norg. geol. Unders.,* 259, 1–108.

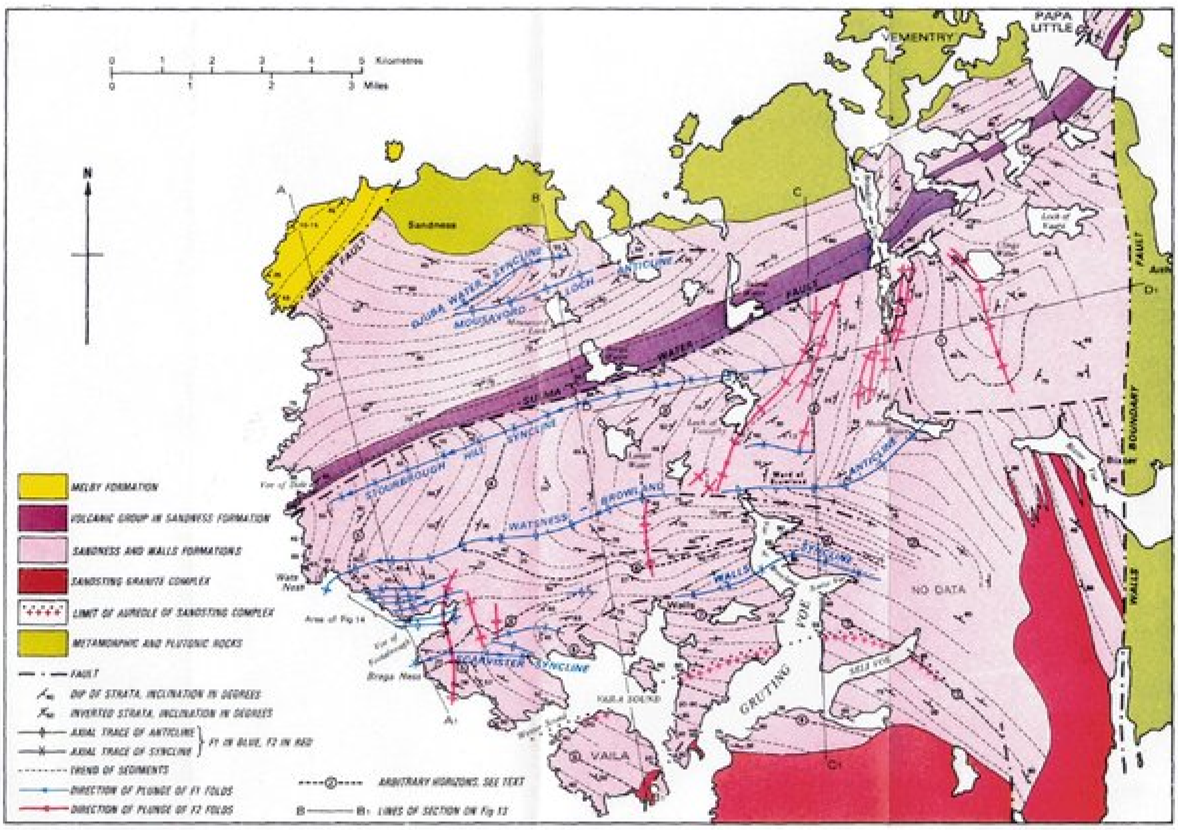
RAASCH, G. O. 1961. (Editor). *Geology of the Arctic.* Toronto.

RAMSAY, J. G. 1967. *Folding and Fracturing of Rocks.* New York.

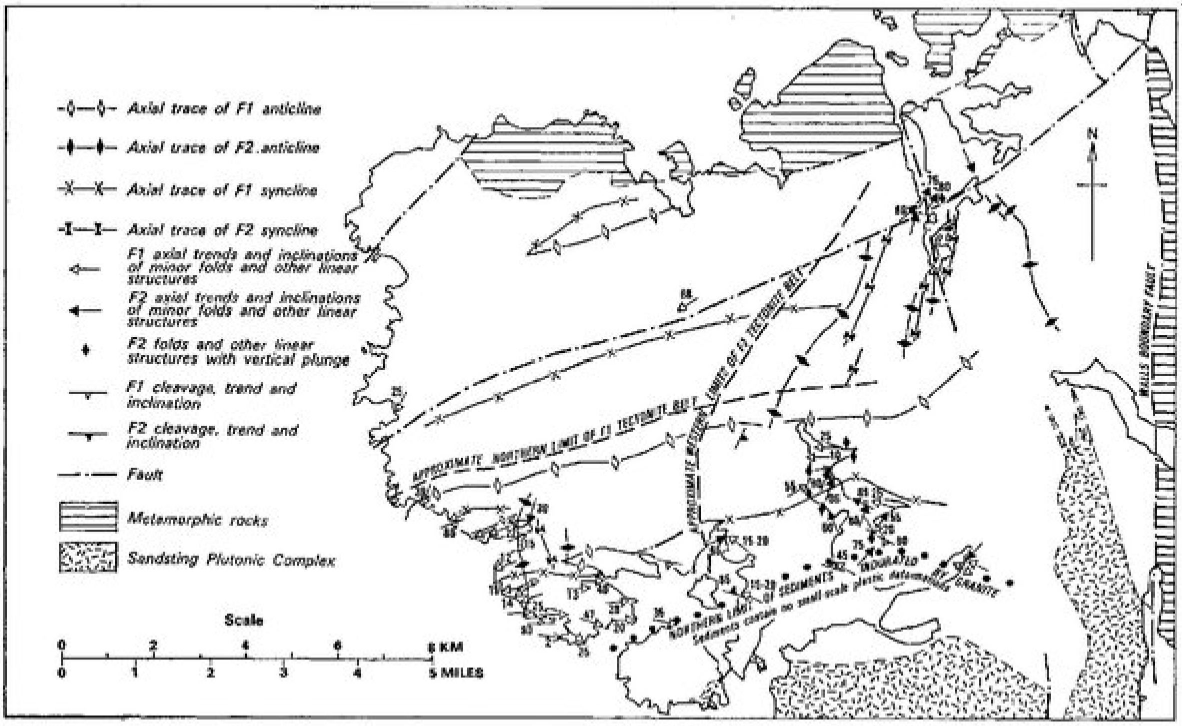
TEN HAAF, F. 1956. Significance of Convolute Lamination. *Geologie Mijnb.,* 18, 188–94.

VOGT, T. 1928. Den Norske Fjelkjedes revolusjons-historie. *Norsk. geol. Tidsskr.,* 10, 97–115.

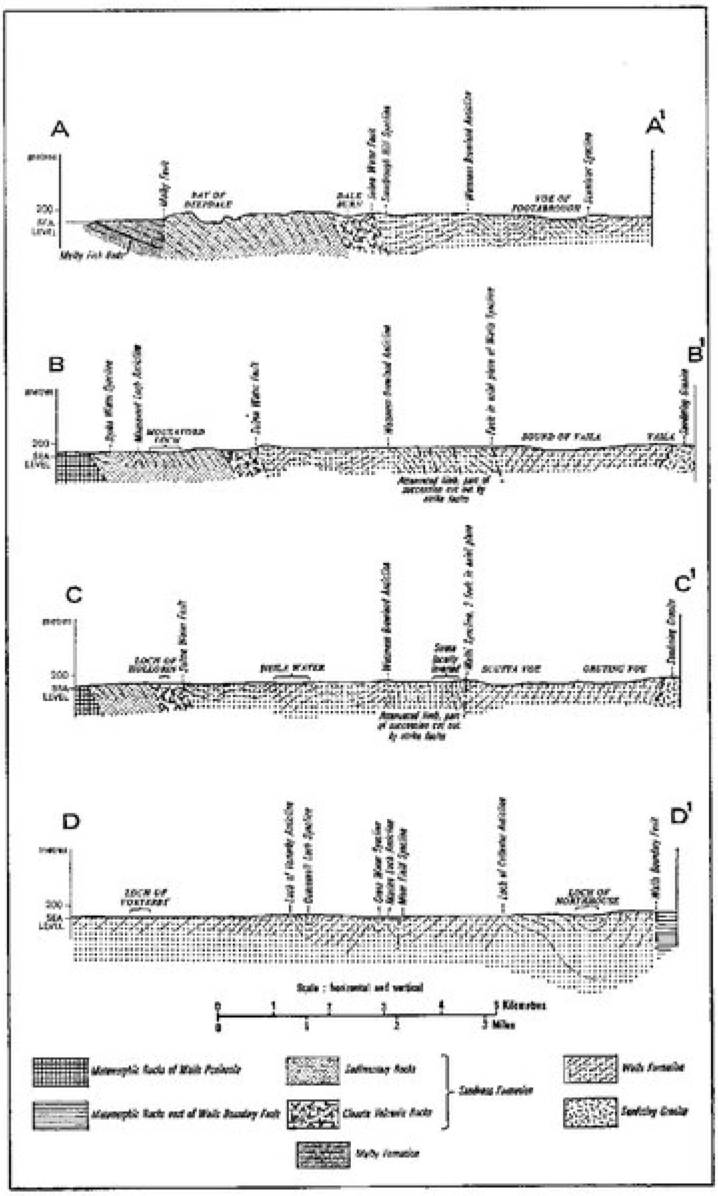
WILLIAMS, P. F., COLLINS, A. R. and WILTSHIRE, R. G. 1969. Cleavage and penecontemporaneous deformation structures in sedimentary rocks. *Jnl Geol.,* 77, 415–25.



(Plate 12) Major stratigraphic and structural features of the Old Red Sandstone sediments and volcanic rocks of the Walls Peninsula.

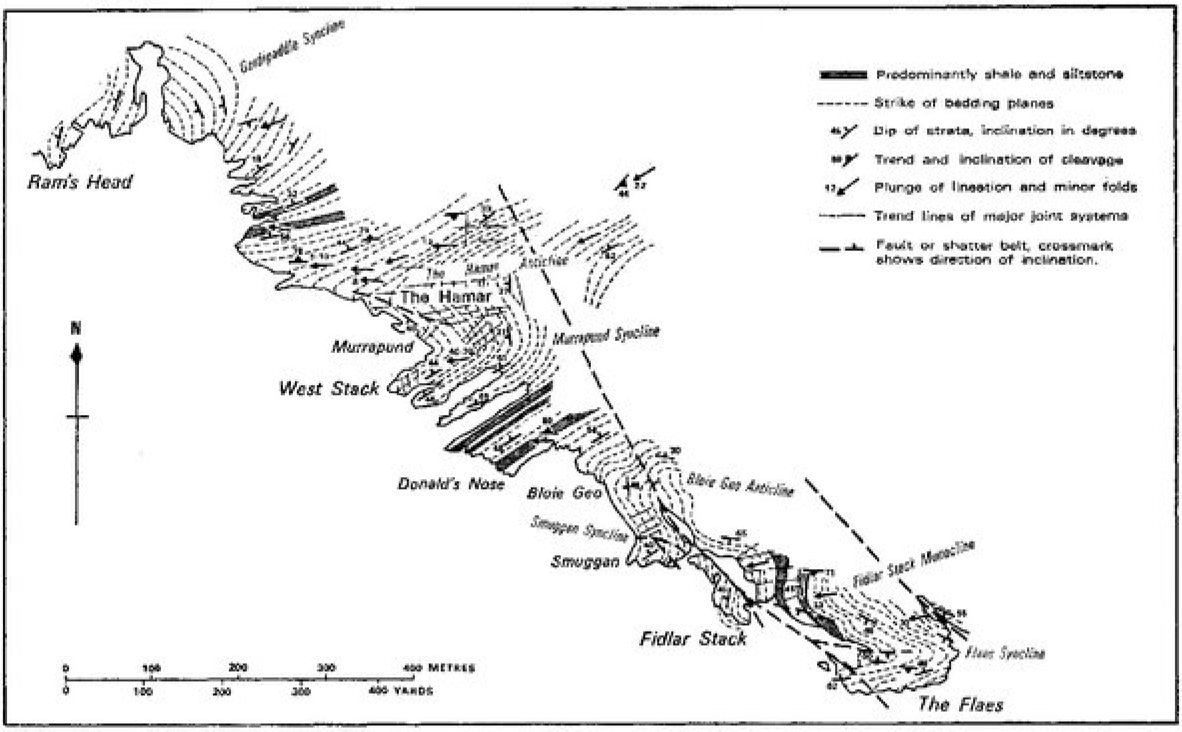


(Figure 12) Location of tectonite belts and prominent linear and planar structures in the Old Red Sandstone of the Walls Peninsula.

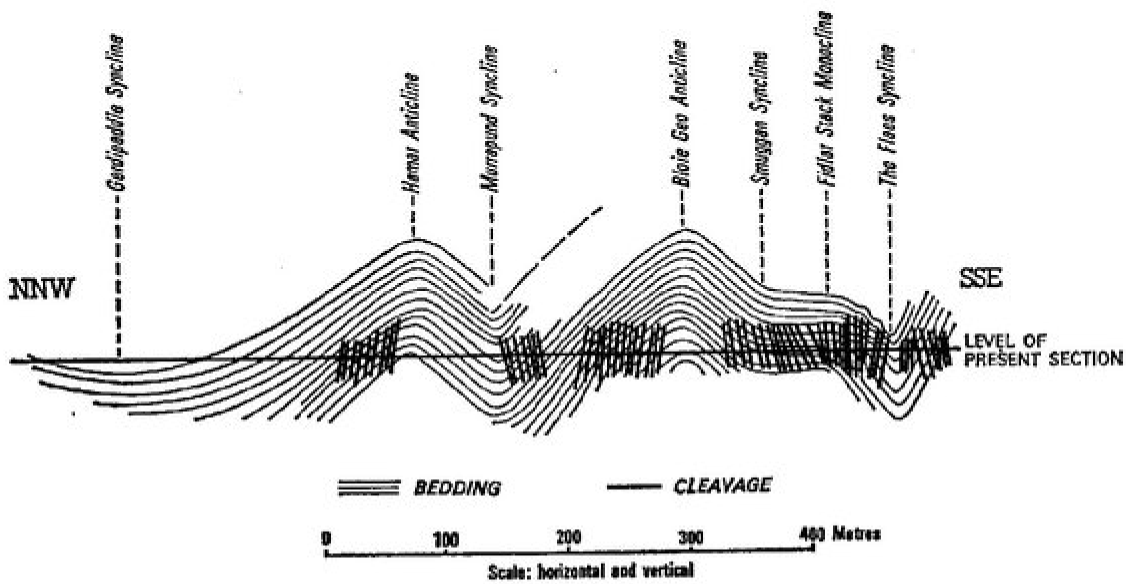


(Figure 13) Horizontal sections illustrating the major structural features of the Old Red Sandstone of the Walls Peninsula Lines of sections are marked on (Plate 12).

(Plate 9) Geological sketch map of the Sandness Formation.



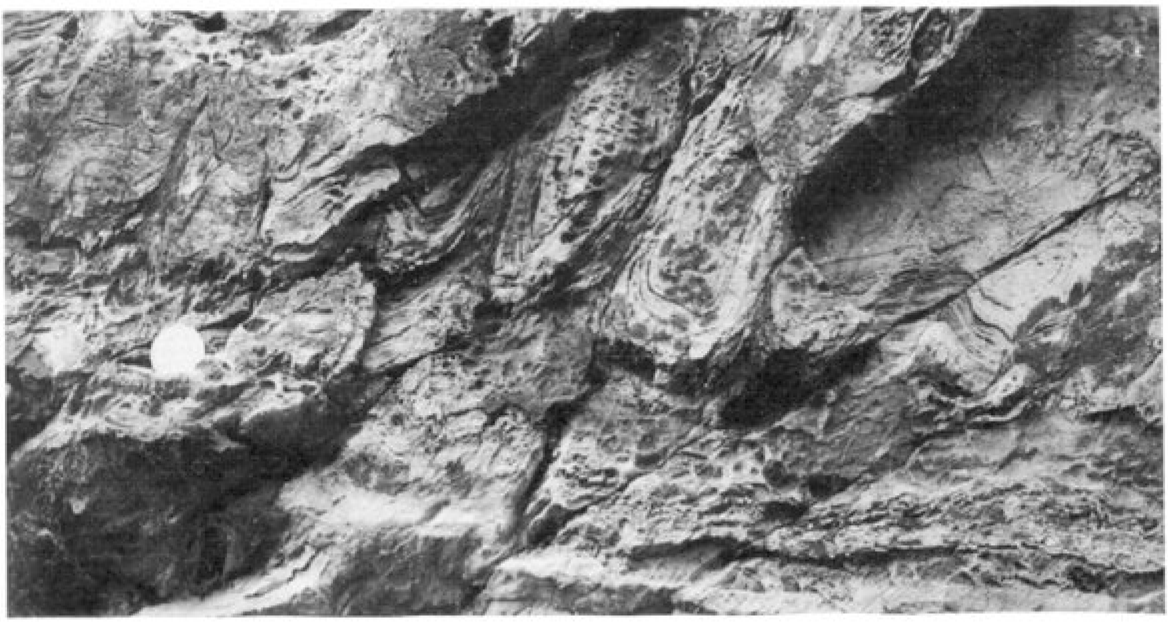
(Figure 14) Sketch-map showing the structure of the sediments of the Walls Formation exposed on the coast between Ram's Head and The Floes.



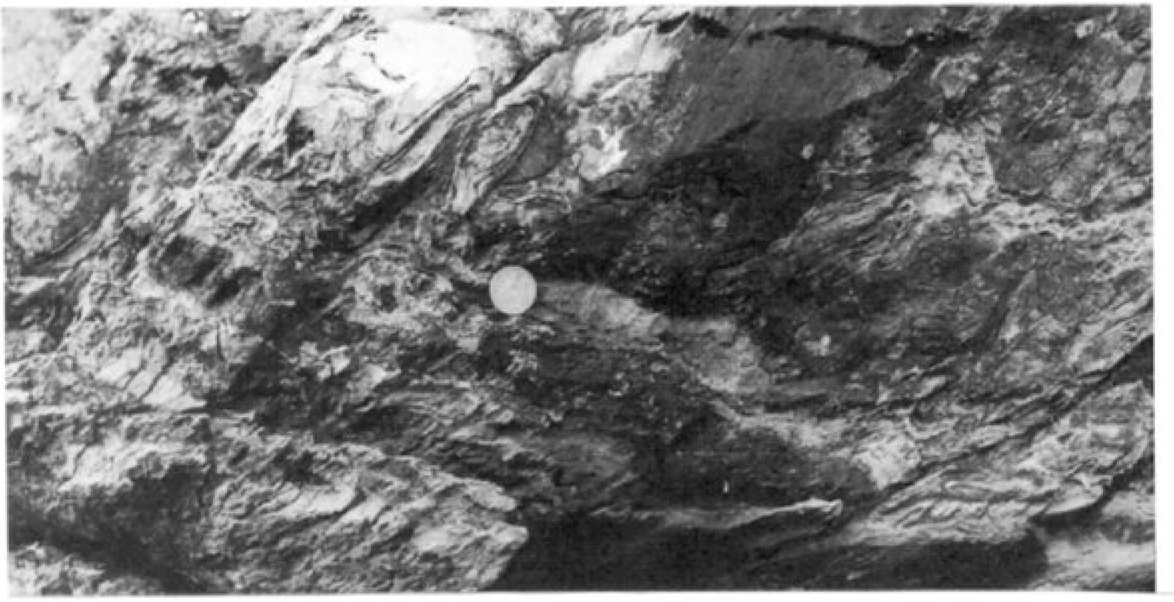
(Figure 15) Idealized horizontal section showing the structural pattern of the folded area along the coast between Ram's Head and The Flaes.

(Plate 15A) Fidlar Geo, south-west shore of Walls Peninsula [HU 190 494]. Strongly lineated siltstone and mudstone of Walls Formation (W.M.).

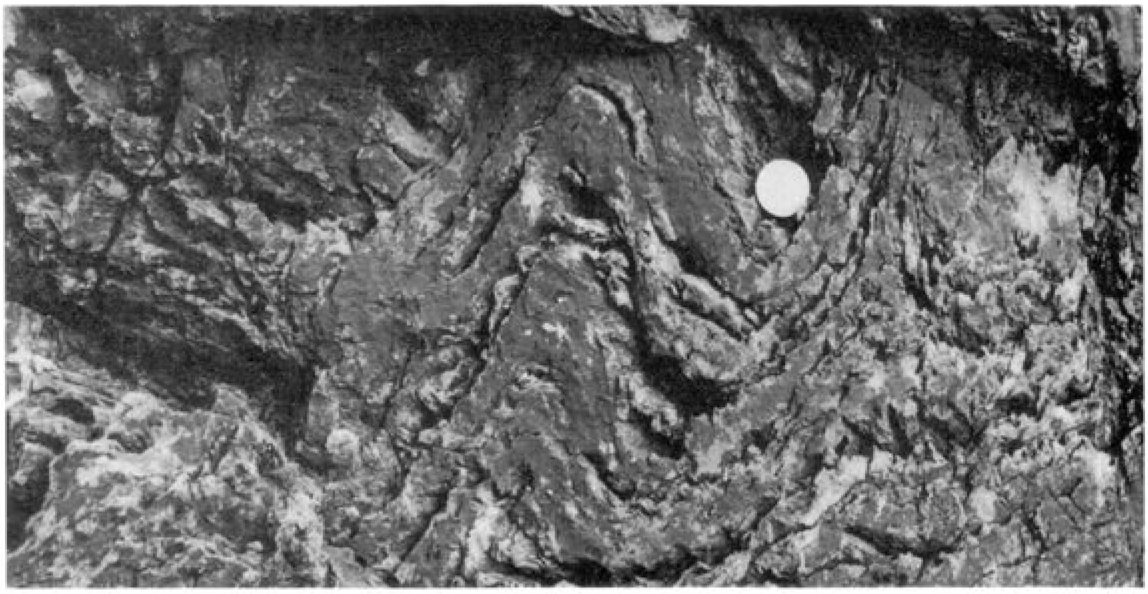
(Plate 14A) Fidlar Geo, south-west shore of Walls Peninsula [HU 190 494]. Thinly bedded siltstone and mudstone of Walls Formation, showing relationship of convolute lamination to cleavage. (D956).



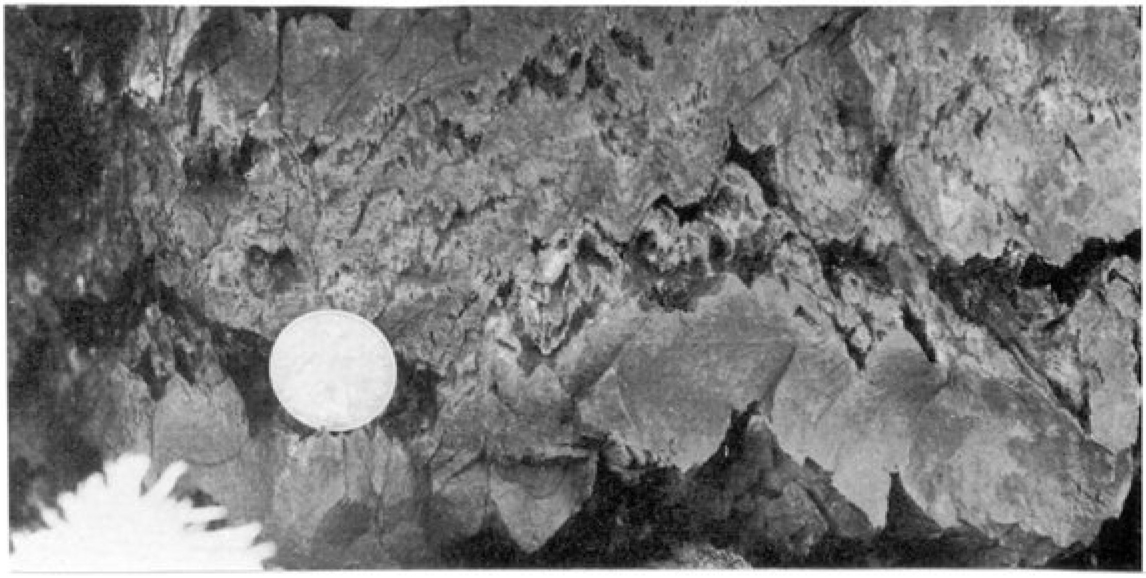
(Plate 14B) Fidlar Geo, south-west shore of Walls Peninsula [HU 190 494]. Thinly bedded siltstone and mudstone of Walls Formation, showing relationship of convolute lamination to cleavage. (W.M.).



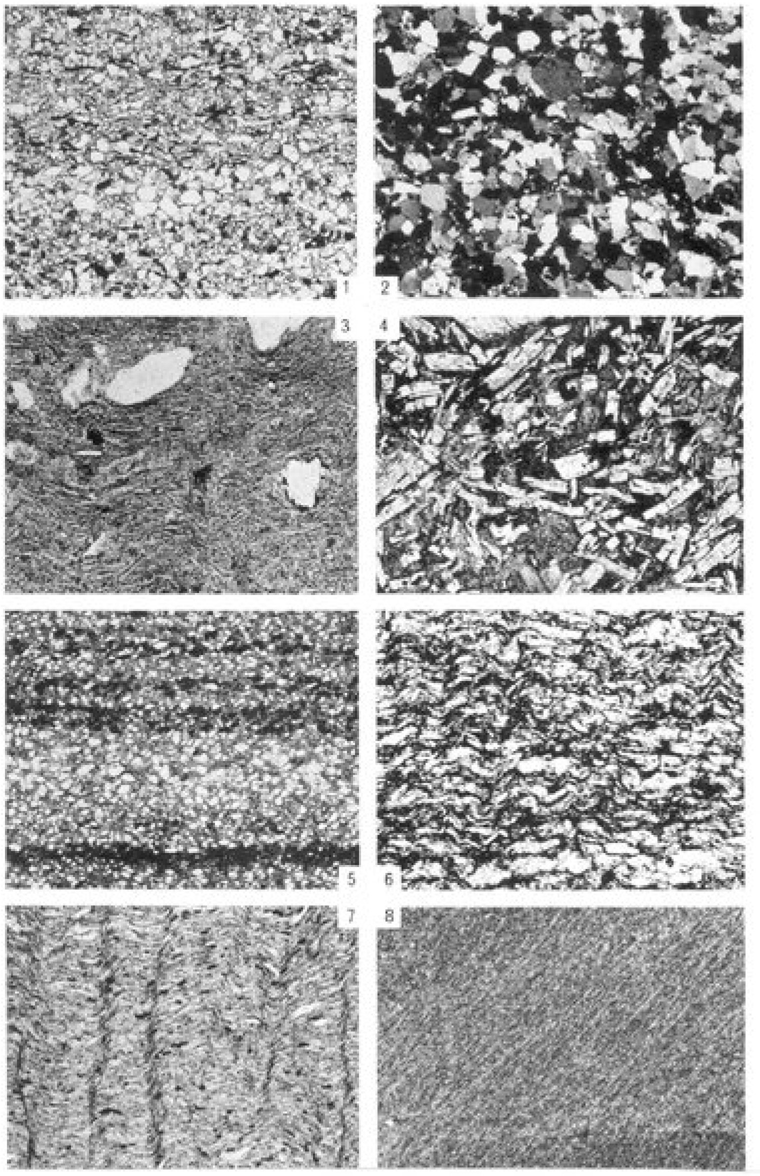
(Plate 14C) Fidlar Geo, south-west shore of Walls Peninsula [HU 190 494]. Thinly bedded siltstone and mudstone of Walls Formation, showing relationship of convolute lamination to cleavage. (W.M.).



(Plate 15B) East shore of Gruting Voe [HU 275 493]. Intense F_1 folds in flaggy sandstone and siltstone of the Walls Formation (W.M.).



(Plate 15C) East shore of Gruting Voe [HU 275 493]. Close-up of intense F_1 folding in fine-grained sandstone and siltstone of Walls Formation (W.M.).



(Plate 13) Photomicrographs of sedimentary and volcanic rocks of the Walls Sandstone Fig. 1. Slice No. (S52737) [HU 296 581]. Magnification × 20. Plane polarized light. Fine-grained flaggy sandstone, Sandness Formation, showing alternate quartz-feldspar and micaceous laminae. Scattered small grains of epidote throughout. West shore of Muckle Head. [HU 297 581]. Fig. 2. Slice No. (S52738) [HU 299 577]. Magnification × 20. Crossed polarisers. Medium-grained arkose, Sandness Formation. Well-graded subangular to subrounded grains. The ratio of quartz to feldspar grains is 60:40. Matrix forms less than 10 per cent of total volume and is composed predominantly of carbonate. North shore of Voe of Clousta, 1225 yd (1100 m) WNW of Clousta School. [HU 298 577]. Fig. 3. Slice No. (S49343) [HU 266 551]. Magnification × 40. Plane polarized light. Part of ignimbrite clast in lapilli-tuff in Clousta Volcanic Rocks, showing flattened and welded shards. Note the bending of shards around quartz clasts. Hillside, 710 yd (650 m) SW of western end of Loch Hollorin [HU 267 552]. Fig. 4. Slice No. (S30773) [HU 328 596]. Magnification × 38. Plane polarized light. Basalt flow in Clousta Volcanic Rocks. Flow-aligned laths of sodic labradorite set in matrix composed largely of secondary amphibole with subordinate grains of epidote and a dusting of iron ore. Aithness peninsula, 220 yd (200 m) SE from north-west corner of peninsula [HU 327 597]. Fig. 5. Slice No. (S51496) [HU 276 498]. Magnification × 16. Plane polarized light. Fine-grained feldspathic sandstone in Walls Formation with laminae of heavy mineral concentrates. Black grains are predominantly iron ore, other heavy mineral grains are apatite, sphene, epidote and tourmaline. North shore of Scutta Voe, 520 yd (475 m) WSW of Lee of Houlland [HU 275 498]. Fig. 6. Slice No. (S52748) [HU 317 564]. Magnification × 100. Plane polarized light. Microfolded sandy siltstone, Walls Formation. Roadside, close to west shore of Loch Vaara [HU 565 316]. Fig. 7. Slice No. (S53696) [HU 278 499]. Magnification × 100. Plane polarized light. Silty shale with F_1 slaty cleavage (horizontal) refolded by F_2 minor folds with incipient fracture cleavage developed along some fold limbs. Walls Formation. North shore of Scutta Voe, 520 yd (470 m) WSW of Lee of Houlland [HU 275 498]. Fig. 8. Slice No. (S53688) [HU 261 503]. Magnification × 100. Crossed polarisers. Microfolded dark grey shale with axial-planar strain-slip *cleavage inclined at 44° to bedding. West shore of Voe of Browland, 1620 yd (1480 m) S4°E of Browster [HU 261 503].*