THE WALLS BOUNDARY FAULT, SHETLAND, BRITISH ISLES

DEREK FLINN

SUMMARY

The Walls Boundary Fault of Shetland is a transcurrent fault on which the displacement has been sufficiently great to prevent correlation in Shetland between the rocks on each side. The fault is chiefly remarkable for the number of coastal sections providing complete exposure of the fault and the cataclastic rocks on either side. Offset on the fault took place on the main fracture marked by a narrow zone of gouge and to a much lesser extent on sub-parallel subsidiary fractures. In plan the faults appear to be composed of relatively straight segments jointed by arcs in which a change of trend of up to 10° takes place over a short distance. The rocks on either side of the faults are heavily crushed for hundreds of meters but show no signs of having contributed to the offset by simple shear type deformation. It is suggested that the crushing is the result of movement on the non-planar faults causing a 'working' of the adjacent rocks due to small scale movements on subsidiary fractures. Neomineralisation is limited to the formation of analcite and laumontite in faults and minor shears. Most of the visible fault structures seem to have resulted from movements in post-Devonian, possible Mesozoic, times which may have given rise to a dextral displacement of the order of 60 km. There is evidence in the form of mylonites for earlier phases of movement under other conditions.

Introduction.

Shetland is a small archipelago on the edge of the north-west European continental shelf about 100 km north of Scotland and 300 km west of Bergen, Norway. The rocks forming the islands are mostly Caledonoid schists and gneisses cut by Devonian granites and in places covered by sandstone of Old Red age (Fig.1).

The Walls Boundary fault cuts the group with a north-south trend. It was first recognised in 1879 by Peach & Horne (1879, 786) when they found it forming a tectonic junction between Old Red Sandstones and schists and gneisses. In the 1930's the Geological Survey of Scotland found further segments of the fault to the north of the part found by Peach & Horne, commented on the associated cataclasis and named it the Walls Boundary fault (Wilson 1933, 77; 1934, 72). Recent investigation of the fault started in 1961 when it was suggested that it was the northern continuation of the Great Glen fault of Scotland (Flinn 1961).

As usual for faults inland exposure is poor to absent, but the complex form of the coastline results in many continuous sections across the main fault and associated faults revealing in detail the faults and the nature of the zones of cataclasis associated with the faults, thus enabling its course to be fixed with considerable accuracy. Examination of these exposures shows that the Walls Boundary fault is a major trans-current fault associated with a number of other lesser trans-current faults which together form the Walls Boundary fault system (Fig. 2).

The distribution of the faults.

The Walls Boundary fault (WBF) crosses the Shetland coast-line fourteen times. There are twelve continuously exposed sections revealing the fault itself and two sections where the fault plane is obscured. In several other places the coastline closely approaches the fault thus providing partial checks on its location.

These sections show that the WBF is accompanied by a zone of strong cataclasis often a kilometer wide or more but the fault itself is a sharply defined zone of gouge 0.5m or less wide. In most sections there is a single zone of gouge but in the two southern-most sections the fault is braided and contains slices of rock over a width of up to 60m. The lithology of the cataclastic rocks on either side of the fault changes abruptly at the gouge zone. This change is not immediately obvious due to the extreme nature of the cataclasis.

If the exposures of the gouge band marking the fault are accurately plotted on the 1:10,000 map they fall on a smooth curve formed by several straight sectors joined by rather abrupt changes of direction. The fault enters Shetland from the south with a true bearing of 0020. About 3 km to the north (north of Bixter Voe) it turns to 0050 and continues on this bearing for 15 km when it turns to 010°. It continues on this bearing for at least 15 km before passing out to sea to the north.

North of Shetland there is little control over the course of the fault. The trend probably increased to 020° to enable it to pass the north-east end of the positive gravity anomaly (A in Fig.1) marking the strip of Lewisian basement between Shetland the West Shetland basin (Bott & Watts 1970, 265; Flinn 1970, 268).

The continuation of the fault beneath the sea to the south of Shetland is better controlled. The geology of the southern part of Shetland and of Fair Isle requires an increase of bearing to about 020° in the latitude of Fair Isle so as to pass to the west of that Island. A possible line for the fault drawn so as to lie along the bottom of submarine valley (Flinn 1961, 589) also lies close to the anomaly to the south-west of Shetland and along the west side of a small positive anomaly just north of Fair Isle (Flinn 1969, fig.1). The negative anomaly was inter-preted as a small basin of sediments younger than the Devonian (Flinn 1969), the Fitful Basin, Fig.1, and later shown by gravity, magnetic and seismic investigations to be a basin of Mesozoic-type sediments overlying Devonian-type sediments and truncated to the east by a fault (Bott & Browitt 1975, Flinn 1975). Oil geologists interpret these sediments as Triassic sandstones (Zeigler 1978, fig. 11).

Thus the fault appears on the map (Fig. 1) as a very flattened "S". This course is made obvious on the aero-magnetic map of the area (IGS 1968) by the anomaly pattern. The east-facing concavity of the "S" is bridged by the Nesting fault, a transcurrent fault with a dextral displacement of 16 km (Fig.2). This fault divides into three splays at its northern end and into several at its southern end in a manner similar to that predicted for such faults by (Chinnery 1966).

The Nesting fault is not as frequently exposed as the Walls Boundary fault. The fault is marked by a zone of rock coarsly powdered by extreme cataclasis but which never attains the state of gouge. It varies in width from about 0.5m in general to as much as 10m in Samphrey. It is usually, but not always vertical and tends to be formed by a series of straight sections connected by rather abrupt changes of direction of up to 10°. Displacement on the fault is confined to the fault itself though in several places it is braided, for instance in Samphrey over a width of 75m.

Several north-south faults with some similar characteristics occur to the east of Walls (Fig. 2). They bring recognisably different rocks into contact along zones of cataclasis. Several coastal sections resemble sections across the Nesting fault much more closely than those across the Walls Boundary fault.

The characteristic views in coastal exposures of the fault planes mentioned above are of narrow zones of coarsly powdered rock or gouge passing out into very heavily cataclastic rock. Only along the Blue Mull Sound splay of the Nesting fault are there exposed faults bounded by coherent relatively unshattered rock weathering out as fault planes. Such faults are common throughout Shetland but unlike the Blue Mull Sound fault rarely show determinable displacement. These exposed fault planes of the Blue Mull Sound fault, separated by several inches of powdered rock, show no slickensides. There are no slickensides visible on the faults of the Walls Boundary fault system. However a cliff at Back of Ollaberry (Fig. 2) formed by the Walls Boundary fault plane faced with gouge shows a large scale horizontal fluting.

The offset on the faults of the Walls Boundary fault.

A 16 km sinistral displacement on the Nesting fault would restore continuity to the offset Graven Complex and at the same time to the metamorphic rocks to the south of the complex. The matching of the metamorphic succession is not perfect as this restoration gives rise to abrupt changes of strike, of sedimentary facies and of the extent of migmatization. However these changes could be due to crustal distortion (drag) during faulting and to facies changes no greater than those observed occurring in areas away from the fault.

The senseandamount of displacement on the Walls Boundary fault is much more difficult to determine. The Walls Boundary fault divides Shetland into two geologically distinct areas between which there is no apparent correlation. Apart, that is, from a small slice of cataclastic schist on the east side of the fault in the Sandsound area which resembles schists more than 30 km farther north to the west of the fault (Fig.2). A sinistral restoration-displacement of 65 km on €he fault would join the positive magnetic anomaly over the Sandsting granite to the small positive anomaly just north of Fair Isle and would restore the supposed Triassic Fitful Basin to the edge of the Moray Firth Mesozoic basin. It would also bring the Walls Sandstones close to the similar sandstones of Fair Isle; both being similar facies of the Old Red (Mykura 1972, 30) and it would bring a suite of scapolite veins common along the west side of the fault in Shetland close to scapolite veins in Fair Isle, the only part of Shetland where they occur on the east of the fault (Mykura and Young 1969).

The Nesting fault offsets the Graven Complex which gives ages of about 400 Ma. The Walls Boundary fault cuts the Sandsting granite which itself cuts Old Red Sandstones and gives ages ranging from 334 to 370 Ma. (Miller & Flinn 1966; Mykura & Phemister 1976, 211). Since these are among the youngest rocks preserved in Shetland an upper limit to the age of the Walls Boundary fault system must be sought outside Shetland.

If the offset on the fault in the region of Fair Isle is of the order of 60 km as seems likely the fault must continue far to the south before dying out. Not far south of Fair Isle the projected course comes close to any reasonable projected continuation to the north of the Great Glen fault of Scotland (Fig. 1). It seems probable that the Walls Boundary fault is the continuation of the Great Glen fault, or a branch of it or runs into it. Holgate (1969) has reported some kilometers of post Devonian dextral displacement in the area Inverness. Seismic work in the Moray Firth shows that movement along the line of the Great Glen fault had ceased by Upper Cretaceous times and can only have been of very limited extent during the Mesozoic. (Bacon and Chesher 1975, Flinn 1975).

The Helmsdale fault is another line along which movement on the Walls Boundary fault may have passed. It is usually held to be anormalfault throwing down to the east but the juxtaposition of Jurassic sediments and crystalline basement may be due either to normal faulting or to transcurrent faulting as in the Fitful Basin.. Its exposure on the coast near Helmsdale shows relatively little disturbed Mesozoic (Jurassic) sediments stacked up against very heavily cataclasic crystalline rocks to the west. The cataclasis of the crystalline rocks is likely to be due to transcurrent faulting though possibly in a phase of movement earlier than that which placed the Jurassic rocks in contact with the crystallines.

The Walls Boundary fault system seems to have resulted from a dextral transcurrent displacement of the order of 60 km at some time in the Trias or soon after. Fig.1 shows the major tectonic feature of the area. The fault lies in the northern end of a stable crystalline block forming Scotland. The major tectonic event in the area in Mesozoic times was the splitting of the crust to the west of Shetland and Scotland to form the constructive plate margin which led to the formation of the Atlantic Ocean. In the early stages a failed arm of the split formed to the east of Shetland and became the Viking Graben. The faults shown in the graben (Fig. 1) are normal faults in pre-Upper Cretaceous rocks but are said to show a small component of dextral displacement. The formation of the Walls Boundary fault seems to have required east-west crustal compression and must therefore be older than the formation of the graben and the split to the west of Shetland which required crustal tension.

The cataclastic rocks associated with the faults.

In general the terminology of Higgins (1971) serves well for the description of these rocks. In this paper the term cataclasite is reserved for rocks with isotropic cataclastic fabrics and the term mylonite for those with a fluxion structure due to cataclasis. Also the term protomicrobreccia is used to complete the cataclastic series microbreccia - cataclasite defined by Higgins (1971, 5).

For material intermediate to Higgins' (1971, 4) fault breccia and fault gouge the name fault power or powdered rock will be used.

Coastal sections through the fault zones show that in general the rocks are increasingly shattered towards the main fault, but the increase is far from uniform and differs for different rocks. Although the fracturing is neither uniformly distributed or uniformly orientated, at least on the scale of the exposure, the cataclastic rocks almost always give the impression of having an isotropic cataclastic fabric.

In granitoid rocks the cataclasis is visible as a network of cracks, sometimes straight and sometimes irregular and anastomosing, on which little if any movement has taken place. The fragments between the cracks vary up to several tens of centimetres across. With increasing cataclasis the cracks and the original nature of the rocks become less distinct. Ultimately the rock becomes a compact mass of mineral fragments and powder of unrecognizable origin. Granitoid rocks pass from a disaggregated stage in which each grain appears to be a separate fragment, though the rock is still easily recognizable, to one in which the rock is losing its identity due to the breaking down of the grains. Schists and layered rocks on the other hand tend to give rise to flaky and powdery masses giving the impression of having been sheared. Marine-eroded, sand-polished surfaces and the continuity of old cross-cutting veins show that this appearance arises from the weathering and not from a later shearing associated with the cataclasis.

Thin sections of cataclastic rocks whose original nature is becoming obscured show them to be microbreccias as defined and illustrated by Higgins (1971, pp. 4–5), and thin sections of cataclastic rocks whose origins are nearly or completely obscured match his cataclasites (Higgins 1971, p. 6). Thin sections of cataclastic rocks whose original nature has not become obscured, such as disaggregated granitoid rocks, are commonly seen to be cut by an isotropic network of fractures enclosing fragments typically 2 mm across. These are the rocks I have called protomicrobreccias (Plate I, 1). Movement on the fractures is barely detectable and the fractures tend to follow grain boundaries. In micaceous schistose rocks the fractures have a tendency to follow the schistosity so that they form anastomosing networks marked by some distortion of adjacent micas. The fractures enclose lenticles rather than angular fragments. These also are protomicrobreccias (Plate 11, 2). Thin sections show that with increasing cataclasis protomicrobreccias develop into typical microbreccias by further fracturing of the fragments. This develops without any sign of a fluxion structure or shearing movements (Plate I, 2). Microbreccias often have an appearance closely resembling ice-floes seen from a high flying aircraft due to spaces between fragments of the original rock being filled by finer grained comminuted material. In quartzofeldspathic rocks the fragments can only be crushed into smaller ones but in some micaceous rocks the mica flakes within the lenticles become irregularly crumpled. Thin sections of cataclasite (Plate 11, 1) show that the breakdown of the fragments (or floes) has progressed to the point where relics of rock fragments make up less than half of the rock, the rest being fragments smaller than the original grains. In the protomicrobreccias the quartz grains are strained, in the microbreccias they are highly strained but in the cataclasites the remaining quartz grain fragments have often become aggregates by new grain boundary formation though the grains are still strongly strained.

A characteristic feature of the zones of cataclasis is a network of fault-like dislocations. Usually they can be easily sorted into two classes. Many seem to be faults marked by steep zones of powdered rock up to 10 m wide. They are often more spectacular and important-looking than the main faults but the individual faults cannot usually be correlated between adjacent sections and none have been shown to result from any great offset. The trends of these faults vary up to 90° to the trend of the main fault. These will be called subsidiary faults.

As the intensity of cataclasis increases a very different network of dislocations develops in the cataclastic rocks between the subsidiary faults. These will be called gouge veins and they are best seen in microbreccias developed from granitoid rocks as cross-cutting networks of vein-like fault gouge varying in width up to several centimetres. The variation in width is accentuated by pinch and swell effects and by anastomosing fusion of subparallel veins sometimes leading to the formation of gouge vein zones a metre or more wide. The network has an isotropic pattern and the veins usually offset rock boundaries and each other by a few centimetres where they cross. The gouge veins erode level with the microbreccias in which they occur, unlike the subsidiary faults. This makes them difficult to see except on smoothed rock surfaces. They tend to develop in schists and gneisses only when these have been reduced to cataclasites. The density of the network increases as cataclasis increases until the whole rock is a mass of consolidated rock powder.

In the field the material in the gouge veins looks like fault gouge but in thin section it appears to be equigranular microcrystalline rather than ultracataclastic like the gouge (Plate III, 2). Nevertheless, it is mostly too fine grained for easy microscope identification and X-ray powder photographs of several occurrences show it to be laumontite (-leonhardite). Analysis of one of these occurrences (441903) of laumontite by Mr. M.S. Brotherton shows that it contains 14.8% CaO, 0.4% Na_2O and 0.9% K_2O. Although the laumontite occurs in what appear to be intensely sheared veins thin sections show no signs of foliation in the laumontite (Plate 111, 2).

Small portions of thin sections of the gouge in the Walls Boundary fault sometimes show little sign of foliation (Plate III, 1) but views of larger areas usually show a crude streaking-out of the constituents.

Layered and schistose rocks are often folded within the zones of cataclasis. The folds are of late type and are sporadically developed especially in the outer parts of the zones. Layered rocks, such as beds of quartzite in schist are folded in a chaotic manner best described as crumpled. Schistose rocks are somewhat more regularly folded by kinking or even by shattering. These folds are too irregularly developed to provide evidence for sense of movement on the faults.

The origin of the cataclastic rocks.

The evidence cited above, especially the field appearance of the cataclastic rocks, indicates that in each fault zone almost all the displacement produced by the faulting has occurred on a single well-defined, very narrow fracture. If this is the case then the cataclasis, folding and subsidiary faulting in the fault zone must be a secondary effect of the movement on the main fault.

The main fault planes are straight for no more than a few kilometres at the most and, on the scale of the exposure, are not even perfectly planar within individual exposures. Therefore, any movement on the faults and especially contemporaneous movement on two non-parallel faults must give rise to rapidly changing stresses in the adjacent rocks. The effect must be enhanced by the varying physical properties of the different rocks involved.

These varying stresses may give rise to subsidiary faulting in the rocks adjacent to the faults. Movement on such faults would not often be great, but with continuing movements on the main fault could be sufficient to cause yet more subsidiary faults less directly related to the main fault. Thus continuing movement on a non-planar main fault could lead to the creation of a network of subsidiary faults. Faults of Riedel and feather type may also develop.

Once the rock is broken, movement on that break takes place more easily than the creation of a new break so that the changing stresses resulting from continued movement on the non-planar main faults would probably result in repeated small movements in many different directions on the subsidiary faults. Although the resultant offsets on the subsidiary faults would usually be small, the total movement on them due to this working could be large, thus explaining the large amounts of powdered rock in many of them.

The working of the fault zone rocks in this way could give rise to the cataclasis as well as the subsidiary faults and the gouge veins described above. The slight offset which can be seen so often on these fractures would have subjected the blocks of rock between them to repeatedly varying stresses tending to crush them down to the commonly observed cataclastic state.

The networks of subsidiary faults and the fabrics of the cataclastic rocks as seen in the Shetland fault zones and in thin sections of the rocks from those zones all appear isotropic. Neither in the field nor in thin section were any regular sets of fractures such as Riedel or feather shears recognised. Within the fault zones of Shetland displacement on non-planar fault planes giving rise to stress systems varying rapidly in time and place have probably either suppressed the formation of simple regular fractures systems or led to their destruction after formation.

Neomineralization is important only locally in the fault zones. The most widespread effect is the alteration of biotite to chlorite, but even this is not ubiquitous. X-ray powder photographs of the gouge from the Walls Boundary fault show lines for analcite among other minerals. Thin sections of hard gouge show cataclastic fragments of analcite. This mineral appears to have grown between episodes of faulting (Plate III,1).

The laumontite filling subsidiary shears (gouge veins) in the more strongly cataclastic rocks is shown by thin-section to be composed of equigranular fine grained aggregates occasionally becoming coarser in irregular patches but containing angular fragments of the adjacent rocks. There are no signs of a fluxion fabric in the laumontite such as might be expected if hydrothermal veins had been sheared after or during formation. It is possible that the laumontite formed due to the mechanical initiation of chemical reactions during comminution of the rock (Lin ~~et al~~ 1975), that is mechano-chemical metamorphism.

According to Higgins (1971) the coherence of microbreccias is due to neomineralization. In Shetland even in thin section there is no sign of neomineralization in the microbreccias. Nevertheless the microbreccias have apparently remained coherent and even rigid during movement on the fault. They never became sufficiently weak to contribute significantly to the displacement across the fault by simple shear type deformation due to drag on the fault planes. The microbreccias may have retained their strength despite their cataclastic state because of confining pressure. In order to deform by fragment boundary sliding the rocks would have had to expand in volume and this would have been prevented by the confining pressure. For the same reason a mass of loose sand in an evacuated rubber bag forms a strong rigid mass. The lack of neomineralisation indicates that conditions were not suitable for plastic deformation of the grains, at least under conditions of rapid movement generally associated with faulting. The stresses needed to deform the microbreccias were evidently greater than those necessary to cause further movement in the already formed faults and shears.

Evidence for early movements on the Walls Boundary fault.

If the 60 km dextral displacement proposed above for the Walls Boundary fault is restored it gives rise to no recognisable continuity in the Caledonian schists and gneisses. Indeed, no apparent correlation of these rocks is possible for any displacement on the fault. An early - or pre-Devonian displacement along the same line must have occurred.

Further evidence for early movement on the fault under conditions different to those operating during the post-Devonian movements is provided by the occurrence of mylonites. Thin sections show that these include protomylonite, mylonite and ultramylonite as defined by Higgins (1971, 9). These rocks occur in the highly cataclastic rocks adjacent to the Walls Boundary fault and as slices within the fault where it is braided (Fig. 2). The most substantial occurrence is a band some meters wide forming the eastern edge of the slice of schist at Sandsound which has been correlated with rocks to the west of the fault. Even in the field these mylonites can be seen to have suffered cataclasis after they became mylonites. Thin section examination confirms this interpretation (Plate IV, 1).

These mylonites could be the result of faulting along a line which gave rise to the pre-Devonian offset on the Caledonian metamorphic rocks mentioned above and which was later followed by the Walls Boundary fault. This faulting would probably be part of the Great Glen fault movement. However, the mylonites could have been formed in an early phase of the post-Devonian movement. The band of mylonite is probably an early abandoned fault now truncated by the Walls Boundary fault (Fig. 2).

Scapolite veins occur along the west side of the Walls Boundary fault (Mykura & Young **1969).** Some, particularly those near the fault, are blastomylonite veins (Plate IV, 2). Mylonites are rare in Shetland except adjacent to the Walls Boundary fault so that these scapolite-mylonite veins may be related to the fault. They'were formed after the Sandsting granite and fragments may be found in cataclastic melanges adjacent to the fault, so that they were probably formed in the early stages of the post-Devonian movement on the Walls Boundary fault.

Conditions of formation of the fault rocks.

The dearth of newly formed minerals in the fault rocks makes it difficult to determine the conditions under which faulting took place. Analcite, found in the fault gouge, is usually considered to form under near surface conditions and probably formed late in the history of the fault. Unbroken crystals have been found near the Nesting fault. Laumontite, formed in the subsidiary shears in the cataclasites, is usually associated with conditions transitional between zeolite and greenschist facies (Hay **1967).** The laumontite possibly formed earlier than the analcite at greater depth and, therefore, in an earlier stage in the erosion of the area. The sodium-rich scapolite of the area is probably stable above 750°C in the pressure range 1-8 kbars (Goldsmith and Newton **1977, 1065).** It may have formed as the Sandsting granite cooled during movement on the Walls Boundary fault in late Devonian times.

The minerals scapolite, laumontite, analcite may have formed in that order during movement on the Walls Boundary fault at decreasing depth due to the continuing erosion.

Summary

The many complete coastal sections across the Walls Boundary Fault, its zones of cataclasis and associated faults reveal some aspects of this type of fault system usually hidden by drift. Transcurrent movement was confined to narrow zones of powdered rock or gouge. These zones or faults were generally vertical and as seen in plan tend to be formed of straight stretches joined by short sectors in which changes of direction or up to 10° take place. The rocks on either side of the Walls Boundary fault are cut by a network of subsidiary shears and several minor faults sub-parallel to the Walls Boundary fault. The rocks between these faults and shears are extensively and heavily crushed. It is suggested that movement in the non-planar Walls Boundary fault has given rise to considerable transient stresses in the adjacent rocks causing subsidiary fracturing. Continuing movement on the main fault accompanied by compensating movements on the subsidiary shears caused the crushing of the rocks between. There is some evidence of movements taking place over long periods of time under different conditions, but it is not possible to determine the times and the amounts of the displacements.

Bacon, M. & Chesher, J. 1975. Results of recent geological and geophysical investigations in Moray Firth, Scotland. Norges geol-Undersokelse Nr. 316, 99104.

Bacon, M. & Chesher, J. 1975. Evidence against post-Hercynian transcurrent movement in the Great Glen Fault. Scot. J. Geol. 11, 79-82.

Bott, M.H.P. & Browitt, G.W.A.1975. Interpretation of geophysical observation between the Orkney and Shetland Islands. Jl. geol. Soc. Lond. 131, 353-71.

Bott, M.H.P. & Watts, A.B. 1970. Deep sedimentary basins in the Shetland-Hebridean Continental Shelf and Margin. Nature, Lond. 225, 265-8.

Chinnery, M. A. 1966. Secondary faulting. Canadian Jour. Earth Sci. 3, 163-190.

Flinn, D. 1961. Continuationofthe Great Glen Fault beyond the Moray Firth. Nature, Lond. 191, 589-591.

Flinn, D. 1969. A geological interpretation of the aeromagnetic maps of the continental shelf around Orkney and Shetland. Geol. J. 6, 279-292.

Flinn, D. 1970. The Great Glen Fault in the Shetland area. Nature, Lond. 227, 268.

Flinn, D. 1975a. Evidence for post-Hercynian transcurrent movement on the Great Glen Fault. Scott. J. Geol. 11, 266-7.

Flinn, D. 1975b. Discussion of M. H.P. Bott and C.W. A.Browitt. Interpretation of the seaward limits of the European Caledonides. Jl geol. Soc. Lond. 131, 540.

Flinn, D. 1977. Transcurrent faults and associated cataclasis in Shetland. Jl. geol. Soc. Lond. 133, 231-248.

Goldsmith, J.R. & Newton, R.C. 1977. Scapolite-plagioclase stability relations at high pressures and temperatures in the system Na Al Si_3O_8-Ca A12 Si_2O_8-Ca CO_3-Ca SO_4. Am. Mineral 62, 1063-1081.

Hay, J.T.C. 1978. Structural development in the northern North Sea. Jour. Petrol. Geol. 1, 65-77.

Hay, R.L. 1967. Zeolites and zeolitic reactions in sedimentary rocks. Spec. Pap. geol. Soc. *Am.* 85.

Halstead, P.M. 1975. Northern North Sea faulting in Jurassic Northern North Sea Symposium 1975, Ed. K.G. Finstad, R.C. Selley.

Higgins, M.W. 1971. Cataclastic rocks. Prof Pap. US geol Surv. 687, 97pp.

Holáate. N. 1969. Palaeozoic and Tertiarv transcurrent fault movements on the Great Glen fault. Scott. J. Geol. 5, 97-139.

Lin, I.J., Nadiv, S. & Grodzian, D.J.M. 1975. Changes in the state of solids and mechano-chemical reactions in prolonged communinution processes. Min. Sci. & Eng. 7, 313-36.

Miller, J.A. Flinn, D. 1966. A survey of the age relations of Shetland rocks. Geol. J. 5, 95-116.

Mykura, W. & Young, B.R. 1969. Sodic scapolite (dipyre) in the Shetland Islands. Rep No. 69/4. Inst. geol Sci.

Mykura, W. 1972. The Old Red Sandstone sediments of Fair Isle, Bull. geol. Surv. Gt. Br. No.41, 1-31.

Mykura, W. & Phemister, J. 1976. Geology of Western Shetland. Mem. Geol. Surv. G.B.

Peach. B.N, & Horne, J. 1879. The glaciation of the Shetland Islands. Q. Jnl. geol. Soc. Lond. 35, 778-811.

Storetvdt, K.M. 1975. Possible large-scale sinistral displacement along the Great Glen fault in Scotland. Geol. Mag. 112, 93-94.

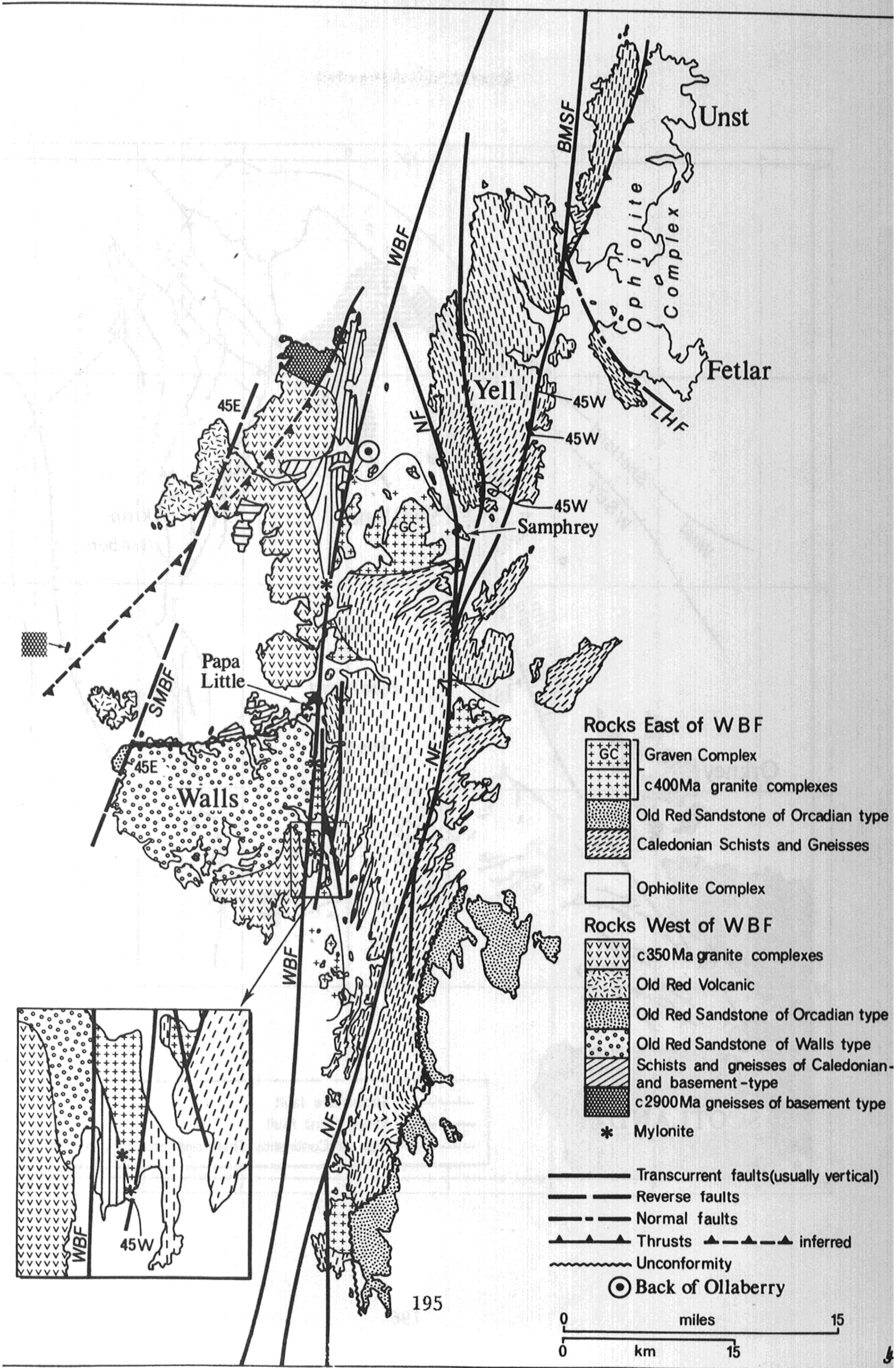
Wilson, G.V. 1933. Shetland in "Summaries of Progress of the Geol. Surv. G.B. for 1932", 77-80. OHMS.

Wilson, G.V. 1934. Shetland in "Summaries of Progress of the Geol. Surv. G.B. for 1933", 70-73. OHMS.

Ziegler, P.A. 1978. North-western Europe: tectonics and basin development. Geol. Mijnbouw. 57, 581-626.

Fig.1 The Walls Boundary fault and its environment. WSBF - West Shetland Boundary fault. WBF - Walls Boundary fault. UF - Unst fault. HF - Helmsdale fault. GGF - Great Glen fault. A - positive gravity anomaly (Bott & Watts 1970, 265).

Fig.2 Shetland geology and faulting. SMBF - St. Magnus Bay fault. WBF - Walls Boundary fault. NF - Nesting fault. BMSF - Blue Mull Sound fault. The shading indicating "schists and gneisses" on either side of the Walls Boundary fault is designed to show the general strike of these rocks. The transcurrent faults are all steep to vertical except in four places indicated above where they dip about 45° west.


Unst
BMSF
Ophiolite Complex
Ophiolite Complex
Fetlar
LHF
WBF
NF
Yell
45W
45W
45W
Samphrey
GC
45E
SMBF
Papa Little
GC
45E
Walls
WBF
NF
WBF
45W
Rocks East of WBF
GC Graven Complex
c400Ma granite complexes
Old Red Sandstone of Orcadian type
Caledonian Schists and Gneisses
Ophiolite Complex
Rocks West of WBF
c350Ma granite complexes
Old Red Volcanic
Old Red Sandstone of Orcadian type
Old Red Sandstone of Walls type
Schists and gneisses of Caledonian- and basement-type
c2900Ma gneisses of basement type
* Mylonite
Transcurrent faults(usually vertical)
Reverse faults
Normal faults
Thrusts inferred
Unconformity
Back of Ollaberry
0 miles 15
0 km 15

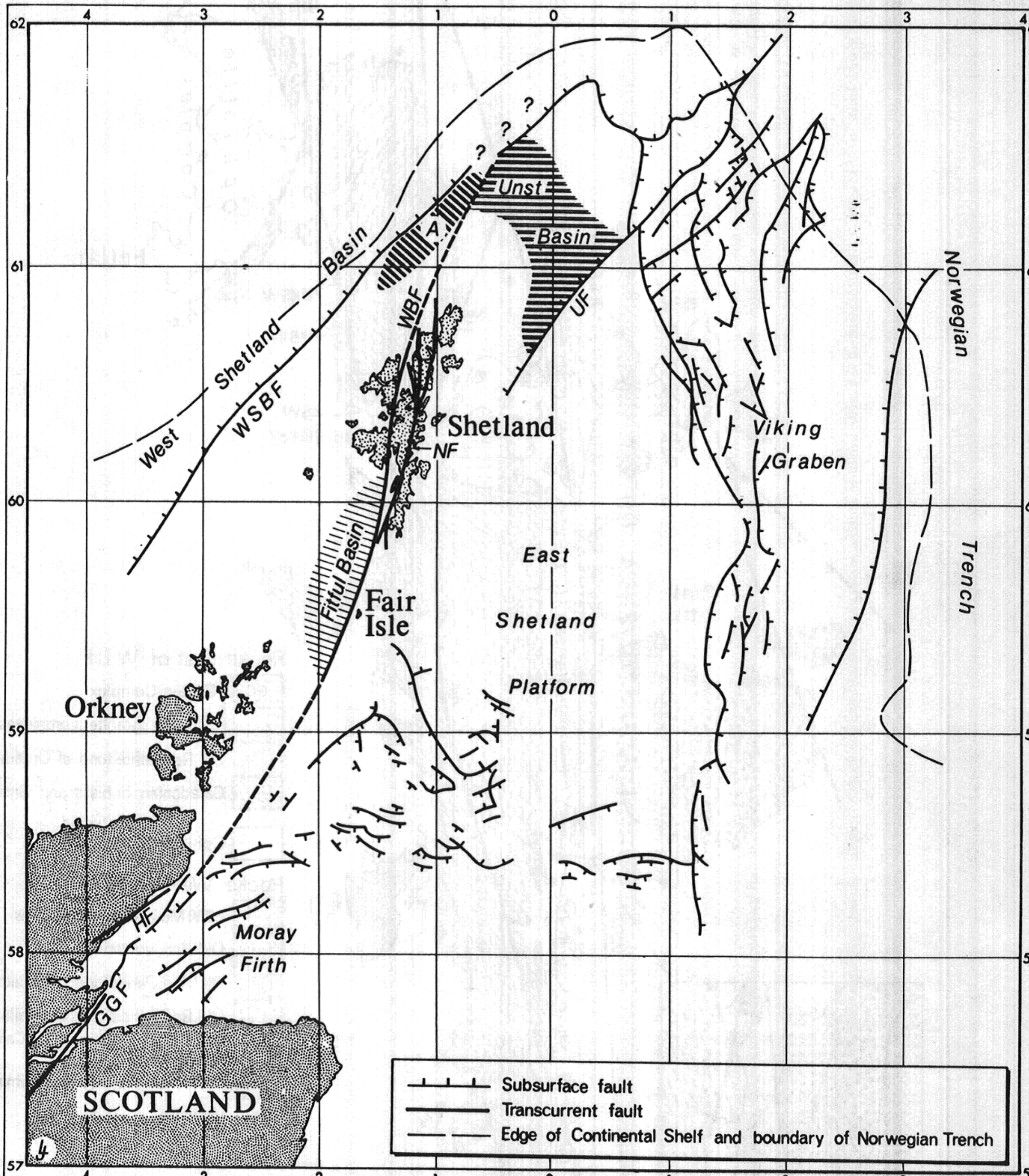
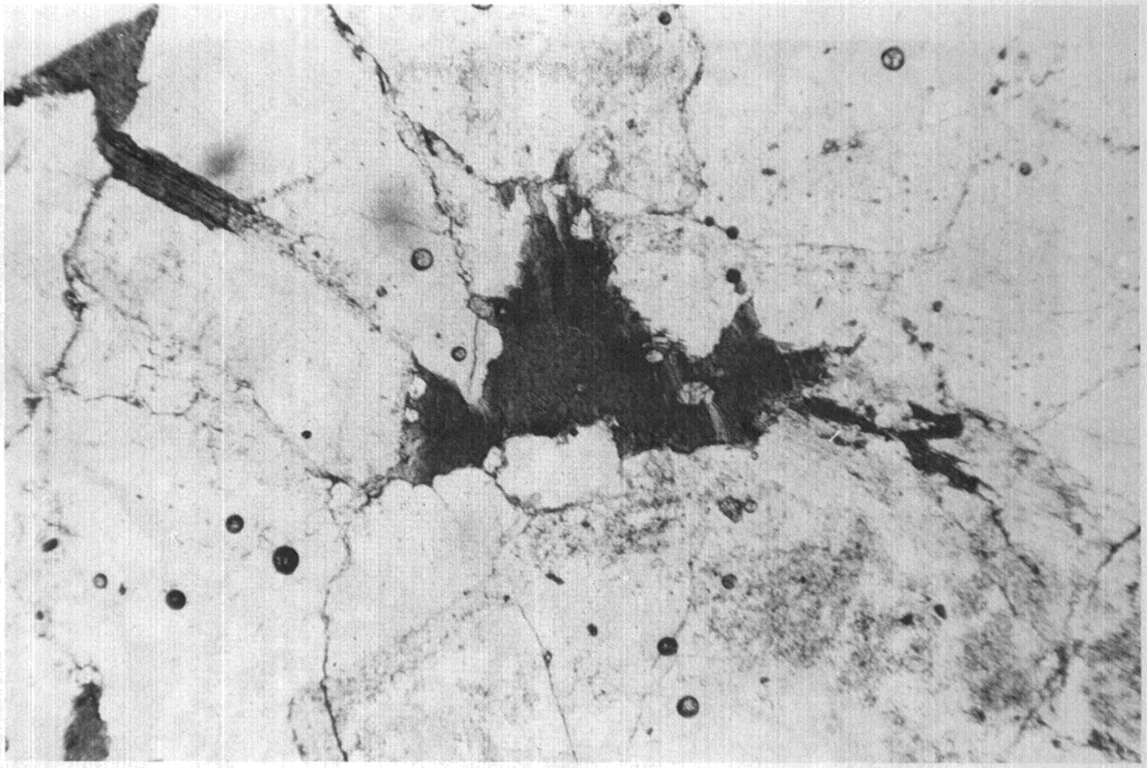
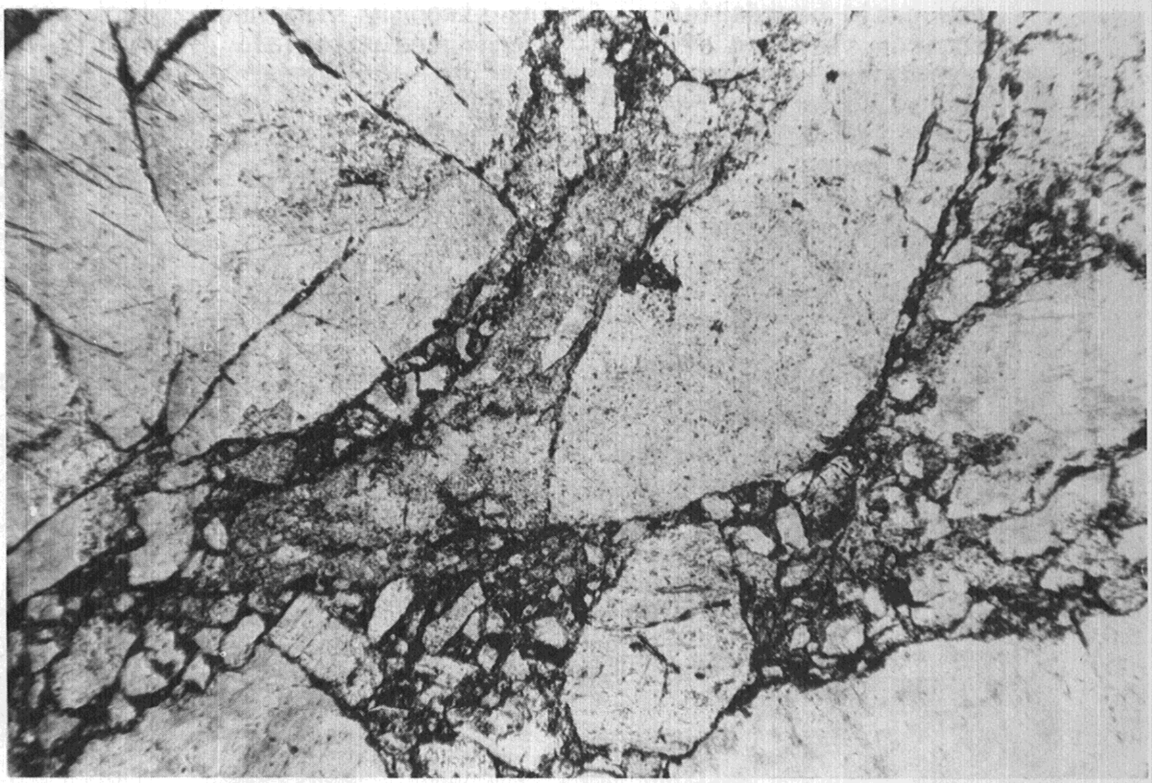

West Shetland Basin
WSBF
A
Unst Basin
UF
WBF
Shetland
NF
Fitful Basin
Fair Isle
East Shetland Platform
Viking Graben
Norwegian Trench
Orkney
HF
GGF
Moray Firth
SCOTLAND
Subsurface fault
Transcurrent fault
Edge of Continental Shelf and boundary of Norwegian Trench

PLATE I

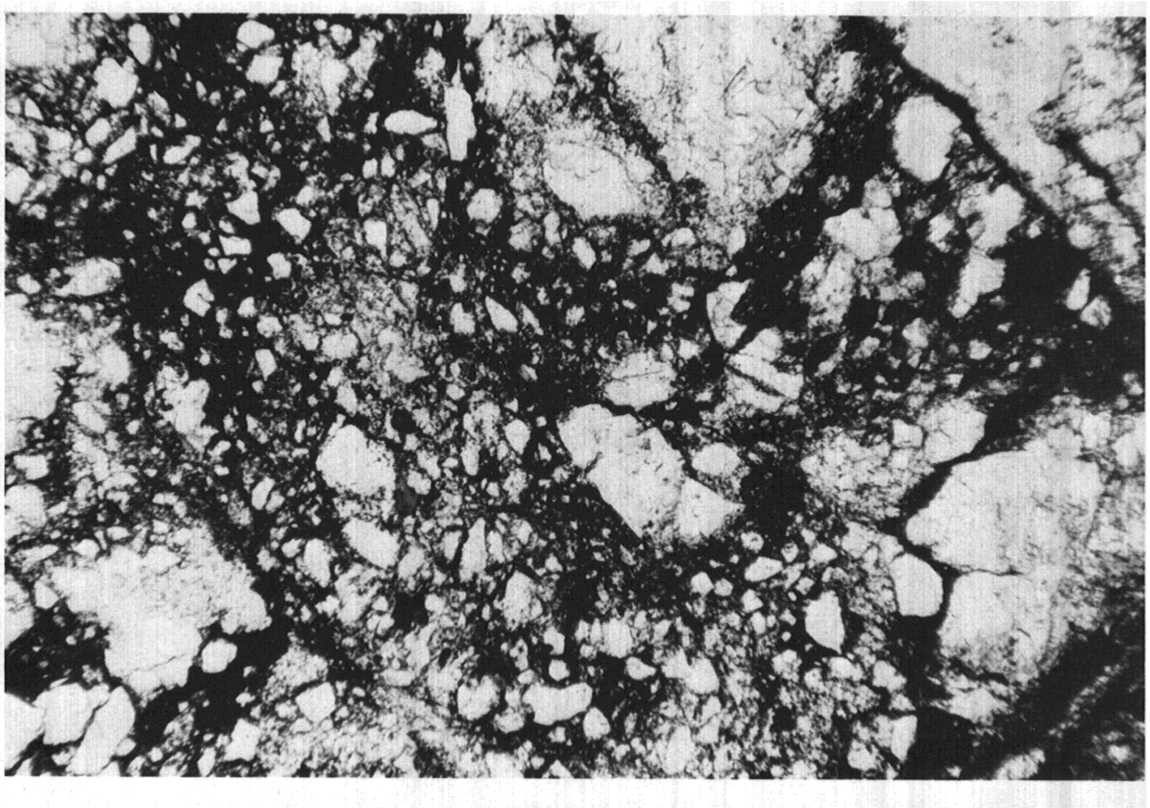


1. Protomicrobreccia. Polarised light. 1.6 x 2.5 mm^2. Quartz-plagioclase-biotite granodiorite. Fracturing along grain boundaries with no detectable offset. Quartz is strained (Univ.Liv. 50228)

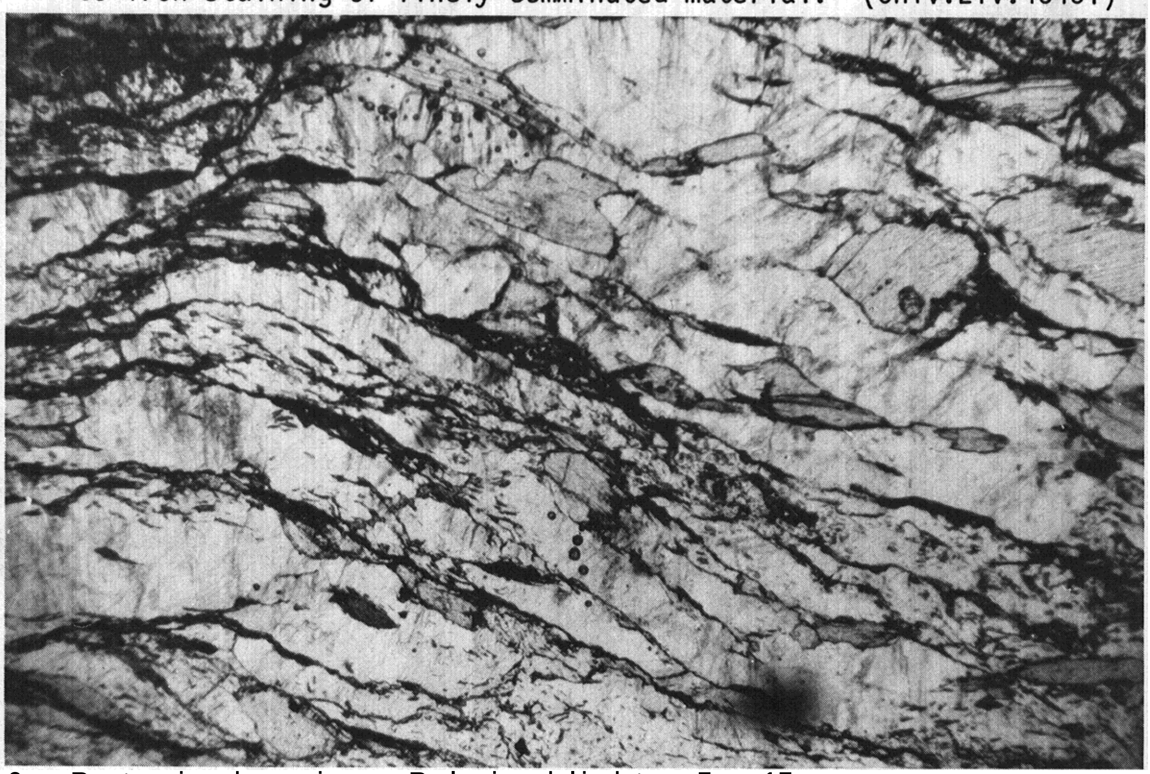


2. Microbreccia. Polarized light. 1.6 x 2.5 mm^2. Ex-granodiorite. Large pale areas are fragments of highly strained quartz and strained acid plagioclase and microcline. (Univ. Liv. 42989)

PLATE II

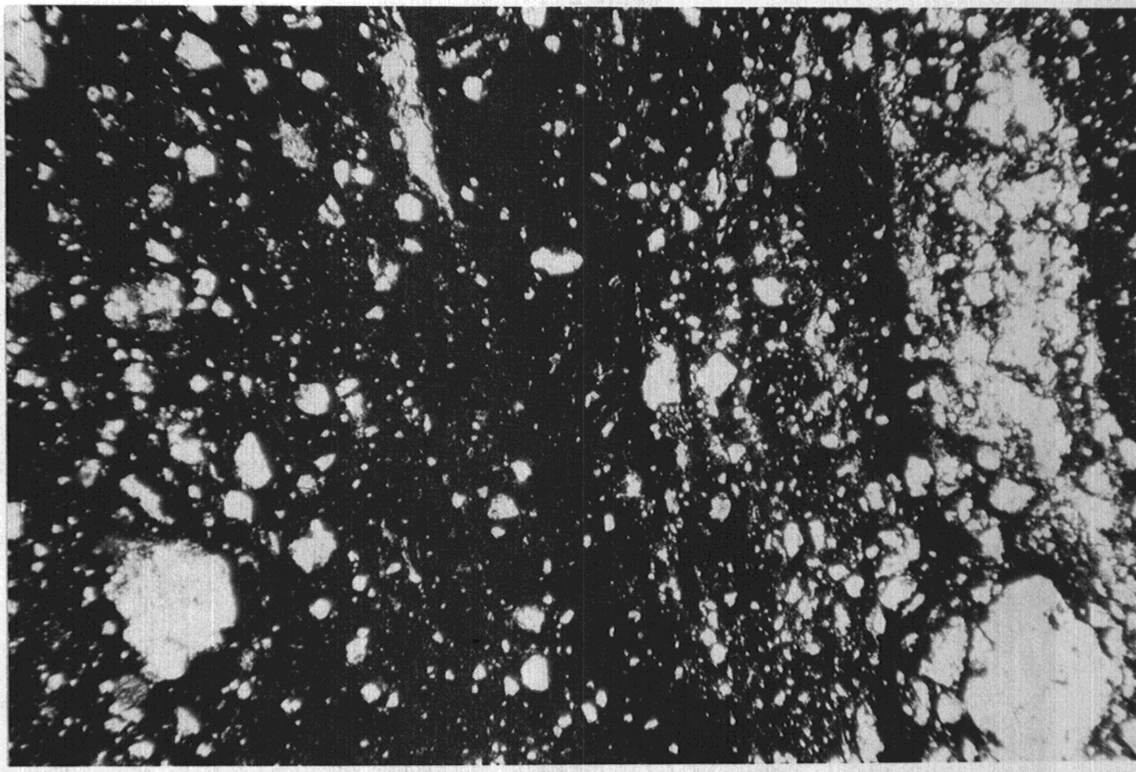


1. Cataclasite. Polarised light. 1.6 x $2.5mm^2$.
Ex-granodiorite. White areas are aggregates of quartz and of microcline and acid plagioclase. Aggregates due to formation of new grain boundaries. Grains strongly strained. Black areas due to iron staining of finely comminuted material. (Univ.Liv.45451)

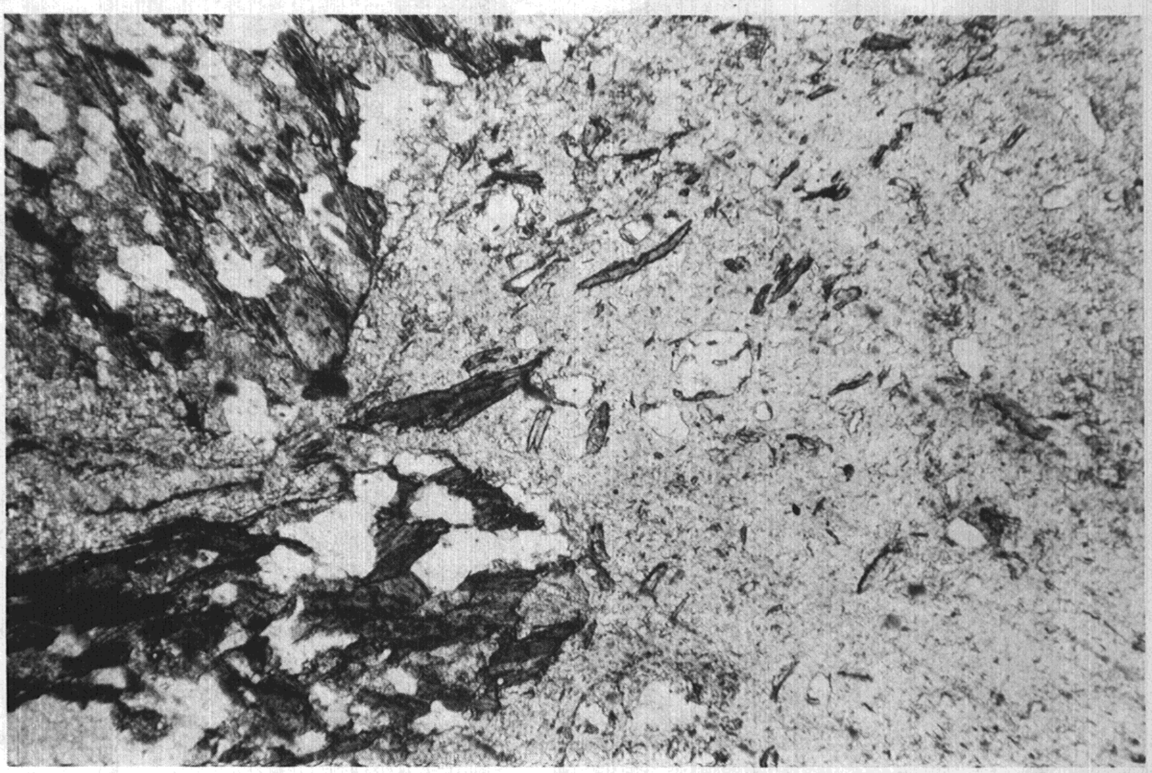


2. Protomicrobreccia. Polarised light. 5 x 15 mm^2.
Biotite-muscovite-quartz schist. Main fracturing without detectable offset parallel to schistosity linking up mica flakes. Minor fracturing at 90° in quartz. (Univ. Liv. 45468).

PLATE III



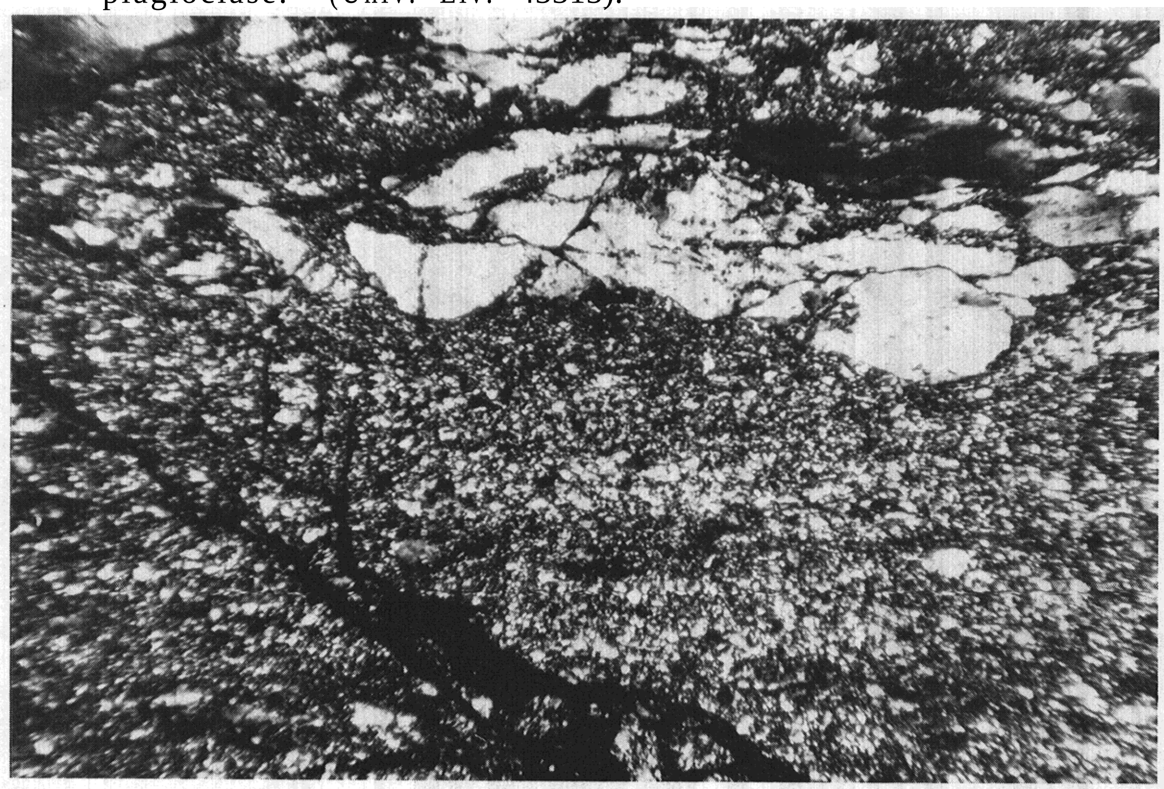
1. Gouge. Polarised light. 1.6 x 2.5 mm^2. White areas are clasts of highly strained quartz and of analcite. Black areas are limonite stained microscopically unresolvable material. (Univ. Liv. 43029).



2. Laumontite vein. Polarised light. 1.6 x 2.5 mm^2. Left-hand side, schist fragments. Right-hand side, fine grained laumontite crystalline aggregate (10-40 microns) with crystalloclasts of quartz and mica. (Univ. Liv. 50231)

PLATE IV

1. Mylonite with late fracturing. Polarised light. 5 x 15 mm^2. Eyes of very highly strained acid plagioclase and of altered plagioclase. (Univ. Liv. 43313).



2. Scapolite - mylonite with late cataclasis. Crossed polars. 1.6 x 2.5 mm^2. Large white highly strained quartz clasts. Scapolite (average 20 microns) crystalline aggregate. Black area, late cataclasite. (Univ. Liv. 47727).