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Deformation in low grade shear zones in the Old Red Sandstone, S.W. Wales

R. J. Knipe
Geology Institute, Leiden University, Leiden, The Netherlands
and
S. H. White
Department of Geology, Imperial College, London, England

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Abstract — Shear zones in sandstones of the Old Red Sandstone at Marloes Sands, S. W. Wales show three stages in their microstructural evolution. The initial phase is dominated by microfracturing and infilling of dilation sites with secondary quartz. This stage occurs before any significant shear displacement parallel to the shear zone borders. The second phase is associated with increased intracrystalline plasticity accompanying shear displacement in the zones. The third phase is characterized by heterogeneous deformation and recrystallization concentrated in zones marking cleavage planes. The high bubble content of grains influenced the sub-grain formation and recrystallization behaviour.

INTRODUCTION

Shear zones in rocks are characterized by a progressive increase in strain towards their centres and are therefore extremely useful for studying the evolution of deformation induced microstructural features (Ramsay & Graham 1970, Beach 1975, Carreras *et al.* 1977). Ductile shear zones developed under greenschist or higher metamorphic grades are characterized by the development of mylonitic foliations and recent field and microstructural studies have revealed that dislocation movement and grain boundary diffusion are the primary deformation processes (White 1976, Schmid 1976, Lister & Price 1978). In contrast shear zones developed under lower grade conditions are characterized by the development of en-echelon vein arrays, spaced cleavages and occasionally by elongate grain fabrics (Beach 1975).

This paper describes the results of a detailed study of the mesoscopic and microscopic features present in low grade shear zones in quartz arenites from the Old Red Sandstone of Marloes Sands, Dyfed, S.W. Wales Nat. Grid Ref. SM 773075). The aims of the study were to examine the processes associated with shear zone initiation and development at low (anchi) metamorphic grades.

MESOSTRUCTURES

The tectonic history of the region has been described by Hancock (1973) and the two-dimensional features of these shear zones described by Beach (1975) and Burger (1977).

The shear zones range from one to twenty centimetres in width, and often exceed two metres in length. They are characterized near the bedding plane surface by the development of three features: (i) an oblique fabric of elongate grains which develops at an average angle of 46° ± 5° to the shear zone direction; (ii) quartz filled en-echelon veins which are initially perpendicular to the grain fabric and which tend to be parallel to the complementary shear zone direction (see Beach 1975); and (iii) spaced cleavage planes marked by zones of preferential weathering and parallel to the elongate grain fabric (Fig. 1). Below the bedding plane surface the shear zones often exhibit a reduction in width and are marked by a single vein trending in the shear zone direction. This change of shear zone morphology below the bedding has also been noted by Wilson (1970).

Figure 2 presents the three-dimensional relationships of deformation features in the shear zones and bedding in the exposures studied. The poles to shear zones, cleavage planes and en-echelon veins, together with the lineation defined by the elongate grains, all lie close to the bedding plane. This suggests that the maximum displacement vector lies close to the bedding plane.

Particular attention was given to embryonic shear zones, where the change in the orientation of deformation features across the shear zone is less than 10°, that is the apparent shear strain is less than 0.4. In these, cleavage planes are restricted to either or both zones already marked by an elongate grain fabric or an array of quartz filled veins. The elongate grain fabric develops inhomogeneously along these embryonic shear zones as oblique lenticular zones alternating with regions of rounded grains. The orientation of the lenticular zones is parallel to the orientation of the quartz filled en-echelon veins (Fig. 3a). Those embryonic shear zones marked by vein arrays exhibit a complete gradation between zones with closely spaced thin (<1mm) veins and widely spaced thick (>2mm) vein arrays (Figs. 3b & c). Cleavage planes present in the shear zones may be composed of a concentration of phyllosilicates or of fine grained quartz. The spacing of cleavage zones is approximately constant along individual shear zones but increases with increasing zone width (Fig. 3d).

Shear zones, where the change in orientation of deformation features across the shear zone is more than 10°, have similar types of cleavage, but in these zones the cleavage spacing often decreases towards the centre (Figs. 1 and 3e). Some of these cleavage planes truncate the elongate grain fabric (Fig. 3e). Cleavage planes pre-

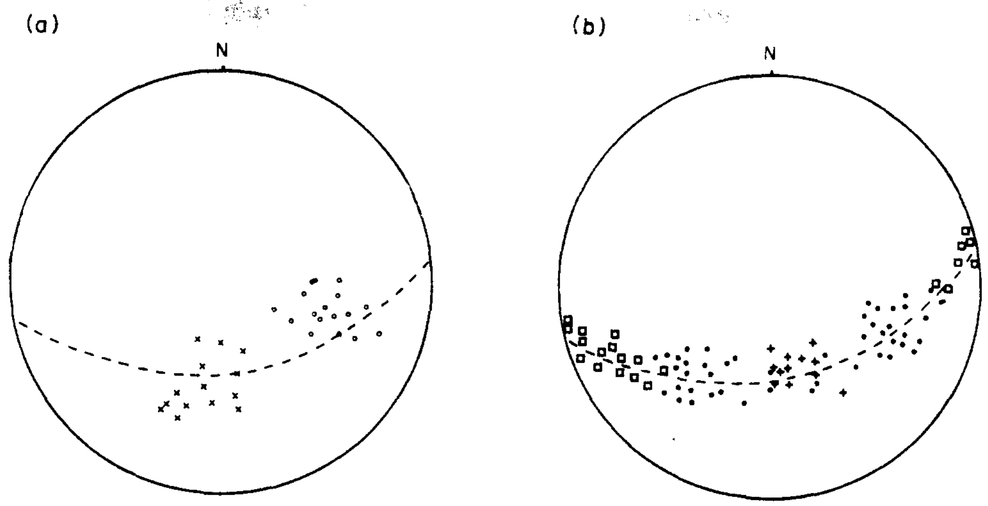


Fig. 2. Orientation of deformation features associated with the shear zones. (a) orientation of poles to dextral (o) and sinistral (x) shear zones and the bedding plane (--). (b) orientation of poles to cleavage planes (□), poles to veins (●) and the lineation defined by the elongate grain fabric (+).

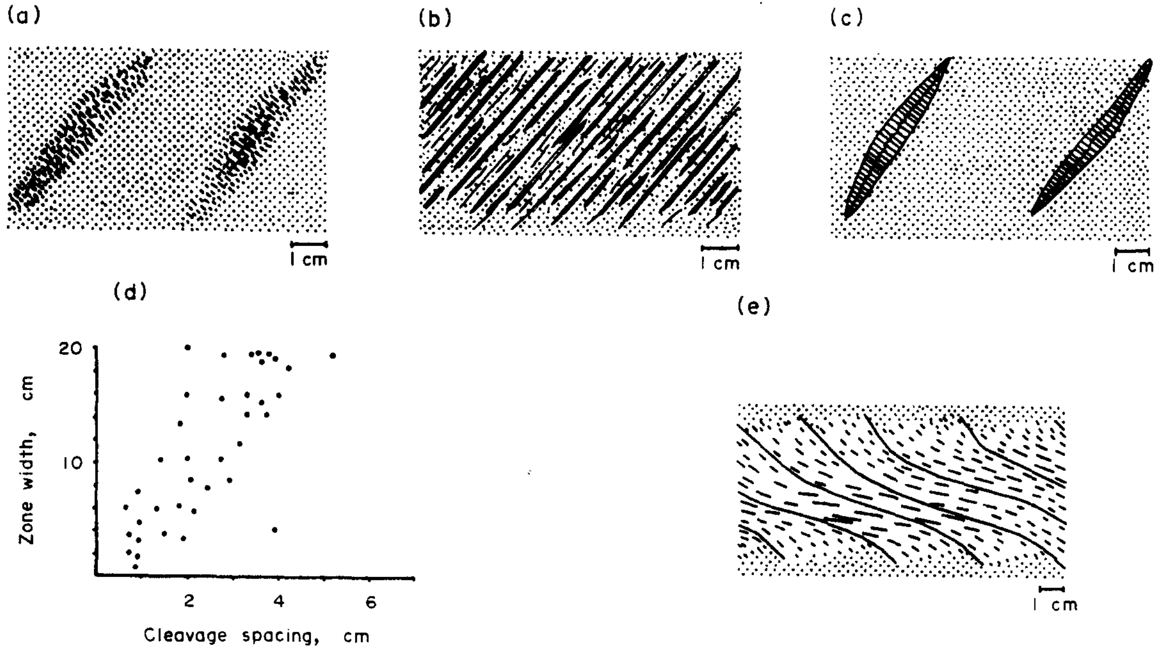


Fig. 3. (a–c) Sketches of embryonic shear zones, (a) lenticular zones with an elongate grain fabric, (b) closely spaced thin veins and (c) widely spaced thick veins. (d) variation in cleavage spacing with shear zone width. (e) sketch of a well developed shear zone illustrating the change in cleavage spacing across the shear zone and the stepped boundary of the elongate fabric at the shear zone border.

sent in zones containing en-echelon veins are generally located at asymmetrical folds in the veins (Fig. 4) suggesting that displacements have occurred parallel to and along the cleavage. The sense of shear on the cleavage planes is the same as the overall sense of displacement on the shear zone in which they are contained. Adjacent veins may decrease in spacing as they pass through the cleavage indicating that there has also been a volume reduction along the cleavage (Fig. 4). However not all veins are deformed by the cleavage zones, and these truncate well developed cleavage planes.

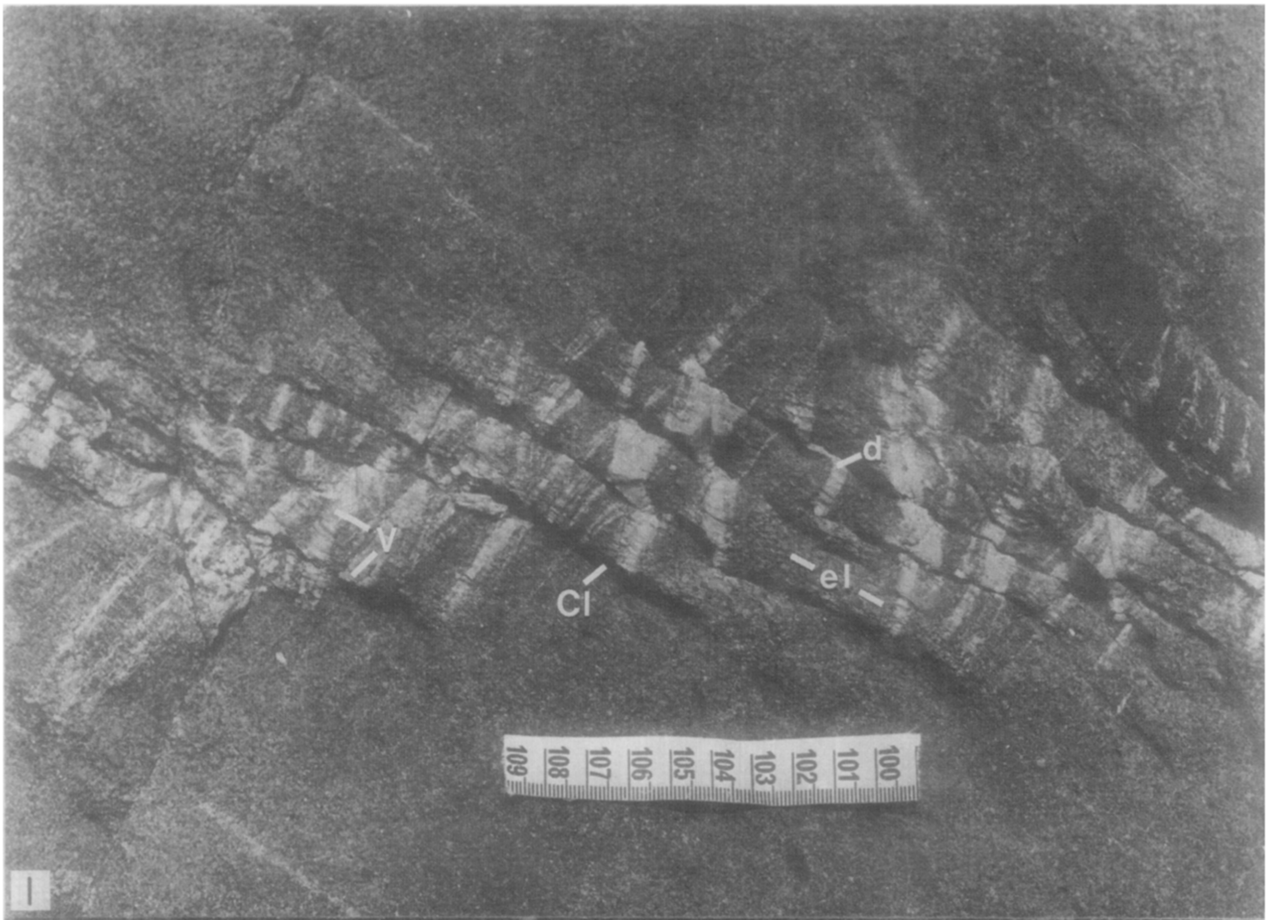
MICROSTRUCTURES

Shear zones exhibiting a well developed elongate grain fabric and a spaced cleavage marked by a concentration of fine grained quartz were selected for detailed microstructural analysis. Orientated specimens were collected and two sets of thin sections were cut. The first set is parallel to the bedding plane and the second set is at various orientations perpendicular to the bedding. Selected areas within the sections were then prepared for High Voltage Electron Microscopy by ion thinning (Barber 1970).

The description of the microstructures is divided into three sections based upon the three characteristic regions associated with the shear zones: *Region I* outside the shear zone; *Region II* at the shear zone border but external to a shape fabric in the quartz grains; and *Region III* inside the shear zone where a shape fabric is present.

Region I

The quartz arenites outside the shear zones are composed of rounded detrital grains (0.1 – 1.5 mm dia.),



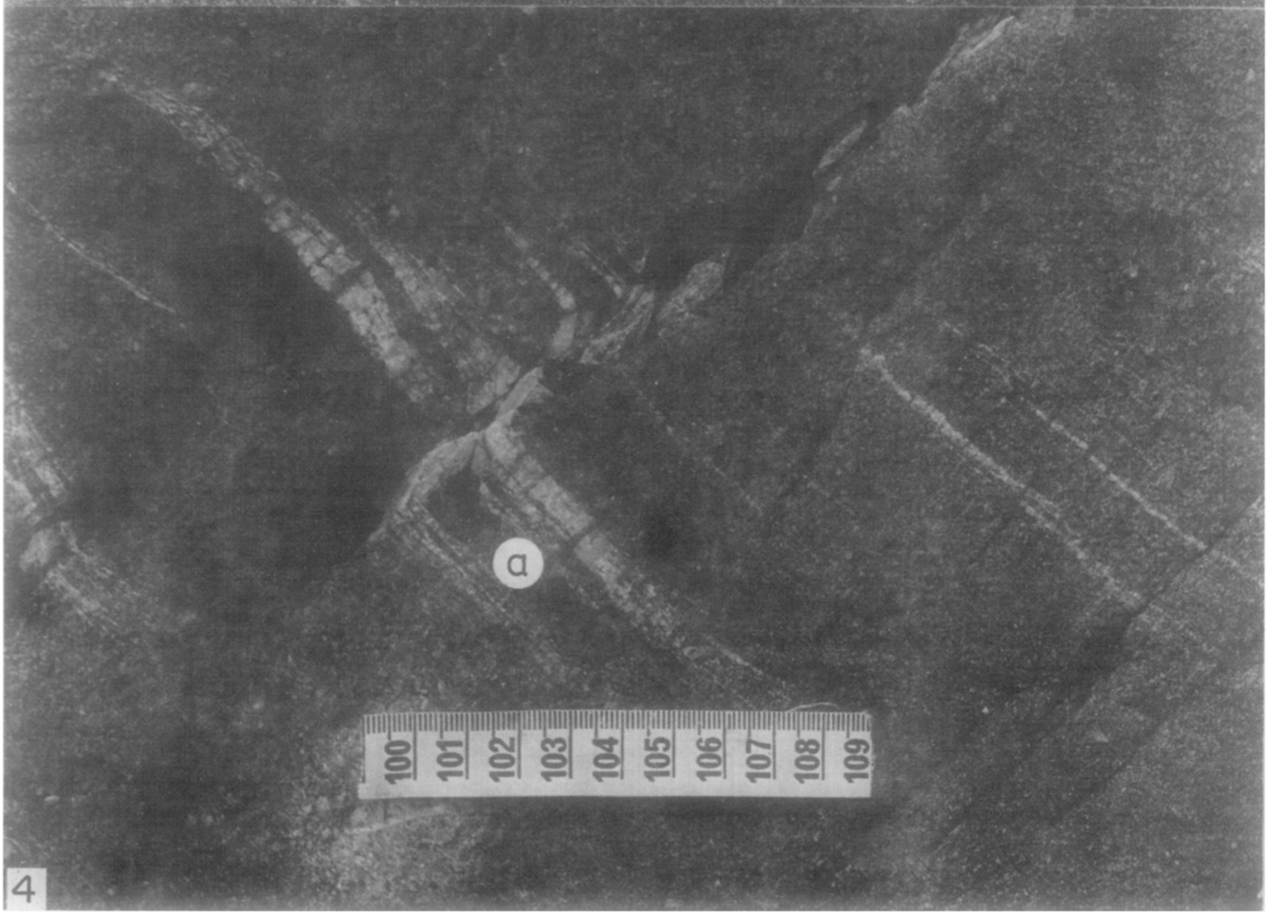


Fig. 1. Well developed shear zone exhibiting, spaced cleavage planes (C1), en-echelon vein arrays (v) and elongate grain fabric (el). Note also the change in cleavage spacing across the zone and the concentrated deformation of veins in the cleavage (d).

Fig. 4. Concentrated rotation of veins within a cleavage zone. The truncation of host rock regions (a) at the cleavage is indicative of a volume reduction in the cleavage.

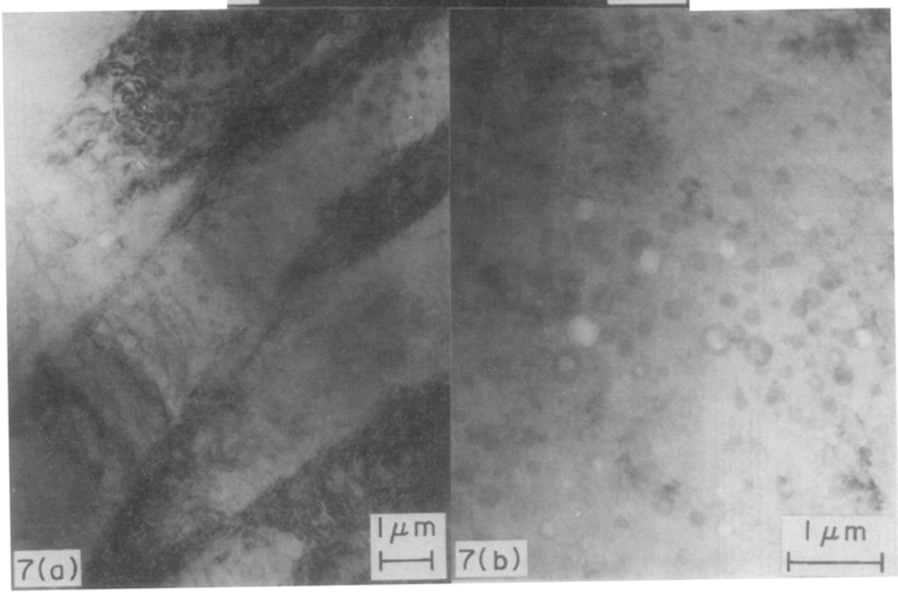
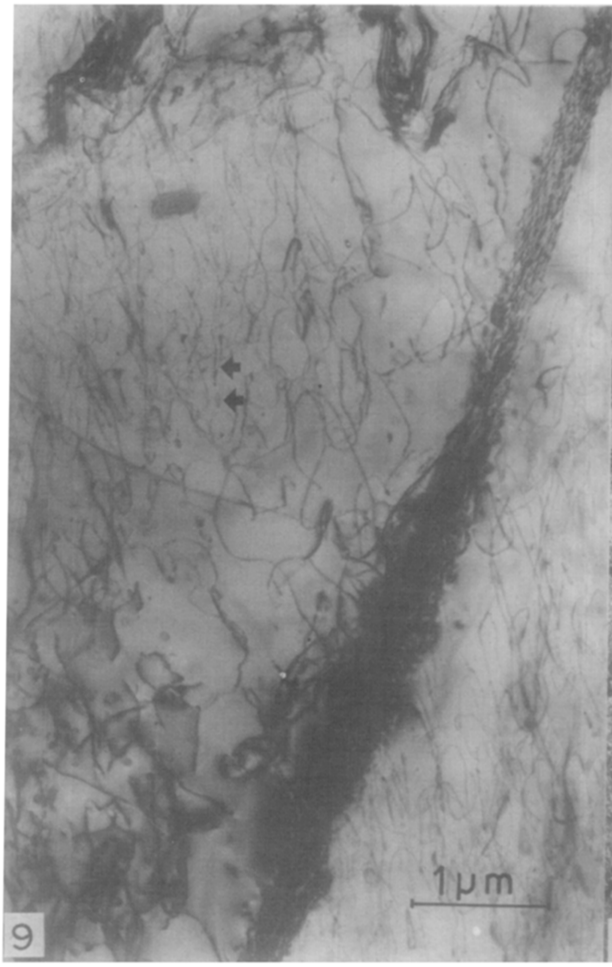


Fig. 6. Electron micrograph of dislocation sub-structure present in detrital quartz grain outside shear zone.

Fig. 7. Electron micrographs of secondary quartz cement outside a shear zone. (a) thin fibres, (b) high bubble content of fibres.



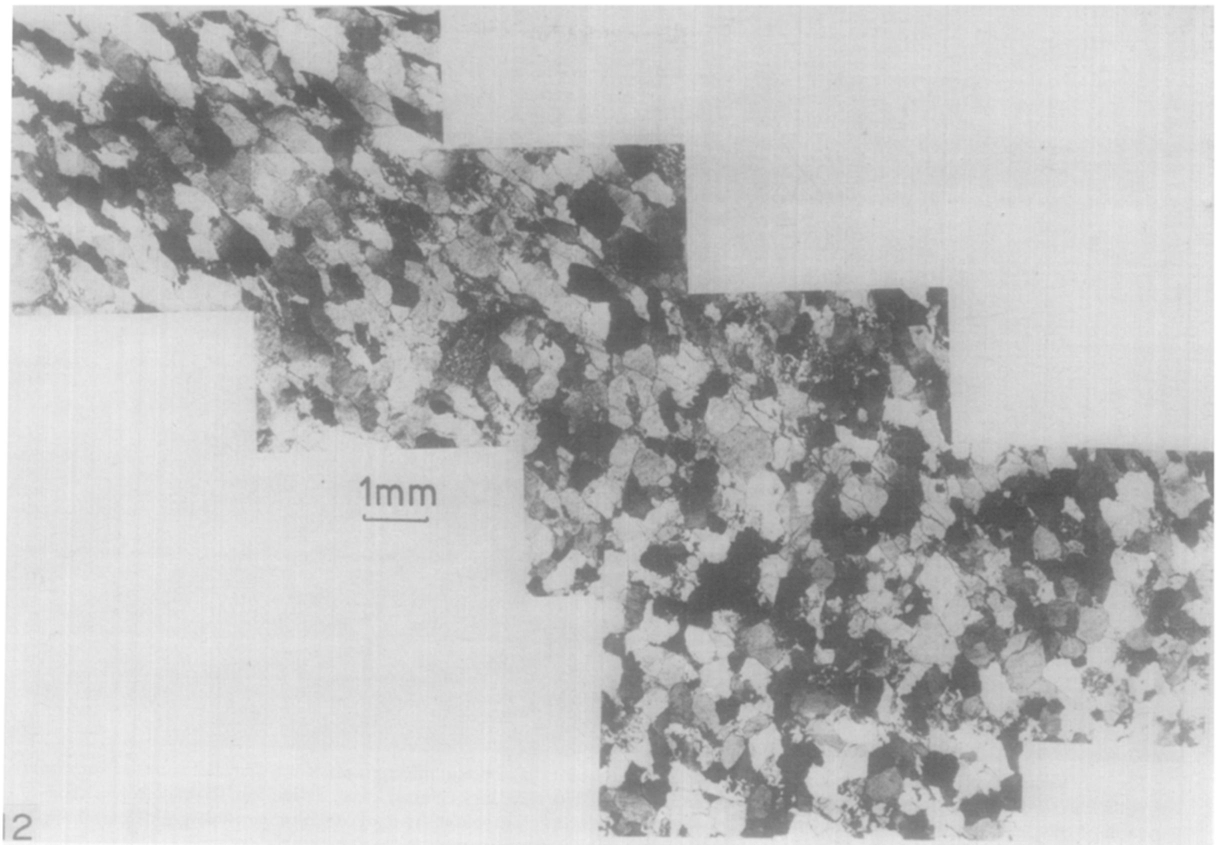
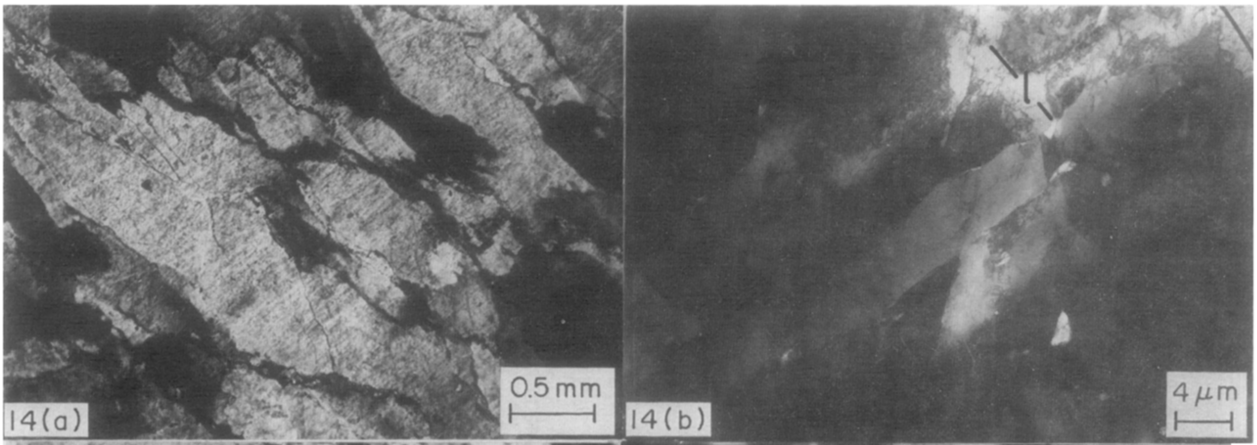
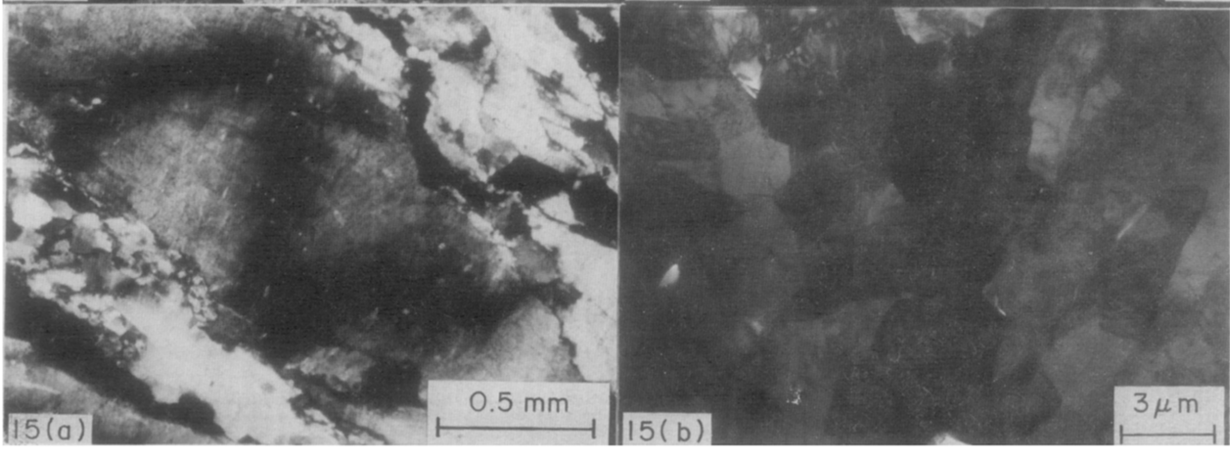


Fig. 9. Electron micrograph illustrating the high dislocation densities and a low angle grain boundary present in detrital quartz at the shear zone boundary. Note the dipoles and loops, arrowed.

Fig. 10. Optical micrograph of sub-parallel bubble arrays developed in quartz grains at a shear zone border.

Fig. 12. Optical micrograph illustrating the development of an elongate grain fabric near the bedding plane surface. Section cut parallel to bedding.





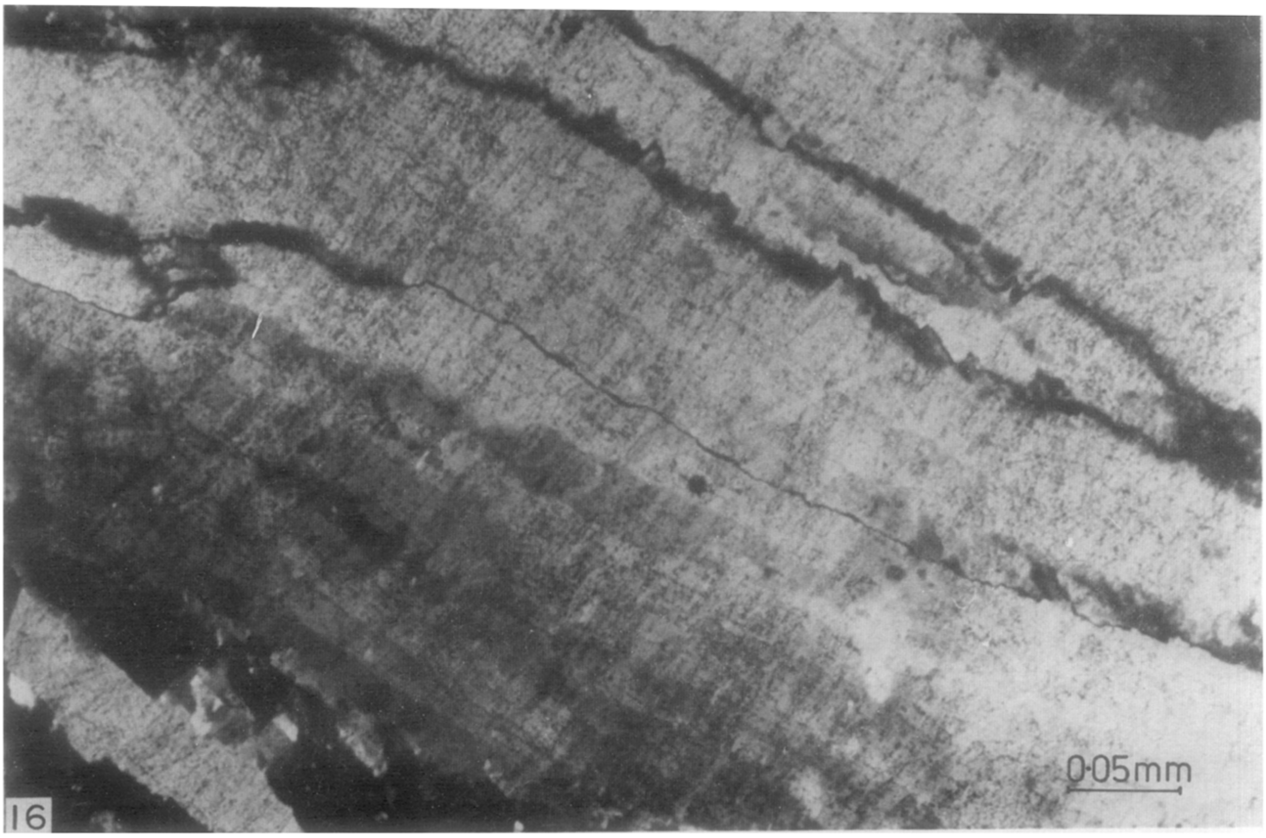
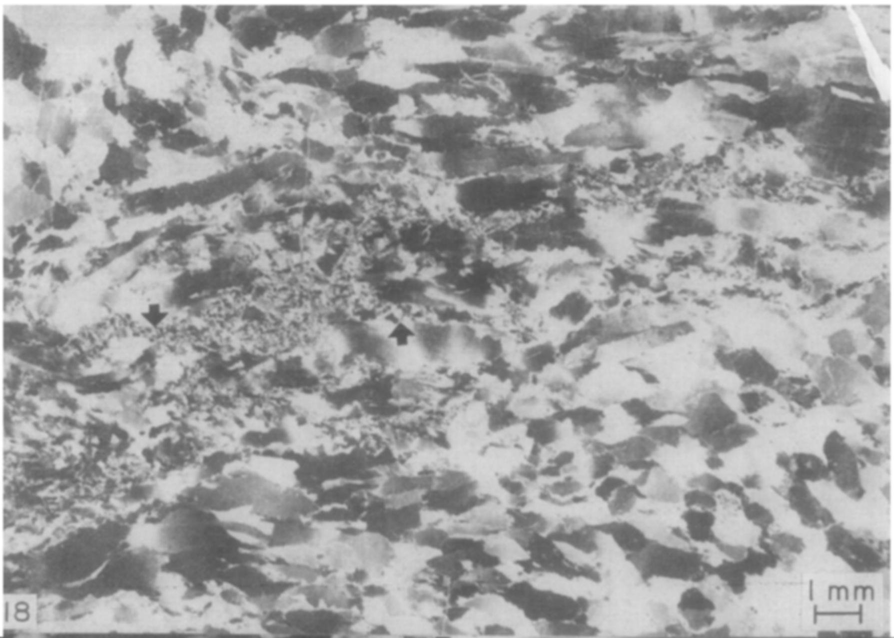
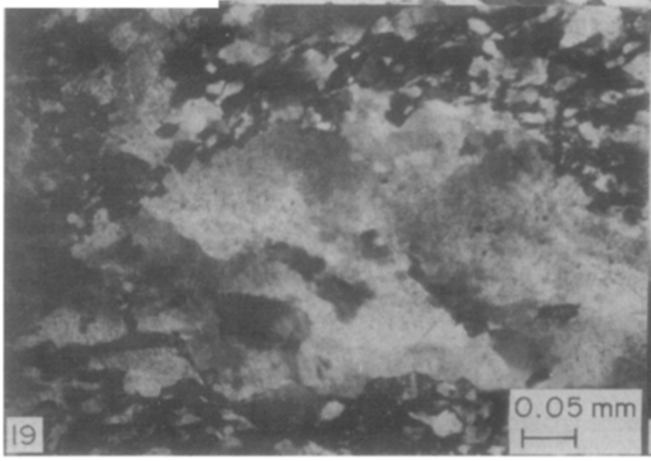


Fig. 14. Microstructures of elongate grains at a shear zone border. (a) Optical micrograph of sub-parallel zones of varying inclusion content orientated at a high angle to grain long axes. Note the lack of undulatory extinction. (b) Electron micrograph of the grain illustrated in (a) with *l* marking the long axis direction. Note the irregular elongate sub-grains parallel to the inclusion trails visible in (a), and the voids along sub-grain walls.

Fig. 15. Microstructure of an elongate grain within a shear zone. (a) Optical micrograph illustrating large amount of undulatory extinction together with visible sub-grains. (b) Electron micrograph from the grain shown in (a) illustrating the equidimensional sub-grains.

Fig. 16. Optical micrograph showing low angle grain boundaries developed in elongate grains within a shear zone. Note the low angle walls are at a high angle to the inclusion trails, the dentate morphology of some walls and the sub-grains.





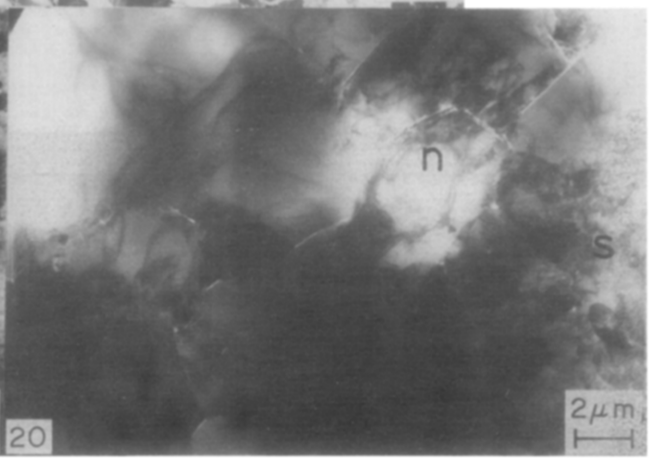


Fig. 18. Optical micrograph illustrating the location of small, strain free recrystallization zones parallel to the elongate grain fabric.

Fig. 19. Optical micrograph showing a recrystallised old grain at a cleavage border. Note that the recrystallization front is diffuse and sub-grain misorientation increases towards the grain boundary.

Fig. 20. Electron micrograph of a sharp recrystallization front illustrating the larger size of new, strain free grains (*n*) compared with adjacent sub-grains (*s*).

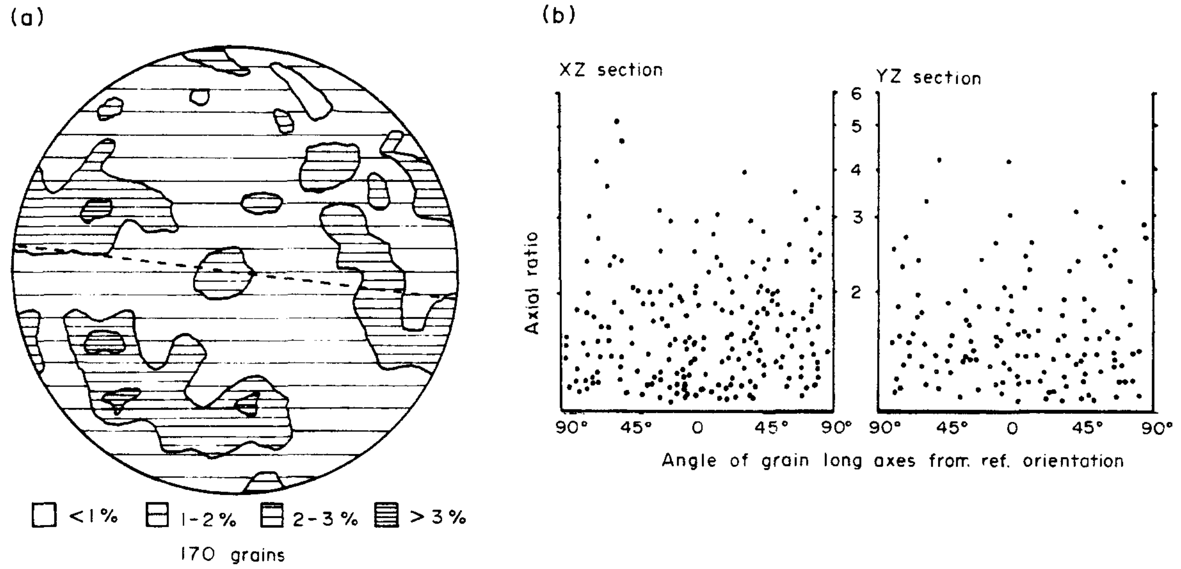


Fig. 5. (a) Orientation of quartz grain *c*-axes outside a shear zone, the dashed line represents the orientation of an adjacent shear zone. (b) Axial ratio of quartz grains (length/width) vs orientation of grain long axes outside shear zones. *XZ* section plane cut parallel to bedding. *YZ* section cut perpendicular to bedding and the lineation in adjacent shear zone.

coated with haematite and set in a secondary quartz cement which accounts for up to 12% of the rock volume. There is no preferred orientation of quartz *c*-axes or of grain long axes (Fig. 5). Undulatory extinction greater than 10° occurs in less than 8% of grains and deformation lamellae are present in less than 1% of grains. The detrital grains do however contain a low concentration of bubbles either as distributed inclusions or as planar arrays generally confined to single grains and with no preferred orientation.

The dislocation sub-structures within the detrital grains are extremely variable as expected for grains which have probably experienced different pre-depositional histories. The dislocations are usually decorated and their density is up to $10^9 cm^{-2}$. Low angle grain boundaries which define either dislocation cells or subgrains (>10μm dia.) are also present (Fig. 6).

The secondary quartz cement consists of thin (<2μm) fibres (Fig. 7a) arranged with their long axes at a high angle to the host grain boundary. Adjacent fibres are usually misorientated by less than one degree and contain moderate dislocation denstities ($10^7 - 10^8 cm^{-2}$), and large concentrations of bubbles (up to $10^{12} cm^{-3}$) (Fig. 7b). Both the dislocation and bubble content vary along the fibre length and blocks with similar densities can be recognised, probably representing different growth bands. The fibre walls themselves are either dense dislocation tangles, often decorated with bubbles, or regions containing small voids and mineral inclusions. The junction between the detrital grains and the overgrowths is also characterized by either or both a concentration of voids and a concentration of impurities.

Region II

Three microstructural changes occur in the grains located at the shear zone borders but external to Region III where a grain shape fabric may be detected. They are: (i) an increase in the frequency of deformation lamellae; (ii) an increase in the amount of undulatory extinction; and (iii) a marked increase in the number of sub-parallel arrays of inclusions. The deformation lamellae have a heterogeneous distribution along the shear zone border and are not confined to a particular angular distribution about the host grain *c*-axes. (Fig. 8a). They are however concentrated into two orientations 70° apart, one of which is approximately parallel to the adjacent shear zone direction (Fig. 8b).

The grains with undulatory extinction tend to occur closer to the shear zone than the grains with deformation lamellae. The former grains contain high dislocation densities together with some low angle dislocation walls (Fig. 9). Their dislocations are not usually decorated and many dipoles and loops are seen. Some of the dislocation arrangements are characteristic of dislocation sources.

The most prominent microstructrual change at the shear zone boundary is the rapid increase in the inclusion content of grains. The inclusions are sub-parallel arrays of bubbles which commonly traverse grain boundaries (Fig. 10) and occasionally splay out from point contacts. The arrays make an angle averaging 135° to the shear zone direction and exhibit an increase in fluctuation below the bedding plane surface, where the shear zones are marked by single veins (Fig. 11). The planar inclusion arrays bisect the two deformation lamellae orientations, indicating that the deformation lamellae are shear features and the inclusion arrays extensional features (cf. Figs. 8b and 11).

Region III

The development of the elongate grain shape fabric, in sections cut parallel to bedding, occurs adjacent to the region where grains contain a large number of inclusions. Below the bedding plane surface the elongate grain fabric is either confined to a narrow zone which

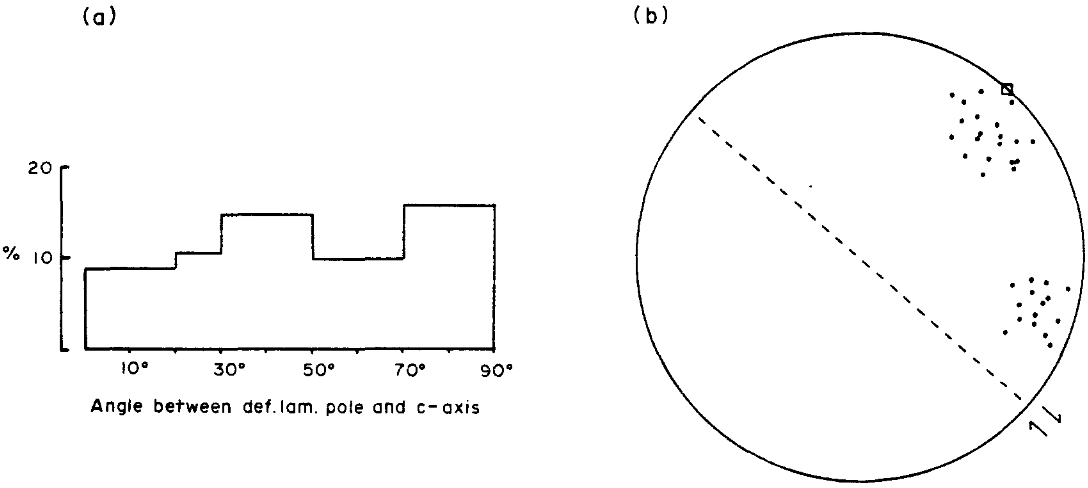


Fig. 8. (a) Orientation of deformation lamellae to host grain *c*-axes. (b) Orientation of deformation lamellae poles relative to the shear zone orientation.

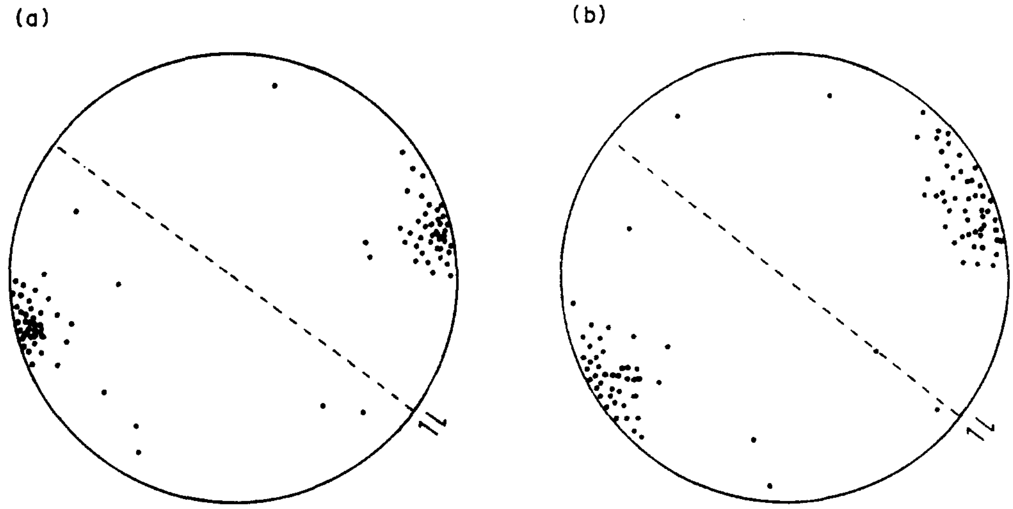


Fig. 11. Orientation of poles to planar bubble arrays at a shear zone border, (a) near a bedding surface, (b) below a bedding surface. The orientation of the adjacent shear zone is indicated.

gives way to a zone of recrystallization or the shear zone is marked by obliquely orientated fibres which span the zone and have diameters approximately equal to the external grain diameter.

Near a bedding plane a shape fabric in the quartz grains gradually develops towards the shear zone centre (Figs. 12 and 13). The fabric that develops is perpendicular to the planar inclusion arrays present in the adjacent rounded grains. Two observations are noteworthy about the initial development of this shape fabric. Firstly the increase in the average axial ratio with no change in the orientation of the grain shape fabric is not consistent with development during a simple shear deformation. Secondly there is either no change or an increase in the width of grains in sections cut parallel or perpendicular to bedding, demonstrating that the volume of individual grains increases with elongation, that is with increasing strain.

The elongate grains contain irregular, rectangular sub-grains which commonly have their walls aligned approximately parallel and perpendicular to the grain length (Fig. 14). Dislocations are present in the sub-grains and bubbles are concentrated along their walls, particularly at triple point junctions. The sub-grains are less than 10 μm in width and have misorientations generally below 2°.

The elongate grains exhibit marked undulatory extinction (Fig. 15) only where the long axes of grains deviate more than 10° from the initial orientation of shape fabric at the shear zone borders, that is when the apparent shear strain exceeds 0.4. Electron microscopy reveals that the sub-grains are more equidimensional (Fig. 15) than those in grains where the apparent shear strain is less than 0.4. It was also observed that sub-grain walls develop parallel to the direction of grain elongation. These dentate walls divide the grains into fibres perpendicular to the finer striations related to bubble arrays (Fig. 16). Similar dentate boundaries with misorientations in excess of 10° occur in the shear zone centre.

The *c*-axes of grains in the shear zone interiors have no marked preferred orientation apart from small areas where a concentration of *c*-axes occurs parallel to the grain elongation direction (Fig. 17).

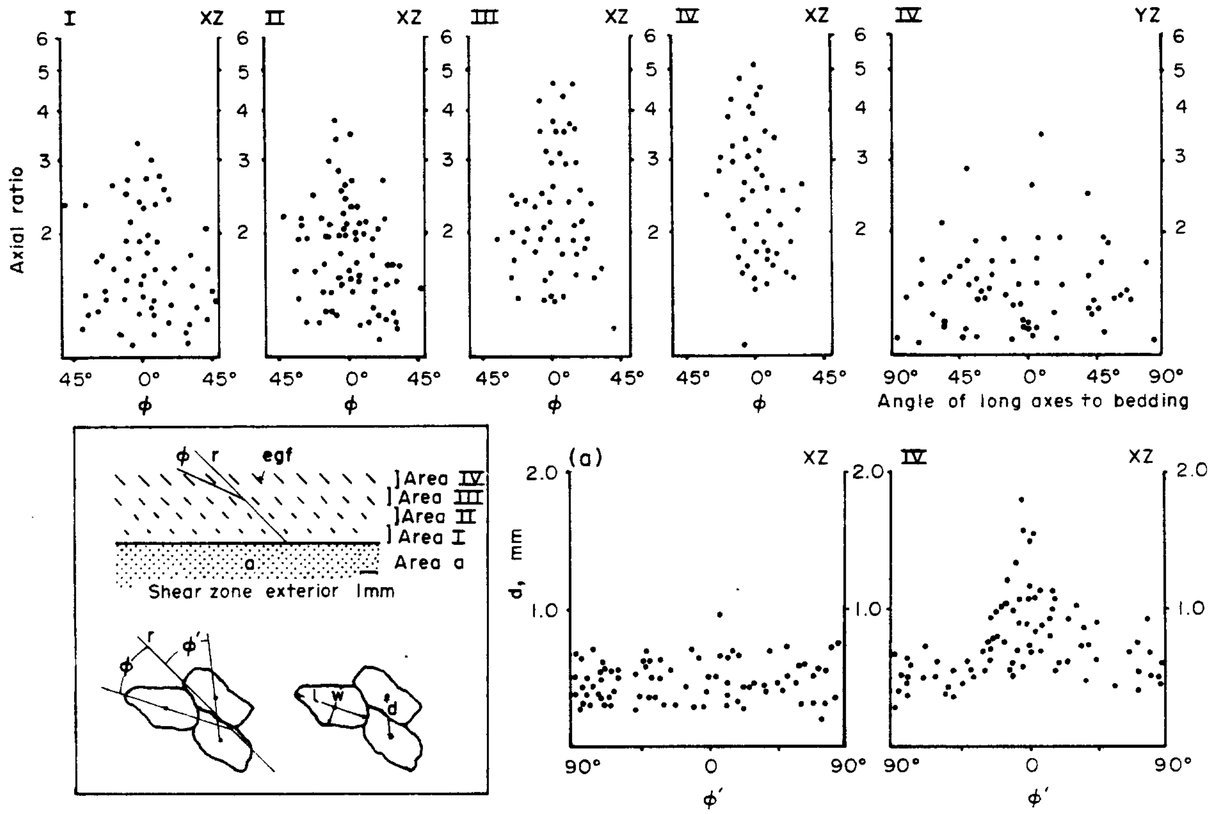


Fig. 13. Diagrams illustrating the development of the elongate grain fabric (*egf* of inset) at the shear zone border. The insert also shows the five areas where measurements were made and the parameters used to define the fabric evolution. *r*—reference orientation at 45° to shear zone direction. The top row of diagrams illustrates the increase in axial ratio of grains (*l/w*) and decrease in the range of ϕ' in *XZ* sections during fabric evolution. The lower diagrams compare the centre to centre dimensions with ϕ', outside (area *a*) and inside (area IV) the shear zone. Note the consistent values of *d* inside and outside the shear zone when ϕ' is at a high angle to *r*.

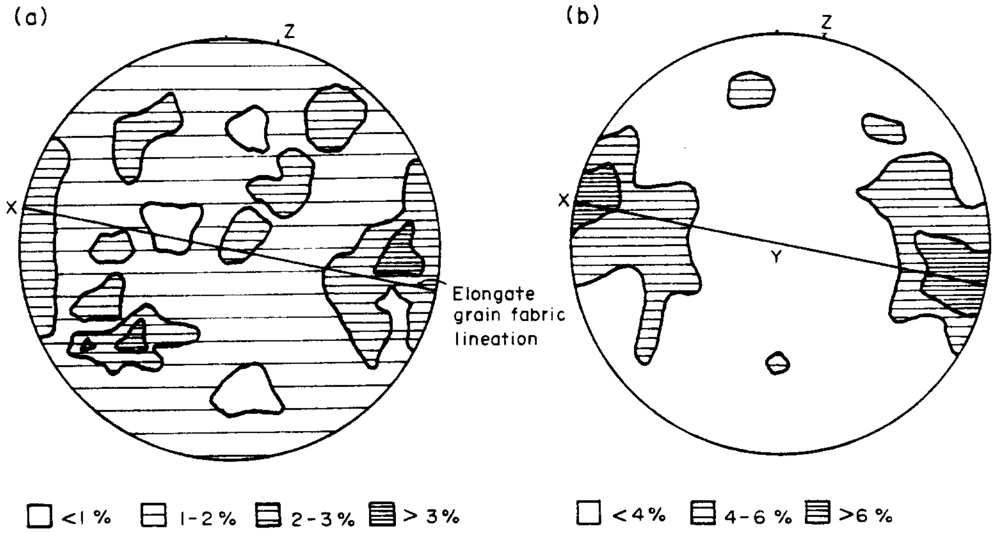


Fig. 17. *C*-axis orientations of quartz grains within a shear zone over an area where the shape fabric has a constant orientation. (a) Orientation of 200 *c*-axes. (b) Orientation of 54 *c*-axes in a smaller area than (a).

The spaced cleavage planes in the shear zones are marked by small strain– and inclusion-free recrystallised quartz grains (Fig. 18). Most are parallel to the elongate grain fabric but some are oblique to it (Fig. 2). The quartz grains commonly have hexagonal outlines and decorated grain boundaries. Deformed grains adjacent to the cleavage zones either exhibit a gradual increase in the sub-grain misorientation towards the recrystallized cleavage zone (Fig. 19), or end abruptly against these zones. In both situations the new strain-free grains are larger than the sub-grains observed with the electron microscope in the adjacent deformed grains (Fig. 20). Some strain-free new grains are also formed within the old deformed grains distant from the cleavage zones.

DISCUSSION

Both the micro and mesostructures of the shear zones studied indicate that brittle deformation (involving microfracturing and fracturing) and ductile deformation (involving crystal plasticity, grain boundary sliding and grain boundary diffusion) processes operated during shear zone evolution. The evidence for each process and their relationship during shear zone development will be discussed below.

Brittle deformation

The planar parallel arrays of bubbles cut across several grains and are interpreted as healed fractures. They occur both within and adjacent to the shear zones, being more abundant in the shear zone grains. It seems likely that microfracturing without significant dilation is the most important initiating mechanism for the shear zones. This conclusion is supported by theory (Lajtai 1969) and by experimentally produced microfractures in sandstones deformed in a brittle regime by Dunn *et al.* (1973).

The secondary quartz cement contains a large number of internal features such as fibre walls, bubbles, and zones of high dislocation densities which can aid the nucleation and propagation of microfractures and thus may have been a critical factor in the localization of microfracturing. Although the mechanisms of microfracturing are not known, the orientation of the microfractures in the inferred operative strain system at the time of their development suggests they are extensional surfaces (see previous section).

It is concluded that the dilation and propagation of microfractures, and their subsequent infilling with secondary quartz accounts not only for the en-echelon fibrous veins and the veins which mark the shear zones below the bedding plane, but also for the elongation of the quartz grains. Three observations from the shear zone border lead to this conclusion : (i) the constant or increased width of the elongate grains irrespective of their length; (ii) elongate grains and fibres within veins are perpendicular to healed fractures; and (iii) fibre width equal to the diameter of grains adjacent to the veins.

The surfaces along which the secondary quartz was deposited are now marked by bubble arrays, which delineate interfaces between sub-grains. The blocky irregular sub-grain structure of these elongate grains is similar to the sub-structure found in quartz overgrowths (Grant & White 1978) and may also have developed during the growth of secondary quartz in the shear zones. The repetitive sequence of microfracturing, dilation and infilling which appears to be responsible for the elongate grain fabric has been described in detail by Knipe (1977) and is similar to the crack-seal mechanism described by Ramsay (1977, pers. comm.).

The variation in the distribution of the microfractures and their associated dilation is primarily responsible for the variation in the shear zone form. Below the bedding plane the dilation appears to be confined to a narrow zone parallel to the shear zone direction and results in the development of oblique fibres which span the shear zone. The fibrous zone is not regarded as a discrete shear fracture but as a shear failure in a zone of extensional microfractures. In contrast, near the bedding plane surface the dilation occurs in en-echelon zones and the number of fractures opened and subsequently filled appears to dictate the deformation features present. A large number of slightly dilated microfractures leads to the development of the elongate grain fabric, whereas a vein is produced when a narrow zone of microfractures undergoes a larger dilation. There is a complete gradation between these two modes of dilation. A similar relationship between the spacing of veins and the amount of dilation in individual veins has also been noted by Beach (1974) in shear zones in greywackes.

The parallelism of veins and microfractures and the orientation relationship of microfractures to deformation lamellae indicates that the en-echelon veins in the shear zones studied arise from the dilation of extension features, and not from the dilation of shear fractures as suggested by Beach (1975).

The reason for the approximate parallelism of en-echelon veins in one shear zone with the complementary shear direction is not known, it is speculated that it may be a result of dextral and sinistral shear zones developing in stress system which differ in orientation either spatially or in time. The initial development of the elongate grain fabric and veins in the shear zones is not accompanied by a measurable rotation of the fabric or a marked increase in the internal deformation of grains. This is taken to indicate that the initial fracture, dilation and infill phase of deformation commences before significant shear displacement in the zones.

Ductile deformation

The development of deformation lamellae, undulatory extinction and recrystallization textures in the grains in the shear zones is indicative of ductile deformation mechanisms. The distribution of these features in the shear zone and their relative chronology is discussed below.

The association of deformation lamellae and high dislocation densities in grains with slight undulatory extinction at the shear zone borders is indicative of work hardening processes. The increased density of undecorated dislocations in grains at the borders and within the shear zones compared with grains distant from the shear zone border, suggests that these dislocation microstructures are syntectonic. However it is unknown whether the inferred work hardening is associated with the early microfractuing events or with a later more ductile phase.

The most marked development of undulatory extinction occurs within the shear zone and is associated with the rotation of the elongate grain fabric. The increase in undulatory extinction is accompanied by a change from elongate irregular sub-grains to more equant ones. This change is a common microstructural trend during increasing strain during dislocation creep deformation (Takeuchi & Argon 1976), and has been recorded in naturally deformed quartz (White 1975). It is concluded that some shear displacement in the zones is accommodated by intracrystalline deformation processes. The small size of the sub-grains is dictated by the large bubble density and palaeostresses cannot be estimated from them (Knipe & White 1976).

Recrystallization textures in the shear zones are concentrated in zones which mark the mesoscopic cleavage planes, the spacing of the cleavage being controlled by the width of the shear zones. These cleavage planes correspond to zones of more intense deformation where deformation was concentrated late during the shear zone evolution. The concentrated rotation of veins in the cleavage and the truncation of the elongate grain fabric by the cleavage are evidence for this. The bubbles present in the old grains are redistributed during recrystallization (see also Kerrich 1976) and are considered here to have had three important effects in facilitating the recrystallization. Firstly they inhibit sub-grain growth which leads to the generation of small sub-grains and a high internal strain energy. Secondly the decoration of sub-grain walls by bubbles restricts sub-grain wall mobility which, with increasing strain, favours an increase in sub-grain misorientation. That is the bubbles can be an important additional factor in the recrystallization of quartz by sub-grain rotation described by Hobbs (1968) and White (1973). The third important effect the bubbles have on recrystallization is their influence on the generation of new grains by the migration of selected sub-grain walls. The escape of pinned walls may arise from the increase in energy of the pinned wall during misorientation or from the coarsening of bubbles and the associated increase in their spacing along sub-grain walls. In both cases recrystallized grains larger than the sub-grains will be formed together with a sharp recrystallization front. The presence of such sharp recrystallization fronts as well as a progressive misorientation of sub-grains at the cleavage zone borders indicates that both sub-grain migration and sub-grain misorientation mechanisms have operated during the recrystallization of the quartz.

The development of small recrystallized grains in the cleavage zones may have induced an increase in the importance of deformation by grain boundary processes (White 1977). This would be helped by the large number of bubbles along the new grain boundaries. The concentration of diffusional mass transfer (pressure solution) and grain boundary sliding in the cleavage zones is indicated by both meso and microstructures (see Figs. 1 and 4).

The volume reduction and shearing processes operating within the cleavage may alter the geometry of the shear zone. For example, shearing along rotated cleavage planes will tend to decrease the angle between conjugate shear zones. Removal of material from the cleavage has the opposite effect. There is evidence for both types of rotation. In most cases it is possible for the shear zone to maintain a more or less constant orientation by a balance between these processes. One consequence of these processes is the slight deviation of the shear zone border orientation between individual cleavage zones away from the overall shear zone direction (see Fig 3e). This deviation makes accurate estimates of shear strains from the orientation of deformation features in the shear zone difficult. Therefore the term 'apparent shear strain' has been used in this paper.

Relationships between deformation mechanisms during shear zone evolution

The above discussion indicates that brittle deformation processes are initially dominant during shear zone evolution but that later stages are dominated by ductile deformation processes. This change is not necessarily indicative of a change in the stress conditions in the shear zones. It can also arise from the different mechanical properties of the secondary quartz concentrated in the shear zone during the early brittle stage. If, for example, the secondary quartz contains more structurally bound water, deformation by dislocation processes may be enhanced (Blacic 1975). It should also be noted that both brittle and ductile deformation phases exhibit evidence for the subsidiary operation of the other mode of deformation. For example, the microfracturing of grains appears to be accompanied by the generation of deformation lamellae and high dislocation densities. The truncation of cleavage zones by undeformed veins also indicates that locally brittle processes still operate during the phase dominated by ductile deformation.

There is also a change from homogeneous to heterogeneous ductile deformation on the scale of the zones. This is associated with the generation of a recrystallized grain texture along cleavage planes and may mark a change to deformation controlled by grain boundary processes.

CONCLUSIONS

The analysis of the low grade shear zones studied reveals that the association and distribution of deformation mechanisms varies during shear zone evolution. Shear zone development involves a change from dominantly brittle to dominantly ductile deformation modes and can be divided into three stages.

(1) An initial phase which is dominated by microfracturing, dilation and infill. The microfracturing mechanisms are unknown but it is suggested that the secondary quartz cement distribution and microstructure may be an important factor. The distribution and orientation of the microfractures is influenced by the proximity of the bedding plane surface. The subsequent dilation and infill of fractures accounts for the development of veins and the elongate grain fabric present in the shear zones. The dilation and infilling with secondary quartz occurs before any significant shear displacement in the zones.

(2) A second phase of shear zone evolution is characterized by shear displacement parallel to the shear zone borders and is associated with the increased activity of ductile deformation mechanisms.

(3) The third phase involves a late heterogeneous ductile deformation which causes recrystallization in zones marking the cleavage. The recrystallization occurs by sub-grain rotation and sub-grain boundary migration processes; both being influenced by the high bubble con-

tent of old grains. Deformation is further concentrated in the cleavage zones by this recrystallization which induces a change in deformation to grain boundary dominated processes.

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