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Shear zones in a pegmatite: a study of albite–mica–quartz deformation

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Abstract—A tectonic foliation of variable intensity is associated with closely spaced discontinuous shear zones in a pegmatite deformed under amphibolite grade conditions at I Mondei, Italian Alps. This hetrogeneous foliation is an alternation of quartz, albite, biotite and/or muscovite layers together with albite–mica mixtures. The foliation is defined by the alignment of micas and the elongation of quartz and albite grain aggregates. An examination of this foliation using optical and electron microscopes reveals significant microstructural differences between individual minerals and within individual layers. Microstructures in deformed albite can be related to both strain and the presence of other phases such as mica. In the pure albite regions there is a ubiquitous development of a coarse polygonal microstructure and abundant peristerite. The recrystallized albites recognised in the mica rich areas have grain sizes appreciably smaller than adjacent mica-poor areas and have a restricted development of peristerite. In areas dominated by muscovite, grains are gently bent, fractured and partly recrystallized with the preservation of relic pegmatitic albite grains, whereas, biotite is deformed into kink-like structures and has been modified by extensive new grain nucleation. Recrystallized quartz crystals have undergone abnormal grain growth, have a subgrain structure and a strong *c*-axis preferred orientation perpendicular to the foliation. The microstructural observations suggest that varying mechanical properties and the distribution of individual minerals control the deformation within the shear zones.

INTRODUCTION

DUCTILE shear zones have been divided into two classes by Burg & Laurent (1978): continuous and discontinuous. The shear zones described in this contribution are discontinuous. That is, it is not possible to measure with any degree of accuracy a systematic increase in γ either into or within the shear zone. The majority of continuous shear zones have been described (e.g. Ramsay & Graham 1970, Coward 1976) from rocks in which grain size, mineral distribution and fabric development are homogeneous on a scale less than the width of the shear zone. In these cases differences in deformation behaviour between individual minerals on a microscopic and submicroscopic scale are insignificant. However, in the case of the deformed pegmatite described here, shear zone development is dependent on the distribution, relative proportion of minerals, and the mechanical and chemical behaviour of individual minerals. It is these factors, that appear to control the relative strain distribution and local microstructural development.

GEOLOGICAL SETTING

The Cava di Mica pegmatite intrudes the Camughera–Moncucco Complex (Bearth 1956) near 'I Mondei', 3.5 km northwest of Villadossola (Val d'Ossola), Italy. The Camughera–Moncucco Complex is immediately adjacent to the Monte Rosa Nappe unit and is folded in the Vanzone–Brevettola Antiform (Klein 1978) to form part of the regional structure referred to as the 'Root Zone' of the Pennine nappes. This is one of a number of pegmatites found in the I Mondei region, and is exposed in an abandoned quarry as a narrow dyke, varying from 10 to 18 m in width. It is characterised by large grain size and a simple mineralogy of quartz, orthoclase, albite, muscovite and biotite (Ferrara *et al.* 1962). The body is tabular and elongate parallel to the foliation observed in the surrounding amphibolite grade (Frey *et al.* 1974) schists, gneisses and ultramafics. Any section through the exposed pegmatite shows a symmetric mineralogical zoning with increasing mica content from east to west. This is believed to reflect an internal zoning formed at the time of crystallization similar to that described by Jahns & Burnham (1969). The lower contact is obscured by undergrowth and debris whereas the upper contact is markedly discordant to an ultramafic body.

The eastern margin of the pegmatite is relatively undeformed and contains graphic intergrowths between albite–quartz or albite–orthoclase–quartz, scattered books of muscovite, areas composed entirely of albite, and unoriented biotite aggregates. The biotite aggregates are truncated by narrow quartz veins, indistinguishable from the quartz in the graphic intergrowth. The central region of the pegmatite contains mica aggregates and narrow foliated mica zones (Fig. 1A) that exhibit varying degrees of deformation. Narrow continuous shear zones are well developed in the mica rich aggregates and can be traced into the micaceous foliae in the more feldspar rich areas. Pre-existing micas in a region up to 2 cm away from the centre of the shear have been rotated into a final position almost parallel to the shear plane. However, this is often obscured by the presence of fine metamorphic micas overprinting the rotated fabric. Quartz is practically absent from the central region. The western margin of the pegmatite is a 3 – 6-m-wide major shear zone, it is strongly foliated and consists of alternating layers of albite and minor quartz with irregularly distributed muscovite and biotite laminae (Fig. 1C) and large mica aggregates. Recrystallization of the principal minerals, feldspar, quartz, biotite and muscovite are the main mineralogical reactions observed within the deformed areas. Most solution effects (Wilson 1977) appear to be late and postdate recrystallization changes except in the case of biotite (Wilson & Bell 1979).

In the minor shear zones of the central region and the main western shear zone the majority of the boundaries between feldspar versus mica rich areas are generally sharp and it is difficult to determine the shear angle. Portions of some pre-existing mica aggregates are obviously rotated, and adjacent to these there is a progressive development of foliation into these zones. The angle decreasing from approximately 45° with increasing proportions of metamorphic micas. The foliation visible on the few exposed *XZ* sections curves with a dextral sense as it is traced into the foliated region. Any component of flattening superimposed on this shear deformation is difficult to evaluate. The axis of curvature is parallel to the intersection of the schistosity and the wall. This is defined by steep south-westerly plunging lenticular quartz–albite aggregates (Fig. 1B), a preferred orientation of the small (1 - 2 mm dia.) muscovite and biotite grains, or lozenge-shaped pods of less deformed material, some of which display relic igneous textures.

In an earlier study of this pegmatite Ferrara *et al.* (1962) suggested that the feldspars are 'granulated' and grain size differences in the micas suggest two generations; the finer is "... a product of secondary Alpine crystallization", the medium and coarse micas represent a primary mica from the pegmatite. This has been confirmed by subsequent work (Wilson 1977). However Marshall & Wilson (1976) interpreted the grain size reduction in deformed albite to be a result of recrystallization and no evidence for 'granulation' in the sense of a cataclastic deformation exists. In this paper it is proposed to describe the microstructures in the albite–mica–quartz rich portions of the sheared pegmatite.

MICROSTRUCTURE

The minerals in this pegmatite exhibit a comprehensive range of micro- and submicroscopic features. On first appearance this appears to be related to the degree of deformation, spatial distribution and magnitude of individual shear zones. However, detailed examination suggests that varying mechanical properties and the distribution of individual minerals control all the microstructures we now observe.

Main shear zone

In the western or strongly foiliated portion of the pegmatite most minerals have been deformed and have undergone extensive recrystallization (Fig. 1D). These areas are dominated by stubby recrystallized micas (Wilson & Bell 1979) and polygonal albite aggregates (grain diameters vary from 0.1 to 0.5 mm). Peristerite is ubiquitous in such regions, this is attributed to grain-growth processes in the albite (Marshall & Wilson 1976). Remnant pegmatitic albite is always recrystallized.

Pegmatitic micas, which are preserved, are primarily $2M_1$ muscovites, only rarely are 1M and $2M_1$ biotites present as relics. All old micas are highly deformed and are generally associated with numerous small recrystallized grains (Wilson & Bell 1979). The grain size of albite associated with a muscovite aggregate is variable. Recrystallized muscovite grains are associated with coarse albites (grain size 0.1 - 0.3 mm) whereas deformed and unrecrystallized old muscovites are always surrounded by fine (approx. 0.01 - 0.04 mm) recrystallized albite. Recrystallized albite in deformed and recrystallized biotite areas have grain sizes of 0.06 – 0.1 mm.

Occasional quartz sheets and elongate quartz lenses parallel the foliation. They are composed of large irregular quartz grains, that resemble the abnormally coarse grains described by Wilson (1973). The grain size is often controlled by the width of the lens or sheet and can vary from 1 mm to 2 cm in diameter. Most grains possess gentle undulose extinction and large subgrains (Fig. 2A). Quartz *c*-axes are aligned at a high angle to the foliation. However, it is difficult to obtain a statistically meaningful group of *c*-axis measurements, because of the coarse grain size.

Minor shear zones

The greatest variation in microstructure is exhibited in these zones. The demarcation between sheared and relatively unsheared material is generally defined by compositional differences, and a progressive increase in strain cannot be established. One feature that is particularly striking is the range in grain size and shape exhibited by albite. This appears to be dependent on the width of the shear zone, the percentage of mica present in a shear zone and whether it is muscovite or biotite.

Albite in the least deformed areas contains subgrains that can be seen optically and under the electron microscope (Fig. 3). The subgrains are bounded by low angle boundaries composed of dislocation rows or complicated dislocation networks (Marshall & Wilson 1976). Towards the centre of a shear zone there is a rapid but irregular spatially distributed increase into well defined grains and the development of high angled recrystallized grains (Fig. 2C). The extent of grain growth and peristerite development is extremely variable.

Relic orthoclase sometimes coexists with the recrystallized albite in quartz albite-areas and occurs as large deformed grains or megacrysts, whose boundaries are enclosed by a recrystallized aggregate of orthoclase, and the interior may contain small recrystallized grains (Fig. 2D).

Where there is an abundance of $2M_1$ muscovite there is significant bending of the (001) cleavages and the formation of microscopic sinusoidal folds. Fracturing

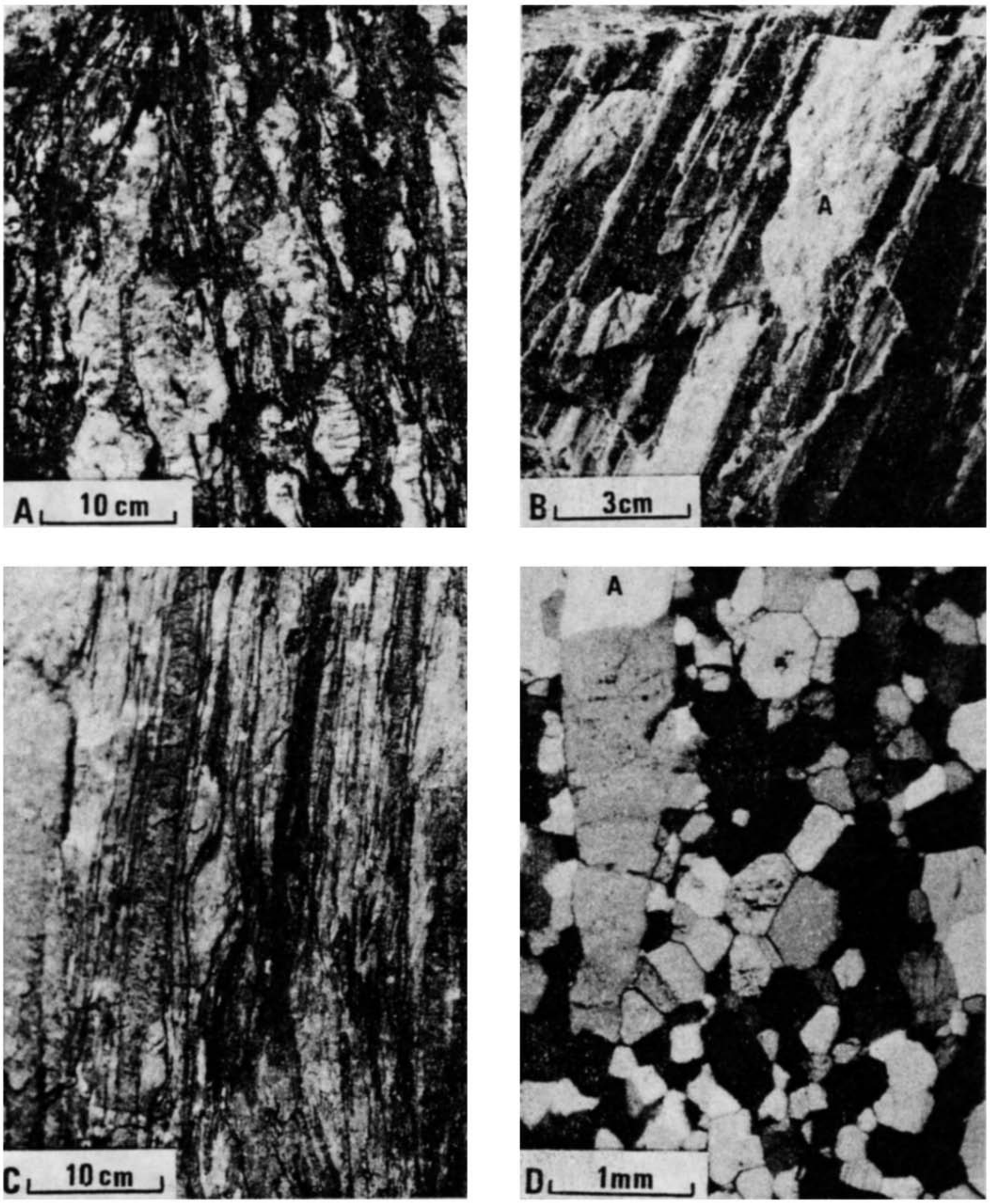

Fig. 1. Structure related to the shear zone development in the Cava di Mica Pegmatite. (A) Foliation in micaceous shear zone (*YZ* face). Biotite folia enclose lenticular albite and quartz lenses. The larger lenses still retain some igneous structures but are extensively recrystallized. (B) Lineation on *XY* face defined by rods of albite (A) and quartz (Q). (C) Foliation (*YZ* face) in major (western) shear zone defined by quartz–albite–mica folia. (D) Optical microstructure showing polygonal recrystallized albite and portion of an individual quartz sheet (A).

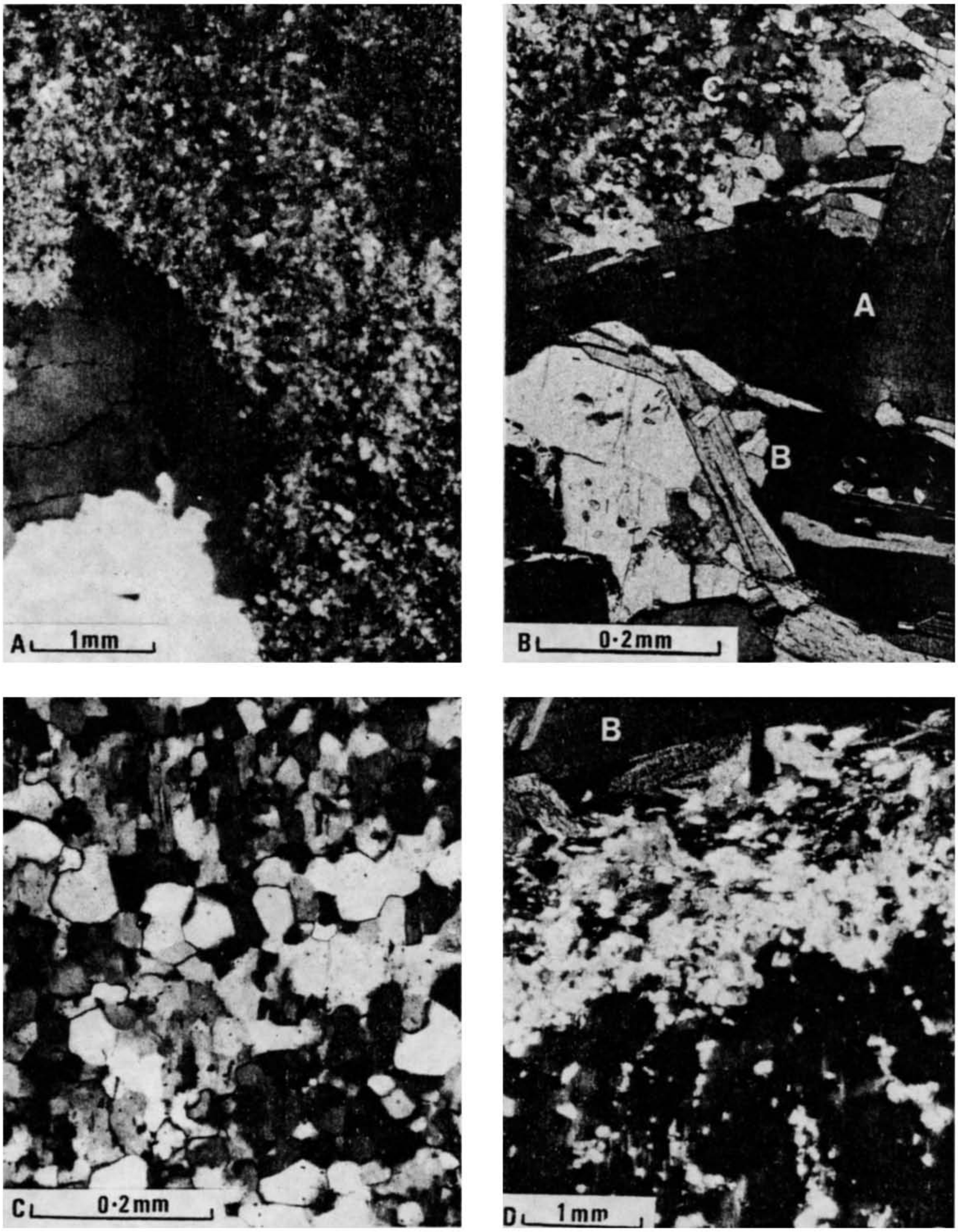

Fig. 2. Microstructures associated with the feldspars. (A) Recrystallized quartz enclosed by fine recrystallized albite. (B) Deformed muscovite (A) enclosing relic albites (B) and surrounded by fine recrystallized albite (C). (C) Deformed albite containing subgrains and recrystallized grains. (D) Deformed orthoclase, a zone of recrystallization occurs on the grain boundary adjacent to a biotite aggregate (B).

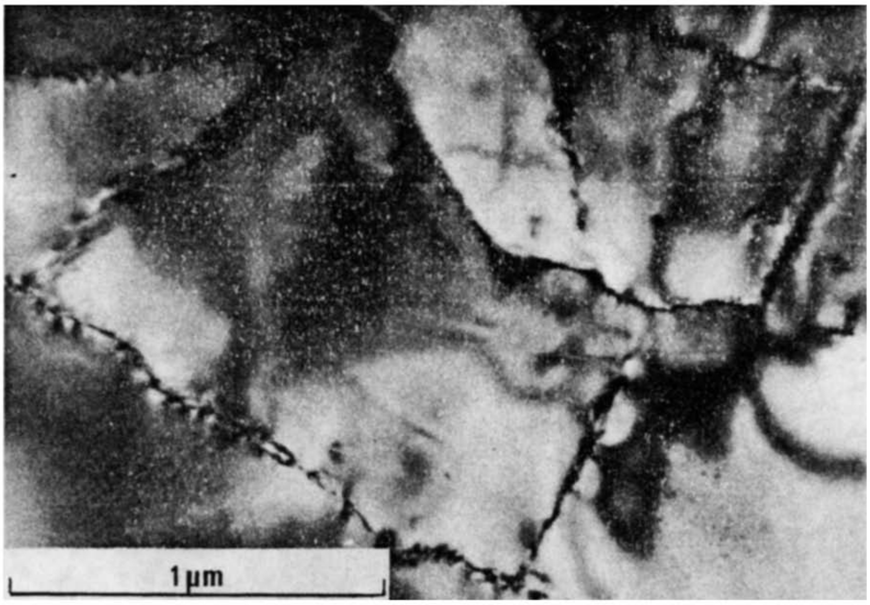

Fig. 3. Bright field transmission electron micrograph of subgrains in relatively undeformed albite.

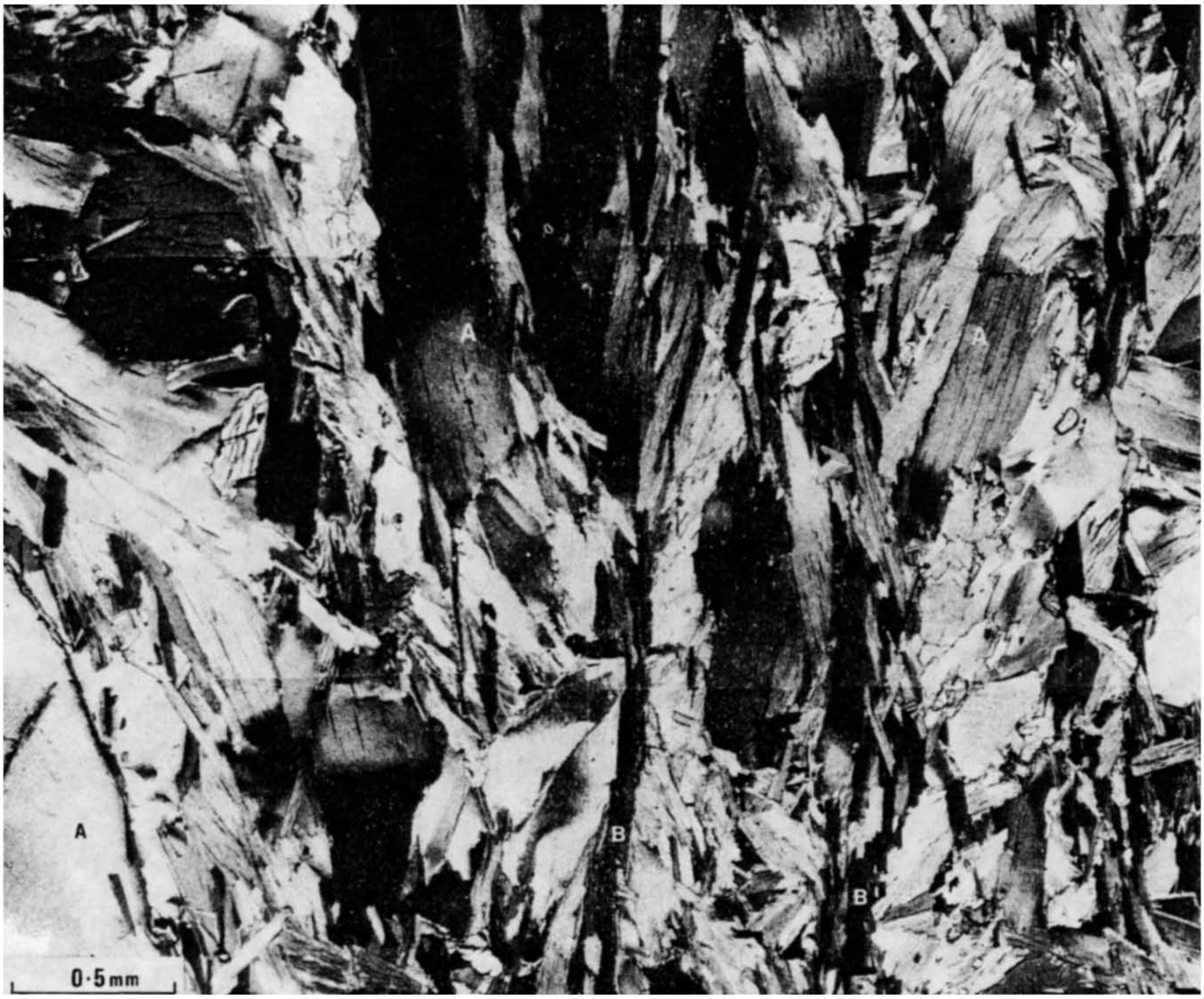

Fig. 4. Microstructural variation observed in a biotite aggregate intersected by a minor shear zone. Deformation is inhomogeneous and is controlled by the relative orientation of grains to one another and the concentration of other phases. A foliation is developed which is defined by an approximate parallelism of deformed pegmatitic biotites (A) and zones of metamorphic biotites (B).

and displacements are obvious in most deformed and folded muscovites both parallel to the axial surfaces and between (001) cleavage planes (Wilson & Bell 1979). There is only limited nucleation and growth of new metamorphic muscovites. Within aggregates of old metamorphic muscovites there is often the preservation of large albite grains (B in Fig. 2B). They contain abundant deformation twinning and have limited recrystallization, whereas, albite areas adjacent to the muscovite aggregate (C in Fig. 2B) are extensively recrystallized. Where biotite concentrations are deformed there is no preservation of relic albites, instead numerous metamorphic biotites have been nucleated in a fine grained recrystallized albite matrix that has a limited amount of peristerite. Deformed biotite aggregates show a multitude of microstructures (Wilson & Bell 1979). Relics of deformed grains, showing various degrees of rotation are aligned subparallel to narrow zones containing large concentrations of highly oriented metamorphic biotites (Fig. 4.). These zones appear to have been areas of high strain concentration; however, the extensive metamorphic growth that overprints these zones makes it difficult to evaluate the magnitude of shear strain.

CONCLUSIONS

In the heterogeneous rock mass described here, changes in deformation are in part a property of individual minerals or groups of minerals, and these govern the morphology of the shear zones and microstructure. The transitions into individual zones of deformation are often marked by an abrupt boundary, with deformation being concentrated in the less competent regions particularly the biotite rich areas. Any measure of shear strain is also complicated by volume changes in biotites (Wilson & Bell 1974) and by an overprinting of the deformed fabric by nucleation and growth of new strain free grains.

To attempt to understand the deformation processes which have occurred to this pegmatite would require combining all deformation features on each level of observation for all mineral species present. For example, in the more highly deformed portions of the pegmatite, it appears that the recrystallized albite-rich laminae rather than the muscovite bearing regions are the areas of high strain. This is reflected in an abundance of deformed muscovite compared with an apparent absence of old pegmatitic albite relics except for the preservation of relic igneous textures within muscovite aggregates. The microstructures developed in areas of coexisting biotite and albite suggest that these regions deformed readily and are weaker than muscovite bearing areas. In the biotite–albite areas extensive plastic deformation and recrystallization accompanies a pronounced foliation development. In contrast, areas containing comparable modal proportions of muscovite and albite have a poorer foliation development, there is less recrystallization of the muscovite and a great abundance of gently bent relic muscovite grains.

REFERENCES

Bearth, P. 1956. Zur Geologie der Wurzelzone östlich des Ossolatales. *Eclog. geol. Helv.* **49**, 267–278.

Burg, J. P. & Laurent, Ph. 1978. Strain analysis of a shear zone in a granodiorite. *Tectonophysics* **47**, 15–42.

Coward, M. P. 1976. Strain within ductile shear zones. *Tectonophysics* **34**, 181–197.

Ferrara, G., Hirt, B., Jäger, E. & Niggli E. 1962. Rb–Sr and U–Pb Age Determinations on the Pegmatite of I Mondei. *Eclog. geol. Helv.* **55**, 443–450.

Frey, M., Hunziker, J. C., Frank, W., Bocquet, J., Dal Piaz, G. V., Jäger, E. & Niggli, E. 1974. Alpine metamorphism of the Alps; a review. *Schweiz. miner. petrogr. Mitt.* **54**, 247–290.

Jahns, R. H. & Burnham, C. W. 1969. Experimental studies of pegmatite genesis: I Model for the derivation and crystallization of granite pegmatites. *Econ. Geol.* **64**, 843–864.

Klein, J. A. 1978. Post-nappe folding south east of the Mischabelruckfalte (Pennine Alps) and some aspects of the associated metamorphism. *Leidse geol. Mededel* **51**, 233–312.

Marshall, D. B. & Wilson, C. J. L. 1976. Recrystallization and peristerite formation in albite. *Contrib. Mineral. Petrol.* **57**, 55–69.

Ramsay, J. G. & Graham, R. H. 1970. Strain variation in shear belts. *Can. J. Earth Sci.* **7**, 786–813.

Wilson, C. J. L. 1973. The prograde microfabric in a deformed quartzite sequence, Mount Isa, Australia. *Tectonophysics* **19**, 39–81.

Wilson, C. J. L. 1977. Combined diffusion–infiltration of uranium in micaceous schists; a study using the fission track method. *Contrib. Mineral. Petrol.* **65**, 171–181.

Wilson C. J. L. & Bell, I. A. 1979. Deformation of biotite and muscovite: optical microstructure. *Tectonophysics* **58**, 179–200.