Journal of Structural Geology, Vol. 2, No. 1/2, pp. 273 to 280.
Pergamon Press Ltd. 1980. Printed in Great Britain.

0191-8141/80/0601-0273 $02.00/0

Microstructural and chemical studies of sheared anorthosites, Roneval, South Harris

F. SODRE BORGES* and S. H. WHITE

Geology Department, Imperial College, London SW7 2BP, England

(*Received* 5 *July* 1979; *accepted* 14 *December* 1979)

Abstract—Microstructural and chemical variations accompanying the mylonitisation of the Roneval anorthosites were studied. The plagioclase in the anorthosite studied has compositions of *ca.* An_{65} or of An_{48} if garnet is present. Huttenlocher and Boggild lamellae are present in undeformed grains of both compositions. The mylonites developed by syntectonic recrystallization with grains containing two sets of lamellae recrystallizing preferentially. Those grains with a composition of An_{65} become more albitic whereas those of An_{48} became more anorthitic during recrystallization. All grains have sodium enriched rims. Grain boundary sliding processes appear to have been the main deformation mechanism in the mylonites after recrystallization.

INTRODUCTION

THE INTERMEDIATE plagioclases have been the subject of many detailed mineralogical studies (see Mackenzie & Zussman 1974, Ribbe 1975, Grove 1977). They have compositions within the range An_{75} to An_{25}, are characterized by **e** satellite reflections in X-ray and electron diffraction patterns (Smith 1974) and consist of submicroscopic domains of slightly different compositions (Marshall & McLaren 1974). However little is known about deformation, recovery and recrystallization mechanisms in this mineral. Shear zones in anorthosite provide material in which these mechanisms can be studied along with deformation induced changes in plagioclase textures and chemistry.

GEOLOGICAL SETTING OF THE SAMPLES

The shear zones studied are from the Roneval anorthosite complex in southern South Harris, Outer Hebrides, N.W. Scotland. The complex comprises a neutral, isoclinal synform which has a core of layered anorthosites and gabbros, enveloped by a gabbroic rim. The layered units can be divided into three zones —'lower' and 'middle' zones of banded anorthosites and an 'upper' zone of schlieren anorthosites (cf. Witty 1975).

The complex is thought to be pre-Scourian (cf. Graham 1964, Witty 1975). It has been subjected to an early Scourian phase of granulite grade metamorphism which has been followed by three phases of retrogressive metamorphism. The first was an early Laxfordian regional amphibolitisation followed by a localized late Laxfordian retrogression in shear zones that vary in width from a metre to a millimetre. The last retrogression was a localized saussuritisation associated with the Outer Hebrides Thrust which cuts the eastern portion of the Complex. This is thought to be of Caledonian age (Sibson 1977).

*Present address: Laboratório de Mineralogia e Geologia, Faculdade do Ciências do Porto, Porto, Portugal.

SHEAR ZONES SELECTED

The shear zones studied are late Laxfordian in age. Great care was taken to obtain fresh specimens. The results reported here are based on detailed studies of two zones: one from a borehole core at a depth of 3·67 m below the surface and the other from a surface outcrop. Both shear zones are narrow, having widths of 5 cm.

The contact between sheared and unsheared anorthosite is sharp in both cases and it was not possible to study the progressive development of a plagioclase mylonite with increasing shear strain.

EXPERIMENTAL METHOD

The plagioclase textures were studied, at a microscopic scale, using an optical microscope fitted when necessary with a universal stage. Selected areas from petrological thin sections were prepared for transmission electron microscopy by ion milling. The specimens were examined in an EM7 microscope operating at 1000 kV. The chemistry of the plagioclase grains was studied on a Cambridge Geoscan probe fitted with wavelength dispersive spectrometers. The microprobe was operated at an accelerating voltage of 15 kV using a filament current of 2.2–2.8 μA. The specimen current varied between 0.035 and 0.053 pA, being kept as small as was consistent with statistical accuracy for light elements. The microprobe output was processed with a correction programme written by Mason *et al.* (1969). Two methods of processing were used. The first was the 'feldspar' method in which only Ca, Na and K were analysed and the results determined as Ab_x An_y Or_z assuming a stoichiometric composition for plagioclase. The second was the 'difference' method in which Ca, Na, K, Si, Al and Fe were analysed and their concentrations were calculated as oxides. The majority of the analyses were carried out utilizing the method 'feldspar' technique. However frequent checks were made using method 'difference'. In all, 2252 analyses were performed on a total of 1138 plagioclase grains. This permitted statistical characterization of chemical variations across a given grain and between grains inside and outside the shear zone. The effects of weathering were determined by comparing analyses of surface samples with those from boreholes.

OPTICAL MICROSCOPY

The nomenclature used for the textural descriptions will be that proposed by Moore (1970) and Kehlenbeck (1972) for granulite facies rocks. The undeformed anorthosite outside both shear zones consists predominantly of plagioclase. The surface zone has amphibole rich bands whereas the borehole specimen has garnet rich bands. The plagioclase has a granoblastic texture (Fig. 1) and contains well developed albite and pericline twins which have the morphology of deformation twins (Vance 1961, Seifert 1964). The grains exhibit undulatory extinction and some have bent twins. Some recrystallization has occurred adjacent to the shear zone (Fig. 1). The recrystallized grains are free from twins and from undulatory extinction.

Both shear zones consist mainly of recrystallized plagioclase grains (Fig. 1) with small quantities of amphibole and scapolite plus remnant corroded garnet grains in the borehole zone. Relict plagioclase grains remain in the recrystallized matrix. The recrystallized grains contain only a few twins which are associated with grain boundary triple points and have simple triangular shapes similar to those in annealed metals (Burke 1950). The grains have dihedral angles close to 120° (120.3°, s.d. 8.7°, 200 measurements) and are much smaller than those outside the shear zone. The grain size decreased from a mean of 0.83 to 0.27 mm in the surface zone and from 0.87 to 0.18 mm in the borehole zone.

ELECTRON MICROSCOPY

The defect sub-structures in the grains outside the shear zones will be described first. Similar results were found for both shear zones. The most commonly encountered defects are quasi-periodic, lamellar structures which in some grains appear to be in three directions (Figs. 2a & b). Individual lamellae are normally straight but in some grains, groups of lamellae form wavelets due to the bifurcation of individual lamellae (Fig. 2c). The lamellae always have diffuse boundaries irrespective of the specimen tilt in the microscope.

The orientations of the lamellae were determined with the aid of selected area diffraction patterns. These are, in order of decreasing frequency, close to the (010) ranging from ($\bar{9}$ 33 8) to (02$\bar{1}$); close to the (10$\bar{2}$) and close to the ($\bar{3}$02) but ranging towards the ($\bar{1}$01). The first set include the narrow bifurcating lamellae as shown in Fig. 2 whereas others in this set together with second and third sets form narrow straight lamellae which tend to be wider than the diffuse set (Fig. 2). It was found that in grains with three sets of lamellae, the third set results from the interference of the other two as illustrated in Fig. 2(b). The (03$\bar{1}$) lamellae may occasionally coexist with ($\bar{1}$01) lamellae and ($\bar{1}$01) with (10$\bar{2}$).

The lamellae planes are consistent with Huttenlocher lamellae (Nissen, 1974, Ribbe 1975). However the set ranging from ($\bar{9}$ 33 8) to (02$\bar{1}$) are also consistent with Boggild lamellae (McConnell 1974). The main microstructural distinction is that the Boggild lamellae tend to occur in one direction in a grain and are normally poorly developed (see Fig. 2c) whereas Huttenlocher occur on several planes and have a planar morphology similar to that in Fig. 2(a). It is concluded that both coexist in the specimens studied (see later) but it was not possible to ascertain if both exist in grains with (03$\bar{1}$) and ($\bar{1}$01) lamellae. The thickness of each lamella type are shown in Table 1.

Table 1. Characteristic microstructural features in plagioclase grains inside and outside the shear zones

Feature	Outside: Original grains	Inside Shear Zone: Relict grains	Inside Shear Zone: Recrystallized grains
Exsolution planes	(i) close to (010), (ii) in range ($\bar{3}$02) to ($\bar{1}$01) (iii) close to (10$\bar{2}$)	(i) close to (010) (ii) close to (10$\bar{2}$)	Not detected
lamellae thickness	(i) from 230 to 620Å average 380Å (ii) & (iii) from 200 to 440Å average 260Å	(i) & (ii) from 300 to 700Å average 400Å	
dislocation density	10^7–10^9 cm^{-2}	10^7–10^8 cm^{-2} in grain interiors, $>10^{10}$ cm^{-2} at grain margins	$<10^7$ cm^{-2}

The plagioclase grains contain dislocations (Fig. 3a) which have densities of 10^9 (intersections) cm^{-2} where the exsolution lamellae are narrow and have lower densities (10^7 cm^{-2}) in grains with well developed lamellae with inter-lamellar spacings approaching 500Å. The dislocations are evenly spread throughout the grains and rarely form sub-grains. However, deformation twins are common. The small recrystallized grains outside the shear zones have defect structures similar to those in the matrix grains in the plagioclase mylonites and will be described below with these.

The defect structures in the large relict grains in the mylonites are similar to those above except that most only have one set of lamellae (Fig. 2d) either of the (010) or, especially, of the (10$\bar{2}$) type. The lamellae have wider average spacings than do those in grains outside the shear zones (Table 1). It appears that grains with Boggild or a single set of Huttenlocher lamellae are preferentially preserved. The dislocation densities in the relict grains are typically between 10^7 and 10^8 cm^{-2}, except at the grain margins where they are in excess of 10^{10} cm^{-2} (Fig. 3b). Sub-grains were not seen.

The recrystallized grains outside the shear zones and the small matrix grains within the shear zones are normally free from exsolution which, if present, is poorly developed. No twins were encountered. The grains are nearly free from dislocations (Fig. 3c), the density always being less than 10^7 cm^{-2}. They are straight and uniformly distributed. In some grains planar defects

Fig. 1. Variation in microstructure across a shear zone boundary in the borehole shear zone. The fine grained plagioclase marks the mylonite in the shear zone. Scale bar = 1 mm.

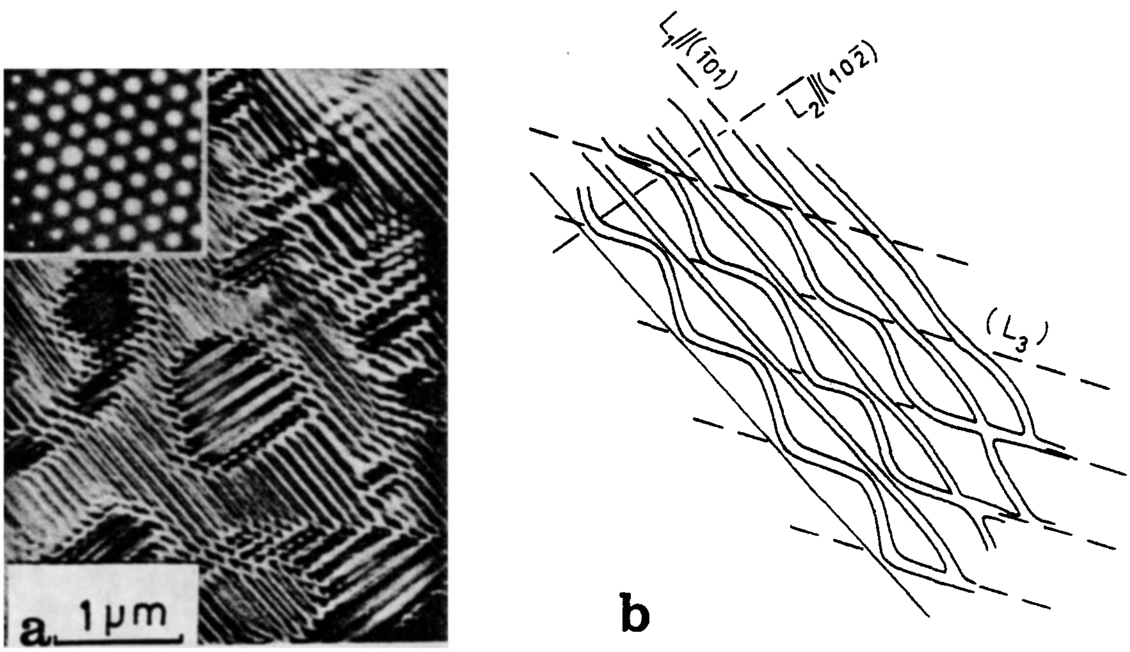

Fig. 2. Exsolution structures typical of grains outside and in relict within the shear zone shown in Fig. 1. These are Huttenlocher lamellae in a (III) section. (b) shows that the third set of lamellae in (a) are due to interference of the other two.

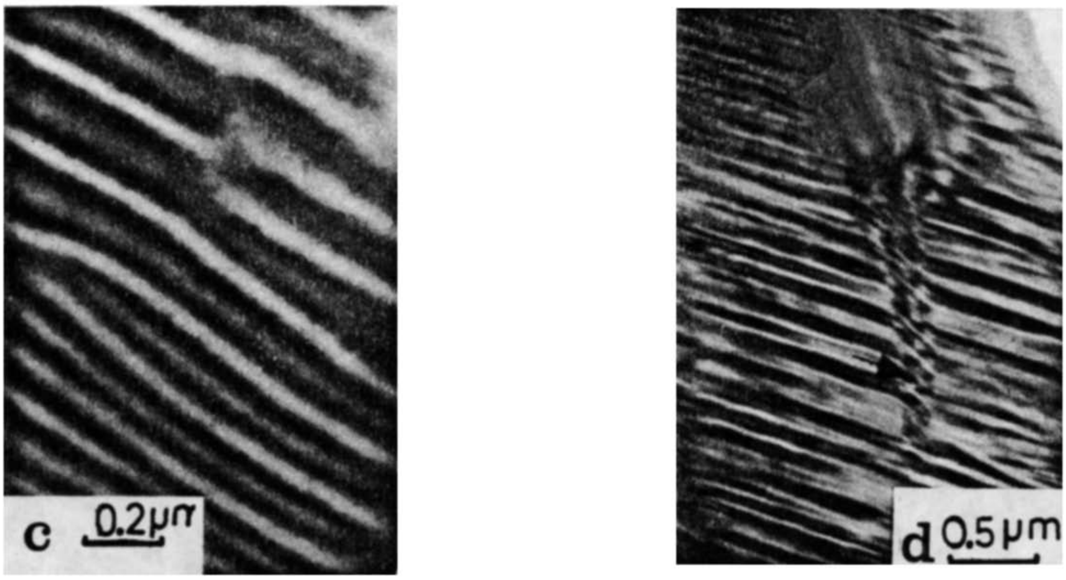

Fig. 2. (c) Boggild lamellae. The lamellae are approximately parallel to the ($\bar{9}$ 33 8) plane. (d) Boggild lamellae in relict grains. A deformation twin is arrowed.

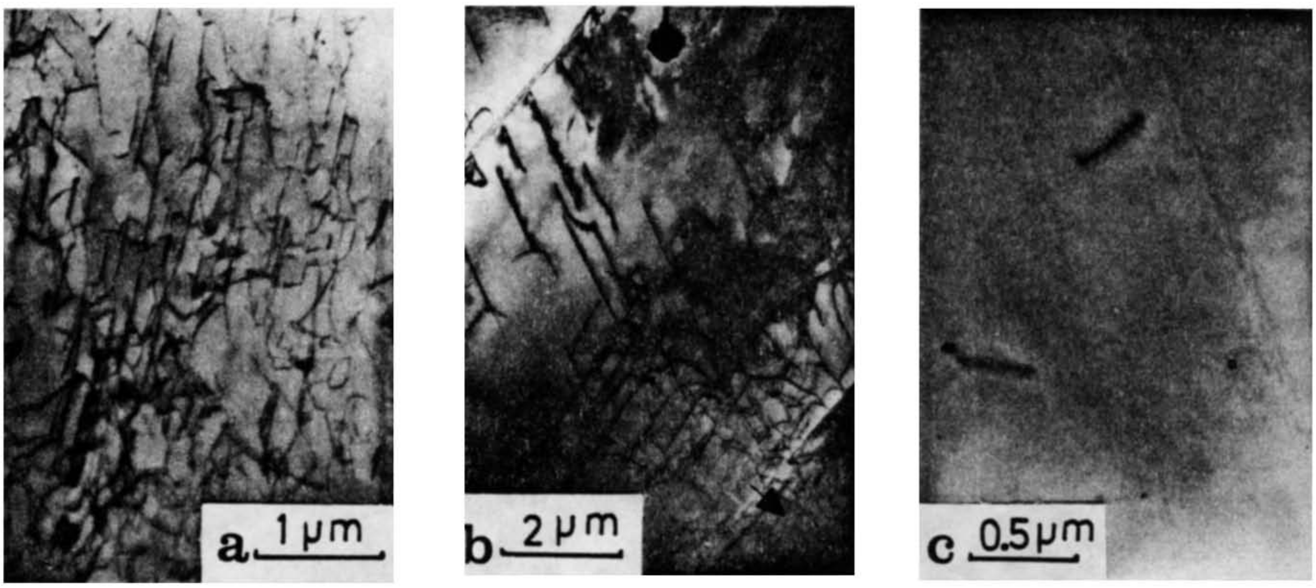

Fig. 3. Dislocation structures in the plagioclase grains. (a) Dislocations in grains outside the shear zone in Fig. 1. (b) Dislocations in relict grains. There is an increase in density towards a grain boundary (arrowed). (c) Dislocations in recrystallized grains. Note the planar features in their wake.

consistent with the dilational stacking faults described by Marshall *et al.* (1976) are associated with the dislocations.

MICROPROBE ANALYSIS

Typical analyses for the plagioclase grains outside the shear zones and for the relict grains and matrix grains within the shear zones are presented in Table 2. The results are presented in the form $Ab_x An_y Or_z$ and also as the number of atoms for each element analysed assuming a total of 32 oxygens in a unit cell. The grains

Table 2. Typical analyses of the plagioclase from the surface shear zone. The grains show slight departure from stoichiometry

	Outside	Inside relict	Inside recrystallized
SiO_2	53.03	54.17	53.67
Al_2O_3	29.53	29.11	28.67
CaO	12.80	12.13	12.62
Na_2O	3.60	3.76	4.59
K_2O	0.12	0.13	0.12
Fe_2O_3	0.11	0.11	0.09
total	99.19	99.41	99.39
No. of atoms in a formula unit based on 32 oxygens			
Si	9.66	9.81	9.78
Al	6.34	6.21	6.08
Ca	2.50	2.35	2.46
Na	1.27	1.32	1.63
K	0.03	0.03	0.03
Fe	0.00	0.00	0.00
Mol%			
Ab	33.49	33.59	39.42
An	65.79	65.56	59.90
Or	0.72	0.86	0.68

show small deviations from stoichiometry – there is a deficiency of Al giving rise to excess Si. The composition of the plagioclase was found to be dependent upon the mineralogy of the anorthosite. Thus in the borehole shear zone it was found that the plagioclase composition in the garnet rich layers differed greatly from those in the garnet free areas (Fig. 4).

Grains were checked for compositional variations. In all cases it was found that there is a marked decrease in An content in the vicinity of grain boundaries. This is a real effect as it is present when adjacent grains have a similar composition (Fig. 5). The composition of the large grains outside the shear zones and the relict grains within the shear zones show only slight internal compositional variations (±1.5% An) away from the boundaries. In contrast, the matrix grains in the shear zones often show compositional heterogeneity; sudden, sharp variations in An content occur within the grains (Fig. 6). Potassium content is constant in all grains. Consequently, all analyses were conducted in grain centres and heterogeneity was checked in recrystallized grains before each analysis.

The chemical differences between plagioclase grains inside and outside the shear zones are listed in Table 3. It can be seen that a difference does appear in the borehole

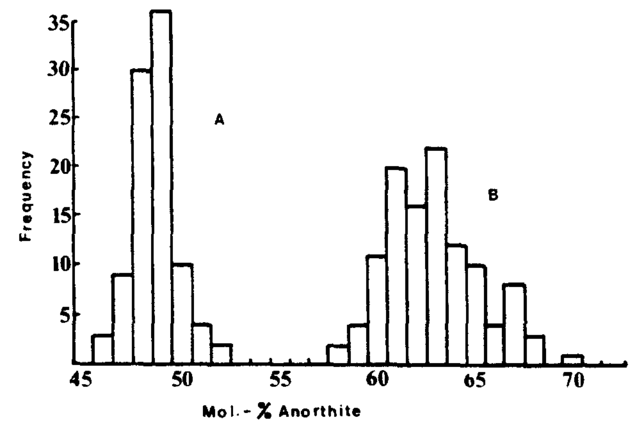

Fig. 4. Histograms showing the composition of plagioclase grains in garnet rich, (a) and garnet free layers, (b) in the borehole shear zone.

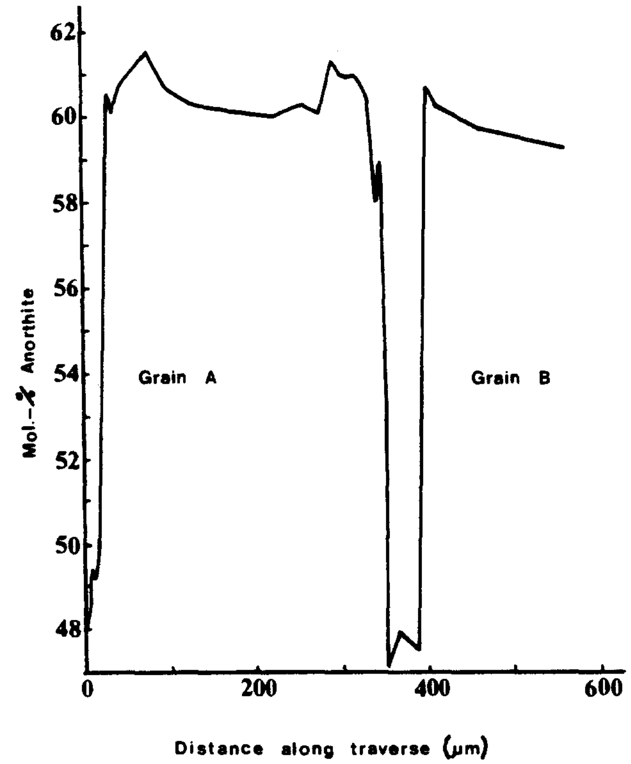

Fig. 5. A microprobe traverse across two recrystallized grains in Fig. 1. A marked decrease in An content is seen adjacent to grain boundaries.

shear zone but it is not as marked in the surface shear zone. Even in the borehole specimens the error bars, as indicated by the standard deviations, overlap in the two analyses. However, in both cases, two populations could be separated after plotting cumulative frequency distribution functions (Fig. 7) and using a Kolmogorov–Smirnov goodness-of-fit test (Stephens 1974). These indicate that the crystallized grains both in and adjacent to the shear zones are slightly more albitic

Table 3. Changes in plagioclase chemistry in the shear zones

		Number of grains analysed	Mean Composition (An)	Standard Deviation
Surface	outside	87	66.5	3.8
Shear Zone	inside	108	63.7	6.4
Borehole	outside	57	64.5	2.8
Shear Zone	inside	220	58.0	6.0

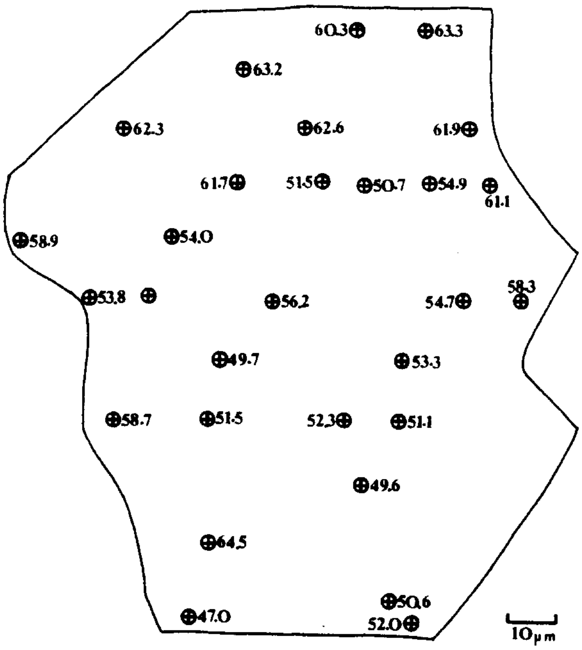

Fig. 6. A grid analysis across a recrystallized grain showing marked compositional variations in the grain. The numbers list the An content at the adjacent point. Analyses close to the grain boundary are not included.

than the relict grains and the large grains outside the shear zone.

The histograms (Fig. 8) show that there are differences between the two zones studied. The surface zone, although having the wider range in composition has a clearly defined single maximum both for the unsheared grains and the matrix mylonite grains. However the matrix grains in the borehole shear zone exhibit double maxima, at An_{52} and at An_{62}. The grains were analysed from the area covered by Fig. 1 which is free from garnets. However a garnet rich band exists a few centimetres away and it is thought to be the cause of the double maxima. A comparison with Fig. 4 shows that the higher peak, An_{62}, can be related to the garnet free composition at circa An_{65} and the lower peak at An_{52} to the peak at An_{48} which is characteristic of the plagioclase in the garnet rich layers. That is, there has been a random mixing in the shear zone of grains from two different parent bands.

DISCUSSION

Microstructural development

The plagioclase mylonites within the shear zone have developed by recrystallization. The presence of relict grains with only one set of exsolution lamellae suggests that those with two sets of lamellae have preferentially recrystallized. This is to be expected, as similar grains outside the shear zone have the highest dislocation density. This, plus the preferential localization of recrystallisation in areas adjacent to grain boundaries, where dislocation densities are highest for a given grain, indicates that the reduction of the internal strain energy

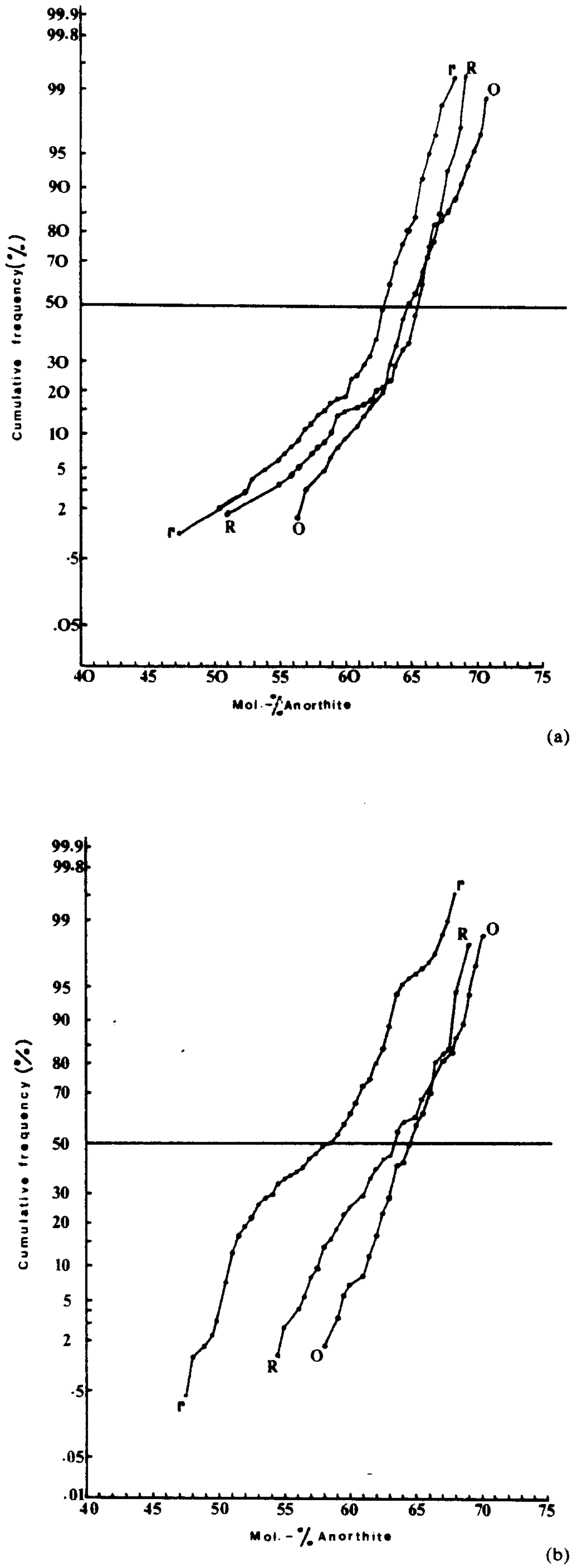

Fig. 7. Cumulative frequency distribution functions for plagioclase grains inside and outside the borehole, (a) and surface (b), shear zones. *O*, the grains outside the shear zone; *R*, relict grains; *r*, recrystallized grains.

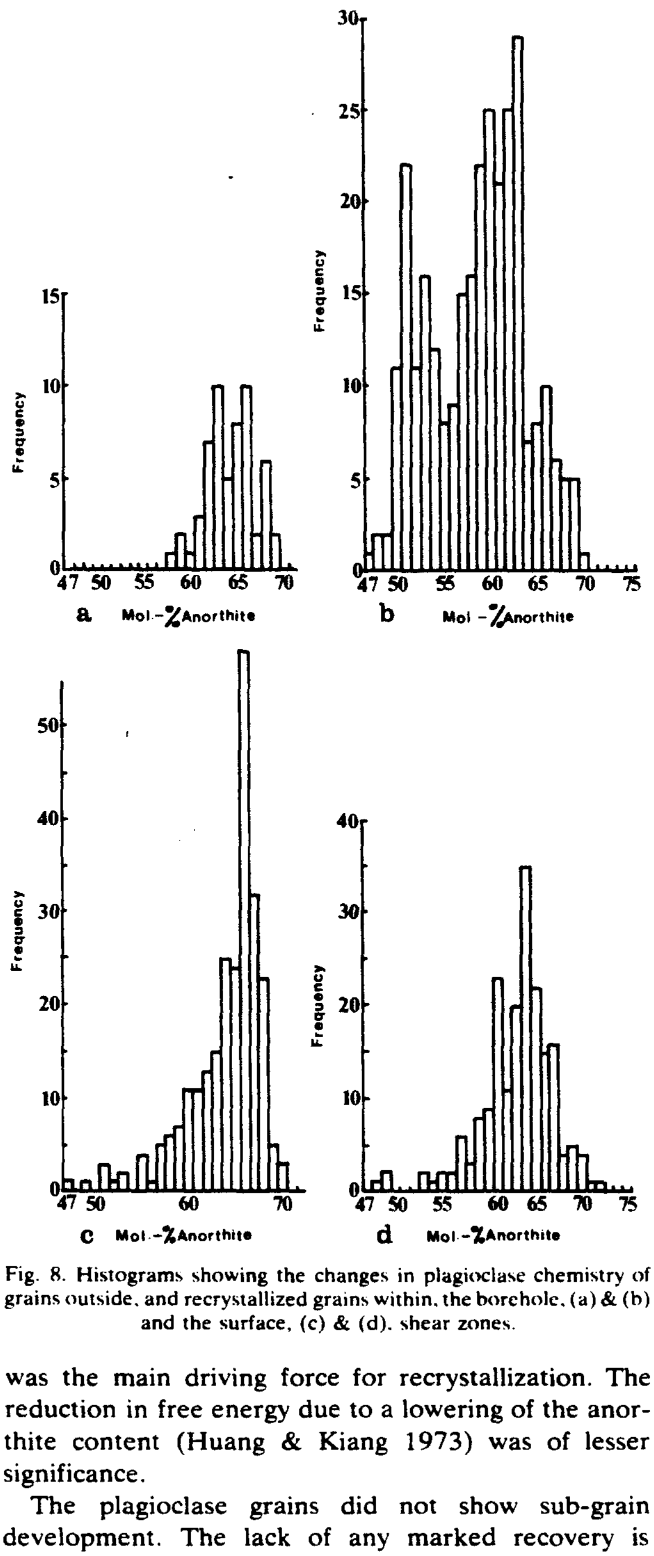

Fig. 8. Histograms showing the changes in plagioclase chemistry of grains outside, and recrystallized grains within, the borehole, (a) & (b) and the surface, (c) & (d), shear zones.

was the main driving force for recrystallization. The reduction in free energy due to a lowering of the anorthite content (Huang & Kiang 1973) was of lesser significance.

The plagioclase grains did not show sub-grain development. The lack of any marked recovery is common if deformation occurred below the disordering temperature (≈ 550°C) of the plagioclase (White 1975) and is consistent with mylonitisation during an amphibolite grade metamorphism. The lack of recovery also means that high densities of dislocations will develop at low strains and would lead to recrystallization before any marked elongation of the plagioclase grains.

The nuclei for recrystallization were not observed but the overall absence of sub-grains means that the two most commonly observed mechanisms, viz. sub-grain rotation and strain induced boundary migration were not important. It is suggested that the new grains occurred by the classical nucleation process similar to that observed in oligoclase by White (1975).

The timing of the recrystallization cannot be easily deduced from the microstructure. The polygonal shape and the 120° dihedral angles of the recrystallized grains plus the morphology of twins and low dislocation densities within them suggest a post shearing annealing. However, in such an event, the relict grains within and the deformed grains adjacent to the shear zones should also be dislocation free. Their high dislocation densities indicate syntectonic recrystallization. However both sets of observations are reconcilable if recrystallization was syntectonic and if it was followed by a change in deformation mechanism to one in which grain boundary sliding was dominant. The mixing of the grains from two different parent bands in the borehole shear zone is good evidence for the occurrence of grain boundary sliding.

The preservation of high dislocation densities in naturally deformed grains is a matter of controversy (White 1979). However the co-existence of high dislocation densities in some grains with grains almost dislocation free indicates that little re-adjustment of the dislocation densities has occurred during uplift. This conclusion is further supported by the correlation between the exsolution lamellae morphology and dislocation density in the samples studied. However grain shape readjustment after deformation to the low energy configuration observed in the mylonites, cannot be ruled out.

Variations in plagioclase compositions

The composition of the plagioclase in the anorthosites away from the shear zones is heterogeneous (see also Witty 1975) and is dependent upon the presence or absence of garnets. Such initial variations make comparisons between the composition of plagioclase inside and outside the shear zones difficult. Nevertheless, our microprobe results indicate that grains with a composition of *ca* An_{65} outside the shear zones underwent a slight decrease in An content during recrystallization whereas those with a content of An_{48} underwent a slight increase. From this, it appears that both of the compositions existent outside the shear zones are equilibrating towards a single composition (*ca* An_{58}) during mylonitization.

The sharp internal composition variations in individual recrystallized grains could arise from the coalescence of grains of different composition during grain growth following nucleation. The preservation of these plus the absence of any marked exsolution suggests that diffusion was sluggish in the plagioclase. Diffusion is slow in plagioclase in dry environments but is enhanced by the presence of water (Wyart & Sabatier 1958, 1959, Smith & Ribbe 1969). It would appear that the shear zones were 'effectively dry' during plagioclase recrystallization and during subsequent deformation, the small amounts of fluids that were introduced remained locked up in the scapolite. There was no microstructural evidence to indicate that large quantities of fluids had been channelled through the shear zones studied.

Finally, all grains show a marked decrease in An content adjacent to their grain boundaries. This is not dependent upon the siting relative to the shear zones, suggesting that the decrease post-dated shearing and might be due to fluids associated with the saussuritisation which accompanied Caledonian faulting in the area.

Coexistence of Boggild and Huttenlocher lamellae

Large grains outside, and the relict grains within the shear zones contain these lamellae. Ribbe (1975) and Smith (1975) list the following chemical ranges for the existence of each, Huttenlocher from An_{65} to An_{90} and Boggild from An_{48} to An_{58}. From this, it can be seen that the composition of the plagioclase studied straddles the boundary between both ranges. It was expected that the more calcic grains would contain Huttenlocher lamellae and the less calcic, the Boggild lamellae. However this is not the case; it was found that the presence of each lamella type is not related to the composition of a grain. This argues against a sharp demarcation between the compositional fields for each lamella type.

CONCLUSIONS

(1). The plagioclase mylonites resulted from the syntectonic recrystallization of the anorthosites. Grain shape readjustment may have followed the recrystallization but there was no extensive post tectonic annealing as high dislocation densities, incipient exsolution and marked intragranular compositional variations have been preserved.

(2). Old grains with two sets of lamellae, especially if narrowly spaced, have the highest dislocation densities and are preferentially recrystallized.

(3). Deformation in the shear zone occurred mainly by grain boundary sliding after the formation of the mylonites and can lead to a mixing of grains of different initial compositions.

(4). Grains which had an original composition of An_{65} became slightly more albitic during recrystallization whereas those with a composition of circa An_{48} became more anorthitic. The overall result is a more uniform plagioclase composition in the shear zones. Although individual recrystallized grains have large variations, these lie within the above compositional ranges indicating grain coalescence during growth.

(5). Grains containing Boggild and Huttenlocher lamellae co-exist in the samples studied.

(6). No evidence was found to suggest that the shear zones studied acted as channelways for the flow of large quantities of water.

(7). There is an increase in the albite content at the margins of all grains and it is thought to post-date shearing.

REFERENCES

Burke, J. E. 1950. The formation of annealing twins. *Trans. Am. Inst. Min. Metall. Engineers* **188**, 1324–1328.

Graham, R. H. 1969. A structural analysis of Lewisian rocks in parts of North Uist and the Sound of Harris, Outer Hebrides. Unpublished Ph.D. thesis, University of London.

Grove, T. L. 1977. Structural characterization of labradorite—bytownite plagioclase from volcanic, plutonic and metamorphic environments. *Contrib. Mineral. Petrol.* **64**, 273–302.

Huang, S. H. & Kiang, W. C. 1973. Gibbs free energy of formation calculated from dissolution data using specific analyses II. Plagioclase feldspars. *Am. Miner.* **58**, 1016–1022.

Kehlenbeck, M. M. 1972. Deformation textures in the Lac Rouvray anorthosite mass. *Can. J. Earth Sci.* **9**, 1086–1097.

Mackenzie, W. S. & Zussman, J. 1974. *The Feldspars*. Manchester University Press, Manchester.

Marshall, D. B. & McLaren, A. C. 1977. Deformation mechanisms in experimentally deformed plagioclase feldspars. *Phys. Chem. Minerals* **1**, 351–370.

Marshall, D. B., Vernon, R. H. & Hobbs, B. E. 1976. Experimental deformation and recrystallization of persisterite. *Contrib. Mineral. Petrol.* **57**, 49–54.

Mason, P. K., Frost, M. T. & Reed, S. J. B. 1969. Computer programs for calculating corrections in quantitative X-ray microanalysis. IMS Report 2, National Physical Lab. London.

McLaren, A. C. & Marshall, D. B. 1974. Transmission electron microscope study of the domain structures associated with b-, c-, d-, e- and f- reflections in plagioclase feldspars. *Contrib. Mineral. Petrol.* **44**, 237–249.

McConnell, J. D. C. 1974. Electron optical study of the fine structure of a schiller labradorite. In: *The Feldspars* (edited by Mackenzie, W. S. & Zussman, J.) Manchester University Press, Manchester 478–490.

Moore, A. C. 1970. Descriptive terminology for the textures of rocks in granulite faces terrains. *Lithos* **3**, 123–127.

Nissen, H. U. 1974. Exsolution phenomena in bytownite plagioclases. In: *The Feldspars* (edited by Mackenzie, W. S. & Zussman, J.) Manchester University Press, Manchester 491–521.

Ribbe, P. H. 1975. Exsolution textures and interference colours. In: *Feldspar Mineralogy*. (edited by Ribbe, P. H.) Mineral Soc. Amer. Short Course Notes. R73–96.

Seifert, K. E. 1964. The genesis of plagioclase twinning in the Nonewaug granite. *Am. Miner.* **49**, 297–320.

Sibson, R. H. 1977. The Outer Hebrides Thrust: its structure, mechanism and deformation environment. Unpublished Ph.D. thesis, University of London.

Smith, J. V. 1974. *Feldspar Minerals*. Springer-Verlag, Berlin.

Smith, J. V. 1975. Phase equilibrium of plagioclase. In: *Feldspar Minerology* (edited by Ribbe, P. H.) Mineral Soc. Amer. Short Course Notes Sm 1–17.

Smith, J. V. & Ribbe, P. H. 1969. Atomic movements in plagioclase feldspars: kinetic interpretation. *Contrib. Mineral. Petrol.* **21**, 157–202.

Stephens, M. A. 1974. EDF statistics for goodness of fit and some comparisons. *J. Am. Stat. Assoc.* **69**, 730–737.

Vance, J. A. 1961. Polysynthetic twinning in plagioclase. *Am. Miner.* **46**, 1097–1119.

White, S. 1975. Tectonic deformation and recrystallization of plagioclase. *Contrib. Mineral. Petrol.* **50**, 287–304.

White, S. 1977. Geological significance of recovery and recrystallization processes in quartz. *Tectonophysics* **39**, 143–170.

White, S. 1979. Grain size and subgrain size variations across a shear zone. *Contrib. Mineral. Petrol.* **70**, 193–202.

Witty, G. J. 1975. The geochemistry of the Roneval anorthosite, South Harris, Scotland. Unpublished Ph.D. thesis, University of London.

Wyart, J. & Sabatier, G. 1958. Mobilité des ions silicium et aluminium dans les cristaux de feldspath. *Bull. Soc. franc. Mineral. Crist.* **81**, 223–226.

Wyart, J. & Sabatier, G. 1959. Nouvelles observations sur la mobilité des ions silicium et aluminium dans les cristaux de feldspath. *Bull. Soc. franc. Mineral. Crist.* **82**, 216.