assumed to be present as hydroxyl ion inasmuch as DTA and TGA results indicate only a single loss of a constituent at approximately 785° C.

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COEXISTING ALBITE AND OLIGOCLASE IN SOME SCHISTS FROM NEW ZEALAND

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INTRODUCTION

A question of considerable concern to many petrographers using the universal stage for the determination of plagioclase compositions is the extent to which the scatter of stereo-measurements may be attributed to real variations of composition within the rock slice. Since the newly

introduced electron probe microanalyzer offers an excellent chance of successfully answering this question, a combined U-stage-microprobe investigation was initiated. The sodic plagioclase of the low grade regional metamorphic rocks were selected for study, principally because of the characteristic freedom from zoning, but also in view of their importance in metamorphism, both in connection with facies definitions and with the low temperature phase relations of the sodic plagioclases. The data so far accumulated, whilst not providing any final conclusions on the above problem, are regarded as sufficiently important to bring to the notice of metamorphic petrographers.

MATERIALS AND METHODS

All but two of the specimens examined were kindly lent by Dr. B. Mason, and the assignment to metamorphic zones is due to him (Mason, 1962). The U-stage determinations were carried out by Professor F. J. Turner and the microprobe analyses by the author. The data obtained are set down in Table 1. Columns 1, 2 and 3 preserve the chronological sequence of the measurements. The results were not shared between the two investigators until columns 1 and 2 had been completed. Column 3 gives the results of a re-examination of some of the rocks with the universal stage in the light of the microprobe results under 2.

The plutonic plagioclase curves of Slemmons (1962) were used in the universal stage determinations. Use was made principally of the twin axis curves for albite and pericline twins, the angle of the rhombic section, and the optic axial angle. The error quoted is an estimate based on the spread of points on the determinative charts.

An ARL electron probe microanalyzer was used to determine Ca and K simultaneously, with an accuracy estimated to be within $\pm 3\%$. Expressed in terms of $An\%$ this is sufficient to provide extremely precise figures in the low anorthite region: as good as $\pm An_{0.05}$ in the An_1 region and $\pm An_{0.5}$ in the An_{20-30} region. An analyzed plagioclase containing 6.9% Ca (An_{46}) supplied by Dr. K. Fredriksson of La Jolla and an analyzed adularia containing 13.6% K served as standards. Corrections for background were made throughout, whereas those for dead time, absorption and fluorescence of potassium $K\alpha$ by $CaK\alpha$ radiation were sufficiently small to be neglected. The analyzed volumes were in all cases approximately 5 microns in diameter. Grain edges were sampled as frequently as grain centers to prevent bias of results by failure to take zoning into account.

DISCUSSION OF RESULTS

Comparison of the universal stage and microprobe results in terms of

TABLE 1. COMPARISON OF MICROPROBE AND U-STAGE DETERMINATION OF PLAGIOCLASE COMPOSITIONS

	Zone	Chief Minerals	1 U-Stage An%	2 Microprobe Mode[1] An	Ab	Or	Range in An%	3 U-Stage An%
759	Chlorite 4	Chlorite, muscovite, plagioclase, quartz, epidote	2±2	0.05	99.55	0.4	0.0 - 1.8	
765	Biotite	Biotite, quartz, muscovite, plagioclase, chlorite, epidote	0	0.15	99.35	0.5	0.05- 0.25	
766	Almandine	Biotite, muscovite, quartz plagioclase, garnet	1±1	0.2 / 24.5	99.45 / 74.8	0.35 / 0.75	0.05- 1.6 / 21.7 -25.6	Ca-plagioclase confirmed 1±1
767	Almandine	Chlorite, biotite, quartz, plagioclase, muscovite, calcite	0	0.2 / 22.6	99.6 / 76.9	0.2 / 0.45	0.05- 2.0 / 21.4 -24.1	0 / 23±3
773	Oligoclase	Biotite, chlorite, quartz, plagioclase, microcline, muscovite, garnet	22±2	0.1 / 20.9	99.65 / 78.6	0.25 / 0.45	0.05- 0.2 / 18.3 -23.2	+ve plagioclase, i.e. <An10 22±2
675	Biotite	Biotite, muscovite, plagioclase, quartz, epidote, calcite	0	0.3	99.1	0.65	0.1 - 0.5	
678	Almandine	Biotite, garnet, muscovite, quartz, plagioclase, calcite	20±5	18.1	81.2	0.85	12 -21	
793	Oligoclase	Biotite, garnet, hornblende, plagioclase, quartz, calcite	28±2	19.9	79.7	0.4	11 -34	Spread 22-35
37M37	Chlorite 4	Actinolite, plagioclase, epidote, quartz, calcite	1±1	0.5	99.05	0.45	0.15- 1.7	
42M6242	Biotite	Porphyroblastic plagioclase, quartz, muscovite, epidote	1±1	0.55	99.2	0.25	0.25- 1.9	

All determinations are in mol %. Ab has been obtained by difference, contents of Ba and Sr having been ignored.
[1] Most frequent measurement; difference from the mean is less than 1.0% An except for specimen 793 where it is 2.8% An.

Rock Locations

759   2 miles south of Clarke Bluff, Haast-Makarora Road, Westland.
765   ½ mile east of Clarke Hut, Haast-Makarora Road, Westland.
766, 767   Nissen Bluff, Haast River (about 1 mile west of Clarke Hut), Westland.
773   Haast River, 1 mile east of Macpherson Creek, Westland.
675   Chancellor Ridge, Fox Glacier, Westland.
678   East end of Cone Rock, Fox Glacier, Westland.
793   Gallery River, near junction with Waiho River, Westland.
37M37   Haast River, Westland.
42M6242   South branch, Waikouaiti River, E. Otago.

An% values is regarded as satisfactory. The only large disagreement was obtained from a rock (sp. 793) whose plagioclase extended over a wide range of composition (see below).

Of rather more significance is the detection by the microprobe of a duality in composition of the plagioclases in three of the rocks examined (see table, specimens 766, 767, 773). Although the universal stage measurements were executed with extreme care by an investigator of considerable experience, this duality was overlooked in all three specimens. In two cases oligoclase was missed and in one case an albite. In the later U-stage work (column 3) the two plagioclase compositions were specifically looked for and found to be present. Evidently there is a tendency in microscope work for small quantities of clear untwinned oligoclase in rocks possessing abundant albite to be mistaken for quartz. Similarly, small amounts of albite in rocks containing abundant microscopically obvious oligoclase can quite clearly be overlooked and regarded as untwinned microcline or, where not in contact with quartz to provide a Becke line distinction, as oligoclase. The amounts of oligoclase in specimens 766 and 767 are actually small relative to the albite, and specimen 773 contains in fact both untwinned microcline and quartz.

One can, of course, only surmise the extent to which similar omissions may have been made by petrographers in the past. In view of the importance of accurate quantitative data on the plagioclases of low grade metamorphic rocks, it seems necessary to stress the amount of care that should be exercised during the determinations, and the desirability of checking every slice for the possible coexistence of two plagioclases, even though the time and labor necessary to do this be considerable. Any empirical approach to the significance of the peristerite break in low temperature metamorphic reactions, for example, will require the accumulation of a large amount of highly reliable data.

The comparative work has shown that where there exists a real variation in composition from grain to grain (which, except for the albite schists, appears to be almost invariably the case) a serious sampling bias may be introduced into the U-stage results. Sampling is biased by the preferential selection of grains for measurement, those usually favored being:

(a) twinned grains as opposed to untwinned grains or grains whose twinning is invisible (*e.g.*, albite twins at An_{20}), (b) grains of low refractive index set in quartz, (c) large grains as opposed to small, and (d) fresh grains as opposed to cloudy.

Selection of twins, (a), tends to bias the final mean toward higher values of An%, e.g., specimen 793 where a U-stage mean of An_{28} compares with a microprobe mean of An_{22}. Specimens 766 and 767 afford extreme examples of case (b); porphyroblasts of An_{23} in specimen 767 were overlooked because they were embedded in micaceous layers. Effect (c) was

also operative in the case of specimen 766, since the mean dimension of oligoclase is much less than albite in 766. Effect (d) may be expected to give rise to low An % values.

The unexpectedly high degree of purity of the albites was revealed only by microprobe analysis. The maximum composition range for albite in eight schists ranging from the chlorite to the oligoclase zones is $An_{0.0}$ to $An_{2.0}$. The compositions more anorthitic than *ca.* $An_{1.0}$ were all obtained from the crystal margins, so that the bulk of the grains are below $An_{1.0}$; indeed, the means and modes of all eight rocks fall between $An_{0.05}$ and $An_{0.55}$. Epidote, together in some instances with other Ca-minerals such as calcite or amphibole, occurs in all the albite parageneses. The albites of the alpine veins (Weibel, 1958) are clearly not unique in their exceptional freedom from anorthite and orthoclase solid solution. Thus, although no broad generalizations can be advanced on the basis of only eight albite analyses, one suspects that further accurate determinations may well reveal that the real range of albite compositions in green-schist facies rocks in many regions is much more restricted than hitherto believed (*e.g.*, An_{0-7}, Turner and Verhoogen, 1960, p. 533). If, as seems likely, plagioclase compositions in low temperature rocks are controlled by the so-called peristerite solvus (Christie, 1959; Rutland, 1961; Noble, 1962), the above measurements suggest that the solvus is at $An_{1(\pm 1)}$ at the temperatures and pressures of greenschist facies metamorphism. This figure agrees particularly well with Brown's (1960) estimate of the composition of the albite phase in peristerites (An_{0-1}) and his observation of unmixing in plagioclases as poor in anorthite as An_2.

The coexisting albites and oligoclases of the New Zealand schists occur side by side as separate grains. In specimen 766 and to a lesser extent in 767 there is a distinct tendency for oligoclase to occur as thin irregular strips along albite grain boundaries. There are no twin or lamellar relationships between the minerals, nor is there any gradation in composition. The minerals are separated by plainly visible Becke lines. There are no embayments of the one against the other nor any other of the textural characters customarily interpreted as indicative of replacement, although replacement of albite by oligoclase must nevertheless remain a possibility. Electron beam scanning photographs of $CaK\alpha$ radiation and back-scattered electrons from specimen 766 illustrate the relationships (Figs. 1 and 2).

At present sufficient evidence is not available to resolve the problem of the origin of these two-plagioclase rocks, but the following are possible explanations: (1) polymetamorphism, (2) unmixing of homogeneous sodic oligoclase, (3) equilibrium crystallization of independent crystals of albite and oligoclase, controlled by the peristerite solvus. Support

MINERALOGICAL NOTES
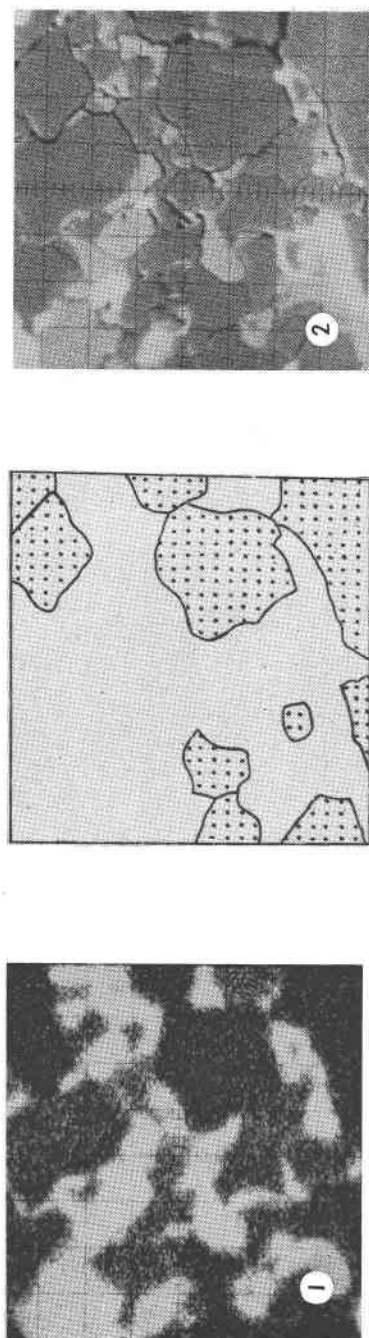
Electron beam scanning photographs of coexisting albite and oligoclase in schist specimen 766. Size of area approximately 180×180 microns. Minerals present are albite, oligoclase, quartz, and mica. The distribution of quartz is shown by the stippled area in the accompanying sketch.

FIG. 1. CaKα radiation. Oligoclase is bright; albite and quartz are nearly black, although albite shows a slightly higher signal than quartz.

FIG. 2. Back-scattered electrons. Degree of brightness corresponds to the mean atomic number of the mineral. Oligoclase is slightly brighter than quartz and albite; mica is very bright.

for the second possibility in the form of textures analogous to those of perthites is completely lacking. The coexistence in equilibrium of albite, oligoclase, and epidote is not precluded by the Phase Rule, although the data of metamorphic petrography indicate that it is unlikely. Conceivably of real significance is a comparison of the Or contents of the coexisting plagioclases; Or is twice as high in the oligoclases as in the albites in all three two-plagioclase rocks (see Table). On the basis of known solid solution relationships, albite in equilibrium with oligoclase should surely contain the greater Or. Thus, in the present case, the oligoclase may have formed at distinctly higher temperatures than the albite. It is intended to explore the validity of this criterion by determining where possible the Or contents of the unmixed components of peristerites with the microprobe.

Microprobe analyses of plagioclases in schists from localities other than in New Zealand have not as yet been conducted in this department. Thus, it is not known to what extent these rocks may be unique. If the coexisting albites and oligoclases were produced by polymetamorphism (and this does not rule out control by the peristerite solvus), two-plagioclase schists may well be far from uncommon. It is hoped that this note will stimulate interest in this problem, and that more abundant and more careful measurements will henceforth be made, with the possibility of dual compositions being borne in mind.

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