Coexisting Orthoclase and Microcline in Altered Volcanic Rocks, West Humboldt Range, Pershing County, Nevada*)

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With 1 Table

Abstract

Coexisting orthoclase and microcline occur in volcanic rocks altered by pervasive potassium metasomatism. The two polymorphs occur together, the microcline as phenocrysts, and the orthoclase in the groundmass with quartz and muscovite. The Or content of the potassic feldspars exceeds 87 percent, and the triclinic K-feldspars have "obliquities" greater than 0.80. No intermediate microclines were detected. The assemblage is best explained by alkali exchange and recrystallization of plagioclase to microcline ($\pm$ muscovite) and sanidine or glass to orthoclase, rather than a transition between the two polymorphs.

INTRODUCTION

The exact nature of the orthoclase-microcline transition still remains in doubt, in spite of many recent attempts to either determine it by experimental methods (GOLDSMITH and LAVES, 1954; TOMISAKA, 1962; WONES and APPLEMAN, 1963; EBERHARD, 1965), theoretical analyses (LAVES and GOLDSMITH, 1961; MACKENZIE and SMITH, 1961), or studies of natural occurrences [MACKENZIE, 1954; WRIGHT, 1964a; HART, 1964; STEIGER and HART (in press); WRIGHT, 1967]. This study was undertaken in hopes of identifying the transition in an alteration aureole, in which TATLOCK (1961) had identified two distinct potassic feldspars.

The aureole occurs in the West Humboldt Range, Pershing County,

Nevada, at 40° 19′ N and 118° 14′ W; and is part of the Rochester Mining District (KNOPF, 1924).

Originally we thought that the two feldspars were related by recrystallization, and that the polymorphism was due to thermal or kinetic effects related to the widespread potassium metasomatism in the area. This does not appear to be the case, and evidence is presented here indicating that alkali exchange and recrystallization of two pre-existing feldspars created the assemblage observed in these rocks.

GEOLOGIC SETTING

The altered rocks were originally silicic volcanic tuffs and flows and interbedded clastic sedimentary rocks of the Koipato Group of Permian and Triassic age (WALLACE, SILBERLING, IRWIN, and TATLOCK, 1959; WALLACE, TATLOCK and SILBERLING, 1960). The original volcanic rocks were presumably rhyolites, quartz latites, or rhyodacites as the predominant phenocrysts are quartz and feldspar. Several types of pervasive alteration have taken place and the history of this material since its original eruptive emplacement is exceedingly complex. Suggestions of flow structure, pumice fragments and amygdules are still present. The present foliation due to a crude orientation of the muscovite formed during alteration may be related to the original foliation of volcanic origin, but this is not proven.

The samples described in this article were collected in the vicinity of the Champion mine, a well known source of dumortierite (KERR and JENNEY, 1935). The material was collected at 100-foot intervals on a single horizontal traverse bearing west of the Champion mine on the north wall of Rolands Canyon (Humboldt Queen Canyon).

PETROGRAPHY

The dumortierite occurs in an alteration aureole which is zoned from the core outward in the following sequence:

Core: Quartz-pyrophyllite (± andalusite, ± dumortierite)
               Quartz-muscovite (± dumortierite)
               Quartz-K-feldspar-muscovite (± tourmaline) Samples
               13—19, Table 1.
"Wall rock": Quartz-potassic feldspar-muscovite ± albite (± tourmaline) Samples 20—21, 23—24, Table 1.

Table 1 gives modal analyses of the samples studied. Quartz and muscovite are common to all samples outside of the core, and no alkali feldspar occurs in the core and the next adjacent zone.

Samples collected outside of these inner two units are porphyritic. Phenocrysts of alkali feldspar and quartz are set in an aphanitic ground-mass of quartz, alkali feldspar and muscovite with allotriomorphic-granular texture. The feldspars and quartz of the groundmass are anhe-dral; the muscovite is subhedral with well developed 001 forms. Nearly every sample contains spherulitic alkali feldspars in rosettes several millimeters in diameter. The rosettes do not contain quartz or muscovite.

The quartz "phenocrysts" are commonly spheroidal intergrowths which are more suggestive of filled vesicles than phenocrysts, although some single rounded and embayed quartz crystals were observed.

The alkali feldspar phenocrysts may be anhedral or euhedral; some are single crystals, others are composite individuals. Many of the pheno-crysts that are now microcline contain muscovite, and the muscovite appears, in thin section, to be concentrated in the core of the phenocryst and to be much larger crystals than the muscovite in the groundmass.

Samples collected from the quartz-K-feldspar-muscovite zone (13—19, Table 1) are devoid of plagioclase feldspar, and contain relatively little unaltered magnetite. The proportion of phenocrysts is variable, and quartz veins and muscovite-rich shear zones are common.

Samples 20—24, Table 1, collected farthest from the highly altered core are a heterogenous group of rocks that can be called "wall rock", although they, too, show signs of pervasive alteration. These rocks may contain plagioclase, and a greater amount of unaltered magnetite. Sample 22, which appears to have been tuffaceous sandstone, contains pure low albite as the only alkali feldspar together with much muscovite.

The accessory minerals were identified by optical methods and x-ray powder diffraction. Goethite, probably formed by weathering, is the most common accessory. Hematite, occurring both as concentrations in shear zones, and as disseminated grains is the second most common accessory. Euhedral magnetite grains are more common relative to hematite and goethite in the less altered rocks. Tourmaline and biotite are the common ferromagnesian minerals. Biotite ($\gamma = 1.630$) occurs in sample 16 as part of K-feldspar-muscovite-hematite-biotite aggregates which can be best interpreted as the result of the decomposition of original biotite pheno-crysts.

THE ALKALI FELDSPARS

The properties of the alkali feldspars are listed in Table 1 so that direct comparisons can be made with the modal analyses and the other feldspars occurring in the sequence.

The 2V measurements were made in thin section with a universal stage and extinction methods. Four to twenty measurements were made on both groundmass and phenocryst feldspars. The fine grain size of the groundmass feldspars made these measurements extremely difficult.

The rocks were crushed and feldspar concentrates were made using heavy liquid techniques. These concentrates, somewhat contaminated with quartz, were used for obtaining the unit-cell dimensions and partial chemical analyses.

The feldspar concentrates were analysed by Joseph I. Dinnin, U.S. Geological Survey, for K_2O, Na_2O, CaO, BaO and Rb_2O. K_2O, Na_2O and Rb_2O were determined by flame emission spectrometry. CaO and BaO were determined by atomic absorption spectrometry using lanthanum as releasing agent. BaO and Rb_2O were below limits of detection (0.1%). The results were recalculated to 100% total Or, Ab and An and are listed in Table 1.

The specimens were examined qualitatively on an electron microprobe and no significant variations in potassium concentrations were detected between phenocrysts and spherulitic feldspars. The sodium and calcium counting rates were below background. The groundmass feldspars are so intimately intergrown with quartz and muscovite that a direct comparison was not possible.

The x-ray powder patterns are of high quality with sharp distinct peaks with no evidence of broadening or asymmetry. It seems clear that the feldspars are either monoclinic (i. e., orthoclase) or nearly maximum microcline. The unit-cell dimensions were determined by least squares analysis of reflections recorded on a diffractometer using CaF_2 ($a = 5.4620$) as an internal standard.

ORVILLE (1964; written communication, 1966) has shown that the unit-cell volumes of the polymorphs of potassium feldspar are nearly identical, and has derived curves for determining composition to ± 2 mol per cent from the unit-cell volume. The compositions of our samples (Table 1), as deduced from these curves, indicate that the feldspars in the highly altered zone are significantly more potassic than those in the "wall rock". WRIGHT (1964b) indicated that the dimensions of the b and c axes may be a measure of structural state of alkali feldspars. In

either the monoclinic or triclinic group of our feldspars these axial dimensions do not differ significantly (by more than twice the errors given in Table 1). By WRIGHT's method of estimation, all of the orthoclase has the lowest possible monoclinic structural state, "low" orthoclase, and all of the microcline has close to the lowest possible structural state, maximum microcline. These conclusions are also supported by the 2V measurements, the separation of the 131—$1\bar{3}1$ x-ray reflections ("Δ" in Table 1), and the interaxial angles, when determinable.

In samples from the quartz-K-feldspar-muscovite zone (samples 13—19) all feldspar phenocrysts are now microcline, but the groundmass feldspar may be either orthoclase or microcline or both (sample 18). Although some of the phenocrysts of microcline have a suggestion of faint albite twinning, they are exceptional in their lack of "quadrille" twinning. Only two or three crystals of the several hundred observed have this type of twinning.

Samples from the quartz-potassic feldspar-muscovite ($\pm$ albite) zone may contain phenocrysts of microcline (sample 21) or orthoclase (sample 24, collected farthest from the core). Phenocrysts of orthoclase are restricted to areas outside of the most strongly altered aureole, and are set in a groundmass that may contain either microcline or orthoclase but apparently not both of these minerals in any given sample.

In summary, the feldspars of the most altered zone are rich in Or content, and are either "low" orthoclase or maximum microcline. Where two polymorphs coexist, the phenocrysts are maximum microcline and the feldspar in the groundmass is orthoclase. The maximum microcline phenocrysts are commonly single individuals, generally lack twinning and commonly contain inclusions of coarse muscovite.

ORIGIN OF THE ALKALI FELDSPARS

There are at least four processes which could form the observed assemblage of orthoclase and microcline:

1. Heating of microcline above the transition temperature to orthoclase, and arresting the process before completion.
2. Alteration of rocks causing the recrystallization of orthoclase to microcline below the transition temperature, and arresting the process before completion.
3. Changing the bulk composition of the rocks by alkali exchange so that

it corresponds to the region of a transition loop between orthoclase and microcline.
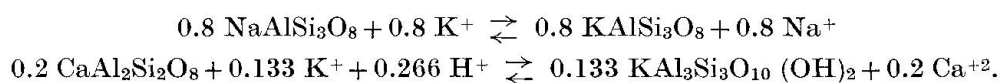
4. Alkali exchange and recrystallization of monoclinic K-feldspar to orthoclase, and plagioclase feldspar to microcline ($\pm$ muscovite).

The fact that the occurrence of microcline and orthoclase in the sequence is not related to the zoning sequence and the lack of correlation of a polymorph with intensity of alteration or grain size makes processes (1) and (2) unlikely.

The consistent compositions of orthoclase and microcline and their textural relationships make process (3) unlikely also. The coarsest feldspars are microcline, and they are neither more nor less sodium-rich than the fine-grained orthoclase.

However, alkali exchange provides a simple and reasonable model which explains most, if not all, of the observations. ORVILLE (1964) and WRIGHT (1964b) have shown that alkali exchange of low albite in a dry environment (KCl melts) will yield microcline, and that dry exchange of plagioclases with intermediate structural states will yield triclinic potassic feldspars with no change in structural state. In nature some change of structural state during alkali exchange is probable. O'NEIL and TAYLOR (1965) have suggested that the exchange process in an aqueous environment is one of complete recrystallization rather than simple cation exchange.

The mineral assemblages described in this study may be explained by the exchange of plagioclase to form triclinic potassic feldspar, microcline, and the exchange of sanidine or the devitrification of glass to form orthoclase. The lack of "quadrille" twinning in the microcline phenocrysts and their muscovite-rich cores suggest that the following reactions took place between a fluid medium and a plagioclase feldspar:

$$0.8 \ NaAlSi_3O_8 + 0.8 \ K^+ \ \rightleftarrows \ 0.8 \ KAlSi_3O_8 + 0.8 \ Na^+$$

$$0.2 \ CaAl_2Si_2O_8 + 0.133 \ K^+ + 0.266 \ H^+ \ \rightleftarrows \ 0.133 \ KAl_3Si_3O_{10} \ (OH)_2 + 0.2 \ Ca^{+2}.$$

In addition to the microcline phenocrysts, many areas of rocks with microcline in the groundmass contain intergrowths of muscovite and microcline without quartz. These intergrowths have a lathlike outline suggestive of former feldspar phenocrysts.

Rocks in which the dominant groundmass constituent was plagioclase would recrystallize to form altered rocks containing microcline ($\pm$ muscovite) whereas those with sanidine or orthoclase as the dominant feldspar, or which contained glass, would recrystallize as orthoclase-rich rocks.

Plagioclase phenocrysts set in a glassy or sanidine-rich groundmass would give rise to microcline phenocrysts set in a groundmass of orthoclase.

It might be expected that the compositions of the two feldspars should differ in their K_2O/Na_2O ratio, but if such a difference exists, it is below the level of detection of the methods used in this study.

The formation of rocks containing two alkali feldspars of the same composition is thus shown to be caused by alkali exchange during pervasive alteration. This process is a common one, especially during the alteration of wall rock (MEYER and HEMLEY, 1959). The West Humboldt Range alteration aureole shows the same sequence outlined by HEMLEY (1959) and is a logical consequence of exchange between volcanic rocks and a circulating fluid medium.

The study has two implications of interest concerning the polymorphism of alkali feldspars. The first is that the coexistence of the two polymorphs is not necessarily a consequence of the recrystallization of one polymorph to another (WRIGHT, 1964a). The second feature of interest is that there is no evidence of intermediate microcline in these rocks, all samples containing orthoclase or maximum microcline.

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Table 1. *Modal analyses of samples and physical and chemical properties of contained alkali feldspars*

Sample Number	Modal Analyses, Accessories[1]		2 V[2] Groundmass	2 V[2] Phenocrysts	a	b	c	α	β	γ	V (Å³)	Estimated Or content	"Δ"[3]	Or	Ab	An
562-13	Quartz 42.4% K-feldspar 39.1% Muscovite 13.7% Other 4.8%	magnetite, hematite, goethite, tourmaline	65° ±5	84° ±2	8.595±0.006 8.586±0.004	12.960±0.008 12.961±0.006	7.211±0.004 7.212±0.003	90° 90° 32′ ±2′	115° 58′ ±4′ 116° 81′ ±2′	90° 87° 47′ ±2′	722.2±0.7 720.7±0.3	99 93	0 0.95	95.5	3.5	1.0
562-13A	Quartz 20.4% K-feldspar 54.9% Muscovite 23.1% Other 1.6%	hematite, goethite, zircon	84° ± 5		8.578±0.003	12.967±0.004	7.215±0.002	90° 38′ ±1′	115° 54′ ±1′	87° 42′ ±1′	721.1±0.2	95	0.96	96.1	3.6	0.3
562-15	Quartz 32.6% K-feldspar 57.7% Muscovite 6.8% Other 2.9%	magnetite, hematite, goethite	not determined	76° ±10	8.591±0.002	12.976±0.003	7.211±0.002	90°	115° 59′ ±2′	90°	722.5±0.2	100	0	96.2	3.2	0.6
562-16	Quartz 22.1% K-feldspar 60.0% Muscovite 6.9% Other 11.0%	biotite, magnetite, hematite, zircon	not determined	76° ±10	8.588±0.002	12.975±0.002	7.209±0.001	90°	116° 2′ ±1′	90°	721.8±0.2	97	0	91.4	7.2	1.3
562-17	Quartz 40.4% K-feldspar 56.1% Muscovite 0.4% Other 3.1%	magnetite, hematite, goethite	76° ±10		8.597±0.011	12.974±0.011	7.198±0.007	90° 25′ ±4′	116° 3′ ±5′	87° 52′ ±5′	720.8±1.0	94	0.94	96.4	3.3	0.3
562-18	Quartz 27.1% K-feldspar 49.8% Muscovite 20.9% Other 1.3%	hematite, goethite, zircon	76° ±10		8.603±0.012 8.576±0.009	12.968±0.011 12.961±0.015	7.211±0.006 7.235±0.017	90° 90° 29′ ±8′	115° 56′ ±7′ 115° 54′ ±5′	90° 87° 57′ ±6′	723.5±0.1 723.0±1.0	100 100	0 0.88	95.8	2.6	1.6
562-19	Quartz 38.3% K-feldspar 30.8% Muscovite 29.5% Other 1.5%	hematite	65° ± 5	84° ± 5	8.589±0.003	12.966±0.004	7.216±0.002	90°	116° 4′ ±2′	90°	721.8±0.3	97	0 0.93	94.5 95.3	4.4 4.4	1.1[5] 0.3[6]
562-20	Quartz 31 % Plagioclase 21 % K-feldspar 32 % Muscovite 12 % Other 4 %	magnetite, goethite, hematite	76° ±10	104° 76° ±10										30.3	59.5	10.2
562-21	Quartz 32.3% K-feldspar 45.4% Tourmaline 19.0% Muscovite 2.1% Other 1.3%	magnetite, hematite, goethite	84° ± 5	72°, 84° ±5	8.581±0.005	12.955±0.006	7.201±0.003	90° 26′ ±2′	115° 57′ ±2′	88° 11′ ±2′	719.5±0.3	90	0.82	95.3	3.8	0.9
562-22	Quartz 53.1% Low albite 4.1% Muscovite 38.6% Other 4.2%	hematite, goethite	104° ± 5		8.137±0.005	12.774±0.007	7.159±0.002	94° 11′ ±2′	116° 37′ ±2′	87° 42′ ±2′	663.4±0.4	0		not determined		
562-23	Quartz 41.9% K-feldspar 30.3% Muscovite 24.4% Other 3.3%	magnetite, goethite	60°, 76°, 84° ±5	65°, 80° ±5	8.577±0.003	12.952±0.007	7.200±0.004	90° 40′ ±4′	115° 59′ ±2′	87° 53′ ±2′	718.5±0.5	87	0.79	93.4	5.7	0.9
562-24	Quartz 54.3% K-feldspar 34.5% Muscovite 10.8% Other 0.4%	goethite	48° ± 5	45°, 60° ±8	8.558±0.003	12.982±0.003	7.196±0.003	90°	116° 4′ ±2′	90°	718.1±0.3	86	0	92.1	7.3	0.6

[1] Based on 1000—1200 counts per sample thin section.
[2] Extinction measurements.
[3] 12.5 ($d_{131} - d_{1\bar{3}1}$).
[4] Feldspar concentrates; analysed for K_2O, Na_2O, CaO; Rb_2O, BaO below dectectable limits (0.1 %); J. I. Dinnin, analyst.
[5] Dominantly groundmass.
[6] Dominantly phenocrysts.