METASOMATIC POTASH FELDSPAR ROCKS ASSOCIATED WITH IGNEOUS ALKALIC COMPLEXES *

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Abstract

Anchimonomineralic potash feldspar rocks (orthosite, alkorthosite, orthoclasite, perthosite, trachyte, feldspathic breccia, etc.) are widespread components of alkalic-carbonatitic complexes or provinces in many localities (*e.g.*, Alnö, Sweden; Mbeya, Tanzania; Chilwa Island, Malawi; Rufunsa Valley, Zambia; Wet Mountains, Colorado, U.S.A.). Textures vary from granitoid to trachytoid to fragmental. Where associated directly with carbonatite, these rocks are generally older, but locally rheomorphic (?) dikes transgress carbonatite. They occur as 1) units within complexes, 2) in wall rocks adjacent to complexes, 3) as veins, dikes, pipes, and linear zones apart from complexes but within alkalic provinces.

Commonly red, owing to abundant minutely disseminated hematite, the rocks also may contain concentrations of rare earths and thorium (as thorite) where cut by younger carbonatite.

The feldspars are turbid (owing to dusty hematite), rarely show gridiron twinning, and may have relict cores of clear, older feldspar. X-ray determinations of their sodium contents indicate that they contain usually less than 5 mole percent albite. Structural state studies show that they are near-maximum microclines with a usual range for $\Delta = 0.65 - 0.92$. Further evidence of their low-temperature genetic environment is advanced by the co-presence of chalcedony, opal, and Schachbrett albite, and associated fluorite, barite, and quartz crystals.

The rocks were formed by potash metasomatism, and are replacements of or variants of fenites, representing a relatively high-level type of alteration associated especially with complexes displaying sub-volcanic or hypabyssal characteristics.

Introduction

Nearly all alkalic subsilicic complexes are enclosed to various degrees in a halo of metasomatically altered wall rocks known as fenites. "Fenitization is such a characteristic type of wall-rock alteration around alkalic complexes that recognition of the presence of fenite essentially insures precognition of the presence of an adjoining alkalic rock intrusion. The fenitic halo is an accoutrement of alkalic massifs more characteristic than are the migmatite zones of catazone granitoid plutons and the tactite zones around granodiorite–quartz–monzonite stocks in carbonate rocks" (Heinrich 1966,

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p. 73). The process of fenitization has been studied in detail for many occurrences, and reviews of the occurrence, mineralogy and geochemistry of fenites have appeared recently (Henrich 1966; McKie 1966; Verwoerd 1966). Suffice it to state here the fenites are found in association with alkalic rocks under the following circumstances.

1. Where the associated complex consists of alkalic silicate rocks plus carbonatite.
2. Where the associated complex consists of alkalic silicate rocks only (*i.e.*, without carbonatite).
3. Where the complex consists essentially of just carbonatite.
4. In alkalic provinces along fractures and faults at considerable distances from parent alkalic complexes.

In the idealized case, where the wall rock is a granitoid gneiss (which, indeed, very often is the case) the transformation to fenite involves:

1. Concentration of all available potassium in feldspars and their recrystallization.
2. Possible introduction of more potassium and aluminum to yield additional potash feldspar.
3. Oxidation of Fe^{2+} to Fe^{3+} and its concentration in sodic pyroxene, in sodic amphibole and as hematite which clouds the feldspars.
4. Concentration of early available sodium and calcium as alkalic pyroxenes and amphiboles.
5. Possible addition of sodium to form albite.
6. Elimination of the quartz.

Thus in the transformation of a granite gneiss to a metasomatic aegirine or riebeckite-arfvedsonite syenite (fenite) the major chemical changes are:

Addition of K, Na, Al
Substraction of Si
Oxidation of Fe^{2+} to Fe^{3+}

Feldspar Rocks

In many alkalic-carbonatitic complexes, a second type of distinctive metasomatic rock has been recognized. These are red, anchimonomineral rocks consisting almost entirely of one or more varieties of potash feldspar. Such rocks have received a wide variety of names: orthosite, alkorthosite, orthoclasite, perthosite, trachyte, pseudotrachyte, feldspathic fenite, feldspathic breccia, feldspathic agglomerate, feldspar rock, sanidinite, red rock, burnt rock. The textures vary widely. Both fragmental and non-fragmental types occur: fine-grained to coarse-grained as well as heterogranular varieties are known. In the non-fragmental variants, textures are granitoid, trachytoid, porphyritic, pseudoporphyritic and microspherulitic. An excellent systematization of the nomenclature and textures of these rocks has been presented by Sutherland (1965B).

First described by Dixey *et al.*, (1937) as part of the Chilwa alkalic series of Malawi, these rocks have been increasingly recognized in African carbonatitic complexes and African alkalic provinces : Toror Hills, Uganda (Sutherland 1965*a*) ; Mbeya (Panda Hill), Tanzania (Fawley & James 1955 ; Fick & van der Heyde 1959) ; Musensi Hill, Tanzania (James 1958) ; Songwe Scarp, Tanzania (Brown 1964) ; Chasweta, Zambia (Bailey 1960) ; Chilwa Island and Tundulu, Malawi (Garson & Smith 1958 ; Garson 1959). Additional examples have been found at the Kaiserstuhl, Germany by Sutherland (1967).

In the United States similar rocks are known in three areas :

1. In Fremont and Custer Counties (Wet Mountains), Colorado, in an alkalic-carbonatitic province that contains three complexes, two of which have associated red feldspar rocks occurring as exterior veins (Heinrich & Dahlem 1966).
2. In Gunnison County, Colorado, associated with the Iron Hill alkalic-carbonatitic complex as red trachyte porphyry dikes and as marginal alterations along thorite veins. (Temple & Grogan 1965 ; Hedlund & Olson 1961 ; Heinrich 1966).
3. In the southern Caballo Mountains, Sierra County, New Mexico, as elongated replacement masses (Staatz *et al.*, 1965).

In all three areas the rocks are red, radioactive (owing chiefly to thorium) and commonly contain concentrations of cerium rare-earth elements.

From these studied examples, occurrences of the red feldspar rocks fall into the following main types :

1. Units within alkalic-carbonatitic complexes.
2. Wall rock replacements adjacent to alkalic-carbonatitic complexes.
3. Breccia pipes and vent breccias in or near alkalic-carbonatitic complexes.
4. Dikes and rheomorphic dikes (trachytic textures) in or near complexes.
5. Replacement veins along fractures, faults or lineaments in alkalic provinces.
6. Fracture-controlled replacement veins in districts devoid of any other manifestations of alkalic igneous activity.

The field relations in numerous examples clearly demonstrate that the relative age of the feldspar rock is : a) post-fenite and b) pre-carbonatite. Not rarely they were shattered during or just prior to the emplacement of carbonatite and may be included as xenoliths within carbonatite (Fig. 1). In a few places, such as on Chilwa Island, there is evidence that the

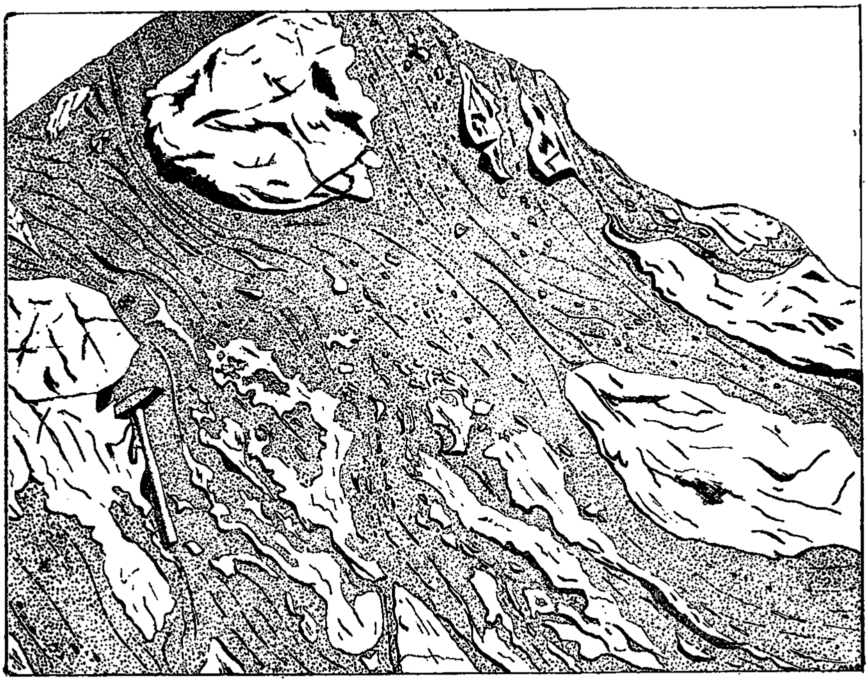

FIG. 1. Feldspathic breccia included as xenoliths in carbonatite, Chilwa Island, Malawi (Garson & Smith, 1958).

feldspathic breccia grades into an "igneous-textured" rock (*i.e.*, trachyte) which was locally remobilized to form rheomorphic dikes that cut the carbonatite, the feldspathic breccia, other rocks of the complex, and even unaltered wall rock. In most complexes that contain both metasomatic feldspar rocks and trachyte dikes the relations between the two are less well-defined. However, a gradation from feldspathic fenite through intrusive feldspathic fenite breccia to porphyritic potash trachyte dikes has been described by Sutherland (1965*a*), associated with the carbonatitic complex of the Toror Hills, Uganda.

PREVIOUS FELDSPAR DETERMINATIONS

Although no general systematic study of the nature of the potash feldspars of these rocks has been completed, feldspars from a number of individual occurrences have been determined (by other investigators, Heinrich 1966) :

1. TorDor Hills, Uganda
   Orthoclase
   Orthoclase + sanidine
   (microcline may be present as a "chips", relict from the fenitized gneiss).
2. Tororo, Uganda
   Orthoclase + some sanidine (?)
3. Chasweta, Zambia
   Pure potassic low-temperature orthoclase
4. Songwe Scarp, Tanzania
   Microcline
5. Musensi Hill, Tanzania
   Orthoclase
   Sanidine (in dikes cutting orthoclasite)
6. Mbeya, Tanzania
   Orthoclase and minor albite
7. Chilwa Island, Malawi
   Orthoclase and/or orthoclase cryptoperthite
   (Or 77.9, 78.0% ; Ab 2.4, 1.4%)
8. Tundulu, Malawi
   Orthoclase (in fenite)
   Orthoclase-microperthite — sanidine (in advanced fenite)
   Sanidine (in dikes)
9. Kaiserstuhl, Germany
   Orthoclase

These results indicate that with the exception of the Songwe Scarp occurrence, in which microcline is present, the feldspars are :

orthoclase,
orthoclase crypto- or microperthite,
sanidine,
or combinations of these.

Furthermore it appears that with an increasing "igneous" nature of the occurrences (*i.e.*, in dikes) sanidine predominates. The Songwe Scarp is a carbonatite dike (Brown 1964), whereas all other feldspar rock occurrences are in or with carbonatitic ring complexes.

Feldspar Rocks in the Wet Mountains, Colorado

Table 1 shows the sequence of rock units in the McClure Mountain-Iron Mountain alkalic–carbonatitic complex (Fig. 2). Red feldspar rock occurs entirely outside the complex itself, as much as 15 miles distant, as :

1. Veins and irregular masses replacing granitic and biotitic gneisses. These contain little or no carbonate but are somewhat radioactive and may contain minor barite, quartz, hematite, and aegirine.

TABLE 1. ROCK SEQUENCE IN THE McCLURE MOUNTAIN–IRON MOUNTAIN ALKALIC COMPLEX, FREMONT COUNTY, COLORADO.

	Within Complex	*Outside Complex*
Youngest		Ba–F Carbonatites
↑	Carbonatites	Simple Carbonatites
		Feldspar rock
		Breccia pipes
		Lamprophyres
	Leucocratic alkalic dikes	
	Nepheline syenite	
	Ijolite	
	Biotite syenite	Fenite
	Gabbro	
Oldest	Peridotite, magnetite — ilmenite lenses	

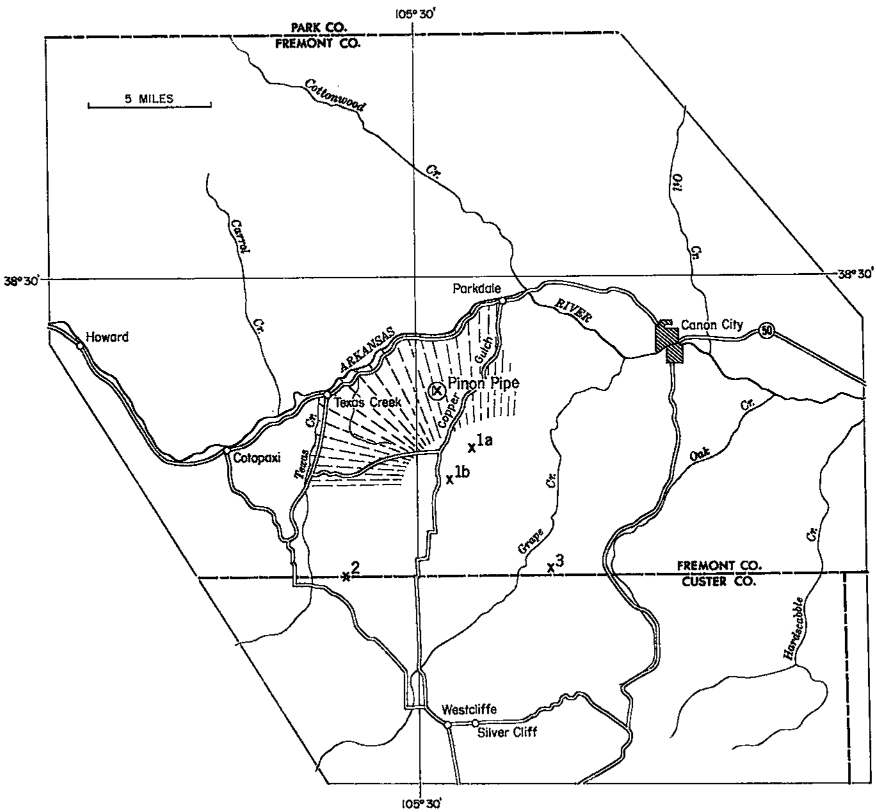

FIG. 2. Index map showing location of alkalic complexes, northern Wet Mountains, Colorado. 1*a* - Iron Mountain, 1*b* - McClure Mountain, 2 - Gem Park, 3 - Democrat Gulch.

2. Composite feldspar rock-carbonatite bodies (Fig. 3). In these the percentage of carbonatite, which is younger and veins and replaces the feldspar rock, varies greatly, from only about 5% to over 50% (Figs. 4, 5). These composite veins are usually markedly radioactive and may contain significant rare earth concentrations.
3. Dikes of fine-grained to aphanitic and porphyritic trachyte. These are weakly radioactive (2× background), probably from ^{40}K, and contain no rare-earth concentrations.

The feldspar rock shows a variety of textures depending on the degree of replacement of the original gneiss or granite. Textures range from gneissic to massive-aphanitic (microgranitoid). A few are trachytoid, in part. Those bodies that were later invaded by carbonatite may display brecciated to mylonitic textures.

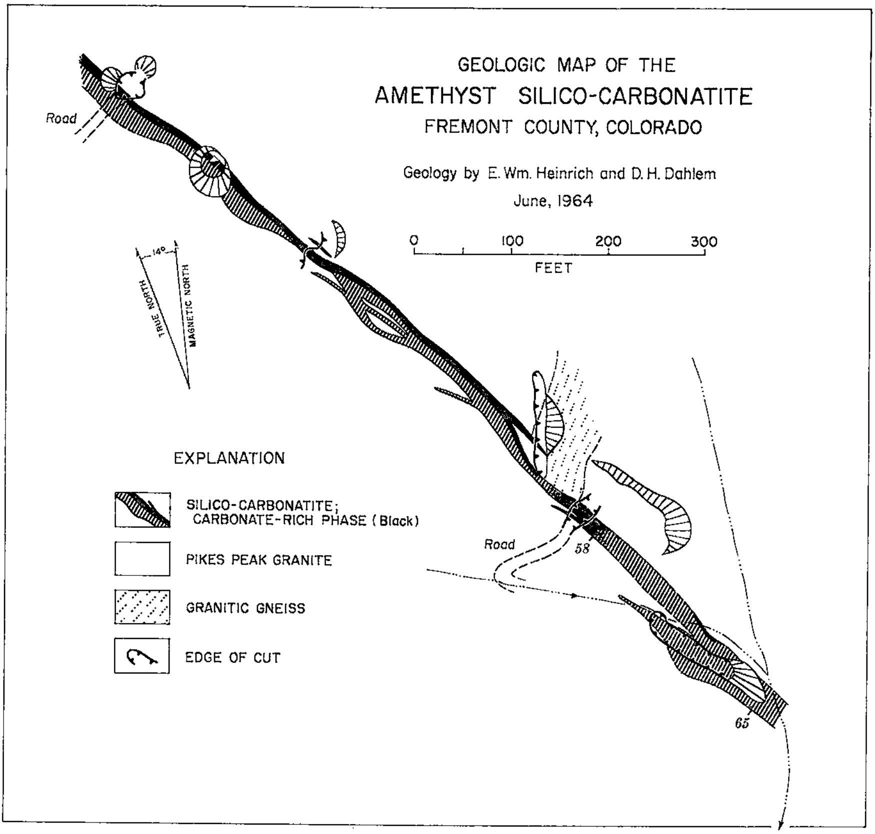

FIG. 3. Map of Amethyst feldspar rock-carbonatite vein. Diagonally ruled = feldspar rock.

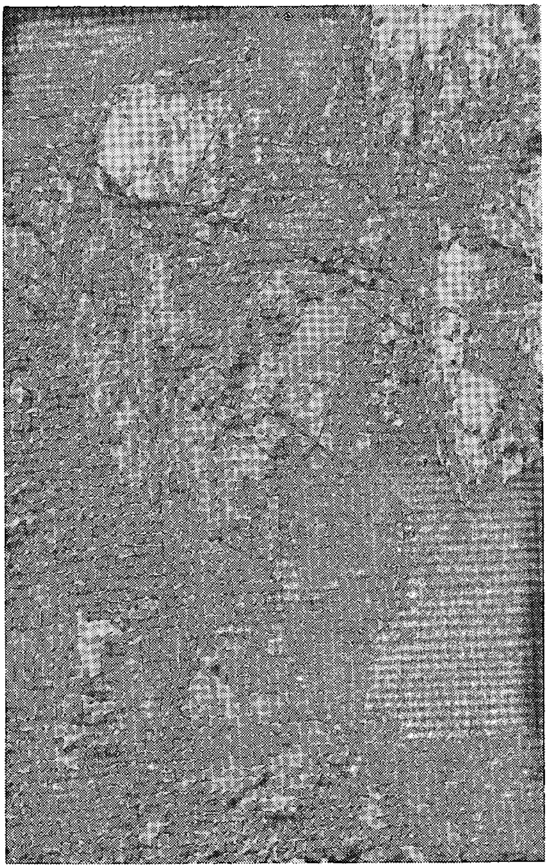

FIG. 4. Vertical vein of feldspar rock in biotite gneiss, Klondyke deposit, Fremont County, Colorado. Contains less than 10% younger carbonate.

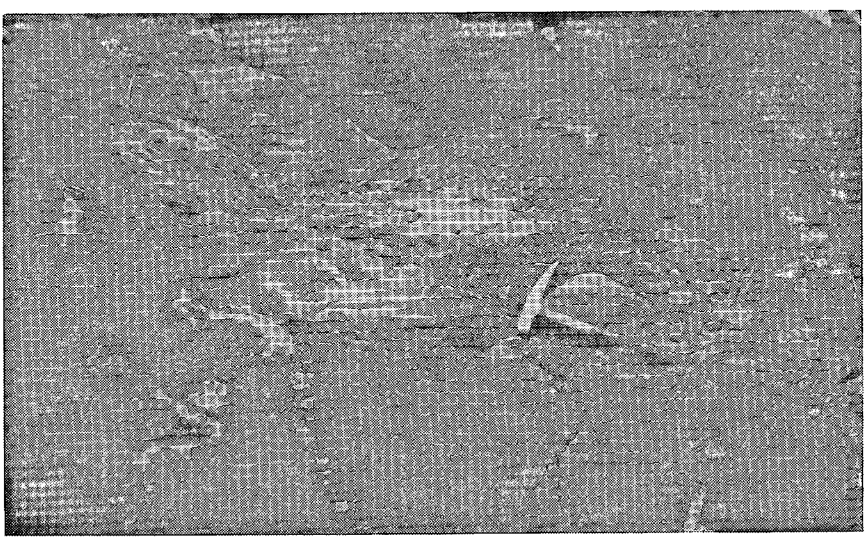

FIG. 5. Sinuous feldspar rock-carbonatite vein in migmatized gneiss, MacIntyre Gulch, Fremont County, Colorado. Carbonatite (about 25%) occupies central part of vein.

Feldspars

The feldspars are nearly all highly turbid owing to minute hematite inclusions. For all deposits but one they are microcline. In the one exception, the Amethyst carbonatite, the new feldspar is orthoclase. The characteristic gridiron twinning very rarely is present, and where present is obscure. Where new microcline forms overgrowths on microcline relict from granite on gneiss (Fig. 6), the two contrast both in twinning and hematite content. Commonly the new microcline shows a pachy domain extinction or fourling twinning (Fig. 7). The latter characterizes adularia of various types of low-temperature veins (e.g., Alpine-type veins) and authigenic microcline from limestones. The presence of this type of twinning indicates that the microcline did not form by inversion from orthoclase. The new red microcline may have narrow overgrowths of clear (non-hematitic) microcline (Fig. 8) which also appears as film-like seams along the cleavages of the hematitic microcline.

X-ray determinations were made of the albite contents and the structural state. All of the microclines checked contain less than 5% of the albite molecule, usually having about 2% Ab.[1] Structural state studies show that

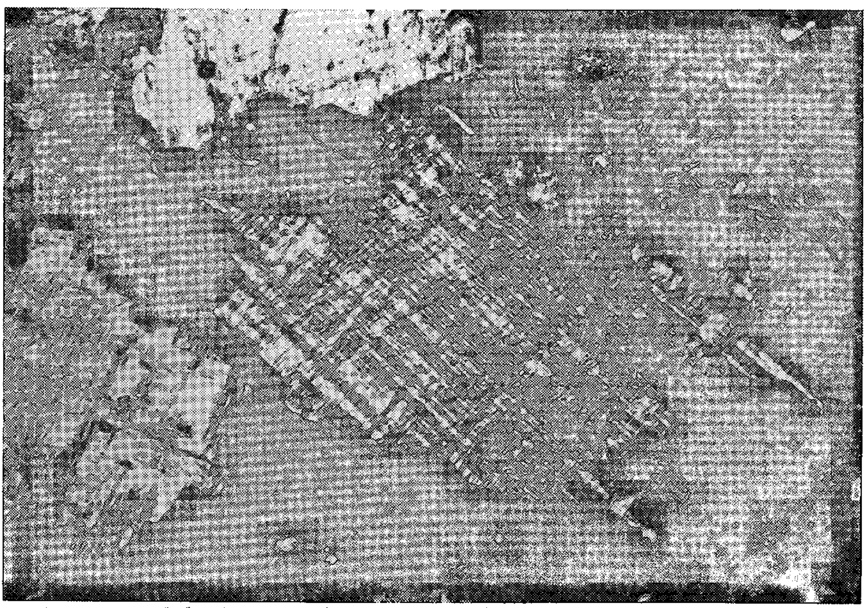

Fig. 6. Corroded relict microcline in matrix of new hematitic microcline. Homestake shaft, Fremont County, Colorado. Polars crossed, × 5.

[1] By means of the 201 spacing and correction for structural state.

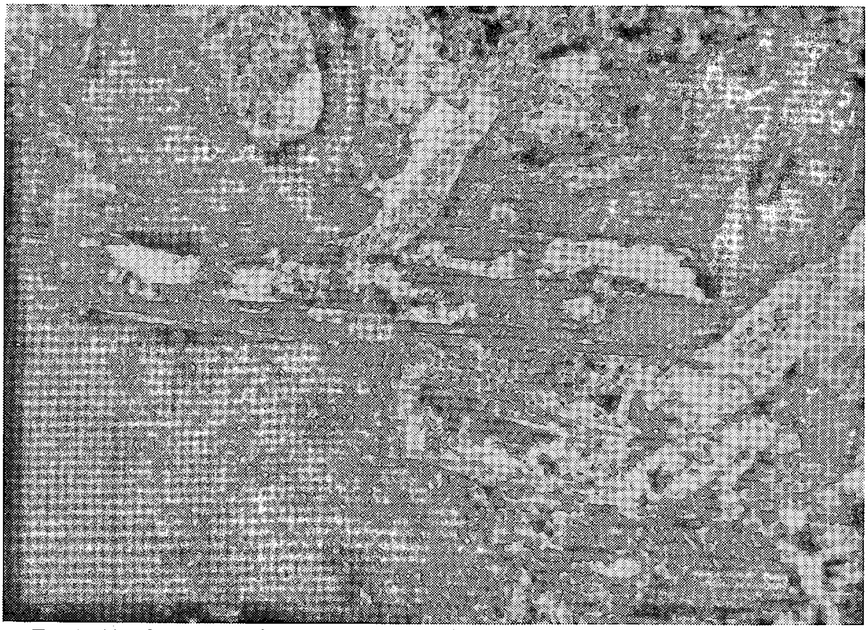

FIG. 7. Fourling twin of microcline, in feldspar rock from Dreamer's Hope carbonatite, Fremont County, Colorado. Polars crossed, × 40.

FIG. 8. Clear, non-hematitic microcline rim on red turbid microcline, both metasomatic. In feldspar rock, Klondyke deposit, Fremont County, Colorado. Polars not crossed, × 40.

they are usually near-maximum microclines with the range $\Delta = 0.65 - 0.75$[1]. Some have mixed structures. In a few composite veins, the values decrease (ordering decreases) toward the carbonatite, indicating that a slight reheating of the microcline accompanied the introduction of the carbonate phase.

Some of the feldspar rock was found to contain hematitic albite. The amount varies from traces to strongly predominant. Albite veinlets consist of platey crystals (Fig. 9), but spherulitic groups also are characteristic (Fig. 10). This albite is younger than the microcline. The albite is nearly pure Ab, with low K_2O and CaO and is, like the potash feldspar, highly ordered. It is concentrated in two geological loci :

1. It increases in amount in veins with increasing distance from the center of the district.
2. In individual deposits it is more abundant in the outer parts.

Thus an idealized sequence from wall to center of a composite feldspar rock-carbonatite vein consists of :

Margin	⟶		*Center*
fenite,	albite,	microcline,	carbonate
		Δ decreases ⟶	

Relations to Trachyte Dikes

Somewhat surprisingly, the trachyte dikes also consist chiefly of microcline $\pm$ sodic plagioclase. However, there are no field relations that even suggest a gradation from metasomatic microcline rock to trachyte. Thus there is no real discernable relationship between the two megascopically similar rocks other than both were formed in pre-carbonatite time and both consist mainly of hematitic microcline. No significant carbonatite occurs with the trachyte dikes.

Caballo Mountains, New Mexico

Specimens from the red feldspar rocks of the Caballo Mountains, New Mexico (Staatz *et al.* 1965) also have been studied, and the results, based on *x*-ray determination of Ab content and structural state, indicate that these microclines are very similar to those of the Wet Mountains of Colorado.

[1] $\Delta = 12.5\ [d(131) - d(1\bar{3}1)]$.

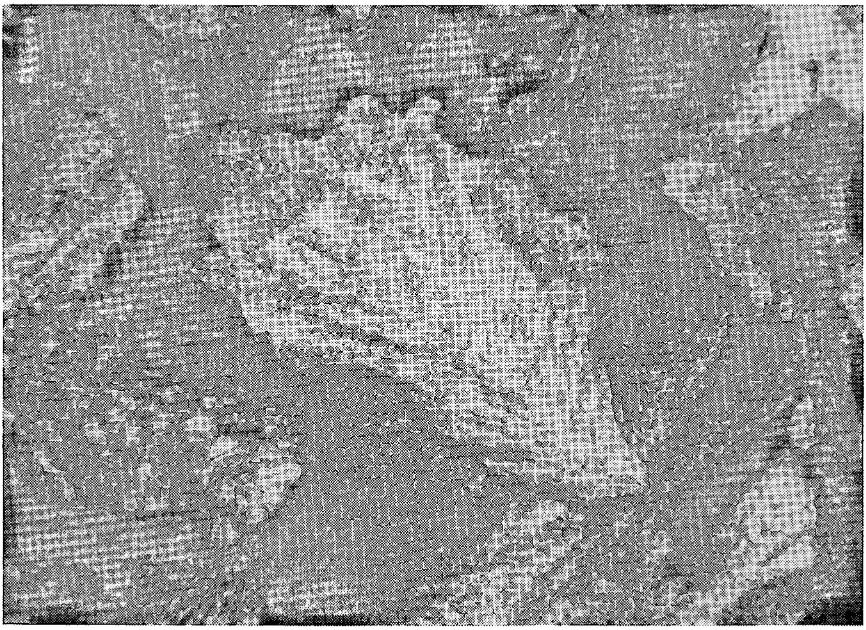

FIG. 9. Platey albite crystals in veinlet cutting microcline. From feldspar rock, Dreamer's Hope deposit, Fremont County, Colorado. Polars crossed, × 40.

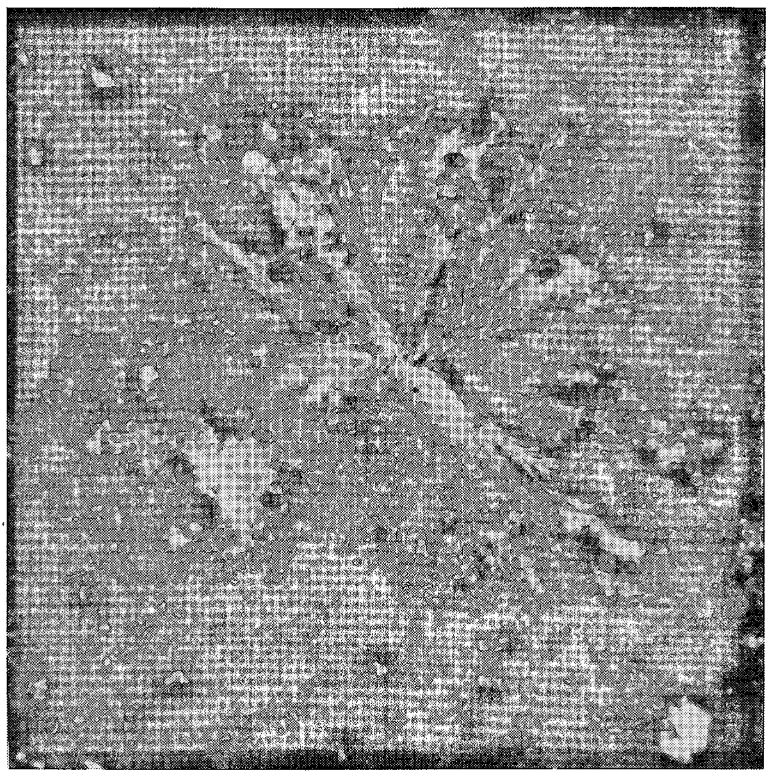

FIG. 10. Spherulitic group of albite crystals in hematitic calcite. In feldspar rock, Dreamer's Hope deposit, Fremont County, Colorado. Polars crossed, × 16.

Conclusions

1. Anchimonomineralic potash feldspar rocks of great textural diversity formed by potassium-iron metasomatism represent a widespread and characteristic type of alteration in or near alkalic-carbonatitic complexes, particularly those displaying sub-volcanic or hypabyssal geological characteristics.
2. The relative age of the feldspathization is post-fenite and pre-carbonatite, although in a few districts reportedly mobilized feldspar rock cuts carbonatite as rheomorphic dikes.
3. Where feldspar rocks occur within complexes the potash feldspar ranges from orthoclase through orthoclase-perthite to sanidine.
4. Where feldspar rocks occur outside complexes or with carbonatite dikes or veins, the feldspar is nearly always low-soda, highly ordered, low-temperature microcline.
5. In the Wet Mountains, Colorado, red albite rock accompanies the microcline, either in peripheral parts of the district or in peripheral parts of individual deposits.
6. The presence of these highly feldspathic metasomatic rocks, adjacent to or near carbonatites, is further evidence that carbonatite magmas carry the alkalies, K and Na, in abundance, which aid in maintaining fluidity at very low temperatures.

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