THE AMERICAN MINERALOGIST, VOL. 52, MAY–JUNE, 1967

CARBONATITES AND ALKALIC ROCKS OF THE ARKANSAS RIVER AREA, FREMONT COUNTY, COLORADO. 4. THE PINON PEAK BRECCIA PIPES[1]

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ABSTRACT

The Pinon Peak breccia pipes in Fremont County, Colorado, are satellitic to the McClure Mountain—Iron Mountain alkalic-carbonatitic complex. They consist mainly of fenitized, locally derived Precambrian gneiss fragments with minor transported biotitized lamprophyre pieces in a subordinate calcitic matrix containing metasomatic aegirine, crocidolite, potash feldspar and hematite with accessory phlogopite, quartz, barite and chlorite. The pipes are post-lamprophyre dikes in age and penecontemporaneous with carbonatite dikes. They resulted from a series of CO_2 gas-rich explosions followed by gas-streaming and hydrothermal alteration. Although breccia pipes are widely associated with alkalic complexes, these are the first to be described in which the effects of fenitization are recorded, thus supporting the doctrine that fenitization is a result rather than the cause of the formation of alkalic complexes.

INTRODUCTION

In a recent paper Heinrich and Dahlem (1966) have sketched the general geology and have described the major intrusive bodies of the alkalic province of Fremont and Custer Counties, Colorado. The Pinon Peak breccia pipes, herein described, are satellitic to the McClure Mountain-Iron Mountain complex, just as the Democrat Creek complex has marginal breccia masses (Christman *et al.*, 1959). However, the Pinon pipes lie at considerable distances (3.3 airline miles) from its consanguineous complex, whereas in Democrat Gulch the breccias are adjacent to or near the syenite body (Fig. 1).

The district lies on the north and northwest sides of the McClure Mountain-Iron Mountain complex in Fremont County, Colorado, mainly on the south side of the Arkansas River (Fig. 1). Because of the rugged terrain and few roads, the area is difficult of access, particularly the strip directly south of the river.

The Pinon Peak breccia pipes are in the N.1/2, SW.1/4, SE.1/4, Sec.7, T.19S., R.72W. They can be reached over a steep logging road that winds up Spring Gulch generally westward for about two miles from the Copper Gulch road. Pinon Peak lies three-quarters of a mile south of the pipes.

Bulldozer exploration of the pipes, performed probably because of

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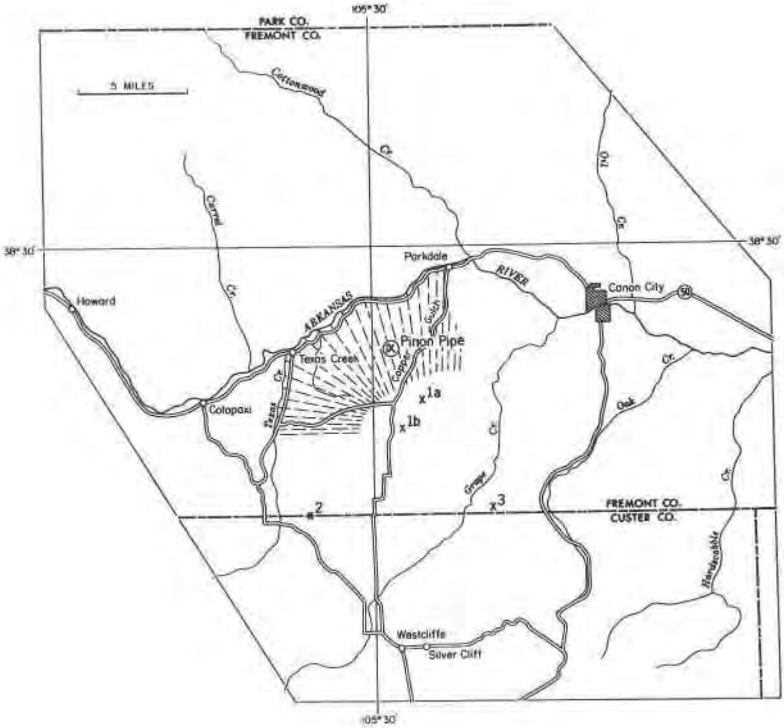

FIG. 1. Index map showing location of the Pinon Peak breccia pipes. 1a—Iron Mountain, 1b—McClure Mountain; 2—Gem Park; 3—Democrat Gulch. Area shaded by dashed lines is the dike halo (mainly lamprophyres and carbonatites) of the McClure Mountain-Iron Mountain complex.

their radioactivity,[1] has completely exposed the northern one, here called Wood Knob. The southern or Gar Knob, is well exposed at the hill top and in a cut just south of the apex of the Knob, but further to the south outcrops are very scanty, and the contacts of the pipe on the south slope of the hill are but vaguely defined, largely on the basis of float (Fig. 2).

GEOLOGY

The Wood Knob pipe is a crude ovoid about 50×35 feet in plan. It lies but 80 feet north of the northern end of the Gar Knob pipe, and it is probable that the two join at depth, for they are similar in structure and petrology, differing chiefly in size and slightly in the intensity of post-emplacement mineralization.

The Gar Knob pipe is apparently an elongate pod about 250 feet long

[1] Geiger counter readings indicate radioactivity up to 0.08% eU_3O_8. The strongest radioactivity is found in highly hematitized material.

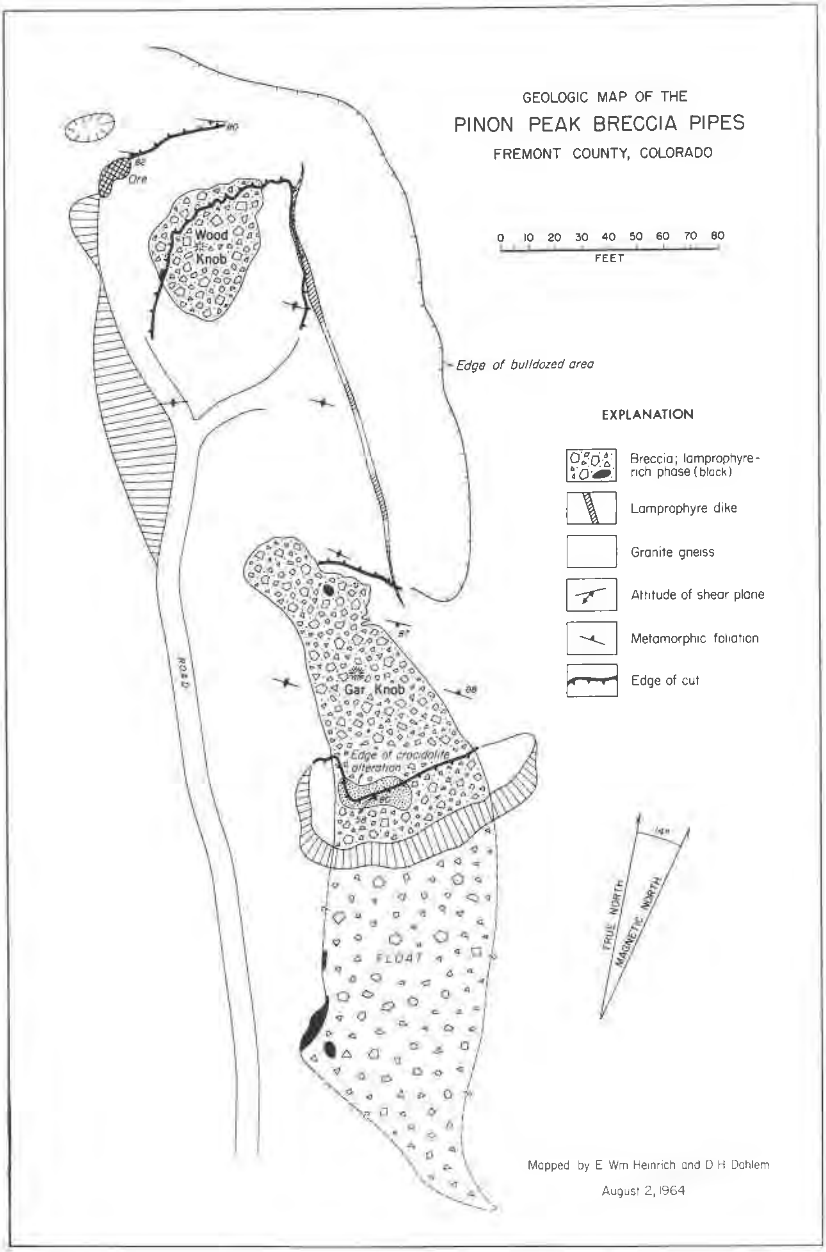

FIG. 2. Geologic map of the Pinon Peak breccia pipes, Fremont County, Colorado.

along a N.25°W. axis, and 20–60 feet wide. Only the northern half is well exposed. Contacts on both bodies are vertical or very steeply dipping.

Both pipes have been punched through a well foliated medium-grained granitoid gneiss which is poor in mafic constituents. The gneissic foliation strikes east-west and is generally vertical. A small unzoned pegmatite cutting this gneiss is exposed at the east end of the face of the bulldozer cut north of Wood Knob.

The only other rock exposed is a lamprophyre dike a foot to several feet thick, which extends for 170 feet between the two knobs (Fig. 2). It strikes N.25°W. parallel with the axis of the Gar Knob pipe. In outcrop this rock is dark gray, very fine-grained and structureless.

The breccia consists dominantly of angular to subrounded fragments of the granitoid gneiss which range in size from a fraction of an inch to several feet, in completely jumbled disorder. Most fragments are at least several inches long. The only other rock type, which is but locally conspicuous, is represented by jet black lamprophyre pieces that range in length from an inch to two feet (Fig. 3). A few such fragments are widely scattered throughout the pipes, particularly in the Gar pipe, but most appear in local concentrations, the two most conspicuous of which are indicated on Fig. 2.

Both the gneiss and the lamprophyre pieces are set in a subordinate matrix that is exceedingly fine-grained and dominantly gray with red mottlings. Surrounding many of the breccia pieces is a reddish, fine-grained, feldspathic reaction rim that ranges in width from 0.1 to 0.5 inches. Such rims, because of the color contrast, are particularly conspicuous around the xenoliths of lamprophyre (Fig. 3).

Along the face of the cut that bisects the Gar pipe (Fig. 2) a fault plane strikes northeast and dips steeply southeast with striations plunging 50–60° southwest. Along this surface and in the breccia near it, the breccia has been coarsely fenitized with megascopic aegirine appearing locally. Even more conspicuous is the development of gray-blue crocidolite,[1] both in the breccia fragments and in the matrix as needles, tufts, rosettes, and felted aggregates. The Wood pipe has been strongly hematitized with abundant disseminated plates, aggregates and veinlets of specular hematite.

The Lamprophyre

The lamprophyre dike consists of a gray rock pockmarked by circular

[1] The crocidolite was identified optically and checked by means of X-ray powder diffraction. It is a riebeckitic amphibole; the strongest lines are 2.703 (10), 8.41 (8), 3.126 (8), 4.475 (6), 3.396 (6).

depressions marking the site of former phenocrysts selectively removed by weathering. The matrix is aphanitic.

The phenocrysts are a titanian augite partly replaced mainly by a pale green actinolitic amphibole and by lesser amounts of a pale tan mica in very fine-grained aggregates. The matrix is made up of thin, unoriented laths of labradorite, interstitial uralitized pyroxene, abundant magnetite subhedra and patches of secondary calcite. The rock may be classified as a somewhat carbonatized, strongly uralitized, slightly alkalic basalt porphyry.

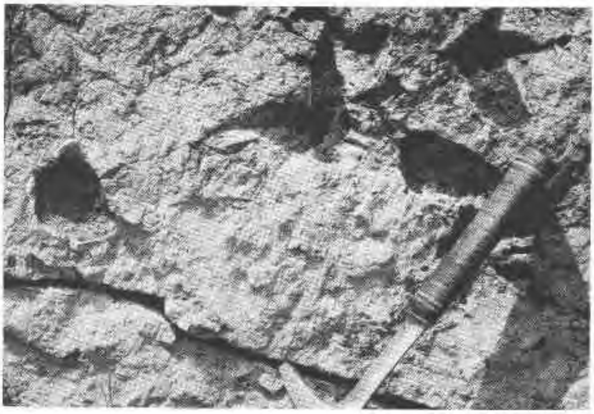

FIG. 3. Outcrop of breccia showing fragments of gneiss and lamprophyre in fenitic matrix; the lamprophyre pieces are outlined by conspicuous feldspathic shells.

From the field relations the age of the dike relative to the pipes is not evident (Fig. 2). However, most of the lamprophyric framgents in the pipes are apparently the altered equivalents of the dike rock, and thus the pipes probably have intersected and brecciated the dike at depth. Since both pipes carry lamprophyric fragments, this further suggests that they merge at depths.

ALTERED GNEISS FRAGMENTS

The microscope shows that the secondary minerals aegirine, crocidolite and hematite, which only locally are sufficiently coarse-grained to be detected megascopically, are actually widely developed in most of the gneiss fragments. These pieces, then, have been fenitized. Such gneiss fragments are blocky (*i.e.*, angular and approximately equidimensional) to rounded.

Locally, however, particularly where the gneiss has been slabbed into sharply bounded, rectangular fragments that are immersed in a very fine-

FIG. 4. Outcrop of slabby gneiss breccia with biotitic matrix.

grained mafic matrix (Figs. 4, 5), the pyroxene-amphibole type of alteration is absent, being supplanted by a biotitic alteration.

Fenitization: The original minerals of the gneiss that are still preserved to varying degrees are quartz, orthoclase and sodic plagioclase. All of any original mafic species (chiefly biotite) have been destroyed. The pieces show marked shattering, with mosaic quartz, granulated quartz and feldspars and bent and offset plagioclase twin lamellae. Both types of feldspar have been rendered turbid owing to the development of myriad specks of sericite and calcite throughout the grains. Some of the larger grains of orthoclase have newly added overgrowths of clear potash feldspar (Fig. 6).

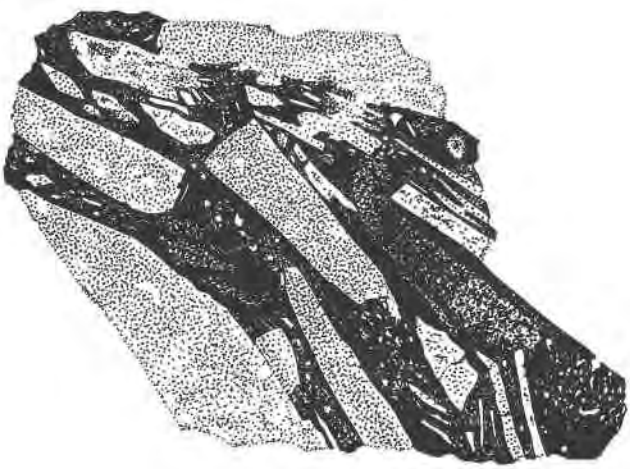

FIG. 5. Atypical brecciation and matrix. Gneiss slabs are set in biotitic matrix. ×1.

Clusters of slender aegirine laths[1] are widespread, and clumps, radial aggregates and subparallel sheaves of crocidolite fibers[2] are much more abundant. The aegirine, as in most fenitized rocks, has been formed chiefly by replacement of quartz, being localized along quartz-feldspar grain contacts and extending into quartz. Much of the pyroxene remains as remnants in clusters of crocidolite (Fig. 7). However, although some of the crocidolite is uralitic in origin, most of it appears to have been formed by direct replacement of quartz (Fig. 7). Anhedral grains and stubby euhedral prisms of rutile are a prominent accessory, associated closely with aegirine, the latter included in aegirine with their *c*-axes parallel.

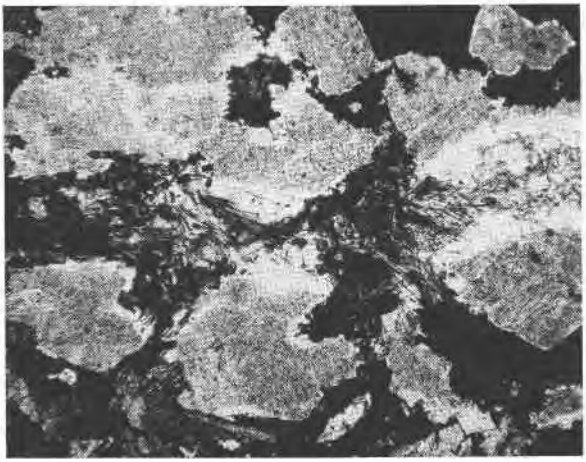

FIG. 6. Fenitized gneiss fragment with aegirine-carbonate aggregates replacing quartz and turbidized feldspar rimmed and veined by clear feldspar. ×32.

Many of the larger aggregates of crocidolite also contain variable amounts of calcite which corrodes and partly replaces the amphibole. Calcite also replaces aegirine. In a few places the crocidolite has been pseudomorphously replaced by fine-grained chlorite and the aegirine by a nearly isotropic aggregate of a ferruginous clay mineral.

In some of the altered gneiss fragments scattered flakes of phlogopite appear in local small clusters. Both crocidolite and calcite replace phlogopite, as does hematite. In a few specimens phlogopite occurs as flakes within aegirine-calcite veinlets that cut across the gneissic structure. This paragenesis of the mica also attests to its pre-crocidolite formation.

[1] Measurements of the n_1 and n_2 indices of cleavage fragments indicate this pyroxene contains 80 percent of the aegirine end-member component.

[2] Measurements of the γ' index of the fibers ($1.689 \pm .002$) and $\alpha \wedge c = 9°$ indicate that the mineral is a magnesian riebeckite.

Hematite is widespread and in places very abundant, forming thin fracture fillings, branching clusters, and irregular patches. Some hematite replaces crocidolite.

Biotitic alteration: Gneiss fragments submitted to biotitic alteration show neither aegirine nor crocidolite. Again the feldspars are turbid with clouds of minute sericite and calcite flecks. Cutting the gneiss are veinlets of olive biotite and calcite, which pair, together with a pale green chlorite, also forms irregular patches in the gneiss, replacing chiefly quartz.

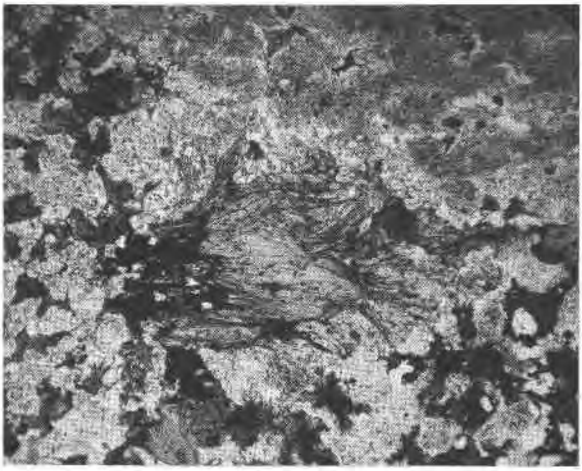

FIG. 7. Large bundle of crocidolite fibers in part formed by replacement of aegirine (remnants of aegirine occur with hematite at left end of bundle). Smaller felted patches of crocidolite replace most of the quartz. Feldspar is turbidized with some clear new feldspar rims. ×32.

Altered Lamprophyre Fragments

The fragments of lamprophyre included in the breccia pipe are so strongly transformed that their identification as a rock originally similar or identical to that of the external lamprophyre dike (Fig. 2) was exceedingly difficult. The pieces now are a biotite-plagioclase rock, whereas initially it was a pyroxene-plagioclase rock (see previous description). The correlation rests primarily on two features: 1) the relict matrix texture and 2) presence of "ghosts" of the pyroxene phenocrysts.

The altered rock contains three types of large mineral units:

1. Pseudomorphs after pyroxene phenocrysts which now consist of

aggregates of biotite, chlorite, hematite, limonite, and a little quartz. These have maintained the euhedral pyroxene outline, and the micaceous species, partly parallelly oriented, extinguish as a unit.

2. A few large euhedra of biotite.
3. Numerous large euhedra of pyrite.

The last two transgress the fabric and are probably metacrysts. The matrix consists of fine-grained biotite and relict bedraggled plagioclase laths peppered with minute biotite flakes and specks of calcite. A few anhedra of potash feldspar are sprinkled throughout, a feldspar identical with that of the reaction rims (see beyond). Accessories are apatite (original) and rutile (introduced?).

The Matrix

Crocidolitic matrix: Except for a few places, the chief type of matrix is mottled gray-red with a "sandy" texture. It consists of the following species whose proportions vary widely over short distances: calcite, potash feldspar, crocidolite, aegirine, hematite and quartz. Biotite and chlorite are locally common. Microfragments of altered gneiss are abundant, as are fragments of individual mineral grains derived from brecciation of the gneiss. Much of the quartz appears to have been so obtained, whereas much of the potash feldspar appears to be fenitic in origin. Aegirine-calcite veinlets follow fractures across both fragments and matrix.

Coarsely crystalline hematite, in plates as wide as an inch, is especially abundant in veinlets and irregular matrix aggregates along the northern edge of Wood Knob. Small quartz crystals, flattened in the plane of the veinlets, accompany the coarser specularite plates. Associated with this intense hematitization are a few vuggy quartzose veinlets 1–2 inches across. These are banded symmetrically, with comb structure quartz on both walls, beginning with a 1/4-inch layer of smoky quartz that grades inward into 1/2-inch layers of milky to clear quartz. Largely filling the central cavity are masses of calcite in irregularly oriented thin plates and central "bow-tie"-shaped clusters of white to red barite plates as much as 1.5 inches long. Interleaved with the subparallel barite crystals are platelets of jet black quartz.

Feldspathic shells: Conspicuously outlining the altered lamprophyre pieces, but also present around some of the gneiss fragments, are thin shells of feldspar. Finely granular, these shells are relatively free of crocidolite as well as many other matrix species. Some calcite is present, and thin calcite seams cut the shells. Minute prisms of apatite are very abundant (*ca.* 8%). The feldspar is fresh and pink to red, owing to the numerous tiny hematite inclusions (Fig. 8). Some of the feldspar grains show "confused," poorly developed "gridiron" type of microcline twinning, and most of it has refractive indices that indicate it is a low-soda potash feldspar. A small amount of albite (Ab_{94}) also is present.

The potash feldspar of the shells is the same feldspar that forms rims over the turbid orthoclase grains in the fenitized fragments of gneiss. Indeed within the shells a few pieces of orthoclase derived from the gneiss are distinguishable by their non-hematitic but turbid aspect.

The thickness of the shells, 1/8–1/4 inch on the average, is independent of the size of the xenolith.

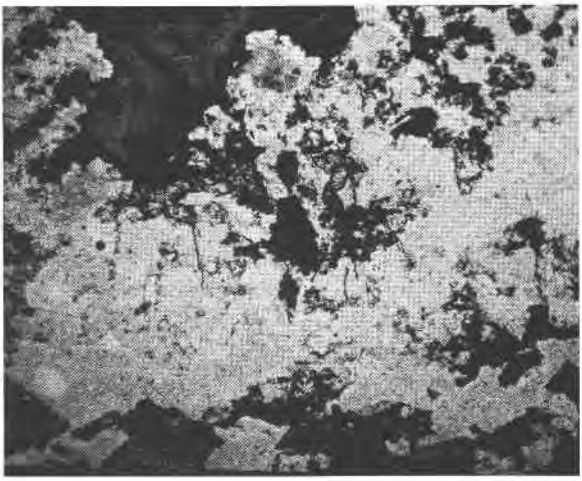

FIG. 8. Part of feldspathic shell around biotitized lamprophyre fragment (upper left). Feldspar is dusty owing to hematite, and coarse hematite patches occur in the inner part of the shell. Normal fenitic matrix with clots of crocidolite appears at bottom and lower right. ×32.

Biotitic matrix: The biotitic matrix, which is present only very locally, is black and very fine-grained (Fig. 5). It consists dominantly of minute biotite flakes (60–70%) and lesser, variable amounts of intimately admixed calcite, hematite, limonite and sericite, in which mixture are set slightly larger subhedra of nearly colorless chlorite (Fig. 9). Disseminated through this aggregate are rounded to ellipsoidal bodies of relatively coarse calcite or quartz-calcite (Fig. 9). In the latter the quartz is in terminated crystals in semi-radial groups with the focus at the edge of the mass and the calcite has overgrown the quartz crystals. These aggregates are probably gas vesicle fillings and the sequence—1. quartz, 2. calcite—is like that of the quartzose veinlets cutting the crocidolitic type of matrix (see above).

Sequence of Mineral Formation

The fenitic minerals of the gneiss fragments are in the main identical with those of main (crocidolitic) type of matrix. The biotitic type matrix, the biotitic alteration of the gneiss, and the alteration of the lamprophyre pieces are all characterized by essentially the same mineral assemblage except for pyrite, which is largely restricted to the altered lamprophyre.

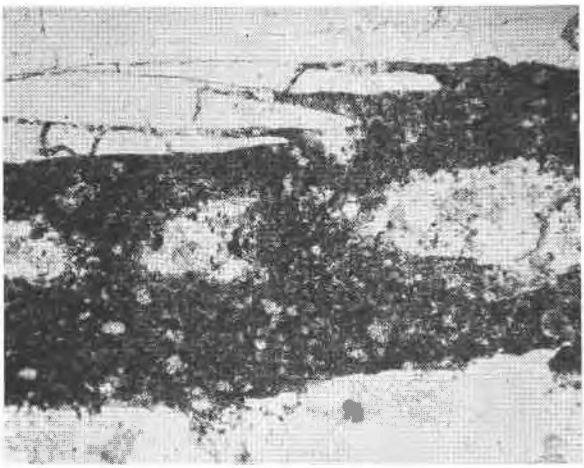

Fig. 9. Thin slabs of gneiss (top and bottom) in biotitic matrix. Large light patches in matrix are quartz-calcite vesicle fillings. Smaller gray ovoids are chlorite crystals. Note veinlets of matrix penetrating shattered gneiss. ×32.

The biotitic alteration apparently preceded the crocidolitic type, inasmuch as fragments of biotitized lamprophyre are included in the crocidolite matrix but are insulated from it by their feldspathic shells. At least some of the biotitic alteration took place below the present erosion surface, for the lamprophyre dike is not biotitized in outcrop, nor is it in contact with the breccia at the present surface. On the other hand there is no evidence to indicate that the gneiss fragments have not been formed essentially *in situ*.

Four main stages of mineral development are readily distinguishable (from oldest to youngest):

I. Biotitic alteration
II. Feldspathic shell formation
III. Fenitization
IV. Vein formation

Within some of the stages differences in the relative ages of the minerals can be determined:

- I. Biotitic alteration
  1. Biotite, pyrite, calcite, sericite, chlorite, quartz
  2. Vesicle fillings of quartz and later calcite
- II. Feldspathic shells
  Hematitic potash feldspar, apatite, calcite, albite
- III. Fenitization
  1. Aegirine, phlogopite, rutile, calcite, hematitic potash feldspar
  2. Crocidolite
  3. Calcite
  4. Hematite, chlorite, clay
- IV. Vein formation
  1. Hematite, quartz
  2. Quartzose veins
     - a. Smoky to clear quartz
     - b. Calcite
     - c. Barite and smoky quartz.

Thus it appears that calcite continued to form throughout the entire period of mineralization. The vesicle fillings (I-2) can probably be equated in time with the quartzose veins (IV-2). Similarily, hematitization appears to have taken place only once (III-4 = IV-1). The early part of the alteration sequence featured chiefly potassic metasomatism (biotite, potash feldspar), whereas the latter part was characterized by sodic metasomatism (aegirine, crocidolite) followed by abundant Fe^{3+} introduction.

Brecciation *at depth* preceded the biotitic alteration; brecciation continued until at least after the formation of the feldspar-rich rock, for pieces of this material appear within the crocidolitic matrix. Some small lamprophyric pieces were broken during feldspathization, for rims pass into veinlets that bisect fragments.

Amphibole Fenitization

The recognition of abundant crocidolite as a secondary mineral in the Pinon Peak breccia pipes adds another example to the growing list of alkalic-carbonatitic bodies in which amphiboles appear as fenitic species. Among these are (Heinrich, 1967): Mountain Pass, California; Fen, Norway; Chilwa Island and Nakalonje Hill, Malawi (Nyasaland); Chishanya, (Southern) Rhodesia; Spitskop and Phalaborwa, South Africa; and the Fukushin-Zan district, Korea (carbonatites absent). Veins of opal-crocidolite-pyrite-apatite rock occur in the Spitskop complex. King and Sutherland (1960, p. 507) state ". . . frequently reported from the fenites is a weakly birefringent amphibole, pleochroic from blue-green to lavendar. This mineral has been shown in some instances to be erkermannite,[1] but from other descriptions it is apparent that variation occurs towards actinolite." If eckermannite is used for an amphibole rich in the end-member component, $Na_3Mg_4AlSi_8O_{22}(OH)_2$ (Phillips and Layton, 1964), then this designation is not incompatible with our describing these amphiboles as magnesian riebeckites. Such amphiboles have also been called rhodusites (see Beyseyev, 1966). An amphibole occurring in late nepheline syenite dikes and as a rim on other amphiboles in "metasomatic rocks" (fenites?) of the Mbozi alkalic complex of Tanzania has composition close to $Na_2CaFe_3{}^{2+}Fe_3{}^{2+}(Si_6, Al_2)O_{22}(OH)_2$ and has been named mboziite, by Brock *et al.* (1964).

Sodic amphibole can occupy one of two positions in the sequence of fenitic minerals (Heinrich, 1967). At Chishanya the riebeckite-albite combination is the initial phase of fenitization, which was then followed by the formation of aegirine. A similar sequence characterized fenitization at Spitskop. On Chilwa Island and at Fen bluish sodic amphiboles formed by uralitization of older aegirine. In the Pinon Peak pipes the development of the crocidolite represents a stage even somewhat younger: all of the amphibole is post-aegirine in age; some of it is uralitic, but much of it replaced quartz directly.

Sequence of Events in the McClure Mountain-Iron Mountain Complex

The McClure Mountain-Iron Mountain complex and its satellitic dikes and mineral deposits have been studied by geologists of the U. S. Geological Survey and the University of Michigan.[2] From these studies and from unpublished field studies by the authors it is possible to establish the sequence of formation of the units in the alkalic-carbonatitic complex (Table 1). The Pinon Peak breccia pipes are post-lamprophyre and, in part, products of explosive carbonatization.

The breccia body of Democrat Gulch (Christman *et al.*, 1959) differs in several respects from the Pinon Peak bodies. It is much larger (1500 $\times$2500 ft); it contains a greater variety of metamorphic rock types, some in much larger fragments (diameter greater than 100 ft!); fragments of the adjacent syenite are included; matrix material is highly subordinate; "black aphanitic dikelets" cut the breccia near its margins; and the fenitization effects are unreported.

[1] Norra Kärr, Sweden and Semarule, Botswana (Bechuanaland).

[2] A complete list of references through early 1966 is collected in Heinrich and Anderson (1965), Heinrich and Shappirio (1966) and Heinrich and Dahlem (1966). Additional new information is in Staatz and Conklin (1966), Singewald (1966) and Heinrich (1967).

Origin

Vent breccias, also referred to as explosion pipes or breccia pipes, are widespread associates of alkalic-carbonatitic complexes (Heinrich, 1967): *e.g.*, Oka, Quebec; Manitou Islands, Ontario; Kentallen, Scotland; Avon area, Missouri. A wide variety of rock types (country rock gneisses, fenite, and all alkalic igneous rocks of the associated complex) is represented, and the matrix is invariably carbonatic. In many examples the disruption appears to have been contemporaneous or penecontemporaneous with the emplacement of a carbonatite stock within the complex or

Table 1. Sequence of Units in the McClure Mountain–Iron Mountain Complex

Within the complex itself	Within the dike halo
	11. Fenitization (local)
10. Carbonatites (rare)	10. Carbonatites (abundant) and Pinon Peak breccia pipes
9. Lamprophyres (rare)	9. Lamprophyres (abundant)
8. Nepheline syenite dikes	8. Nepheline syenite dikes (rare)
7. Nepheline syenite	
6. Ijolite	
5. Syenite and trachyte dikes (abundant)	5. Syenite and trachyte dikes (rare)
	4. Fenitization
3. Syenite	
2. Gabbro	
1. Peridotite and magnetite ilmenite rock	

with the emplacement of carbonatite dikes within and/or outside the complex. Usually most of the fragments, from their petrology, shape and size, give little evidence of having been transported vertically for any significant distances. Not uncommonly, however, such rock fragments generated essentially *in situ* are accompanied by a subordinate number of smaller rock pieces that *have* been elevated (*e.g.*, kimberlites and lamprophyres).

The Pinon Peak pipes, which probably coalesce with depth, appear to have been formed as the result of highly localized CO_2 gas-rich explosions, followed by some gas-streaming and fluidization which moved lamprophyre fragments upward and deposited calcite. Fenitization followed. Some alteration, *i.e.*, the biotitic type, preceded the last explosion, inasmuch as biotitized lamprophyre and matrix pieces have been elevated. The Pinon Peak breccia pipes are apparently the first to be described in which fenitization accompanied and followed the brecciation. This lends further support to the thesis that fenitization in alkalic complexes may be multiple and that it is a *consequence* of the ". . . differentiation and crystallization of the alkalic complex as a whole" (Heinrich, 1967, p. 291) rather than being the *cause* of the formation of the rocks of the complex.

Acknowledgments

We acknowledge with thanks assistance in the field and laboratory from Dr. R. W. Vian, I. S. Zajac, R. A. Garwood and Derwin Bell. The investigation has been supported by National Science Foundation Grant GP 3449.

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Manuscript received, May 5, 1966; accepted for publication January 31, 1967.