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ALKALIC ROCKS AND CARBONATITES OF THE ARKANSAS RIVER CANYON, FREMONT COUNTY, COLORADO. 3. THE AMETHYST CARBONATITES[1]

E. Wm. Heinrich and Joel R. Shappirio,[2]
The University of Michigan, Ann Arbor, Michigan.

Abstract

The Amethyst carbonatites in 12-Mile Park, Fremont County, Colorado are the northernmost representatives of the dike halo around the Iron Mountain-McClure Mountain alkalic complex. The deposits contain three main phases: 1) exomorphic zones of hematitized and feldspathized granite; 2) calcite-barite carbonatite and 3) veins of amethystine quartz. The first represents a variant of fenite; the last is a variation of the late-stage silicification common in many larger carbonatites. In the carbonatite, each of several calcite generations is characterized by a distinctive minor element assemblage. The deposits appear to have been begun in the magmatic stage and were concluded in the hydrothermal.

Introduction

Numerous thorium veins were explored during the radioactive boom of the 1950's in the Wet Mountains and the adjacent Wet Mountain Valley in Fremont and Custer Counties, Colorado (Christman *et al.*, 1959; Singewald and Brock, 1956; Heinrich, 1958). During this period a group of radioactive carbonate-rich deposits about one mile west of 12-Mile Park, in Fremont County (sec. 34, T. 17S., R. 72W.), was prospected. Subsequently, to the south, a major district of alkalic intrusives and related mineral deposits has been discovered (Parker *et al.*, 1962; Parker and Hildebrand, 1963; Heinrich and Dahlem, 1966). The thorium deposits herein described are the outermost representatives of the dike halo of the McClure Mountain-Iron Mountain complex; they are about 15 airline miles from the center of the complex; indeed they are the "farthest travelers" (Fig. 1).

Actually these deposits have long been known, but under a different guise—they were first explored as amethyst deposits (Sterrett, 1909; Sinkankas, 1959). Sterrett (1909, p. 808) described the deposit as follows:

"The amethyst is found in a vein or system of veinlets, ranging from several inches to 3 feet in thickness associated with a pegmatite streak. The amethyst occurs in streaks and veinlets varying from less than 1 inch to 3 or 4 inches in thickness and opening out into irregularly shaped pockets 8 or 10 inches across. The greater part of these streaks are (*sic*) vertical and parallel to the walls of the veins, though in some cases they are inclined and transverse to the vein. The veinlets are made up of layers of amethyst and smoky quartz

[1] Contribution No. 282 from the Mineralogical Laboratory, Department of Geology and Mineralogy, The University of Michigan, Ann Arbor, Michigan.

[2] Present Address: Institute for Exploratory Research, Army Electronics Command, Fort Monmouth, New Jersey.

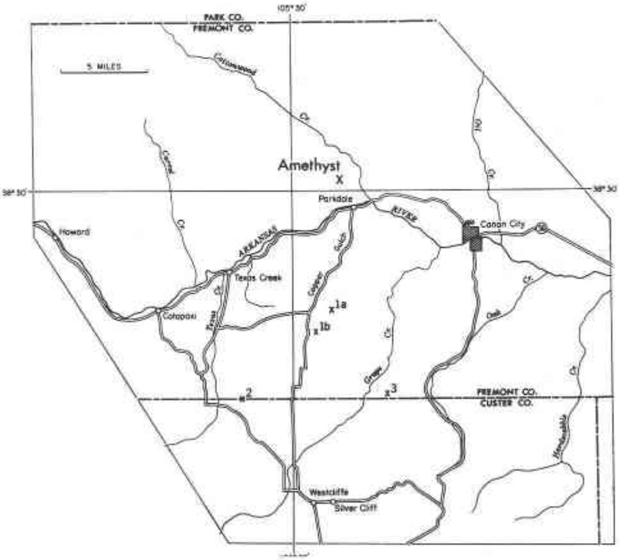

FIG. 1. Index map of Fremont and Custer Counties, Colorado showing location of Amethyst carbonatites. 1a–1b, Iron Mountain-McClure Mountain alkalic complex; 2, Gem Park alkalic complex; 3, Democrat Gulch alkalic complex.

crystals with comb structure. Nearly all the cavities have been completely filled with amethyst, so that few are obtained with perfect crystal form. Pink calcite forms a part of the vein filling in places. The wall rocks have been partly decomposed and hardened by silicification. The order of formation of parts of the vein appear (*sic*) to be: Fissuring, silicification of wall rock, deposition of calcite, more fracturing, deposition of smoky quartz, deposition of amethyst, deposition of shells of white quartz or amethyst crystals."

GEOLOGY

A dozen deposits have been found in a belt about 3000 feet long and 1000 feet wide whose long axis trends northwestward (Fig. 2). The area lies about one mile southwest of Cottonwood Creek in foothills of Precambrian rocks flanking the downfaulted wedge of Jurassic-Cretaceous strata that floors Cottonwood Creek Valley, which here broadens to form 12-Mile Park. The host rock of the dikes is the gneissoid Pikes Peak granite of Precambrian age whose foliation strikes generally northeastward and dips steeply to the southeast. The trend of the dike swarm is essentially at right angles to that of the host-rock structure. The zone of fractures along which the dikes were emplaced strikes parallel with the major thrust fault that marks the western margin of 12-Mile Park, separating Mesozoic strata from Precambrian granite (Shappirio, 1962, Plate I).

Locally within the Pikes Peak granite are blocky masses of fine-grained quartz-feldspar-biotite gneiss (Fig. 3), which apparently are xenoliths of paragneisses assignable to the Idaho Spring formation, the chief wall rock of the Pikes Peak batholith in this part of Colorado.

The only other rock that crops out in the area of the dike swarm is a thin lamprophyre dike, exposed for about 100 feet along the side of the access road to Shaft 3 (Fig. 2). Black and very fine-grained in hand specimen, this rock, microscopically, shows a microporphyritic texture with microphenocrysts and glomeroporphyritic clusters of titanian

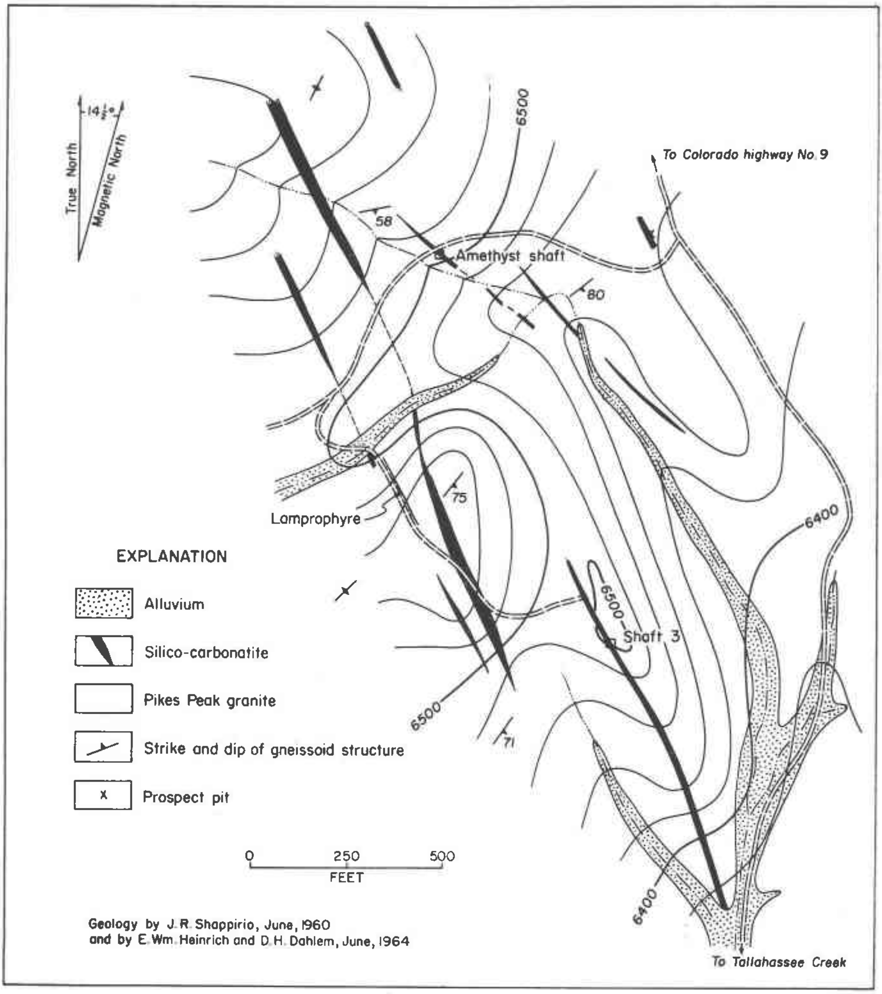

FIG. 2. Geological map of the Amethyst carbonatite area, Fremont County, Colorado.

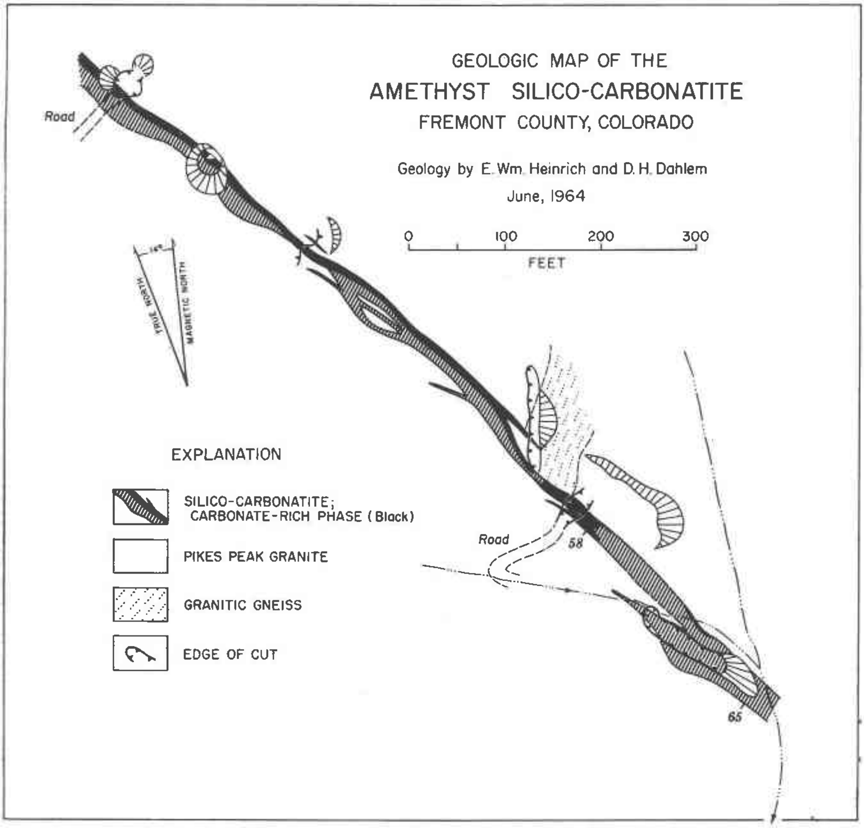

FIG. 3

augite (exceptionally developed "hour-glass" zoning!). These are dispersed throughout a much finer matrix that consists of abundant titanian augite, alkalic amphiboles, calcite and magnetite, with lesser altered plagioclase, and accessory apatite, quartz and possibly a little altered alkalic feldspar. The matrix augite, in subhedral to enhedral stubby prismatic crystals, is partly uralitized by arfvedsonite. This amphibole also forms as separate elongate prisms which are rimmed by thin zones of riebeckite. From its relief, the zoned plagioclase is apparently calcic, but so badly is it sericitized and zeolitized that even its approximate composition is not determinable. In addition to the phenocrysts, irregular patches of calcite and clumps of anhedral pyrite grains stud the rock. Some of the latter occupy the central part of glomeroporphyritic augite clusters. The rock can probably be assigned to the alkalic basalt porphyry group.

Individual carbonate dikes are 2–30 feet thick and some are traceable for 1000 feet. Poorly exposed except where prospected by means of bulldozer trenches, they are nevertheless readily traceable by float from the conspicuous reddish feldspathic wall-rock alteration zones.

Geology of the Main Dike

Only one of the dikes (the southeasternmost) is well exposed throughout most of its length (Fig. 3). It displays pinch-and-swell structure and numerous apophyses, the large ones of which diverge from the main dike at sharp angles, usually 15–20° (Fig. 3). Along the southeasternmost quarter, the internal structure is highly heterogeneous; separate units are not mappable. Northwest of the main cut the mineralized zone is well differentiated into a carbonate-rich phase and hematitic feldspar-rich phase (Fig. 4).[1]

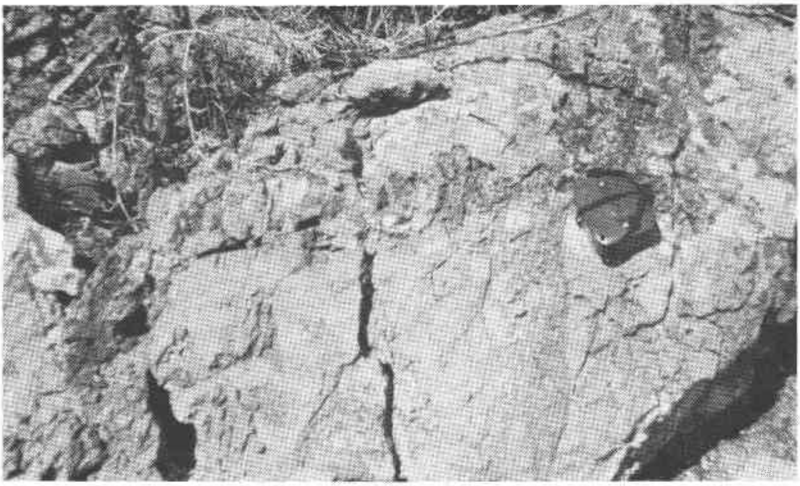

FIG. 4. "Burnt rock"—hematitized and feldspathized, fractured and brecciated Pikes Peak granite—forms the outer unit of the deposits.

The carbonate rock unit is 6–20 feet thick and is flanked on its southwest side by the feldspar rock. Since the carbonate rock unit dips 58–80° SW., the main feldspathic zone overlies it and is best developed on its hanging-wall side. The hematitic feldspar rock results from the alteration of Pikes Peak granite, strongly fractured, sheared and brecciated. Contacts of the carbonate rock with the "burnt rock" are sharp (Fig. 5). Along this fractured, brecciated zone the carbonate rock was emplaced.

[1] Locally called "burnt rock" or "red rock" by prospectors.

Numerous stringers of carbonate cut not only altered hanging-wall rock but the less altered footwall Pikes Peak granite as well.

In the shallow shaft at the top of the hill towards the northwestern end of the body, the dip changes to vertical, and a more complex zonal structure appears. Here the dike is about 6 feet thick, most of which is carbonate rock in which numerous elongate, angular xenoliths of feldspathized wall rock are suspended. A thick zone of altered red granite (about 15 feet wide) borders the dike on the southwest side. On the northeastern side of the dike is a zone, ½–1 foot thick, of barite-rich rock; this, in turn, is flanked to the northeast by a narrow zone of altered granite.

FIG. 5. Contact between "burnt rock" (dark, lower) and carbonatite (light, upper).

The texture and grain size of the dike are highly variable. Much of it shows multiple fracturing and brecciation (Figs. 6, 7). Locally, in unbroken parts, calcite rhombs as much as 6 inches across appear, and barite grains attain several inches in length. In contrast, large parts of the dike consist of angular particles of calcite, barite, hematitized and feldspathized granite, a fraction of an inch to several inches long, set in a pink to red to reddish brown, fine-grained to aphanitic matrix. Locally around some of the wall-rock fragments cockade-structure rosettes of pink to white calcite are developed, and similar rosettes radiate for an inch or less from nuclei that consist of a rounded crystal of an earlier calcite, zoned olive centrally and flesh-colored marginally.

Cutting both this brecciated rock and the adjacent hematitized, feldspathized and somewhat less brecciated granite are veinlets of hema-

Fig. 6. Brecciated carbonatite. Hanging-wall contact extends diagonally across upper right of photograph with "burnt rock" above.

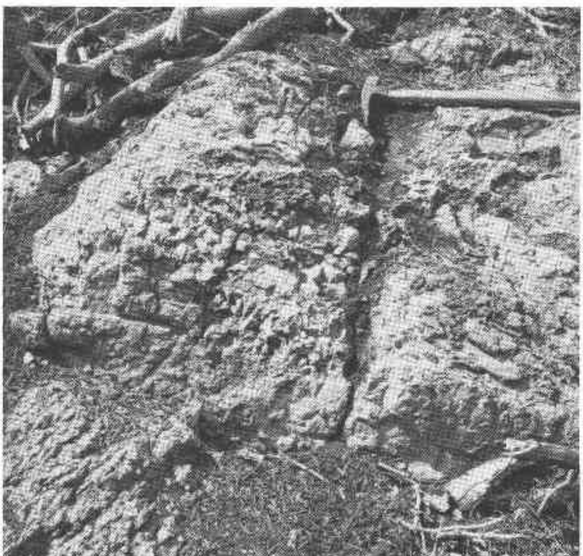

Fig. 7. Brecciated carbonatite. Xenoliths of altered wall-rock stand in weathered relief in lower right corner of outcrop.

tite, limonite and veins of quartz, chiefly amethystine and smoky. These too have been fractured and broken, and in places fragments of amethyst crystals have been incorporated in the carbonate breccia. Some amethyst groups also form cockade rosettes over coarse single rhombs of early calcite; the weathering solution of these leaves calcimold cavities in the base of the quartz crystals. Most of the veins are completely filled, but narrow, crystal-lined vugs as much as several inches long are not uncommon.

Mineralogy

Carbonatite. Thin section studies of the carbonatite show that the "fine-grained to aphanitic" matrix actually represents the micro-equivalent of the megascopic breccia. Micro-fragments of early calcite, of barite, of granite, of individual granite minerals, and locally even of vein quartz

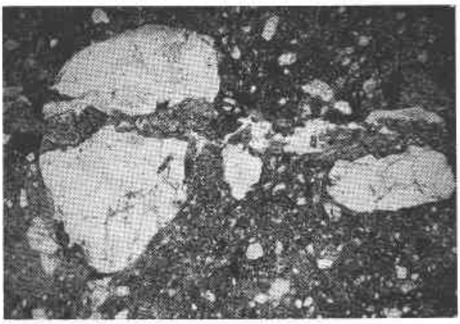

Fig. 8. Brecciated and mylonitized "burnt rock." Large pieces are granitic quartz fragments cut by a veinlet of ferroan calcite. Polars not crossed, ×16.

grade down to a size beyond optical resolution (Fig. 8). Thus locally this matrix becomes dark, cryptocrystalline to isotropic, and is indeed ultramylonitic in character. The chief minerals of the carbonatite, beyond those mineral fragments derived from the altered Pikes Peak granite, are calcite, barite and hematite. Coarse barite is abundant locally, and in the shaft at the top of the hill, forms an essentially monomineralic zone. Minor minerals of the carbonatite are chlorite, hematitic potash feldspar, quartz, illmenite (now mainly leucoxene) and magnetite (Table 1).

Because of extensive and recurrent fracturing, the sequence of mineral formation is unusually difficult to decipher. Fracturing opened the channelways; fracturing followed the initial deposition of calcite and barite, continued through a second carbonate stage, preceded the formation of quartz veins, and finally shattered some of these comb-structure veins.

A great number of different "varieties" of carbonate can be recognized from combined hand-specimen and thin-section examination: The main types are:

A coarse-grained zoned calcite with olive centers and pink margins (Calcite I).
A strongly zoned (Fe-rich) ferroan calcite.
A pink, fine-grained ("sugary") calcite, turbid microscopically.
White to pink calcite blades in radial clusters, plumose groups and comb-structure aggregates (Calcite II).
Thin veinlets of clear calcite (Calcite III).
Central fillings and crystal groups of calcite in vugs of amethyst veins (Calcite III).

Staining tests on numerous sawed surfaces with Alizarin Red S show that nearly all of the carbonates are calcite. Only a few grains of dolomite were found in several pieces, but the paragenetic position of the dolomite could not be determined.

Table 1. Mineralogy of the Deposits

Unaltered Pikes Peak granite	"Burnt rock"	Carbonatite	Quartz veins
quartz →	(quartz) →	(quartz)	smoky quartz
microcline →	(microcline) →	(microcline)	amethyst
oligoclase →	(oligoclase) →	(oligoclase)	milky quartz
biotite →	chlorite I	chlorite II	brown cherty quartz
		quartz	
schorl →	(schorl)	barite	
	hematite	hematite	hematite
	hematitic potash feldspar	hematitic potash feldspar	chlorite III
	ferroan calcite	ferroan calcite	
	calcite I	calcite I	
		calcite II	
	galena	ilmenite-leucoxene	calcite III
	chalcopyrite	magnetite	
	thorite		

Parentheses indicate a relict species.

The oldest of the carbonates appears to be a strongly zoned, ferroan calcite most of which was subsequently destroyed. Rhombohedral crystals and crystal remnants showing hematitic zones alternating with clear zones are associated with hematitic potash feldspar near carbonatite-"burnt rock" contacts and also appear as scattered relicts in barite aggregates. Elsewhere, in later carbonate, these rhombohedral zone outlines are pseudomorphously preserved as "ghosts" in a completely transgressive fabric of granular calcite.

Much of calcite I is post-barite in age. After deposition of barite, frac-

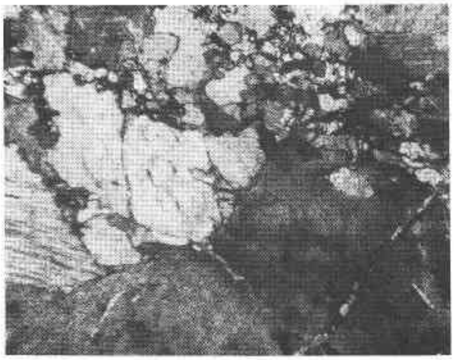

Fig. 9. Coarse barite (lower 2/3ds) showing fracturing, undulatory extinction and bent deformation twins (lower left). A vein of calcite I with rosettes of hematite platelets cuts the barite aggregate diagonally (upper 1/3d) and minute veinlets of calcite transect individual barite grains. Polars crossed, ×25.

turing was renewed: barite locally is brecciated with rotated pieces showing wavy extinction and bent twin lamellae. These are veined and marginally replaced by calcite I (Fig. 9), which may also show shearing and twin gliding. Breccia pieces of calcite I served as nuclei for initiation of replacement growth of rosettes of calcite II and of quartz. Calcite III forms thin veinlets across all other minerals and also appears as innermost fillings of amethyst veins.

Analyses of the calcites (Table 2) show that the early ferroan calcite is low in Sr, but that Sr is concentrated greatly in calcite I. The ferroan calcite is enriched in Mg as well as in Fe.

Two analyses of barites for Sr by *x*-ray fluorescence methods were made by Dr. Richard W. Vian (Heinrich and Vian, 1966):

AME-35	0.5% SrO
AM-6	0.65

Table 2. Composition of the Calcites (wt. %)

	Ferroan calcite (av. of 2)	Calcite I	Calcite II
Sr	0.01	1.5	0.27
Ba	0.12	0.31	0.26
Mg	0.44	0.05	0.11
Mn	0.18	0.16	0.08
Fe	1.26	0.15	0.18
Al	0.05	0.05	0.03
Si	0.20	0.07	0.08

Analyzed by S. H. Quon (1965), quantitative spectrographic methods.

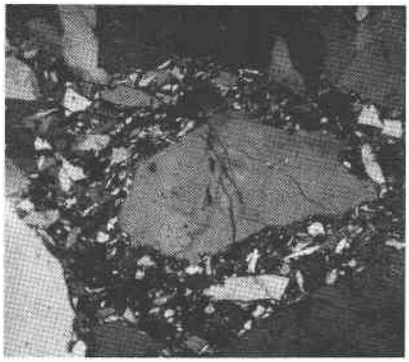

FIG. 10. Brecciated "burnt rock." Isotropic matrix around central quartz fragment consists in part of "amorphous" ultramylonitic material. Polars crossed, ×16.

These represent the highest Sr values obtained from barites from the Wet Mountain District. Barites from six other deposits have $SrO = 0.3 - 0.04\%$, average 0.12% (Heinrich and Vian, 1966).

"Burnt rock." The conspicuous red altered wall rock consists of fractured, brecciated and replaced Pikes Peak granite (Fig. 10). Biotite of the granite has been chloritized (chlorite I). Of the new minerals, the most abundant are hematite and a red hematitic potash feldspar which forms overgrowths on microcline fragments (Figs. 11a, b) and also replaces quartz. This process of feldspathization is a variation of fenitization in which chiefly K and Fe are added to the wall rock and Si is ab-

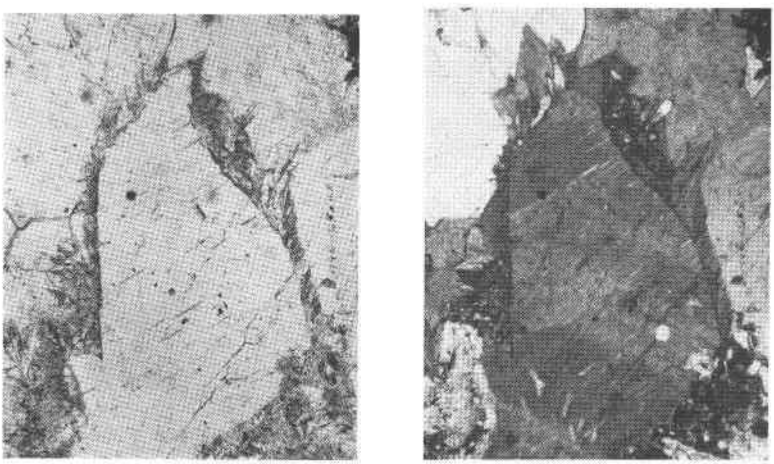

FIG. 11. Fragment of granitic microcline in "burnt rock" with overgrowth of new hematitic microcline. a. Polars not crossed; b. Polars crossed, ×16.

stracted (Heinrich, 1966). All Fe, present and added, is oxidized to Fe^{3+}, and much of it appears as nearly submicroscopic hematite flakes included in the new potash feldspar. From its optical properties this feldspar is a low-soda microcline, although the gridiron twinning is submicroscopic or obscured by the turbidity of the grains. Sodic pyroxenes or amphiboles are usually not developed as in more typical fenitization effects. However these minerals *do* occur with the same feldspar rocks to the south in the Wet Mountain District (Heinrich, 1958).

Such feldspar rocks may be developed as relatively large bodies, as, for example, in some of the alkalic carbonatitic ring complexes of eastern Africa, *e. g.:*

Mbeya, Tanganyika (Fick and van der Heyde, 1959)
Rufunsa Valley, Northern Rhodesia (Bailey, 1960)
Chilwa Island, Nyasaland (Garson and Smith, 1958)
Tundulu, Nyasaland (Garson, 1959)

These bodies of feldspar rock generally are pre-carbonatite in age. Later they may be brecciated, remobilized and intruded as rheomorphic dikes or carbonatized (Heinrich, 1966). They also have been developed in alkalic provinces even in the absence of directly associated carbonatites or other alkalic rocks. Brown (1964) has described occurrences in the Mbeya Range, Tanganyika, that are linear zones as much as 10 feet across and a mile long, formed by the replacement of various schists along their foliation. Staatz *et al.* (1965) have found elongate bodies of brick-red microcline replacing quartz monzonite in the southern Caballo Mountains of New Mexico. These rocks, just as in the Wet Mountain province of Colorado, are anomalously radioactive owing to Th (in thorite). The "burnt rocks" of the Amethyst deposits are identical with those of the "thorite veins" of the Wet Mountain district, 15–25 miles to the south (Christman *et al.*, 1959; Singewald and Brock, 1956; Heinrich, 1958; Phair and Fisher, 1961; Dahlem, 1965).

Minor amounts of carbonate are present in the "burnt rock," chiefly ferroan calcite and less calcite I.

Some of this rock has been so strongly granulated that it is essentially aphanitic in texture. This variant generally is the darkest red in color and is cut by additional seams of hematite. Also it is usually the most highly radioactive of all the rocks in the deposits. Many specimens of "burnt rock" show radioactivity values up to 0.3% e U_3O_8, but locally in vuggy limonitic zones formed along seams and fractures in the brick-red aphanitic variety values as high as 1.1% e U_3O_8 were obtained. The radioactive mineral is thorite (or thorogummite) (Shappirio, 1962). Uranium, as in the other deposits in the main part of the Wet Mountains District, is essentially absent (Christman *et al.*, 1959).

A strong fetid odor may be detected briefly, after striking or breaking the "burnt rock" and some of the carbonatite. Heinrich and Anderson (1965) have shown that this odor stems from a gaseous mixture of fluorinated C_5 and C_6 hydrocarbons.

Locally, particularly in the strongly radioactive zones, sulfides appear in the "burnt rock"—galena and chalcopyrite disseminated in grains as large as ¼ inch across.

Amethyst veins. In contrast to the carbonatite the paragenesis of the amethyst veins is readily determinable owing to crustification. Only two minerals appear, quartz and calcite.

The zoned quartz crystals, some as much as 3 inches long, are in comb-structure arrangement. The succession from the walls inward, generalized from numerous veins, is:

	% of crystal length
1. Wall rock—either carbonatite or "burnt rock"	
2. Milky crystal base	10
3. Smoky	25
4. Amethyst	12.5
5. Smoky	2.5
6. Amethyst	37.5
7. Milky	11.5
8. Smoky caps	1.0
9. Brown cherty quartz *or* calcite III	

Minor fracturing occurred locally after (8), inasmuch as broken pieces of amethyst appear here and there in brecciated carbonatite. The color of the amethyst is relatively uniform with essentially no zonal or edge concentrations, but the presence of numerous internal fractures limits the suitability to cabachon stones. Fracture zones across amethyst crystals are milky in color.

Not all the quartz formed by means of fracture-filling; some developed within carbonatite by replacement (Figs. 12, 13).

Only the widest veins show the complete color sequence listed above. Deposition of quartz was initiated at different times in different places in the deposit. Some veins of just smoky quartz and some of milky quartz also can be found.

Calcite III 1) may fill the entire central cavity; 2) may appear as clear vug crystals of scalenohedral habit; 3) combine 1) and 2); and 3) with marginal seams of chlorite III may form thin veinlets across quartz crystals (Fig. 14).

Late-stage silicification is, of course, a common phenomenon in many carbonatites; *e.g.*, Mountain Pass, California; Iron Hill, Gunnison Co., Colorado; Amba Dongar, India; Nachomba, Northern Rhodesia. Much of this late quartz appears as a hematitic cherty rock, but coxcomb veins

FIG. 12. Rosettes of quartz grains radiating from nucleus of a fragment of calcite I (bottom, center). In carbonatite. Polars crossed, ×16.

also are known. The appearance of the SiO_2 as amethyst is, however, unusual in this environment.

Quartz is a widespread constituent of the thorium veins of the Wet Mountain District; most " . . . is white and massive, but euhedral crystals are common and many are smoky and zoned" (Christman et al., 1959, p. 520), Dellwig and Hill (1960) found that smoky zones were

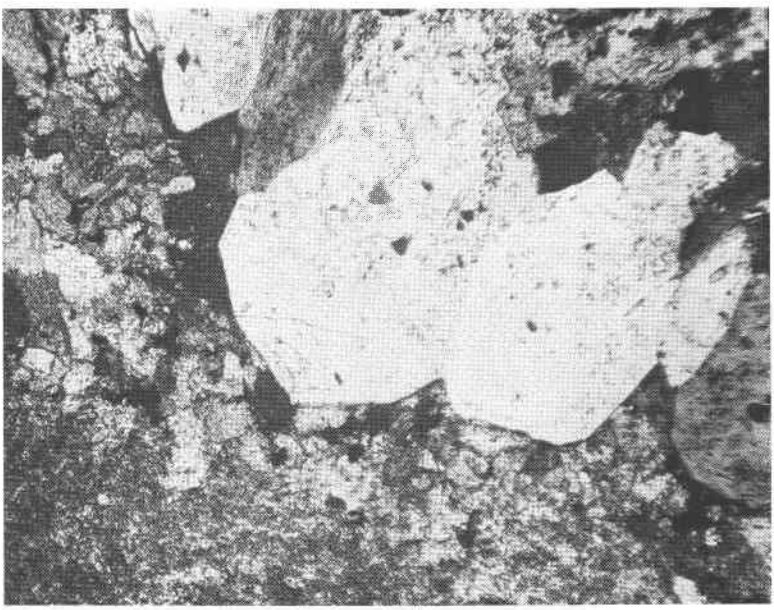

FIG. 13. Amethystine quartz crystals in comb structure arrangement, replacing carbonatite. Polars crossed, ×50.

invariably biaxial with 2V's up to about $7\frac{1}{2}-8°$, whereas the colorless zones were either uniaxial or biaxial with 2V's of "less than several degrees." The smoky zones contain slightly higher amounts of Mg, V and Al, the last element being in all likelihood responsible for the smoky color.

Amethyst in carbonatite also has been reported by Kukharenko and Dontsova (1962) who state only (p. 34) "The greatest number of fluid inclusions in crystals of morion, milk-white quartz and amethyst occurring in ankeritic-calcitic carbonatites are most often destroyed in the temperature range between 375° and 400°."

One of the principal changes during fenitization is the subtraction of relatively large amounts of SiO_2 from granitoid wall rocks to form fenites (metasomatic alkalic syenites). Several investigators have suggested

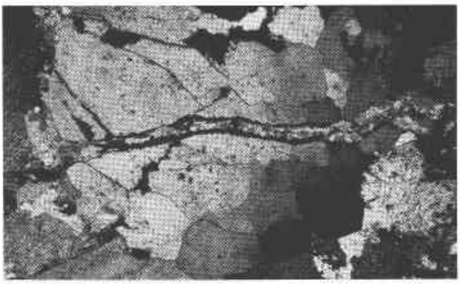

FIG. 14. Amethystine quartz cut by veinlet of calcite III that has thin selvages of chlorite. Polars crossed, ×16.

that this silica remains in solution until post-carbonatite time when it is reutilized to form veins and replacement masses of quartz (Heinrich, 1966).

PARAGENESIS

Because of the many periods of intra-mineralization fracturing, the paragenetic sequence is difficult to decipher. The period of wall rock alteration apparently overlapped to some extent the early stages of crystallization in the carbonatite, for *some* hematitic microcline has replaced barite, which is one of the earliest carbonatite species. However, many xenoliths of "burnt rock" in carbonatite appear to have been incorporated *after* their alteration from Pikes Peak granite. The following generalized sequence of events has been reconstructed (capital letters indicate major or important component; lower case minor or accessory component):

1. Intense fracturing, brecciation and mylonitization of Pikes Peak granite. Much of the micro-fragmentation appears to have resulted from explosive activity; even many of

the very small fragments are angular and sliver-like and show little or no effect of having abraded one another (Fig. 10). (Less commonly some abrasion rounding has taken place—Fig. 8). The rock along the zones was literally blown to microsmithereens.

2. Feldspar-barite stage

In "burnt rock"	*In carbonatite*
HEMATITIC MICROCLINE	BARITE
chlorite I (after biotite)	FERROAN CALCITE
ferroan calcite	chlorite II (seams)
	ilmenite
	magnetite

3. Fracturing

4. Calcite stage

In "burnt rock"	*In carbonatite*
calcite I	CALCITE I
hematite	
quartz	

5. Fracturing

6. Thorite stage

In "burnt rock"	*In carbonatite*
HEMATITE	CALCITE II
THORITE	hematite
galena	quartz
chalcopyrite	
calcite II	
quartz	

7. Fracturing

8. Amethyst stage
   a. QUARTZ (see sequence under "Mineralogy—Amethyst veins")
   b. Fracturing
   c. Chlorite III
   d. CALCITE III

9. Supergene stage
   Limonite, malachite, anglesite

Discussion

Age. In their structure and mineralogy the Amethyst carbonatites are essentially identical with those studied by Dahlem (1965) in the Lookout Mountain area to the south and southwest and with the thorite veins of the remainder of the Wet Mountain district still further south (Christman *et al.*, 1959). The Lookout Mountain deposits are genetically related to the alkalic complex of Iron Mountain-McClure Mountain and those further south to the Democrat Gulch complex. The age of the syenite of the Democrat Gulch complex has been determined by the Larsen zircon method to be 595 my (Christman *et al.*, 1959). Syenite of the Iron Mountain-McClure Mountain complex is very similar to that of Democrat Gulch, and, indeed, the two complexes have other features suggesting consanguinity (similar dike rocks, associated gabbro, associated breccia pipes). Thus it appears that these alkalic complexes and their associated dikes and mineralization all are of youngest Precambrian (or earliest Cambrian?) age. If this is indeed the case, there remains to be explained the localization of the Amethyst deposits along fracture zones that parallel the fault bounding 12-Mile Park on the west—a fault of Laramide or Tertiary age. This northwest direction of faulting is a major fault-fracture direction throughout the Arkansas River Canyon area and may represent rejuvenation of movement along faults initiated in Precambrian time.

Phair and Fisher (1961), however, suggest that the breccia zones were feldspathized and mineralized by heated groundwaters trapped beneath caps of impervious lavas (of Tertiary age). Neither the geology of the deposits nor the vertical range of their distribution with respect to the elevation of lava remnants, *for the area as a whole*, supports this hypothesis.

Carbonatitic features. It is perhaps noteworthy that of all the carbonatites studied in the area, those of the Amethyst group display the most intensely developed fracture and brecciation structures, suggesting violent initial emplacement and recurrent shattering. In addition, they are the most distant representatives of the Iron Mountain-McClure Mountain dike swarm. This combination of characteristics attests to the enormous propulsive and explosive power the parent fluids must have possessed.

Both the mineral assemblages and the structures and textures indicate that the formation of the bodies extended from magmatic to hydrothermal conditions. Early-stage characteristics include sharp contacts, lack of "replacement-type" textures, unsupported xenoliths of altered wall-rock and the abundance of high-Fe and high-Sr calcites. Later-stage features, suggesting deposition from lower temperature, more dilute hydrous fluids, include the rosette overgrowths, comb-structure veins and the abundance of low-Sr calcite and smoky and amethystine quartz.

In short, even as in most core-type carbonatites, these relatively small dikes display many features typical of their larger relatives: 1) evidence of explosive activity, 2) wall-rock alteration, 3) evidence of forceful intrusion of a carbonate-rich fluid, and 4) evidence of multiple-stage development with several generations of carbonate species showing systematic compositional variations.

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