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Geology and Beryllium Mineralization Near Apache Warm Springs, Socorro County, New Mexico

by PATRICK D. HILLARD

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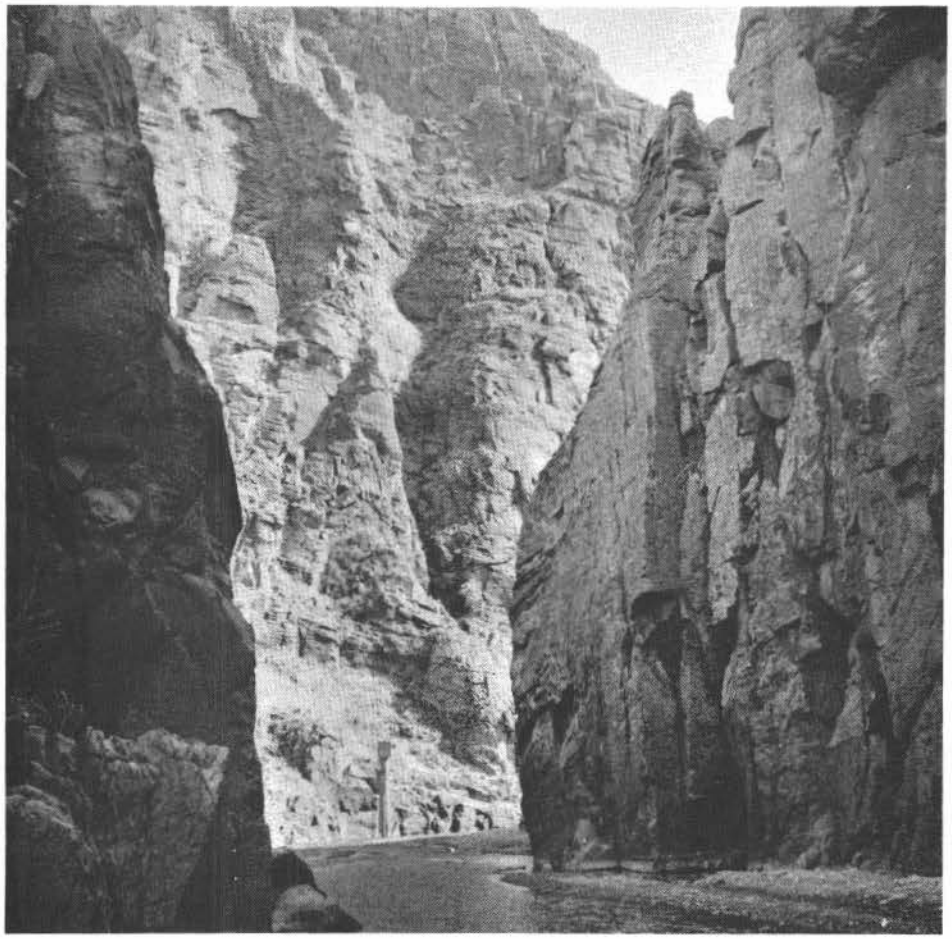

Andesite along Monticello Canyon "box". Looking east in upper part of canyon. Flow layering dips northeast. The water originates from warm spring rising in the stream bed.

Abstract

The volcanic rocks exposed southeast of Apache Warm Springs, Socorro County, New Mexico, include Tertiary pyroclastics, andesites, latites, rhyolite tuffs, and flow rhyolites. The pyroclastics, andesites, and latites are older than the Datil Formation and are propylitized. The rhyolite tuffs and flows are equivalent to lower Datil and are altered only locally.

Quaternary Winston beds probably equivalent to the Santa Fe Group occur along the west edge of the mapped area. They consist of locally derived sandstone, siltstone, and conglomerate.

In 1961, beryllium mineralization was discovered near the west end of Monticello Canyon and subsequently was explored by drilling. The ore mineral has been identified as bertrandite and is associated with widespread hydrothermal kaolinitization, alunitization, montmorillonitization, and silicification of the country rock. The ore mineral bertrandite is restricted to one highly faulted and brecciated zone in an altered rhyolite tuff. The mineralized breccia contains from 0.05 to 2.5 per cent beryllium oxide. The bertrandite occurs as light yellow-green fibrous crystals coating breccia fragments and as spheres, not more than 50 microns in diameter, disseminated in a clay matrix. To date, no beryllium has been commercially produced.

Introduction

A small amount of uranium was reportedly produced from the highly altered area about half a mile south of "The Box" at the western end of Monticello Canyon, Socorro County, New Mexico. Beryllium mineralization was also discovered there by M. Howard Milligan in November 1961 while he was prospecting with a berylometer. Subsequent sampling and drilling by Winston Mines, Inc., disclosed a small body of fault breccia and fault gouge containing bertrandite ($H_2Be_4Si_2O_9$). To date, no beryllium has been commercially produced from the deposit.

Previous work in the general area includes mapping and mineral studies by Jahns and Glass (1944) at Iron Mountain, about 6 miles to the south. The Luera Spring 30-minute quadrangle was mapped by Willard (1956). Between 1961 and 1965, Winston Mines, Inc., did considerable drilling and sampling and Milligan did a limited amount of mapping.

The field work for this report, consisting of geologic mapping and sampling, was done during the summers of 1965 and 1966. Laboratory work, consisting of spectrographic analyses, X-ray analyses, and thinsection studies, was done in the spring and fall of 1966.

ACKNOWLEDGMENTS

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Thank are due M. Howard Milligan, mining geologist and registered professional engineer of Albuquerque, for making available to me drill-hole logs and cuttings, samples and results of a geochemical sampling program, maps of the altered area, and the use of his house in Winston during field work.

I also wish to express appreciation to James Cox and Mrs. Eunice Travis for granting access to their land for field work.

LOCATION AND CLIMATE

The area studied covers approximately 5.5 square miles at the north end of the Sierra Cuchillo and includes the eastern half of Warm Springs Apache Indian Reservation (abandoned); sec. 35 and the western half of sec. 34 in T. 8 S., R. 7 W.; sec. 1, sec. 2, the western half of sec. 3, the northern half of sec. 12, the northern half of sec. 11, and the northwest quarter of sec. 10 in T. 9 S., R. 7 W.

The beryllium deposit lies about half a mile south of the west end of the Monticello Canyon "box". Apache Warm Springs lies in the northwest corner of the area. Alamosa Creek flows through Monticello Canyon across the northern part of the area.

Elevation ranges from 6000 to 7100 feet. Topography of the western fifth of the area is gently rolling and grass-covered. Cedar, pinon, and a few pine trees are widely scattered, except on north-facing slopes where they are fairly thick. The eastern four fifths of the area are rugged with many near-vertical faces and steep-walled arroyos and canyons. Vegetation includes grass, cactus, and scattered cedar and pinon trees.

Winston is 15 miles to the south of Apache Warm Springs via N. Mex. 52, of which the first 6 miles are well-graded dirt, the remainder paved secondary road. Truth or Consequences lies 39 miles southeast of Winston and is reached from Winston by 30 miles of paved N. Mex. 52 and 9 miles of U.S. 85. Flash floods two or three times each summer render N. Mex. 52 impassable for several hours.

Climate is mild during the summer with temperatures reaching a low of 45°F at night and a high of 90°F during the day. Afternoon thunderstorms are common in late summer. Winter temperatures range from a nighttime low of 0°F to a daytime high of 50°F. The winter daytime temperature sometimes does not exceed 30°F for several days. Snowfall is generally light, but snows of 5 or 6 inches occur during some winters.

Apache Warm Springs near the Monticello Canyon "box" discharge about 2000 gallons of water a minute at a temperature of about 85°F. This water is legally assigned to the people of Monticello village about 17 miles downstream.

Geology

The area studied contains Tertiary andesites, latites, rhyolites, and rhyolite tuffs with sediments derived from them. The andesites and latites show moderate to strong propylitization. An unconformity exists between the rhyolite interval and the andesite-latite interval. Dikes of andesite, latite, and quartz latite intrude the andesite-latite flows. Some of the dikes of the area have a phaneritic texture, but because they are genetically related to the flow rocks, they are given names commonly applied to eruptive volcanics. According to the reconnaissance map of the Luera Spring 30-minute quadrangle (Willard), the andesite-latite units are older than the Datil Formation and the rhyolite sequence here lies at the base of the Datil Formation.

The area is highly faulted, being on the eastern edge of the graben between the Sierra Cuchillo and the Black Range.

The beryllium deposit consists of bertrandite ($H_2Be_4Si_4O_9$) deposited in fault gouge bordering a down-faulted block of altered rhyolite tuff. A much smaller concentration of beryllium mineralization occurs in a small part of a fault in the adjacent altered andesite-latite flow rock.

PYROCLASTIC LATITE

The pyroclastic latite occupies the eastern section of the area along Monticello Canyon. Its contact with the overlying latite-andesite flows is exposed on the nearly vertical cliff on the south side of the canyon. Here the pyroclastic latite is a minimum of 600 feet thick. All beds are nearly horizontal or dip gently to the southeast. Whether these are initial dips or the result of tilting is not known.

Colors range from very light gray to very dark gray. Clasts range from 5 feet across to a fraction of a millimeter. Some are composed of andesite, others are latite. No clasts of a composition other than andesite or latite were observed.

The matrix material is latitic, composed of very small irregular grains of plagioclase and potash feldspar. Larger single crystals of magnetite, bleached biotite, plagioclase, and potash feldspar are present. A very few fairly well-rounded glass fragments about half a millimeter in diameter were observed.

Sorting is poor but recognizable. The large clasts in the sorted beds are approximately 9 inches across. The larger clasts are generally surrounded by material 10 mm or less in size and are not in contact. Other beds up to 20 feet thick contain only material below 10 mm in diameter, with no large clasts. Some of the better sorted beds are at least 20 feet thick and are graded, the clasts being moderately well rounded. This may indicate that a part of the pyroclastic latite unit is the result of water deposition, but it could also reflect abrasion of large clasts during transportation in an ash flow.

Topography on the pyroclastic latite consists of steep but even slopes and rounded hilltops. Cliffs do not form except where capped by a more resistant formation, as in the cliff on the south side of Monticello Canyon.

ANDESITE–LATITE FLOWS

Flows of propylitized andesite and latite comprise the principal rock unit in the area *(frontispiece)*. They are intruded by dikes of similar composition and contain xenoliths of coarse- to fine-grained granite, some of which have a gneissic structure. These xenoliths range in size from several inches to 70 feet or more across.

Flow layers are commonly on the order of 1 inch thick, but slightly to the south and east of the center of the area, individual layers are 3 or 4 feet thick. Preferred orientation of platy and prismatic minerals is present in the thinner flow layers but not in the more massive ones. The thin layers weather out in thin flat slabs while the thick massive layers weather out in blocks that tend to be spheroidal.

Table 1 lists the modal compositions of a latite and a quartz latite from the area based on thinsection and stained-slab observations. Texture is porphyritic with phenocrysts of andesine, quartz, orthoclase, hornblende, and pyrite. The groundmass is also composed of these minerals in grains approximately 0.05 mm across.

Quartz occurs both as phenocrysts and as part of the groundmass. As phenocrysts, it is generally not more than 1 mm across and is very irregular in shape because of corrosion. In the groundmass, quartz grains are rounded and irregular in shape with a single grain often being composed of several crystals. Irregular extinction is common. Potash feldspar phenocrysts are up to 3 mm square. In the groundmass, they are euhedral to irregular in shape. Alteration products are white mica and kaolin.

Andesine phenocrysts 12 mm long are slightly corroded. Andesine in the groundmass is lath-shaped with no apparent corrosion. Alteration of andesine to epidote, sericite, and kaolin is generally severe, so much so that in some rocks only the crystal outline is left.

Hornblende forms lath-shaped crystals both in the groundmass and as phenocrysts up to 4 mm long. Alteration products are epidote, magnetite, and hematite.

Magnetite occurs as octahedral crystals and irregular aggregates up to 2 mm across. Some of these aggregates are

TABLE 1. MODAL ANALYSES

MINERAL	LATITE	QUARTZ LATITE	MASSIVE RHYOLITE	LATITE DIKE	QUARTZ LATITE DIKE	PORPHY-RITIC ANDESITE DIKE	BASALTIC ANDESITE DIKE
Quartz	8	15	70	10	15	5	2
K-feldspar	20	25		32	6	20	
Plagioclase (undiff.)				30			
Andesine	25	25			20	40	75
Hornblende	10	10					
Augite							10
Sanidine			20				
Albite					28		
Biotite				5	3	3	
Apatite							minor
Opaque minerals	5	8	5	5	5	3	10
White mica	7	3	4	5	3	5	
Epidote	15	6	1			14	
Kaolin	8	8		5	10		
Chlorite				3	5	10	3
Calcite	2			5	5		

enclosed by andesine. Pyrite occurs as cubic crystals 0.25 to 1.5 mm square, some of which are badly corroded. Goethite-limonite and hematite are alteration products of hornblende and pyrite.

In the west-central part of the area, latites and quartz latites are the predominant rocks. The flow bands are contorted to degrees varying from slight flexures to almost isoclinal folds (pl. 1; fig. 1 a, b).

In these contorted areas, fault zones a foot or so wide contain clasts of flow-banded latite in random orientation. These zones are completely filled and healed with more latite that shows no flow banding.

Associated with the more intensely contorted latite are certain flow zones consisting of several adjacent flow layers containing spheroids of latite from 1 inch to 6 inches in diameter; these are harder than the rest of the rock. Only the flow layers roughly tangential to the spheroids are deflected. There is no evidence of flow banding in the latite spheroids; hornblende and plagioclase prisms are randomly oriented.

Some of the spheroids are almost all quartz latite with only scattered stringers of chalcedony, while others have a small central filling of quartz, amethyst, calcite, fibrous epidote, and chalcedony. A few have a central vug that allows for good development of the above-mentioned crystals. One of these spheroids contained a well-developed but slightly corroded light green fluorite octahedron about 3 mm long and several barite crystals of similar size, all formed on a matrix of clear quartz crystals. No mineralized areas were observed in the immediate vicinity. The spheroids differ from varioles and spherulites in that they have either a random or concentric internal structure rather than a radial one. Primary origin in some way connected with the primary flowage of the latites is indicated for these spheroids. They are restricted to certain flow layers, cause warping of the flow banding, occur only in the most contorted areas of the flow, and are unrelated to postflow phenomena. Except for small irregular stringers of chalcedony and the above-mentioned minerals, which sometimes occur in the center, their composition is the same as that of the flow in which they occur.

The presence of fluorite and barite inside these primary openings indicates that the constituents of these minerals were contained in solution in the original flow, although no other such occurrences of fluorite, barite, or related minerals were noted.

Faulting is widespread in the andesite-latite sequence. Along the larger faults, gouge zones are as much as 40 feet wide. They contain clasts of rock from both sides of the fault in a very fine altered claylike matrix. This extensive faulting causes rugged topography with many cliffs and very steep-walled arroyos along the faults.

INTRAVOLCANIC SEDIMENTS

In some places, the massive rhyolite is underlain by flow andesite and at other places by a sedimentary unit composed of grains from silt to sand sizes in well-sorted beds, some ranging from 1 mm to 10 mm thick. In the southeast corner of the area, a few of these beds are slumped and rolled up. These beds at places contain fragments of andesite and latite up to 30 mm across. The fragments show no preference for a particular bed and appear to have been dropped into the sediment from a source unrelated to the rest of the deposition. These clasts locally comprise as much as 20 per cent of the total rock.

Where the grains of the sediments are large enough to see with a petrographic microscope, they are mainly quartz, potash feldspar, plagioclase, magnetite, epidote, calcite, chlorite, and white mica. The flat or elongate grains show a preferred orientation parallel to the bedding planes.

This unit is up to 30 feet thick in the southeast and northwest sections of the area and is absent in between.

The sediment appears to have been deposited during the waning stages of, or immediately following, the andesite-latite interval, as indicated by the clasts of andesite and latite. For this reason, and because outcrops are small and widely scattered, the unit is mapped as part of the andesite-latite interval.

RHYOLITE TUFF

Rhyolite tuff occurs under flow-banded rhyolite and on top of the flow andesite. At many places, there is a pale green glass or black vitrophyre at the base. Color ranges from lavender gray to white, with pink to light reddish-brown the most common. Texture is felsitic to porphyritic with widely scattered vugs up to 8 mm in diameter containing small quartz crystals.

Clasts of sanidine, quartz, and biotite up to 4 mm in diameter are present, generally not exceeding 5 per cent of the rock. Some of the biotite is bleached copper red. The groundmass is aphanitic and is welded to varying degrees. As a general rule, white tuff is least welded and pink tuff is most welded, lavender tuff being intermediate. Some of the pink tuff contains, in addition to the clasts mentioned, some small angular, subangular, euhedral, and rounded quartz fragments 0.05 to 0.25 mm in diameter that make up as much as 40 per cent of the rock. Other outcrops of pink tuff contain none of these small clasts and only 1 to 2 per cent of the large ones. No shards were observed in any of the tuff.

The only outcrop of white tuff is just to the west of the beryllium ore body. It contains euhedral sanidine laths, rounded quartz fragments, and fresh biotite flakes. Because of its topographic position and fault contacts, it is impossible to determine its stratigraphic position with respect to the lavender tuff which crops out a short distance to the north of the ore body. However, the fact that the white tuff is more nearly like the flow-banded rhyolite in composition (number of phenocrysts) suggests that it may lie above the lavender tuff.

Topography on the tuff is generally subdued and gently rolling; however, the pink tuff forms prominent outcrops at

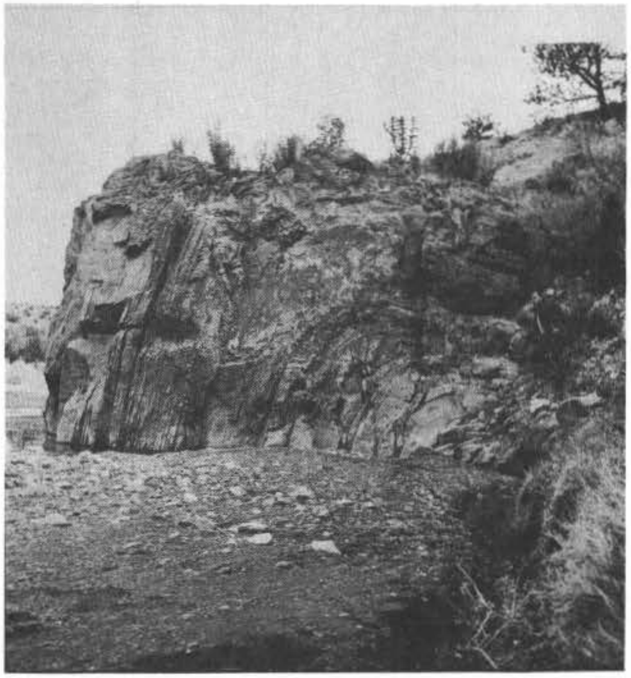

Figure 1a
Primary flow folding in Latite. In Monticello Canyon 1/4 mile east of the mapped area

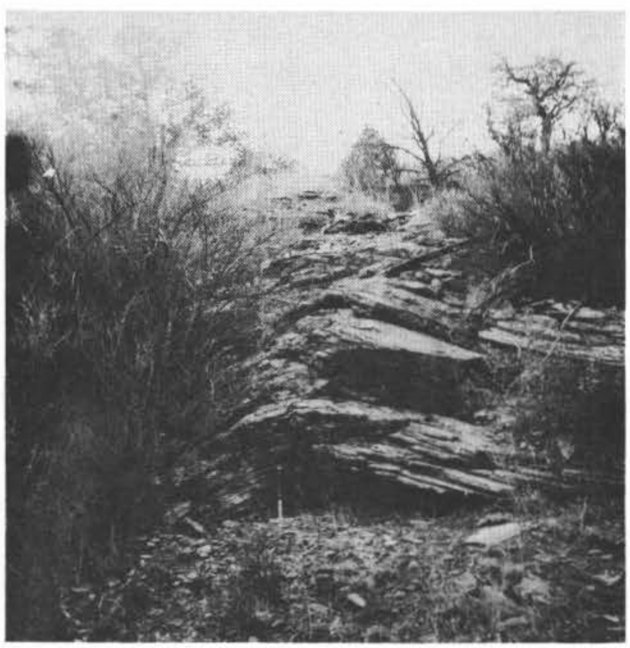

Figure 1b
Primary flow folding in quartz Latite.
West central part of mapped area.

some localities along faults, probably because of a greater degree of welding. In the north-central part of sec. 35, T. 8 S., R. 7 W., prominent spires are formed by differential weathering at the probable junction of two faults in the pink tuff.

MASSIVE RHYOLITE

Massive rhyolite occurs in a roughly linear group of outcrops along a northwest-southeast line through the center of the area. The highest stratigraphic unit where it occurs, it is a white massive rock containing rounded and corroded quartz grains up to 10 mm in diameter and altered sanidine phenocrysts up to 15 mm.

Table 1 also gives a visual estimate of composition based on sodium cobaltinitrite staining and thinsection.

About 10 per cent of the rock consists of sanidine phenocrysts from 0.5 to 15 mm long and another 10 per cent is composed of quartz phenocrysts from 0.5 to 10 mm in diameter. The other constituents listed make up the groundmass and are about 0.05 mm in diameter.

The sanidine is partly altered to white mica. A sodium cobaltinitrite stain test indicates that it is high in potassium. The quartz phenocrysts are rounded and corroded with many deep re-entrants. Some quartz phenocrysts were broken when the rock was nearly solidified, as shown by matrix material between fragments of quartz that could be fitted together perfectly. The opaque minerals are magnetite and hematite or limonite pseudomorphs after magnetite. The epidote occurs as isolated grains.

Massive rhyolite from the southeast corner of the area has a much finer, almost glassy, matrix and a higher percentage of rounded quartz phenocrysts. The massive rhyolite is a tabular unit 25 to 40 feet thick parallel to the underlying units. It is locally tilted at angles up to 35 degrees. On hillsides, it often forms prominent outcrops because of crude columnar jointing.

FLOW–BANDED RHYOLITE

Flow-banded rhyolite occurs only in the north-central part of the area. Immediately to the north, it constitutes a major portion of the surface rocks.

The flow-banded rhyolite outcrops range in color from medium gray to white. The flow banding is composed of irregular but generally parallel bands of finely pumiceous material alternating with compact glassy material. Individual bands are 1 to 8 mm thick with the pumiceous bands tending to be somewhat thicker. The glassy bands contain isolated stringers of quartz. Euhedral sanidine laths up to 5 mm long are distributed evenly throughout the rock, comprising about 8 per cent of it. An equal percentage of euhedral quartz phenocrysts and angular fragments is present.

The groundmass is too fine-grained to be analyzed microscopically, but a sodium cobaltinitrite stain test indicates that it is composed of some potassium-bearing mineral, most likely a feldspar or a potassium-rich glass.

The flow-banded rhyolite is very brittle, and wide zones of breccia and gouge have developed along faults. In the northeast section of the area, the fault gouge between the flow-banded rhyolite and the pyroclastic latite consists largely of flow-banded rhyolite fragments.

The flow-banded rhyolite forms steep-walled canyons. Columnar cooling joints cause it to form very prominent outcrops, especially where it caps hills of rhyolite tuff.

WINSTON BEDS

Winston beds, probably an equivalent of the Santa Fe Group (Jahns and Glass), occupy roughly the western fifth of the mapped area. They are a locally derived sedimentary unit exhibiting graded bedding with particle sizes from silt to 2-foot boulders. Maximum thickness is at least several hundred feet.

Clasts are almost entirely flow-banded rhyolite. A few clasts of the rhyolite tuff and andesite, present close to outcrops of these rocks, are often large and very angular, indicating little transport. On the other hand, clasts of flow-banded rhyolite are generally not more than 8 inches in diameter and are moderately to well rounded. In the graded beds containing large clasts, the interstices are filled with smaller rock particles, down to silt size, and are cemented with calcite. Other beds contain only gravel, sand, or silt with calcite cement.

Faulting has produced some major displacements between the Winston beds and other rock units. At the head of the "Monticello Box," Winston beds lie on rhyolite tuff and are faulted against flow andesite. It is possible that the sediments were deposited on the rhyolite tuff before faulting and the displacement is the thickness of the rhyolite tuff plus at least the 500 feet of flow andesite exposed; or the Winston beds could have been deposited on the tuff during faulting, in which event their total displacement is something less than that of the tuff. Other faults within the Winston beds are indicated by alignment of drainage patterns.

Topography on the Winston beds is gently rolling with an occasional vertical arroyo bank a few feet high.

LATITE DIKES

Latite dikes occur in the northeast, west-central, and southeast sections of the area. Most of these dikes are approximately 12 feet wide. However, one near the eastern edge of the area in Monticello Canyon is extremely variable in width, reaching a maximum of almost 400 feet. Cooling joints perpendicular to the sides are present. The color of the latite dikes ranges from light greenish-gray to brown.

Plagioclase phenocrysts up to 10 mm long and flat altered pseudohexagonal biotite crystals up to 2 mm across are common. Quartz grains generally do not exceed 1 mm in diameter. The groundmass is composed primarily of potash feldspar with lesser amounts of plagioclase, quartz, and highly altered biotite.

The dike along Monticello Canyon possesses a planar structure parallel to its sides. This structure is due to parallel alignment of biotite crystals, plagioclase laths, and irregular quartz stringers and is further accentuated by many planes of slickensiding within and parallel to it.

This dike is intruded by a narrow dike of porphyritic andesite. It is doubtful whether this latter dike is related to the intrusion of the latite dikes.

A sample from the latite dike in Monticello Canyon (table 1) was too badly altered to permit accurate determination of the variety of plagioclase, but one or two of the least altered crystals may be labradorite.

The other latite dikes are regular in shape and have vertical dips. They are porphyritic to phaneritic, and there are no visible planar or linear structures other than cooling joints.

PORPHYRITIC ANDESITE DIKES

Porphyritic andesite dikes intruding the andesite-latite flows and the pyroclastic latite are common throughout the area. They range in width from about 1 foot to 15 feet.

These dikes are usually dark olive-green, largely due to the great amount of alteration they have undergone. Plagioclase and ferromagnesians have altered to chlorite and epidote. The few fresh porphyritic andesite dikes in the area have a dark gray groundmass with white plagioclase phenocrysts.

The dikes in some places form an anastamosing or bifurcating pattern, as in the southwest and south-central parts of the area. It is likely that the pattern is equally complex in three dimensions.

An approximate composition of a sample of the porphyritic andesite is shown in Table 1. In some areas, the dikes were much more altered than the one from which this sample was taken; in other areas, the dikes were somewhat fresher. Quartz occurs in the groundmass as grains 0.25 mm and smaller. In the groundmass, andesine occurs as phenocrysts up to 10 mm long and as needlelike laths no longer than 0.5 mm. The phenocrysts are almost completely altered to epidote and calcite, while the andesine of the groundmass is noticeably less altered. Potash feldspar is restricted to the groundmass and is partly kaolinized. The opaque minerals are irregular grains of magnetite and small masses of hematite.

The porphyritic andesite dikes have small influence on topography, partly because of their usually small size. However, they are generally somewhat more resistant to erosion than the surrounding rock, forming slight topographic highs along their outcrops.

BASALTIC ANDESITE DIKES

The largest basaltic andesite dike extends from the center of the area to the west-central edge of the volcanics. It averages about 200 feet in width. Where fresh, it is a dense, dark gray rock with some inclusions of wall rock, including a latite dike that borders it to the north. Many of these inclusions are highly pyritized.

Where altered, the basaltic andesite dike rock is reddish-yellow to white and quite soft. In the most altered areas, basaltic andesite dikes are difficult to distinguish from andesite-latite flows.

The composition of a relatively unaltered sample of the basaltic andesite is shown in Table 1.

About midway along the length of the dike, there is an abrupt S curve. This may be initial, but it could also result from the northeast-trending fault that intersects the dike near the middle of the curve. The rock in the area of this curve is altered and broken to such an extent that it is impossible to differentiate between dike material and andesite-latite flow rock. No fault in the area was observed to have appreciable strike-slip movement; therefore, offset of the dike would imply that it dips northward. The dike is vertical in the arroyo that crosses it near its western end, but it may have departed from this at other places.

This basaltic andesite dike has no obvious influence on topography, apparently having about the same resistance to erosion as the andesite-latite sequence it intrudes.

Another basaltic andesite dike about 6 feet wide lies along the west side of a quartz latite dike. It crosses Alamosa Creek in the center of the northeast quarter of the area. Inclusions of the first basaltic andesite dike are common in this one.

One other basaltic andesite dike occurs in the southeast corner of the area. It is about 3 feet wide and is exposed at the surface for only a short distance. Its composition is similar to that of the first dike just described.

QUARTZ LATITE DIKE

A quartz latite dike passing from north to south through the middle of the area averages 60 feet in width. It cuts the pyroclastic latite and the andesite-latite flow sequence. It has border phases about 3 feet wide that are finer grained and darker in color than the inner part of the dike. Cooling joints perpendicular to the sides of the dike are present.

Compositionally, the most striking thing about the dike is the presence of large phenocrysts of albite as single crystals or Carlsbad twins up to 25 mm long. In outward appearance, these crystals are identical to orthoclase, but the sodium cobaltinitrite stain test for potassium does not even faintly stain them, and in thinsection they are optically positive.

Composition of a sample from approximately the middle of the dike is shown in Table 1. This sample is highly altered, although an effort was made to obtain as fresh a sample as possible. The feldspars are altered to calcite, kaolin, and white mica. However, some of the white mica present appears to be primary in the form of pseudohexagonal plates. Alteration of the albite to sericite implies introduction of potash from outside or transfer of potash from nearby potash feldspars or micas. Biotite is altered to chlorite, magnetite, and hematite.

Quartz grains measure up to 2 mm in diameter. A few of the smaller ones are somewhat euhedral, but most of the grains, regardless of size, are highly corroded with numerous rounded re-entrants. Andesine laths are euhedral and range up to 3 mm in length. Biotite occurs as flat flakes generally not more than 1 mm wide. Potash feldspars are very irregular in shape and very highly altered; they range up to 3 mm in diameter.

The groundmass is composed primarily of albite, quartz, and andesine grains averaging approximately 0.25 mm in maximum dimension. This occurrence of both andesine and albite in the same rock is unusual and no satisfactory explanation is readily available. It is possible that the albite was formed by some alteration process.

The quartz latite dike dips more than 85 degrees westward. Near the center of the area it has been faulted out. It is more resistant than the rocks it intrudes, forming the backbone of ridges and causing abrupt local steepening of arroyos.

QUARTZ MONZONITE INTRUSIVE PLUG

A fine-grained quartz monzonite intrusive plug in the south-central part of the area gives no definite indication of its age other than the fact that it cuts the andesite-latite extrusives.

It is roughly circular in plan, is about 175 feet in diameter, and forms the top of a very steep hill. About 30 feet of exposed quartz monzonite, possessing crude columnar jointing, forms the cap of this hill.

Outcrops are light reddish-brown. Composition of the quartz monzonite is about 25 per cent quartz, 25 per cent plagioclase, and 50 per cent pink potash feldspar. Minor amounts of magnetite are present. The few phenocrysts present are of quartz and plagioclase up to 3 mm long. The rock is relatively unaltered. No other outcrops of this composition were observed.

Structure

ORIGIN

The area mapped borders the eastern edge of the graben structure forming the valley between the Sierra Cuchillo on the east and the Black Range on the west. Most of the major faults of the area trend north parallel to the graben structure and are downthrown to the west. A Quaternary age for the faulting is suggested by the presence of faults in the Winston beds. Faulting began in Tertiary time during the volcanic interval and has continued up to the present, with some periods of greatly increased activity.

The major fault trend in the area is northeast. Faults with this strike are the longest and most persistent. The northeast-trending fault in the northwest quarter of sec. 35, T. 8 S., R. 7 W. and the east-central part of the Indian reservation has a displacement of at least 700 feet downthrown to the west. Displacements on the rest of the northeast-trending faults are probably much less than this; however, most of them are downthrown to the west, so total displacement between the northwest corner and the southeast corner of the mapped area may be considerable.

A north- and north-northwest-trending system of cross faults exists. These generally have less displacement than the northeast-trending faults, but a few, such as the one across the northeast corner of the area, have displacements of at least 600 feet.

The few nearly east-west faults have considerable displacement, on the order of about 500 feet maximum.

The region covering the southeast quarter of sec. 2 and the northeast quarter of sec. 11, T. 9 S., R. 7 W. is an upfaulted block of the andesite-latite flow unit and is composed mostly of andesite. Here the quartz latite dike has been faulted out.

Dikes in the area undoubtedly followed faults. Almost all of them parallel a major fault system. Therefore, the fault pattern had its beginning during at least part of the volcanic interval. Subsequent movements on old faults and development of new faults have modified the pattern.

STRUCTURAL CONTROL OF ORE SOLUTIONS

Areas of clay alteration and silicification show such close correlation to faults that it is almost certain that faults were conduits for the mineralizing solutions. The most highly altered area occurs in the vicinity of the beryllium deposit; here, the faults have the greatest displacements and are most concentrated. Clay alteration is restricted to an area of about 50 feet on either side of the northeast-trending fault about 0.4 mile east of the beryllium deposit. In the northwest quarter of sec. 11, T. 9 S., R. 7 W., silicification is most intense in the fault zone; the fault breccia is highly silicified but still recognizable in places. Away from the fault, the amount of silicification decreases rapidly and is restricted to zones parallel to flow layering in the andesite-latite flows.

In some places, both silicification and clay alteration occur, as in the altered andesite-latite immediately northeast of the beryllium deposit. This silicification may be related to either montmorillonitization or alunitization.

There is definite evidence for at least two periods of alteration, as shown by the anomalous occurrence near the ore body of kaolin, alunite, and montmorillonite. The kaolin and alunite occur in a zone separate from the montmorillonite but adjacent to it.

Regardless of whether one, two, or three periods of alteration occurred, the hydrothermal solutions traveled along pre-existing faults. The more permeable and generally the larger fault zones allowed for better circulation of solutions.

Summary of Geologic History

The prevolcanic bedrock of the area may be granite or it may consist of Paleozoic sediments. Numerous xenoliths of granite are present in the andesites and latites of the area, but there are no xenoliths of sedimentary rock. There is a possibility that any limestone fragments were assimilated in the igneous rock, but it is not likely that all of them, especially the very large ones, disappeared without leaving a trace. Sandstone or shale included in the igneous rock would probably be recognizable as such if either were present.

According to Willard's reconnaissance map and Jahns' map of Iron Mountain (Jahns and Glass), the latite tuff is probably the lowest volcanic unit in the area and prevolcanic rocks directly underlie it.

The latite tuff accumulated on the prevolcanic surface as a primary pyroclastic and was locally reworked by water. A few well-bedded ashfall tuffs occur within the sequence of coarser pyroclastics. Faulting was undoubtedly going on at this time.

The andesite and latite then flowed out over the tuff, starting out andesitic and becoming more latitic as volcanism continued. The extreme degree of contortion and complexity of some of the folds in the andesite-latite sequence indicates that the folds and contortions formed while the rock was still plastic, probably as a primary flow structure. Fault zones filled with latite in the latite flow rock indicate that faulting took place while at least a part of the latite was still plastic.

The latite spheroids and their contained minerals appear to have been produced by a reduction in pressure in certain zones within the latite flow as a result of folding of the still plastic rock. Volatiles migrated to these zones of reduced pressure and formed pockets into which the least viscous and latest crystallizing solutions migrated.

Continued displacement occurred along pre-existing faults, and new faults were formed. Much of the present fault pattern was established by this time.

Dikes of andesite, latite, and quartz latite intruded the earlier volcanics and probably the underlying rock.

The planar structure in the large latite dike along Monticello Canyon in the eastern part of the area is probably the result of flowage during emplacement. The slickensides in the dike may also have been formed during its emplacement. The possibility that this is a composite dike is suggested by its irregular shape and slickensided nature.

As volcanic activity slackened, an erosion surface developed on the early flow rock. Fine sandstone and siltstone accumulated in local basins. Occasional pyroclastic surges in the waning andesite-latite volcanic activity deposited small fragments of andesite and latite in the basins along with the sediments. Dikes were still being intruded. A few of these penetrated the sediments and may have reached the surface to form small flows.

Renewed volcanic activity locally deposited welded tuff on the erosion surface; massive rhyolite was deposited elsewhere. Later, flow-banded rhyolite flowed out over the tuff. At the same time, faulting continued as renewed movement on existing faults and developed new ones.

Volcanic rocks younger than the flow-banded rhyolite, if they did exist, have been removed by erosion.

Intense faulting associated with formation of the graben between the Sierra Cuchillo and the Black Range provided channels for hydrothermal solutions. At least two periods of alteration and/or mineralization occurred.

The Winston beds were not present during the period of hydrothermal alteration, for nowhere are they altered. At places, they directly overlie hydrothermally altered rock and contain clasts of it.

After deposition of the Winston beds, faulting of appreciable magnitude occurred, and the present erosion surface began to form. Minor movement along existing faults is probably going on at present.

HISTORY

The earliest evidence of ore production in the general area is the shaft and adit known as theTaylor prospect near the center of sec. 25, T. 9 S., R. 7 W. From evidence at the mine site, including machinery and degree of weathering of the dump and timbers, it appears that the mine was last worked in the early 1920's or early 1930's. Dump samples indicate that low-grade copper and lead ores were mined from the white quartz vein on which the shaft is sunk. A qualitative spectrographic analysis shows copper and lead in moderate concentrations and zinc, silver, and bismuth in smaller amounts.

The shaft is not more than 100 feet deep and about 6 feet square. There is considerable waste rock on the dump, some of which has washed away. An estimate of the maximum ore production would be about 25 tons, and it is possible that none was ever shipped.

During the uranium boom, approximately one pickup-truck load of uranium ore was reportedly shipped from the highly altered area in the vicinity of the beryllium deposit. The nature and exact location of the uranium deposit are unknown.

No beryllium has been commercially produced from the bertrandite deposit discovered by Milligan, although intensive core drilling was carried out there during the summers of 1963 and 1964.

ALTERATION

Four types of alteration are recognizable in the area: silicification, kaolinization and alunitization, montmorillonitization, and replacement by amorphous silica.

Silicification occurs along faults, replacing the fault breccia and wall rock. Original textures and structures tend to be wiped out. Associated with the replacement quartz veins are malachite, pyrite, and galena, with minor amounts of zinc, bismuth, and silver. Some of the veins contain zones of almost pure calcite. The two veins in the middle of sec. 9, T. 9 S., R. 7 W. are mostly calcite at one end and mostly quartz and light-green octahedral fluorite at the other. The southwesternmost of these two veins contains quartz with a little fluorite, galena, and malachite at its southwest end. At its northeast end, there is little quartz and no sulfides or fluorite, calcite comprising the vein filling. The northeasternmost of the two veins is pure, very coarsely crystalline calcite at its western end and quartz with abundant fluorite at its eastern end. Southeast of the beryllium deposit about a quarter of a mile is a fault along which the wall rock is silicified. Almost straight east of the beryllium deposit on the same fault is a vein of calcite about 12 feet wide. About 0.6 mile east and slightly north of the beryllium deposit is a vein about 40 feet wide of almost solid calcite with no associated quartz. Spectrographic analyses of several of the calcite samples showed no heavy metals and no anomalous amounts of rare earths or other unusual elements.

The quartz with its associated fluorite and sulfides is probably of hydrothermal origin. The solutions followed faults, depositing material in them and replacing fault breccia and wall rock. It is probable that the calcite is from the same hydrothermal origin. It is also possible that the calcite veins result from the deposition of calcite removed from underlying limestone beds. A further speculation is that since the calcite veins are often associated with quartz veins containing sulfides and fluorite, limestone may have been dissolved at depths during replacement by sulfides, quartz, fluorite, and associated minerals.

No anomalous concentrations of beryllium were found in any of the quartz or calcite veins. One small, deep, purple, massive fluorite occurrence in the center of sec. 10, T. 9 S., R. 7 W. contained approximately five times the normal concentration of beryllium. (The normal concentration of beryllium here is considered the average beryllium content of the country rock away from known areas of beryllium mineralization.) This sample showed no radioactivity above background when checked with a scintillometer.

Plate 2 shows the alunitized and kaolinized area near the beryllium deposit. Kaolinization appears to occur as the initial stage of a process that ends in alunitization.

Probably both rhyolite tuff and andesite have been altered to kaolin and alunite. In the areas where it is likely that the altered rock was rhyolite tuff, the original texture has been destroyed by the alteration and faulting. In some places, the original flow banding is still visible in alunitized and kaolinized latite or andesite.

Alunitization turns the rock snow white and bright red. In some of the white alunite, very fine segregations of iron oxide turn the rock red when it is crushed or struck with a hammer. The red areas of alunite and kaolin are probably due to the iron oxide existing in a finely divided state throughout the rock. Some of the alunite and kaolin is very hard, so much so that it looks and feels like unglazed porcelain. Other samples, especially those high in kaolin, are soft and have a soapy feel.

The distinct boundary between the montmorillonite and the kaolin-alunite areas, in addition to the absence of samples containing both kaolin or alunite and montmorillonite, suggests two stages of alteration, possibly but not necessarily with an intervening interval of faulting.

Kaolin and alunite generally result from alteration in an acid environment, while montmorillonite generally forms under alkaline conditions.

In the formation of kaolin from a calcic latite (Willard and Proctor, 1946), there are apparently small losses of potassium, sodium, and aluminum and major losses of iron. Most of the silica remains with the kaolin. All the calcium is removed. In the formation of alunite from a calcic latite, most of the original sodium and iron and 10 to 15 per cent of the silica are removed. The potassium content remains constant and 15 to 23 per cent sulfite is added.

The critical requirements for formation of alunite from a rock of the type found in the area appear to be removal of silica and introduction of sulfite. These conditions are somewhat of a paradox, for silica tends to become mobile in alkaline solution, while sulfite is transported in acid solution. No satisfactory explanation of this phenomenon is readily available.

No abnormal beryllium concentrations were found in any of the alunite or kaolin samples analyzed (table 2).

Plate 2 shows the area of montmorillonite alteration that includes the beryllium ore body. In outcrop appearance, there is no difference between the montmorillonite area and the kaolinite area. Both kinds of alteration affect the same rock types. However, they must have occurred under significantly different conditions and probably at differennt times, since kaolinization and alunitization are acid alteration and montmorillonitization is an alkaline alteration.

Plate 2 also shows the area where the rock has been replaced by amorphous silica. This alteration has affected both the andesite-latite flow rock and the rhyolite tuff. Original textures are preserved, although the rock is highly altered. Color of the altered rock is white, yellow, orange, or red.

Most of these rocks give a positive benzedine dihydrochloride test for montmorillonite but do not give montmorillonite peaks on an X-ray chart. If montmorillonite is present, it occurs in minor concentrations. The X-ray charts of these rocks give only quartz peaks. When significant percentages of quartz (approximately 30 per cent or more) are added to the X-ray sample, the quartz peaks are greatly increased in intensity. Therefore, there must be appreciable quantities of some amorphous mineral present. From microscopic examination of these rocks, it appears that this mineral is amorphous silica.

The source of the silica is pure speculation at this point. It may be silica that was removed from the latite, andesite, and rhyolite tuff during formation of kaolinite and alunite. It could also have been introduced by relatively cool hydrothermal solutions.

BERYLLIUM ORE DEPOSIT

The bertrandite deposit occurs in faults bordering a downfaulted block of highly altered rhyolite tuff. The two main faults bordering the tuff on the east and west strike almost due north and dip approximately 55 degrees west. Some secondary fractures in the tuff dip about 40 degrees west. The block of tuff is bordered on the north by an east-striking fault with an approximately vertical dip. These faults form gouge zones up to 40 feet wide.

Plate 3 shows an idealized diagram of the main part of the ore body. A major part of the bertrandite mineralization falls in the projected fault zones and all high concentrations occur in the altered rhyolite tuff. This has been verified by study of drill-hole logs and examination of the cuttings. Weak beryllium mineralization occurs in a small outcrop of altered andesite-latite just south of the main bertrandite deposit. The mineralization, which appears to occur outside the projected faults, may be due to irregularities in the faults or additional faults not detected at the surface.

The beryllium ore containing 0.05 to 2.5 per cent beryllium oxide consists of altered rhyolite tuff fault breccia with a claylike matrix. Clasts in the fault breccia are up to 40 mm across, averaging approximately 7 mm. The clay is largely montmorillonite with no kaolin or alunite detectable by X ray. Some very fine quartz is also present.

Bertrandite occurs as light yellow-green crusts of fibrous crystals up to 2 mm thick on the clasts and as small spheres of radiating crystals in the matrix. No beryllium mineralization occurs within clasts of the fault breccia; it is restricted to the crusts and to the clay material. The spheres do not exceed 50 microns in diameter, averaging approximately 15 microns. Individual crystals from the coatings on the breccia reach a maximum of 20 microns across. Optically, the bertrandite crystals are length slow and have indices of $n_\alpha = 1.591$; $n_\beta = 1.605$; $n_\gamma = 1.614$.

The X-ray pattern for bertrandite is shown below (Williams and Vernon, 1960):

BERTRANDITE ($H_2Be_4Si_2O_9$) X–RAY POWDER PATTERN

(Bertrandite, Mica Creek, Queensland;† $CuK\alpha_1$ radiation; λ = 1.5405 Å ; camera diameter 114.6 mm)

d(Å)*	I(est.)	d(Å)*	I(est.)	d(Å)*	I(est.)	d(Å)*	I(est.)
7.56	1.	2.02	0.5	1.305	4.	0.940	0.5
4.85	<0.2	1.983	2.	1.251	1.	0.899	0.5b
4.38	10.	1.923	0.5	1.233	0.5	0.860	1.
3.94	4.	1.787	0.5	1.220	2b	0.843	0.2
3.80	0.7	1.698	1.5	1.167	1b	0.838	0.3
3.19	9.	1.650	1.	1.117	1.5	0.828	0.5
2.93	1.	1.628	<0.2	1.105	0.3	0.813	2.
2.88	1.	1.579	0.3	1.090	<0.2	0.800	0.2
2.54	8.	1.555	3.	1.076	1.	0.790	1.
2.42	0.5	1.491	<0.2	1.057	<0.2	0.783	1.
2.28	6.	1.465	3.	1.015	<0.2	0.778	1.
2.22	6.	1.440	1.	0.986	0.2b		
2.18	0.2	1.363	0.2	0.970	0.2b		
2.10	0.3	1.338	0.3	0.953	<0.2		

***Interplanar spacings corrected for film shrinkage.**

†An identical pattern was obtained for bertrandite from Mt. Antero, Colorado.

b Denotes broad line.

TABLE 2. BERYLLIUM CONTENT OF VARIOUS ROCKS

Be(ppm)	ROCK
0.2	Kaolin
0.4	Alunite
0.8	Amorphous silica and quartz
0.3	Kaolin
0.4	Andesite fault gouge
0.6	Kaolin
0.5	Alunite
0.4	Partly altered latite
0.4	Dacite dike
0.4	Latite pyroclastic from south-central part of area
0.6	Galena and green fluorite from shaft at center of area
0.3	Massive rhyolite
0.8	Latite
0.1	Granite xenolith
0.3	Green fluorite and quartz from vein northeast of shaft
0.6	From monzonite plug
3.–	Purple fluorite from southeast corner of area
0.4	Andesite fault gouge
0.3	Amorphous silica and quartz
0.6	Pyritized latite xenolith from basaltic andesite dike
0.8	Galena, quartz, malachite from dump in center of area
0.4	Quartz latite
0.5	Latite
0.8	Rhyolite tuff in north-central part of area
1.2	*Assayed 1.4 ppm Be
1.0	*Assayed 1.2 ppm Be
1.0	*Assayed 1.2 ppm Be
2.4	*Assayed 2.2 ppm Be
0.8	*Assayed 1.0 ppm Be
0.7	*Assayed 1.5 ppm Be
1.2	*Assayed 2.3 ppm Be

*Analyzed by John Wilson, analytical chemist, on a Perkin-Elmer atomic absorption unit. Using Wilson's analyses as standards, an order of magnitude of the accuracy of the spectrograph is obtained. If enough standards were available, a set of sensitivity factors could be established for these rocks.

All samples run on ARL Spectrograph Analyzer model 2600-1. Film-Kodak Spectrographic Analysis number 1. Electrodes: Ultra Carbon 101L (lower) and 101U (upper). Samples were run for 30 seconds with the bottom electrode negative at low intensity, full waveform, filter setting A, rotating log sector; followed by 1 minute 45 seconds with the bottom electrode positive, high intensity, full waveform, filter setting A, rotating log sector. (The initial 30 seconds with the bottom electrode negative at low intensity aids considerably in preventing the sample from popping out of the lower electrode.)

10 mg of sample mixed with 10 mg of graphite were used in all the analyses above.

A sample of bertrandite obtained by scraping the crust off several pieces of fault breccia showed 4.38Å, 3.94Å, 3.19Å, 2.54Å, 2.28Å, and 2.22Å.

There are also some coatings of quartz and iron oxide on the breccia clasts. No fluorite was found in the beryllium deposit or the area immediately surrounding it, although I looked for it. Some psilomelane is present in fault zones as coatings on breccia clasts and in the matrix material.

The coatings of bertrandite on the fault breccia and the spheres of radiating bertrandite crystals in the fine fault material indicate that beryllium mineralization occurred after faulting, and that the faults served as conduits for the circulation of mineralizing fluids.

It is possible that the bertrandite is concentrated in fault breccia of altered rhyolite tuff because the tuff, in some unknown way, influenced deposition. However, the texture of the rhyolite tuff crusted with bertrandite does not indicate replacement. Pieces of breccia partly coated with bertrandite are not so altered as other pieces from the same sample which contain no bertrandite. Within the same sample, two pieces of breccia may be identical in appearance and degree of alteration, one being crusted with bertrandite and the other having none. This lack of correspondence between degree of alteration and amount of bertrandite present suggests that the altered tuff may have served merely as the physical site of deposition rather than have played an active role in chemical precipitation.

The presence of montmorillonite and lack of kaolin and alunite in the bertrandite deposit suggest that the beryllium-bearing solutions may have been alkaline, although beryllium is usually carried in acid solution.

In summary, it appears that there was intense premineral faulting. Later, hlydrothermal solutions flowed along the faults, altering the fault breccia and adjacent rock. The kaolin-alunite area and the montmorillonite area probably represent two different periods of alteration, the former acid and the latter alkaline. The alkaline solutions or a later solution contained the beryllium deposited on clasts and in the fine material in the rhyolite tuff fault breccia. Subsequent faulting has modified the structure of the area by an undetermined amount.

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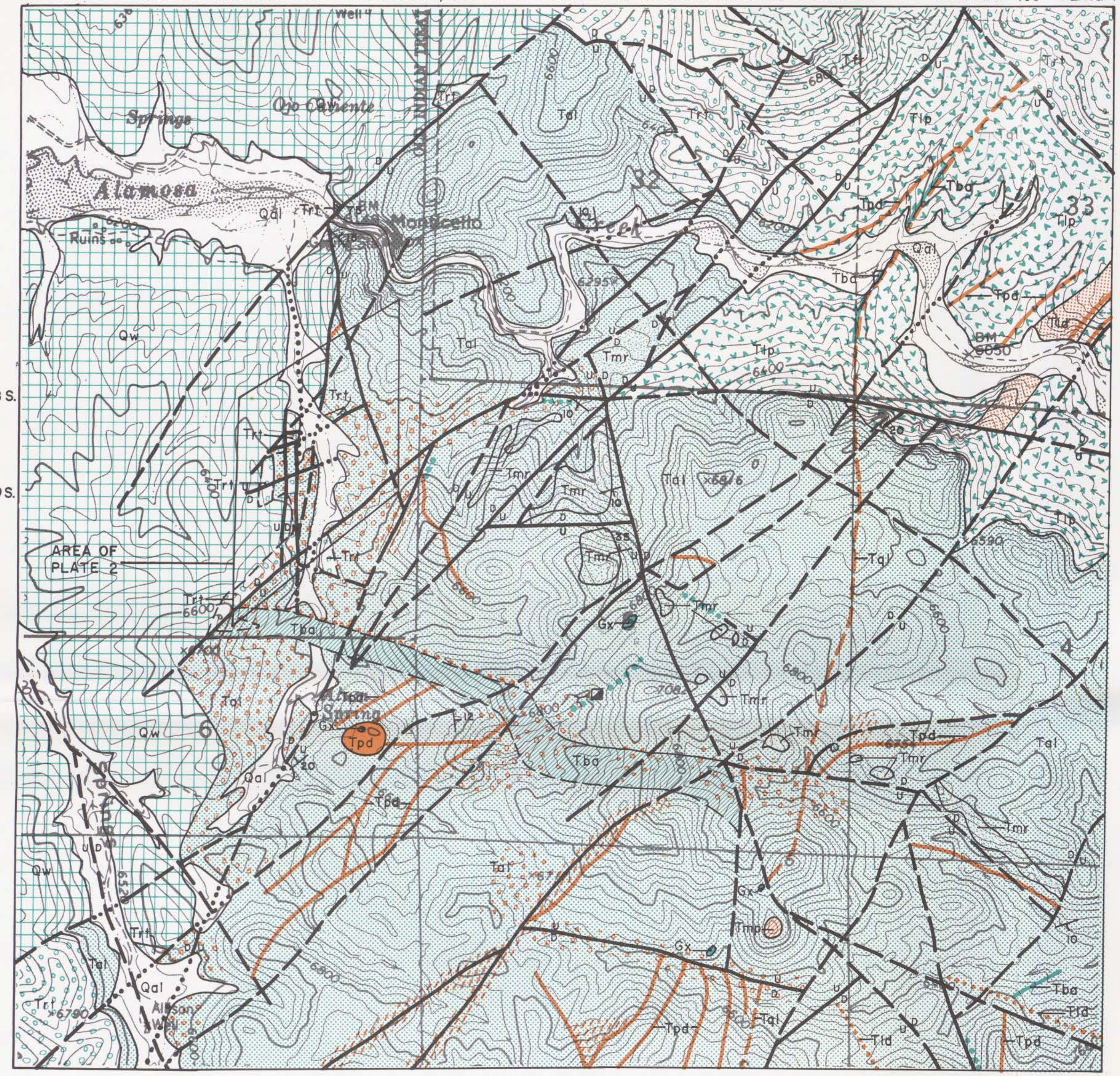


T.8 S.

T.9 S.

R. 7 W.

GEOLOGY OF APACHE WARM SPRINGS AREA

by Patrick D. Hillard

0 1/2 1 Mile

Scale

EXPLANATION

Qal
Alluvium
Locally derived sand and gravel.

Qw
Winston Beds
Locally derived silt, sand, gravel, and boulders. Graded beds, calcite cement. Equivalent to or older than Santa Fe group.

Trf
Flow-banded rhyolite.
White to light gray. Abundant sanidine.

Trt
Rhyolite tuff.
Lavender to pink or white. Contains phenoclasts of sanidine, biotite and quartz. Locally has green or black glass at base. Welded to varying degrees.

Tmr
Massive rhyolite.
White to buff. Contains phenocrysts of rounded quartz and altered K-feldspar. Has crude columnar jointing.

Quartz and calcite veins. Contain some sulfides locally.

Altered zones. Montmorillonite, kaolin and alunite, or replacement by amorphous silica.

Silicified areas. Some sulfides present locally.

U N C O N F O R M I T Y

Tal
Andesite-latite flows
Reddish brown to gray. More andesitic near the bottom of the unit. Has well-developed flow layering. Phenocrysts of plagioclase and hornblende.

Tlp
Pyroclastic latite
Contains clasts of andesite and latite up to 5 feet across. Latite groundmass.

Gx
Granite xenoliths
Xenoliths of pink granite. Coarse to fine texture. Up to 70 feet across. Occur in Tal and Tpd.

Tmp
Monzonite
Plug of fine-grained pink monzonite. Gray outcrops.

Tql
Quartz latite dike
Greenish gray, 60 feet wide. Contains albite up to 20 mm as single crystals or Carlsbad twins. Has border phases.

Tba
Basaltic andesite dikes
Dark gray to black, locally altered dark olive green. Three feet to 200 feet wide.

Tpd Tld
Porphyritic andesite dikes (Tpd) and latite dikes (Tld)
Tpd is altered to dark olive green. Has plagioclase phenocrysts up to 10 mm long. Tld is light gray to brown with phaneritic texture. One dike is porphyritic with altered biotite and plagioclase parallel to the sides.

N

Contact

20
Strike and dip

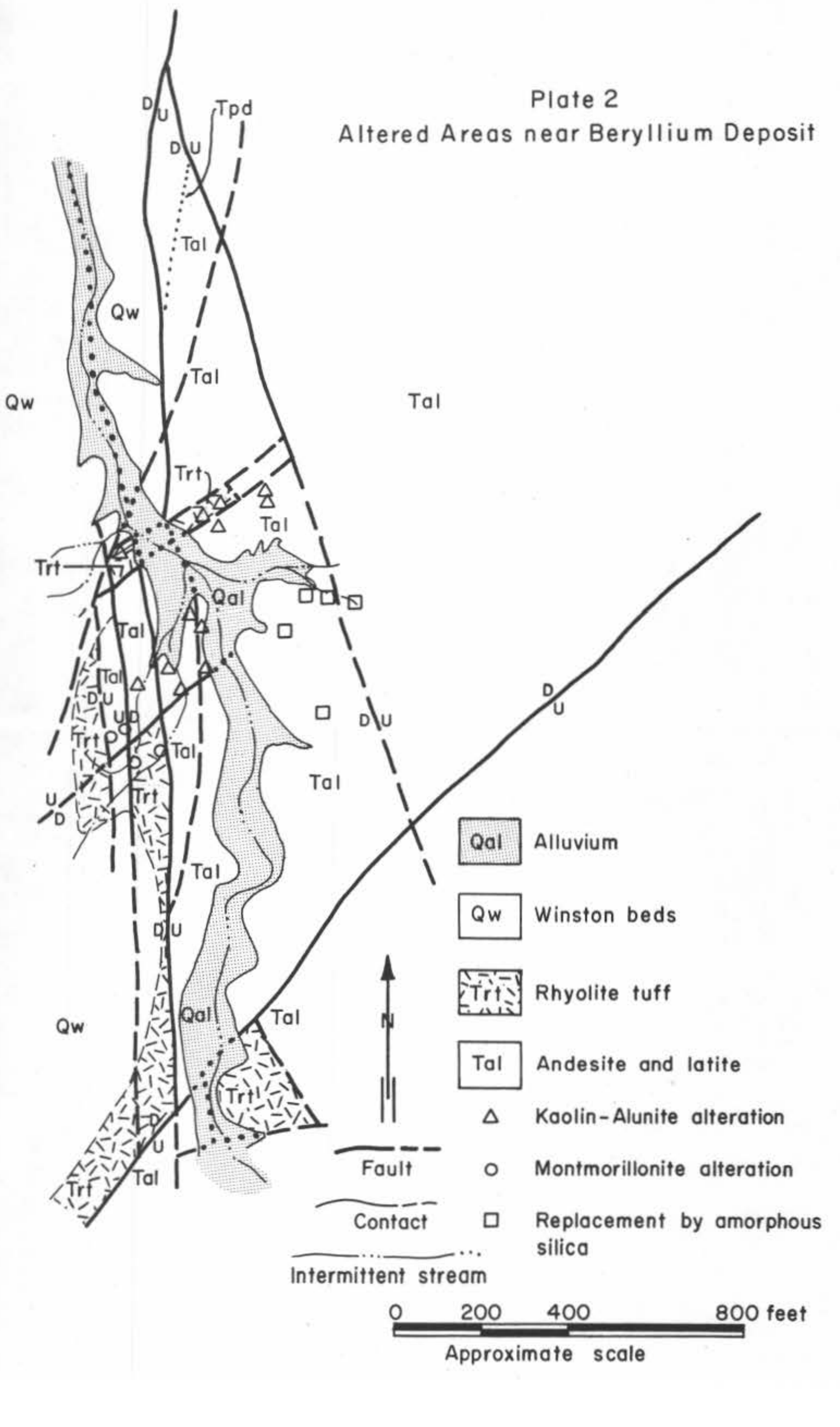
Fault

Shaft

Adit

NEW MEXICO

Plate 2
Altered Areas near Beryllium Deposit



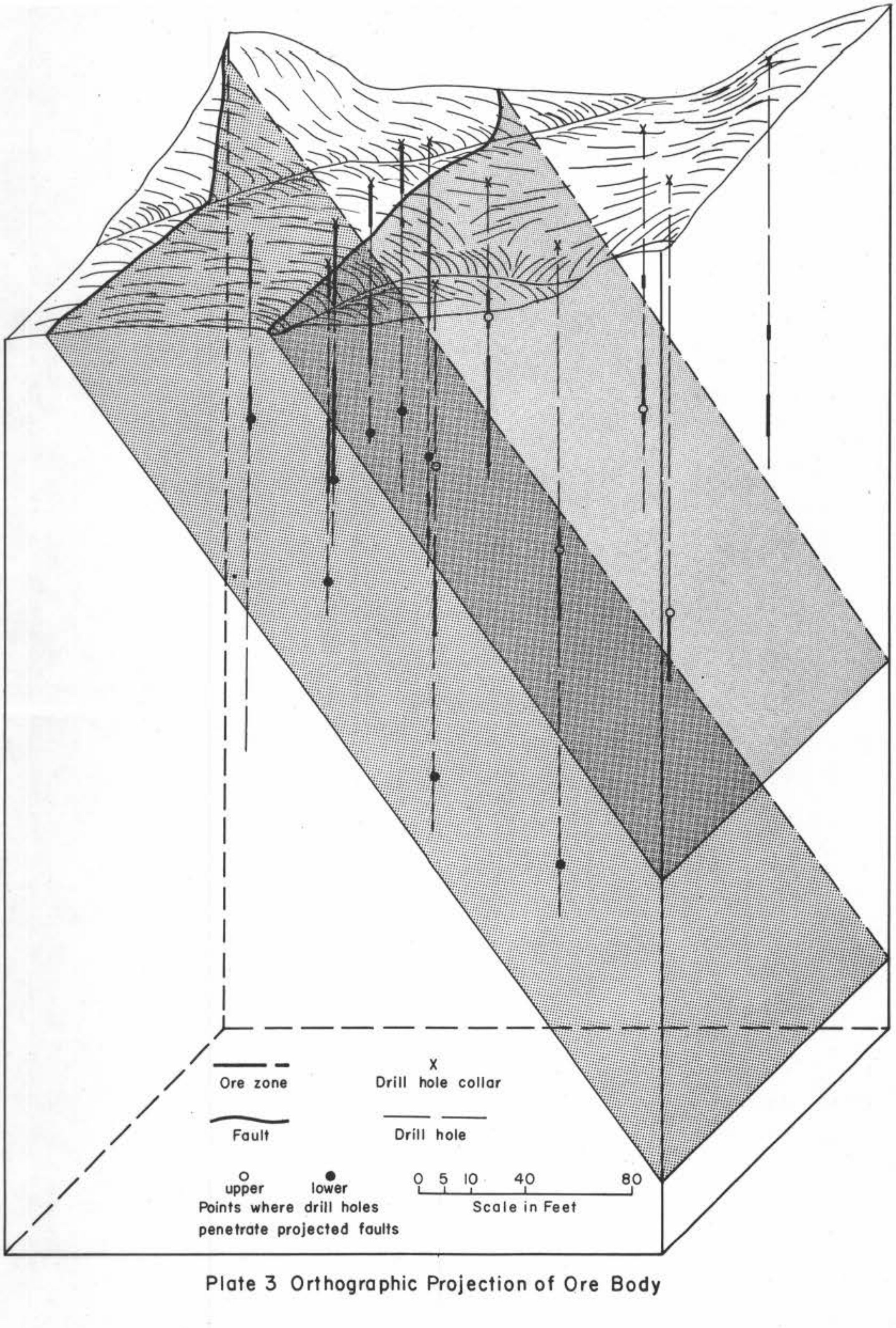


Plate 3 Orthographic Projection of Ore Body