GENERAL GEOLOGY AND BERYLLIUM MINERALIZATION NEAR APACHE WARM SPRINGS, SOCORRO COUNTY, NEW MEXICO

by

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TABLE OF CONTENTS

PLATES

FIGURES

TABLES

Abstract

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

Quaternary Winston Beds consist of locally derived sandstone, siltstone and conglomerate.

Types of alteration indicate at least two periods of hydrothermal activity. The beryllium ore is restricted to one highly faulted area in altered rhyolite tuff. It consists of bertrandite in the fault breccia, deposited after the faulting.

INTRODUCTION

During the uranium boom a small amount of uranium was reportedly produced from the highly altered area about one-half 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 of 1961 while 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 area includes mapping and mineral studies by Jahns and Glass (1944) at Iron Mountain, about six 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 a geologic map and sampling, was done during the summers of 1965 and 1966. Laboratory work, consisting of spectographic analyses, X-ray analyses and thin section studies, was done in the spring and fall of 1966.

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Thanks are due M. Howard Milligan, mining geologist and registered professional engineer of Albuquerque, New Mexico, for making available to the writer 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.

The writer also wishes to express his appreciation to James Cox and Mrs. Eunice Travis for granting access to their land for field work.

Location of the area.--The area studied covers approximately 5 1/2 square miles at the north end of the Sierra Cuchillo and includes the eastern half of Warm Springs Apache Indian Reservation (abandoned); in T8S R7W, section 35 and the western half of section 34; in T9S R7W, section 1, section 2, the western half of section 3, the northern half of section 12, the northern half of section 11, and the northwest quarter of section 10. DESCRIPTION IS WRONG

The beryllium deposit lies about one-half mile south of the west end of the Monticello Canyon "box." Apache Warm Springs lie 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 one-fifth of the area is gently rolling and covered with grass. 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 is rugged with many near-vertical faces and steep-walled arroyos and canyons. Vegetation includes grass, cactus and scattered cedar and pinon trees.

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

Climate is mild during summer with temperatures reaching a low of 45°F at night and a high of 90°F in daytime. Afternoon thunderstorms are common in late summer. The 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 snowfalls of five or six inches may be expected during some winters.

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

GEOLOGY

General.--The area studied contains Tertiary andesites, latites, rhyolites and rhyolite tuffs with sediments derived from them. The andesites and latites show moderate to strong propylization. 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 volcanics. According to the reconnaissance map of the Luera Spring 30-minute quadrangle (Willard, 1956) the andesite-latite units are older than the Datil Formation and the rhyolite sequence here is at the base of the Datil.

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 ($H_2Be_4Si_2O_9$) deposited in fault gouge bordering a downfaulted 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 (plate 8). 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 while others are latite. No clasts of a composition other than andesite or latite were observed.

The matrix material is latitic, being 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 one-half mm in diameter were observed.

Sorting is poor but recognizable. The average maximum size for clasts in sorted beds is approximately nine inches. There is enough material from about 10 mm on down that the larger clasts are generally not in mutual 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 settling of large clasts during transportation by an ash flow.

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

Andesite-Latite Flows

Flows of propylized andesite and latite are the principal rock unit in the area (plates 5, 6). 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 up to 70 feet or more across.

Flow layers are commonly on the order of one inch thick, but slightly to the south and east of the center of the area individual layers are three or four feet thick.

Preferred orientation of platy and linear 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 which tend to be spheroidal.

Table 2 lists the modal compositions of a latite and a quartz latite from the area based on thin section 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 1/20 mm in diameter.

Abundance of visible quartz ranges from 0 to 15 per cent. Per cent potash feldspar ranges from 15 to 60, plagioclase 25 to 60 and hornblende 4 to 10. As might be expected the quartz content of the rocks appears to be directly related to the amount of potash feldspar and inversely related to the amount of plagioclase and hornblende.

Quartz occurs both as phenocrysts and as part of the groundmass. As phenocrysts it is generally not more than 1 mm in diameter and is very irregular in shape due to corrosion. In the groundmass quartz grains are rounded to 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 are up to 12 mm long and 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 in both the groundmass and as phenocrysts up to 4 mm long. Alteration products are epidote, magnetite and hematite.

The opaque minerals are magnetite, pyrite, hematite and goethite-limonite.

Magnetite occurs as octahedral crystals and irregular aggregates up to 2 mm across. Some of these aggregates are enclosed by andesine. Pyrite occurs as cubic crystals 1/4 - 1 1/2 mm square, some of which are badly corroded. Goethite-limonite and hematite are alteration products of hornblende and pyrite.

In the west central portion 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 (plates 1, 2, 3).

In these contorted areas there are fault zones a foot or so wide containing clasts of flow banded latite in random orientation. These zones are completely filled and healed with more latite which shows no flow banding (plate 4).

Associated with the more intensely contorted latite are certain flow zones consisting of several adjacent flow layers that contain spheroids of latite from one inch to six inches in diameter that are harder than the rest of the rock. Only the flow layers which are 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 throughout 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 which allows for good development of the above mentioned crystals.

In addition one of these spheroids was observed to contain 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 structure.

Primary origin in some way connected with the primary flowage of the latites is indicated for these spheroids by the fact that 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 post-flow 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.

Where the grains of the sediment 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. In many instances there is a pale green glass or black vitrophyre at its base. Color ranges from lavender gray to white, with pink to light reddish-brown being the most common. Texture is felsitic to porphyritic with widely scattered vugs up to 8 mm in diameter which contain 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 above, some small angular, subangular, euhedral, and rounded quartz fragments 1/20 to 1/4 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 1-2 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. Due to its topographic position and fault contacts it is impossible to determine its stratigraphic position with respect to the lavender tuff which outcrops 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 (i.e. number of phenocrysts) suggests that it may be above the lavender tuff.

Topography on the tuff is generally subdued and gently rolling; however, the pink tuff forms prominent outcrops at some localities along faults, probably because of a greater degree of welding. In the north central part of section 35 T8S R7W, 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. It is 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.

A visual estimate of composition based on sodium cobaltinitrite staining and thin section is given in table 2.

About 10 per cent of the rock is sanidine phenocrysts from 1/2 to 15 mm long and another 10 per cent is composed of quartz phenocrysts from 1/2 to 10 mm in diameter. The other constituents listed make up the groundmass and average about 1/20 mm in diameter.

The sanidine is partially altered to white mica. A sodium cobaltinitrite stain test indicates it is high in K. The quartz phenocrysts are rounded and corroded with many deep reentrants. Some quartz phenocrysts were broken when the rock was nearly solidified as shown by matrix material between fragments of quartz of similar composition, orientation, and texture which would fit together perfectly. The opaques 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 sometimes tilted at angles up to 35°. On hillsides it often forms prominent outcrops due to crude columnar jointing.

Flow-Banded Rhyolite

Flow-banded rhyolite occurs only in the north central part of the area. Immediately north of the area 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 1-8 mm wide with the pumiceous bands tending to be wider than the glassy ones. 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 determined microscopically, but a sodium cobaltinitrite stain test indicates that it is composed of some potassium-bearing mineral, most likely a feldspar or a K-rich glass.

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

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, 1944), occupy the western 1/5 of the area mapped except for the southwest corner. They are a locally derived sedimentary unit exhibiting graded bedding with particle size from silt to two-foot boulders. Maximum thickness is at least several hundred feet.

Clasts are almost entirely of flow-banded rhyolite. A few clasts of the rhyolite tuff and andesite are present close to outcrops of these rocks. These clasts 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, 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 case 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.

Alluvium

The alluvium consists of locally derived silt, sand, gravel and boulders. It is restricted to the bottoms of arroyos and canyons.

Latite Dikes

Latite dikes occur in the northeast, west central and southeast portions of the area. Most of these dikes are approximately 12 feet wide. However, one near the eastern border of the area in Monticello Canyon is extremely variable in width reaching a maximum of almost 400 feet (plate 11). 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 are generally not over 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. This lineation is further accentuated by many planes of slickensides within and parallel to its sides.

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

A sample from the latite dike in Monticello Canyon is shown in table 2. The sample was too badly altered to accurately determine the variety of plagioclase by the Michel-Levy method, but it appears that 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 a foot up to 15 feet.

These dikes are usually dark olive green, however, this is 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 pattern formed by the dike outcrops in some places is anastamosing or bifurcating, as in the southwest and south central portions 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 2. In some areas the dikes were much more altered than the one from which this sample was taken; in other areas they were somewhat fresher.

Quartz is in the groundmass as grains 1/4 mm and smaller. In the groundmass, andesine occurs as phenocrysts up to 10 mm long and as needle-like laths no longer than 1/2 mm. The phenocrysts are almost completely altered to epidote and calcite while the andesine of the groundmass is noticeably less altered. The potash feldspar is restricted to the groundmass and is partially kaolinized. The opaque minerals are irregular grains of magnetite and small masses of hematite.

The porphyritic andesite dikes have small influence on topography partially 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. Its average width is on the order of 200 feet. Where fresh, it is a dense dark gray rock with some inclusions of wall rock, including a latite dike which 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 cannot be distinguished from andesite-latite flows except in a few places where original textures are preserved.

The composition of a relatively unaltered sample of the basaltic andesite is shown in table 2.

Some augite and magnetite are included in the larger plagioclase crystals. Texture is phaneritic with an average grain size of approximately 1/2 - 1 mm. A few scattered individual plagioclase laths are up to 3 mm long.

Quartz Latite Dike

A quartz latite dike passes from north to south through the middle of the area and averages 60 feet in width. It cuts the pyroclastic latite and the andesite-latite flow sequence. It has border phases about 3 feet wide which 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 (plate 10).

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 thin section they are optically positive.

Composition of a sample from approximately the middle of the dike is shown in table 2.

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 are 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 reentrants. Andesine laths are euhedral and range up to 3 mm in length. Biotite occurs as flat flakes generally not over 1 mm wide. Potash feldspars are very irregular in shape and are very highly altered. They range up to 3 mm in diameter.

The groundmass is composed primarily of albite, quartz and andesine grains averaging approximately 1/4 mm in maximum dimension. This occurrence of both andesine and albite in the same rock is unusual and no good explanation is readily available. It is possible that the albite was formed by some alteration process.

The quartz latite dike dips more than 85° 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 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 top 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 have the same general trend as the graben structure and are downthrown to the west. Quaternary faulting is indicated by 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 in the area.

The northeast trending fault in the northwest quarter of section 35 T8S R7W and the east central part of the Indian reservation has a displacement of at least 700 feet downthrown to the west (plate 7). 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 that 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, probably on the order of 500 feet maximum.

The region covering the southeast quarter of section 2 and the northeast quarter of section 11 T9S R7W 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 the dikes of the area are parallel to 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 is in the vicinity of the beryllium deposit; here the faults have the largest 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 miles east of the beryllium deposit. In the northwest quarter of section 11 T9S R7W 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, then it dies out.

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

SUMMARY OF GEOLOGIC HISTORY

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

According to Willard's reconnaissance map (Willard, 1956) and Jahns' map of Iron Mountain (Jahns, 1944), the latite tuff is probably the lowest volcanic unit in the area and pre-volcanic rocks directly underlie it.

The latite tuff accumulated on the pre-volcanics 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 were formed while the rock was still plastic, probably as a primary flow structure. The fault zones healed 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 migraged, i.e. those containing silica, calcium carbonate, fluorite, barite and possibly others.

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 extrusive 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 deposited welded tuff on the unconformity at places; massive rhyolite was deposited elsewhere.

Later flow-banded rhyolite flowed out over the tuff. All the while faulting was going on both as renewed movement on existing faults and development of new faults.

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 hydrothermal activity for nowhere are they altered. At places they directly overlie hydrothermally altered rock and contain clasts of it.

After deposition of the Winston Beds there was faulting of appreciable magnitude, and the present erosion surface began to form. Minor movement along existing faults is probably presently going on.

ORE DEPOSITS

History.--The earliest evidence of ore production in the area is the shaft and adit known as the Taylor prospect near the center of section ~~23~~ 5 T9S R7W. 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 spectographic analysis shows copper and lead in moderate concentrations and zinc, silver and bismuth in smaller amounts.

The shaft is not over 100 feet deep and about 6 feet square. There is considerable waste rock on the dump; some of it has been washed away. An estimate of the maximum ore production would be approximately 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.

Classification.--There are four types of alteration recognizable in the area. They are silicification, kaolinization and alunitization, montmorillonitization, and replacement by amorphous silica.

Silicification.--Silicification occurs along faults where it replaces fault breccia and wall rock with quartz. Original textures and structures tend to be wiped out. Associated with the silicified veins are malachite, pyrite and galena with minor amounts of zinc, bismuth and silver.

Some silicified veins have zones in them which are almost pure calcite. The two veins in the middle of section 9 T9S R7W 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 being 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 1/4 mile is a fault along which the 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 miles 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 also of hydrothermal origin and was deposited in the same way as the quartz.

It is also possible that the calcite veins are the result of 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, the 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 silicified or calcite veins. One small deep purple massive fluorite occurrence in the center of section 10 T9S R7W contained approximately five times the normal concentration of beryllium. (The normal concentration of beryllium here is taken to be 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.

Alunitization.--Figure 1 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 suspected that rhyolite tuff has been altered, the original texture has been destroyed by 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 to bright red. In some of the white alunite there are very fine segregations of iron oxide which 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 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 area and the kaolin-alunite area, in addition to the absence of samples containing both kaolin or alunite and montmorillonite, is suggestive of two stages of alteration, possibly but not necessarily with an intervening interval of faulting.

Kaolin and alunite are generally the result of 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 K, Na and Al and major losses of Fe. Most of the silica remains with the kaolin. All the Ca is removed.

In the formation of alunite from a calcic latite (Willard and Proctor, 1946) most of the original Na and Fe and 10-15 per cent of the silica are removed. The K content remains constant and 15-23 per cent SO_3 is added.

The critical requirements then for formation of alunite from a rock of the type found in the area appear to be removal of silica and introduction of SO_3. These conditions are somewhat of a paradox, for silica tends to become mobile in alkaline solution while SO_3 is transported in acid solution. No good explanation of this phenomenon is readily available.

No abnormal beryllium concentrations were found in any of the alunite or kaolin samples analyzed. (See table 1).

<u>Montmorillonitization</u>.--Figure 1 shows the area of montmorillonite alteration which 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 different times since kaolinization and alunitization are acid alteration and montmorillonitization is an alkaline alteration.

Replacement by amorphous silica.--The area where the rock has been replaced by amorphous silica is shown in figure 1. This alteration has affected both 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 test for montmorillonite but do not give montmorillonite peaks on an X-ray chart. If any montmorillonite is present it is 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 the mineral is amorphous silica.

The source of this silica is pure speculation at this point. It may be silica which was removed from the latite, andesite and rhyolite tuff during formation of 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 which border the tuff on the east and west strike almost due north and dip approximately 55° West. There are some secondary fractures in the tuff which dip about 40° 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.

Figure 2 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 of it occurs in the altered rhyolite tuff. This has been verified by study of drill hole logs and examination of some of the cuttings. There is one minor exception. Slightly south of the main bertrandite deposit, weak beryllium mineralization occurs in a small area of altered andesite-latite. The mineralization which occurs outside the projected faults may be due to irregularities in the faults or additional faults which were not detected at the surface.

The beryllium ore containing .05 to 2.5 per cent BeO consists of altered rhyolite tuff fault breccia with a clay-like matrix. Clasts in the fault breccia are up to 40 mm across and average 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 up to 2 mm thick of fibrous crystals on these 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 outside of the clasts and to the clay material. The spheres are not over 50 microns in diameter and average approximately 15 microns. Individual crystals from the coatings on the breccia are a maximum of 20 microns wide. Optically the bertrandite crystals are length slow. $n_\alpha = 1.591$; $n_\beta = 1.605$; $n_\gamma = 1.614$.

The X-ray pattern for bertrandite is shown on the following page (Vernon and Williams, 1960):

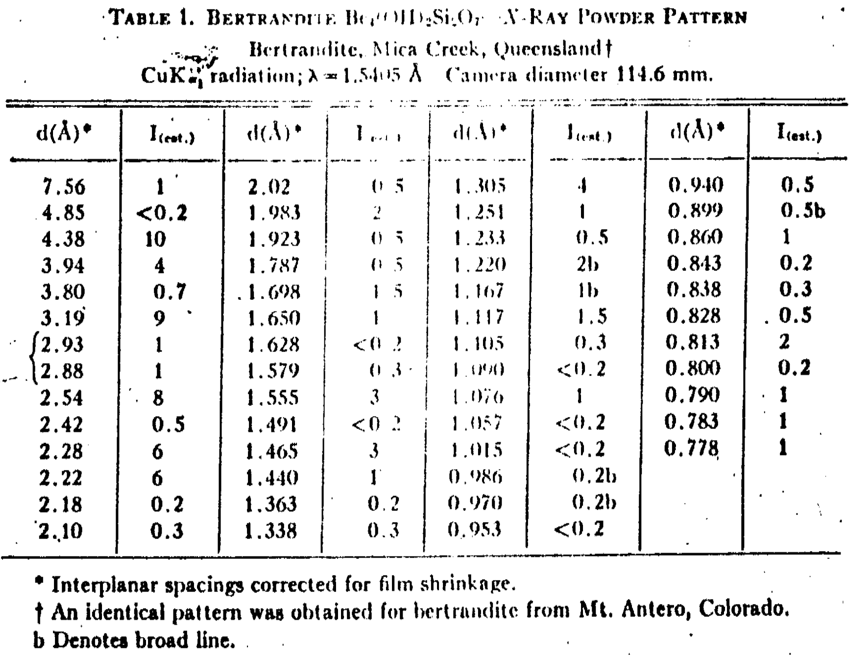

TABLE 1. BERTRANDITE $Be_4(OH)_2Si_2O_7$ X-RAY POWDER PATTERN

Bertrandite, Mica Creek, Queensland†

CuKα_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.

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

There are also some coatings of quartz and iron oxide on the breccia clasts. No fluorite was found in the beryllium deposit or the immediately surrounding area although it was sought for. 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, using the faults as conduits for ore-bearing fluids.

It is very likely that the bertrandite is concentrated in fault breccia of altered rhyolite tuff because for some unknown reason the tuff was a better host rock. However, texture of the rhyolite crusted with bertrandite does not indicate replacement.

Pieces of breccia partially coated with bertrandite are not as altered as some 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 been merely a physical site of deposition rather than playing an active role in chemical precipitation.

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

In summary, it appears that there was intense pre-mineral faulting. Later, hydrothermal 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 being acid and the latter alkaline. The alkaline solutions contained the beryllium which was deposited on clasts and in the fine material in the rhyolite tuff fault breccia. Subsequent faulting has modified the post-mineralization structure of the area to an undetermined extent.

Plate 1

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

Plate 2

Primary flow folding in quartz latite. West central part of mapped area.

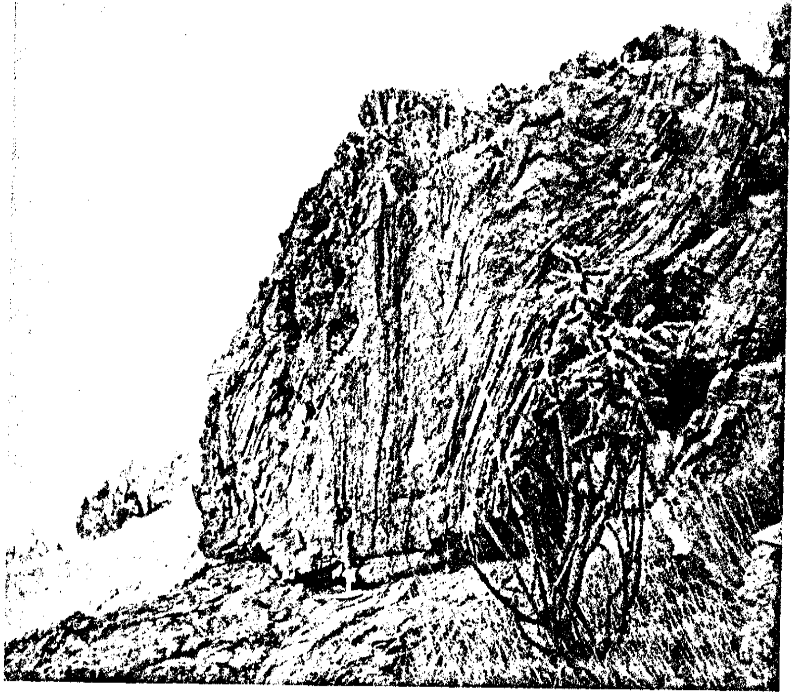

Plate 3

Primary flow contortions in quartz latite. West central part of mapped area.

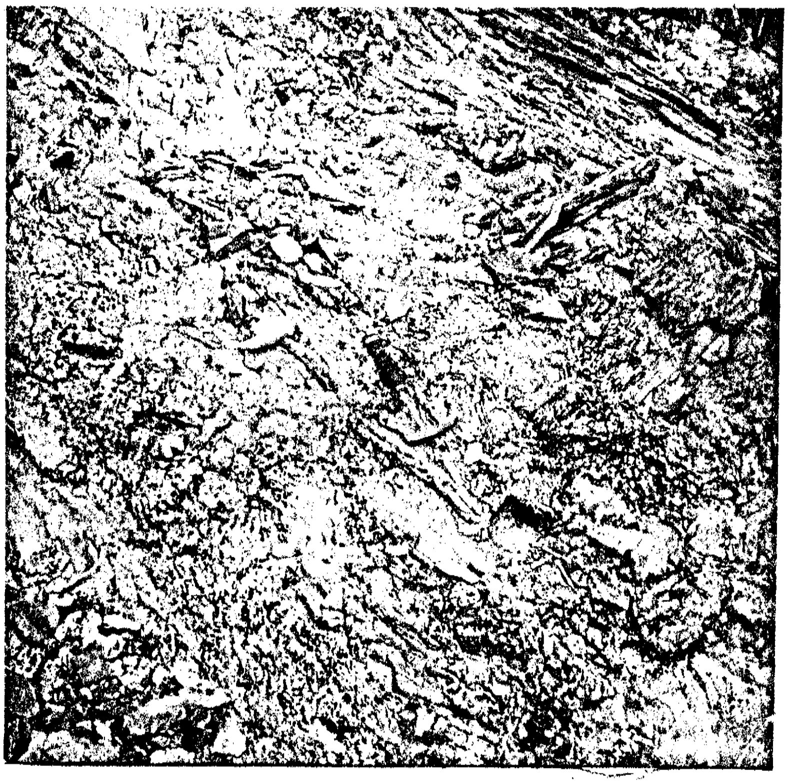

Plate 4

Flow breccia of quartz latite. Clasts have the same composition as the matrix material. Attitude of flow layering here can be seen in the upper right corner. West central part of mapped area.

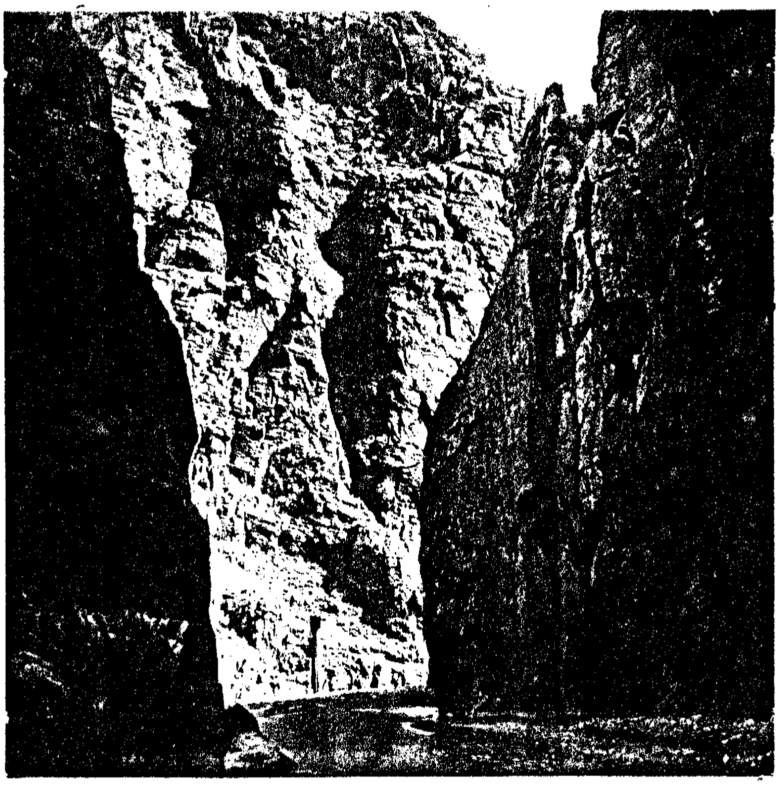

Plate 5

Andesite along Monticello Canyon "box." Looking east in upper part of canyon. Flow layering dips northeast. The water originates from warm springs upstream north of the canyon and from warm springs rising in the stream bed at the head of the "box."

Plate 6

Looking east along Monticello Canyon in the north central part of the mapped area. Interlayered andesite and latite. The dark layers are andesitic, the light ones are more latitic.

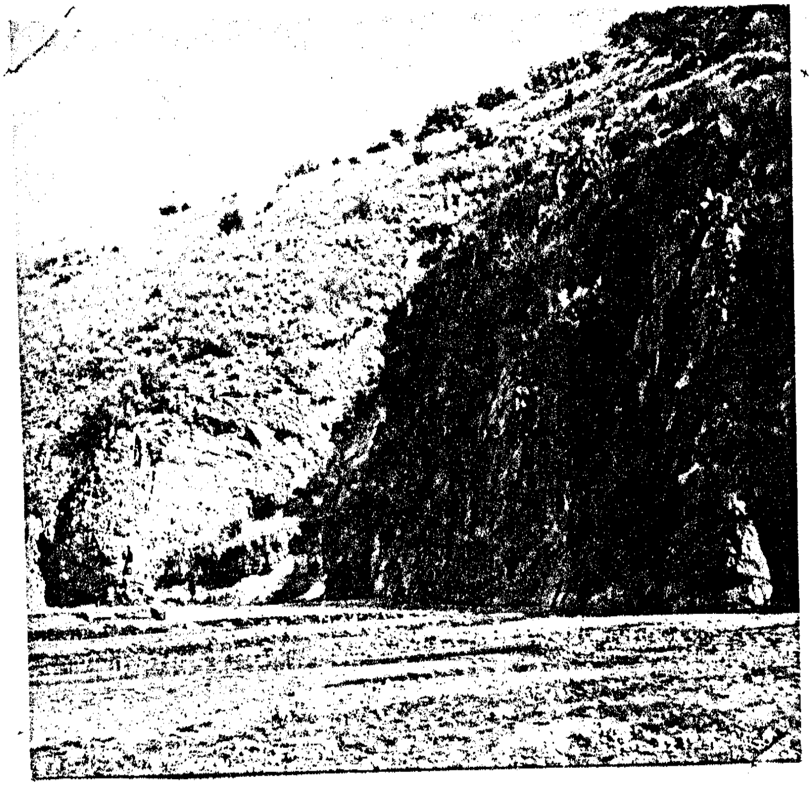

Plate 7

North side of head of the "box." A northeast-trending fault separates rhyolite tuff on the left from andesite on the right. There is a minimum of 700 feet displacement on this fault.

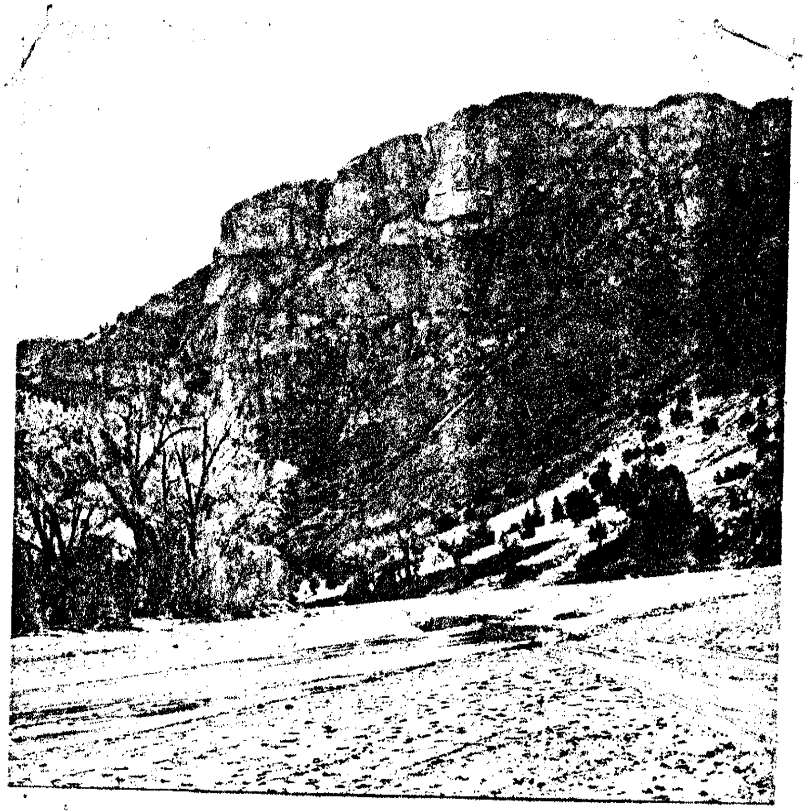

Plate 8

Southern side of Monticello Canyon, showing contact between pyroclastic latite (bottom) and andesite-latite sequence (top). A large fault parallel to the cliffs is buried by talus.

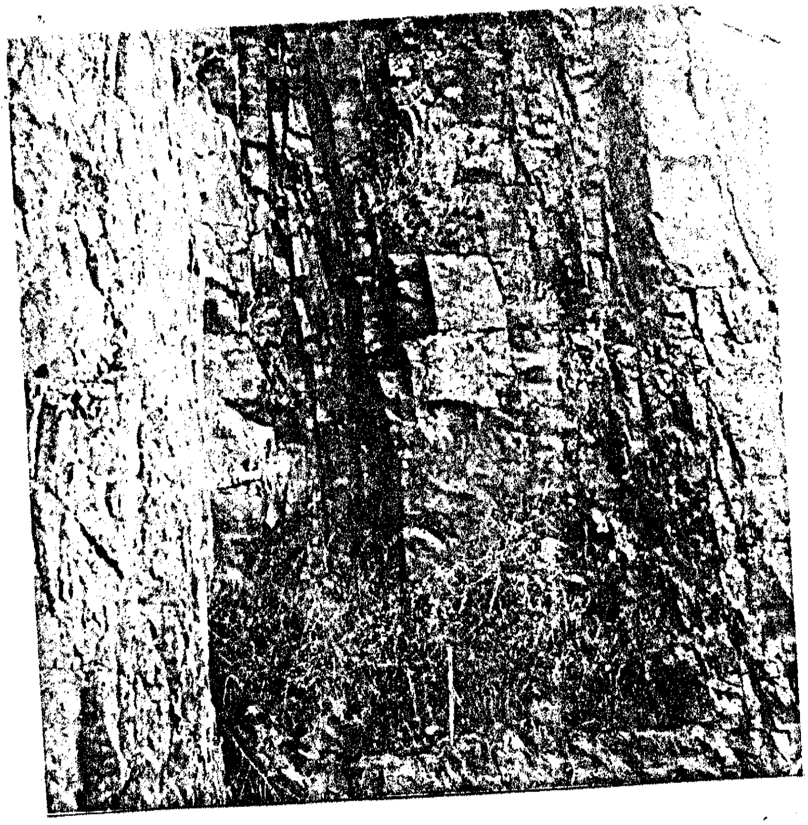

Plate 9

Basaltic andesite dike about 6 feet wide on the south side of Monticello Canyon. A large quartz latite dike borders it on the left side of the photograph.

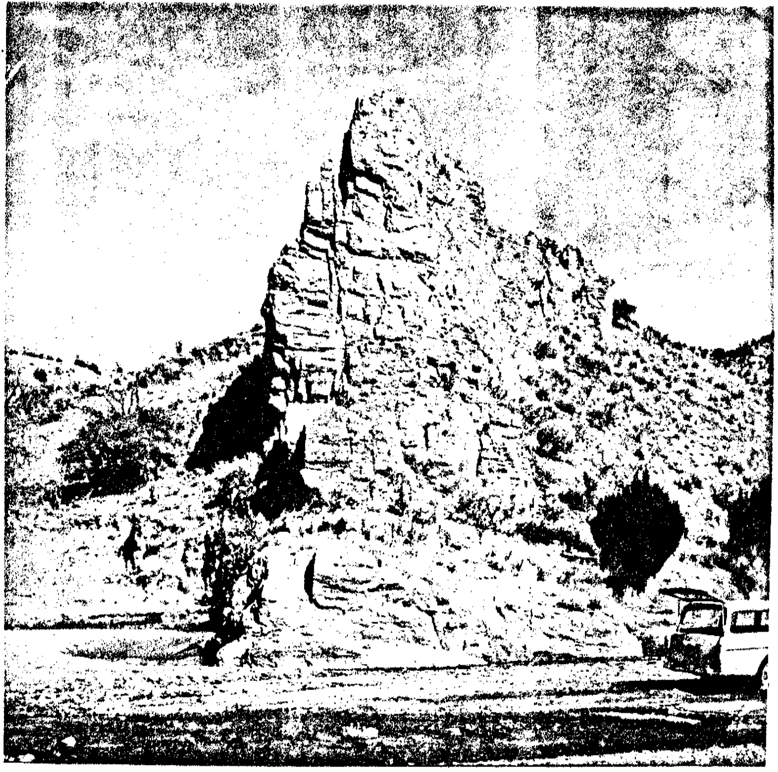

Plate 10

Quartz latite dike on the north side of Monticello Canyon across from the location of plate 9.

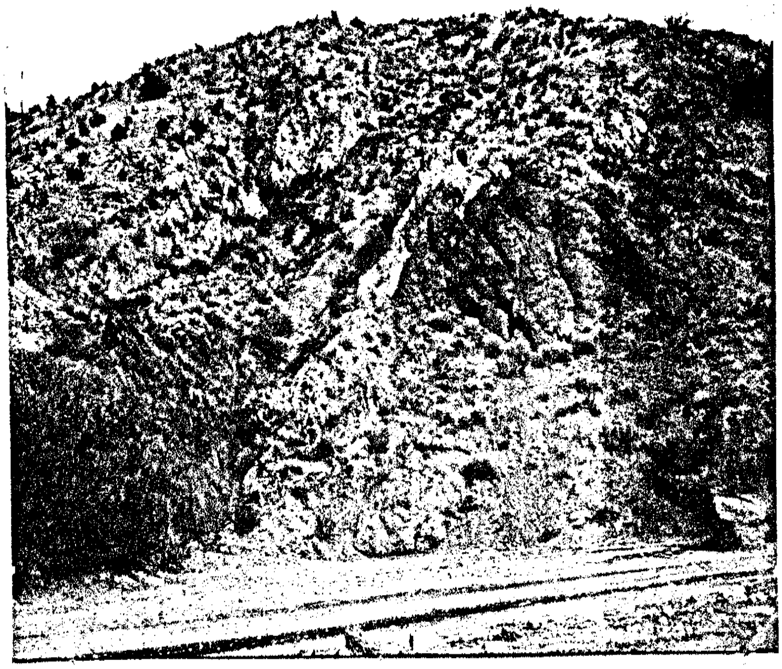

Plate 11

Large latite dike (light colored on the left half of the photo) intruding pyroclastic latite (dark colored on the right half of the photo). Behind the bush on the left side of the photo is a porphyritic andesite dike which has intruded the latite dike.

TABLE 1

Beryllium content of various rocks

Sample number	Be Content (ppm)	Comments
10B	.2	Kaolin
11D	.4	Alunite
12B	.8	Amorphous silica and quartz
12E	.3	Kaolin
12G	.4	Andesite fault gouge
13B1	.6	Kaolin
13C1	.5	Alunite
103	.4	Partially altered latite
110	.4	Dacite dike
111	.4	Latite pyroclastic
119	.3	White quartz and green fluorite from south central part of area
124	.6	Galena and green fluorite from shaft at center of area
131	.3	Massive rhyolite
136	.8	Latite
137	.1	Granite xenolith
140-A	.3	Green fluorite and quartz from vein northeast of shaft
154	.6	From monzonite plug
163	3.	Purple fluorite from southeast corner of area
164	.4	Andesite fault gouge
166	.3	Amorphous silica and quartz

TABLE 1 (cont.)

Sample number	Be Content (ppm)	Comments
167	.6	Pyritized latite xenolith from basaltic andesite dike
168	.8	Galena, quartz, malachite from mine dump in center of area
175	.4	Quartz latite
177	.5	Latite
178	.8	Rhyolite tuff in north central part of area
1-1002	1.2	*Assayed 1.4 ppm Be
1-1003	1.0	*Assayed 1.2 ppm Be
1-1005	1.0	*Assayed 1.2 ppm Be
1-1006	2.4	*Assayed 2.2 ppm Be
1-1010	.8	*Assayed 1.0 ppm Be
1-1012	.7	*Assayed 1.5 ppm Be
1-1020	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 spectograph is obtained. If enough standards were available a set of sensitivity factors could be established for these rocks.

All samples run on ARL Spectograph Analyzer model 2600-1. Film-Kodak Spectographic Analysis #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 was used in all the above analyses.

TABLE 2: MODAL ANALYSES

	Latite	Quartz latite	Massive Rhyolite
Quartz	8	15	70
K-feldspar	20	25	
Plagioclase (undifferentiated)			
Andesine	25	25	
Hornblende	10	10	
Augite			
Sanidine			20
Albite			
Biotite			
Apatite			
Opaque Minerals	5	8	5
White Mica	7	3	4
Epidote	15	6	1
Kaolin	8	8	
Calcite	2		

	Latite Dike	Quartz latite Dike	Porphyritic Andesite Dike	Basaltic Andesite Dike
Quartz	10	15	5	2
K-feldspar	32	6	20	
Plagioclase (undifferentiated)	30			
Andesine		20	40	75
Hornblende				
Augite				10
Sanidine				
Albite		28		
Biotite	5	3	3	
Apatite				minor
Opaque Minerals	5	5	3	10
White Mica	5	3	5	
Epidote			14	
Kaolin	5	10		
Chlorite	3	5	10	3
Calcite	5	5		

REFERENCES CITED

Jahns, R. H., 1944, Beryllium and Tungsten Deposits of the Iron Mountain District Sierra and Socorro Counties New Mexico: USGS Bull. 945-C, pp. 45-79.

Willard, Max E., 1956, Reconnaissance Geologic Map of Luera Spring Thirty-Minute Quadrangle: New Mexico Bureau of Mines and Mineral Resources.

Williams, K. L., and Vernon, R. H., 1960, Bertrandite from Mica Creek, Queensland: Am. Min. v. 45, pp. 1300-1303.

This thesis is accepted on behalf of the faculty of the
Institute by the following committee:

Clay T. Smith

Max E. Willard

Robert H. Weber

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Date: March 14, 1967

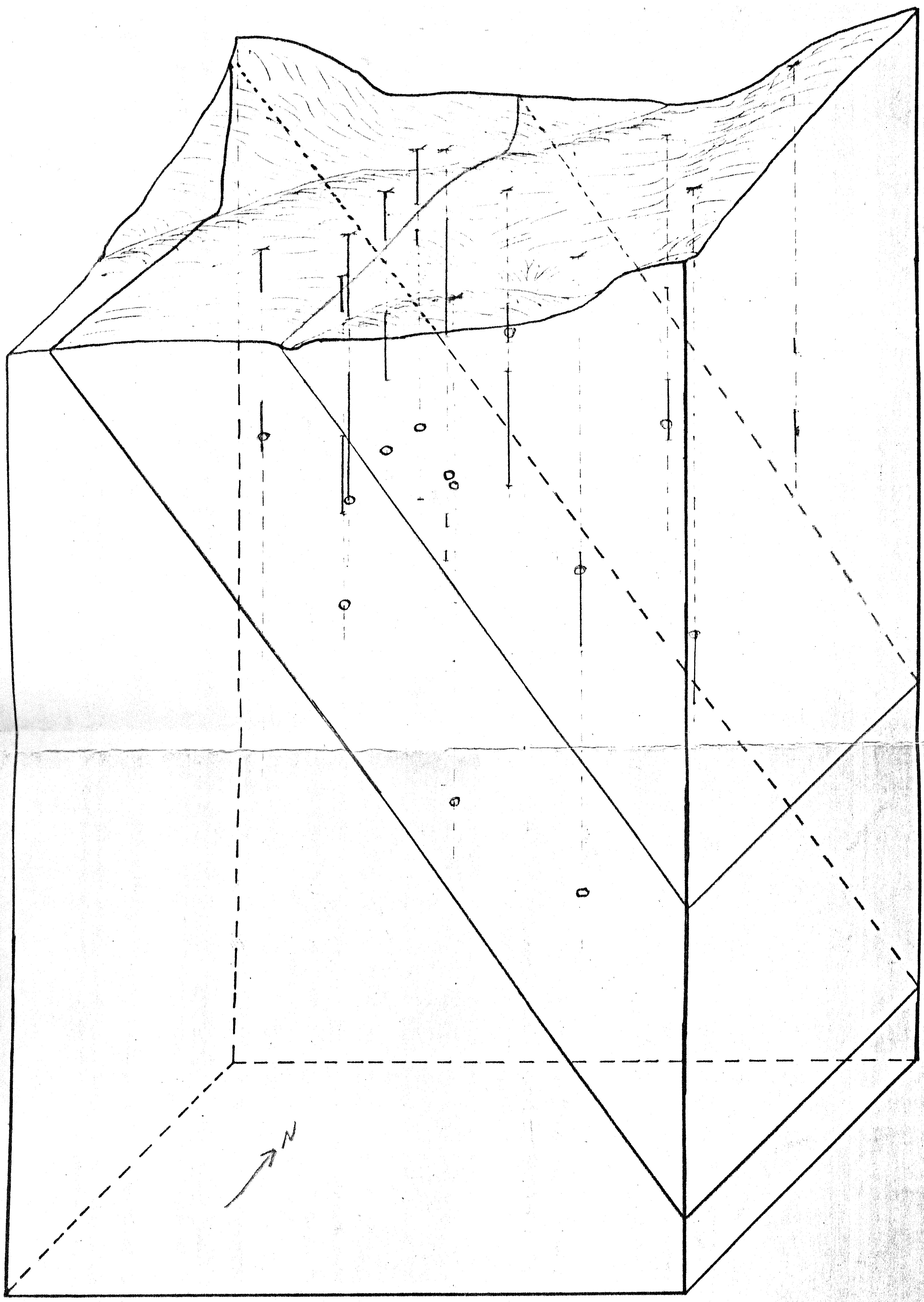


Fig. 2
ORTHOGRAPHIC PROJECTION OF ORE BODY
SCALE: 1"=40'

— — Fault
- - - - Drill hole
▬ Ore zone
+ Drill hole collar
o o Points where drill holes penetrate projected faults

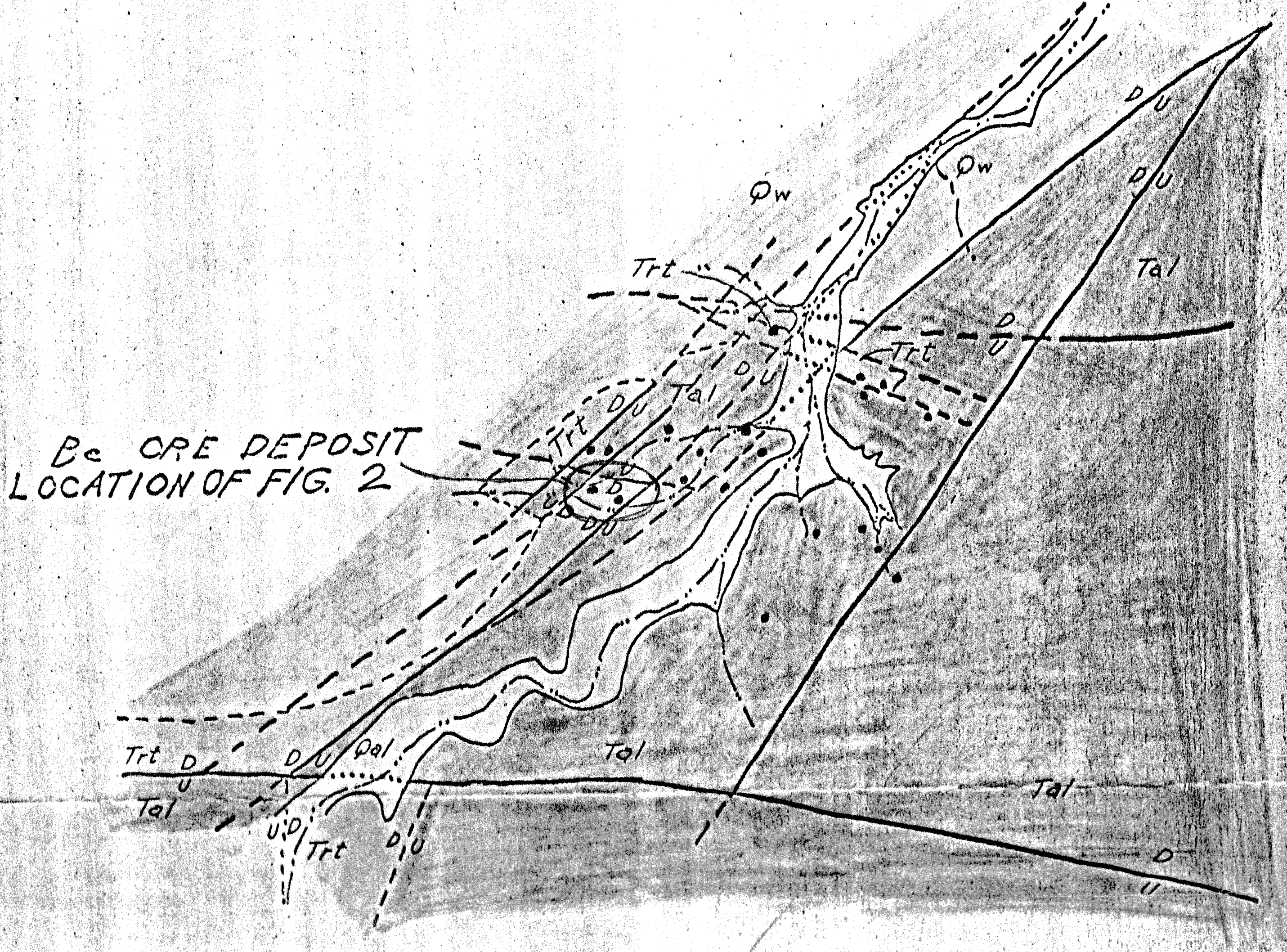
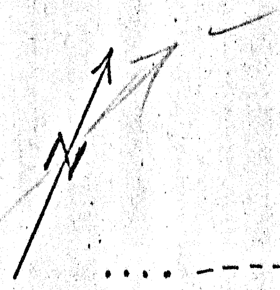


Fig. 1



- Qal Alluvium
- Qw Winston Beds
- Trt Rhyolite tuff
- Tal Andesite and latite
- ● Kaolin-Alunite alteration
- ● Montmorillonite alteration
- ● Replacement by amorphous silica
- .... - - - - —— Fault
- - - - - —— Contact
- —.. —.. —— Intermittent stream

0' 200' 400' 800'
Approximate scale

To [illegible]
400'