

University of Nevada

Reno

A Geochemical Study of the Barite Deposits  
of Mineral County, Nevada

A thesis submitted in partial fulfillment of the  
requirements for the degree of Master of Science  
in Geology

by

William Joseph Tafuri


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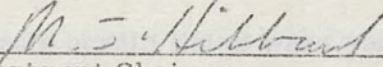
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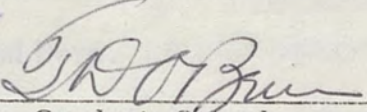
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The thesis of William Joseph Tafuri is approved:

  
\_\_\_\_\_  
Thesis Advisor

  
\_\_\_\_\_  
Department Chairman

  
\_\_\_\_\_  
Dean, Graduate School

University of Nevada

Reno

December 1973

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Access to the Columbus and Little Summit Mines was made through the courtesy of Mr. Richard Horne of Mina, Nevada.

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## ABSTRACT

The barite deposits of Mineral County, Nevada are localized along the intersection of the Walker Lane and the Antler Orogenic belts. There are two distinct types of barite deposits within Mineral County, bedded deposits and vein deposits. The bedded barite deposits occur in the Ordovician Palmetto formation as barite beds that are conformable to the host rocks. These beds can be massive and of commercial grade. The vein deposits occur in a variety of host rocks and are always discordant to the host. These are epithermal appearing veins and they may also be of ore grade.

Strontium analyses made on purified barites of both types showed that the barite of the vein deposits contains significantly more strontium than the barites of the bedded deposits. The average strontium content of the bedded barites was 289 ppm while the average strontium content for the vein deposits was 1,738 ppm. No selenium or lead was detected in any of the barite samples from either type of deposit.

Sulfur isotopic analyses made on samples from both types of deposit have shed some light on the possible genesis of the deposits. The bedded deposits appear to be syngenetic with the sulfate being derived from Ordovician oceanic sulfate. The vein deposits appear to be epithermal with an equilibration between the barite and the associated sulfide minerals being

reached at 170°C. The sulfate source for the barite veins may have been the underlying Ordovician barite bearing sediments.

*[Faint, illegible text from a table of contents, likely listing chapters and page numbers.]*

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## INTRODUCTION

The barite deposits in Mineral County are localized along the intersection of the Walker Lane and the Antler orogenic belts. Horton (1963, pg. 1) and Archbold (1966, pg. 12) both had previously mentioned the localization of the barite deposits along these strong structurally disturbed zones. While it is not clearly known why areas of high tectonic activity frequently contain much barite they do appear to be a localizing agent for barium rich solutions. Hanor (1967, pg. 91) gives the following criteria for a barite province; one, a large scale area of uplift either domal or linear; and, two, a region of non-alkaline and non-basic magmatic activity. This does not mean that all such areas contain barite but Mineral County does fit this model.

Bedded and vein deposits occur in Mineral County and they are structurally, mineralogically, and texturally different. The bedded deposits occur in the Ordovician Palmetto formation as beds conformable to chert and slate sequences. They are essentially of simple mineralogy consisting only of barite, clay minerals, and traces of organic material. Texturally they are formed of tan to grey, saccharoidal textured, massive barite beds which may be locally brecciated. Clay minerals may be present as thin envelopes surrounding the barite on the margins of the beds, but the host rocks are not altered near the bedded deposits. The vein deposits are characterized by coarsely crystalline, almost pure white barite.

The veins are always markedly discordant to the host rock and form fissure fillings that often include brecciated clasts of the host. In vein deposits traces of metallic sulfides and oxides are common along with accessory quartz, calcite, and siderite. The host rocks are commonly silicified or argillized in contact with the barite veins.

The regional association of the two types of deposits are also quite distinct. The bedded deposits occur in Paleozoic sediments that have been extensively folded and faulted into a vertical or near vertical position. This barite occurs as concordant beds and pods in the host. Vein deposits are associated either with known deposits of gold-silver, metallic sulfides, or widespread alteration zones and occur in Triassic or Jurassic volcanic rocks.

The following study was undertaken to attempt to see if there was a chemical difference between the two types of barite deposits. It was hoped that by studying the trace element and isotopic composition of the barites that some light would be shed on the genesis of the barite deposits. Only purified barites were analyzed so that the results would reflect only differences in the barite crystal chemistry. Thusly, the study could be expanded to other geographic areas without making allowances for the varying types of gangue minerals in other deposits.

Theoretically, strontium and lead can substitute for barium in the barite crystal lattice and selenium can substitute for sulfur. Barite,  $\text{BaSO}_4$ , forms a solid solution series with celestite,  $\text{SrSO}_4$ , and as such most barite

contains some strontium. Lead is much more restricted in its substitution for barium and is only found as traces in barite. Selenium substitution only occurs at high temperatures, usually in mesothermal or hypothermal environments.

Sulfur isotope analyses were also made on selected purified barites. Here the objective was to see if the isotopic analyses would help to point to a genetic difference for the sulfur in the two types of deposits. These analyses would hopefully shed some light on whether the sulfur was derived from a magmatic, volcanic, or oceanic source.

The field and laboratory work was done during 1967 and 1968. During the course of this study, twenty-five barite deposits were visited. The deposits were mapped if they were of significant size and not previously mapped by Archbold for his report of 1966. Except for the isotope analyses, all of the laboratory work was conducted by the author at the Nevada Mining Analytical Laboratory. The isotope analyses were made by Dr. M. L. Jensen of the University of Utah, Laboratory of Isotope Geology.

This thesis will be presented in four parts: Part I will cover the sample collection, preparation and analytical procedures; Part II will cover the location and description of the deposits; Part III will discuss the analytical results and their significance; and Part IV will present the conclusions.

## PART I

### Sample Collection, Preparation and Analytical Procedures

#### SAMPLE COLLECTION

Since this work was primarily concerned with the chemistry of each occurrence and not the economic value of the deposit, the sampling was limited to one or a few samples from each deposit. Larger deposits were sampled at various intervals along the structure in order to determine the variability within the deposit. Other occurrences being only as large in extent as a desk top were only sampled once. In all cases, chip samples weighing three to four pounds were cut perpendicular to the structure. All of the samples were taken from surface exposures.

#### SAMPLE PREPARATION

The rock chip samples were reduced to minus  $\frac{1}{2}$  inch in a laboratory steel faced jaw crusher. Barite grinds easily so the usual intermediate step of using rolls was eliminated and the jaw crusher product was fed directly into the steel faced Braun pulverizer. After pulverizing the sample was sieved and the minus 42 mesh plus 65 mesh fraction was deslimed by washing with water and then saved for analysis. This size range was chosen

because it was easily handled and it freed most of the impurities. Since this study was intended to investigate the trace element chemistry of the pure barite and not of the mine run ore the coarse fractions and the slimes were discarded. The coarse fractions contained a high amount of quartz and the slimes contained much clay and iron oxides.

A Frantz isodynamic separator was used to remove the magnetic mineral impurities along with the iron introduced in the grinding process. Minerals of a specific gravity less than 3.3 were removed by floating them off with diiodomethane. The diiodomethane was removed from the sample and reclaimed by washing the sample with acetone. Non-magnetic sulfides and iron stained barite still remained in the sample. A two day leach in aqua-regia dissolved the remaining sulfides and iron stains, leaving the remaining barite visually free from impurities.

It was suspected that the aqua-regia may have also removed some of the trace strontium. To test this, a high strontium sample was chosen and pellets were made of non-leached 65 mesh barite, leached 65 mesh barite and leached 400 mesh barite and subsequently analyzed. It was found that all of the test pellets contained the same concentration of strontium, thereby setting aside the fear that such an intense purification process might remove some of the strontium.

The remaining purified barites were then ground to 95% minus 400 mesh in a Fisher automatic mortar using an alumina mortar and pestle. An arc spectrographis analysis was then made for each sample and silicon, mag-

nesium and aluminum were detected in each sample. This contamination was probably the result of the final grinding process as the mortar and pestle was made out of a ceramic material; the amount of these contaminants stayed constant. All of the contaminants were present in trace amounts only and since their atomic numbers were so much lower than strontium, lead, or selenium their presence would make no appreciable difference on the results when using x-ray fluorescence methods of analysis.

Pellets for x-ray analysis were prepared according to the method of Volborth (1962, pg. 5). By using exactly  $1\frac{1}{2}$  grams of barite per sample the desired one millimeter of sample thickness was obtained. All of the pellets were pressed at 18,000 p.s.i., as higher pressures caused the barite to flow and lower pressure did not sufficiently set the bakelite backing. The final pellet measured  $\frac{1}{4}$  inch thick and  $1\frac{1}{4}$  inches in diameter; the barite center was one millimeter thick and one inch in diameter and had a glass-smooth surface.

By faithfully adhering to the above procedure, the analyses were as closely as possible the result of varying amounts of trace elements in the barite and not inconsistencies in sample preparation.

## ANALYTICAL METHODS

### Trace Element Analysis

An x-ray spectrograph was used for the trace element analysis because it is fast, precise, non-destructive, and accurate. High accuracy and precision is desirable in any trace element study and the ability to obtain these features by x-ray analysis has been shown by many previous workers. The non-destructive nature of x-ray analysis allows one to analyze the same sample for all of the elements in question. Barite, being extremely insoluble, is difficult to handle by wet chemical means and in order to do so one must resort to organic complexing or fluxing procedures. Since the sample must be ground and purified for either wet chemical or x-ray analysis, it is much quicker to analyze a powder with the x-ray and thereby eliminate the complicated wet chemistry and possible attendant errors. The elements which theoretically could naturally substitute into the barite crystal lattice, strontium, lead, and selenium (Deer, Howie, Zussman, 1964, p. 462) all are easily detectable with x-ray fluorescence equipment.

### Sulfur Isotope Analysis

Purified barites and associated sulfide minerals were sent to Dr. M. L. Jensen at the University of Utah for isotope analysis. The sulfur of the barite and the sulfur contained in the sulfide samples was reduced to sulfur dioxide gas and the resulting gas isotopically analyzed on a mass spectro-

meter. The analyses were reported as permil deviations from the standard sulfur from the Cañon Diablo meteorite.

#### Miscellaneous Qualitative Analyses

Purified barites were all checked for purity by means of a Bausch and Lomb D.C. arc spectrograph. The low detection limits of this instrument along with its very fast rate of analysis made this check feasible.

Various minerals associated with the barites were identified with a Norelco x-ray diffractometer. In most cases the small grain size of the associated minerals necessitated the use of this instrument.

#### Gravimetric Analysis

The ground mine-run barites were tested for specific gravity using an air pycnometer. A sample weighing approximately five grams was used. It must be emphasized that this step was not to evaluate the deposit but only to get an idea of the specific gravity of the mine-run barite ore in the sample before it was purified.

### THE X-RAY SPECTROGRAPHIC PROCEDURE

#### Standards

Precise quantitative results can be obtained with an x-ray spectrograph only when there are adequate standards to work with. Artificial

standards had to be prepared for this work since neither analyzed barite nor analyzed reagent grade barium sulfate was available. This was accomplished by adding known amounts of strontium carbonate, Bakers Analyzed 99.0% pure, to ten grams of purified quartz, 99.9% pure. The prepared mixes were very carefully pulverized and homogenized and pressed into pellets in the same manner as the barites.

It would have been more desirable to have standards made with a barite matrix but since this was not possible a quartz matrix was used. Other readily obtainable purified or analyzed minerals, such as calcite, were tried but they either interfered with the strontium, lead or selenium spectrum or they emitted a high background count during the actual analysis.

As a result of this there may be a very slight variance between the actual strontium content in the standard and the analyzed strontium content of the barite; however, this affects only the absolute value of the result and not the relative values which are used as the basis of discussion in the following text.

Standards were made containing 100, 300, 596, 1196, 2384, and 4768 ppm strontium. Three pellets were made of each standard and subsequently analyzed to check for deviation in the standards and linearity of the calibration curve. All of the pellets of a particular concentration gave identical values for strontium except the 100 ppm standard; this particular one involved the addition of such a small amount of strontium carbonate to the silica that it probably did not homogenize properly. This

standard was therefore discarded. The resulting calibration curve was linear and I felt justified in extrapolating the curve to 50 ppm strontium.

The Nevada Mining Analytical Laboratory had excellent standards prepared for both selenium and lead and these were used for those analyses. These standards were prepared in a granitic matrix.

#### Equipment

A Norelco Universal Vacuum Path X-ray Spectrograph was used for this work. Standard equipment was used in conjunction with this and consisted of a tungsten target tube x-ray source, a LiF analyzing crystal, scintillation counter, and pulse height analyzer. Instrumental conditions for the strontium analyses were as follows: source power was 50 KV and 35 MA, counter voltage 750 V, the base line was set at 5.4 V and the window at 42.0 V, the SrK $\alpha$ 1 line was used at 25.15°2 $\theta$  angle, a 5 mill collimator and a vacuum path was used in the sample chamber and goniometer.

Many different instrumental setups were made for the lead and selenium analyses. Every logical combination of parameters was tried but no lead or selenium was encountered in any of the barite samples.

#### Procedure

A preliminary run of analyses was made on the barite samples in order to get a rough idea of the amount of strontium in each sample. The samples

were then grouped so that in every loading of the sample holder for the final data run, two of the eight sample positions were standards that bracketed the range of strontium values in the samples. Each sample was counted four times for 32 seconds and averaged. The background was counted on each side of the peak, averaged and subtracted from the peak value. A calibration curve was constructed by plotting the concentration of strontium in the standards against the intensity of the emitted radiation in counts per second. The measured intensity of the unknown was therefore plotted against the calibration curve which yielded the concentration of strontium in the barite.

#### Precision of the Method

Very high precision was obtained by using these methods. The samples with the lowest concentrations of strontium had relative deviations of 1.5% while the samples containing high amounts of strontium had relative deviations of 0.4%. Thus, an analysis reported as containing 100 ppm strontium is reproducible within  $\pm 1.5$  ppm while an analysis of 3,000 ppm strontium is reproducible to  $\pm 12$  ppm.

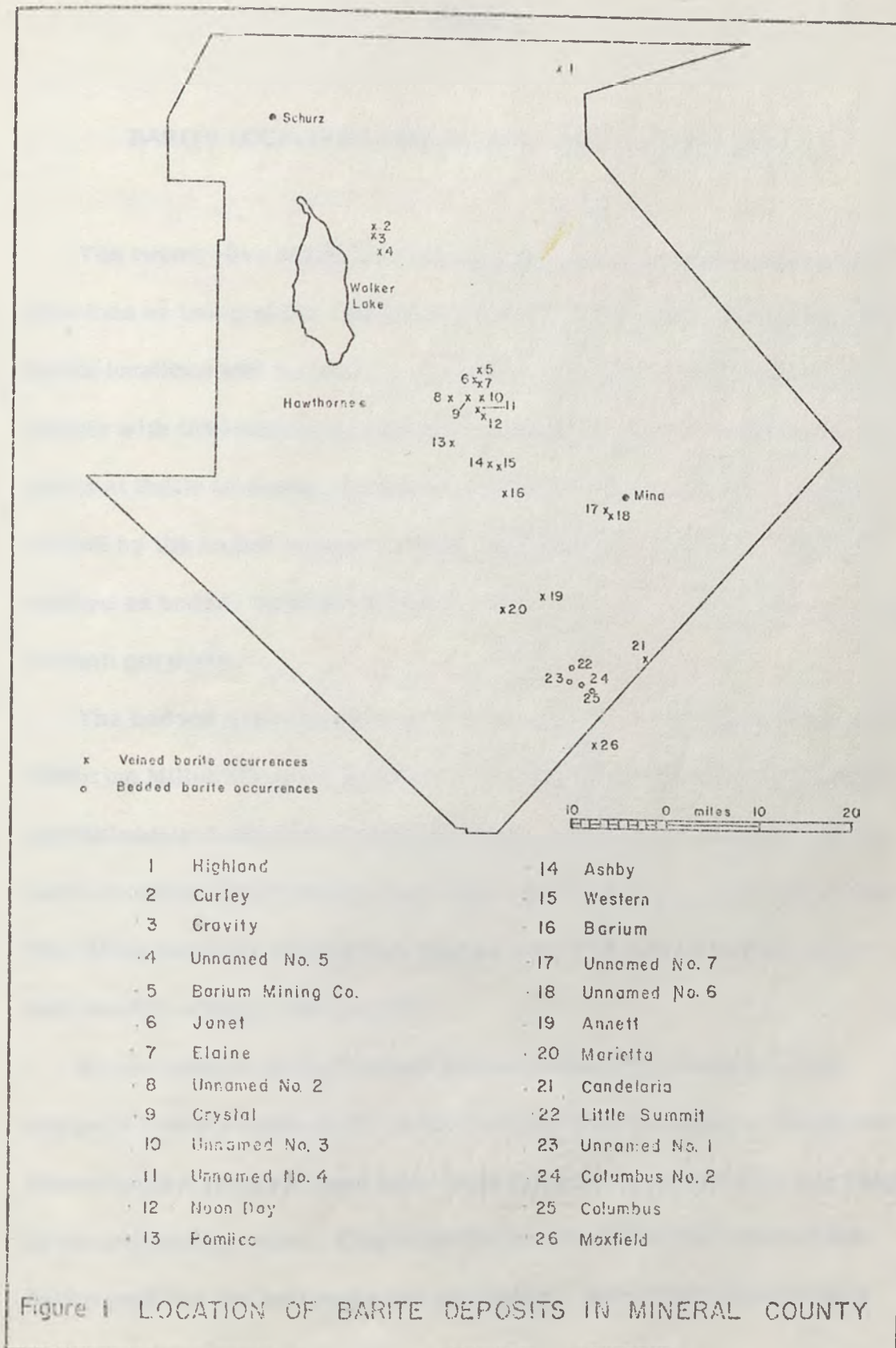


Figure 1 LOCATION OF BARITE DEPOSITS IN MINERAL COUNTY

## PART II

## BARITE LOCALITIES AND DESCRIPTIONS OF THE DEPOSITS

The twenty-five barite localities visited are listed under two main subdivisions as being either bedded or veined. Within each subdivision, the barite localities will be listed as they occur from north to south in Mineral County with the location of each deposit shown in figure 1. The barite deposits at Battle Mountain and Northumberland Canyon, while not actually visited by the author and not in Mineral County, are well known and described as bedded barites and are included in the bedded category for comparison purposes.

The bedded deposits occur in the Ordovician Palmetto formation and the Cambrian Miller Mountain formation. The Palmetto formation is composed of approximately 4,000 feet of slates and chert (Ross, 1961, pg. 13). At the barite localities the Palmetto is actually a weak phyllite rather than a slate. The Miller Mountain formation is composed of 5,600 feet of marble, slate, and hornfels (Ross, 1961, pg. 11).

At the deposits in the Palmetto formation the barite occurs as beds and pods that are conformable to the host phyllites and cherts. Diagenetic squeezing has recrystallized some of the barite or injected it into pod shapes in the sedimentary rocks. Clay minerals may form envelopes around the barite pods but the host rocks are not altered. This type of barite has a

fine grained saccharoidal texture and a tan or grey color. A fetid odor evolves when this barite is ground or vigorously beat with a hammer thusly indicating the presence of organic matter. No sulfides were noted in these deposits. A total of five bedded deposits were studied.

The one deposit in the Miller Mountain formation, the Maxfield Mine, is not actually in Mineral County but it is the only deposit close to the border so it was included in this study. At this locality the barite forms crystalline white pods in the marble and may actually be a bedded replacement deposit. The pods of barite appear to be conformable to the general structure of the marble but it is hard to be positive in this metamorphosed sequence.

The vein deposits occur in a variety of host rocks ranging from felsic volcanic rocks to a monzonite stock. These deposits may be associated with known deposits of gold and silver such as at Ashby, Highland, and Pamlico or widespread alteration zones such as the general area of the Gravity and Curley prospects. The veins are always discordant to the host and they form fissure fillings that often include brecciated clasts of the host rock. Common gangue minerals in the barite veins are quartz, calcite, siderite, magnetite, hematite, and limonite. In some instances traces of galena, chalcopyrite, or pyrite is found but the total amount of sulfides in the vein is usually less than  $\frac{1}{2}$  of a percent. Textures in the veins varied from massive crystalline barite to coarsely crystalline barite with tabular sub-hedral crystals. Iron oxides often filled vugs in the barite veins and the

host rocks were frequently argillized or silicified in the walls of the barite veins. Barite in the vein deposits was always bright white in color. A total of twenty vein deposits were studied.

#### BEDDED BARITE LOCALITIES

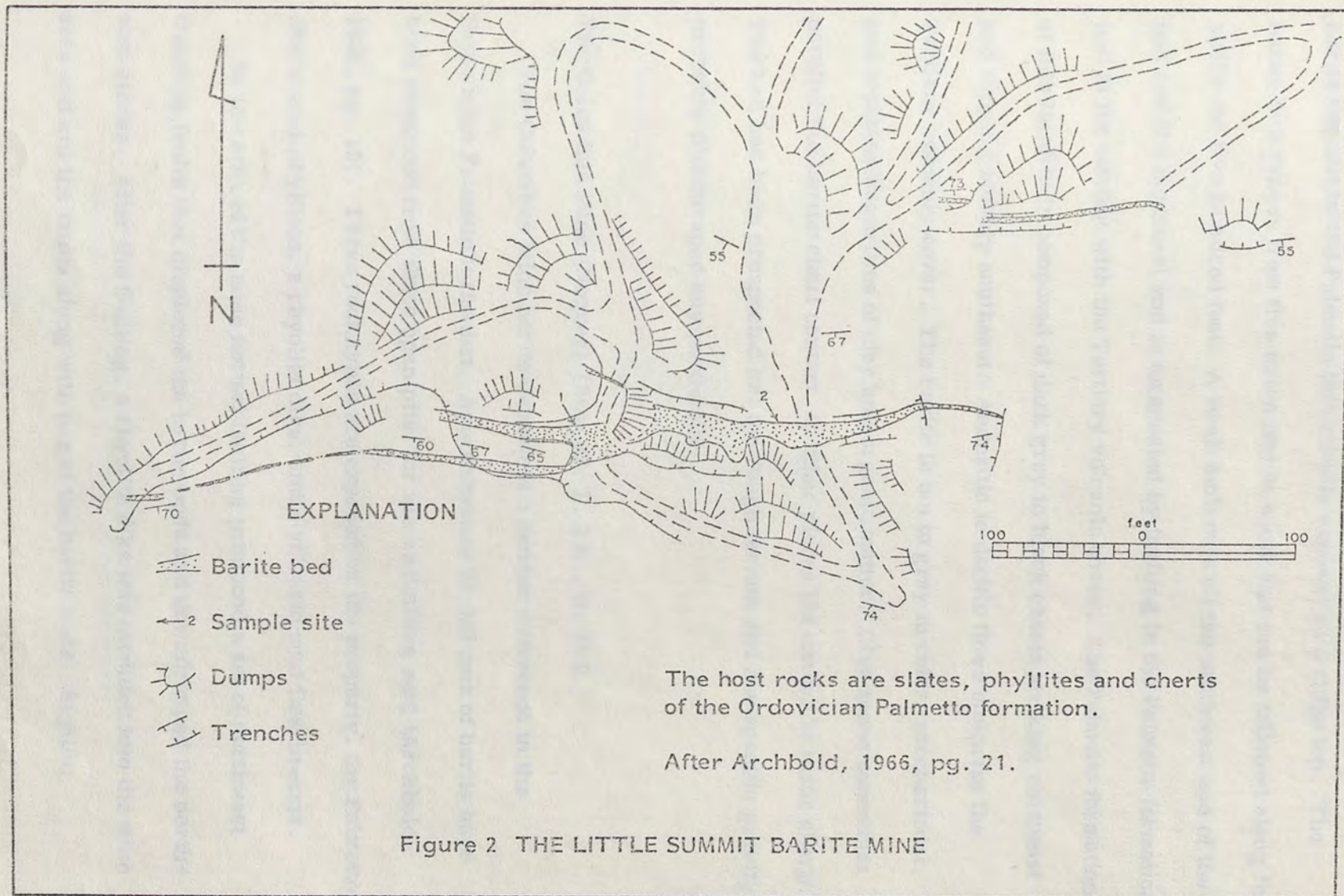
##### The Little Summit Mine (Sec. 8, T. 3 N., R. 34 E.)

The Little Summit Mine has produced barite from a bedded deposit in the Ordovician Palmetto formation. At this locality the Palmetto formation is composed of shales and cherts with a steep southerly dip and an easterly strike. Barite occurs as conformable pods and lenses in the cherts, the largest lens being 40 feet wide and 200 feet long. The barite zone may be traced discontinuously for nearly 2,000 feet.

The barite is tan to gray in color with a saccharoidal texture. Some of the lenses are brecciated and bordered by a clayey zone. Only a few of the barite lenses are of ore grade; clay minerals and organic materials being the chief impurities. During the grinding of this barite a distinct fetid odor evolves indicating the presence of organic material although no organic particles can be seen in a hand specimen. No sulfide minerals or quartz was observed in the barite.

##### Unnamed Number One (Sec. 8, T. 3 N., R. 34 E.)

One mile south of the Little Summit Mine, another conformable bedded

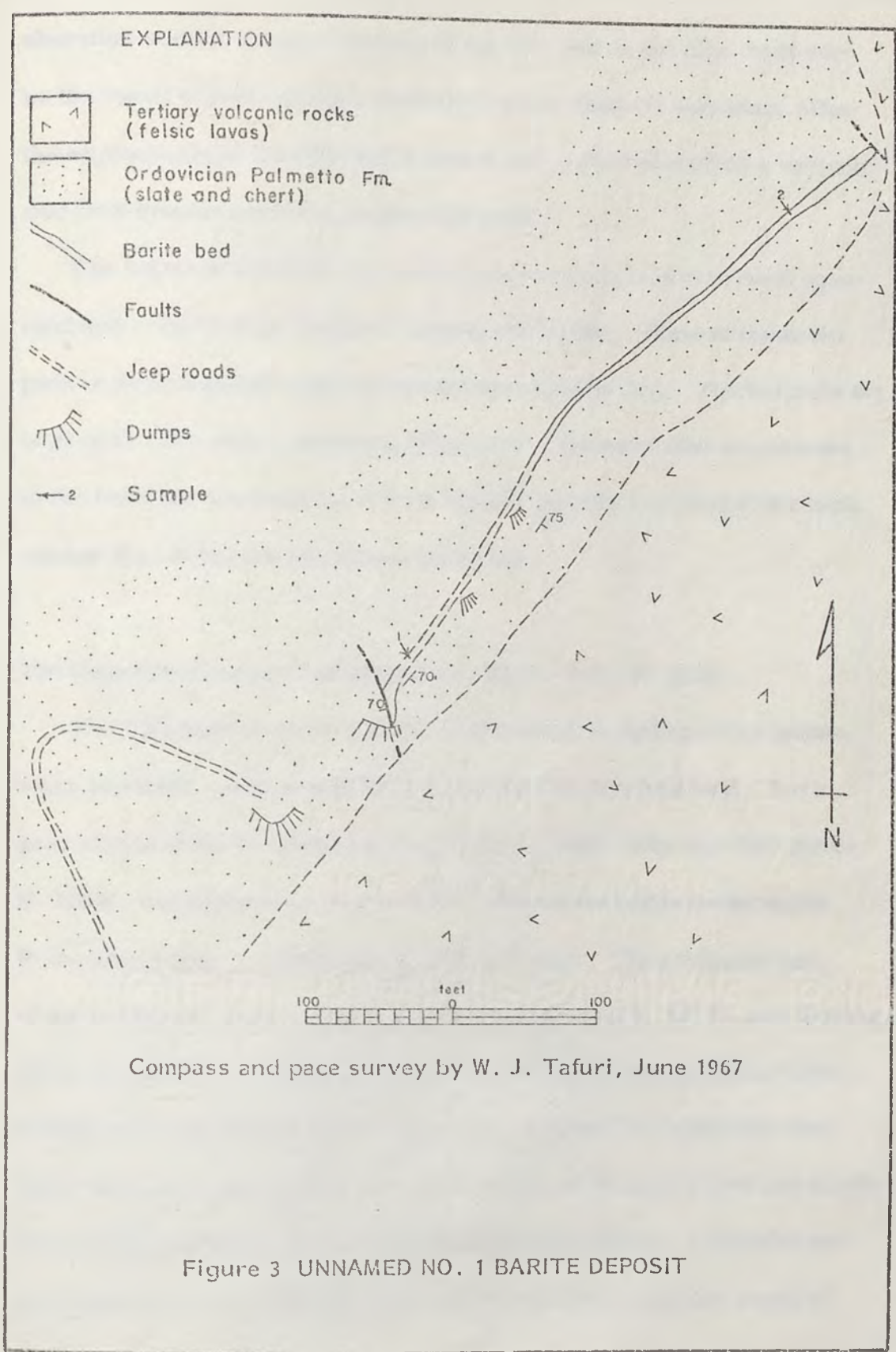


barite deposit in the Palmetto formation is exposed on a ridge top. The barite bed ranges from five to ten feet in width and can be followed along its strike for five hundred feet. A small fault cuts off the southwest end of the bed and the northeast end is terminated by faulting in the Palmetto formation just at the contact with the Tertiary volcanic cover. The Palmetto formation at this locality is composed of dark gray to black cherts striking northeast and dipping steeply southeast. Andesitic to dacitic flows comprise the Tertiary volcanic cover. The barite is tan to gray in color, saccharoidal, and contains impurities of clay and organic matter. Clay zones sometimes parallel the barite-chert contact, in other places the contact is razor sharp. The bed has been prospected but the rough terrain and low specific gravity probably discouraged any production.

The Columbus Mine (Noquez) (Sec. 22, T. 3 N., R. 34 E.)

The Columbus Mine barite deposit is a bedded occurrence in the Ordovician Palmetto formation. Approximately 25,000 tons of barite have been produced from three open pits, for use as drilling mud (Archbold, 1966, pg. 19). Three rock types are exposed on the property, the Palmetto cherts and phyllites, a rhyolite dike, and a volcanic mud flow breccia.

In the area of the mine normal faulting produced a set of northwest trending faults that displaced the barite beds and downdropped the northeast blocks. After the faulting, a rhyolite dike was intruded into the mine area and cut the faults along with one of the barite beds. Argillic



alteration seen in the near vicinity of the dike and in the dike itself may be the result of post intrusion hydrothermal or deuteritic solutions. After the emplacement of the dike and a subsequent period of erosion a volcanic mud flow breccia partially covered the area.

The barite is found as disjointed beds and pods that have been squeezed and mobilized by the local faulting and folding. Some of the barite pods in fault zones are surrounded by envelopes of clay. The barite is tan to gray in color with a saccharoidal texture. Traces of clay are present in the beds but the barite is of high specific gravity and most of the beds thicker than three feet have been mined out.

#### The Columbus Number Two Mine (Sec. 16, T. 3 N., R. 34 E)

The Columbus Number Two Mine consists of an open pit that follows a ten-foot wide barite bed in the Ordovician Palmetto formation. Dark gray cherts of the Palmetto formation form the host rocks and they strike N. 75° W. and dip steeply to the north. The barite bed is conformable to the cherts and is exposed for 60 feet in the pit. The northwest end of the barite bed is cut off by a normal fault striking S. 80° W. and dipping 65° to the north; the southeast end of the bed appears to grade into chert. The SW striking normal fault in the pit has dropped the north side and either brought volcanic mud flow breccia against the barite bed and cherts or the volcanic debris flowed up against the fault scarp. A massive saccharoidal texture typifies the light gray to tan barite and thin seams of

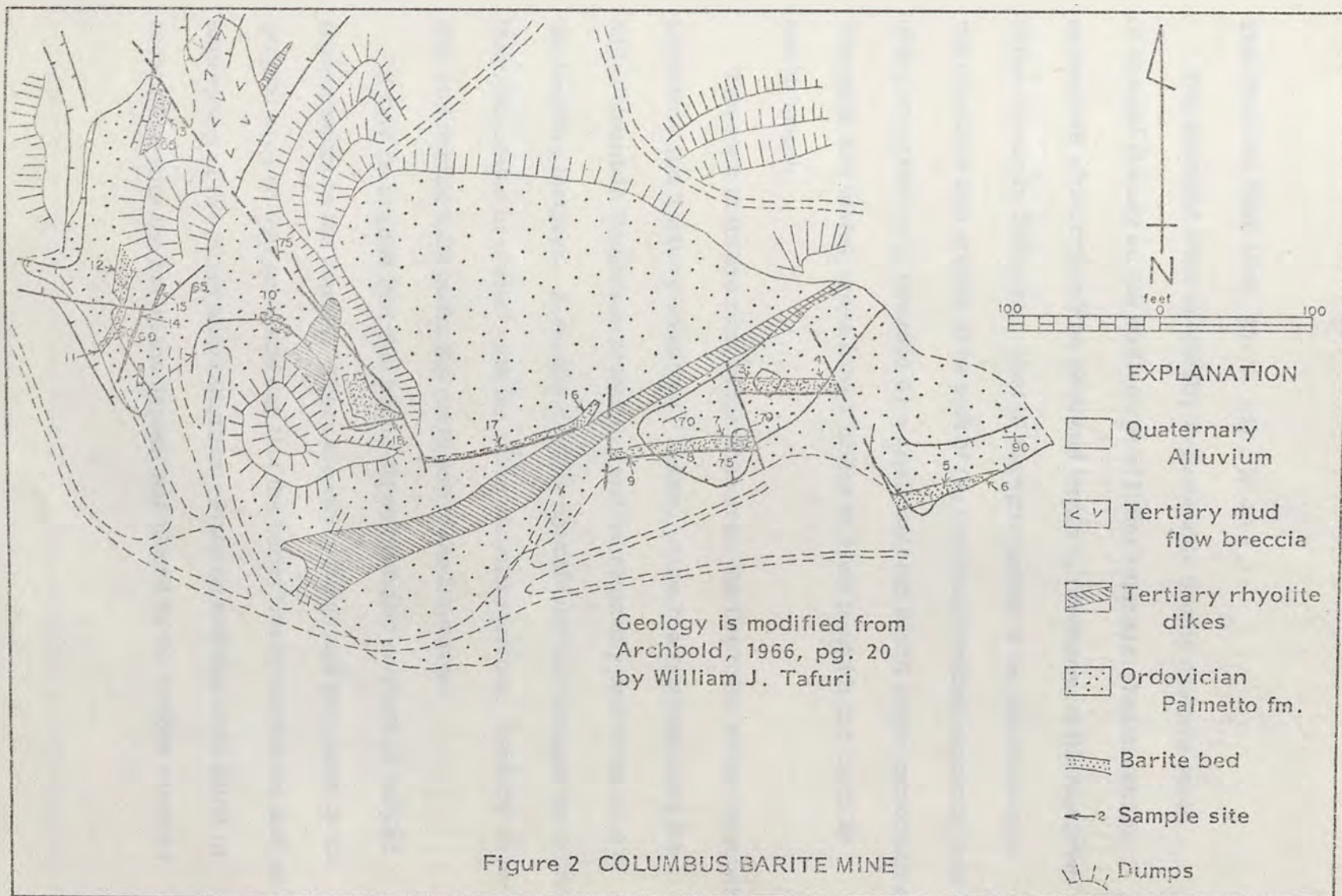


Figure 2 COLUMBUS BARITE MINE

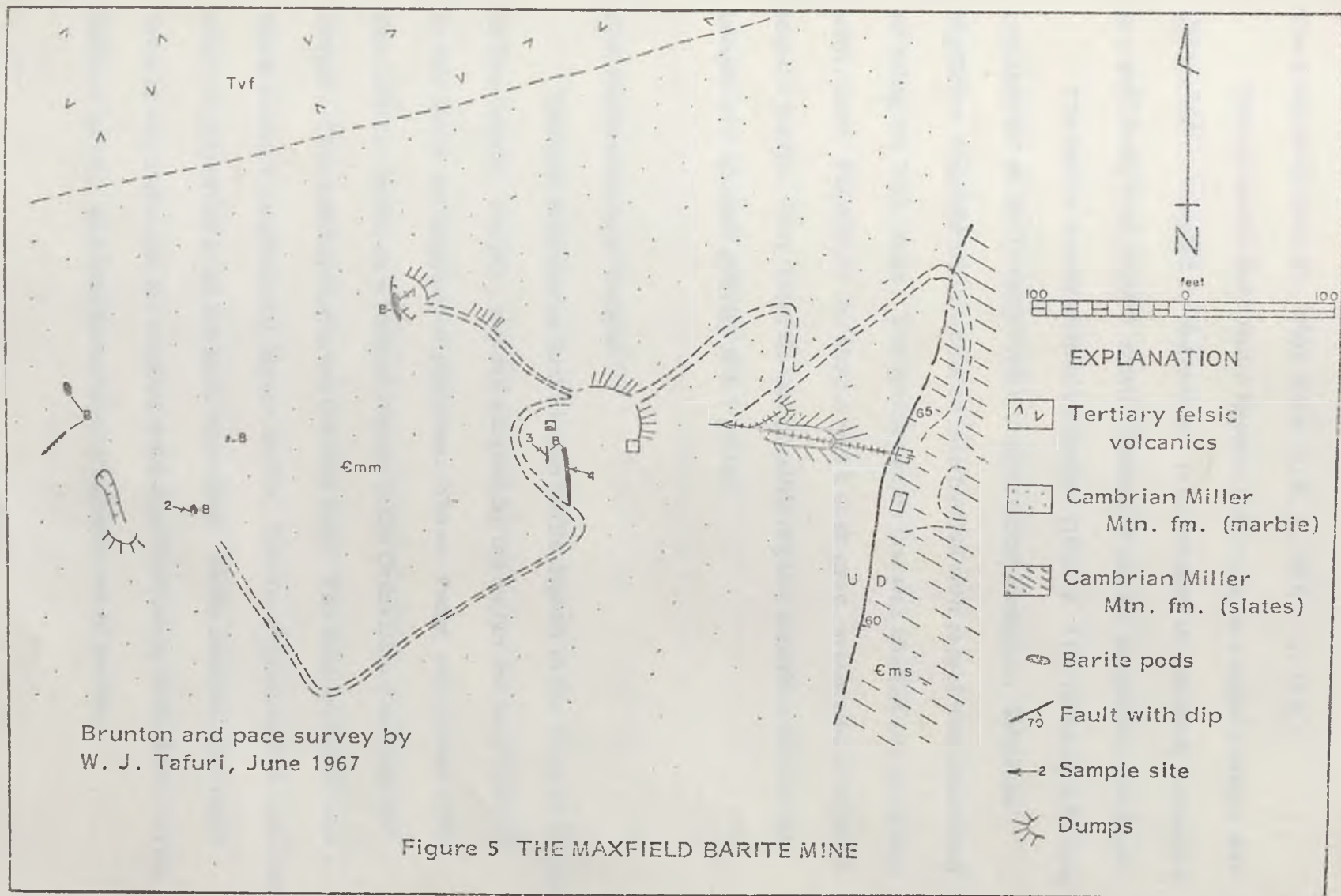
manganese oxides and limonite can be seen in the bed.

The Maxfield Mine (Sec. 15, T. 2 N., R. 34 E.)

The Maxfield Mine is actually in Esmeralda County one mile south of Mineral County on the south slope of Miller Mountain. Barite occurs as massive white crystalline pods and lenses in limestones of the Cambrian Miller Mountain formation. Most of the pods appear to be conformable to the limestone and appear to be part of the original limestone sequence; one of the occurrences is bounded by a small fault but it still seems conformable. The pods and lenses range from 6 inches to 3 feet in width and up to 20 feet in length.

Two rock units are seen in the mine area; the Cambrian Miller Mountain Limestone and Tertiary volcanics. Metamorphism has recrystallized the Miller Mountain limestones to marbles and consequently destroyed most of the bedding features. A steeply dipping normal fault has brought the Miller Mountain slates in contact with the Miller Mountain marble. Tertiary rhyolitic and dacitic tuffs cover the north end of the mine area.

It may be argued that this barite deposit actually consists of bedded replacements in the marble. There are silver mines and prospects in the general area so that one could say that the barite was hydrothermal and an expression of the silver mineralization. Since no sulfides were found in association with the barite the deposit was placed in the bedded category.



The Food Machinery Co. Mine (Secs. 5, 6, T. 28 N., R. 44 E.)

This property near Battle Mountain, Nevada, in Lander County, was not visited or sampled by the author. It is included in this study because it is a well described deposit which I desired to use for comparison purposes.

The barite was described by Brobst (1958, p. 113) as being a bedded replacement in the Pennsylvanian Pumpernickel formation. Siliceous argillites, argillite and limestones interbedded with cherts were described as being the host rocks. The barite sample that was studied was in contact with chert. Physically the sample was a dark gray, sacchariodal textured, impure barite. Clay minerals and possible organic materials diluted the sample to a specific gravity of 4.1 gm/cc.

#### East Northumberland Canyon

The East Northumberland Canyon barite deposit in the Toquima Range in Nye County, Nevada, was not sampled by the author but was included in this study for comparison purposes. Shawe, Poole, and Brobst (1967) describe the barite as a bedded deposit in the Ordovician Pine Cone formation. Thin bedded cherts are the host rock. The sample studied was a black massive sacchariodal impure barite. Quartz, organic matter, and clay minerals appeared to be the main impurities. Barite rosettes with radiolaria as the nuclei for the rosettes were described along with cherty barite, nodular barite, and interformational conglomerates of barite.

## VEIN BARITE LOCALITIES

## The Highland Group

The Highland Group barite deposit in the Eagleville district has been previously mapped by Archbold (1966, pg. 17) and mentioned by Ross (1961, pg. 94). Barite occurs as a discontinuous vein in the Excelsior formation volcanics. The Eagle gold mine lies south of the deposit approximately a quarter of a mile. Production from the Eagle was noted by Ross (op. cit.) as being less than 50,000 dollars, and was derived from two northwest striking gold quartz veins which contained much barite. No surface barite was found at the Eagle mine either by Ross or the author.

Stratigraphically, the area is composed of three units, the oldest being the Excelsior Formation volcanics of Triassic age. A small quartz-diorite stock intrudes the Excelsior in the northwest part of the district. Tertiary volcanics consisting of rhyolite flows and tuffs with possible dacites unconformably overlie parts of the area.

The Excelsior appears to consist of sodic andesites which are in part altered and metamorphosed. Bleaching and sericitization of the volcanics is seen in varying degrees up to two feet distant from the margins of the barite veins and in the vicinity of the Eagle mine. Adjacent to the contact of the granitic stock, the volcanics appear to be recrystallized to a coarser grained more dioritic rock.

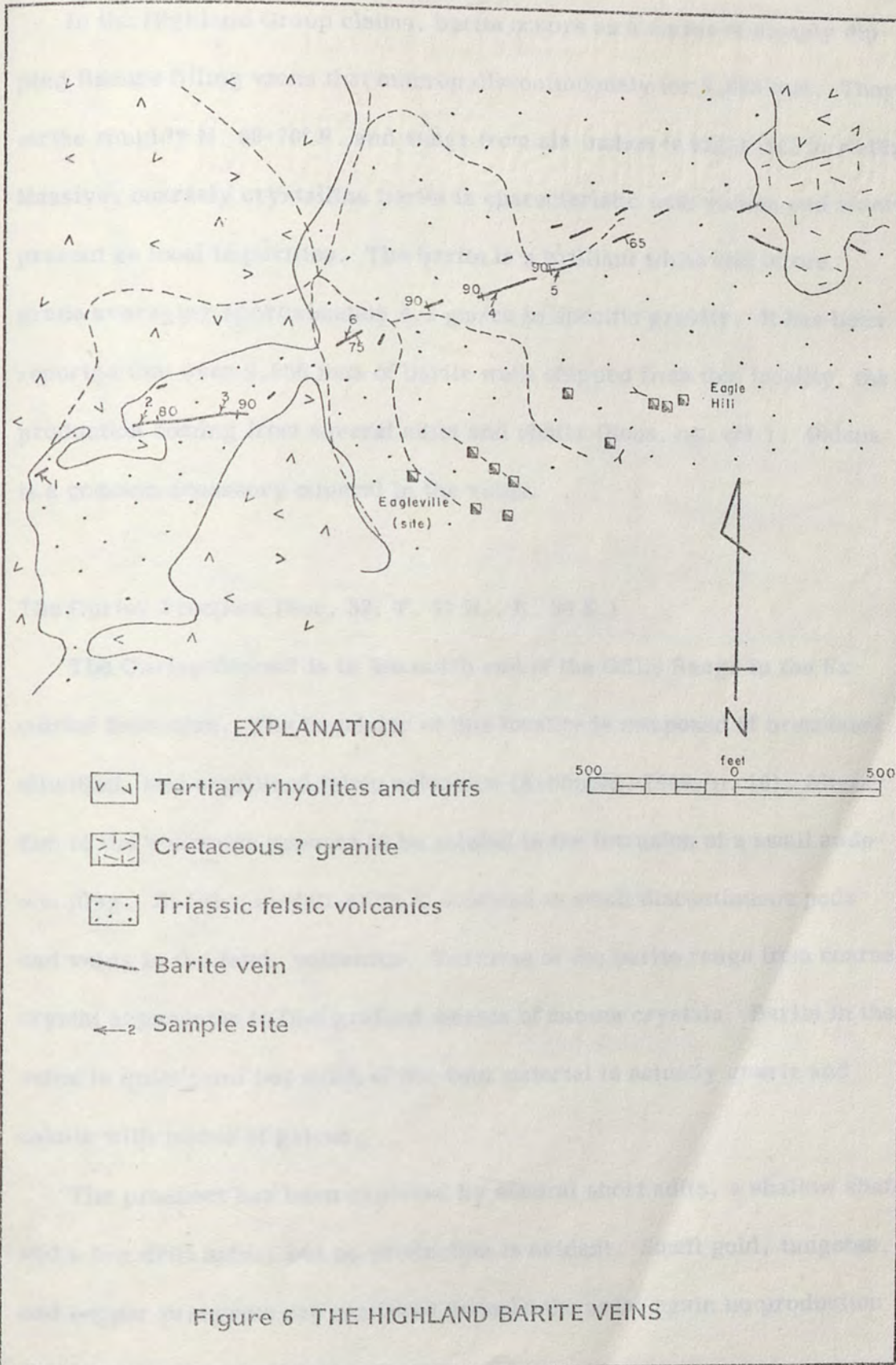


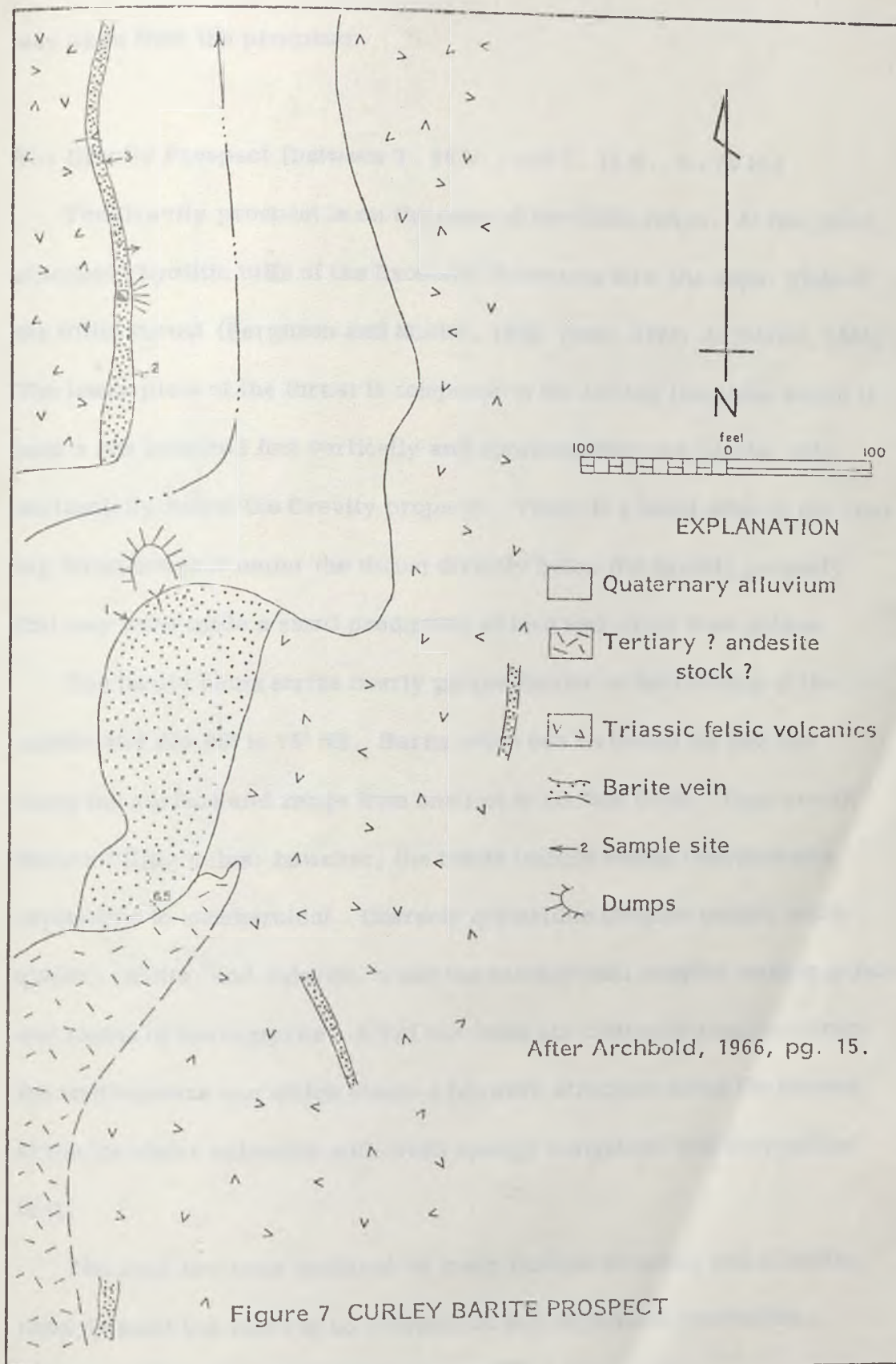
Figure 6 THE HIGHLAND BARITE VEINS

In the Highland Group claims, barite occurs as a series of steeply dipping fissure filling veins that outcrop discontinuously for 3,000 feet. They strike roughly N. 60-70° E. and range from six inches to eight feet in width. Massive, coarsely crystalline barite is characteristic with galena and siderite present as local impurities. The barite is a brilliant white and of ore grade averaging approximately 4.2 gm/cc in specific gravity. It has been reported that over 9,000 tons of barite were shipped from this locality, the production coming from several adits and shafts (Ross, op. cit.). Galena is a common accessory mineral in the veins.

#### The Curley Prospect (Sec. 32, T. 11 N., R. 30 E.)

The Curley deposit is in the north end of the Gillis Range in the Excelsior formation. The Excelsior at this locality is composed of brecciated, silicified, and argillized felsic volcanics (Archbold, 1966, p. 16). Alteration of the volcanics appears to be related to the intrusion of a small andesite plug. Barite mineralization is confined to small discontinuous pods and veins in the felsic volcanics. Textures of the barite range from coarse crystal aggregates to fine grained masses of minute crystals. Barite in the veins is quite pure but much of the vein material is actually quartz and calcite with traces of galena.

The prospect has been explored by several short adits, a shallow shaft and a few drill holes; but no production is evident. Small gold, tungsten, and copper prospects are scattered through the area, again no production



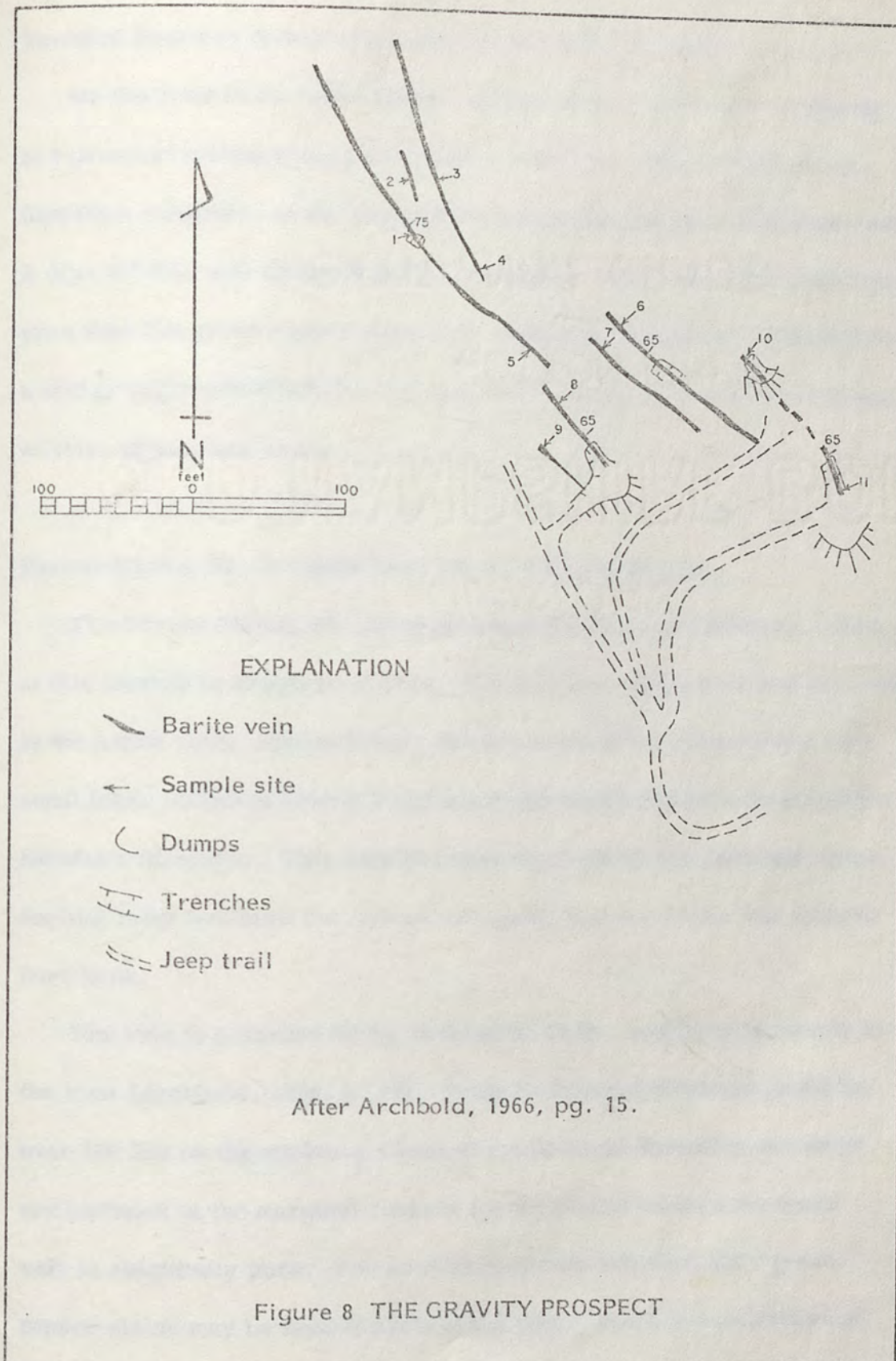
was made from the prospects.

The Gravity Prospect (between T. 10 N., and T. 11 N., R. 30 E.)

The Gravity prospect is on the crest of the Gillis range. At this point, silicified rhyolitic tuffs of the Excelsior Formation form the upper plate of the Gillis thrust (Ferguson and Muller, 1949; Ross, 1961; Archbold, 1966). The lower plate of the thrust is composed of the Luning limestone which is seen a few hundred feet vertically and approximately one quarter mile horizontally below the Gravity property. There is a small mine in the Luning formation just under the thrust directly below the Gravity property that may have made a small production of lead and silver from galena.

The barite veins strike nearly perpendicular to the bedding of the Excelsior and dip  $65^{\circ}$  to  $75^{\circ}$  NE. Barite veins can be traced for 800 feet along the surface and range from one foot to six feet thick. They are all fissure filling veins; however, the barite texture varies from coarsely crystalline to saccharoidal. Coarsely crystalline samples contain much quartz, calcite, and siderite, while the saccharoidal samples contain galena and traces of chalcopyrite. All of the veins are distinctly massive except the southeastern one which shows a boxwork structure along the contact of the Excelsior volcanics with much spongy manganese and iron oxides in it.

The area has been explored by many shallow trenches and a loading ramp as built but there is no evidence of any significant production.



Unnamed Prospect Number Five (Sec. 2, T. 10 N., R. 30 E.)

On the crest of the Gillis range, approximately  $\frac{1}{4}$  mile south of Gravity is a prospect pit exposing a small barite vein. The vein in the Excelsior formation volcanics, is six inches wide and is exposed for nearly three feet. It dips  $40^{\circ}$  NW. and strikes S  $80^{\circ}$  E. No sulfides were seen in the essentially pure vein but green copper staining is evident in the footwall. The vein is a coarse aggregate of tabular crystals that range up to 20 mm in length and massive crystalline barite.

Barium Mining Co. Prospect (Sec. 10, T. 8 N., R. 32 E.)

The Barium Mining Co. prospect lies in the Excelsior formation which at this locality is composed of tuffs. The tuffs are highly silicified adjacent to the barite vein. Approximately 100 feet south of the barite vein a very small felsic intrusive outcrops and quartz stringers radiate from it into the Excelsior formation. This vein has been explored by two small pits and a loading ramp was built but it does not appear that any barite was shipped from here.

The vein is a fissure filling striking N.  $15^{\circ}$  W., and dipping steeply to the west (Archbold, 1966, p. 19). It can be followed discontinuously for over 200 feet on the surface. Clasts of the Excelsior formation volcanics are included in the marginal zones of the vein but otherwise the barite vein is essentially pure. Traces of chalcopyrite and secondary green copper stains may be seen in parts of the vein. There is a small area of

pink barite in the largest pit which appears to be due to very fine disseminations of hematite. The maximum exposed width of the vein is nearly five feet, but this is atypical and the average width is less than one foot.

Texturally, the vein is solely of the massive crystalline type with grains more than 5 mm and less than 15 mm in size.

#### The Elaine Prospect (Sec. 10, T. 8 N., R. 32 E.)

The Elaine Prospect is also in the Excelsior formation volcanics, which here are rhyolitic and dacitic tuffs. The barite occurs as small discontinuous veins that strike due west and may be traced for nearly 1,000 feet on the surface. Again the veins are fissure fillings with a coarse crystalline texture with the grains being over 5 mm in size. None of the veins are pure as they contain clasts of the wallrock along with much secondary green copper staining; no sulfides were seen. The typical vein that was sampled was only six inches thick, three feet long, and struck due west with a 35° north dip.

#### The Janet Prospect (Sec. 10, T. 8 N., R. 32 E.)

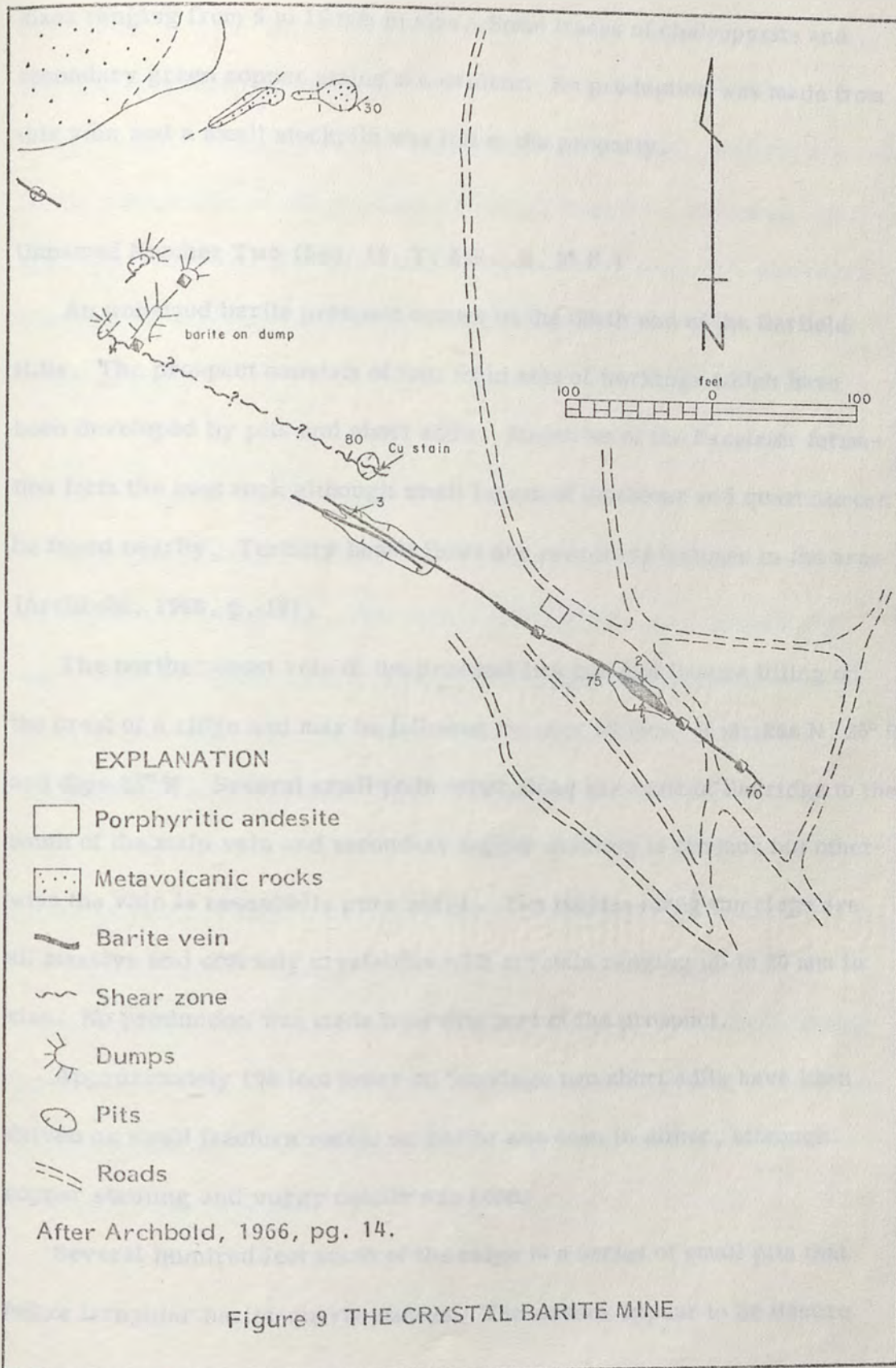
The Janet Prospect is on a small fissure-filling vein in the Excelsior formation. A shallow incline was sunk along the dip of the vein, which strikes N. 15° W. and dips 45° N., and a prospect pit was dug on the vein 50 feet north of the incline. The vein is 80 feet long, less than 2 feet wide and composed of nearly pure coarsely crystalline barite with crystal

fillings along discontinuous easterly fractures that dip steeply northward. They are irregular in size and range from one foot to 10 feet in width and up to 30 feet in length. The barite is medium grained with crystals ranging from 1 mm to 5 mm in size and some traces of chalcopyrite can be seen along with secondary copper stains. Quartz occurs with some of the masses as envelopes surrounding the barite. There was some production from this section but probably much less than 100 tons.

Another prospect pit nearly 300 feet south of the latter exposes a series of brecciated barite lenses. The barite is essentially pure with sporadic traces of galena in it and the texture ranges from saccharoidal to coarsely crystalline. The barite lenses range up to 20 feet in length and 5 feet in width and can be followed discontinuously along fracture zones in the pit for almost 100 feet. Some production may have been made from this pit but it must have been very small.

#### The Crystal Mine (Sec. 21, T. 8 N., R. 32 E.)

The Crystal Mine produced a considerable tonnage of barite in the early 1900's (Vanderberg, 1937; Archbold, 1966, p. 12) from a large fissure vein  $\frac{1}{2}$  to 12 feet wide, in the Excelsior formation andesites. Production was via several shafts sunk on the vein to a depth of approximately 100 feet. The surface expression of the vein can be sporadically followed for close to 600 feet. A small zone of copper mineralization parallels the barite vein for approximately 200 feet and several small shafts and inclines



sizes ranging from 5 to 15 mm in size. Some traces of chalcopyrite and secondary green copper stains are evident. No production was made from this vein and a small stockpile was left at the property.

Unnamed Number Two (Sec. 19, T. 8 N., R. 32 E.)

An unnamed barite prospect occurs in the north end of the Garfield Hills. The prospect consists of four main sets of workings which have been developed by pits and short adits. Andesites of the Excelsior formation form the host rock although small lenses of limestone and quartzite can be found nearby. Tertiary basalt flows are prominent features in the area (Archbold, 1966, p. 18).

The northernmost vein of the prospect is a one foot fissure filling on the crest of a ridge and may be followed for over 50 feet. It strikes N. 25° E. and dips 65° W. Several small pods occur along the crest of the ridge to the south of the main vein and secondary copper staining is obvious but otherwise the vein is essentially pure barite. The barites along the ridge are all massive and coarsely crystalline with crystals ranging up to 20 mm in size. No production was made from this part of the prospect.

Approximately 100 feet lower on the ridge two short adits have been driven on small fracture zones; no barite was seen in either, although copper staining and vuggy calcite was seen.

Several hundred feet south of the ridge is a series of small pits that follow irregular barite-quartz masses. The masses appear to be fissure

explore it. A layer of pediment gravels up to 5 feet thick covers the area and obscures much of the vein.

Traces of chalcopyrite and secondary copper staining occur in the vein on the northwest end and gradually diminish toward the southeast end of the vein. Quartz is present throughout the vein. Texturally, the vein is composed of coarsely crystalline massive white barite with grains up to 15 mm in size.

#### Unnamed Number Three (Sec. 22, T. 8 N., R. 32 E.)

One mile due north of the Crystal Mine, there are two prospect pits that expose a barite vein. The vein is probably less than one foot wide and brecciated and obscured by talus but it appears to be vertical and striking east-west. Hematite stains the massive crystalline white barite. The host rock is the Excelsior formation andesite.

#### Unnamed Number Four (Sec. 27, T. 8 N., R. 32 E.)

Approximately a mile south of the previous unnamed prospect is another prospect on a small barite vein. The one foot vein may be traced for 30 feet and dips  $75^{\circ}$  S. along a N.  $35^{\circ}$  W. trend. Clasts of the Excelsior formation wall rocks are found in the vein but otherwise the massive crystalline barite is pure.

The Noon Day Prospect (Sec. 27, T. 8 N., R. 32 E.)

The Noon Day Claims are located two miles southeasterly from the Crystal Mine. A one- to two-foot wide fissure filling vein of massive white coarsely crystalline barite occurs in the Excelsior. The vein may be traced continuously for 175 feet on the surface and an en echelon zone of small pods, possibly connected at depth, can be traced for 350 feet along the surface. Siderite was probably present in the vein but only fluffy limonite is now seen. Disseminations of quartz occur throughout the vein as crystalline and irregular masses ranging from 1 mm to 10 mm in size.

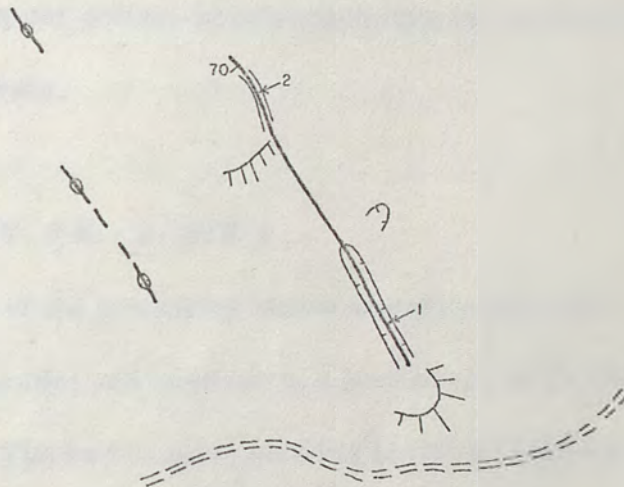
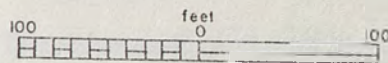
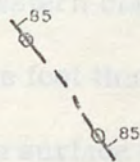
A short adit and several prospect pits expose the vein but no production was made and the barite was stockpiled on the property.

Many shafts and prospects explore a zone of copper mineralization in the Excelsior  $\frac{1}{2}$  to 1 mile south of the Noon Day Prospect. Chrysocolla, quartz, and calcite occur along small fractures in andesitic volcanics but no barite was observed in this zone.





The Pamlico Area (Secs. 24 and 13, T. 7 N., R. 31 E.)

Two small occurrences of barite were found by Archbold (personal communication) in the Pamlico area. The first, sec. 24, T. 7 N., R. 31 E., is obscured by talus but appears to be a steeply dipping vein of essentially pure massive crystalline barite. This locality was not tested for the present study. The second, sec. 13, T. 7 N., R. 31 E., is a specular hematite-barite vein in the Excelsior, that strikes N. 90° W. and dips 55° SW. It is

Host rock is andesite of the Excelsior formation



#### EXPLANATION

-  Barite vein
-  Pits and trenches
-  Jeep trail
-  Sample site

Brunton and pace survey  
W. J. Tafuri, August 1967

Figure 10 NOON DAY BARITE PROSPECT

characterized by coarse crystalline textures with crystals ranging up to 10 mm in size and is one foot wide and 5 feet long.

#### The Western Prospect (Sec. 26, T. 7 N., R. 32 E.)

The Western claim lies east of the Ashby district one mile. A brecciated three foot thick barite vein is exposed in a small pit; it cannot be seen on the surface due to alluvial cover. The vein strikes N. 10° E., and dips 55° E. and has a shaly host rock (Archbold, 1966, p. 18). Traces of chalcopyrite, secondary copper stains, hematite and limonite are visible in the massive crystalline vein.

#### The Ashby Mine (Sec. 27, T. 7 N., R. 32 E.)

A small pit next to one of the producing shafts at Ashby exposes a chrysocolla-quartz vein parallel and adjacent to a barite vein in the Dunlap formation volcanic rocks. The barite vein, striking N. 55° E. with a vertical dip, is characterized by coarsely crystalline barite with tabular crystals ranging up to 30 mm in length. The vein is only a few inches wide and two feet long and cannot be traced laterally outside of the pit.

The Ashby mine produced \$38,000 in gold during 1934-1938. Steeply dipping quartz veins striking N. 10° E. and cutting the Dunlap volcanics carried free gold, pyrite, and minor silver (Vanderberg, 1937; Ross, 1961). No mention was made of barite in the veins but the vein sampled was one of the producing veins.

The Barium Prospect (Sec. 7, T. 7 N., R. 33 E.)

At the Barium prospect numerous small pods and veins of barite are exposed in an altered granitic stock of approximately one quarter of a square mile in areal extent (Archbold, 1966, p. 16). The pods of barite are usually less than five feet long and the veins are close to one foot wide and less than twenty feet long. Siderite, fluffy limonite, and quartz are common constituents of the vein. Massive coarsely crystalline barite with individual crystals up to 40 mm long is characteristic; siderite normally fills the space between the crystals. Fluffy limonite commonly seen between the crystals is probably the leached product of siderite. The granite is argillized altered and the barite veins are bordered by a clayey alteration zone.

Unnamed Number Seven (Sec. 23, T. 6 N., R. 34 E.)

Three small discontinuous sub-parallel barite veins are exposed on an unnamed prospect three miles southwest of Mina. The veins are vertical fissure fillings that cut the Excelsior formation. Clasts of chert are suspended in the veins and hematite stains are prevalent. The longest vein can be followed discontinuously for 30 feet and is less than one foot wide.

Unnamed Number Six (Sec. 24, T. 6 N., R. 34 E.)

Several small prospect pits have been dug on an unnamed claim, sec.

24, T. 6 N., R. 34 E., where an impure barite vein cuts the Excelsior (Archbold, 1966, p. 18). At this locality the Excelsior consists of andesites and cherts and clasts of both are suspended in the vein. The massive crystalline vein is a fissure filling striking N. 10° W., and dipping 50° easterly. It can be traced laterally for 300 feet and is four feet wide at the widest point but averages closer to one foot wide. No production was made from the vein.

#### The Annett Group (Sec. 13, T. 5 N., R. 33 E.)

The Annett prospect, located on the crest of the Excelsior range, is reached by a winding dirt road near Marietta. Two semi-parallel veins approximately 100 yards apart and striking N. 60° E. cut the Excelsior volcanics with a nearly vertical but sinuous dip. The western vein can be traced continuously for 200 feet and the eastern vein can be traced discontinuously for 400 feet. Both veins are mostly barite but contain much quartz and traces of galena. Texturally, they are massively crystalline with some tabular crystal aggregates composed of crystals ranging up to 20 mm in length. The veins range from one to six feet wide with the average width being close to four feet. An 80 foot adit was driven on the west vein but the high quartz content probably discouraged any production.

#### Marietta (Sec. 34, T. 5 N., R. 32 E.)

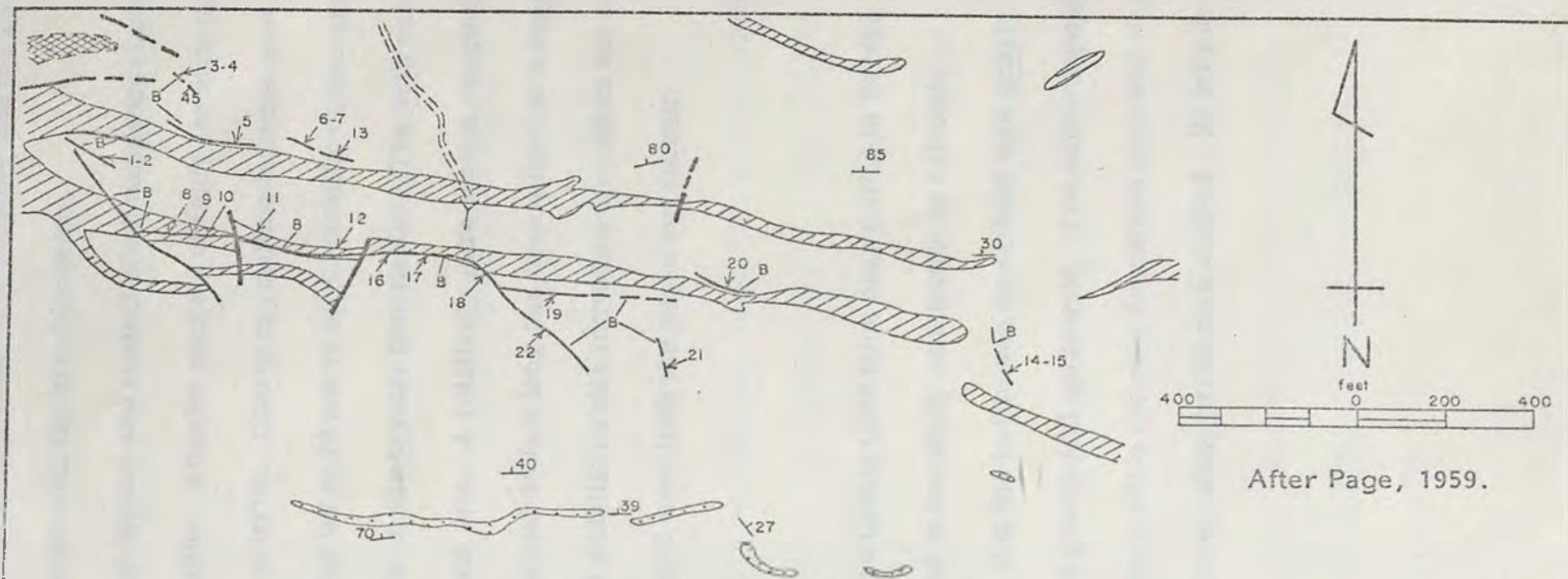
A small lens of barite is exposed in the main canyon west of Marietta

about 100 feet vertically above the northwest side of the road. The vein strikes NE and dips vertically and is one foot wide and ten feet long. Some traces of chalcopyrite are seen along with secondary copper stains and clasts of the host Dunlap formation andesite are found in the vein. The barite is white and massively crystalline with grains up to 10 mm in size.

#### Candelaria (Sec. 34, T. 4 N., R. 35 E.)


An extensive veined barite deposit is located on the east end of the Candelaria Mining district. The mining district, surrounding areas, and the barites were mapped and described by Page (1959, pg. 60).


At the barite locality, lower Triassic shales of the Candelaria formation form the base of the sequence and were intruded by felsic dikes of probable lower Jurassic age. During the middle Jurassic the dikes and Candelaria formation shales were dissected by normal faulting. In the upper Jurassic, the barite veins were deposited in fissures in the Candelaria shales and in the dike system. The barite veins were the first to be formed and were followed by metallic ore bearing veins, which were in turn followed by the emplacement of barren quartz veins, (Page, 1959, pg. 56). The barite veins are the most remote structures in the district that are related to the producing mines. The actual positioning of the veins as pre-ore is tenuous because the barite veins are only seen on the eastern margin of the district and not described in the vicinity of the ore bearing veins. Manganese and iron oxides have been described as common ore associates and they are




After Page, 1959.

EXPLANATION

 Jurassic quartz monzonite dikes

 Triassic Candelaria fm. (grits)

 Triassic Candelaria fm. (shales)

 Barite beds

 Sample site

Figure 11 CANDELARIA BARITE MINE

quite prevalent in the barite veins; therefore, it is possible that the barite emplacement is contemporaneous with the ore deposition.

The barite veins are very impure and contain much manganese oxides, goethite, hematite, and limonites. Angular pockets of fluffy limonite in the barite appear to be after siderite. Coarse crystalline textures predominate with crystals ranging up to 20 mm in size. Metallic oxides are commonly found as thin seams on the crystal boundaries. The vein varies in width from six inches to four feet. A relatively pure section ranging from one foot to four feet wide and 50 feet long has been stoped to a depth of 80 feet. The percentage of metallic oxides increases upward in the veins and also increases both east and west from the mined out section.

#### Carlin

A sample of barite from the Carlin Gold Mine near Carlin in Eureka County, Nevada, was included in the study as a matter of curiosity. Hausen (1968, p. 933) stated that the barite was associated with quartz porphyry dikes and contained galena and sphalerite. The barite deposition occurred in the early Cretaceous while the gold deposition occurred in the Tertiary. A coarsely crystalline, white barite was studied. No sulfides were present in this sample.

## MICROSCOPIC FEATURES OF SELECTED BARITE SAMPLES

Thirteen thin sections were prepared from barite samples from the Candelaria, Curley, Columbus, Northumberland, and the Food Machinery deposits. This study was not intended to be comprehensive but only a survey of the typical barite types encountered. The resulting observations helped to accentuate the differences that were observed in the field.

Two different textures are evident in the samples from the Food Machinery Co. bedded deposit. One type shows small (less than 5 mm.) nodules of barite formed out of minute tabular crystals of barite that radiate outward from an indistinct nucleus composed of clay and barite. The second type is composed of an indistinct mush of minute barite grains intermixed with clay and what may be organic material. The barite chert contact is razor sharp and no replacement features were noted.

The sample from the Northumberland bedded deposit was similar to the Food Machinery sample. The majority of the slide was again an indistinct mush of minute barite grains with clay and organic material. Under very high magnification, 360x, this texture was seen to be caused by minute grains of barite that were randomly stacked with clay and organic matter trapped between the barite grains. Nodules of barite were also present but these nucleated from flecks of clay or radiolaria and they ranged up to ten millimeters in size.

Three thin sections were also cut from barite samples taken from the Columbus deposit. Two of the sections were composed entirely of a polygonal mosaic of barite grains in the  $\frac{1}{2}$  to  $1\frac{1}{2}$  millimeter size range. This barite was visually free from impurities with no clue as to why the barite was grey in the hand specimen. The third section showed the same polygonal mosaic recrystallizing from an indistinct mush of barite, clay, and organic material. This type of recrystallization is a typical example of stress recrystallization. In this case the stress was probably supplied by the diagenetic squeezing that the barite has suffered since its deposition as a barite bed in the Ordovician.

Samples from the Curley vein prospect contained subhedral crystals of barite in a matrix of calcite and quartz. The grain sizes ranged up to ten millimeters. The barite crystals were clear and visually free from impurities. The percentage of barite in the three thin sections ranged from 25% to 75%.

Three thin sections were cut from barite samples taken from the Candelaria vein deposit. All of these showed subhedral to euhedral crystals of barite that ranged up to twenty millimeters in size. The barite crystals were usually pure with traces of magnetite or limonite on the grain boundaries. Traces of siderite were also noted in the section. Minor recrystallization was noted on some of the barite grain boundaries giving evidence to some post-crystallization stress.

While one cannot draw sweeping conclusions from such a limited study it does appear that the bedded barites at the Columbus deposit are recrystallized from a barite similar to the Northumberland deposit. The saccharoidal textures observed in the bedded deposits are thusly seen to be polygonal mosaics of barite that have been recrystallized due to external stress such as dynamic metamorphism.

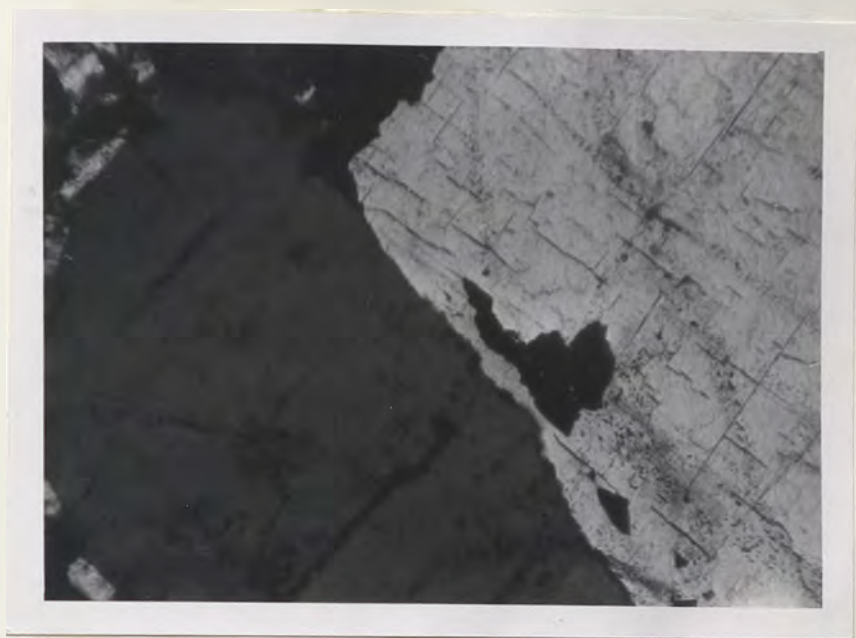


Plate 1-Photomicrograph (360x, under crossed polarizers) of typical barite from the Candelaria barite mine. Note the large subhedral crystals. The irregular-shaped, black blotch is magnetite.

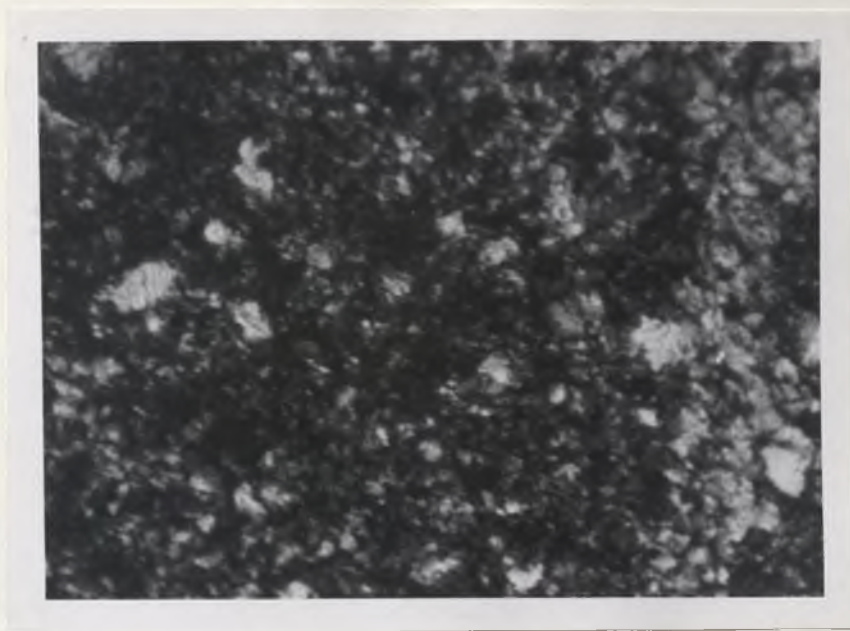


Plate 2-Photomicrograph (360x, under crossed polarizers) of typical barite from the Food Machinery Company barite mine. This texture typifies the indistinguishable mush of barite, clay, and organic material that was mentioned in the preceeding text. The barite is of ore grade (spg.=4.23) in spite of the impurities that are visible in this thin section.



Plate 3-Photomicrograph (360x, under crossed polarizers) of a sample from the Columbus barite mine. Note the well-formed polygonal mosaics of barite crystals that are forming from the fine aggregate of barite in the left hand portion of the photo. The fine grained aggregate of barite is similar in appearance and composition to the barite from the Food Machinery Co. deposit.

## PART II

## Results and Discussion of the Trace Element Analyses

Barite,  $\text{BaSO}_4$ , is a very common mineral and it is stable in a wide range of environments. Celestite,  $\text{SrSO}_4$ , forms an isomorphous series with barite and is isostructural with barite. As a result, barite often contains strontium in the barite crystal as a diadohic substitution for barium. Anglesite,  $\text{PbSO}_4$ , is also isostructural with barite but it does not form an isomorphous series with barite. Lead can substitute for barium in the barite crystal lattice but it does so in trace amounts only. Selenium can substitute for sulfur in the barite crystal, but it usually does so only at elevated temperatures.

With the above possible substitutions for barium in mind, all of the purified barite samples were analyzed for strontium, lead, and selenium. Strontium in varying amounts was found in every sample, but no lead or selenium was found in any sample. The x-ray fluorescence equipment used in this study had a detection limit of 15 ppm for lead and 50 ppm for selenium.

There are two possible reasons for the lack of lead in these barite samples; one, the vein systems were always deficient in lead; two, the lead was deposited as a sulfide in a higher temperature zone at some

distance away from where the barite was deposited as a sulfate leaving the migrant barium bearing solution free of lead. Since sulfides were scarce in these deposits and traces of galena were only noted of at the Gravity, Annet and Highland deposits, these results are not surprising.

The lack of selenium, in detectable amounts, was anticipated due to the mesothermal environment needed to make the selenium for sulfur substitution possible. The barites that were studied for this thesis were epithermal veins or what appeared to be syngenetic barite beds.

There are several geologic conditions that may exert some control over the amount of strontium that may be present in a barite crystal. The temperature of the crystal-forming environment can play a strong role as the ease of diadocic substitution increases with a corresponding increase in temperature. Therefore, a barite crystal that formed in a hot strontium rich-environment may contain more strontium than a barite crystal that formed in a cool strontium-rich environment. This process could be a significant factor when you compare a barite that formed in an oceanic environment against one that formed in an epithermal or mesothermal environment.

The composition of a granitic melt will also control whether or not barium and strontium is available in the late cooling stage fluids. A melt which crystallizes the potassic feldspars before the calcic feldspars will capture the available barium in the potassium feldspar crystal as a substitution for potassium. If the melt is high in calcium, the plagioclase will

crystallize first, thusly, enabling the barium to be concentrated in the latter water saturated phases and escape from the melt before the potassium feldspar crystallizes. This mechanism has been proposed by Dunham and Hanor (1967, pg. 91) as a possible method of supplying barium to barite provinces. Strontium, however, can substitute into both the plagioclase crystal as a replacement for calcium and into the potassium feldspar crystal as a replacement for potassium. As a result of this, a late stage fluid resulting from the cooling of an intermediate magma may be depleted in strontium but rich in barium.

The diagenetic recrystallization of aragonite to calcite may also have some control over the relative abundance of barium and strontium in the barite crystal. Both barium and strontium can substitute for calcium in the aragonite crystal. However, when aragonite recrystallizes to calcite the barium and strontium is largely expelled from the crystal (Gilson, 1960, p. 632). Usually there is more strontium than barium in the aragonite crystal since strontium is closer in ionic radius to calcium than barium ( $\text{Ca} = .99$ ,  $\text{Sr} = 1.12$ ,  $\text{Ba} = 1.34 \text{ \AA}$ ) (Mason). Some corals were found to contain up to twice as much strontium in the aragonite portion as did the calcite portion (Deer, Howie, Zussman, 1966, p. 498). When the aragonite to calcite conversion takes place and strontium and barium are liberated these elements may join with conate sulfate to form barite and celestite. The possible larger amounts of strontium that are thusly libera-

ted may enter into the barite crystal rather than just crystallizing as celestite.

The foregoing discussion is not all-encompassing and it does not give a source for the barium, strontium or the sulfate. However, these are common geologic processes that may have some control on the composition of a given barite crystal.

The strontium analyses showed a relatively distinct break in strontium concentrations between the bedded deposits and the vein deposits. Strontium concentrations in the barite of the bedded deposits ranged from 50 ppm to 1,140 ppm strontium with an arithmetic average of 289 ppm strontium. Strontium concentrations in the barite of the vein deposits ranged from 250 ppm to 3,550 ppm strontium with an arithmetic average of 1,738 ppm strontium. There is one spurious result in the bedded group, the Maxfield deposit, and one in the vein group, the Barium deposit.

With the exception of the Maxfield deposit, the bedded deposits were remarkably similar in geology and strontium concentration. As previously described, these deposits consisted of beds of barite in a conformable position with the enclosing slates, phyllites, and cherts. The chief impurities were clay and organic matter. They had saccharoidal textures and were grey to tan in color. The host rocks were apparently deposited in the same environment as evidenced by the similarity of composition and structure in the various host rocks.

The uniformity of the host rocks and of the barite beds is reflected in the uniformity of the strontium concentration in the bedded barite samples. If these barite beds are syngenetic, which they appear to be on the basis of their field relations, then the strontium concentration in the beds must be a reflection of their depositional environment. Thusly, the low concentration of strontium in these samples either reflects a low concentration of strontium in the seas that the barites were precipitated from, or, it points out that if higher concentrations of strontium were present the strontium cannot substitute for barium in large amounts at oceanic temperatures. The latter explanation does not seem plausible because high strontium marine barites are known to exist.

The barite from the Maxfield Mine contains almost seven times the strontium as the well defined bedded deposits. This can be due to the known ability of aragonite to concentrate strontium, since the host rocks here are marbles. When the aragonite inverted to calcite, the strontium was expelled and joined with connate sulfate in the barite crystal to form a strontium rich barite.

The vein deposits show a broader range of strontium concentrations but they average significantly higher than the average for the bedded deposits. The difference in strontium concentrations between the two types of deposits is accentuated by difference in the modes of occurrences of the deposits. Vein barites are usually pure white, form coarse tabular crystals, are associated with gangue minerals of quartz, siderite, calcite, and iron

oxides. The veins commonly form fissure fillings and the host rocks are altered. This type of deposit appears to be an epigenetic, epithermal type of deposit.

Epithermal deposits are not noted for consistency and it would be only fortuitous for such veins to contain similar concentrations of strontium in the barite. The strontium in the barites may have been derived from several sources. It could have been leached out of the rocks that the barite bearing hydrothermal fluids traveled through. These rocks could have been, in part, the underlying Ordovician sediments that contained the barite beds. These fluids may have also been derived from magmatic sources in the form of late stage fluids. Connate oceanic waters that have been heated by tectonism or unseen intrusions may also form the hydrothermal fluid that carried the barium and strontium.

Recent work on the transport of barium ions in solution by chloride rich waters (Holland, 1967, p. 425-428) shows that barite is soluble in significant quantities in a chloride rich brine even down to 150°C. Thusly, a heated oceanic derived connate water would provide the high concentration of chloride ions necessary to transport barite in a dissolved state.

It is seen from these strontium analyses that there is indeed a compositional difference between the bedded barite deposits and the vein barite deposits. However, the reasons for this difference are masked by the complexity of the variables involved.

## ANALYTICAL DATA

Table 1

Deposit	Host Formation and Age	Host Rock	Sample No.	*spg of Sample	Sr in ppm	$\delta S^{34}_{as SO_4}$	$\delta S^{34}_{as S}$
<u>Bedded</u>							
Columbus	O Palmetto	phy., ch.	4	4.33	150	+14.23	N.A.
Columbus	O Palmetto	phy., ch.	9	4.31	170	+14.54	N.A.
Columbus	O Palmetto	phy., ch.	18	4.11	100	+15.26	N.A.
Little Summit	O Palmetto	phy., ch.	1	4.15	260	+16.46	N.A.
Unnamed No. 1	O Palmetto	phy., ch.	1	3.90	50	+14.67	N.A.
Battle Mountain	P Pumpnickel	arg., ls., ch.	1	4.10	140	+22.52	N.A.
Northumberland	O Pine Cone	ch.	1	4.18	300	+14.39	N.A.
Maxfield	C Miller Mountain	ls.	1	4.20	1,140	+37.27	N.A.
<u>Veined</u>							
Curley	T Excelsior	ls., fv.	1	3.85	1,090	N.A.	N.A.
Curley	T Excelsior	ls., fv.	2	3.78	1,050	+13.85	N.A.
Curley	T Excelsior	ls., fv.	3	3.90	1,230	N.A.	N.A.
Candelaria	T Candelaria	sh.	15	3.97	610	+12.60	N.A.
Candelaria	T Candelaria	sh.	18	4.11	930	+15.42	N.A.
Candelaria	T Candelaria	sh.	22	4.21	900	+10.46	N.A.
Highland	T Excelsior	f.v.	1	4.20	2,790	N.A.	N.A.
Highland	T Excelsior	f.v.	2	4.31	3,150	N.A.	N.A.
Highland	T Excelsior	f.v.	3	4.15	3,550	N.A.	N.A.
Highland	T Excelsior	f.v.	4	4.18	2,680	N.A.	N.A.
Highland	T Excelsior	f.v.	5	4.21	2,680	N.A.	N.A.
Highland	T Excelsior	f.v.	6	4.22	2,680	+11.74	-11.66 ga.
Annet	J Dunlap	and.	1	4.38	1,480	+6.66	-14.84 ga.
Annet	J Dunlap	and.	2	3.90	2,180	N.A.	N.A.
Annet	J Dunlap	and.	3	3.89	2,000	N.A.	N.A.

## ANALYTICAL DATA

Table 1 (cont.)

Deposit	Host Formation and Age	Host Rock	Sample No.	*spg of Sample	Sr in ppm	SS <sup>34</sup> as SO <sub>4</sub> <sup>=</sup>	SS <sup>34</sup> as S <sup>=</sup>
Gravity	T Excelsior	f.v.	1	3.90	1,150	N.A.	N.A.
Gravity	T Excelsior	f.v.	2	3.84	1,130	+14.32	N.A.
Gravity	T Excelsior	f.v.	3	3.78	1,460	N.A.	N.A.
Gravity	T Excelsior	f.v.	4	4.01	770	N.A.	N.A.
Gravity	T Excelsior	f.v.	5	4.15	1,750	N.A.	N.A.
Gravity	T Excelsior	f.v.	6	3.83	900	N.A.	N.A.
Gravity	T Excelsior	f.v.	7	3.87	1,070	N.A.	N.A.
Gravity	T Excelsior	f.v.	8	3.91	1,570	N.A.	N.A.
Gravity	T Excelsior	f.v.	9	3.95	1,300	N.A.	N.A.
Gravity	T Excelsior	f.v.	10	4.04	860	N.A.	N.A.
Crystal	T Excelsior	and.	1	3.95	1,960	+12.39	-10.61 cpy.
Crystal	T Excelsior	and.	2	4.03	1,870	N.A.	N.A.
Unnamed No. 2	T Excelsior	and.	3	4.05	1,870	N.A.	N.A.
Unnamed No. 2	T Excelsior	and.	2	4.20	2,950	+11.09	-8.13 cpy.
Unnamed No. 2	T Excelsior	and.	3	4.31	2,920	N.A.	N.A.
Unnamed No. 3	T Excelsior	and.	1	4.01	2,600	N.A.	N.A.
Unnamed No. 4	T Excelsior	and.	1	4.05	2,340	N.A.	N.A.
Unnamed No. 5	T Excelsior	and.	1	3.97	1,690	N.A.	N.A.
Unnamed No. 6	T Excelsior	and.	1	4.29	1,410	+7.62	N.A.
Unnamed No. 7	T Excelsior	and.	1	3.87	680	N.A.	N.A.
Elaine No. 1	T Excelsior	and.	1	3.85	600	N.A.	N.A.
Western	J Dunlap	sh.	1	4.25	1,660	+10.22	-12.20 cpy.
Pamlico	T Excelsior	and.	1	4.27	1,500	+10.88	N.A.
Janet No. 1	T Excelsior	and.	1	3.85	2,410	+11.47	N.A.
Noon Day	T Excelsior	and.	1	3.95	2,620	+12.61	N.A.
Barium Mining Co.	T Excelsior	and.	1	3.92	2,270	+9.56	N.A.
Barium	K Monzonite	monz.	1	3.94	250	+9.18	N.A.
Ashby	J Dunlap	and.	1	4.10	2,970	N.A.	N.A.
Carlin	S Roberts Mtn.	ls.	1	N.A.	610	N.A.	N.A.
Marietta	J Dunlap	and.	1	4.21	2,070	N.A.	N.A.

## EXPLANATION FOR TABLE 1

K	=	Cretaceous
J	=	Jurassic
T	=	Triassic
P	=	Permian
O	=	Ordovician
C	=	Cambrian
phy.	=	phyllite; includes shales and slates
ch.	=	chert
arg.	=	argillite
ls.	=	limestone
f.v.	=	felsic volcanic rocks
sh.	=	shale
and.	=	andesite
monz.	=	monzonite
*	=	specific gravity of the mine-run barite ore, not the analyzed sample

- Range of bedded deposits
- Range of vein deposits
- Range of sulfides
- Bedded Deposits
  - Unnamed No.1
  - Columbus
  - Little Summit
  - Moxfield
  - Food Machinery
  - Northumberland
- Vein Deposits
  - Curley
  - Candelaria
  - Highland
  - Gravity
  - Barium Mining Co.
  - Janet
  - Unnamed No.2
  - Crystal
  - Noon Day
  - Pamlico
  - Western
  - Barium
  - Unnamed No. 6
  - Annet

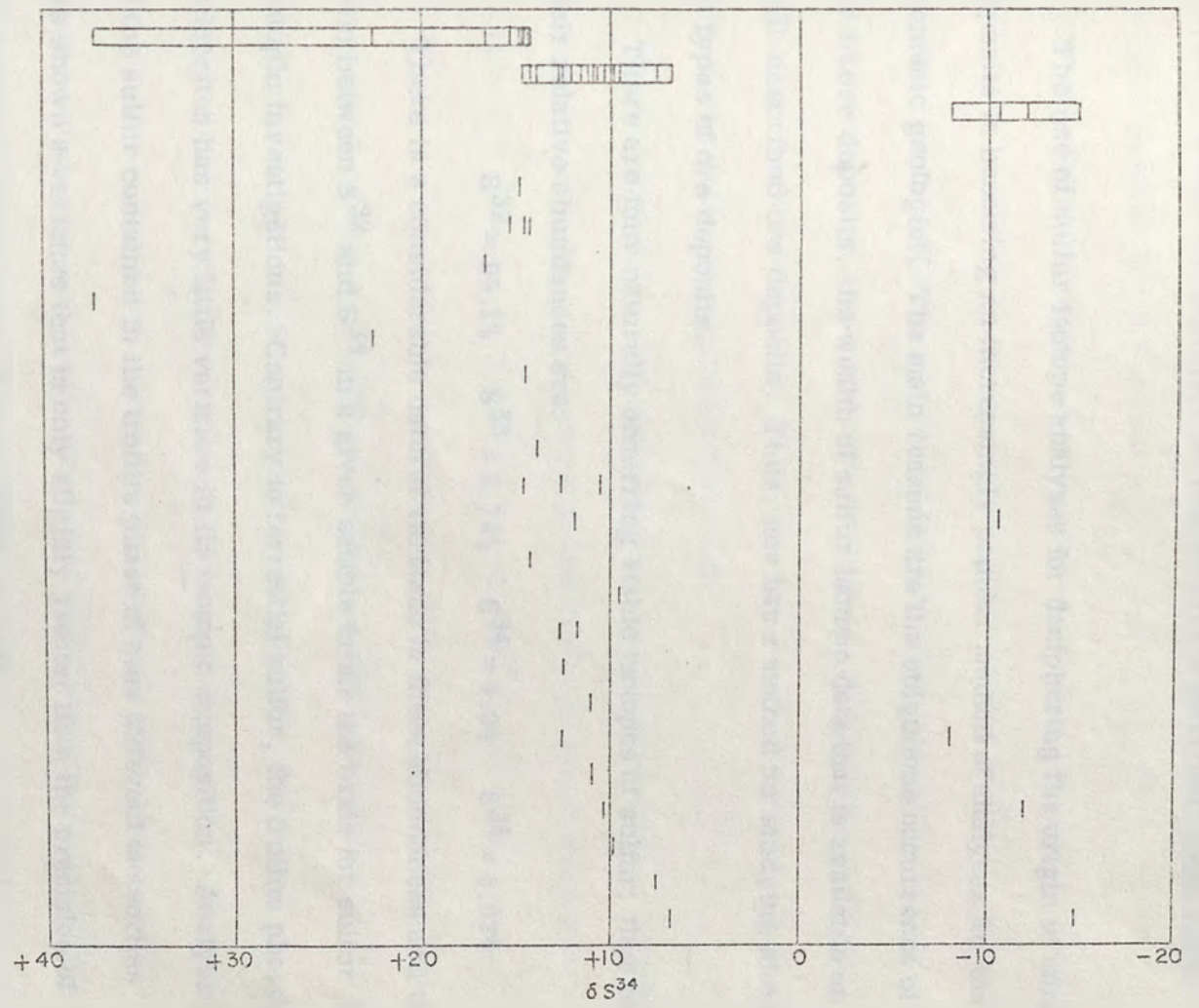


Figure 12 Sulfur Isotopic Ratios of Barite and Sulfide Samples

## RESULTS AND DISCUSSION OF THE SULPHUR ISOTOPIC ANALYSES

The use of sulfur isotope analyses for deciphering the origin of mineral deposits is becoming an increasingly popular method of analyses for the economic geologist. The main reasons are the ubiquitous occurrence of sulfur in ore deposits, the wealth of sulfur isotope data that is available on well-described ore deposits. Thus, one has a method for studying almost all types of ore deposits.

There are four naturally occurring stable isotopes of sulfur; they and their relative abundances are:

$$S^{32} = 95.1\% \quad S^{33} = 0.74\% \quad S^{34} = 4.2\% \quad S^{35} = 0.02\%$$

There is a considerable natural variance in these abundances and the ratio between  $S^{32}$  and  $S^{34}$  in a given sample forms the basis for sulfur isotopic investigations. Contrary to terrestrial sulfur, the troilite phase of meteorites has very little variance in its isotopic composition. Analyses of the sulfur contained in the troilite phase of nine different meteorites has shown a variance that is only slightly greater than the precision of the isotopic measurement (Jensen, 1967, p. 144).

All isotopic analyses are compared to the standard, the Cañon Diablo meteorite, which is assumed to have an  $S^{32}/S^{34}$  ratio of 22.220 (Jensen, 1967, p. 145). Variations from this ratio are expressed by  $\delta S^{34}$  in the following equation: (Jensen, 1967, p. 145)

$$\delta S^{34} \text{ permil} = \left[ \frac{S^{34}/S^{32} \text{ Sample}}{S^{34}/S^{32} \text{ Std. (Cañon Diablo)}} - 1 \right] \times 1000$$

In using this method of reporting isotopic ratios an isotopic measurement can be made to  $\pm 0.1$  permil.

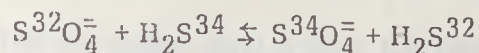
Terrestrial sulfur can be seen to vary as much as 150 permil (Jensen, 1967 p. 145). There are many natural processes that cause this extensive fractionation of sulfur in nature and these processes may be biogenic or strictly inorganic. Since this investigation is primarily concerned with the isotopic composition of sulfur in barites, I will limit the discussion to those processes which are relevant to this study.

The barite samples that were analyzed for this investigation all show an enrichment in the heavy isotope giving  $\delta S^{34}$  ratios that range from +6.66 to +37.27 permil. This enrichment in  $S^{34}$  and the wide range of  $\delta S^{34}$  ratio can be caused by many means. However, it is necessary to look at each deposit in the light of its field relations in order to arrive at a viable conclusion concerning genesis of its contained sulfur.

The bedded deposits show the widest range of  $\delta S^{34}$  ratios, from +14.23 permil to +37.27 permil. The field relations of these deposits show them to be bedded syngenetic appearing barite beds that were deposited contemporaneously with the chert and shale host rocks. Since these are marine sediments the  $\delta S^{34}$  ratio of the sulfate in such a bed should conform to oceanic  $\delta S^{34}$  ratio of the sea at its time of deposition, unless biogenic or volcanic factors altered this picture.

Sulfate reducing bacteria can enrich the  $SO_4^{=}$  in  $S^{34}$  and correspondingly enrich the sulfides produced by the reduction of the sulfate in  $S^{32}$ .

The following isotopic exchange reaction demonstrates this mechanism:



In actuality this reaction is rarely in equilibrium and, thusly, when bacteria play an important role in the reduction of sulfate ions a wide range of isotopic ratios result. Also, the sulfide that was produced by this reaction will be enriched in  $\text{S}^{32}$  relative to the sulfate that it was derived from. Unfortunately, no sulfides were found in the bedded barites so this comparison could not be made.

Volcanic emanations such as hot springs, and fumarolic deposits also show a wide range of  $\delta\text{S}^{34}$  ratios in the sulfate phase. Sakai, 1957, p. 153, showed that ranges of up to 30 permil were easily possible in the  $\delta\text{S}^{34}$  ratios of sulfates in a volcanic environment.

The wide range of  $\delta\text{S}^{34}$  ratios shrinks to a very small range of 2.23 permil when you only consider the Ordovician barite deposits, which you must do in order to assure a similar environment of a similar time.

Present sea water sulfate has a  $\delta\text{S}^{34}$  ratio of 20.45 permil; however, it has been demonstrated that sea water sulfate has varied over a 20 permil range since the Cambrian (Lusk, 1972, p. 170). Mid-Ordovician sulfate had a  $\delta\text{S}^{34}$  ratio of 27 permil or 7 permil heavier than the present sea water sulfate (Lusk, 1972, p. 170). However, I do not feel that this holds true for this particular area. The six Ordovician barites that were tested for this study are too similar in isotopic composition to be anything other than a reflection of the isotopic composition of the sea water sulfate.

It would be extremely fortuitous if six Ordovician barite samples from four different deposits, one 100 air-miles distant from the rest, were this close in isotopic composition if sulfate reducing bacteria or volcanic exhalation contributed any significant sulfate to the Ordovician sea in this area. There is also a complete lack of Ordovician volcanic activity in the region.

The Cambrian and Permian barites may have been effected by bacteriogenic action. This is especially probable for the Maxfield deposit where such high amounts of heavy sulfur is present in the barite; however, more isotopic analysis would be necessary to be positive of this.

The vein barites have a  $\delta S^{34}$  range of 8.86 permil for the 16 isotopic analyses. This is a fairly well restricted range of  $\delta S^{34}$  ratios, especially for sulfates. Sulfur that has been homogenized by the granitization of rocks at the base geosynclinal prism or by the extreme metamorphism of sediments would be expected to show  $\delta S^{34}$  ratios in this range. Being as so, most crustal sulfur is enriched in  $S^{34}$  (Jensen, 1967, p. 159) the ore deposits that are derived from crustal sources are also enriched in  $S^{34}$  and have  $+8^{34}$  ratios.

The problem with constructing such a model for these vein deposits is that they are scattered along the full length of Mineral County and not related to any one intrusion. The other possibility is that these are epithermal deposits that resulted in barite being deposited from a gradually cooling hydrothermal solution. The restricted range of isotopic ratios may be a reflection of sulfur bearing source rocks with a restricted iso-

topic composition. Such a source may have been the underlying Ordovician Palmetto formation that contained the bedded barites. The remobilization of the barite by hydrothermal solutions could have partially depleted the barite in  $S^{34}$  and brought the isotopic composition closer to zero permil. During the transport of the  $SO_2$  as a gaseous phase the  $SO_2$  is again oxidized to  $SO_4^{2-}$ . As the solutions cooled below  $150^\circ C$  the barium and sulfate ions would become unstable (Holland, 1967, p. 426) and barite would form in the vein.

The sulfide minerals associated with the barite in the veins also have a relatively restricted range of  $\delta S^{34}$  ratios. These minerals show  $\delta S^{34}$  ratios of -8.13 permil to -14.84 permil for a range of 6.71 permil. The average difference between the  $\delta S^{34}$  ratio as a sulfide and the corresponding sulfate pair is approximately 22 permil. This enrichment of  $S^{34}$  in gaseous  $SO_2$  and enrichment of  $S^{32}$  in gaseous  $H_2S$  can be reached during equilibrium conditions of a temperature of  $170^\circ C$  (Jensen, personal communication, 1968). The  $SO_2$  would eventually oxidize to  $SO_4^{2-}$  and join with barium to form barite and the  $H_2S$  would react with a metal ion to form the sulfide phase in the vein. This system was probably not in equilibrium due to the small amount of sulfides found in the veins. However, the temperature quoted does fit an epithermal model quite well.

The sulfur isotopic analyses do not positively point to a source for the sulfur in the barite deposits but the analyses do help to point out that there is a genetic difference between the two types of barite deposits. It now

appears that I can say, with a moderate degree of certainty, that the bedded barite deposits are syngenetic on the basis of the sulfur isotopic analyses and the field relationships of the barite deposits. In the same light it may be said that the vein deposits are epigenetic epithermal deposits but that the barite in them may be derived from an underlying sedimentary source and was remobilized by heated connate brines.

## CONCLUSIONS

The two types of barite deposits, vein and bedded, in Mineral County can be differentiated chemically as well as physically. The diagnostic physical characteristics for the bedded deposits are the fine grained saccharoidal textures, impurities in the barite consisting of clay and organic matter, their concordant relation to the host rock, and the fetid odor that evolves when these barites are ground. The vein barite deposits are characterized by coarse tabular crystalline textures, their bright white color, gangue minerals of quartz, calcite, siderite, metallic sulfides, oxides and a marked discordant relation to the host rocks. In a regional sense the bedded barite deposits occur in areas of folded and faulted Ordovician sediments while the vein barite deposits occur in Jurassic and Triassic volcanic and sedimentary rocks. The vein barite deposits have the outward attributes of epigenetic epithermal veins, while the bedded deposits have the physical attributes of syngenetic bedded barites.

Strontium analyses made on samples of both types of barite deposits show a strong chemical difference between the two types of deposits. The strontium content of the vein barite samples is almost a whole order of magnitude higher than the strontium content of the bedded barite samples.

The sulfur isotopic analyses of the barite samples from the two types of deposits have helped to decipher the genesis of the sulfur in the deposits.

From this investigation, it appears that the bedded deposits are syngenetic and deposited in an oceanic environment. The vein deposits show the characteristics of epithermal veins but the sulfur may have been derived from the underlying barite bearing sediments.

These combined methods of distinguishing between the vein and bedded barite deposits of Mineral County does appear to work fairly well within the confines of Mineral County. It may be possible to expand this investigation to other areas of the state where the same problem exists, such as the Eureka-Battle Mountain mineral belt.

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