University of Nevada

Reno

Geology of Some Bedded Barite Deposits North Central Nevada

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

by

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ABSTRACT

Barite deposits in Nevada are localized along the Antler orogenic belt and occur as bedded and vein-type deposits.

Two bedded deposits in the Northern Shoshone Range, Nevada, were studied. The barite forms lens-shaped replacement bodies conformable to bedding in the Slaven Chert. Localization of the ore is controlled both structurally and stratigraphically.

The study included geologic mapping, petrographic study of ore and host, and geochemistry of barite and associated rocks. The geologic relations demonstrate a close association between ore and igneous dikes. Replacement textures are common in both ore and host. The geochemistry includes sulfur isotopes, and trace amounts of elements contained in the ore and host.

The evidence for origin of the barite includes features which can be interpreted as sedimentary and others which can be interpreted as hydrothermal. The origin probably includes both sedimentary and hydrothermal features with sulfate originating in seawater and barium from a hydrothermal system.

TABLE OF CONTENTS

	Page
ACKNOWLEDGEMENTS	ii
ABSTRACT	iii
TABLE OF CONTENTS	iv
LIST OF ILLUSTRATIONS	v
INTRODUCTION	1
GEOLOGY	
Introduction	8
Ordovician Valmy Formation	14
Devonian Slaven Chert	15
Tertiary Limestone	18
Tertiary Instrsives	19
Tertiary Flows	20
STRUCTURAL GEOLOGY	21
BARITE ORE DEPOSITS	
Introduction	24
Structure and Lithology	25
Igneous Associations	31
Petrography	33
Geochemistry	38
Sulfur Isotopes	38
Uranium Content	44
Other Lines of Evidence	45
COMMENTS ON ORIGIN	50
CONCLUSION	54
BIBLIOGRAPHY	56

LIST OF ILLUSTRATIONS

Page

FIGURE 1 - Location Map of Barite Occurrences..... 3

FIGURE 2 - Relation of Barite to Tectonic Features 9

FIGURE 3 - Paleogeographic Map of Nevada..... 10

FIGURE 4 - Stratigraphic Column..... 13

FIGURE 5 - Photo of Barite Lense..... 27

FIGURE 6 - Partial Replacement of Chert by Barite. 28

FIGURE 7 - Selective Replacement Along Bedding Planes..... 34

FIGURE 8 - Partial Replacement of Chert by Barite. 35

FIGURE 9 - Barite Replacement Front..... 36

FIGURE 10 - Barite Fronts Engulfing Chert..... 37

FIGURE 11 - Sulfur Isotope Values Chart..... 41

TABLE I - Sulfur Isotope Values of Barite..... 42

TABLE II - Chemical Analyses, Barite & Host Rock.. 46

TABLE III - Barium Content of Dikes and Chert..... 48

PLATE I - Barite Occurrences and Slaven Chert..... Back Pocket

PLATE II - Geologic Map of Argenta..... Back Pocket

PLATE III - Isometric Diagram Miller Mine. Back Pocket

INTRODUCTION

Although bedded barite occurrences are abundant in the state of Nevada, little has been written regarding their geology. During the last seven years the writer has been studying the geology and mining of barite which needed to be investigated, particularly since it is becoming more valuable and harder to find.

The major use for barite is in drilling muds, in fact more than 80 percent of the world production of barite is used as a weighting agent in drilling muds for oil and gas exploration and therefore it is of vital importance to the continuing search for energy supplies. An understanding of the geology of barite therefore is essential to maintaining a continual supply to the energy industries.

Barite is also used in many other industries, although in small quantities. Food Machinery and Chemical Corporation (1961) listed over two thousand uses for barium chemicals. Barite is used as a flux in glass making to add clarity and brilliance, in paint and rubber as a filler and for pigment, and it is added to fine paper, linoleum, and brake linings. It is used in the production of barium chemicals such as barium carbonate, barium hydroxide and barium chloride which are then used as reagents and catalysts in various industrial processes, as well as in the textile industry, medicine, insecticides, steel, TV

tubes, welding fluxes, ceramics, and in the construction industry for pavement and concrete. It is certainly a versatile mineral and its uses are expanding.

The purpose of the following study was to determine, if possible, the origin of bedded barite in north-central Nevada. This was done by (1) mapping in detail the local geology around several bedded occurrences to determine the structural and stratigraphic relationships which contributed to localization of the barite, (2) by petrographic studies of thin sections from barite ore bodies, and (3) by geochemically analyzing samples in and around mineralized areas. The geochemical studies included investigation of sulfur isotopes, uranium content of barite, phosphorus content of barite, the depositional environment of the sediments, and barium content of the associated rocks around barite.

The areas of study are in the northern Shoshone Range in north-central Nevada near Battle Mountain (Figure 1) where two separate areas of barite were examined. The Argenta area is located in sections 13 and 24, T32N, R46E and sections 18 and 19, T32N, R47E, approximately 22 kilometers east of Battle Mountain and is accessible by 6½ kilometers of gravel road going south from the Argenta exit on Interstate Highway 80. The second area, known as the Miller Mine, is located in section 25, T31N, R46E, about 24 kilometers southeast of Battle Mountain over a gravel road known as Hilltop Road.

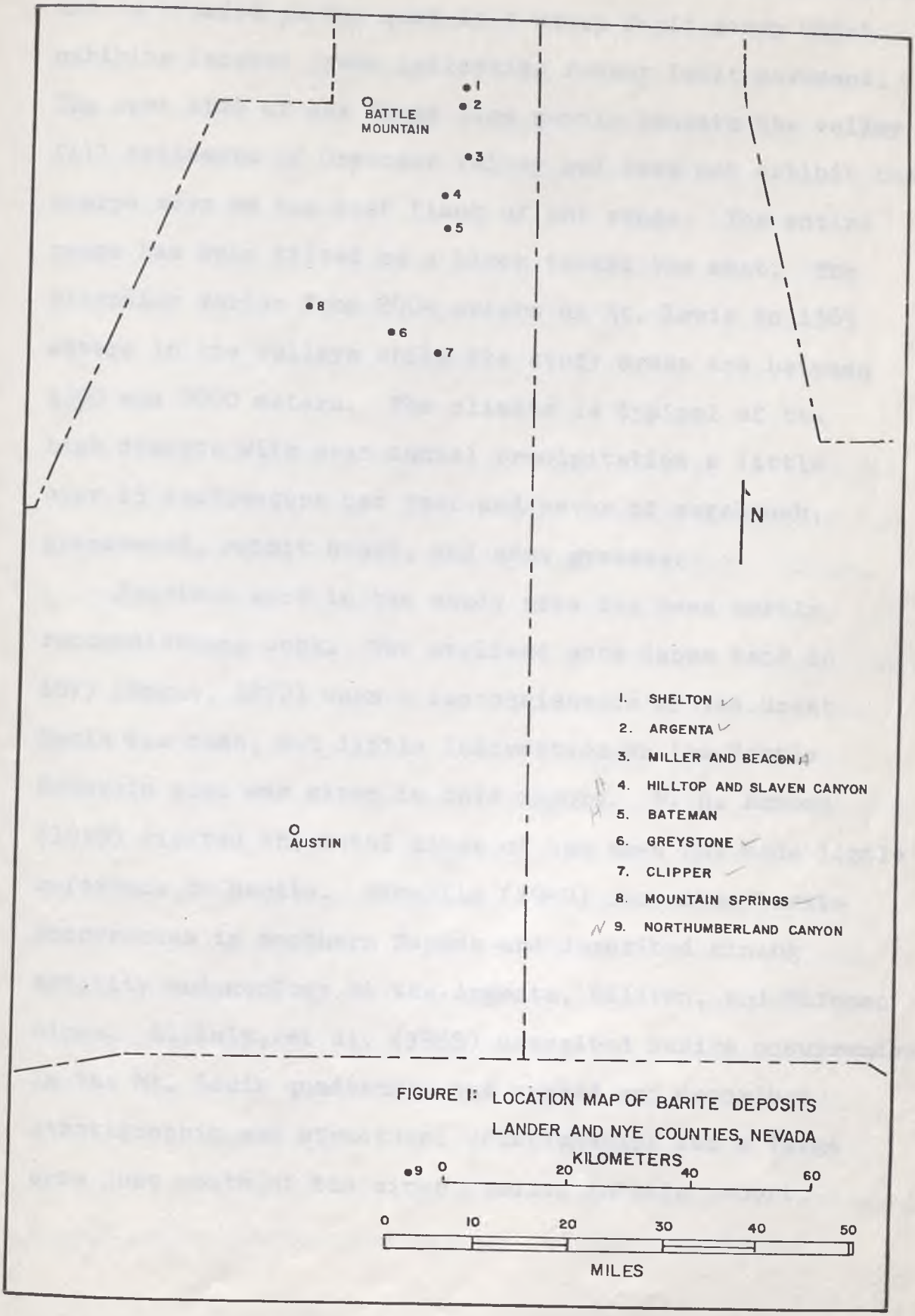

FIGURE 1: LOCATION MAP OF BARITE DEPOSITS
LANDER AND NYE COUNTIES, NEVADA

The Shoshone Range is in the Basin and Range province and is bounded on the west by a steep fault scarp which exhibits faceted spurs indicating recent fault movement. The east side of the Range dips gently beneath the valley fill sediments of Crescent Valley and does not exhibit the scarps seen on the west flank of the range. The entire range has been tilted as a block toward the east. The elevation varies from 2904 meters at Mt. Lewis to 1365 meters in the valleys while the study areas are between 1500 and 2000 meters. The climate is typical of the high deserts with mean annual precipitation a little over 15 centimeters per year and cover of sagebrush, greasewood, rabbit brush, and some grasses.

Previous work in the study area has been mostly reconnaissance work. The earliest work dates back to 1877 (Hague, 1877) when a reconnaissance of the Great Basin was made, but little information on the Battle Mountain area was given in this report. W. H. Emmons (1910) visited the metal mines of the area but made little reference to barite. Gianella (1940) described barite occurrences in northern Nevada and described mining activity and geology at the Argenta, Hilltop, and Bateman mines. Gilluly, et al, (1965) described barite occurrences in the Mt. Lewis quadrangle and mapped and described stratigraphic and structural relationships for a large area just south of the mines studied in this report.

Hanor (1966) and Dunham and Hanor (1967) discussed possible regional controls on barite mineralization in the western United States. Zimmerman (1969), Ketner (1963), and Shawe, et al, (1969) discuss possible means of origin for bedded barite in several localities in Nevada. Other writers have described and tabulated barite occurrences and their characteristics such as Brobst (1958, 1970), Goldberg, et al, (1969), Horton (1963), Hull (1970), Miller, et al, (1972), Mills, et al, (1971), and Tafuri (1973).

Barite was first mined in Nevada in 1916 in Churchill County (Gianella, 1940) and in 1935 mining at Argenta was begun by the Shelton family of Battle Mountain. These early operations supplied the paint industry and were located in close proximity to railroads because transportation is such a large factor in the economics of barite. The first large corporation to examine barite near Battle Mountain was the Glidden Paint Company in 1934, who needed it for a filler and for pigment in paint. This use has declined in recent years because of new technology in paints, but it is still used to a limited extent. Food Machinery and Chemical Corporation followed in 1938 to find barite for barium chemicals and other industrial uses. The most recent group to enter the area was the drilling fluids industry who now use most of the barite production. Baroid Division, N. L. Industries Incorporated, established an operation in 1947, followed by Dresser

Industries Incorporated, in the early 1950's, Milchem Incorporated in the late 1960's, and International Minerals and Chemical Company in the early 1970's. The interest in bedded barite occurrences in Nevada was spurred by depletion of reserves in Missouri and Arkansas where transportation to the active oil exploration areas was much cheaper. During the period 1971 to 1975, production of barite in Nevada leaped from 23 percent of the total national production to 69 percent. Because of this rapid shift to Nevada ores, the history of development has also undergone an evolution with early projects located in accessible areas near the railroad and later projects located in more remote areas as prices for barite increased.

During the early production, the paint industry required low tonnages of 4.30 specific gravity (93% Ba SO_4) product. This was achieved by removing overburden, cleaning the upper surface of the barite ore very thoroughly, and then drilling and blasting it. The grade was often maintained by hand picking waste from the ore. As the highest grade ores were utilized and larger production was demanded, it became necessary to install mechanical means to remove waste from the ore. The Yuba Milling Company built a heavy media plant at Argenta in 1958 to float the waste out of the barite. This was followed by Baroid who built a flotation plant in 1964 and by Milchem who built a jig plant in 1968. The jigs

produced a clean product for less cost than the other methods so by 1975 jigs were operating at five sites in north-central Nevada. During the period in which demand was expanding for barite, it became more difficult to find enough high grade ore to maintain the 4.30 specific gravity and as a result the requirements were lowered until today a 4.20 specific gravity (90% Ba SO_4) is required for use in drilling muds.

GEOLOGY

Introduction

The geologic history of Nevada is in large part the evolution of the Cordilleran geosyncline (Figure 2 and 3). The sediments of early and middle Paleozoic age contain two distinct facies consisting of a western or siliceous facies and an eastern or carbonate facies, with a transition zone between. These facies represent (1) a shelf facies where warm shallow waters were the site of carbonate deposition, (2) a deeper water siliceous and clastic facies, and (3) the transitional facies combining characteristics of both the other facies. The western facies consists of clastics, chert, and volcanics of andesitic to basaltic composition with an estimated total thickness of up to fifteen thousand meters (Roberts, 1958). This facies contains both the Paleozoic formations included in the study areas, which are the Ordovician Valmy Formation and the Devonian Slaven Chert. The eastern facies contains primarily limestone and dolomite with some shale and quartzite and is estimated to be less than six thousand meters in thickness. The transitional facies contains cherts, clastics and volcanics as well as some limestone.

Deposition in the geosyncline occurred from Cambrian to late Devonian time when the uplift of the Antler orogenic belt (Figure 2) began and as a result, great sheets of the western facies slid eastward over the

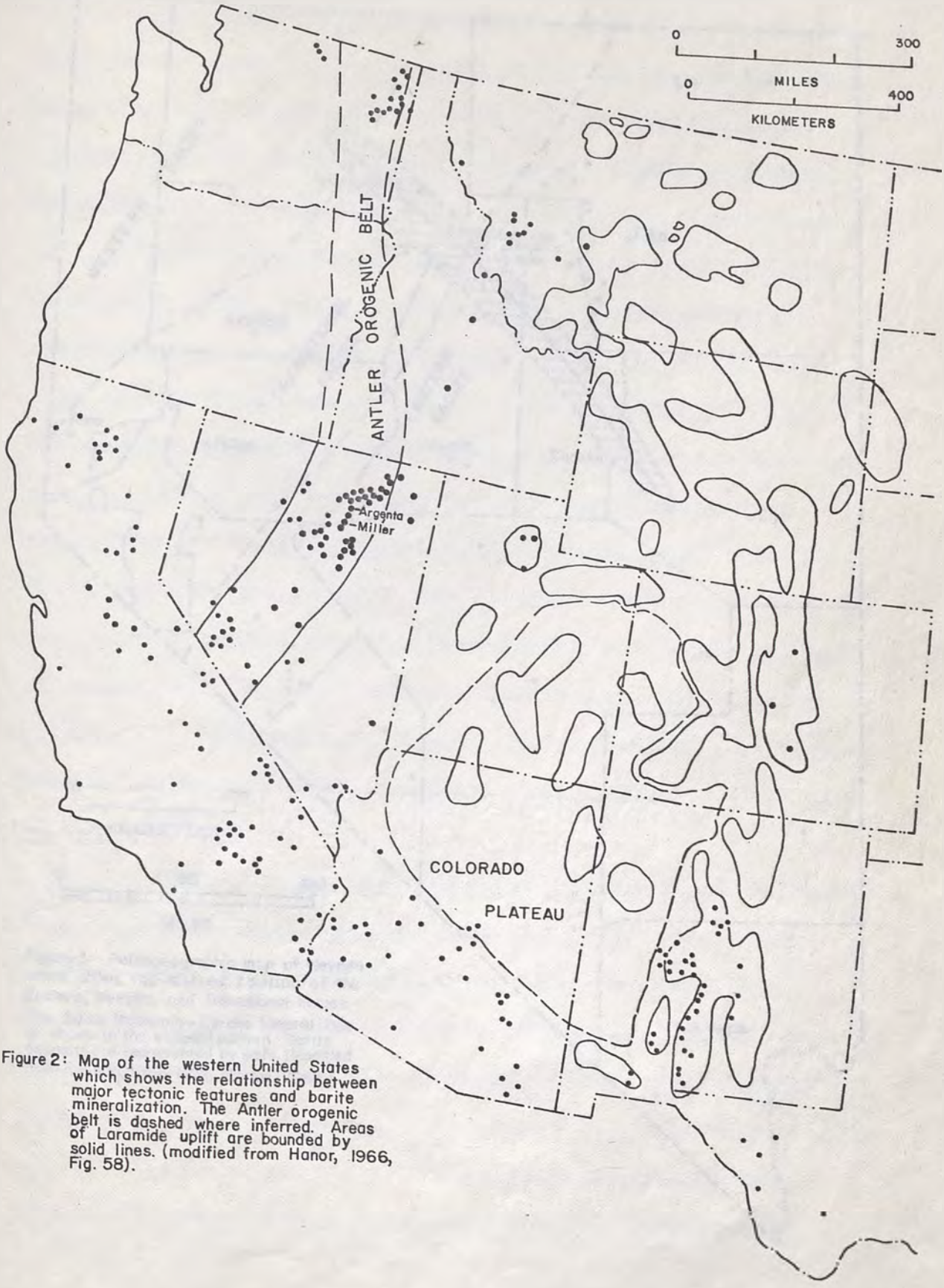

Figure 2: Map of the western United States which shows the relationship between major tectonic features and barite mineralization. The Antler orogenic belt is dashed where inferred. Areas of Laramide uplift are bounded by solid lines. (modified from Hanor, 1966, Fig. 58).

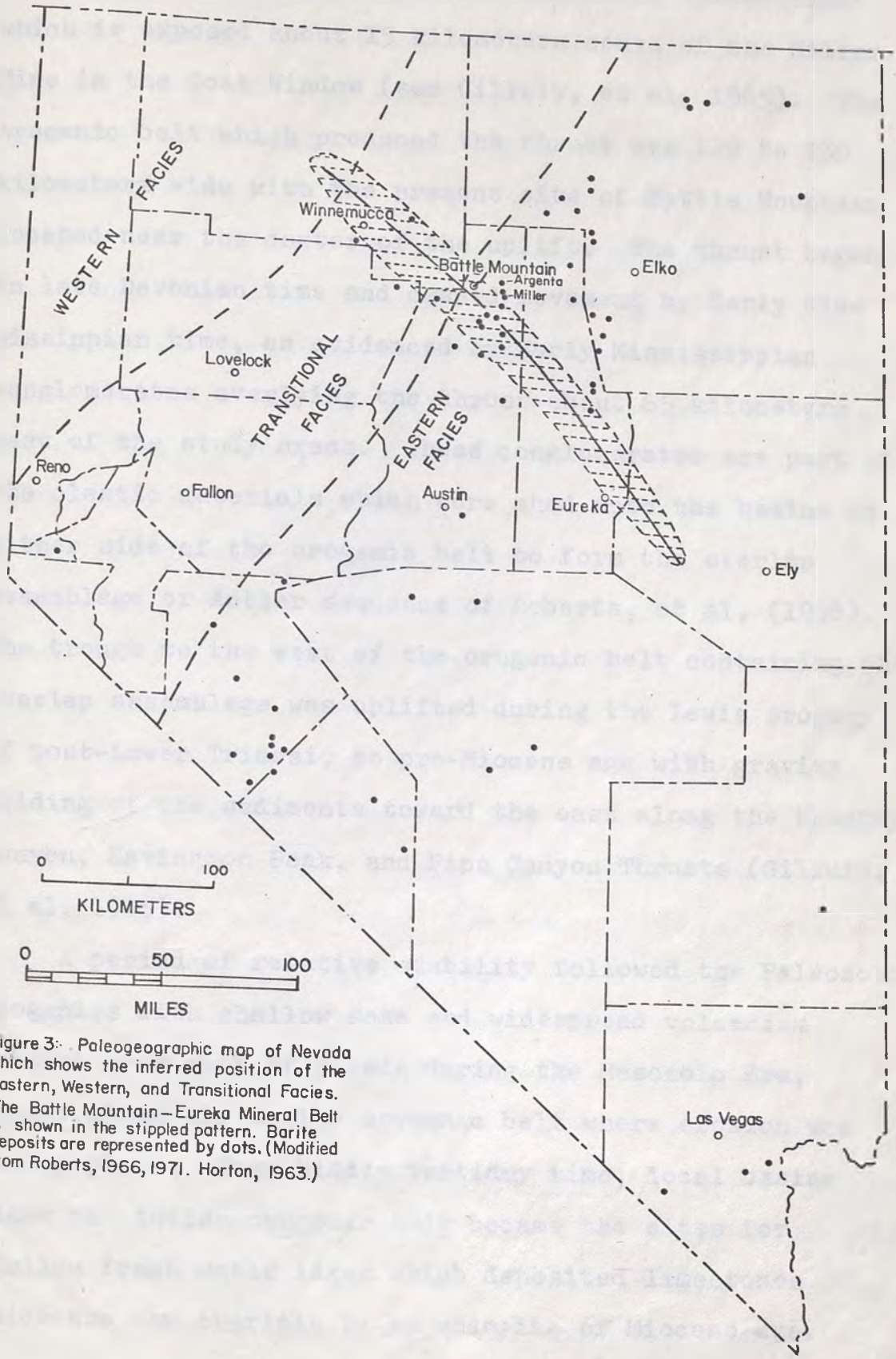

Figure 3. Paleogeographic map of Nevada which shows the inferred position of the Eastern, Western, and Transitional Facies. The Battle Mountain–Eureka Mineral Belt is shown in the stippled pattern. Barite deposits are represented by dots. (Modified from Roberts, 1966, 1971. Horton, 1963.)

eastern facies along the Roberts Mountains thrust fault which is exposed about 15 kilometers south of the Miller Mine in the Goat Window (see Gilluly, et al, 1965). The orogenic belt which produced the thrust was 120 to 130 kilometers wide with the present site of Battle Mountain located near the center of the uplift. The thrust began in late Devonian time and ceased movement by Early Mississippian time, as evidenced by Early Mississippian conglomerates overlying the thrust about 65 kilometers east of the study areas. These conglomerates are part of the clastic materials which were shed into the basins on either side of the orogenic belt to form the overlap assemblage or Antler sequence of Roberts, et al, (1958). The trough to the west of the orogenic belt containing the overlap assemblage was uplifted during the Lewis orogeny of post-Lower Triassic to pre-Miocene age with gravity gliding of the sediments toward the east along the Whiskey Canyon, Havingdon Peak, and Pipe Canyon Thrusts (Gilluly, at al, 1965).

A period of relative stability followed the Paleozoic orogenies with shallow seas and widespread volcanism present over much of Nevada during the Mesozoic Era, except along the Antler orogenic belt where erosion was taking place. Near Middle Tertiary time, local basins along the Antler orogenic belt became the sites for shallow fresh water lakes which deposited limestones which are now overlain by an andesite of Miocene age.

This andesite unit could be up to 500 meters thick although faulting may have repeated the section and it is probably thinner. The andesite is capped by a thin layer of basalt of probable Pliocene age, but it may be Miocene (Gilluly, et al, 1965). These Tertiary units are all exposed in the ridges south and east of Argenta.

Basin and Range faulting began in Oligocene time over much of the state, but if this is true in the Shoshone Range, the evidence has been obscured because the faulting has cut the Pliocene basalt unit referred to above. Movement along the Basin and Range faults has been intermittent from Plio-Miocene to the present and they have tilted the entire range to the east as is demonstrated by the attitudes of the Tertiary limestone and volcanics at and near Argenta.

Upper Paleozoic and Mesozoic rocks are not exposed within the study areas because they were never deposited there due to the uplift of the Antler orogenic belt, or they have been eroded away. The upper Paleozoic strata present in the Mt. Lewis quadrangle to the south are isolated remnants of thrust sheets which carried these units in. The stratigraphic column for the northern Shoshone Range is illustrated in Figure 4 and it shows the gaps in the section due to thrust faulting and erosion. This figure shows formations not exposed in the study areas but will help provide a picture of stratigraphy in the area around the barite occurrences. The most wide-spread

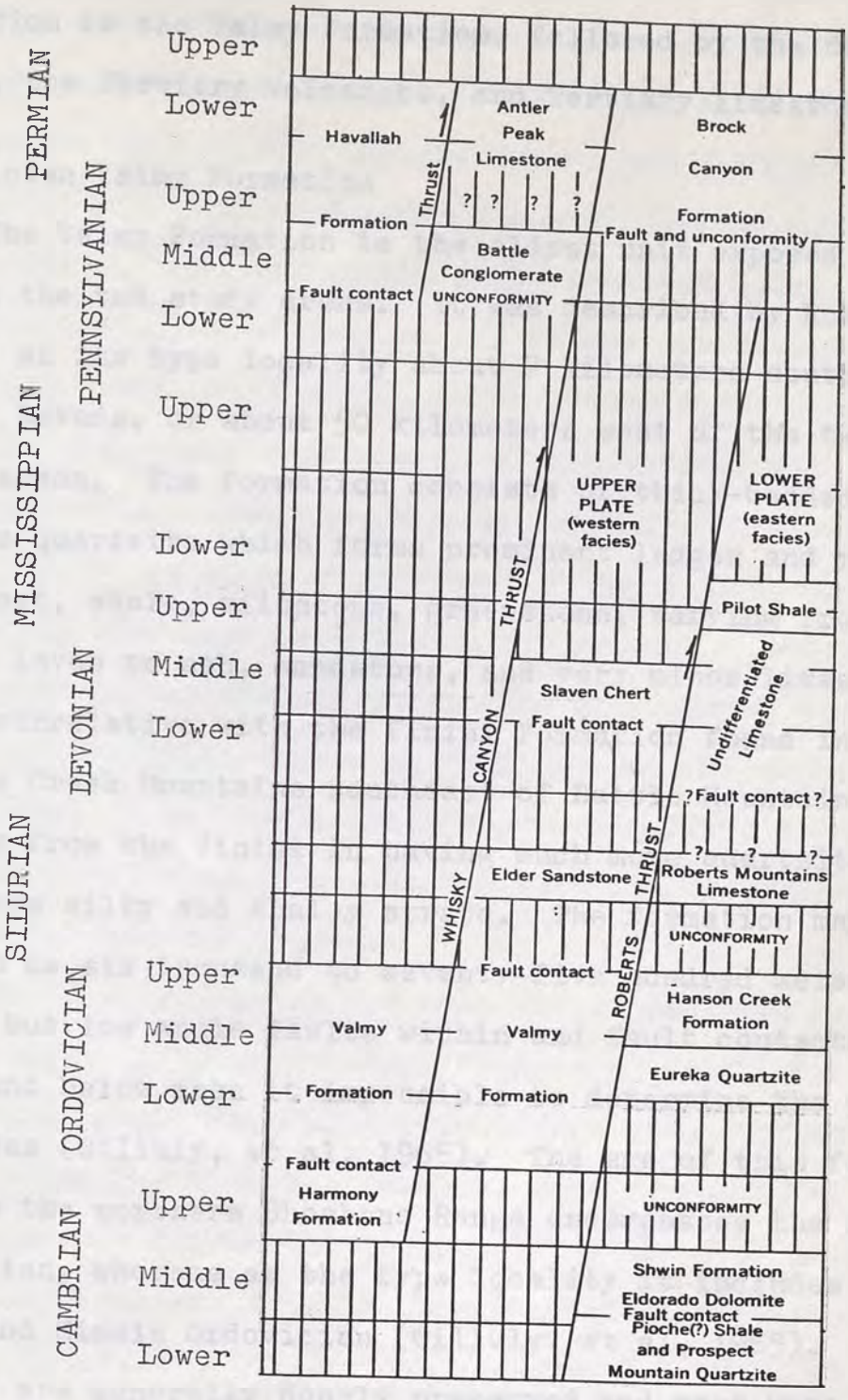

FIGURE 4 - PALEOZOIC STRATIGRAPHY OF THE NORTHERN SHOSHONE RANGE, NEVADA (Modified from Gilluly, et al, 1965) The vertical lines indicate the time spans are not represented by rocks in this area due to faulting or erosion.

formation is the Valmy Formation, followed by the Slaven Chert, the Tertiary volcanics, and Tertiary limestone.

Ordovician Valmy Formation

The Valmy Formation is the oldest unit exposed within the two study areas. It was described by Roberts (1951) at its type locality about 7 kilometers south of Valmy, Nevada, or about 50 kilometers west of the two study areas. The formation consists of thick-bedded massive quartzite which forms prominent ledges and ridges, and chert, shale, siltstone, greenstone, varying from pillow lavas to ash, sandstone, and very minor limestone. It is correlative with the Vinini Formation found in the Roberts Creek Mountains southeast of Battle Mountain, but differs from the Vinini in having much more quartzite and much less silty and shaley strata. The formation may be as much as six thousand to seventy-five hundred meters thick, but low angle faults within and fault contacts above and below make it impossible to determine the exact thickness (Gilluly, et al, 1965). The age of this formation in the northern Shoshone Range encompasses the entire Ordovician, whereas at the type locality it includes only Early and Middle Ordovician (Gilluly, et al, 1965). Fossils are generally poorly preserved and none were examined during this study, but presumably the Valmy is of similar age at the Argenta and Miller areas as in the Mt. Lewis quadrangle to the south.

The quartzites of this formation are quite pure, although some sparse grains of chalcedony, biotite, hornblende, augite, barite, and pyrite are present; the latter two minerals presumably being authigenic (Gilluly, et al, 1965). The quartzites form prominent ledges to the west and north of Argenta and to the east and west of Miller. The chert of the Valmy Formation is usually black to gray, with some green and red colors, and, on fresh surfaces, intricate webbings of darker lines are seen. Quartz veining is prominent on bold outcrops of the chert. The chert and quartzites are very similar chemically and mineralogically. The greenstones are highly altered, but where the original composition can be detected it is evident that they varied from pillow lavas to ash. Closely associated with the greenstones are small limestone lenses.

The Valmy Formation has been thrust over the eastern facies rocks along the Roberts Mountains thrust fault and in places overlies the Slaven Chert along thrust faults which are branches from the main thrust. The upper plate of the thrust contains many such low angle faults as illustrated in the cross sections of Gilluly, et al, (1965).

Devonian Slaven Chert

The type section for the Slaven Chert is in Slaven Canyon in T30N, R46E, where it is exposed over most of the area in the canyon (Plate I). It weathers into

smooth featurless slopes with very little outcrop except where silicified or faulted.

The formation consists predominantly of black to gray chert in beds two and one-half to 10 centimeters thick with thin selvages of clay between beds which are contaminated by iron oxides, radiolaria, sericite and organic matter. The formation also contains carbon rich argillite, which makes up as much as 50 percent of the stratigraphic column, and small amounts of siltstone, sandstone, limestone and dolomite. The argillite layers contain round to subrounded concretions from pea size up to 75 centimeters in diameter. These concretions are made of radiating blades of calcium carbonate, with small patches of pyrite, barite and some radiolaria, and they are evidently primary features since bedding planes wrap around them. Small lenses of brown-weathering limestone, varying from 60 centimeters to 9 meters in thickness and up to 300 meters in length, are present in the formation, but they are not very abundant. The footwall of the ore body at the Miller Mine is formed by this limestone, but at Argenta the limestone lenses are much rarer (Plate II).

The limestone contains fossils which have been identified as conodonts and ostracodes: Palmatolepis sp, Ozarkadina and Spathognathodus (J. Huddle, personal communication, 1973, and T. J. Dutro, personal communication, 1974). These fossils were found at Argenta and Miller Mine and have been found in the Pilot Shale elsewhere in Nevada. Brachiopods found in barite at the

Miller Mine have been identified as the genus Dzieduszyckia by Dutro (personal communication, 1973). They occur in the life position with both valves intact and were present in the limestone before it was replaced by barite because the interior of the fossils is calcium carbonate with the outer surrounded by barite. Brachiopods found in several other local barite occurrences were identified as Halorella (Gilluly, et al, 1965). This faunal assemblage proves an Upper Devonian (Lower Famenian) age for the portions of the Slaven Chert enclosing the barite occurrences. The fossil evidence that Gilluly, et al, (1965) collected indicated the formation to be Middle Devonian and perhaps, in part, Upper Devonian, and thus the barite occurrences are in the upper portions of the formation. This is borne out by the structural relations seen at the Miller Mine where the upper thrust contact between the Valmy Formation and the Slaven Chert is less than 100 meters stratigraphically higher than the ore body.

The formation has been tightly folded and many of the folds have broken along the crests to form bedding plane faults. It is difficult in most areas of Slaven Chert to find a strike or dip which is representative of any large area and, therefore, strikes and dips are indicated in Plate II only where they represent an attitude which is constant over 20 or 30 meters of strike length. The complex deformation of the formation was caused by intrastratal slippage and accompanying

folding of the individual beds, primarily during the Roberts Mountains thrust faulting, but some deformation probably took place during the Lewis orogeny and Basin and Range faulting. Contacts above and below the Slaven Chert are fault contacts and therefore the actual thickness can only be guessed. Roberts, et al, (1958) estimated that in Slaven Canyon the unit could be 1200 meters thick. Over much of the area south of the study areas, the Slaven Chert has been caught up as a sliver within the Valmy Formation and, as a result, the structural complexities within the formation are awesome. Because of the intimate structural relations between the Valmy Formation and the Slaven Chert, and because of similar lithologies within the two units, it is not always possible to be sure of distinguishing the two. The best guide is that if quartzite or highly colored cherts are present, then the rock is Valmy Formation.

Tertiary Limestone

Overlying the Slaven Chert at Argenta and over large areas south and east is a Tertiary limestone. This limestone is tan to yellow, very dense in portions, and in other portions consisting of a hash of oolites and gastropods with ostracodes and conodonts. The ostracodes and conodonts were examined by I. G. Sohn (personal communication, 1974) who concluded that ostracodes in the samples may belong to the genus Tuberocypris Swain. Pollen in the same sample was

identified as no older than Miocene and probably Mio-Pliocene. Based on some poorly preserved fossils, the formation could be Paleocene-Eocene (Ali Patet, personal communication, 1975), and the ostracodes identified as Herpetocypris, sp.2, Cypria, sp.4. This formation, which is up to 12 meters thick, immediately underlies the Tertiary volcanics of the area. The lower 1 to 1½ meters contain fragments of chert and barite which are very angular, indicating that the limestone was deposited in a very local basin on the Tertiary surface, probably prior to Basin and Range faulting. It forms a fluffy soil when dry but very clayey soil when damp. The entire block upon which this limestone lies at Argenta has been tilted toward the east about 30 degrees. The unit is a very useful marker to determine recent structural dislocations in the area.

Tertiary Intrusives

Tertiary olivine diabase dikes striking N 10°-15°W traverse the Argenta area and much of the northern portion of the Shoshone Range. They vary in width from 1½ to as much as 25 meters, and in length from a few hundred meters to over a kilometer. They are composed of olivine diabase, the same composition as the overlying basalts. In thin sections, fresh samples from the interior of the dikes show ophitic textures and contain laths of plagioclase comprising 40 to 50 percent of the rock, with about 10 percent olivine rimmed with magnetite, and abundant augite.

The dikes form lines which are easily distinguished on aerial photographs because of the clay content in the soil formed over the dikes. The portion of the dike nearest wall rock is nearly always altered to a yellow or greenish clay, while the interior portion is much fresher and contains crystalline barite and amygdules filled with chalcedony. The age of the dikes is very similar to that of the overlying basalts as indicated by the fact that some of the dikes cut the basalt and some do not, although both types fill the same fracture trends and are of the same composition. There were two phases of intrusion; one before the flows and one after.

A sill of olivine diabase has been identified in drill holes in the southern part of Argenta and a similar igneous body is present at Miller. At the Shelton Mine the entire hill containing the ore body seems to have been floating in intrusive material with small apophyses protruding from the main body into the overlying Slaven Chert. Intrusive activity has been present on each property studied.

Tertiary Flows

Overlying the Paleozoic strata are a series of flows varying in composition from basalt to andesite. East of Argenta these flows form sheer cliffs. The thickness of these volcanics may be up to 500 meters.

STRUCTURAL GEOLOGY

The structural geology of the Great Basin has been greatly influenced by the development of the Cordilleran geosyncline and its associated orogenies. Three main structural episodes are recorded in the northern Shoshone Range:

(1) The Antler orogeny which produced the Roberts Mountains thrust fault of Late Devonian to Early Mississippian age.

(2) The Lewis orogeny, of Gilluly, et al, (1965) which may possibly be correlated with the Sonoma orogeny to the east. The age is uncertain due to lack of remaining upper plate material, but it occurred between post-Lower Triassic and pre-Miocene (Gilluly, et al, 1965).

(3) Basin and Range faulting which began in Oligocene time elsewhere in Nevada, but probably started in Plio-Miocene in the Shoshone Range and has been intermittent since then.

The Roberts Mountains thrust fault can be seen over a large area of central Nevada where two contrasting facies of similar ages are exposed in many windows through the upper plate. Movement is inferred to have been eastward on the order of 90 kilometers (Gilluly, et al, 1965). The thrust is not exposed in either of the study areas,

but is probably present at some unknown depth. There are subsidiary thrust faults within the upper plate which form an imbricate structure much like the shingles on a roof. East of the Miller Mine Valmy quartzites have been thrust over Slaven Chert along one of these subsidiary faults. At Argenta the thrust surfaces have been down-faulted so that they are not exposed, but are present at depth with Valmy Formation overlying Slaven Chert. Barite occurrences are found in both mines studied to be very near to the thrust and perhaps the thrust may have had some influence on the localization of barite.

Both upper and lower plates of the thrust were deformed during movement. This is well displayed in the folding and bedding plane faulting within the Slaven Chert.

The second episode of orogeny took place following deposition of clastics eroded from the uplifted Antler orogenic belt. The formations which were carried in along the thrusts are nearly all eroded away, but their presence in the Mt. Lewis quadrangle to the south records this orogeny, which superimposed still further deformation upon the upper plate of the Roberts Mountains thrust.

Basin and Range faulting began in Oligocene time in many parts of Nevada, but probably began in Plio-Miocene time in the northern Shoshone Range since faults of this episode cut the basalt unit of probable Pliocene age which caps the eastern part of the Range.

Superimposed on the depositional and orogenic history of the geosyncline is a series of linear breaks which trend northeast and northwest across the State. They represent weaknesses in the basement which date to Precambrian times and are presumably responsible for the trends in Nevada along which mineral districts and intrusives are aligned (Roberts, et al, 1958, Roberts, 1966). Roberts (1966) states that the mineral belts may have developed as a set of fractures normal to the geosynclinal trend. They have been intermittently active since Precambrian time and therefore have been superimposed upon the sediments deposited in the geosyncline. The Battle Mountain-Eureka mineral belt (Figure 3), one of the northwest trends, passes through the northern Shoshone Range and has offset the entire range by right lateral strike slip movement (Shawe, 1965). The same type of offset can be seen southeast along the belt in the Cortez and Simpson Park Ranges. The strike slip movement caused tension fractures trending N 5° W in the Cortez and Simpson Park Ranges (Robinson, 1970) while in the Shoshone Range the trend is generally N 5° W to N 15° W. It is within these tension fractures that dike swarms were intruded in each of the three ranges, and at Argenta the fractures probably acted as a hydrothermal plumbing system through which barium-rich solutions were carried into the Slaven Chert.

BARITE ORE DEPOSITS

Introduction

On a worldwide basis most barite occurrences fall into one of the following three categories: (1) vein and cavity filling occurrences, (2) residual deposits, and (3) bedded types. This paper will deal with a description of two of the bedded type occurrences and will examine possible modes of origin based upon the observations made. Three major ideas to explain the origin of bedded barite in Nevada have been proposed by writers who have examined them: (1) syngenetic deposition of barite on the sea floor (Hanor, 1966), (2) diagenetic replacement of sediments shortly after deposition (Shawe, et al, 1969), and (3) epigenetic replacement of sediments long after their deposition (Ketner, 1965). Movement of barium into or within the sediments has undoubtedly occurred, as shown by replacement textures, but the age of the movement has not been well established.

In order to study these bedded barite occurrences a number of features of the ore bodies will be considered. These are: (1) the structure and lithology of the ore bodies, (2) the close association of barite with igneous bodies, (3) the petrography of the ore, and (4) the geochemistry of barite and the surrounding host rocks. These subject areas will then provide a basis upon which to build a discussion of possible modes of origin of the barite.

Structure and Lithology

Barite deposits in Nevada have an obvious spatial relationship to an 80 to 120 kilometer wide zone trending along the Antler orogenic belt (Figure 2), with bedded barite in the center of the trend and vein type occurrences on either side. This same trend may extend into Idaho and Washington where barite is associated with a similar tectonic feature, as is illustrated in Figure 2 (Hanor, 1966). The significance of this linear feature is related to structure within the Antler orogenic belt and to the sedimentary history of this particular zone within the geosyncline, since both the proper structure and stratigraphy are required for localization of barite.

Both of the barite occurrences studied here are located in areas of great structural complexity where high angle faults are abundant. Many of these faults contain igneous dikes whose relationship to the barite will be discussed in the section on igneous associations.

Stratigraphic control is evident wherever bedded barite occurrences are examined in Nevada. At Battle Mountain the major bedded occurrences of barite are restricted to the Slaven Chert while elsewhere one formation in each area seems to be the major host for the barite. Small occurrences with low specific gravity barite may be found in formations other than the major host, but they are seldom of economic interest.

The barite bodies are generally lens-shaped and conformable to the bedding of the host rock (Figure 5), with lenses as much as 300 meters long and thicknesses occassionally exceeding 30 meters. A series of disconnected lenses may be found along a strike length of several thousand meters. Individual lenses are commonly separated into several layers by beds of limestone or chert.

The barite is usually dark gray or black, but can be white near igneous contacts where some of the impurities have been baked out. This baking usually results in an increase of specific gravity. The barite beds are more massive than the enclosing host rocks and have beds as much as 30 centimeters or more in thickness. Relict bedding planes, or laminations, 1 to 3 millimeters apart, are present in the barite and in chert, but not in limestone or argillite, distinctly indicating replacement of chert rather than limestone or argillite. The laminations represent microscopic concentrations of organic matter, pyrite, iron oxides and clay (Figure 6). A smaller portion of the barite in the area is a replacement of limestone because there are still small islands of unreplaced limestone within the ore. This is particularly well displayed at the Shelton Mine and in the basal portions of the Miller Mine.

FIGURE 5 - PHOTO OF BARITE LENSES IN CHERT

The light colored areas are barite; the dark areas are chert. Notice areas of partial replacement where the lighter colored barite and the darker colored chert are intimately intermixed. These small lenses have the same characteristics as the large ore bodies and show the discontinuous nature and the pinching and swelling along strike. This photo is 30 centimeters across.

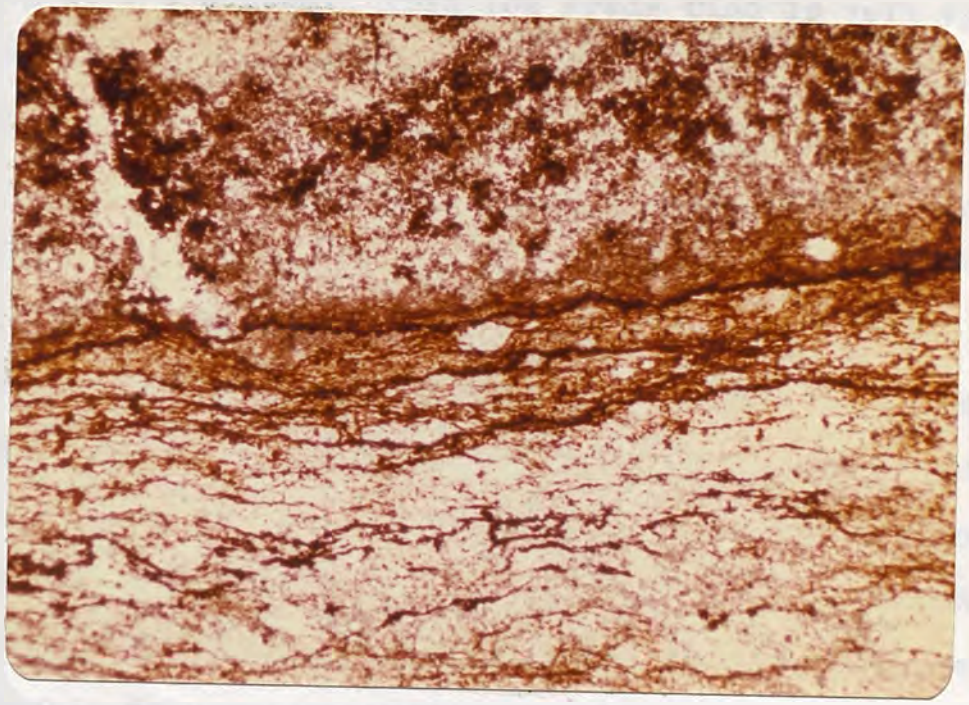

FIGURE 6 - PHOTOMICROGRAPH OF BARITE FROM ARGENTA

The white spot in the center of the photograph is a radiolaria 185 microns across. The lower portion of the photograph is massive barite; the upper portion is partially replaced chert. Dark areas in the upper portion are unreplaced remnants of chert with white spots of barite. Organic matter, seen as black lines and brown stain in the barite, has collected along the bedding planes. (uncrossed Nicols)

The barite commonly varies in specific gravity from the top to the bottom of the ore zone. For example one ore body at Argenta known as the Area F ore body has a low specific gravity (4.10) in the upper portions, increasing to 4.35 in the center and then decreasing again at the bottom. This low grade rind is very common along with a clay envelope which is usually about 1 meter thick and can sometimes be up to 3 meters thick.

The barite and the enclosing sediments have been intricately folded and faulted. The portion of the formation which contains the barite is near the thrust contact between the overlying Valmy Formation and the Slaven Chert. This contact is the Slaven Thrust Fault (which is nicely exposed just east of the Miller Mine) where the thrust is less than 100 meters stratigraphically above the barite. During movement on the thrust, considerable deformation within the Slaven Chert took place so that in most places strikes and dips in the chert change so radically in a small area that it is impossible to map them. The folding was aided by the intrastratal layers of clay which acted as a lubricant between the chert beds during movement. Often the barite is also folded within the sediments, although the very small scale folding is not as common in barite as in the host. This indicates that barite was probably deposited early in the history of the sediments so that when tectonic movements began the barite bodies acted in

larger units than the chert. Movement caused large scale folds and created the gouge layer or clay envelope described above. Brecciated barite is also common at the tops and bottoms of ore bodies where the movements took place. The gouge layer and brecciated zones in and around the barite indicate origin of barite early in the history of the rocks.

At the Miller Mine, where limestone is closely associated with the barite (Plate III), small islands of limestone and chert, generally less than 1 centimeter across, can be seen in the barite where replacement has been incomplete, and the beds are thin and shaley with a specific gravity as low as 3.60. These low grade beds contain abundant pyrite, which has been oxidized, and the pyrite is leached away, leaving spongy iron stained zones with many vugs. Some of the limey areas have a similar condition where the unreplaced remnants of lime in the barite have been leached out, leaving vuggy areas in the barite. This has happened above the water table where the rock has been exposed to oxidation.

A typical stratigraphic sequence at Miller is as follows, (top to bottom):

(1) Black carbonaceous argillite.

(2) Massive high grade barite 8 meters thick with local areas up to 20 meters thick. The barite zone commonly contains contaminating layers and lenses of chert or argillite.

(3) Intimately intermixed barite and limestone with abundant pyrite. This zone is 1 to 3 meters thick.

(4) Massive limestone up to 12 meters thick.

(5) Gray green chert with some pyrite. The full thickness of this unit has never been drilled, but it exceeds 30 meters.

At Argenta the barite is usually overlain by chert and underlain in places by highly carbonaceous argillite. The barite shows gradational values for specific gravity with low values at the top, high values in the center, and low values at the bottom.

Igneous Associations

Many barite lenses in the northern Shoshone Range are cut by igneous dikes, which also can be observed in many of the barite occurrences throughout central Nevada, and is such a frequent association that they must be genetically related to the barite. The dikes are post-barite in age and often contain fragments or xenoliths of barite. The structures now occupied by dikes are the most important feature and these open zones may have acted as hydrothermal plumbing systems to carry barium-rich solutions to the ocean floor or into the sediments during diagenesis, or possibly epigenetically after consolidation of the sediments. The dikes probably acted as feeders for the overlying volcanics,

which are Pliocene or younger, since they overlie the Mio-Pliocene limestone.

At both Argenta and at Miller the dikes are olivine diabase in composition. They vary in width from 1 meter to as much as 25 meters, with a highly altered zone near the contact with wall rocks and a fresh inner core. Small amygdules up to about 5 millimeters in diameter are filled with white chalcedony. The altered dike material is a light yellow to tan clay, which often penetrates the fractures in barite near the dike-barite contact. Barite is not always noticeably altered near dikes, although a narrow bleached zone 1 centimeter or so wide can frequently be seen at the contact where heat drove off the organic material in the barite. In a few places where the dikes are very large and contained considerable heat, the bleached areas are several feet across. The portions of ore bodies nearest to the dikes are generally the highest specific gravity, often 4.40 or higher. The yellow staining in clay selvages between chert beds is most prevalent immediately adjacent to the dikes. This alteration in the clay was caused by fluids and heat from the dikes and the probable introduction of iron.

At Argenta the dikes form a swarm with a N 5° W to N 15° W trend (Plate II). The origin and significance of this trend is discussed in the section on structure.

Petrography

Replacement textures within barite are readily seen under the petrographic microscope. Islands of unreplaced host rock are common and can even be seen in hand samples. Replacement of favorable zones in the host rock took place along bedding planes (Figure 7) and fractures, and began at the site of impurities in the rock such as radiolaria, clay particles, or organic matter. Replacement radiated outward (Figure 8) from the growth center, eventually engulfing the entire rock if replacement became complete. As barite growth proceeded, the replacement front swept impurities before it so that a selvage of organic matter and other impurities collected at the suture line between barite and the host or between barite fronts where they met (Figures 6 and 9). Contacts between barite and chert are usually gradational on a microscopic scale (Figure 10), but where impermeable clay layers are present, the contacts are sharp. The grain size of each growth center was extremely small during early stages of growth, but as replacement proceeded, the growth centers became larger and eventually coalesced until they formed a solid mass of barite. The grain size of the barite was controlled by the number of growth centers which started during the early stages of growth. The areas which are highest in specific gravity seem to have had a larger number of growth centers and therefore more complete replacement. Areas

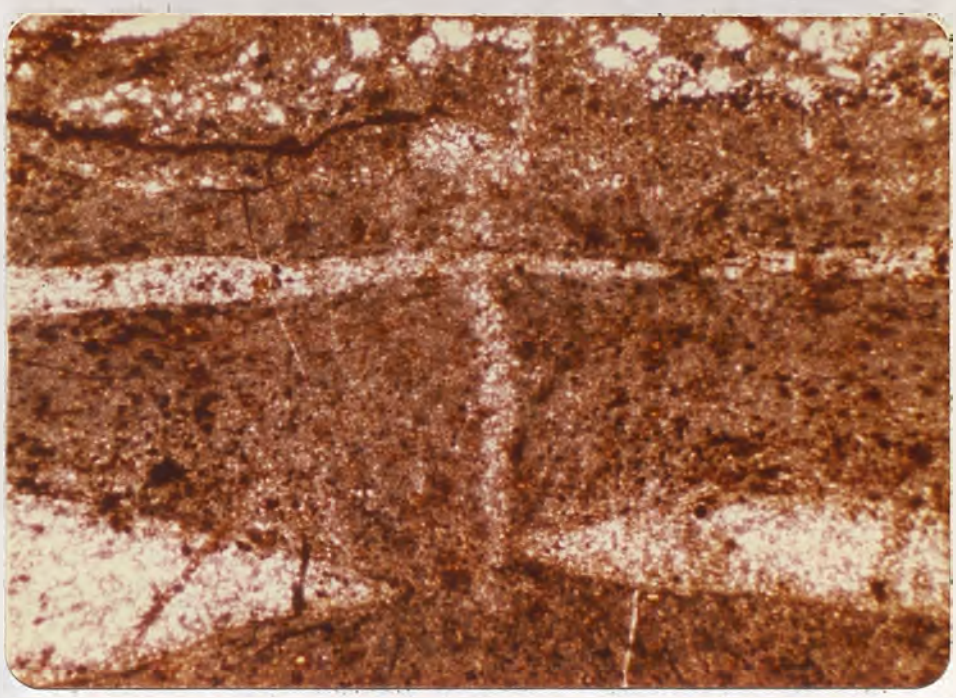

FIGURE 7 - EXAMPLE OF SELECTIVE REPLACEMENT ALONG BEDDING PLANES

The white areas are barite and the blue-green are chert with impurities such as organic matter, mica and clay. Radiolaria at top of photo are about 120 microns across. (uncrossed Nicols)

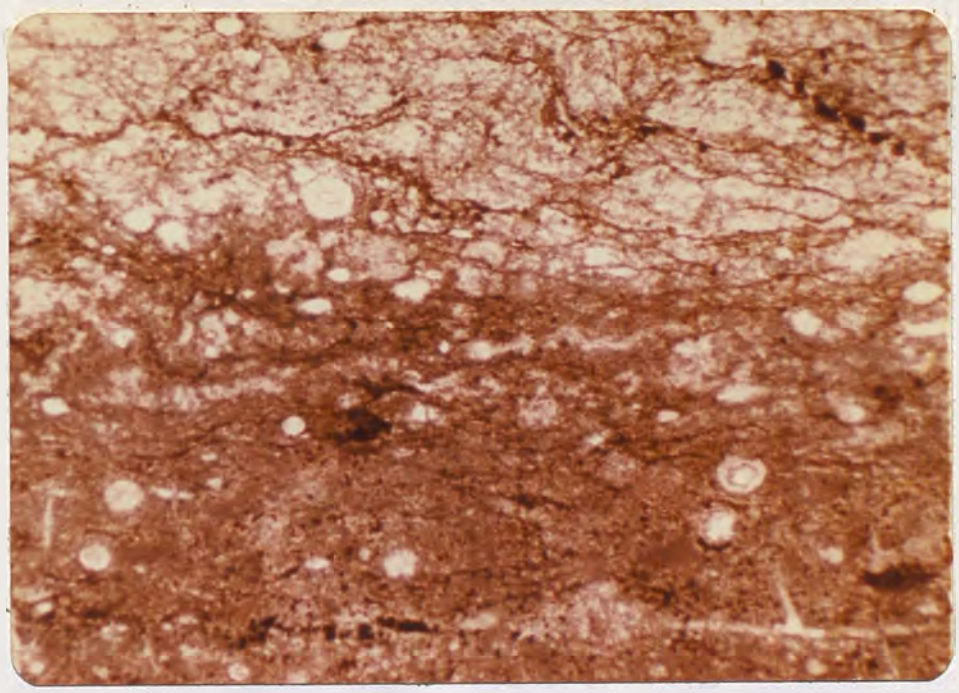

FIGURE 8 - MASSIVE BARITE ABOVE WITH CHERT BELOW

Barite begins replacement along bedding planes and at radiolaria. The largest radiolaria at upper left center is about 150 microns across. Growth was centered around the radiolaria and has proceeded outward, as evidenced by the two different layers of barite around the radiolaria. (uncrossed Nicols)

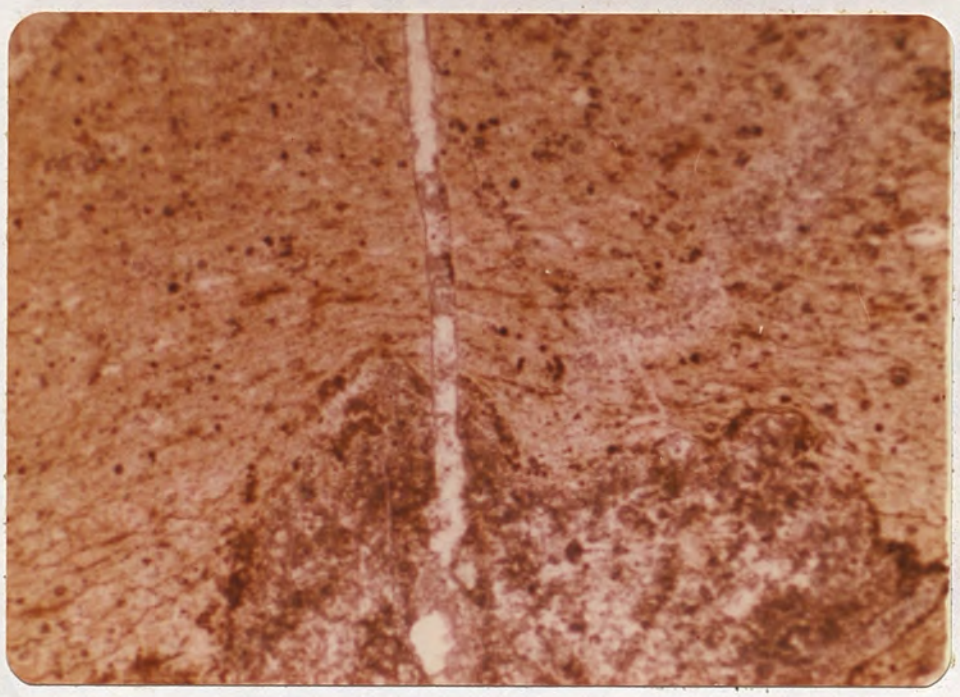

FIGURE 9 - BARITE REPLACEMENT FRONT

Barite replacement front (below) joined by a barite veinlet (center) 100 microns wide. Notice that the replacement front is sweeping organic material before it. (uncrossed Nicols)

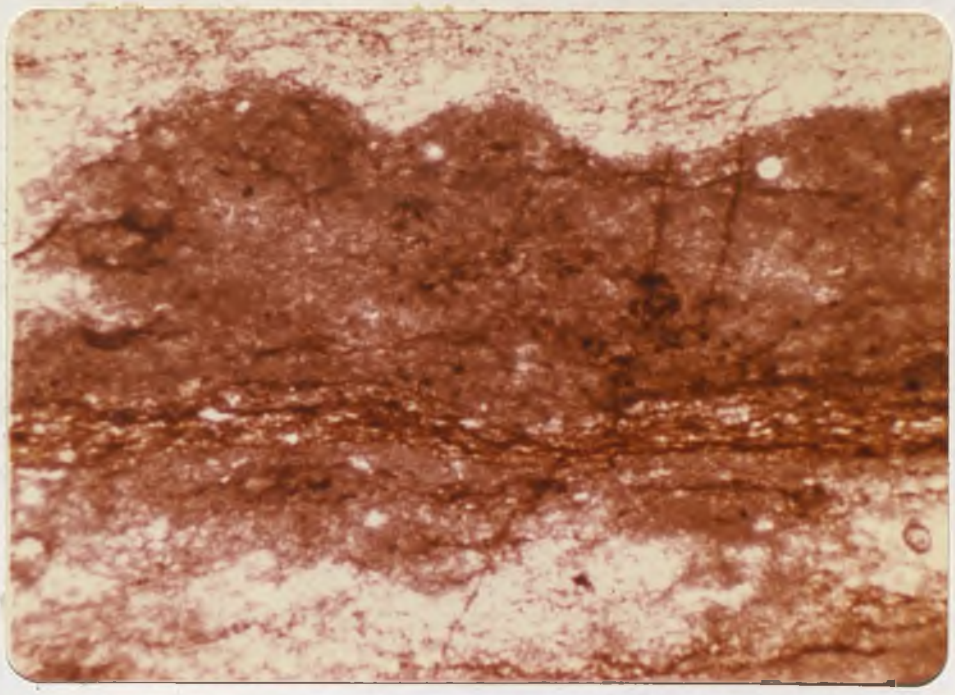

FIGURE 10 - TWO BARITE FRONTS ABOUT TO ENGULF THE REMAINING CHERT

Notice that partial replacement of the chert has already begun where a faint trace of white indicates widely scattered, very tiny growth centers of barite (center right and left). Radiolaria in lower right is 120 microns across. (uncrossed Nicols)

where mineralization is weakest are characterized by barite rosettes up to 15 centimeters and more in diameter. Each rosette represents one growth center which grew until it formed a set of radiating sheaves of barite.

Geochemistry

A number of geochemical approaches were taken to determine possible origins of the bedded barite studied. Sulfur isotope ratios were determined on 23 samples; the uranium content of five samples was studied; and the content of barium in the host and dike rocks was studied, as well as were the trace elements in the barite. Other lines of evidence were also considered.

1. Sulfur Isotopes

In recent years sulfur isotopes have become very popular as a means of studying ore deposits because sulfur is so commonly associated with ore deposits and it can be studied fairly easily with a mass spectrometer.

Sulfur has four stable isotopes in the following abundances:

S^{32} 95.1%; S^{33} 0.74%; S^{34} 4.2%; S^{35} 0.02%

Isotopes are atoms which have the same number of protons but different numbers of neutrons and, hence, different masses. Because of the different masses, they have different properties in reactions. Bonds formed by the lighter isotopes are more readily broken than bonds made by the heavier isotopes and, as a result, the lighter

isotopes tend to react more readily. These slight differences in reactivity lead to changes in the isotope ratios which may be related to possible modes of origin.

Great variations in sulfur isotope ratios have been noted in nature, but it was determined that meteorites have a rather constant ratio, so they were chosen as a standard (Jensen, 1967).

Isotopic analyses are compared to the standard which has an S^{32}/S^{34} ratio of 22.220 (Jensen, 1967). It has become customary to report sulfur isotope analyses as relative enrichment of S^{34} in the samples in parts per thousand or permil. Since the meteorite value is the standard, it is considered as zero and the enrichment of S^{34} is reported as plus or minus variations from this value. The S^{34} values are calculated as follows:

$$S^{34} \text{ permil} = \left[\frac{S^{34}/S^{32} \text{ Sample}}{S^{34}/S^{32} \text{ Standard}} - 1\right] \times 1000$$

Isotopic fractionation can occur due to three main processes:

(1) Isotope exchange reactions.

(2) Kinetic processes.

(3) Fractionations due to other effects.

In the case of sulfur, oxidation-reduction reactions are particularly important and occur either geochemically or biochemically. Deposits of biologic origin generally have a wide range of isotope values, while those of

hydrothermal systems have a narrow range. However, wide variations can occur in both types and therefore a good knowledge of geologic information is necessary to reach any sound conclusions about origins.

For this study, 23 samples of barite were submitted to Dr. M. L. Jensen in Salt Lake City, Utah, for sulfur isotope analysis. They were analyzed on a mass spectrometer and reported as permil deviations from the standard. Values of -1.5 permil to +57.1 permil were recorded for the samples tested, with the bulk of the values falling between +19 permil to +34 permil (Figure 11, Table I). Each mine sampled showed both high and low values with no occurrence showing consistently high or low values. The wide spread in values is therefore representative of bedded barite deposits in this region. These values would suggest an exchange reaction between H_2S and SO_2, or reduction of seawater sulfate to H_2S which would concentrate S^{34} in the sulfate left in the seawater. Another explanation is bacterial action on the SO_4 in seawater to produce wide variations in the S^{34} content (M. L. Jensen, personal communication, 1974). The bacterial origin is supported by research on fatty acids in barite (Miller, et al, 1972) which are the same fatty acids found in living anaerobic sulfate reducing organisms today. They suggest that anaerobic bacteria were trapped during sedimentation and were responsible for producing hydrogen sulfide by decomposing and

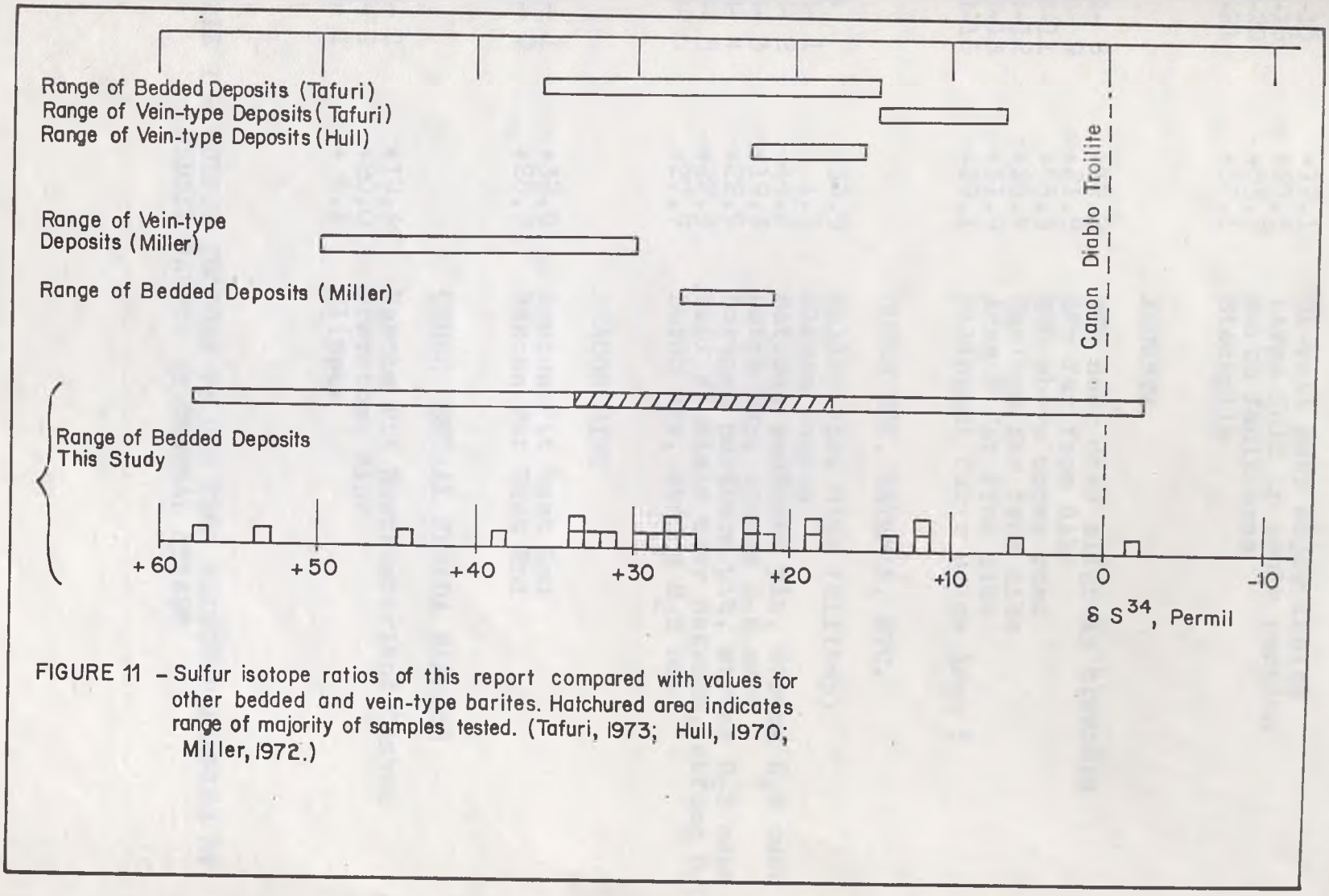

FIGURE 11 – Sulfur isotope ratios of this report compared with values for other bedded and vein-type barites. Hatchured area indicates range of majority of samples tested. (Tafuri, 1973; Hull, 1970; Miller, 1972.)

		MILLER
M-15	+12.1	Hi-wall near major faults
M-16	+27.5	Large fold in south portion
M-20	+33.7	North fault area
M-21	+57.1	Stockpile
		ARGENTA
AR- 8	+12.2	BK6 near dike slightly bleached
AR- 9	+21.9	BK6 far from dike
AR-11	+53.3	BK6 above upper road
AR-12	+26.4	Shelton far from dike
AR-13	+31.9	Area F far from dike
AR-16	+29.1	Filippini curve below Area F
		DUTCH BOY, BATEMAN, ETC.
DA	+38.9	Valley View Mine (Hilltop)
DB- 1	- 1.5	Slaven Canyon
DB- 2	+44.2	Bateman southern pit, strong H_2S odor
DB- 3	+19.3	Dutch Boy, strong H_2S odor
DB- 4	+22.7	Bateman northern pit, strong H_2S odor
DB- 5	+22.3	Tiff #3 claim near Bateman, strong H_2S odor
DB- 6	+27.7	Dutch Boy, strong H_2S odor
		BEACON MINE
DL- 1	+32.9	Beacon Pit West End
DL- 2	+28.7	Beacon Pit East End
		OTHER CENTRAL NEVADA SAMPLES
N- 1	+19.3	Nareco Pit Northumberland Canyon
G- 1	+20.0	Greystone Mine
NC- 1	+ 6.1	Clipper

TABLE I - SULFUR ISOTOPE VALUES FROM SELECTED SAMPLES OF BEDDED BARITE IN CENTRAL NEVADA

reducing associated organic matter to produce the fetid odor in barite. Degens (1965) suggested that the proper conditions may develop to precipitate barite from seawater around localized areas where decaying organic matter is present.

The sulfur isotope values of vein type barite occurrences are generally slightly lower than those exhibited by bedded barite (Figure 11). Miller, et al, (1972) report values for vein type deposits ranging from +14.23 permil to +37.27 permil, which is an anomaly compared to the other vein types tabulated in Figure 11. Results were found by Hull (1970) for a vein type barite from Creede, Colorado, with values from +17.00 permil to +23.94 permil, and Tafuri (1973) with values from +6.66 permil to +15.42 permil. The sulfur isotope values for bedded barite fall in a group for the three studies tabulated in Figure 11 with the majority of samples ranging from +15 permil to +35 permil. The sulfur isotope data for the bedded barite suggest a sedimentary origin for the sulfate because of the wide spread in values. The exchange reactions suggested by Jensen as occurring in seawater, are the probable cause of the wide spread and generally positive values while biological processes may also have contributed to producing the observed values by depleting the seawater of S^{32}.

2. Uranium Content

Uranium content has been cited by Mills, et al, (1971) as a distinguishing feature between bedded barite of marine origin and hydrothermal vein-type barite. Marine barites show a uranium content of 5-35 ppm by weight while hydrothermal types show concentrations of less than 2 ppm (Mills, et al, 1971). Analyses of five barite samples from the Argenta and Miller mines indicated no detectable uranium content. The uranium content was determined fluorimetrically in this study by Skyline Laboratories of Golden, Colorado. This technique has the same lower limit of detection as the neutron activation technique used in the study by Mills, et al, (1971), although it does not have the same degree of precision. None of the samples analyzed showed any uranium down to the lower detection limit of 2 ppm. The lack of gamma emitters in barite has been used as an exploration guide for barite in the northern Shoshone Range, using down-the-hole gamma ray probes which can distinguish between barite and chert because of the extremely low gamma ray emission from barite (as low as one count per second), while chert can give off 50 or more counts per second. In fact, the fewer the counts, the higher the specific gravity of the barite. Since uranium or other gamma emitters are lacking in the bedded barite of the northern Shoshone Range, this would suggest a hydrothermal origin for the barite.

3. Other lines of evidence

The presence of phosphorus in barite at Northumberland Canyon is cited by Shawe, et al, (1969) as strong evidence for sedimentary origin of the barite since phosphatic nodules are universally accepted to be of sedimentary origin. Analyses published on bedded barite deposits in the northern Shoshone Range, however, show no detectable phosphorus (Table II). This lack of phosphorus could allow a hydrothermal origin, but would not be conclusive evidence.

The environment of deposition would be a critical feature to a primary sedimentary origin for the barite. The environment was able to support abundant aquatic life, now preserved in the sediments as carbon, which indicates a reducing environment. The presence of limestone lenses indicates a fairly shallow warm water and it also encloses a life assemblage of brachiopods which prove that the environment was not too harsh to support life during deposition. It would be difficult for sulfate to survive the reducing environment unless it united with barium prior to reaching the seafloor.

Shawe, et al, (1969) conclude that barite was formed during diagenesis because the barite needed room to grow in the sediment in order to form the rosettes which are observed. Examination of some vein-type occurrences indicates that barite can form laths and rosettes in very dense silicified materials

	Si	Ca	Ba	Al	Ag	B	Co	Cr	Cu	Fe
Valley View Mine										
Chert Outside	44.2%	1500	1500	7000	0	30	0	3	30	7000
Mineralized Area	45.1%	700	300	300	Tr	70	0	7	70	1500
Chert In	44.3%	1500	4000	7000	0	0	30	3	70	3000
Mineralized Area	44.2%	3000	3000	7000	0	30	0	3	30	3000
Limestone In	21,000	36.8%	3000	15	0	0	0	Tr	3	700
Mineralized Area	29,000	36.4%	700	1500	0	0	0	Tr	7	1500
Barite	7,000	300	57.3%	700	0	0	0	Tr	7	1500
	18,000	700	55.0%	1500	0	0	0	Tr	15	700
Bateman Mine										
Chert Outside	42.4%	3000	700	15000	0	70	0	7	300	7000
Mineralized Area	43.0%	7000	15000	7000	Tr	30	0	15	30	3000
Chert In	41.3%	300	7000	30000	Tr	150	0	30	14	1500
Mineralized Area	42.3%	1500	15000	15000	0	30	3	7	30	3000
Barite	0	150	58.6%	150	0	0	0	0	15	30
	18,000	150	54.2%	1500	0	0	0	Tr	7	1500
Greystone Mine										
Chert In	43.0%	1500	15000	7000	0	70	0	7	15	1500
Mineralized Area	39.4%	700	38000	15000	0	150	0	15	70	3000
Barite	20,000	1500	55.0%	1500	0	0	0	0	7	700
	56,000	700	48.9%	1500	0	0	0	3	30	1500
	5,000	200	Major	1000	NA	NA	NA	NA	2	200
Mountain Springs Mine										
	20,000	200	Major	4000	NA	NA	NA	2	4	600
National Lead Mine Dunphy, Nevada										
	10,000	600	Major	400	NA	NA	NA	NA	20	100

Phosphorus looked for but not found

TABLE II - CHEMICAL ANALYSES OF HOST ROCK AND BARITE - Northern Shoshone Range, Nevada, in PPM except where noted. Modified after Gilluly, et al, (1965) and Brobst, (1958).

Ca	K	Mg	Mn	Mo	Na	Ni	Pb	Sc	Sr	Ti	V	Zr
0	0	300	300	0	500	15	0	0	30	700	?	Tr
0	0	150	70	0	700	15	0	0	0	70	15	15
0	0	300	70	0	500	?	0	0	15	150	15	15
0	0	300	150	0	500	15	0	0	15	300	15	70
0	0	300	1500	0	500	3	0	0	300	500	15	Tr
0	0	700	3000	0	500	0	0	0	300	300	15	Tr
0	0	10	15	0	700	0	0	0	150	700	0	0
0	0	30	15	0	700	0	0	0	300	700	Tr	0
Tr	7000	700	70	0	500	7	0	7	15	700	30	30
0	7000	300	70	Tr	700	3	0	0	30	300	30	15
15	15000	1500	70	0	500	0	70	7	30	700	150	70
0	7000	300	300	0	500	30	15	0	30	150	30	15
0	0	10	Tr	0	700	0	0	0	1500	300	0	0
0	0	10	70	0	500	Tr	0	0	700	0	7	0
0	0	300	30	0	500	Tr	NA	0	70	70	30	15
Tr	7000	700	70	0	700	3	NA	7	150	70	30	15
0	0	30	Tr	0	700	0	NA	0	1500	70	Tr	0
0	0	700	15	0	700	0	NA	7	1500	7	15	Tr
0	NA	50	40	0	NA	0	NA		500	NA	NA	NA
0	NA	200	NA	0	NA	0	NA	NA	10	50	10	NA
0	NA	NA	NA	0	NA	0	NA	NA	100	NA	NA	NA

as it replaces them so that an unconsolidated sediment is not necessary for this condition to occur. The presence of laths or rosettes is not conclusive evidence of diagenetic origin.

The composition of various rock types in and around barite deposits is shown in Tables II and III. The chert in mineralized areas is much higher in barium than chert outside mineralized areas. For instance, the Valley View or Hilltop Mine shows values of 300 and 1500 ppm barium in chert outside the mineralized area and 3000 and 4000 ppm barium within the mineralized area. At the Bateman mine, the values in chert are 700 ppm and 15,000 ppm barium outside the mineralized area and 7000 and 15,000 ppm barium within the mineralized area. This one is anomalous but may have been inadvertently collected near barite. At Argenta the chert outside the mineralized area shows 1000 ppm barium and 7000 ppm barium within the mineralized area. The chert host rock near barite ore bodies usually has been enriched 3 to 15 times that shown in non-mineralized areas. Barium has obviously been introduced into the host rock to form barite ore bodies. This fact can also be seen microscopically where small replacement centers of barite are present in the chert surrounding ore bodies (see section on petrography). Chert in the study area, whether near barite or not, is generally high in barium content (Gilluly, et al, 1965) compared

DIKE SAMPLES

		ppm Ba
AR- 1	Dike from north side BK-6 pit	550
AR- 2	Dike from south side BK-6 pit	4000
AR- 3	Dike near barite on Second Chance Claim	1400
AR- 4	Dike on north side BK-6	1200
AR- 5	30 foot channel sample from dike north of BK6	7400
AR- 6	Dike from BK-6 in contact with barite	1000
AR- 7	Unaltered dike BK-6	1300
AR-14	Dike from Yuba pit near barite	450
AR-15	Dike from Shelton pit near barite	4400
AR-17	Channel sample across altered dike, Shelton	700
AR-22	Unaltered intrusive, Shelton haul road	650

CHERT SAMPLES

		ppm Ba
AR-10	Chert interbeds in barite, BK-6	7000
AR-24	Chert, Shelton haul road, no barite near	1000
15	Within mineralized area	15,000
19	Within mineralized area	7000
30	Within mineralized area	3000
32	Within mineralized area	4000
305	Outside mineralized area	700
307	Outside mineralized area	1500
313	Outside mineralized area	300

TABLE III - BARIUM CONTENT OF DIKE ROCK AND CHERT BOTH NEAR AND FAR FROM BARITE OCCURRENCES COLLECTED BY THE WRITER. Samples 15, 19, 32, 307, and 313 are from Gilluly, et al, (1965).

to cherts elsewhere in the world. This could be interpreted to mean that barium was deposited with the original sediments or it might mean that barium was introduced over a wide area after deposition of the sediments.

Tertiary dikes associated with barite were also analyzed and it was found that in mineralized areas they had up to 7400 ppm barium as shown in Table III. According to Krauskopf (1967), olivine basalt has a normal barium content of 310 ppm. All of the samples taken, whether near barite or not, exceed this norm by as much as 24 times. This could be interpreted to mean that the magma chamber from which the igneous material originated was high in barium content and therefore was the source of the barium or it could also mean that as the dikes cut the barite during intrusion they assimilated some barite from pre-existing beds and therefore incorporated abnormal amounts of barium. Again this offers no conclusive proof of the origin of these ore bodies.

COMMENTS ON ORIGIN

An effort was made in this study to examine as many features as possible which would help to unravel the history of these bedded barite occurrences. The features which seem to indicate a sedimentary origin are: (1) the stratabound nature of the occurrences in which crosscutting relations between barite and chert cannot be demonstrated, (2) the stratigraphic control of the ore and the restriction of barite to formations of the western facies, (3) the wide spread in sulfur isotope values, (4) the relatively high content of barium in the formations containing barite, (5) the gouge and breccia zones at the top and bottom of barite, indicating existence of barite during severe tectonic movements early in the history of the rocks, (6) the crosscutting dikes which indicate barite preceded them, and (7) the lesser amount of folding in barite than in the host, indicating an early deposition of barite and later folding, which barite resisted but chert reacted to readily. On the other hand, hydrothermal processes are indicated by (1) the structural control indicated by a regional alignment of barite occurrences, (2) the close association of igneous dikes and plugs with bedded barite in a large number of occurrences in Nevada, (3) the great stratigraphic thickness of the ore bodies as compared to lateral

extent, (4) the wide spread in ages of the sedimentary formations containing barite (Cambrian, Ordovician, Silurian, and Devonian), and (5) lack of uranium in the barite. The replacement textures could be explained as hydrothermal replacements, as replacements related to diagenetic processes, or as post depositional movements of barite. The environment of host rock deposition was reducing, yet it supported brachiopods on the bottom for at least a brief period during limestone deposition. Neither the reducing environment nor the brachiopods would be consistent with primary deposition of barite unless barium united with sulfate prior to reaching the bottom. The very high barium content immediately surrounding barite ore bodies indicates a definite enrichment or introduction of barium to these areas.

With the characteristics enumerated above, a few constraints on modes of origin can be established. The sulfur isotope data indicate sulfate originated from seawater, probably by geochemical means, perhaps assisted by biochemical processes. The folding relationships and the gouge and breccia layers indicate deposition early in the history of the rocks. The stratigraphic control could indicate an early age, although it does not demand it. The high barium content of the enclosing formation over wide areas would suggest primary deposition. The structural pattern which localized barite

may very well have originated very early in the history of the geosyncline and when the upheavals of the Antler began they provided the system by which barium could be introduced.

A possible scheme of origin could go something like this: As the geosyncline developed, structures opened up along the edge of the trough and allowed hydrothermal fluids rich in barium to be released into the sea. The barium then united with sulfate from sea-water to form barite which was precipitated on the sea-floor. After deposition, the barite was remobilized to its present site to form the replacement textures observed. This explains the structural and stratigraphic features as well as the geochemical features observed. Bedded sulfides associated with barite in sedimentary sequences could be explained this way also by the addition of metals.

Other possibilities could include a two stage process with deposition in the carbonates in the lower plate and later remobilization to sites within the upper plate. Although this could be possible, it does not explain as well the high barium content of the host rocks over wide areas, or the gouge and breccia layers at the top and bottom of ore bodies, since the largest tectonic movements would have taken place prior to remobilization of the barite. Also barite in carbonates is by far more frequent as clearly epigenetic veins

rather than as possibly syngenetic or diagenetic replacement and the veins have very different sulfur isotope values. Only one replacement in eastern carbonate rocks of the magnitude necessary for such a process was observed during this study. Surely more original source beds would remain in carbonate rocks if they are the source for bedded barite in the state. Local euxinic basins can be the site for sulfide deposition and similar restricted basins could be the site for barite deposition, but, without the addition of large quantities of barium, this would not explain many of the observed features. The combination of a local basin and a structure could produce the features observed.

CONCLUSIONS

Based upon all the features observed it seems that the most likely pattern for origin of the two bedded barites examined would combine features of both hydrothermal and sedimentary processes. The most likely scheme includes a structure or structures along the edge of the geosynclinal basin which provided barium to what may have been a local restricted basin. The barium was then able to unite with seawater sulfate enriched in S^{34} to form barite, which was precipitated on the seafloor. This barite was then probably mobilized and concentrated during diagenesis to form the replacement textures observed in thin sections and hand specimens. After deposition, the tectonic movements of the Antler orogeny caused brecciation of the upper and lower portions of the barite bodies and the formation of gouge zones. The barite responded as a large mass and had predominantly large folds imposed upon it while the chert was tightly folded. The structures which provided the plumbing system for introduction of barium were then intruded by dike material during late Tertiary time.

Some areas for future study to test the above concepts might include a large-scale sampling of host rocks near and far from barite along the entire trend of the barite belt. Sulfur isotope work should be expanded to include the pyrite associated with barite.

Other analytical methods might include testing a larger number of samples for uranium and including thorium analyses on the same samples as suggested by Goldberg, et al, (1969). Since Nevada is an important barite producing state, more detailed study of the many barite deposits in the state should be undertaken.

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