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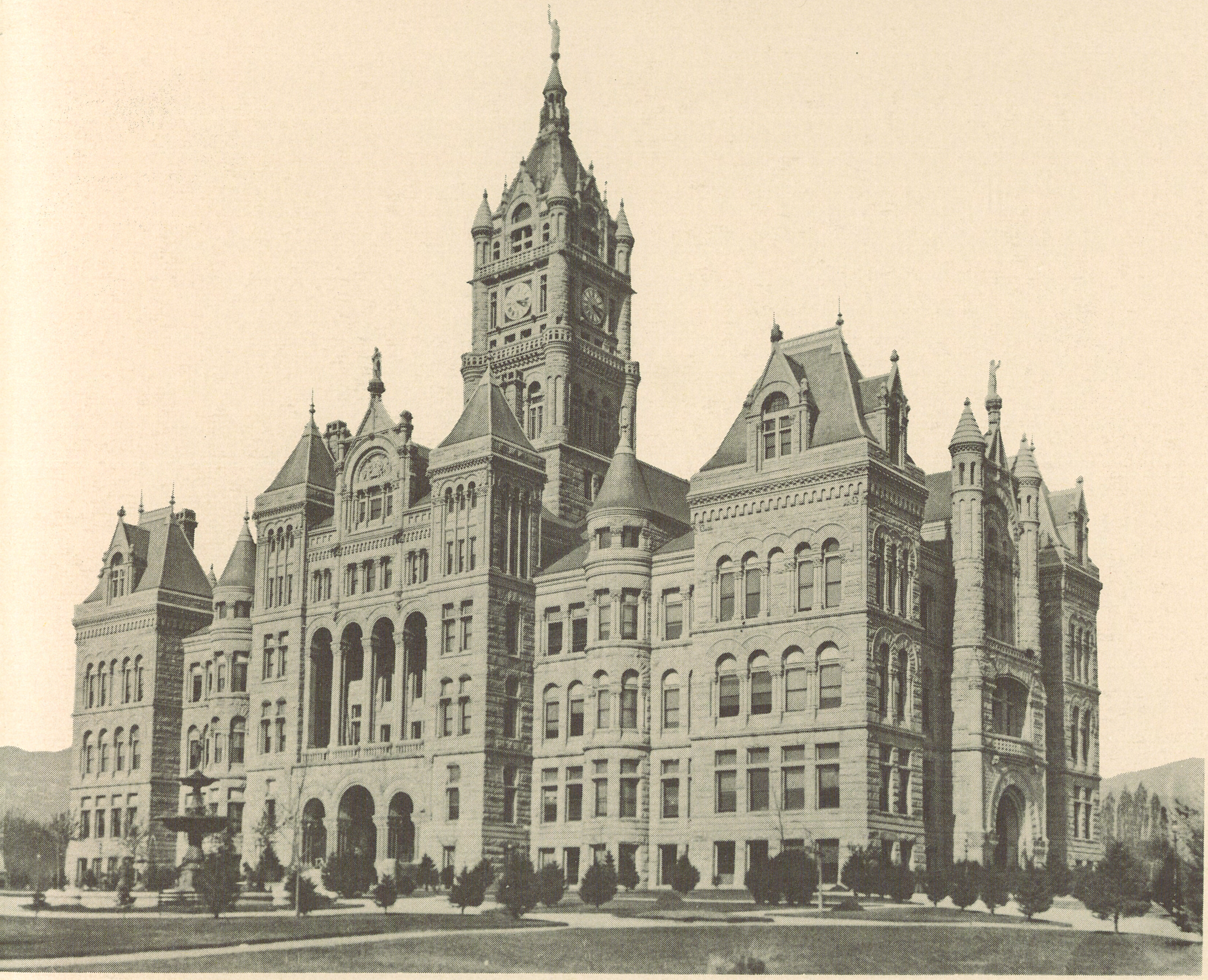

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GEOLOGICAL AND MINERAL SURVEY UTAH

Utah Geology

Vol. 3, No. 1 Spring, 1976

CONTENTS

Cover photograph courtesy of Utah Historical Society: Salt Lake City and County Building in 1902.

It is the policy of UTAH GEOLOGY to publish two issues per year containing short papers of geologic interest. Most of the papers will describe some aspect of Utah's geology, but a few will discuss topics of general geology.

Contributions from practicing geologists and students are welcome. Papers are to be typewritten, double-spaced, and no more than 60 pages long. Illustrations and photographs should be professional quality, ready to print. Where practical, measurements should be reported in the metric system.

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WEATHERING OF THE SALT LAKE CITY AND COUNTY BUILDING DIMENSION STONE

by Bruce N. Kaliser[1]

ABSTRACT

Study of thirteen cores and a hand specimen taken from the dimension stone of the Salt Lake City and County Building indicates that the weathering results mainly from mechanical rather than chemical processes. Penetration of water into the stone with alternate freezing and thawing is considered to be the most important process at work.

The principal dimension stone is Kyune Sandstone, an informal name for several sandstones in the Colton and North Horn Formations (Upper Cretaceous-Paleocene) near Castle Gate and Kyune Junction, Carbon County, Utah. The lithology, bedding, cementation, and porosity of this sandstone is closely related to various weathering effects and characteristics observed.

Built from 1892 to 1894, the building is now undergoing extensive repair and renovation.

INTRODUCTION

Historical Background

Washington Square, named on August 22, 1847, is the site of the City and County Building in Salt Lake City, Utah. Donated to the city in 1887 for use as a public park by the Church of Jesus Christ of Latter-day Saints, the 10-acre plot has hosted semiannual cattle drives, circuses, carnivals, medicine shows, sporting tournaments, baseball games and has also served as a park, haymarket, and skating rink.

From the beginning of the 81-year history of the City and County Building, geology has played a key role. First, foundation conditions had to be considered: the nature of the strata beneath the building, its bearing capacity, and the influence of subsurface water. Then there was the selection of rock types for construction and decoration: sandstone, onyx, slate, granite, and marble. Since construction, earthquakes have shaken the edifice, and some of the building stone has succumbed to the ravaging effects of weathering.

This study concerns the effects of weathering. The Utah Geological and Mineral Survey agreed to study the weathering phenomena of the dimension stone at the request of city and county commissioners, following a joint resolution by them to engage an architect who would guide the remedial work on the building's exterior. The Utah Geological and Mineral Survey's study was coordinated with the overall program of project architect, Burch W. Beall, Jr.

Renovation began in October 1974 and continues to the present (figures 1 and 2). The work is to be accomplished in small increments probably extending over a decade or more; the length of time depends on the amount of money budgeted to the project from year to year by the city and the county. A preliminary cost estimate of the entire project was \$3,173,000 in 1974, with the cost of the first phase, the east entrance, estimated at \$390,000. In July 1975, however, the cost of the east entrance, still not completed, had reached \$337,000, which indicates that inflation and necessary changes in methods and scale of work will increase the total cost considerably over the years. Only 80 years ago the original cost of construction of the City and County Building was \$900,000. This paper is an expanded version of the original report of the investigations conducted by the Utah Geological and Mineral Survey in February 1973 (Kaliser, 1973).

Method of Investigation

The writer, assisted by Sam Quigley, obtained thirteen one-inch (2.5 cm) diameter core samples from the rough hewn sandstone of the building on January 10, 1973. The cores, ranging in

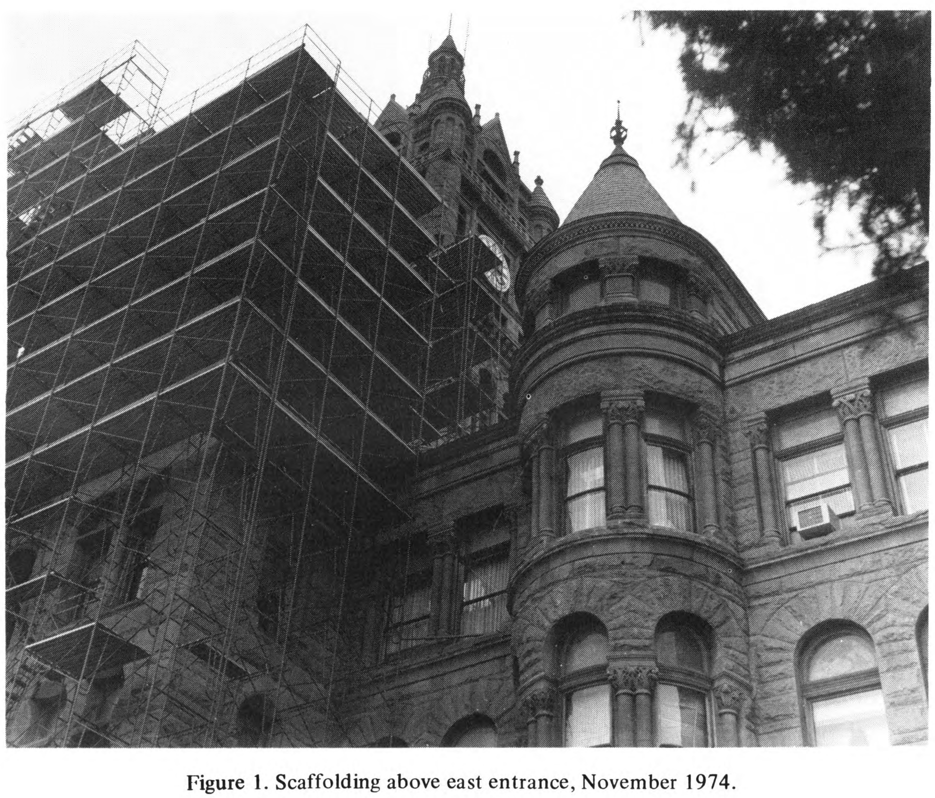

Figure 1. Scaffolding above east entrance, November 1974.

[1] Chief, urban and engineering geology section, Utah Geological and Mineral Survey, Salt Lake City, Utah 84112.

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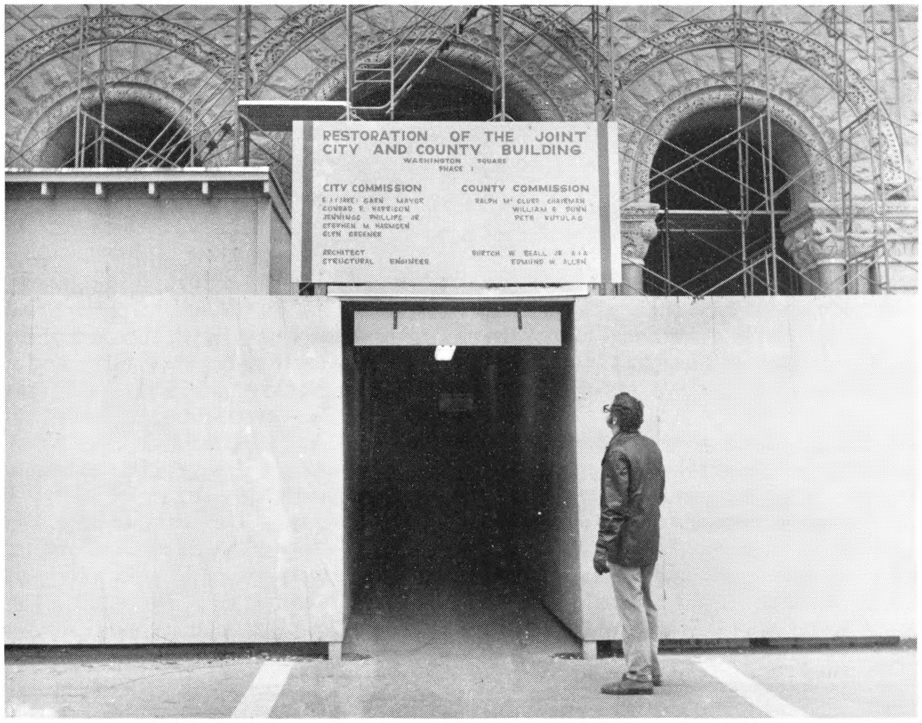


Figure 2. Protective walkway over east entrance, November 1974.

length from 5 to 11 inches (13 to 28 cm), came from locations from the first floor to the tower (see *Observations of Cores and Hand Specimen*). In addition, a hand specimen was extracted from layers that were slaking off the stone facing.

The purpose of cores was to supplement megascopic observation and to make possible the cutting of transverse and longitudinal thin sections for microscopic study of the dimension stone from its weathered outer surface to its interior.

After recording megascopic data from the core, eight cores were submitted to the laboratory for thin-sectioning. All specimens were impregnated with blue-dyed epoxy resin to prevent them from being damaged by cracking and crumbling and to make void spaces between grains of the sandstone appear blue in color for ready quantitative determination. Following the coating with epoxy the cores were sawed in half. The fresh faces of each half were then coated with epoxy and one half was impregnated under vacuum. Grinding and reimpregnation followed until a smooth section of rock 0.03 mm thick could be precisely cut. The thin sections were stained red for dolomite over half the section length and yellow for potassium feldspar over the other half. Finally with a glass cover over the thin section, the specimen was ready for study through the petrographic microscope.

All cores, particularly those where thin sections were not made, were also studied under a binocular microscope. This permitted three-dimensional observation of the rock cores and hand specimen at several magnifications.

LONG TERM WEATHERING EFFECTS

In his speech at the building's dedication rites, the Masonic Grand Master perhaps gave indication of what was to come when he spoke of "the lapse of the ages, the fury of the elements, or the slow but certain ravages of time . . ." (*Salt Lake Herald,* July 26, 1892). But it has not taken ages for the effects of nature to manifest themselves on the sandstone. Maintenance of the structure's sandstone, which shows conspicuous signs of weathering, is possibly the single greatest expenditure in the history of the building. Parapets and balconies have exhibited peeling and gargoyles have disintegrated. Spalling has removed as much as five inches from some stone surfaces. Sharp edges and corners of stone blocks have been rounded off through chemical and temperature changes that penetrate the rock more deeply where exposed surfaces are irregular.

Concern for the rate of weathering of the City and County Building was expressed as early as the 1920's (Gillett, 1971). The first estimate for restoring and waterproofing the building's exterior, published in May 1950, which included dressing down, hardening, and waterproofing of stone surfaces, was $124,500 (Kaliser, 1971).

Chimney capstones and a statue of Columbia atop the tower were removed after the earthquake of March 12, 1934 (*Salt Lake Tribune,* March 13, 1934). Over the years four other copper statues were also removed, mostly because of weathering of the supporting stonework. Replicas of five statues are to be returned to their former positions as part of the current renovation. The first was lifted to the top of the building on August 26, 1975 (*Salt Lake Tribune,* August 27, 1975).

In a letter prepared for the city, P. K. Evans (1954) recommended emergency repairs to the upper structure. The work, which was completed in 1954, entailed removing chimney caps, heavy stone railing directly below the clock, and railing on the fourth floor at the south end, and waterproofing the masonry at the chimney. Dehydratine sealer was applied to some masonry. The large sill area around the center of the building above the main roof ridge was chipped, sealed off, and treated with mastic, fabric, and cement-colored coating. In addition, the east and west statues, together with supporting masonry, were removed. In 1963 an unsafe stone railing on the third floor, north side, was removed.

In 1965 an estimate to facelift the building placed the cost at about $250,000 (*Deseret News,* June 2, 1965). Another estimate in a joint report by the city engineer and county surveyor in 1968 quoted a figure of $350,000 to $400,000 (*Salt Lake Tribune,* January 15, 1968). These proposals were not acted upon.

The granite stone, which appears in the building as polished columns and cornerstone, shows virtually no effects from weathering (figure 3). Where protected, as in the east and west entrances, even the sandstone is relatively unweathered.

KIND AND SOURCE OF CONSTRUCTION MATERIALS

Several types of stone were used in construction, most of it from Utah (Kaliser, 1971). Most of the sandstone came from the Castle Gate-Kyune Junction area of Carbon County. Figure 4 is a promotional letterhead, prepared by the Kyune Graystone Company, which

Figure 3. Granite cornerstone laid in 1892 shows virtually no effects from weathering.

touts the alleged virtues of the company's stone. Red, highly polished granite from the eastern United States was substituted for sandstone in the last stages of construction for the sixty exterior columns; the cornerstone is a gray Utah granite. The roof of the building was covered with "Utah slate," the likely source of which was Slate Canyon southeast of Provo. In the interior, imported English slate was used for twenty-two urinals, and Italian marble was used for the drinking fountains. Utah onyx, more properly called onyx marble, was used extensively for wainscotting the hallways.

As previously mentioned, the stone that has caused the principal problem in the building is the sandstone. It was selected for its even gray color. Most appears to have been quarried from the Colton Formation, but some must have come from the North Horn Formation, because mention was made that "coal seams were rejected" (*Salt Lake Times,* July 24, 1892). Tests performed on the stone at Illinois State University before 1891 indicate that it cracked "under a ten minute pressure of 16,000 pounds per square inch and broke under the same of 20,800 pounds" (Manly and Litteral, 1891-1892, p. 21).

In choosing the principal stone for the building, Kyune Sandstone was also favored over stone available from Park City because it was considered easier to carve (Culmer, 1891-1892, p. 27). In all likelihood this attribute meant that it was also the softer of the two and, therefore, the most susceptible to weathering.

Kyune Sandstone

Kyune Sandstone, an informal name, is an arkosic sandstone consisting of an assortment of minerals. About one-half of the grains are quartz; next in abundance are carbonate minerals, both calcite and dolomite, and a slightly lesser amount of various feldspar minerals. Several percent of the grains are lithic fragments and clay; the clay possibly results from decomposition of the lithic fragments, which are pellets and angular fragments of shale and mudstone. Biotite is the most abundant dark mineral, but a suite of ferromagnesian minerals and accessory minerals occurs both dispersed throughout the rock and concentrated along bedding planes.

Grains are in contact with one another at several points because of their irregular and angular to subangular shape. The sandstone is quite compact, but cement does not actually bind all individual particles together. Void spaces between grains, where matrix or cement was either never deposited or was removed subsequent to deposition, account for one or two percent of the total volume of the rock. Porosity of the rock is not evenly distributed.

Bedding of Kyune Sandstone

Kyune Sandstone, being a compact rock of uniform grain, gives little outward indication of its bedding from visual examination. Possibly for this reason, blocks of the sandstone were laid in all three possible orientations in construction of the City and County Building: (1) laid on its natural bed with stratification horizontal; (2) "edge" bedded with the laminations vertical and perpendicular to the face; (3) "face" bedded with the laminations vertical and parallel to the face of the wall (therefore, not exposed). Since laminae tend to separate when the stone is exposed to weather, the most desirable position is the first. Both "edge" bedding and "face" bedding produce undesirable weathering effects, particularly "face" bedding, which has proved especially susceptible to damage by spalling where the stone is rough hewn.

Kyune Sandstone also exhibits cross bedding, which is lamination inclined to the normal plane of stratification. Observation indicates that often cross-bedded sandstone blocks show added effects of weathering.

OFFICE OF

The Kyune Graystone Company,

70 CULMER BLOCK.

G. F. CULMER, PRESIDENT,
[redacted]
H. L. A. CULMER, SECRETARY & TREASURER.

DETROIT, MICH., Dec. 9th, 1892.

MR. W. H. JENNINGS,
Superintendent of the Kyune Gray Stone Co.
Salt Lake City, Utah.

DEAR SIR:

A sample of the Kyune Stone was sent me by a friend in your city. The stone is of a very desirable color, and is capable of resisting atmospheric agencies. It gave in the test to me the idea that when it was first quarried it must be soft; after a long exposure I found that it became very hard. The density of its character, and being of a very fine grain, I found it could be ***Easily Worked*** and susceptible of being ***Finely Carved;*** after I had exposed the stone to the weather, I found it becomes ***Very Hard,*** and becomes more expensive to work. In my opinion the stone is ***Fully Equal*** to the best quality of Ohio Amherst Buff Stone, which is regarded as one of the best building stones in the country. In my test I thoroughly soaked the stone in boiling hot water and let the stone absorb all the water it could, then I exposed the sample to the weather, when the Thermometer was 20 degrees below zero, the result was ***the stone stood this severe test;*** I then tested the stone by placing it in the furnace under the boilers, the fire only darkened the stone, ***it stood the test most remarkably.*** I then had the surface redressed, which showed conclusively that the heat had but a very trifling effect on the stone.

The stone is about ***96 per cent. pure Silica*** and contains but a very small item of iron, and small trace of Lime, Magnesia and moisture. The stone from its denseness absorbs a very small quantity of water. The difference of comparison between color of the stone, after I had exposed it to atmospheric influence, was that it has a characteristic bluish gray tint, and showed in no respect any sign of deterioration. The stone contains so small a quantity of iron which is an evidence to me, that when it is dressed and put in position in a building and exposed to the weather for a long time that no trace of the effect of iron stains would appear. ***I regard the Kyune Stone to be of a very superior quality; and in every respect suitable for building purposes.*** The result of my test convinced me that exposure to the weather increased the ***beauty*** of the ***color*** of the ***material.*** It is certainly a material that will ***resist*** very successfully the effect of ***fire*** and the ***elements. I made the tests of the stone in anticipation of recommending it to be used in the construction of your Capitol Building.*** Your quarry certainly is more extensive than those in Ohio, being so easily quarried and capable of supplying blocks even of unusual size, is certainly remarkable. I am, Yours very truly,

E. E. MYERS.

Mr. E. E. Myers is the Architect of
THE MICHIGAN CAPITOL BUILDING,
THE TEXAS CAPITOL BUILDING,
THE IDAHO CAPITOL BUILDING,
THE COLORADO CAPITOL BUILDING,
AND THE UTAH CAPITOL BUILDING.

Salt Lake City, Utah, March 20/94

Joint City and County Bldg Com.
Salt Lake

Gentlemen,

We beg to acknowledge receipt of your order of March 13th for 12 Cars of "Kyune" Saw. Blocks, which will receive our careful attention.

Weather permitting, we will commence operations at our quarry on Friday, March 23rd, and will execute your order before everything else making our first shipment early next week.

Thanking you for the order, we are,

Respectfully Yours,
Kyune Graystone Co.
J. Boehmer
Ass't. Supt.

Figure 4. Testimonial on letterhead of company that furnished the principal building stone.

EXFOLIATION AND GENERAL WEATHERING

Exfoliation is defined as "the breaking- or peeling-off of scales, lamellae, as concentric sheets from bare rock surfaces, by the action of either physical or chemical forces" (American Geological Institute, 1957). From all observations it is clear that exfoliation is the most obvious and damaging problem to be contended with at the City and County Building. The principal process of exfoliation at work here is physical, the result of freezing that causes a ten percent expansion of water in pore spaces and incipient fractures of the rock. Fluctuations of temperature about the freezing point of water are considerably more damaging than continuous sub-freezing temperatures. Such diurnal freeze-thaw cycles are common in Salt Lake City's meteorological environment. It is the conclusion of this investigation that alternate freezing and thawing is the single most important factor in the weathering and exfoliation of the stone.

A small amount of exfoliation is due to "face" bedding (figures 5 and 6). Most exfoliation planes or surfaces are parallel to the exposed surface of the stone face as illustrated by weathering of cylindrical columns (figures 7 and 8). Close examination reveals flaking that is independent of the orientation of bedding.

In a sandstone, resistance to weathering is often determined by the chemical stability and cementing properties of the material forming the cement (matrix). When the interstitial cement is a mixture of materials, chemical weathering may be complicated. Kyune Sandstone is cemented with both clay and calcite, neither of which is very satisfactory. Clay has no real cementing properties because it softens on wetting with water. Calcite is readily soluble in mild acids and thus reacts with moisture in the air that may contain sulfur in solution. The cement or matrix in the Kyune Sandstone generally is distributed in irregular fashion, a factor which leads to irregular patterns of weathering (figure 9). Careful observation under the petrographic microscope has failed to reveal evidence of chemical alteration of either primary grains or matrix material. It had been suggested earlier (Kaliser, 1971, p. 9) that the acid character of the atmosphere might contribute to the deterioration of the Kyune Sandstone, but the process of sulfatization does not appear to be important in this instance (figure 10).

Figure 5. Bedding is essentially vertical in this block. Because stone is corner block, it has been "face" bedded (bedding parallel to one face of the wall) with respect to wall perpendicular to photo surface. Note vertical cracks well behind right face of stone: these cracks are along original bedding surfaces. Net weathering effect is same as exfoliation.

Porosity differences closely associated with erratic cementation also produce notable weathering effects. Selective patterns of weathering and pockmarking are shown in figures 11 and 12.

Weathering may also be associated with faulty craftsmanship; defects in the

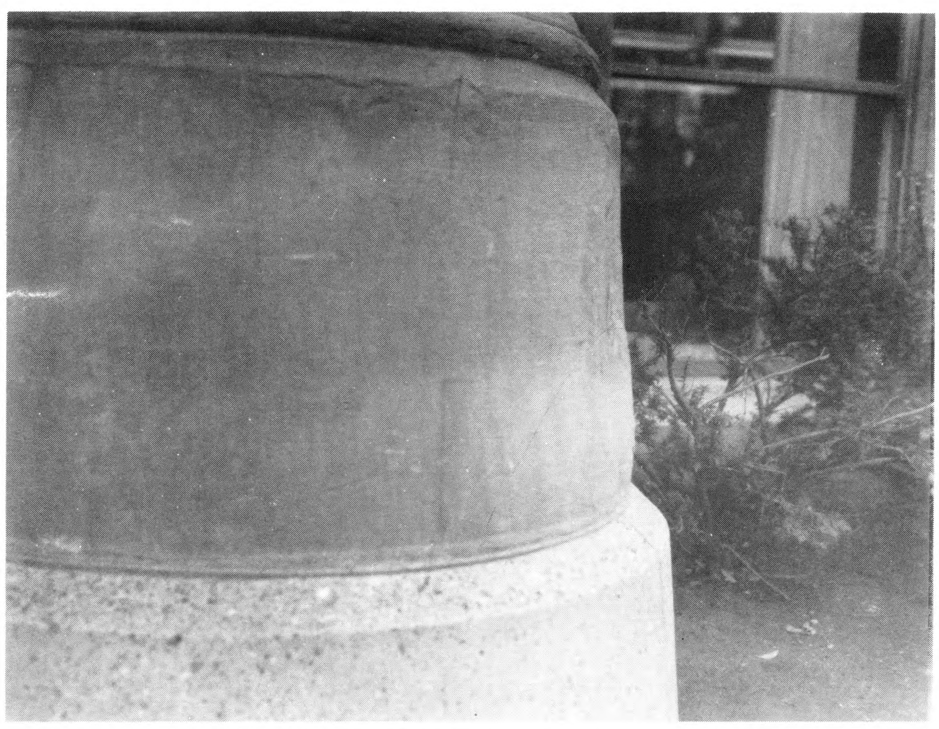


Figure 6. Almost vertical bedding has truncated pillar on the right. Concrete over base of pillar has afforded protection to base.

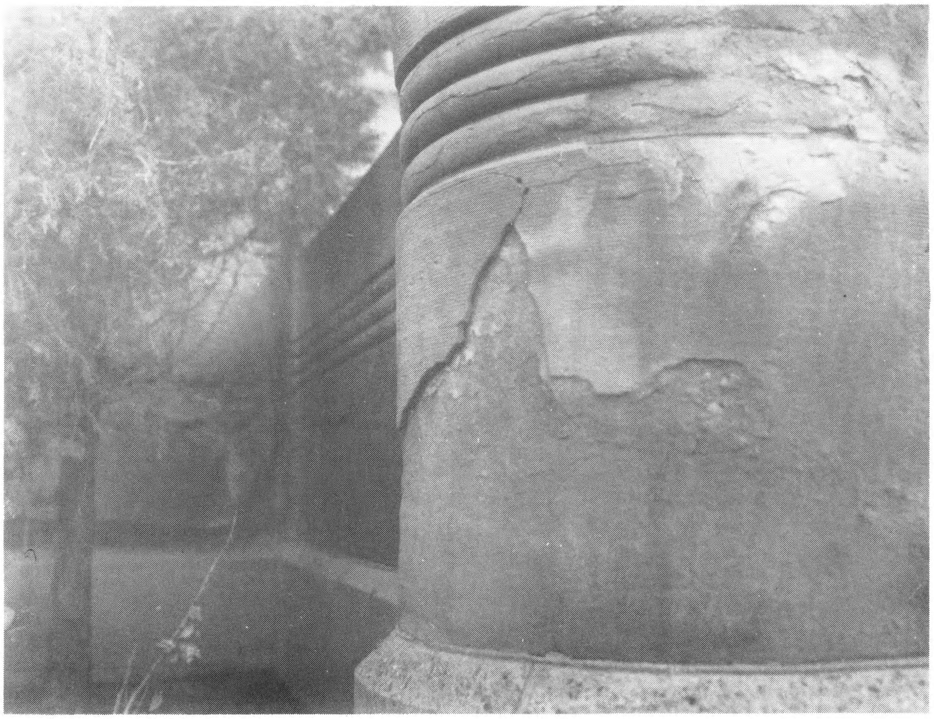


Figure 7. Exfoliation of pillar illustrates how exfoliation surface rather precisely parallels exposed face of original stone. Note that tool marks are still preserved on outer surface of exfoliated layer.

Figure 8. Exfoliation of stone block illustrates how exfoliation cracks very closely approximate original surface of rough-hewn stone. Block in focus is about to exfoliate; original concave surface is still intact.

stone may occur from lack of skill in manipulation in the quarry and in handling. With the acceleration of production required to meet the immediate demand of the city and county in 1892, it is likely that some less skilled individuals were employed to help meet the quota of the quarry. In quarrying operations heavy charges of powder used in blasting may have induced minute cracks in the stone that provide an entrance for moisture and thereby accelerate the rate of decay. Some methods of dressing may also "bruise" the stone, which tends to decrease its resistance to weathering.

Random distribution of micaceous minerals, biotite in particular, makes a dressed surface slightly more friable, but this does not appear to be a serious factor in the weathering of the Kyune Sandstone. Use of cross- or current-bedded sandstone for moldings, carvings, or turned work appears to have contributed to some of the damage in those affected areas.

Sandstone at or just above the ground line has experienced the worst recession of its face; this probably is due to absorption and upward soaking of sodium chloride solution from winter dispersal of salt for melting snow and ice. Crystallization of the salt with disruption of the weakened stone could then cause accelerated weathering in subsequent dry periods. Splashing of rain or dripping melt water could also account for some of the severe recession of sandstone faces close to the ground line.

Depth of Weathering

The cores and longitudinal continuous thin-sections permitted the writer to determine to what extent individual effects of weathering were penetrating the stone. Thin sections were valuable in revealing cracks, exfoliation planes, and incipient exfoliation planes (figures 13a, 13b, and 13c) besides the mineralogy. Some cracks were visible with the unaided eye and some with a binocular microscope; others may be seen only in thin section with a petrographic microscope.

Cores were taken on each side of the ground floor of the building. Cracks penetrating as deep as 1.6 inches (40 mm) were found. The greatest penetration was from a sample on the west side of the building; a result consistent with local wind direction data. Winds during periods of precipitation would increase the penetration of water into the stone.

Two pairs of samples were taken for comparison at the ground floor level. The location of cores 1 and 2 were picked by contrasting the appearance of stone blocks in proximity to one another (figures 14 and 15). The stone with the least weathered appearance (core 1) was found to be devoid of cracks; the weathered stone block (core 2) was found to have cracks (incipient exfoliation planes) to a depth of more than 0.2 inch (5 mm). Cores 3 and 4 were taken from the same block on the south side of the building but from different areas of exposure. The eastward facing exposure of the block from which core 3 was taken is slightly protected in a window well; core 4 was taken from the south-facing part of the block. Core 4 has crack penetration to 0.4 inch (9.5+ mm); core 3 has crack penetration to only 0.3 inch (8 mm). With a far greater frequency of winds from the south this result is not unexpected.

Also, as would be expected, handrails fare very poorly because of penetration of moisture from all sides of up to 3.1 inches (78+ mm). Cracks in handrails intersect one another because of the 360 degree circumferential exposure that aggravates the weathering condition.

Table 1 summarizes penetration of cracks and direction of exposure of the face in each of the samples.

There appears to be a rough correlation with wind directions, particularly to westerly exposures against which rain is most usually driven by storms. However, caution should be used in making generalizations based on the very

Table 1. Summary of penetration of cracks related to direction of exposed stone faces.

Core number	Direction stone faces	Depth of penetration of cracks in stone block (in millimeters)
1	east	none
2	east	5+
3	east	8
4	south	9.5+
5	west	40
6	west	4
7	west	15+
8	south	40
9	east	78+
10	south	none
11	north	14.5
12	west	25+
13	north	7+

limited number of samples taken in this study.

OBSERVATIONS OF CORES AND HAND SPECIMEN

Core 1:

Location–ground floor, east side, southeast corner of wall. (Note: good rock face on stone block; compare with core 2.)

Length–8.7 inches (22 cm); complete core recovery, in two pieces, broken 6.1 inches (16 cm) from outside edge; taken from relatively unweathered stone; no visible cracks.

Thin section observation: greater than average porosity in outer 7 mm; bedding barely visible (78 degree angle with face of stone blocks); no cracks.

Core 2:

Location–ground floor, east side, southeast corner of wall. (Note: poor rock face on stone block; compare with core 1.)

Length–8.15 inches (20 cm); 2+ inches (5+ cm) lost from outside; taken from deeply weathered block; spalled chips collected from core vicinity; bedding planes (62 degree angle with face of stone block); concentrations of dark minerals along apparent bedding.

Thin section observation: bedding barely discernible (about 66 degree angle with face of stone block); greater porosity between 3 to 4 cm; no cracks.

Core 3:

Location–ground floor, south side, southwest corner; window well, facing east. (Note: core orientation is perpendicular to core 4.)

Length–8.5 inches (22 cm); tool marks remain on outside edge of core; complete core recovery, in two pieces; broken 2.4 inches (6 cm) from outside edge.

Thin section observation: no bedding visible, cracks in outside 8 mm, but outside 6 mm is devoid of cracks.

Core 4:

Location–ground floor, south side, southwest corner; window divider, facing south. (Note: core orientation is perpendicular to core 3.)

Length–8.4 inches (22 cm); some loss from outside; recovered in two pieces; broken 5.3 inches (14 cm) from outside edge; cracks visible parallel to weathered face of stone block.

Thin section observation: no bedding visible, increased porosity at 3.5 cm;

Figure 9. Irregular pattern of weathering developed in pillar.

cracks visible at 2.4 mm, 4.7 mm, 5.8 mm, 8.0 mm, and 9.5 mm from outer edge of thin section.

Core 5:

Location–ground floor, west side, southwest corner of wall.

Length–5.0 inches (13 cm); about 5.0 inches (13 cm) remains in borehole; complete recovery, in five pieces; broken at 0.35 inch (9 mm), 0.55 inch (1.4 cm), 0.85 inch (2.1 cm) and 1.45 inches (3.7 cm) from outside edge; parallel cracks in outer 1.5 inches (3.8 cm).

Thin section observation: no bedding obvious (only very slight indication that bedding may be perpendicular to face of stone block); open cracks at 9 mm, 16 mm, 24.5 mm, and 40 mm from outside edge.

Core 6:

Location–ground floor, west side, base of column.

Length–7.5 inches (19 cm); complete recovery, in three pieces; broken at 3.3 inches (8.4 cm) and 5.2 inches (13.2 cm) from outside edge; latter break makes 70 degree angle with core orientation; crack visible 4 mm from outside edge (verified with binocular microscope).

Core 7:

Location–fourth floor, north side, west facing stone on the balcony. (Note: drilled completely through the stone block.)

Length–6.0 inches (15.3 cm); about 0.25 inch (7 mm) lost from outside; penetrated brick at core terminus; bedding planes have concentrations of dark minerals (63 degree angle with face of stone block); cracks as noted under microscope were either poorly visible or not visible.

Thin section observation: bedding intersects face of block with 75 degree angle; greater porosity at 2.5 cm from outside edge; numerous cracks in outer 9 mm of thin section, at 1.2 mm, 2.2 mm, 3.1 mm, 4.5 mm, 5.5 mm, 6.5 mm, and 9.0 mm from outside edge of thin section.

Core 8:

Location–fourth floor, south side, top of balcony handrail. (Note: drilled completely through the handrail.)

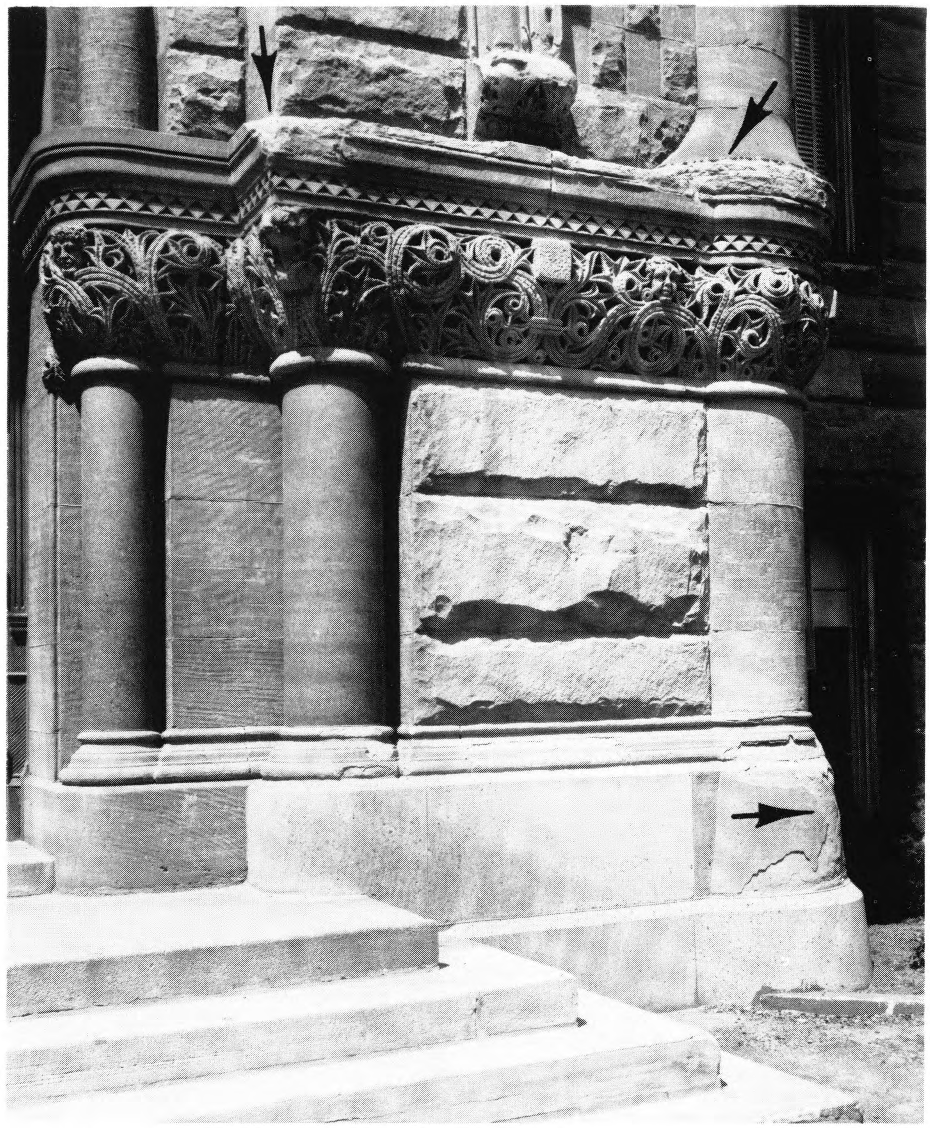


Figure 10. Arrows point to weathered sandstone on cornice and beneath pillar at west entrance of building. Intricate basketwork carving in Kyune Sandstone has survived with little weathering in this semiprotected situation.

Length–11.4 inches (29 cm) about 1 inch (2.5 cm) lost from outside; four pieces, broken at 4.9 inches (12.5 cm), 7.4 inches (18.8 cm), and 9.3 inches (23.6 cm) from beginning of core (inside edge of handrail); fracture surfaces are at 75 degree and 78 degree angles from core orientation; cracks observed at 7 mm and 14 mm under binocular microscope.

Core 9:

Location–third floor, east side, top of balcony handrail. (Note: drilled completely through the handrail.)

Length–8.1 inches (21 cm); about 1+ inch (2.5+ cm) lost from outside; four pieces, broken at 3.2 inches (8.2 cm), 5.4 inches (13.7 cm) and 7.7 inches (19.5 cm) from beginning of core (inside edge of handrail). Cracks visible up to 2 inches (5 cm) from edge of inside of handrail and up to 1.5 inches (4 cm) from outside of handrail.

Thin section observation: numerous cracks to 5.2 cm, from inside edge of thin section (total length of thin section is 17.7 cm); only very slight indication of bedding discernible perpendicular to face of stone block.

Core 10:

Location–tower balcony, south side.

Length–5.7 inches (14.5 cm); complete recovery; tool marks remain on outside edge of core. No cracks visible, megascopically or under binocular microscope.

Figure 11. Difference of porosity is exerting strong influence on selective weathering of part of stone. Differential porosity is a factor in the weathering process, but normally it is not as easily recognized as in this example.

Core 11:
Location–tower balcony, north side.

Length–7.3 inches (18.6 cm); complete recovery; cracks in outer 0.5 inch (1.3 cm) of core parallel to face of stone block and one crack of 0.45 inch (1.2 cm) long parallel to the core; bedding very slightly discernible, about 85 degree angle with face of stone blocks (perhaps controlling crack paralleling length of core).

Figure 12. Differential porosity has pockmarked this stone.

Thin section observation: cracks visible at 1.2 mm, 1.32 cm, and 1.45 cm from outer edge of thin section; no bedding obvious.

Core 12:
Location–tower balcony, west side.

Length–7.1 inches (18 cm); some lost; three pieces, broken at 0.4 inch (1 cm) and 3.7 inches (9.4 cm) from outside edge of core; cracks in outermost 1 inch (2.5 cm).

Binocular microscope observation: cracks observed at 0.7 cm, 0.9 cm, 1.2 cm, 1.8 cm, and 2.5 cm from outer edge of core.

Core 13:
Location–ground floor, north side, northeast corner.

Length–8.8 inches (22.3 cm); about 0.25 inch (7 mm) lost; bedding at 68 degree angle with face of stone block (towards the face); dark mineral concentrations along the bedding; one crack along the bedding in the outer 0.3 inch (8 mm).

Binocular microscope observation: one crack observed at 1 mm from outer edge of core.

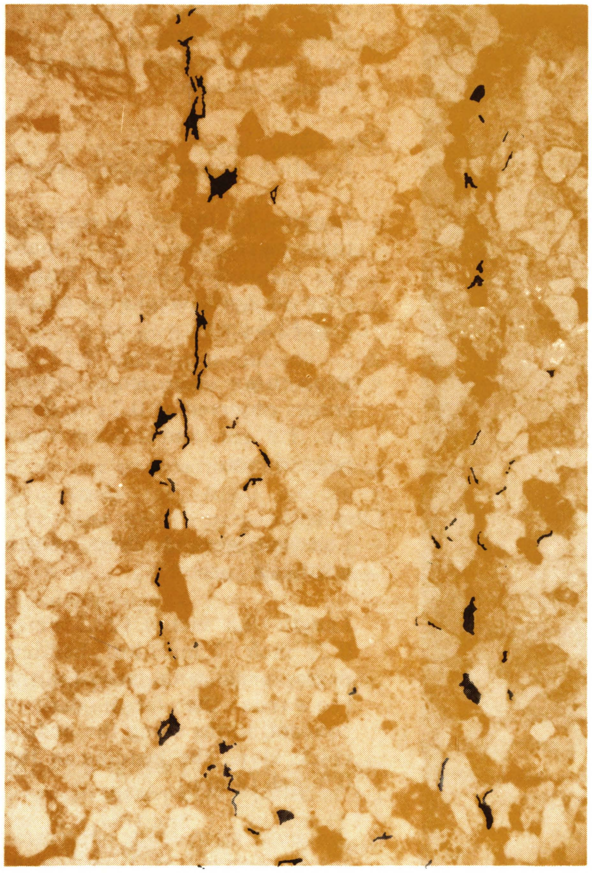
Hand specimen:
Location–ground floor, west side, step-rail pillar form.

Exfoliated layer–10 to 14 mm wide; tool marks almost perfectly preserved on outside; concentration of cracks from 5 mm to 9 mm from outside edge clearly paralleling the curved outer pillar surface in greater portion of hand specimen; specimen is bounded in interior by exfoliation surface.

Thin section observation: 11 mm to 13 mm wide; parallel edges; no cracks visible (verified in hand specimen in area where thin section was taken).

CONCLUSIONS

The deterioration of the Kyune Sandstone of the City and County Building is believed to be caused by physical rather than chemical factors. All evidence points to creation of exfoliation surfaces by penetration of water and its repeated freezing and thawing. Weathering started soon after completion of the building (Stewart, 1908) and has become progressively worse since. The depth of penetration by incipient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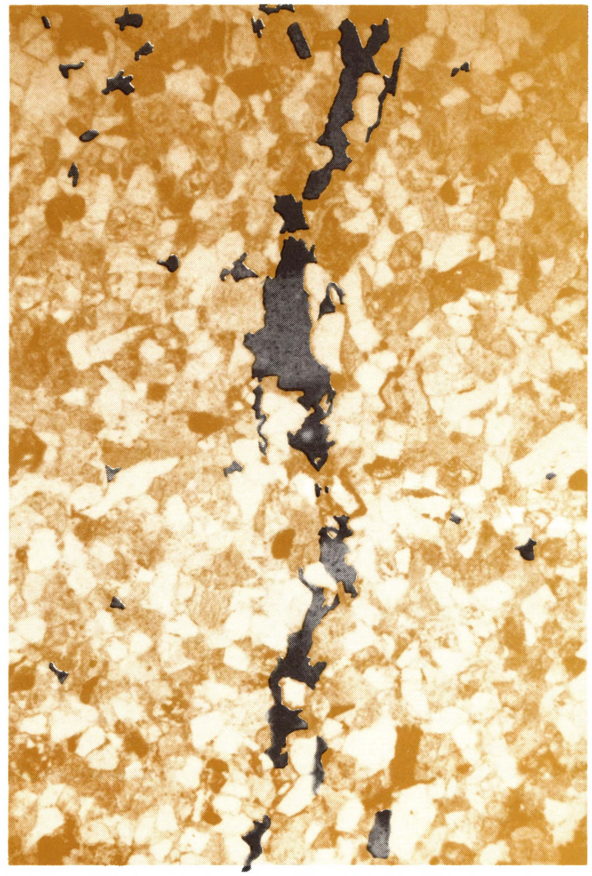
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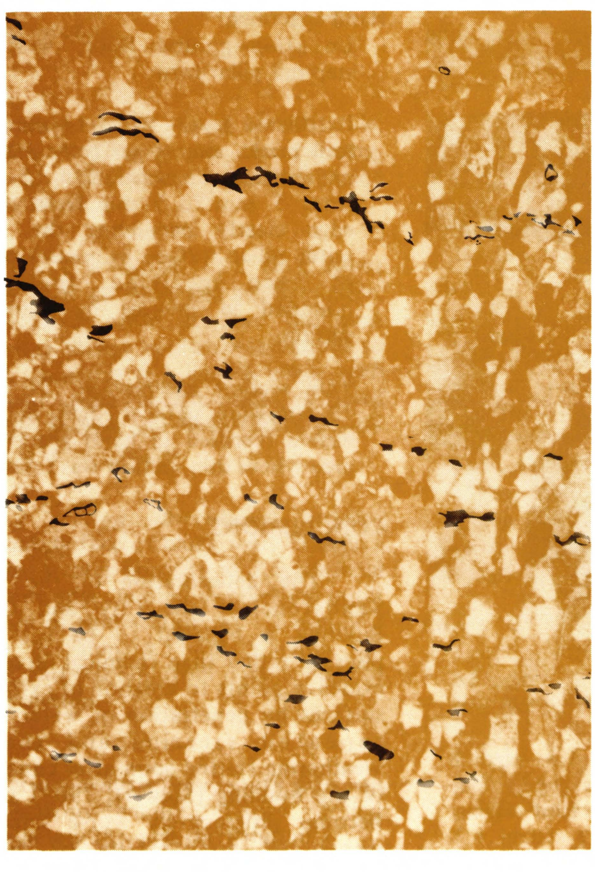
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Figure 13. (a) Parallel, incipient exfoliation planes in thin section from core 4, 4.7 mm and 5.8 mm from outside edge (to the right). (b) Exfoliation crack in thin section in core 9, 4.2 cm from outside edge (to the right). (c) Long dimension of photo parallels bedding in thin section from core 7. Numerous incipient exfoliation planes at about 75 degree angle to bedding. Top of photo is 6 mm below outside edge of thin section.

Figure 14. Bore holes 1 and 2 are shown. Note exfoliation cracks of thin layer bounding blocks on the right (tool marks remain).

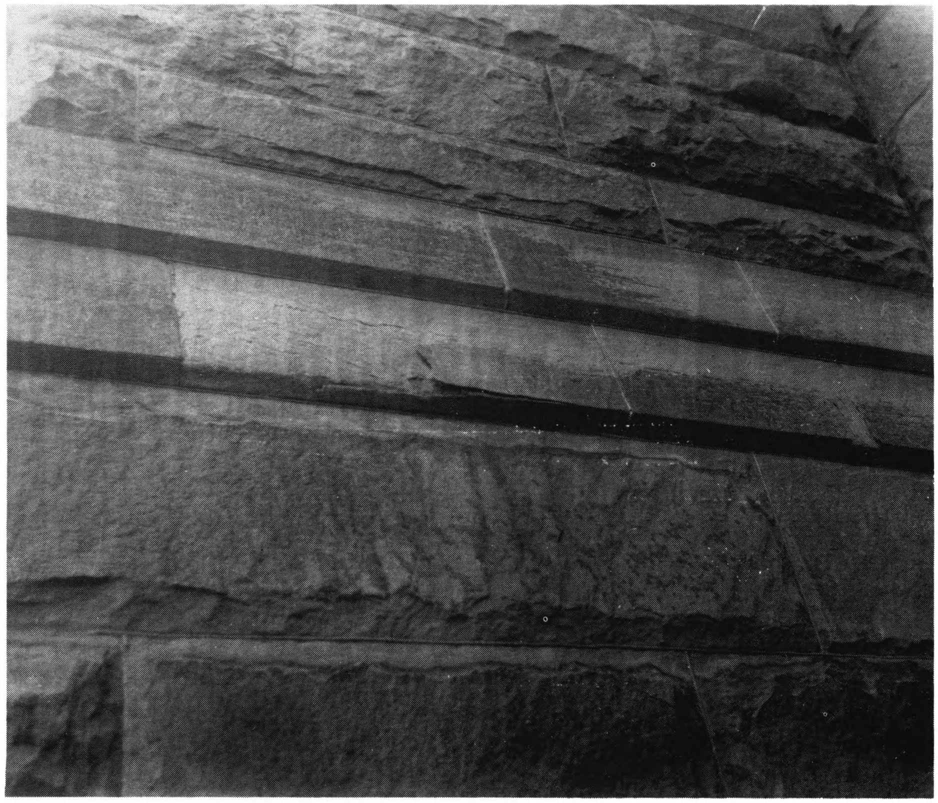

Figure 15. Exfoliated layer of face (center of photograph) is flat since exfoliation plane parallels face of stone.

exfoliation planes is normally less than one inch (2.5 cm) and commonly about 0.3 inch (8 mm). Individual blocks, however, may be expected to exhibit penetration that will vary considerably.

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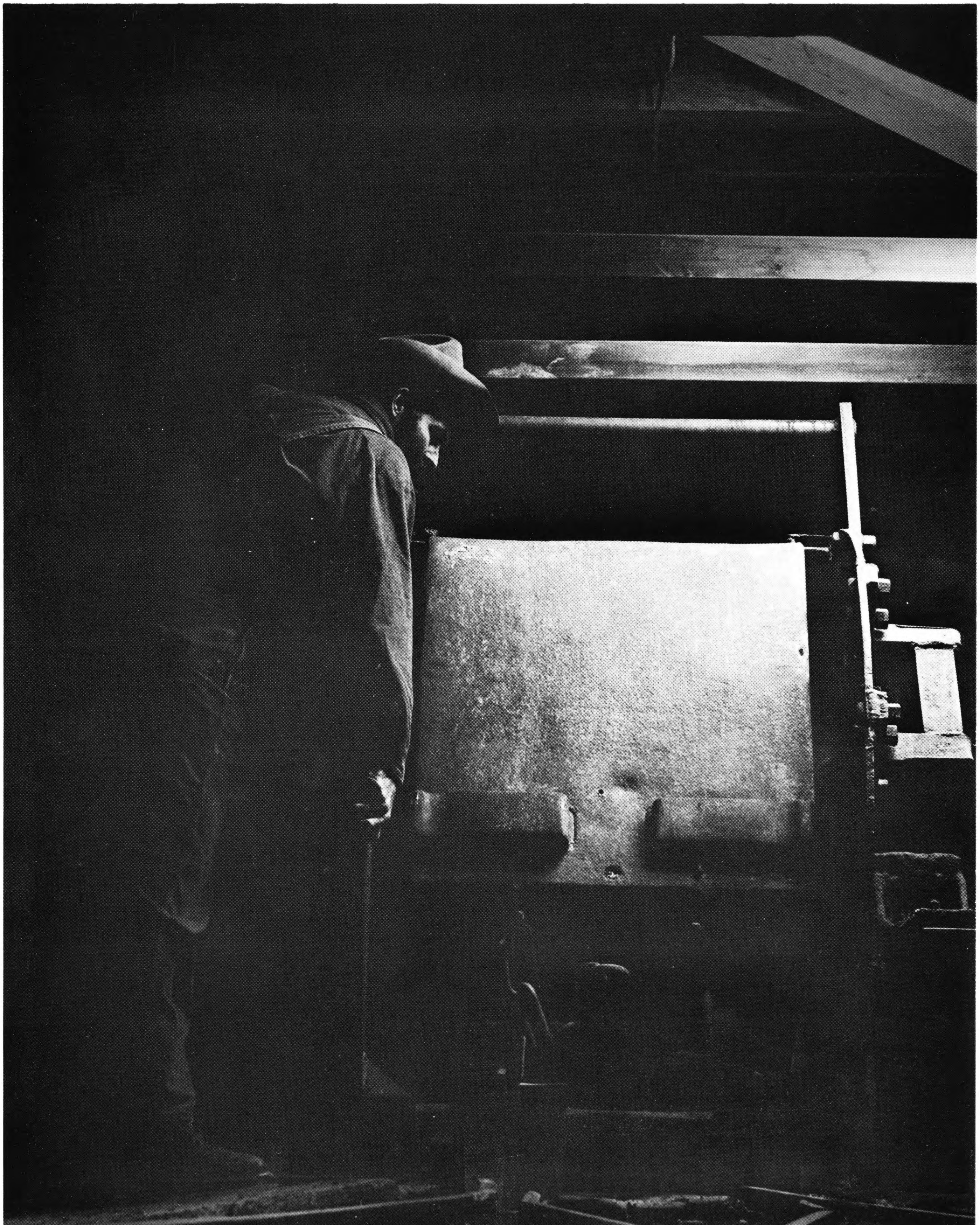

AMATRICE HILL VARISCITE DEPOSIT, TOOELE COUNTY, UTAH

by Hellmut H. Doelling[1]

ABSTRACT

Variscite ($AlPO_4 \cdot 2H_2O$) is found in Utah in three principal deposits: Clay Canyon, Lucin, and Amatrice Hill. Amatrice Hill, on the east flank of the Stansbury Mountains near Stockton, is the most recently found deposit and the only one mined at present. The mineral occurs as nodules in faulted and brecciated limestones of the Pennsylvanian-Permian Oquirrh Formation.

Variscite resembles turquoise in color and is used similarly in jewelry. It is softer, however, and generally not as durable. Larger pieces are used for decorative stone. Three principal types based on pattern and color are recognized: jade, apple blossom, and cobweb. A blue color variant has been called variquoise.

INTRODUCTION

Utah's variscite deposits and the rare phosphatic minerals that accompany the gemstone are well known and adequately discussed in scientific literature and in various "rockhound" and lapidary journals. Interest in these deposits is rekindled from time to time, especially when a volume of new material is found. In 1972 a new cluster of variscite nodules was found on the Amatrice Hill deposit through the work of Dale James, Claude Atkin, and Irvin Jones, all of Tooele, Utah. The writer is indebted to them for providing exemplary specimens, for description, and for allowing full access to the property and workings. They presently own the property under the name of Three Queens Gem Corporation. This paper describes the Amatrice Hill variscite so that the reader may compare it mineralogically with Utah's world famous deposit in Clay Canyon, in Utah County.

SYNOPSIS AND HISTORY OF UTAH'S VARISCITE DEPOSITS

Of Utah's several variscite deposits, three are considered the most important: Clay Canyon, Lucin, and Amatrice Hill. In 1893 variscite was discovered in Utah in an altered zone along a fault on the north slopes of Clay Canyon about five miles west of Fairfield, Utah County. The deposit was claimed as a gold mine by Frank Butt and his brother. They evidently gave one of the nodules with the green mineral to F. T. Millis of Lehi, Utah, who shipped the specimen to George P. Merrill, then curator for the U. S. National Museum (Smithsonian Institution). Packard (1894) reported on Merrill's findings and stated that the variscite occurred as "nuggets" in a quartz vein. He described the occurrence of the variscite and listed the deposit as the second discovered in the country. The first may have been that found in 1877 in Montgomery County, Arkansas.

In the first few years the deposit at Clay Canyon changed hands several times. The material proved to contain no gold, and it took some effort to develop a market for the green mineral. Don Maguire took over the mine and attempted to publicize the variscite as a gem material. In 1904, he reported in the *Salt Lake Mining Review* a siliceous vein 12 feet wide and 700 feet long. The nodules ranged in size from walnuts to coconuts. Not many nodules were found at that time; in four years only 200 carats had been produced.

An attempt by Maguire to put variscite on the American market proved unsuccessful; most of the production went to China and a little to Europe. Into the early 1920's the deposit was mined sporadically by Maguire and others as a surface mine until the "easy" material was gone. Much was sold to Ward's Natural Science Establishment in Rochester, New York.

In 1936 the deposit was relocated by Arthur Montgomery and Edward Over who started underground work. They were successful in striking two fresh zones of nodules, the first in 1937 and the second in 1939; the nodules were as much as eight inches in diameter. Montgomery, a geology teacher, saw to it that the nodules were preserved as mineral specimens. He donated many to the Smithsonian Institution and made others available for study of the rare phosphatic minerals found with the variscite.

Esper S. Larsen, Jr., and E. S. Larsen, III, studied the mineralogy in depth and identified several new minerals. Their work appeared in various issues of *American Mineralogist* (see *Selected References*); a partial list of the minerals includes the following: deltaite, dehrnite, englishite, crandallite, variscite, gordonite, lehiite, lewistonite, davidsonite, wardite, millisite, montgomeryite, overite, and sterrettite.

Since 1940 the Clay Canyon deposit has been reworked for ever-diminishing returns. Little is currently found there except for an occasional lucky find. Undoubtedly more pockets may be found in the future but not without some expense. Several tons of material have been mined over the years.

The Lucin deposit lies about five miles north of the Lucin railroad siding in western Box Elder County on a prominence known as Utahlite Hill. The hill rises 350 feet above the desert floor and is mainly an outcrop of the Rex Chert Member of the Permian Park City Formation. The first claim, for gold and copper, was located by C. J. Burke in 1902. He dug a shaft 22 feet deep and, after obtaining negative assays, abandoned it. Green oxide copper mineralization is common in the area, especially to the south in the northern Pilot Range (Copper Mountain). The first variscite claims were located by Frank Edison in 1905, but no work was done until 1909. At that time Edison and Edward Bird, both of Montello, Nevada, began work in earnest. Sterrett (1911) of the U. S. Geological Survey, who has had one of the Clay Canyon phosphatic minerals named after him, visited the property and reported on it. Since then the property has changed hands several times and has been operated intermittently. The present owners are Dwight Bates and Leland Turner of Provo, Utah. It is estimated that total production over the years is in the tens of thousands of pounds valued at between \$50,000 and \$100,000. The variscite-bearing area of Utahlite Hill consists of a mineralized zone 1,000 feet in length and about 50 feet wide. The Permian Rex Chert, the host formation, is highly fractured chert with minor amounts of limestone. Variscite occurs as breccia fillings and replacements of chert nodules. The

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replacements are generally eye-shaped and a darker green than that found in the breccia fillings. Alteration is less pronounced than in the other deposits; other minerals include metavariscite, chalcedony, limonite, and perhaps a little wardite. Since the rock is difficult to mine and shatters easily, most of the recovered pieces of variscite are small. Some of the Lucin variscite is translucent.

Amatrice Hill, on the east flank of the Stansbury Mountains, was the last major variscite deposit to be found. Edward Bird, one of the early Lucin deposit owners, is credited with the discovery in 1905. Partners A. J. Bruno and A. O. Evans obtained control and formed the Occidental Gem Corporation. They marketed the variscite as "amatrice," a trade name meaning American Matrix. In 1908 Occidental reported the production of 45,000 carats of high quality variscite equal to 19.8 pounds avoirdupois. Zalinski (1909) and Sterrett (1909) are credited with first describing the property. As at Clay Canyon, production continued into the 1920's when the market diminished. The deposit was generally idle until 1944 when Dr. A. L. Inglesby, a well-known collector of minerals, acquired half interest and mined a considerable quantity of variscite. After a time he thought the area to be mined out and willed his interest to Ruth Waldo of Salt Lake City, Utah. In 1972 after nearly twenty years of inactivity the property was leased and subsequently purchased by James, Atkin, and Jones of Tooele, Utah, who soon discovered a remarkable find of nodules containing several tons of material. James contacted this writer in September 1972 shortly after the new material was found, and Utah Geological and Mineral Survey Report of Investigation 74 was written (Doelling, 1973). This new material was gathered up and described in this report. Three Queens Gem Corporation has continued to mine the deposit, but only small amounts of additional variscite have been found up to the summer of 1975.

VARISCITE

Variscite has had many names. Breithaupt in Germany first described peganite in 1830 and variscite in 1837. Peganite was later shown to be identical to variscite. The peganite was found at Striegis, near Freiberg, Saxony; the original variscite was found at Messbach, Voigtland, Saxony. The ancient name for Voigtland is Variscia, named for a Germanic tribe that had settled there. In 1865 variscite was rediscovered in a Celtic grave as callainite by DaMour in Lockmariaquer, Brittany. In Pontevedra, Spain, the mineral was called bolivarite. Schaller (1916) called the Lucin mineral "lucinite," which has since been shown to be identical to variscite. Trade names under which variscite has been marketed include chlorutahlite and utahlite of Maguire (1904) and amatrice of Zalinski (1909). Recently blue varieties have been called "variquoise."

Variscite ($AlPO_4 \cdot 2H_2O$) is isostructural with strengite ($FePO_4 \cdot 2H_2O$) and has a dimorphous form called metavariscite. It is an orthorhombic mineral and occurs as crusts, in rounded nodules, and in crystalline aggregates or in veins. The Mohs hardness is 4 to 5 and the specific gravity is 2.5. Variscite is listed as hardness 4 by Dana; some varieties may contain some minor amounts of chert or chalcedony to produce a harder material. In contrast, turquoise ($CuO \cdot 3Al_2O_3 \cdot 2P_2O_5 \cdot 9H_2O$), a related mineral, has a hardness of 5 to 6 and a specific gravity ranging from 2.6 to 2.83. As a gem material, variscite is not as durable as turquoise.

The color of variscite is mostly a shade of green, although pure variscite is supposed to be white. Some of the green coloration is attributed to minute quantities of chromium. Most color descriptions include dark green, apple green, blue green, light green, and yellow green. Many shades of variscite can be found in a single mineral specimen.

Variscite has been found or reported in other places in Utah: the Empire mine in the Lucin district, Promontory Point in Promontory district, and Utahlite Hill near Snowville–all in Box Elder County; the Golden Gate, Mercur, and Sparrowhawk mines in the Mercur district of Tooele County. In Washington County, a material similar to the Lucin variscite, which occurs as breccia fillings in white or light gray chert, is found 15 miles from St. George. Outside the state in Esmeralda County, Nevada, variscite is found in several locations in altered rhyolite, cherty limestone, and sandy shale, where the rock is faulted and brecciated. In Arizona, variscite is found in small scattered locations.

LOCATION AND GEOGRAPHY

Amatrice Hill is a small knoll located on the east side of the Stansbury Mountains about eight or nine miles east of Stockton, Utah, and nine or ten miles south of Grantsville (figure 1). The knoll,

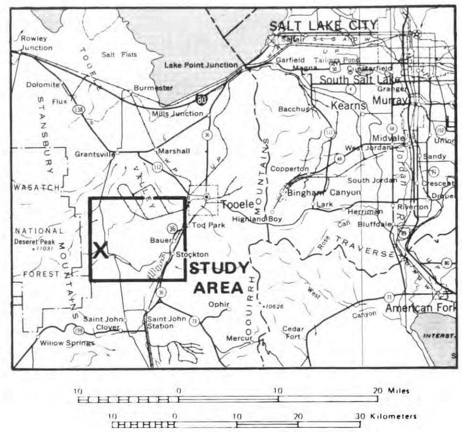

Figure 1. Location map for area of study.

in sec. 22, T. 4 S., R. 6 W., Tooele County, is surrounded by dry farms producing wheat. Amatrice Hill is approximately 1,500 feet long in a north-south direction and 1,100 feet wide with a maximum elevation of 5,934 feet. The hill rises almost 200 feet from a base elevation of 5,750 feet; it is rounded with no particularly steep walls on any side.

Access is provided by a dirt road extending southeasterly from the Grantsville-St. Johns road. A road has been cut completely around the knoll as a sort of "loop road"; all the principal workings can be reached along it. The access road connects with the "loop road" at the northwest part of the knoll (figures 2, 3, and 4).

GEOLOGY AND STRUCTURE

The entirety of Amatrice Hill is labeled as Oquirrh Formation on the available geologic map of the area (figure 2). Several hundred feet of the formation is exposed. The strike of the beds is generally north ranging from N. 20° W. to N. 15° E. The dips are moderate to steep, 15° to 80° west, mostly 45° to 75° west. The hill is completely surrounded by fanglomerate and soil. The rocks of the Stansbury Mountains, which are exposed immediately to the west, are also mapped as Oquirrh Formation. Several additional knolls project through the fanglomerate to the east but expose older rocks of Devonian to Mississippian in age. These older rocks lie at similar attitudes as those on Amatrice Hill. The Oquirrh Formation of the Great Basin is Permo-Pennsylvanian, and the sequence at Amatrice Hill is suspected to be Pennsylvanian in age.

The exposed rock consists mostly of a crystalline cherty limestone. In addition there are a few quartzite and

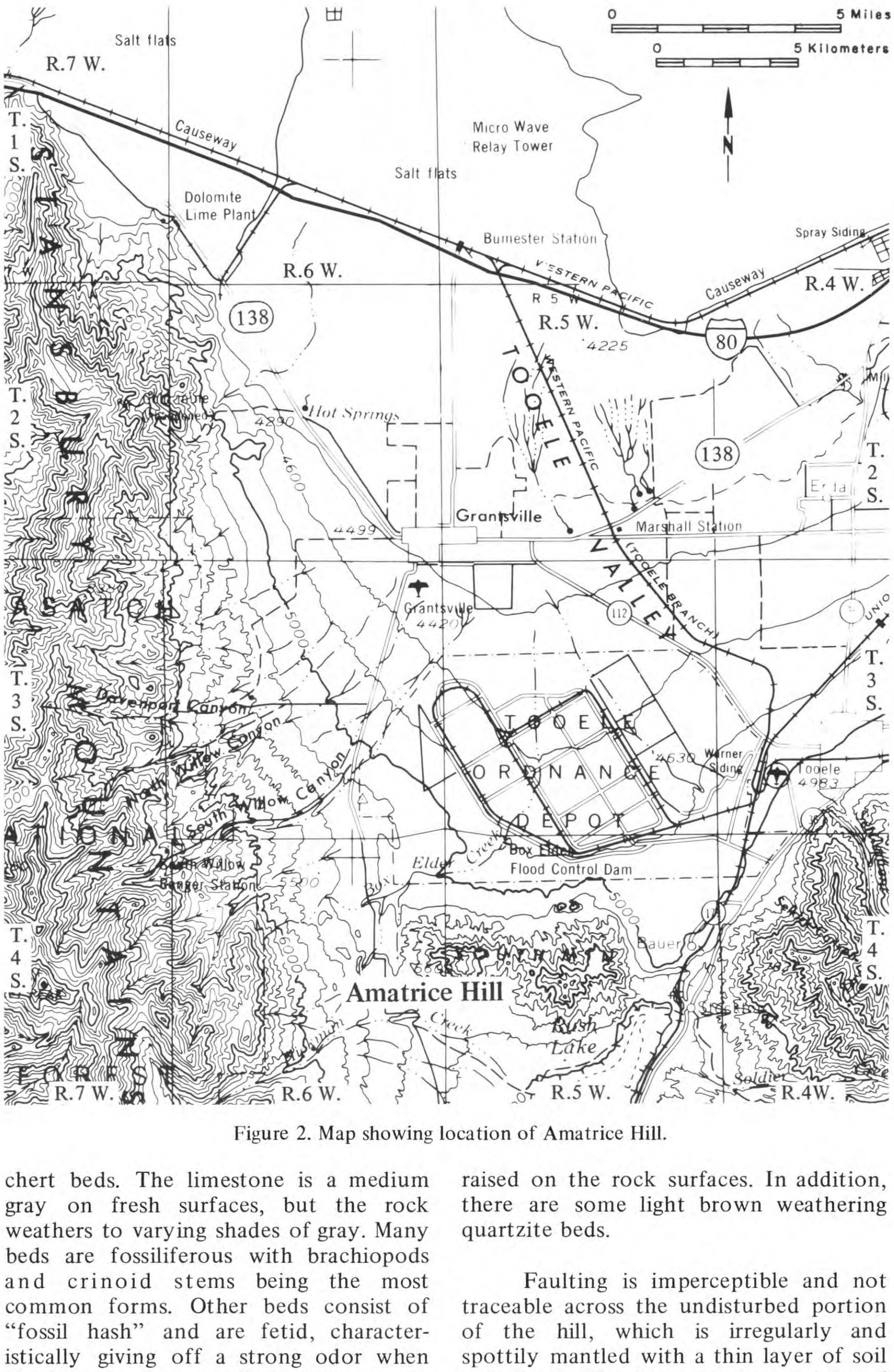

Figure 2. Map showing location of Amatrice Hill.

chert beds. The limestone is a medium gray on fresh surfaces, but the rock weathers to varying shades of gray. Many beds are fossiliferous with brachiopods and crinoid stems being the most common forms. Other beds consist of "fossil hash" and are fetid, characteristically giving off a strong odor when struck with a hammer. These beds may be the source of the phosphate required for variscite formation. Bedding is thin to massive; the thinner units are mostly sandy and weather to shades of yellow and brown. The massive units are most resistant and form slight almost imperceptible ridges or ledges across the smooth rounded hill. Irregular nodules of chert are common in all the limestone beds. Fresh chert is tan, brown, and, in some places, black. Most of the chert is more resistant than the limestone and appears raised on the rock surfaces. In addition, there are some light brown weathering quartzite beds.

Faulting is imperceptible and not traceable across the undisturbed portion of the hill, which is irregularly and spottily mantled with a thin layer of soil and float. The float consists mainly of chips and plates of the thinner bedded, sandy limestone and small broken pieces of nodular chert. The faults are detected only where brecciation has been severe enough to affect the more massive projecting limestones, or where the bulldozer has cut away the surface mantle. At least three faults have been noted, and all are surrounded by altered, brecciated, or mineralized ground, which again is rarely perceptible on undisturbed areas. It is in the fault zones that the variscite is found. The faults strike nearly parallel to the beds and exhibit a slightly steeper westward dip than the beds.

ALTERATION AND MINERALIZATION

At least three altered, mineralized, or brecciated zones have been recognized on Amatrice Hill, and two have contained variscite. To date all the discovered zones are on the southeast end of the hill. In Utah Geological and Mineral Survey Report of Investigation 74 (Doelling, 1973, p. 2), four or five zones were observed. Additional study shows that several of these zones are really part of the same fissure system. At least two of the three zones have produced variscite; all lie parallel to each other. The zones are separated by massive, unaltered cherty limestone.

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The most important fissure zone is the westernmost and will be referred to as the west fissure or west pits (figure 5). The rock is a very cherty (40 to 50 percent chert) gray limestone, thin to medium bedded, crystalline, and it contains some minor thin-bedded chert. The thickest observed chert bed is about one foot and varies in color from light gray to almost black. The fault is outlined with a limonitized and argillitized selvage zone. Colors exhibited in the altered zone include all shades of tan, red, brown, gray, and white. The heaviest alteration includes patches and bodies of conchoidally fracturing clay of almost pure white color. In some places in the west pits subsidiary faults and jointing, which tend to widen the zone about 75 feet, are subparallel and conjugate to the main fault. Of most importance are the chert nodules which have been severely attacked in places by the alteration processes. These chert bodies remain resistant and comprise the ore. Whereas the wall rock of altered limestone is mostly earthy or crumbly, the chert bodies remain intact. Fresh chert, normally dark brown or black, is altered within the zone into various colors of grays, purples, lavenders, browns, yellows, and greens in curious patterns and combinations. Some nodules exhibit banding, egg-shaped oolitic and botryoidal arrangements of colors, convolutions, and other patterns. The principal mineral in most of these specimens is indoubtedly chalcedony, but unidentifiable phosphatic minerals may also be present. When cut and polished these nonvariscitic nodules produce very interesting pieces of jewelry or ornamental stone (figures 6, 7, 8, 9, 10, 11, and 12).

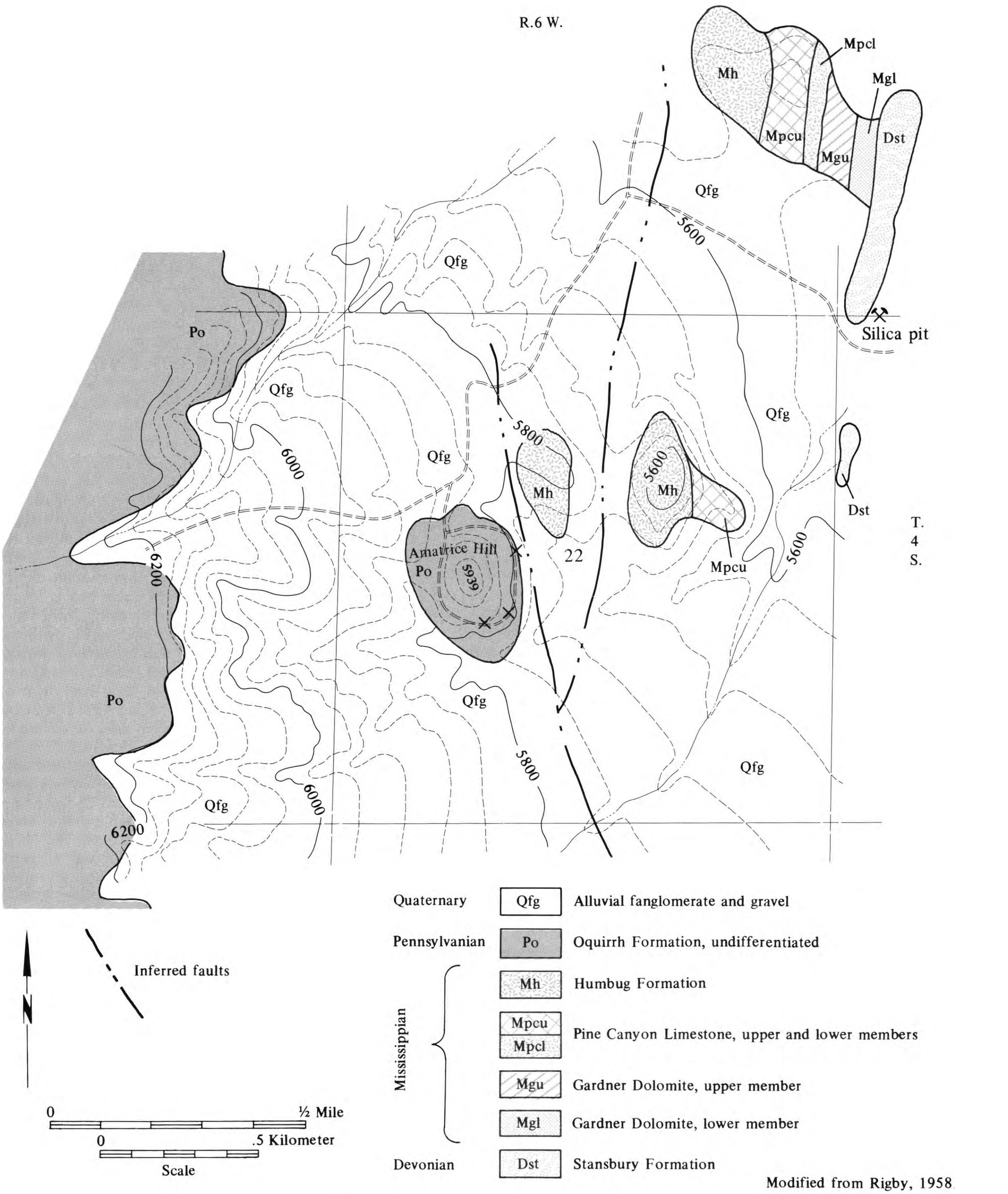


Figure 3. Geologic map of the Amatrice Hill area.

Figure 4. Amatrice Hill from the east. Stansbury Mountains in the background.

The choice nodules contain variscite and range in size from very small bodies to ovate bodies more than two feet across. Many of them exhibit a characteristic pattern: an outer concentric zone, ranging in thickness

Figure 5. West pit fissure and alteration zone. From this pit many tons of variscitic material were mined.

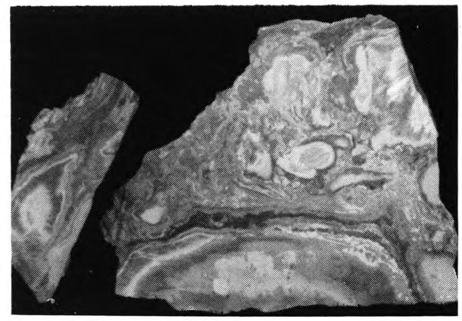


Figure 6. Slab cut through a cluster of variscite bodies. The lower part of large slab is about four inches in diameter. Most of the upper part consists of small bodies (light areas) filled with varying shades of green variscite and white phosphatic interiors. The irregular interarea is gray to lavender chalcedony and thin crusts of variscite.

from a few millimeters to several centimeters, of chalcedony and phosphatic minerals typical of nonvariscite-bearing altered nodules. This outer zone exhibits myriad patterns and colors and surrounds the variscite and other associated phosphatic minerals. The interior variscite is also in nodular form as a single nodule, groups of nodules, or clumps of connected nodules. One nodule containing a "clump" of variscite bodies weighed 200 pounds. Along the chalcedony-variscite contact a distinct banding follows the outline of the variscite body. Most of the outside band is dark brown chalcedony ranging in thickness from 0.5 mm to a centimeter. Then there is a 3 to 10 mm layer of chalcedonic material laminated in eggshell thicknesses in varying shades of tan. The interior body is mostly variscite or alterations of variscite. Peculiar variations of color and patterns are within the variscite and other phosphatic minerals of the interior body. The related phosphates, which probably include some wardite and a little crandallite, exhibit shades of yellow, gray, and white. Many of the smallest bodies are solid variscite, whereas most of the largest have gray porous phosphatic mineral interiors (figures 13, 14a, and 14b).

Three distinct patterns are identified in the variscite part of the nodule. These were first described by Zalinski (1909). The first is jade type and involves the deepest green coloration, mostly with little or no pattern. Much of the variscite is translucent and the nodules or bodies small. Zalinski noted a preponderance of jade type in the southernmost part of the west pits. He noted the nodules were ¼ to ¾ inch (6 to 19 mm) in diameter, some with irregular outlines. He stated that the largest became lighter green and completely

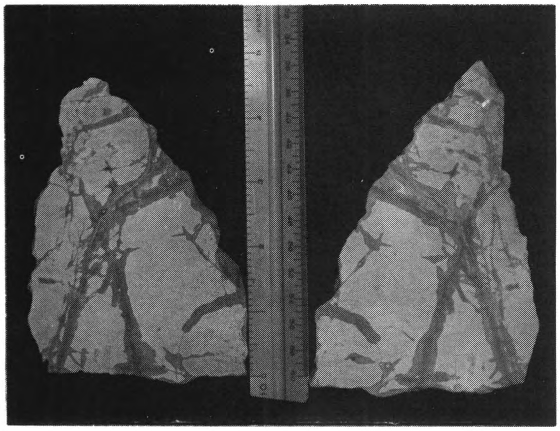


Figure 7. Fractured and recemented variscite. The darker areas, dark green in color, are where fracturing and recementing has taken place. The intervening areas are light green to green-white in color. The scale is in inches.

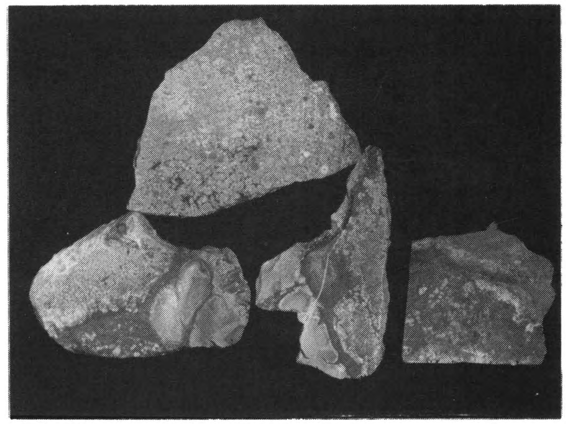


Figure 8. Slabs of cobweb-type variscite. The upper part of the top slab is an interior of a variscite body that has been shattered and recemented. The lower part is recemented with lavender chalcedony; the interior of each cell is variscite. On the far right, jade-type variscite is cobwebbed by purple chalcedony; the upper right is brown chalcedony.

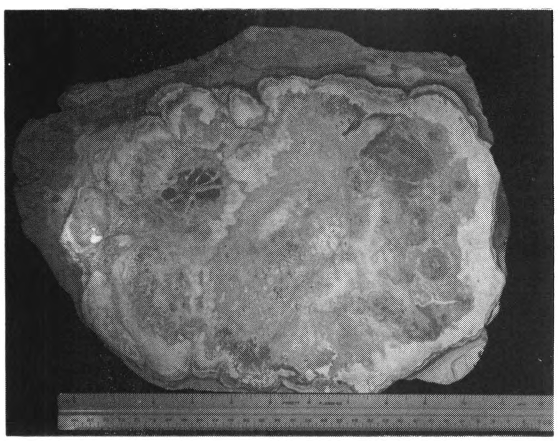


Figure 9. Large variscite nodule with a long diameter of 11 inches. The light outer rim is light green and the darker areas around the rim are dark green or blue green. The interior is white or gray phosphatic material. The circular fractured dark area about 1.5 inches across in the upper left area is dark-gray chert.

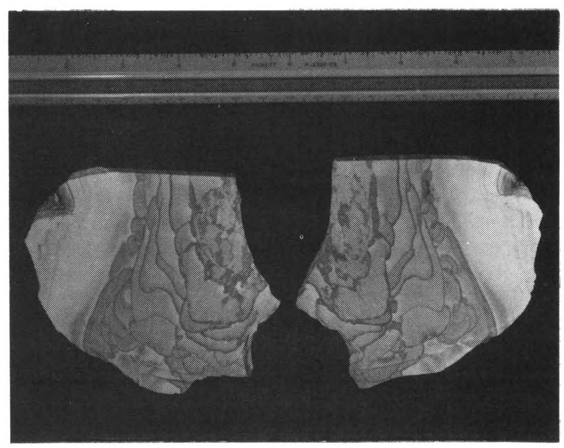


Figure 10. Slab of chalcedony rock from east pits. Color presents all shades of lavender to white. Scale is in inches.

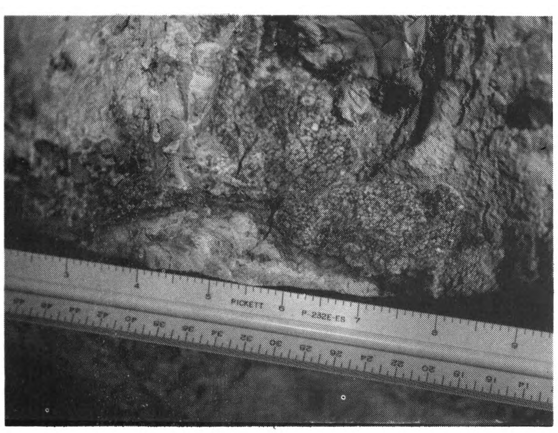


Figure 11. Rough break on large, raw nodule showing cobweb pattern. Light areas are light green, and dark areas are dark green or brown.

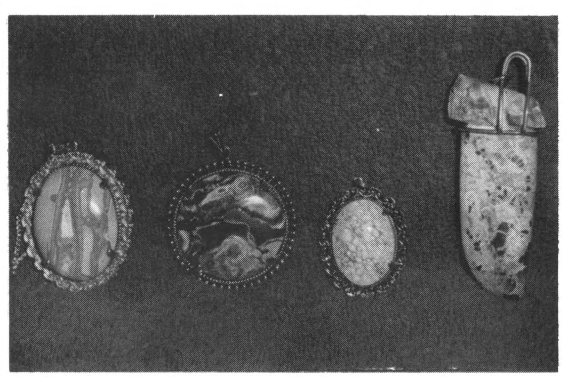


Figure 12. Pendants fashioned from Amatrice Hill variscitic nodules. In the left pendant there is fractured and recemented variscite (see figure 7). The middle left is a curious pattern of variscite (light areas) and chalcedony (lavender to black). The middle right is of a light green cobweb material. The dagger is fractured light green variscite with dark chalcedony and chert.

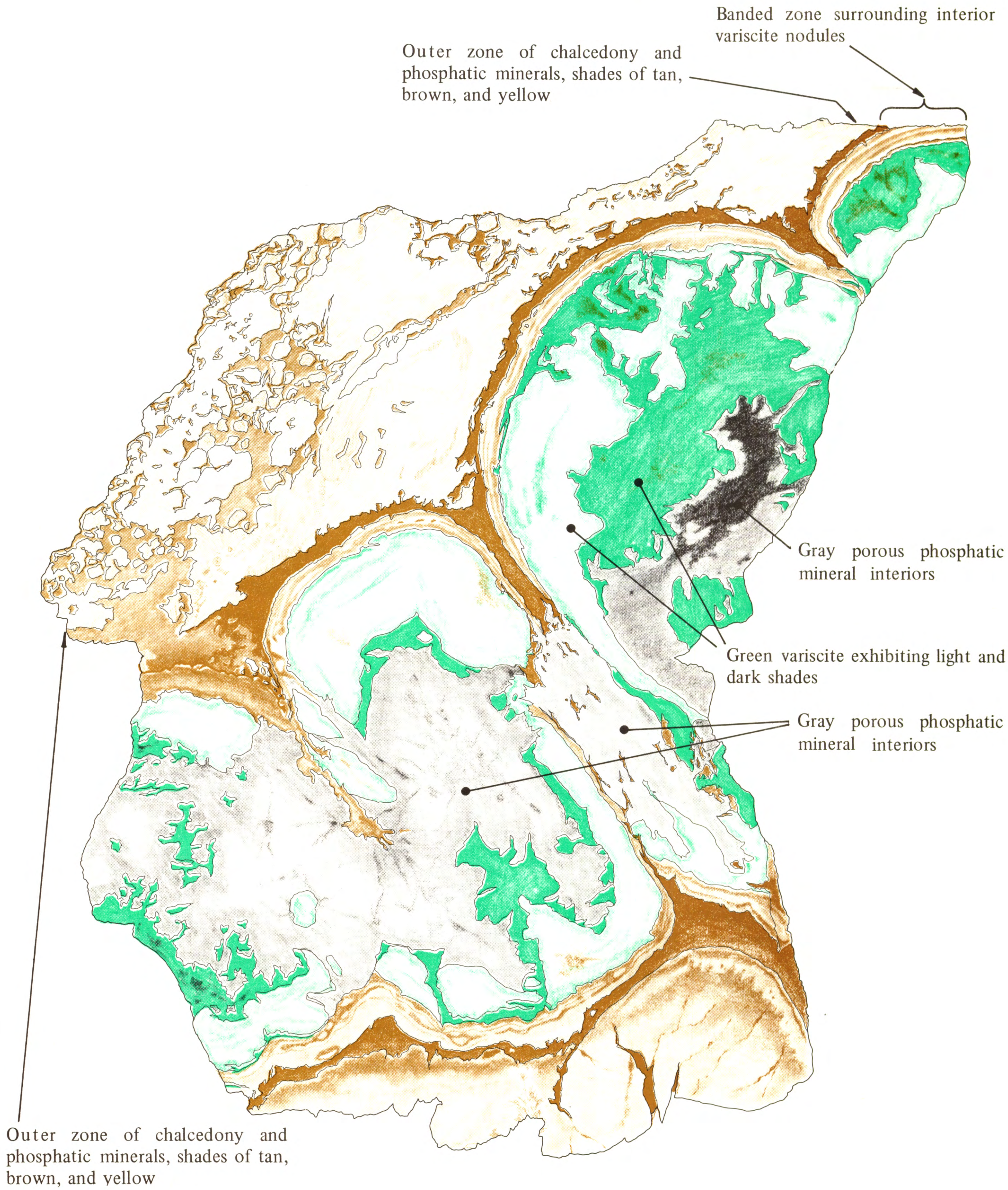
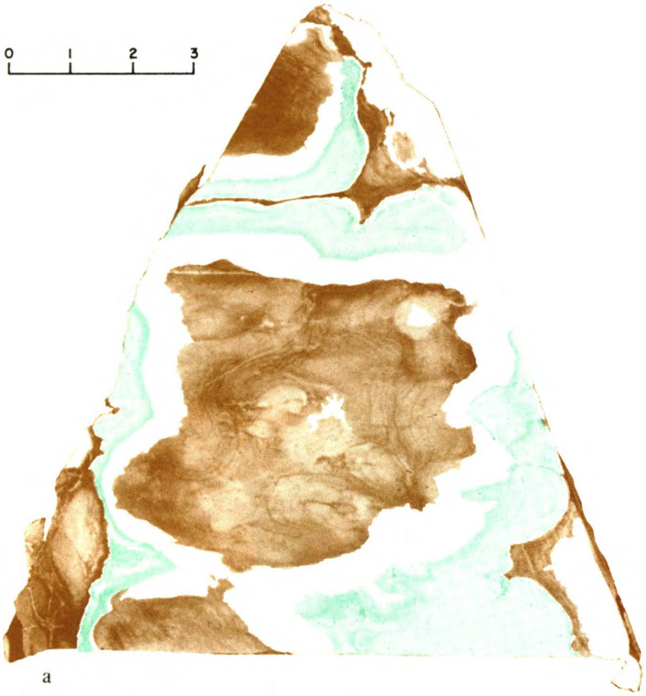


Figure 13. Diagrammatic sketch of variscite body,



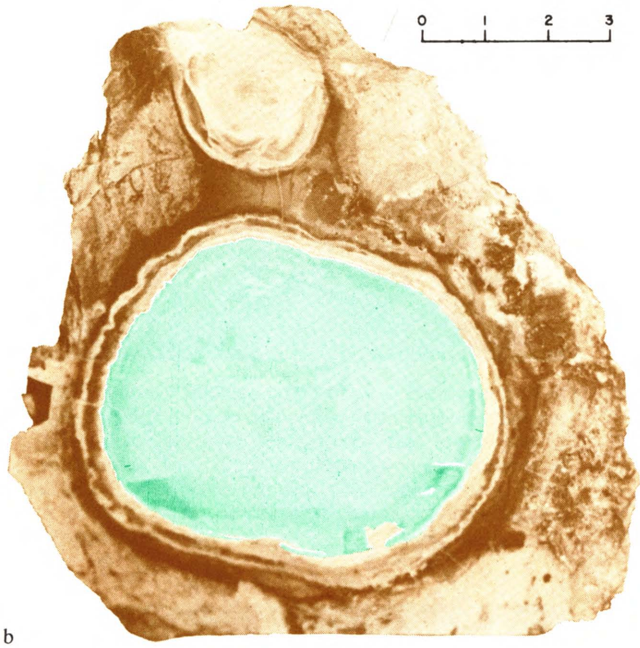


Figure 14. (a) Triangular slab of variscite and chalcedony. This variscite encloses an irregularly shaped body of lavender chalcedony, a rare find. The scale is in inches. (b) A perfect variscite nodule with part of a small body near the top. The interior is solid green, slightly darker around the edges. The dark encasing layer is brown chalcedony or jasper. The darker blotches on the outermost encasing material, especially to the right, is red-brown jasper. The scale is in inches.

white in the center. Most of the work of James, Atkin, and Jones has been at the north end of the west mineralized zone where additional jade-type material was found.

The apple-blossom type of variscite, perhaps the most common of the new material, is exemplified by nodules with white centers and green edges (white blossoms on a green background). The outer edge greens are of varying shades and patterns. The common pattern is crudely banded and broad—a large area of greenish white surrounded by varying areas of darker green.

The third type, known as cobweb variscite, indicates a network patterning. It can be formed in several ways and can be combined with the other two types. One cobweb variation is due to fracturing of one generation of variscite and a later recementation with more variscite. Generally the older variscite is lighter in color than the enclosing material. Each enclosed cell ranges in size from 2 to 8 mm. In some places the fracturing is recemented with chalcedony, or with hematite, limonite, or other phosphatic mineral to form other varieties of cobweb. In these cases much of the variscite is dark green and looks as if it were a grapelike conglomeration of very small nodules. Cobweb is prevalent on the outer edges of apple-blossom bodies or jade-type nodules.

In addition to these varieties, variscite has been found in many unpredictable forms. As in the cobweb type, fractured variscite of a light green color is recemented with darker variscite but in larger scale with the material exhibiting complex offsets and displacements. Most of the cementing material is finely laminated parallel to the breaks. In rare specimens the interior bodies containing the variscite are filled with the red-brown, lavender, and gray chalcedony or jasper, and the outer edge is lined with variscite as a crust. In still others the chalcedony has been fractured and recemented with variscite.

A second alteration zone lies about 150 feet east of the first. It is bounded on each side by massive, medium gray, cherty resistant limestone which grades into the light gray medium-bedded limestone found between them. Chert, in nodules and as thin beds, is lighter in color in this sequence. Limonitization and hematitization become more pronounced as the fissure is approached. Near the fault the chert is a very light gray, brittle, and is bedded. Little variscite has been found along this feature; the pieces and nodules have been small. Most of the variscite occurs as isolated blebs cementing the brecciated chert. Patterned chalcedony is common in this zone. The stratigraphic distance between the two massive limestones is about 35 feet.

Another fissure may be present at the extreme southeast corner of the hill, but exposures are not clear. Several cuts in this area have unearthed a few pieces of variscite and some patterned chalcedony; it is not known whether this is in place or is float from the east fissure. Mineralization along both the east and west fissure is known to extend southward from the workings down to the fanglomerate. It is not known how far north the alteration may extend. Many years ago along the east edge of Amatrice Hill, an adit was driven to intercept the two zones underground. The opening cuts across a fissure along which there has been brecciation of the limestone but only a minor amount of accompanying alteration. The working was explored, but no heavy alteration was noted. In some parts of the mine the limestone is bleached and marbleized.

WORKINGS

Workings on the west fissure consist of several shallow pits and areas where the soil has been removed to bare the bedrock. These pits begin near the south

Figure 15. East pit and short 25-foot adit. Only small amounts of variscite have been discovered here, but polishable chalcedony, chert, and jasper is plentiful.

end of the hill, and the last one is found at least halfway up the hill. The latest digging–to about 35 feet–is the deepest. Mining equipment has consisted of bulldozer, backhoe, and jackhammer, supplemented by hand tools; some recent mining has involved blasting. The development has barely proceeded into the hill.

The variscite has come mainly from this west fissure, and the presence of nodules has been scattered. The larger nodules have been more common on the east or footwall side of the fissure. In the 1972 diggings, several tons of gem nodules were removed; the finds at present are less prolific, and the bodies are smaller and more widely scattered. Alteration on the pit faces is very pronounced, leading to the belief that the opportunity for finding a new area of nodules is good. However, the mineralization may fade out to the north.

The workings of the east fissure consist of a pit extended by a shallow adit following the strike of the fissure (figure 15). The adit is about 25 feet (10 m). Several shallow cuts are found south and east of this principal working. The only other development is the previously mentioned adit designed to intersect both fissures north of the surface workings.

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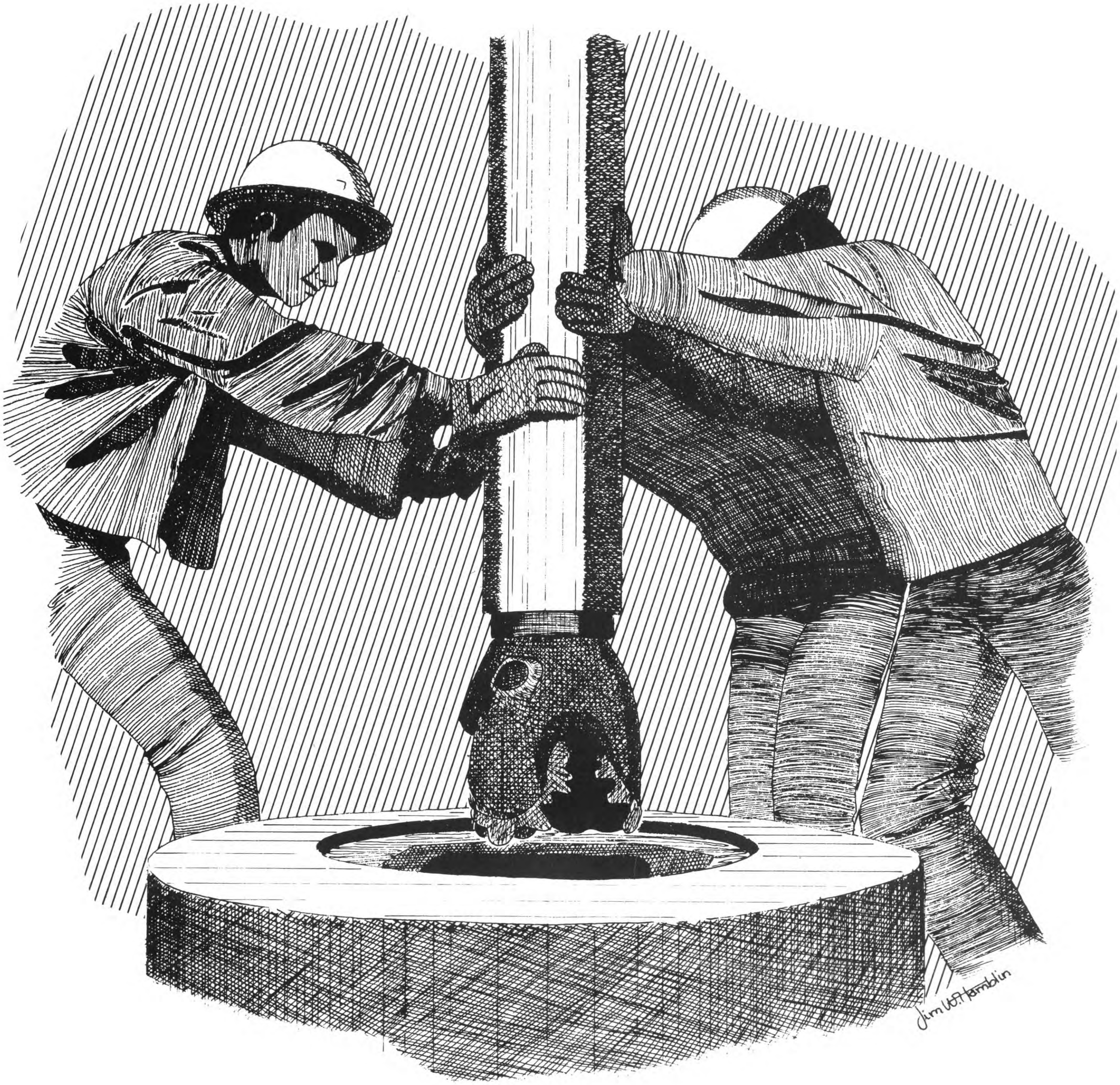

GOLD SPRINGS MINING DISTRICT, IRON COUNTY, UTAH, AND LINCOLN COUNTY, NEVADA

by Lee I. Perry[1]

ABSTRACT

Gold and silver mineralization in the Gold Springs mining district on the Utah-Nevada border is restricted to veins in Tertiary volcanic rocks. Mining began in 1897 and continued intermittently until the early 1940's. The principal mines have been the Jennie, Little Buck, Snowflake, Independence, Aetna, and Jumbo. Three mines had mills where ores were beneficiated. However, these mills were primitive and met with varying success. Few records were kept; nevertheless the district is credited with producing 9,335 ounces of gold, 40,279 ounces of silver, 12,031 pounds of copper, and 19,268 pounds of lead.

.The past production and this study of the surface and the underground workings indicate that the ore deposits are small but high in grade.

INTRODUCTION

Gold Springs is a small mining district located in western Iron County, Utah, with a part of its mineralized area extending into Lincoln County, Nevada. The center of the district is 60 miles (97 km) west of Cedar City, Utah, and 40 miles (64 km) east of Pioche, Nevada (figure 1).

Mineralization at Gold Springs is restricted to veins in extrusive volcanic rock. The veins bearing gold and silver and very little amounts of lead and copper occupy open fissures. Gold is generally in the native form, finely disseminated, and probably derived from gold-silver tellurides (Butler and others, 1920). Most of the gold is light in color and contains considerable silver. Some cerargyrite or horn silver has been found, but it is not common. Most of the ore is oxidized and, near the surface, secondary enrichment has increased the tenor. In the deeper workings sulfide minerals have been mined. The major gangue minerals are quartz, calcite, and adularia. The proportions of gangue minerals vary greatly in different parts of the veins. Little gold and silver is found in calcite, and often these parts of the veins were left in the mines while the adjacent higher grade ore was mined. A rule of thumb in the camp at the turn of the century was that adularia and quartz made the better gold and silver ore. Adularia, which can be up to half of the vein material, made higher grade ore than quartz, although most quartz was a shippable grade.

Records for Gold Springs are incomplete and do not list some of the earliest production. The district has been credited with approximately $500,000 in gold, silver, lead, and copper[2] (Asher, 1959; Butler and others, 1920; Tschanz and Pampeyan, 1970; Block, 1971). The value of the ore is in gold and silver as lead and copper are insignificant by-products.

LOCATION

Gold Springs is in the southwestern part of Utah in the western end of Iron County and in the eastern end of Lincoln County, Nevada, adjacent to the Stateline mining district.[3] The Utah-Nevada border passes through the district dividing it into an eastern or Utah portion, called the Gold Springs mining district, and a western or Nevada part, called the Eagle Valley mining district. For the purpose of this report, this area, shown in plate 1 (a combination of the two districts), will be referred to as Gold Springs mining district. Mineralogically and geologically these two districts are the same.

Gold Springs is approximately 70 miles (113 km) west of Cedar City, Utah, and 40 miles (64 km) east of Pioche, Nevada. From Cedar City the easiest route is 52 miles (84 km) via Utah Highway 56 to Modena, Utah, a spur on the Union Pacific Raliroad. Outside Modena, 2¾ miles (4.4 km) west on Highway 56, an improved dirt road leading off to the northwest to Gold Springs intersects with the highway. The townsite of Gold Springs is 12 miles (19 km) from the intersection.

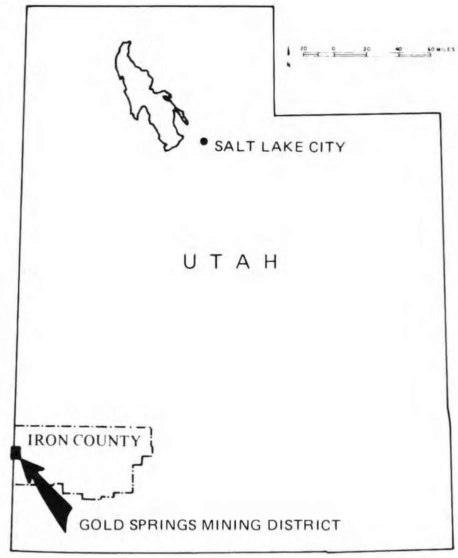

Figure 1. Index map of Gold Springs mining district.

GEOGRAPHY

The climate of Gold Springs is arid; annual precipitation is 11 inches (27 cm), and temperatures range from 101°F (38°C) to -32°F (-35°C). Vegetation in the higher areas consists of juniper and pinyon; in the flats sagebrush is most common (Thomson and Perry, 1975, p. 27).

Several small springs are found in the area, but the principal one is Gold Springs near the townsite of Gold Springs. The springs are perennial, but flow is reduced during periods of drought. Alluvium in the washes usually absorbs the spring's runoff a short distance below its source. Gold Springs supplied culinary water for the town of Gold Springs and furnished water for the Jennie mine and mill. In drier years when it was not adequate for the Jennie mine, water had to be piped from springs in Nevada.

Local topographic relief is 1,650 feet (503 m): the southern end of the study area is approximately 6,400 feet (1,950 m) above sea level; Bull Hill in the northwest corner of the area is 7,668 feet (2,337 m). Gold Springs townsite is at 6,720 feet (2,048 m). Many roads cut

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[2] Gold at $35.00 an ounce.

[3] For report on Stateline mining district, see "Reconnaissance Study of the Stateline Mining District, Iron County, Utah," by Kenneth C. Thomson and Lee I. Perry, *Utah Geology*, Vol. 2, No. 1, Spring 1975.

through the area, allowing easy access, but some are in poor repair and require a four-wheel drive vehicle for safe passage.

The town of Gold Springs is now abandoned. Four cabins and the pump house at the springs are all that remain of the once thriving community (figure 2). In the surrounding area where mining took place, mine dumps, abandoned cabins, mill buildings and foundations are common.

HISTORY OF THE DISTRICT

Gold Springs, or Pike's Diggings as it was known in earlier days, was discovered fairly late in relation to other mining districts of the west. Little prospecting had been done in the area, except for the work of "Old Man Pike" who started prospecting here in the 1870's. His attempts to trace the high-grade float found in the district back to its place of origin were in vain, and he died without striking the bonanza of his dreams. It was not until the discovery in 1896 of gold and silver veins in the State-line mining district, a few miles to the north, that any great number of prospectors were attracted to the area (Thomson and Perry, 1975). The first locations since Pike's work were made in 1897 (Tschanz and Pampeyan, 1970) on the Jumbo and Wild Irish claim groups (*Salt Lake Mining Review,* 1903). The rest of the veins were prospected and located shortly thereafter. The prospector had little trouble in tracing a vein because the silicification caused it to stand in bold relief above the adjacent ground. Much rich float was present that pointed to the veins and the type of ore to be found in them.

The town of Gold Springs was established in the late 1890's, and in 1908 it boasted of a population of 250 (*Salt Lake Mining Review,* 1908). The townsite was in the middle of the district, east of the Utah-Nevada border. Adequate water for all immediate purposes was obtained from Gold Springs for which the town was named.

AVAILABLE MAPS AND METHODS OF STUDY

Topographic maps available are the Army Map Service (AMS) map of Caliente (NJ 11-9) and the 7½-minute quadrangle, Deer Lodge Canyon, Nevada-Utah. The AMS map is at a scale of 1:250,000 and the 7½-minute quadrangle is at a scale of 1:24,000. A preliminary geologic map by William Block was available to the author at a scale of 1 inch equals 1,000 feet. The 7½-minute quadrangle and the geologic map were enlarged to 1 inch equals 800 feet and used in the field. No additional surface geologic mapping was done by the author. Underground mapping of accessible workings and field work were done during the summer of 1974 and the spring of 1975. Samples were cut at right angles to the vein structure and sent to the Union Assay Office, Salt Lake City, Utah, where they were fire assayed for gold and silver.

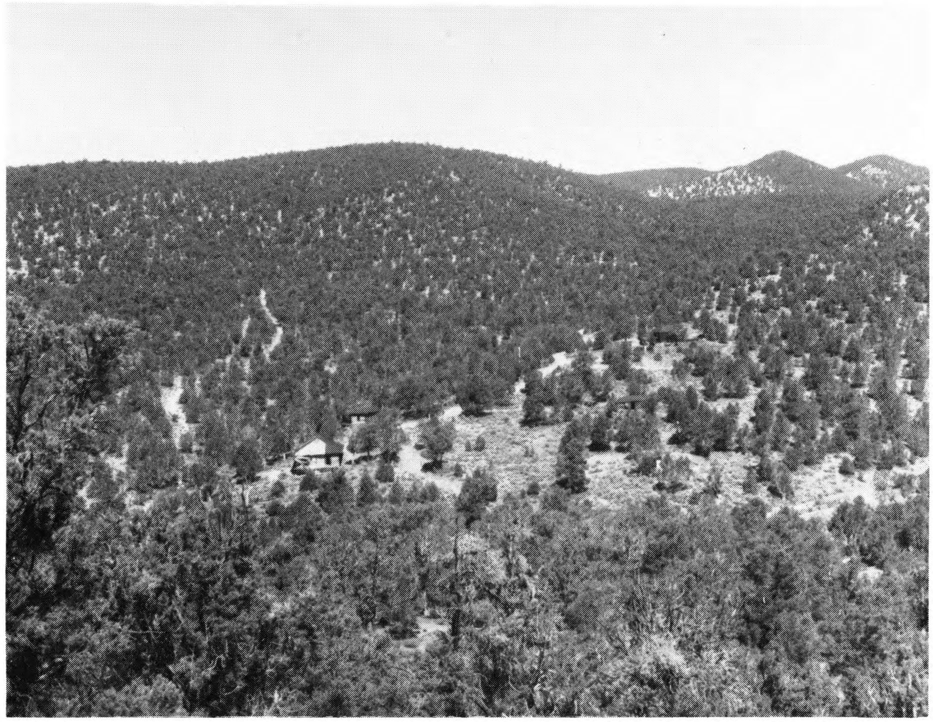


Figure 2. Town of Gold Springs as seen from U. S. Land Monument 2 (USLM 2), looking north.

GEOLOGY

Stratigraphy

Most of the rocks in the study area are Tertiary igneous rocks; the rest are Tertiary and Quaternary sediments (Block, 1972). The igneous rocks are divisible into five extrusive units and five intrusive units. The extrusive rocks are broken down into four rhyolite flow units and an andesite unit consisting of several flows lumped together into one mappable unit. The intrusive rocks consist of two rhyolite porphyrys, the mappable brecciated part of one of the porphyrys, and two types of dikes. The sedimentary rocks consist of Tertiary water-laid tuff and Quaternary alluvium.

Sedimentary Units

The Tertiary unit (Tt) is water-laid tuff derived from an underlying igneous unit (Tr_1), a lithic crystal tuff. The Quaternary unit is alluvium that occupies the southwestern part of the area where it buries all of the other units.

Alluvium (Qa)

Alluvium described by Block (1972) as "outwash material" is composed of pieces of igneous rocks and vein material that range in size from boulders to sand particles. Where observed this unit is unsorted. Alluvium covers the southern and western part of the study area, lapping up on the west flank of Buck Mountain and extending to the south and west for a considerable distance beyond the study area (plate 1).

Water-Laid Tuff (Tt)

A water-laid tuff, derived from the underlying igneous unit (Tr_1), a lithic crystal tuff, was deposited shortly after the deposition of Tr_1. The water-laid tuff is composed of pumice and lithic fragments that have been reworked and slightly sorted by water. This unit lies conformably upon the lithic crystal tuff. Exposures are seen in two areas: The best outcrop is one-half mile north of the Gold Springs townsite on a hill where more than 200 feet (61 m) of water-laid tuff is exposed. The second exposure is on the west side of a gully cutting into Bull Hill in NE¼ sec. 29, T. 1 N., R. 71 E., Nevada.

Igneous Units

The extrusive rock units include a series of rhyolites overlying andesite flows. The andesites are the host rock for most of the gold and silver veins in the district. The intrusives are rhyolite plugs that are probably the source of the rhyolite flow units (Block, 1972). In addition to the rhyolite plugs, two types of dikes are found that are composed of rhyolite and perlite.

Platy Rhyolite (Tr_4)

The uppermost platy rhyolite flow rock is the youngest of the rhyolite units (Block, 1972). It consists of a thick uniform section of tuffaceous flows ranging in color from medium to dark gray and weathering to a platy appearance. The only exposure is along the eastern edge of the study area in NE¼ sec. 36, T. 33 S., R. 20 W., Utah (plate 1) where it occupies the top of the mountains.

Rhyolite Tuff (Tr_3)

The rhyolite tuff is the next to youngest unit in the district. This unit is not as thick as the overlying platy unit and is discontinuous throughout the district. It has a well-developed welded zone containing solid and hollow lithophysae, which distinguish it from the tuff unit below. The outcrop area, the smallest of the rhyolite units, is only found on the northeast side of Bull Hill in sec. 29, T. 1 N., R. 71 E., Nevada.

Rhyolite Tuff (Tr_2)

This rhyolite tuff unit is the next to the oldest of the rhyolite units of the area. It is similar in appearance to the tuff unit above but has a perlitic vitrophyre at its base and does not contain lithophysae as in the unit above. The exposures are small and found along the east side of the map area. The best exposure is in NE¼ sec. 36, T. 33 S., R. 20 W., Utah, where it overlies the lithic crystal tuff and is capped by the platy rhyolite.

Lithic Crystal Tuff (Tr_1)

The lithic crystal tuff is the lowest of the rhyolite flows and is the most widespread of the four units. Except for the andesite flows, it covers the largest area of any unit in the district. The unit is composed of ten percent quartz crystals, which are generally broken, ten percent lithic fragments, and flattened pumice lapilli, which make up the remainder of the rock. The rock ranges in color from light pink to pinkish brown. The distinguishing features of this unit are the unwelded pumice lapilli, lithic fragments, and broken quartz crystals. The best exposures are northeast of the Jennie mine, on the hill that is almost entirely made up of this unit. According to Block (1972) the source of this flow was probably Bull Hill.

Porphyritic Andesite Flow (Ta)

The porphyritic andesite flow is the most extensive unit in the area and the most important because it is the host rock for all but one of the veins. This unit consists of several andesitic flows that have been lumped together for mapping. The unit has large (up to 5 mm) plagioclase crystals in a matrix of aphanitic glass. The lower flows are locally fragmented in parts of the district. In some places along the vein contacts, the andesite is kaolinized or silicified. A good example of kaolinization is seen in the E-2 adit where the wall rock has been altered almost completely to kaolin. Silicification of the andesite is seen in the Snowflake and Aetna vein where the wall rock is almost a jasperoid near the veins. A good exposure of this unit can be seen in the hill east of Gold Springs townsite and south of Gold Springs Wash.

Intrusive Rock

Bull Hill Rhyolite Porphyry (Tbh)

The Bull Hill rhyolite porphyry makes up one of the two rhyolite plugs that are located in the district. It was named by Block (1972) after the hill which it occupies. The unit, light purple to pinkish brown in color, is more resistant to erosion than the surrounding flow rocks. The area of outcrop is small and occupies only the top of Bull Hill. This unit serves as the host rock for a small gold-bearing fluorspar and hematite vein that occurs on the southeast side of its exposure. Block suggests that the plug on Bull Hill is the source of the lithic crystal tuff unit (Tr_1) which crops out southeast of Bull Hill.

Buck Mountain Rhyolite (Tmbr) and Brecciated Rhyolite (Tbmb)

The Buck Mountain rhyolite is the second of two rhyolite plugs found in the district. The unit was named by Block (1972) after Buck Mountain, the top of which is made up of the unit. It has been divided into two mappable units: a brecciated eastern part of the plug and an unbrecciated western exposure. The rhyolite is the host for two perlite dikes, which strike N. 15°-35° W. on the eastern slope of Buck Mountain.

The brecciated unit has been resilicified into a distinctive green jasperoid. Its eastern contact with the andesite flows parallels roughly the N. 20° W. strike of the Snowflake vein. No mineralization has been found in either rhyolite unit to date.

Rhyolite Dikes (Tdr)

Rhyolite dikes are found in two places in the district. These dikes are lithologically similar and are probably related to either the Bull Hill or Buck Mountain rhyolite plugs. The best exposure of a dike is 800 feet (244 m) west of Gold Springs townsite. This dike, which has been displaced by a fault, strikes N. 15° W. to N. 10° E. for 1,600 feet (488 m). The southern end of the Thor (Talisman) vein has been displaced by the same fault, which dates the dike as the same age or earlier than the mineralization of the Thor vein. Another exposure of a rhyolite dike is about 1,000 feet (305 m) north of the Little Buck mine in sec. 32, T. 1 N., R. 71 E., Nevada. This exposure does not have the linear shaped outcrop seen in the exposure west of Gold Springs.

Perlite Dikes (Tdp)

Two perlite dikes are found on the eastern slope of Buck Mountain. These dikes are very glassy and occur in the Buck Mountain rhyolite. The larger one of the dikes starts near the south line of sec. 32, T. 1 N., R. 71 E., Nevada, strikes N. 15° W., and extends 2,000 feet (610 m) to the northwest. Near the southern end the dike has a thickness of 20 feet (6 m), but near the northern end it narrows to about 2 feet and then dies out. The second and smaller dike starts near the south line of sec. 32, strikes north, and merges with the larger dike after a few hundred feet. Both dikes dip about 70 degrees to the west into the Buck Mountain rhyolite.

STRUCTURE

Sedimentary rock ranging in age from Cambrian to Triassic underlies the Tertiary volcanics of the surrounding region. Prevolcanic deformation is localized along northeast-trending axes. Narrow belts of deformed rocks are adjacent to broad areas of undeformed Paleozoic rocks. The exposed sequence of volcanic rocks occupies basins formed on top of these Paleozoic rocks. In the undeformed volcanics, the Paleozoic rocks lie disconformably; in deformed areas the contact is an angular unconformity (Cook, 1965; Block, 1971).

In the Gold Springs area ignimbrites have accumulated in a basin 2,500 to 3,000 feet (762 to 914 m) thick and are believed to rest on an erosional surface of lower Paleozoic rocks. The nearest exposed Paleozoic rocks (Middle Cambrian, Highland Peak Limestone) are 10 miles (16 km) to the north (Cook, 1965).

The volcanic rocks dip gently to the east, and the only noticeable structural features are the veins that are believed to be associated with faulting. These veins trend roughly northwest and dip 50 to 75 degrees east. Close examination of the district shows two ages of faulting cutting Tertiary volcanic rocks. These faults can be classified as premineral and postmineral faults, although Young (1934) suggests some movement took place during emplacement of the vein materials. As a general rule, the premineral faults have a northerly strike varying a few degrees to the east or west, while the postmineral faults strike northeast to east. Premineral faulting broke the ground and formed open spaces, which allowed deposition of ore and gangue minerals. Faulting provided a plumbing system that allowed ore-bearing solutions to permeate the rock. The premineral faults might well represent Paleozoic fault systems extended into the volcanics. Postmineral faults with their northeast to east strike tend to cut off the mineralized veins, such as the Jennie vein north of the Jennie shaft. Faults of both ages are normal and displacements are small.

MINERALOGY

The metals of economic value in the veins are gold, silver, lead, and copper. The oxidized part of the vein contains gold in the native state and, also, a small amount of silver. Most of the gold can be seen with a hand lens. Colors can be panned with ease from a sample crushed in a mortar. In the bottom of the pan the gold is fine and a hand lens is usually necessary to see it. Cather (1975), a mineralogist for the U. S. Bureau of Mines, reported that the gold in all of the samples "is rather pale and may contain small amounts of silver." Gold is generally free from any gangue, but some locking does occur generally with limonite and occasionally with quartz.

Lead and copper have been recovered from the ores, but the quantities are small making them insignificant by-products. The Jennie, Little Buck, Big Buck, and Pope mines have been the main producers of the by-product metals (U. S. Bureau of Mines, oral communication).

Some limonite, common in the ores mined in the district, is associated with gold. It is suggested that the gold may have been brought in with pyrite and then later oxidized to limonite. Limonite is massive or pseudomorphic after pyrite. In a sample from the Thor vein, Cather (1975) found gold locked in the limonite (figure 3).

Gangue minerals that are found in veins in their order of abundance are quartz, calcite, and adularia. The quartz occurs in several different forms: as druse, the filler for vugs or cavities, as large white fine-grained masses, as small stringers running in all directions in silicified rock, and as chalcedony. Calcite is banded or crustified and generally coarsely crystalline but may be massive. Quartz that has replaced calcite is found in parts of the veins. Adularia is found in most of the veins, giving them a yellowish green or greenish gray cast; it may fill up to half of the vein. The gold seems to be associated with the adularia, which is generally fine grained and massive or in some places coarsely crystalline.

Young (1934) suggests that there is evidence to support at least two ages of calcite and quartz mineralization. He suggests the first mineralizing solution brought in the calcite and deposited it on the walls of the open fissures. The next solutions entering the fissures brought in the adularia, gold, silver, and most of the quartz. This was followed with a second influx of calcite followed by another of quartz. The last quartz stage had very little gold associated with it.

There is little doubt that secondary enrichment has increased the value of the veins near the surface (Young, 1934). The gradual decrease in value with depth, the boxwork left by the pyrite, and the presence of manganese stains on the calcite reinforces this idea. According to Young the effect of secondary enrichment is limited to the upper 200 feet of the veins.

No placers have been found in the district. Young suggested that gold might have been carried downward in the vein faster than erosion could remove the vein material. There is a possibility that the size of the gold removed by erosion was too fine to allow it to be deposited in any concentrated amounts in the immediate area.

LOCATION OF MINES

The mines and workings of the district have been located by two methods: township and range and the Universal Transverse Mercator system (UTM) (table 1).

VEINS AND ASSOCIATED MINES

The principal veins in the district are listed from east to west: Jumbo, Independence, unnamed vein on Sigbee

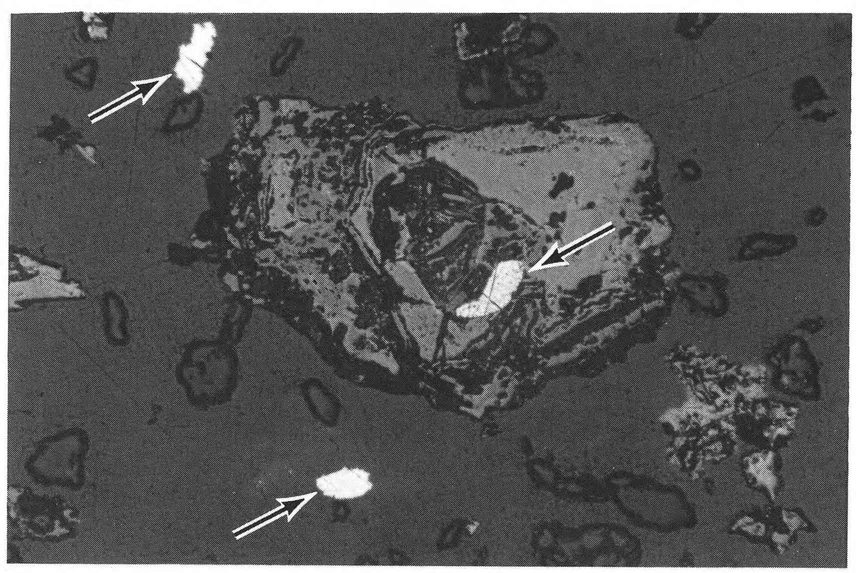


Figure 3. Polished section magnified 160 times shows the locking of gold in limonite. Sample is from Thor vein. Arrows indicate gold locked in limonite and isolated as grains in the bakelite matrix.

Table 1. Location of mine workings.

Name	Township and range	Universal Transverse Mercator	
		North (in meters)	East (in meters)
Jumbo shaft	NW¼SE¼ sec. 25, T. 33 S., R. 20 W., Utah	4198710	761370
Independence shaft	NW¼SE¼ sec. 25, T. 33 S., R. 20 W., Utah	4198690	761020
Independence adit	NW¼SE¼ sec. 25, T. 33 S., R. 20 W., Utah	4198720	761130
Aetna shaft	SW¼SW¼ sec. 36, T. 33 S., R. 20 W., Utah	4196740	760590
Adit on Aetna vein	SE¼NW¼ sec. 1, T. 34 S., R. 20 W., Utah	4196030	760790
E-2 adit	E½ sec. 26, T. 33 S., R. 20 W., Utah	4198440	759820
Jennie shaft	Lot No. 4 sec. 26, T. 33 S., R. 20 W., Utah	4198480	759470
Thor crosscut	E½ sec. 32, T. 1 N., R. 71 E., Nevada	4198450	759250
Uvada adit	E½ sec. 32, T. 1 N., R. 71 E., Nevada	4198700	759300
Little Buck shaft	NW¼ sec. 32, T. 1 N., R. 71 E., Nevada	4199140	758640
Big Buck shaft	NW¼ sec. 32, T. 1 N., R. 71 E., Nevada	4198960	758670
Snowflake quarry	SW¼ sec. 32, T. 1 N., R. 71 E., Nevada	4199690	758800
Red Eagle adit	SW¼ sec. 32, T. 1 N., R. 71 E., Nevada	4198270	759020
Pope shaft	SW¼ sec. 29, T. 1 N., R. 71 E., Nevada	4199770	758720
Charley Ross shaft	NW¼ sec. 32, T. 1 N., R. 71 E., Nevada	4199400	758930
Adit below Charley Ross shaft	NW¼ sec. 32, T. 1 N., R. 71 E., Nevada	4199290	758930
Adit southeast of Charley Ross shaft	Lot No. 2 sec. 32, T. 1 N., R. 71 E., Nevada	4199030	759030
Adit one-quarter mile west of Pope mine on northwest side of gully	SW¼ sec. 29, T. 1 N., R. 71 E., Nevada	4199770	758280
Adit one-quarter mile west of Pope mine on southeast side of gully	SW¼ sec. 29, T. 1 N., R. 71 E., Nevada	4199770	758280
Shaft on Bull Hill	NW¼ sec. 29, T. 1 N., R. 71 E., Nevada	4200580	758580
Adit one mile south of Buck Mountain	SW¼ sec. 4, T. 1 S., R. 71 E., Nevada	4196840	758650

claim, Aetna or Etna, E-2, E-1, Jennie, Thor or Talisman, Snowflake, Charley Ross, Pope, and an unnamed vein on Bull Hill. These veins all strike northwest with the exception of the Jumbo, an unnamed vein on Sigbee claim, the Pope, and the vein on Bull Hill. The Jumbo has a northerly strike. The unnamed vein on Sigbee claim, the Pope vein, and the unnamed vein on Bull Hill have a northeast strike.

Jumbo Vein

The Jumbo vein, the easternmost vein in the district, is in the eastern half of sec. 25, T. 33 S., R. 20 W., Utah. The outcrop can be traced on the surface for 2,500 feet (762 m); for the greater part of this distance it stands out in bold relief as a massive white quartz vein (figure 4). The vein strikes north and dips steeply to the east. The southern end of the vein is cut off by a fault; the northern end feathers out and is lost in the country rock. The vein is formed by filling with quartz an open fissure or breccia zone. The bulk of the vein material is white, massive quartz, crystalline quartz, and fine drusy quartz in vugs. Cavities and vugs are common through the vein. Very little calcite is observed in outcrop, but drilling indicates an increase in calcite with depth. At the apex, the vein is 50 feet (15 m) wide, and the silicified outcrop stands 20 feet (6 m) above the country rock. Sample 4-16-1 (table 2) is a 10-foot (3 m) cut across the vein at the apex against the hanging wall. The sharp contact of the vein footwall commonly produces a wall 10 feet (3 m) high in places. The heaviest silicification appears along the footwall; the hanging wall is indefinite and grades into the altered country rock. Inclusions or horses of partially silicified country rock are common in the vein.

A sample of ore was taken from the footwall at the southern end of the Jumbo vein at its intersection with a small northwest-striking vein. Panning the Jumbo vein in the field reveals abundant gold and an unidentified dark gray sulfide. This sample was submitted to Cather (1975) for determination of gold and silver mineralogy. The sample was crushed and separated by a heavy liquid; the residue heavier than the liquid, called the heavy fraction, was briquetted, polished, and examined with a reflecting microscope. Cather (1975) reported that the main gangue mineral was quartz and that gold was common, generally occurring as free grains in the polished section. The gold was pale suggesting dilution by silver. Argentite was also common and occurred as free grains up to 400 by 200 microns in size. Limonite was the other common constituent of the heavy fraction.

Jumbo Mine

Several excavations have been made on or near the Jumbo vein with the largest being the Jumbo mine. The Jumbo mine consists of a single compartment shaft, a crosscut from the west near the southern end of the vein, and an adit on a parallel vein. The shaft, approximately 100 feet (30 m) deep, is on the hanging wall of the vein (figure 5). A grab sample, 4-16-3, from the shaft dump is listed in table 2. Sample 5-12-1 is a grab sample of ore stockpiled on the shaft dump. According to Asher (1959) the vein was accessible by a crosscut adit from the west (this adit was caved in when the author visited the area in 1974). He stated that the vein had then been followed 100 feet (30 m) north and 100 feet (30 m) south. The crosscut showed a heavy gouge zone on the vein hanging wall. In the gully near the southern end of the vein, an adit was driven north for approximately 75 feet (23 m) on a parallel vein, which is 100 feet (30 m) west of the Jumbo vein. The portal of the adit is caved in, but access is possible through a 15-foot (5 m) shaft that intersects the adit about 50 feet (15 m) from the portal. From the bottom of the shaft the drift extends northeast 25 feet (8 m). A 3-foot (1 m) sample, 4-16-4, was cut in

Figure 4. Jumbo vein, looking northwest. Note resistance to erosion caused by the hardness of the vein in relation to the country rock.

the face of the drift in the vein. The sample consists of quartz stained by limonite (table 2). Approximately 100 yards (91 m) south of the apex of the vein a 10-foot (3 m) shaft has been sunk on the vein. A grab sample, 5-12-2, was taken from the dump and is shown in table 2. East of the vein and about 100 feet (30 m) below the apex, an adit has been driven west to crosscut the vein. The portal is caved in, but material on the dump shows the vein was reached. The vein material on the dump is brecciated, altered country rock surrounded with quartz. A small amount of ore was stockpiled on the dump, and sample 4-16-2 is a grab sample from the pile on the dump.

Table 2. Assays of samples from Jumbo and Independence mines.

Sample number	Width	Gold (ounces/ton)	Silver (ounces/ton)
4-16-1	10 feet	0.010	0.4
4-16-2	grab	0.010	6.4
4-16-3	grab	0.080	0.8
4-16-4	3 feet	0.035	0.4
5-12-1	grab	0.120	26.5
5-12-2	grab	0.040	1.4
5-12-3	grab	1.020	3.9

Independence Vein

The Independence vein is in the central part of sec. 35, T. 33 S., R. 20 W., Utah, about 1,000 feet (305 m) west of the Jumbo vein. The exposure of the vein is not good, but where visible it is 2 to 5 feet (0.5 to 1.5 m) in width. Workings along the vein delineate its length, which is about 1,500 feet (457 m). The strike of the vein is variable ranging from N. 30° W. to N. 40° W.; the dip varies from 70 degrees south to steeply north. The Independence vein is composed of massive and crystalline quartz, calcite, and some limonite. The limonite is pseudomorphic after pyrite, and some residual pyrite is seen in the limonite. Native gold can be found in the pseudomorphs, suggesting that it was introduced with the pyrite. The gold is fine, but some can be seen with the naked eye.

Independence Adit and Shaft

The Independence adit is driven along the Independence vein about 800 feet (244 m) north of the road leading to the southern end of the Jumbo vein. The drift is caved in approximately 75 feet (23 m) from the portal, but the amount of dump material suggests workings of several hundred feet (figure 6). The material on the dump is moderately veined with quartz; a few fine blebs of native gold may be seen, especially in the limonite that is pseudomorphic after pyrite. A high-grade sample of the ore, listed as 5-12-3 in table 2, on the dump of the adit at the southern end of the vein contains visible gold.

A sample of ore from the dump of the Independence adit was submitted for examination to Cather who reported that microscopic examination revealed limonite as a common constituent of the heavy fraction. Some of the limonite was pseudomorphic after pyrite and contained residual cores of pyrite. Argentite and gold were scattered constituents, and both were generally free from locking. The vein can be traced northwest from the adit portal for about 200 feet (61 m) into the southern end of an open cut extending along the vein for about 400 feet (122 m). The open cut is approximately 5 feet (1.5 m) wide, and all of the vein material has been removed to an indeterminable depth (figure 7). Near the southern end of the open cut a small amount of vein material, containing residual pyrite and specks of native gold in blebs of limonite, was left on the east side of the excavation. The dump from the open cut is composed of altered andesite and quartz containing limonite.

The Independence shaft is approximately 75 feet (23 m) southwest of the northern end of the open cut. The shaft, cut on a small vein that is parallel to the Independence vein, dips 70 degrees south and is 200 feet (61 m) deep (*Salt Lake Mining Review*, 1903) (figure 8). A crosscut was probably run east from the shaft to inspect the Independence vein. The dump from the shaft contains a fresh, light blue andesite, a large amount of calcite, and a small amount of siliceous vein material. Two-hundred feet (61 m) south of the shaft, a 15-foot (5 m) pit exposes a 4-foot (1.3 m) quartz vein not seen on the surface that strikes N. 40° W. and dips 65 degrees south. About 1,200 feet (366 m) northwest of the Independence shaft on the north side of Gold Springs Wash is a caved in adit that is driven along a 2- to 3-foot (0.5 to 0.75 m) quartz vein containing pyrite. The adit

Figure 5. Jumbo shaft, looking southwest.

Figure 6. Independence adit. Arrow indicates the partly caved in portal as seen from the dump, looking northeast.

Figure 7. Open cut on the Independence vein as seen from the dump on the southern end, looking northwest.

Figure 8. Illustration copied from a photograph in the *Salt Lake Mining Review* (1903) of the shaft of the Independence mine as it appeared in 1903.

is said to have about 700 feet (213 m) of workings (Haigh, oral communication).

Unnamed Vein on Sigbee Patented Claim

An unnamed vein crops out on the Sigbee patented claim striking N. 20° E. and dipping 70 degrees east. The vein can be traced for 800 feet (244 m) as a bold white quartz outcrop up to 15 feet (5 m) wide. Slickensides on the hanging wall side of the vein suggest postmineral movement. The hanging wall of the vein forms an abrupt contact with the country rock; in places the vein stands 20 feet (3 m) above the ground (figure 9).

Workings on the Unnamed Vein on the Sigbee Patented Claim

At least three prospects were dug on this vein in search of ore, but little or no ore was produced from them. According to Burgess (oral communication) the vein was sampled and panned in several places but with little or no color found.

Aetna (Etna) Vein

The Aetna vein is in the southern part of the study area with the northern end of the vein in sec. 36, T. 33 S., R. 20 W., Utah, and the southern end extending into sec. 1, T. 34 S., R. 20 W., Utah. The vein strikes N. 80° W. and dips 70 degrees west. In outcrop it appears as small quartz and calcite stringers, which thicken to 10 feet (3 m) at the Aetna mine.

Aetna Shaft

The main development on the vein consists of the Aetna shaft in the SW¼ sec. 36, T. 33 S., R. 20 W., Utah (figure 10). It is an inclined shaft with several hundred feet of workings on the 100-foot level and three winzes below this level to the 175-foot level. Figure 10 contains a map of the 100-foot level. The shaft is collared in the footwall of the vein and is inclined 69 degrees west. The vein is crosscut on the 100-foot level, 10 feet (3 m) west of the shaft, and drifts run north and south in the vein. The drift extends approximately 200 feet (61 m) north of the shaft station at which point it is caved in. The vein has been mined almost to the surface with a little ore left as pillars for support. Two winzes go below the level at 60 and 120 feet (18 and 37 m) north of the shaft station. These winzes connect to the 175-foot level but are flooded to within 10 feet (3 m) of the 100-foot level. A drift follows the vein south for at least 60 feet (18 m). At this point the vein is displaced by a postmineral fault. Close examination of slickensides on the fault surface indicates that the north side of the faulted vein rakes downward 51 degrees to the east for an unknown distance. A branching drift extends farther to the south but is caved in at the fault zone. Stoping above the level extends to a height of approximately 50 feet (15 m). Ten feet (3 m) south of the shaft station, a winze has been sunk below the level for an unknown distance. This winze, like the others north of the shaft, is filled to within 10 feet (3 m) of the level with water. The extent of stoping below the level is unknown owing to its flooded condition.

Other Workings

There are two small shafts and an adit on the Aetna vein besides the Aetna shaft. One shaft is approximately 400 feet (120 m) south of the Aetna shaft collar, and the other is near the southern end of the vein just north of Newels Spring. Both of these shafts are shallow and were not entered. An adit has been driven into the west side of the gully that parallels the vein to the east. The portal is approximately one-half mile (805 m) south of the Aetna mine and was driven into the hillside about 50 feet (15 m) above the bottom of the gully (plate 2a). The adit is driven N. 75° W. for approximately 225 feet (69 m), crosscutting several stringers of quartz and calcite. The stringers range from the width of a pencil to 6 feet (2 m). One 6-foot (2 m) vein is crosscut 190 feet (58 m) from the portal. From this point the vein is followed by the workings north for 60 feet (18 m). Intense argillic alteration and moderate to intense limonitic alteration is associated with quartz and calcite in the stringers and veins intersected by the crosscut. Two samples were taken in this adit and the results are shown on plate 2a.

An open cut about 150 feet (46 m) south of the Aetna shaft exposes the Aetna vein. Two samples were taken across a part of the vein in the open cut. The sampled vein consists half of stringers of quartz and limonite-stained calcite and half of silicified andesite. Sample PJ-3 is a 3-foot (1 m) cut; sample PJ-4 is a 3-inch (7 cm) cut across an intensely limonitically-altered calcitic-quartz part of sample PJ-3; results are shown in table 3. Sample PJ-4 was resampled and sent for examination to Cather, who reported that the gangue minerals were mainly quartz containing small amounts of limonite. The heavy fraction of a heavy liquid separation contained limonite, a small amount of pyrite, and gold.

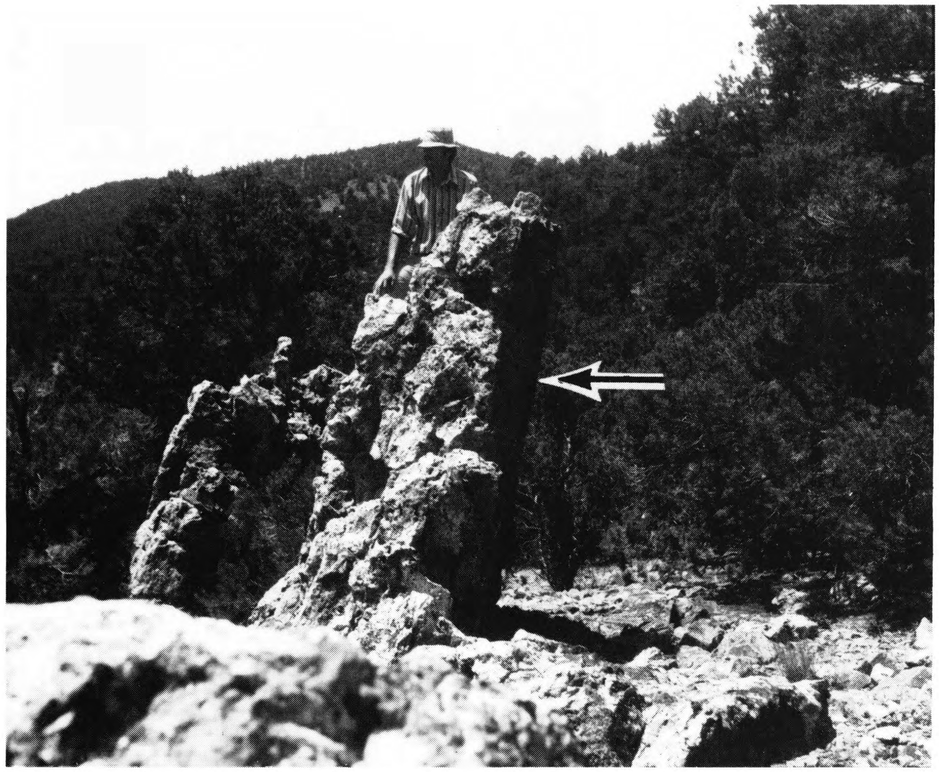


Figure 9. Unnamed vein on the Sigbee patented claim, looking south. Arrow indicates the contact of the sharp hanging wall with the country rock.

E-2 Vein

The E-2 vein in the southern half of sec. 26, T. 33 S., R. 20 W., Utah, strikes north and dips steeply to the west. The outcrop of the vein, with an average width of 2 feet (0.6 m), is traceable on the surface for about 400 feet (122 m). Much argillic alteration accompanies the vein, and intense alteration is found on the hanging wall of the vein. Quartz, hematite, and limonite are also in the vein.

E-2 Workings

Development of the E-2 vein consists of a shaft and an adit, one on each side of the road between the Gold Springs townsite and the Jennie mine. The shaft on the downhill side of the road is sunk on the vein. At the time of the investigation the shaft was caved in, but the amount of material on the dump suggests that there is at least 50 feet (15 m) of workings. The adit is on the uphill side of the road, and its dump is adjacent to the road. The map of this adit is shown in plate 2b. The adit has 150 feet (46 m) of drifting along the vein. In the portal the vein is 2 feet (0.6 m) wide and consists of quartz and limonite. Much white clay, possibly kaolin, and hematite are on the hanging wall side of the vein, and some white clay is on the footwall side. The argillic alteration extends for a couple of feet on either side of the vein. Approaching the face of the drift the vein becomes less argillaceous, and the quartz disappears. Five samples were taken from the adit; the results are shown in plate 2b.

E-1 Vein

The E-1 vein, in sec. 26, T. 33 S., R. 20 W., Utah, lies between the Jennie and E-2 veins. The vein outcrop is subdued and can only be traced by float for most of its strike length. The vein is composed of quartz, calcite, and adularia. The adularia gives the vein a greenish yellow color that is characteristic of most of the veins in the area.

E-1 Workings

Workings on the E-1 vein consist of a shallow inclined shaft and a short adit. The shaft is inclined about 65 degrees and is 30 feet (9 m) deep. At the shaft collar, the vein is approximately 3 feet (1 m) wide but narrows to almost a foot (0.3 m) near the bottom of the shaft. The vein has been cut off in the bottom of the shaft by a fault striking N. 40° E. and dipping N. 70° W. The displacement along this fault is probably small. A

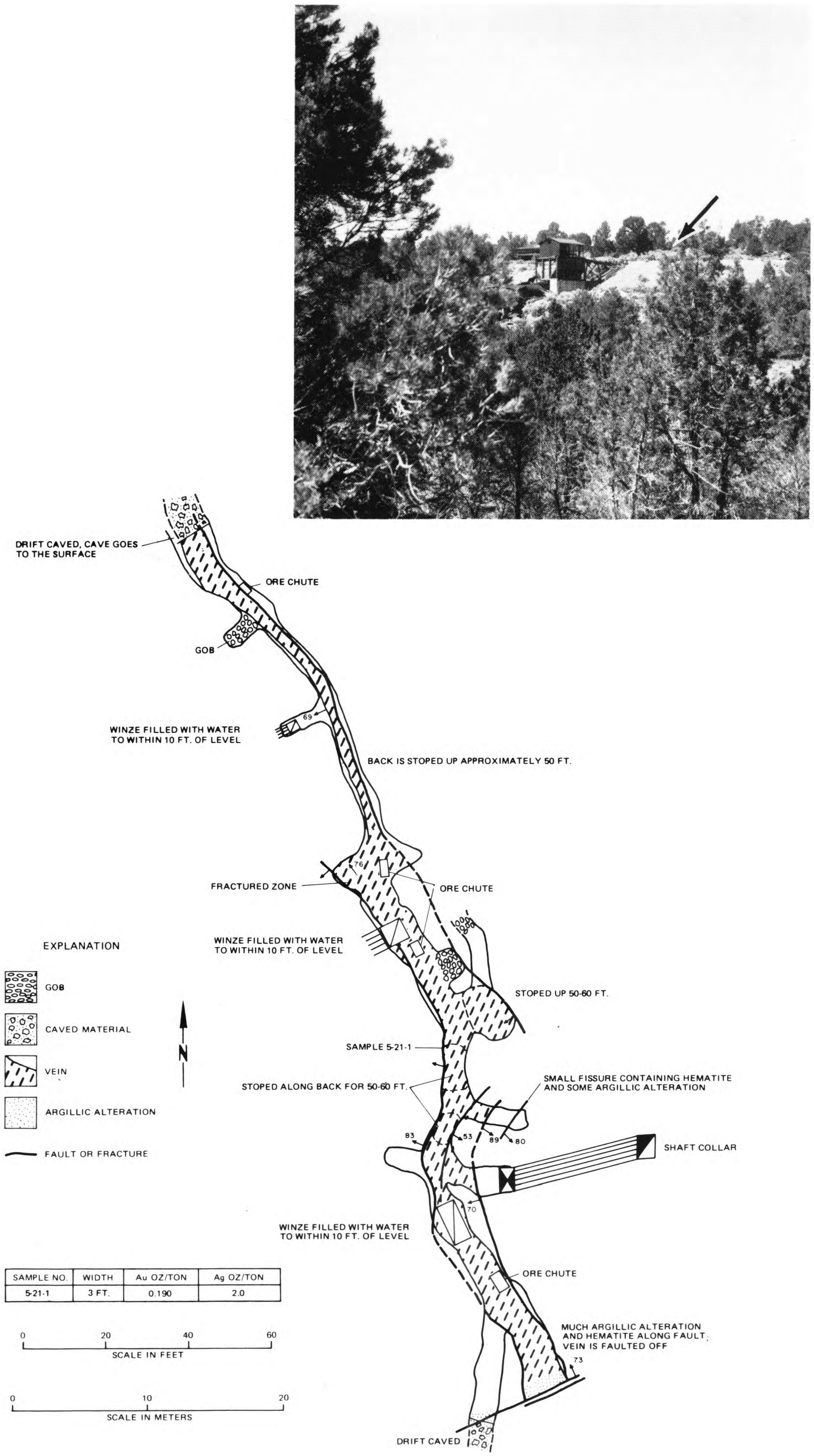


Figure 10. Map of 100-foot level of Aetna mine. Photograph shows the Aetna mine and mill as seen from across the gully, looking southwest; arrow indicates the position of the shaft collar. Assay of ore sample is shown in table.

Table 3. Assays of samples from open cut, Aetna vein.

Sample number	Width	Gold (ounces/ton)	Silver (ounces/ton)
PJ-3	3 feet	0.730	2.3
PJ-4	4 inches	1.230	4.6

14-inch (36 cm) wide sample taken across the vein in the bottom of the shaft above the fault shows a trace of gold and 0.4 ounce of silver. Near the southern end of the vein a short adit has been driven along the hanging wall of the vein for about 25 feet (8 m). No stoping was done from the adit.

Jennie Vein

The Jennie vein is 4 to 6 feet (1.2 to 1.8 m) wide with some swells of 10 to 20 feet (3 to 6 m). According to Standish (1939) the vein occurs in andesite and is intersected at intervals by 4- to 24-inch (0.1 to 0.6 m) ore stringers which branch out at acute angles from the main vein. The junctions of the stringers and the vein provide thicker vein material and a concentration of gold and silver. The vein, which strikes N. 15° W. and dips 55 to 70 degrees east, is composed of quartz and calcite and has well-defined walls. Standish reported that the best ore is found "in the hard blue quartz, which carries about 35% free milling gold, and the balance are in the oxides of iron." The vein material fills an open fissure and is distinctly banded and crustified. Standish reports that the calcite was first to form and later replaced by quartz and adularia.

Jennie Mine

The Jennie mine on the Jennie vein is the largest producer in the Gold Springs district (figure 11). It is on the Utah-Nevada border on the western edge of sec. 26, T. 33 S., R. 20 W., Utah. Mining had commenced at the turn of the century, but production was first reported in 1907 and last in 1948, although no substantial production was reported after 1937. According to the U. S. Bureau of Mines the total production of the Jennie mine is 16,391 tons of ore containing 3,647 ounces of gold, 21,535 ounces of silver, 70 pounds of copper, and 140 pounds of lead. This total gives an average grade for the ore at 0.22 ounce of gold and 1.3 ounces of silver per ton.

The Jennie mine has been developed on the 60-, 100-, 200-, and 300-foot levels. The levels are serviced by a single compartment shaft collared on

Figure 11. Headframe and rock house of the Jennie mine as seen in 1974 from the dump, looking north.

the hanging wall side of the vein and bottomed on the footwall side. The vein is cut by the shaft between the 60- and 100-foot levels. Development on the levels follow the vein northwest and southeast of the shaft. A composite level map and two cross sections by Standish (1939) are included as figures 12, 13, and 14. Figure 13 is a N. 45° W. longitudinal section through the mine. Figure 14 is a N. 75° E. section across the vein.

An attempt was made by the author to examine the workings of the Jennie mine in May 1975. The 60-foot level north of the shaft was open, and no additional work appeared to have been done other than shown in figure 15. Forty feet (12 m) south of the shaft the drift is caved in, and the workings past that point could not be examined. The 100-foot level was reached through the stopes from the 60-foot level north of the shaft. This level was open for approximately 75 feet (23 m) south of the shaft at which point it was caved in. North of the shaft the drift, open for 50 feet (15 m), was examined. On the 100-foot level the footwall of the vein consists of 6 to 8 feet (1.8 to 2.4 m) of white- to gray-banded calcite. This part of the vein has been left intact, and 4 to 5 feet has been mined on the hanging wall of the vein. The back of the stope was sampled approximately 50 feet (15 m) north of the shaft; assays show a trace of gold and 0.2 ounce of silver to the ton. An ore chute is open just south of the shaft from the 100-foot level to the 200-foot level, but it was not explored because of badly caving ground.

The cross section (figure 15) by Ferri shows that the Jennie vein was cut off above the 300-foot level. This is explained by Mallory (1928) (figure 16) to be the result of a series of north-south faults dipping to the west that have cut the Jennie vein into at least four segments. According to Mallory, the faulted segments from the west to the east are the Thor or Talisman, Jennie, and the E-1. He suggests that an undiscovered vein segment would be found to the east of the E-1 vein (figure 16). The surface was examined in the vicinity of the Jennie mine for these faults, but owing to heavy soil cover and abundant vein float no evidence could be found to support or disprove Mallory's idea. Block's mapping (1972) of the surface does not show any north-south faults in this area. Perry (this paper) found vein float just below the contact of the andesite and lithic crystal tuff on the hill northeast of the Jennie by which he infers the possibility of a concealed vein as suggested by Mallory.

A fault striking N. 80° E. and dipping 55 degrees south has displaced the Jennie vein north of the shaft. According to Mallory this north fault block is displaced 147 feet (45 m) to the east. No drifting has been done to look for the faulted part of the vein. Float located northeast of the Jennie implies that the displaced vein might be under Jennie Hill but is concealed by the lithic crystal tuff.

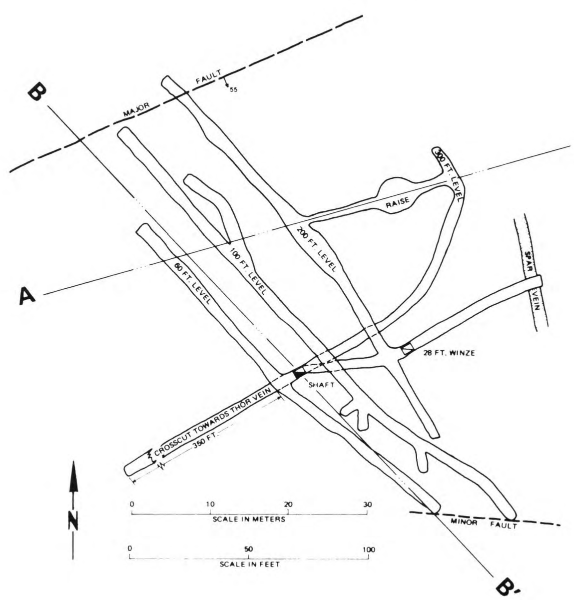


Figure 12. Composite map of the levels in the Jennie mine, modified after Standish (1939).

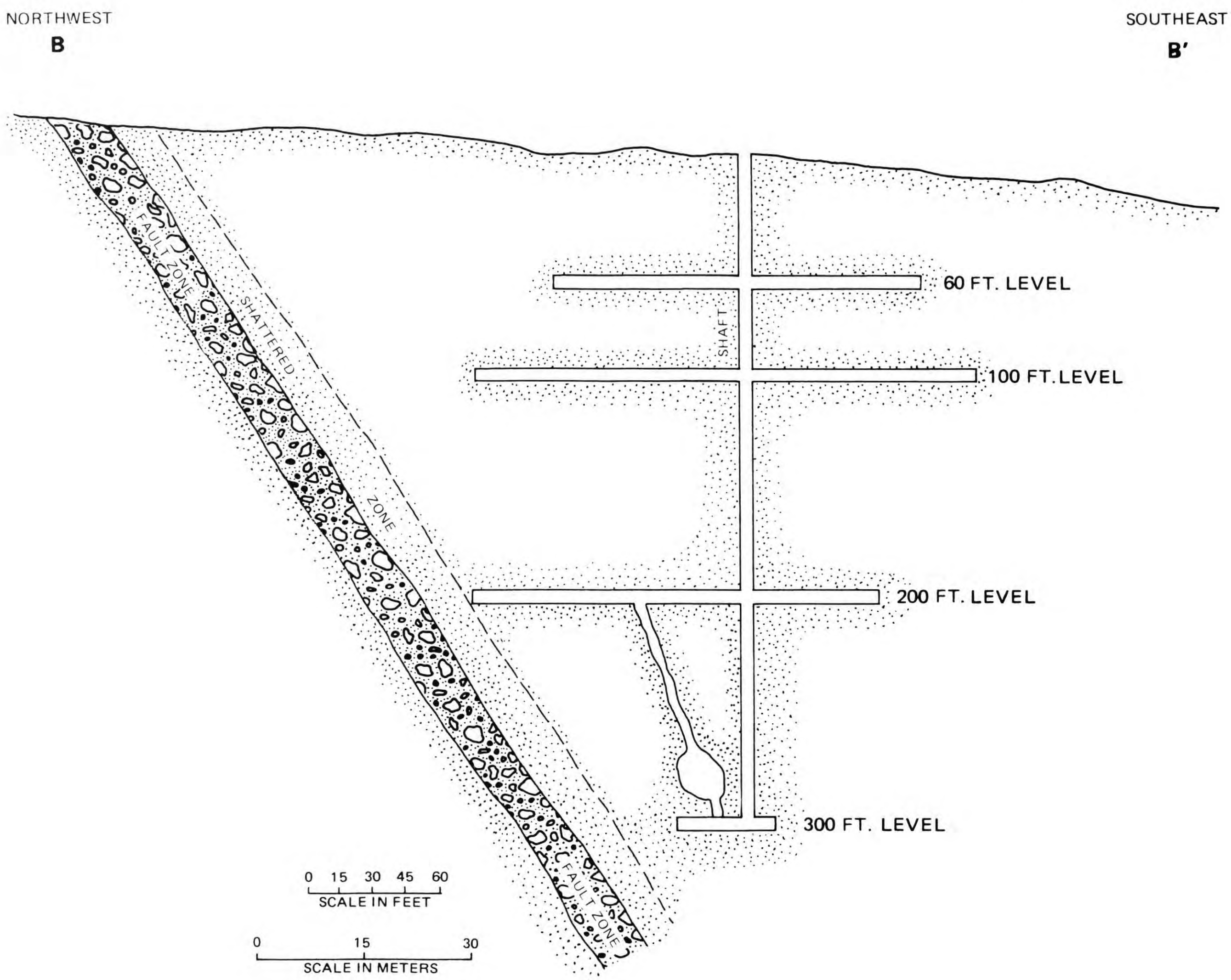


Figure 13. Inclined section of Jennie mine through B-B′ (see figure 12), modified after Standish (1939).

Vein Cut by Uvada Tunnel

A vein is intersected by the Uvada tunnel, which is approximately 800 feet (244 m) northwest of the Jennie shaft. This is probably the northern end of the offset Jennie vein. The vein ranges from 2 feet (0.6 m) to 4 feet (1.2 m) and averages 3 feet (1 m) in width. The vein is mostly calcite that is stained with manganese. Disseminated and blebby manganese oxides are throughout the calcite in the vein.

Uvada Tunnel

The Uvada tunnel (plate 2c) was driven to crosscut the Thor and Jennie veins. From the portal to the face it is 960 feet (293 m). One major vein, 520 feet (158 m) from the portal, is crosscut in the workings. The entire length of the adit is in andesite that is slightly to intensely fractured and contains argillic alteration. Stringers of calcite are common, ranging from one-sixteenth of an inch (1 mm) to a foot in width. An area of massive calcite, 25 feet (8 m) in width and approximately 50 feet (15 m) from the face, may possibly be the Spar vein in the Jennie mine (figure 12). A calcite vein containing manganese oxides, which is probably the Jennie vein, was intersected 520 feet (293 m) from the portal, and a drift was driven along it to the north for 170 feet (52 m). Three samples were taken along this vein, and only one showed gold and silver. Assays from the Uvada tunnel are shown in plate 2c.

Thor (Talisman) Vein

The Thor vein is in the SE¼ sec. 32, T. 1 N., R. 71 E., Nevada, approximately 600 feet (183 m) west of the Jennie mine. The vein is poorly exposed but can be traced for approximately 1,000 feet (305 m) on the surface. The vein strikes N. 20° W. to N. 15° E. and dips 55 degrees east. The vein, which ranges in width from 2 to 20 feet (0.6 to 6 m) with the widest point near the central part of the vein, consists of much calcite, adularia, and a small amount of quartz.

Thor Workings

The main workings on the Thor vein consist of two open cuts and two adits. The adits intersect the vein approximately 50 feet (15 m) vertically below the surface outcrop (figure 17). The Thor adit (plate 2d), driven in an easterly direction for 240 feet (73 m), crosscuts the Thor vein 65 feet (20 m) from the portal; at this point a drift follows the vein south for 140 feet (43 m). No stopes were developed in the drift to the south. At 120 feet (37 m) from the portal another drift to the south was driven along a small calcite fissure. Seven samples were taken in the Thor underground workings; the results are shown in plate 2e. Another adit was driven to cut the vein south of the Thor adit. The portal is near the ore bin and was caved in at the time of visit. From the open cuts on the outcrop the ore has been along the hanging wall of the vein. This rock is mostly calcite and a little adularia and quartz. Some native gold can be seen with a hand lens and can be concentrated by panning.

Surface buildings consist of the remains of three cabins that served as tool shops or living quarters. An inclined track runs from the open cuts to an ore bin at the level of the Thor crosscut. From the open cuts the grade of an old track can still be seen going south around the hill to the Herzog mill in the bottom of the gully southeast of the workings. Other workings on the Thor vein consist of at least two small prospect pits near the southern end of the vein.

A sample from the hanging wall of the vein in the largest open cut southeast of the Thor adit was submitted to Cather. In the sample, gold, which can be seen with the hand lens, is associated with limonite. According to Cather's report the sample consisted "primarily of coarsely crystalline quartz, subordinate adularia, and minor amounts of limonite. Gold was seen primarily as free grains ranging up to almost 0.25 millimeters. Some locking of gold with limonite was also seen."

The Thor vein is cut off by post-mineral faults on both ends. In addition the fault on the north displaces the Jennie vein in the Jennie mine. The fault on the southern end of the vein terminates the known outcrop of the Thor and also cuts the E-2 vein located 1,500 feet (457 m) to the east.

Vein on Bull Hill

A vein on Bull Hill in SE¼ sec. 29, T. 1 N., R. 71 E., Nevada, strikes N. 20° E. and dips steeply to the west; it averages 2 feet in width but has swells up to 3 feet wide. The vein consists of purple and green fluorspar and some hematite containing gold and silver. Purple fluorspar is much more common than the green. The hematite-rich material on the shaft dump will yield good color in the pan.

Shaft on Bull Hill

A shallow shaft, 30 feet (9 m) deep, has been sunk into the vein on Bull Hill

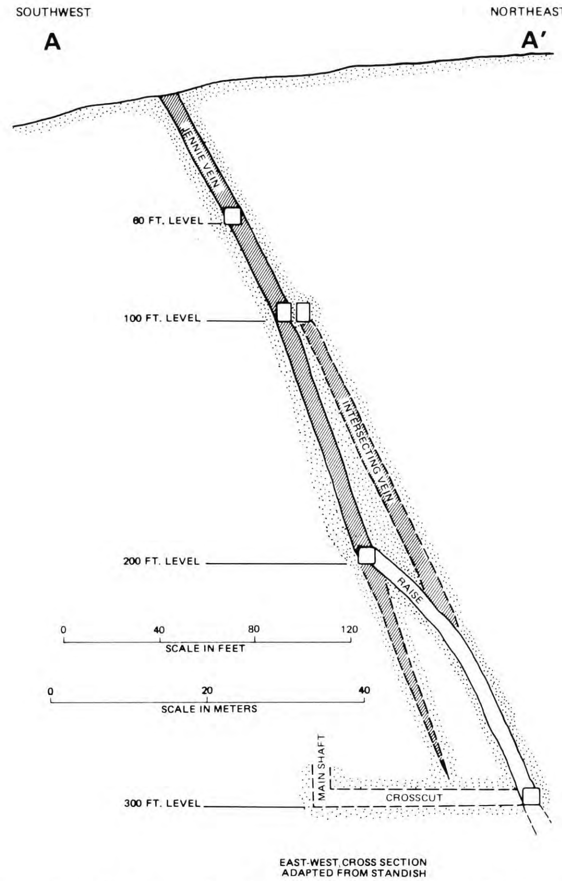


Figure 14. Vertical section of Jennie mine through A-A' (see figure 12), modified after Standish (1939).

(figure 18). In the bottom of the shaft the vein splits into two stringers, each one foot wide. An attempt has been made to upgrade the ore from the shaft by screening the ore and retaining the fine-grained gold-bearing hematite. The shaft was examined and samples were taken 25 feet (7.5 m) below the collar (table 4). Sample 5-12-1 is a grab sample of fluorspar and hematite from the shaft dump. Sample 5-12-2 is a grab sample from the dump of the fines that were saved after screening. Sample 7-17-1 is a 1-foot cut in purple fluorspar and hematite on the north side of the shaft 15 feet (5 m) below the collar. Sample 7-17-2 is a 1-foot cut across a stringer of purple fluorspar and hematite in the bottom of the northeast corner of the shaft. Sample 7-17-3 is a 1-foot cut across purple fluorspar and hematite in the bottom of the southwest corner of the shaft. Sample 7-17-4 is a 2-foot cut across purple fluorspar and hematite on the west side of the shaft 25 feet (7.5 m) below the collar.

Charley Ross Vein

The Charley Ross vein in the NW¼ sec. 32, T. 1 N., R. 71 E., Nevada, strikes N. 30° E and dips 72 degrees northwest; it is made up of quartz, calcite, and much dark red hematite stained clay. Argillic alteration has intensely altered the andesite wallrock to a whitish clay that is possibly kaolin. The outcrop of the vein is subdued and can be traced, although with difficulty, for 400 feet (122 m) on the surface.

Charley Ross Mine

The Charley Ross mine consists of an inclined shaft and an adit to explore the Charley Ross vein and the altered area associated with it. The Charley Ross vein is 1,000 feet (305 m) northeast of the Little Buck shaft. The shaft and adit are in the NW¼ sec. 32, T. 1 N., R. 71 E., Nevada. According to the *Salt Lake*

Table 4. Assays of samples from the shaft on Bull Hill.

Sample number	Width	Gold (ounces/ton)	Silver (ounces/ton)
5-12-1	grab	0.080	0.8
5-12-2	grab	0.430	0.6
7-17-1	1 foot	0.040	0.2
7-17-2	1 foot	0.020	1.1
7-17-3	1 foot	0.025	2.6
7-17-4	2 feet	0.085	0.2

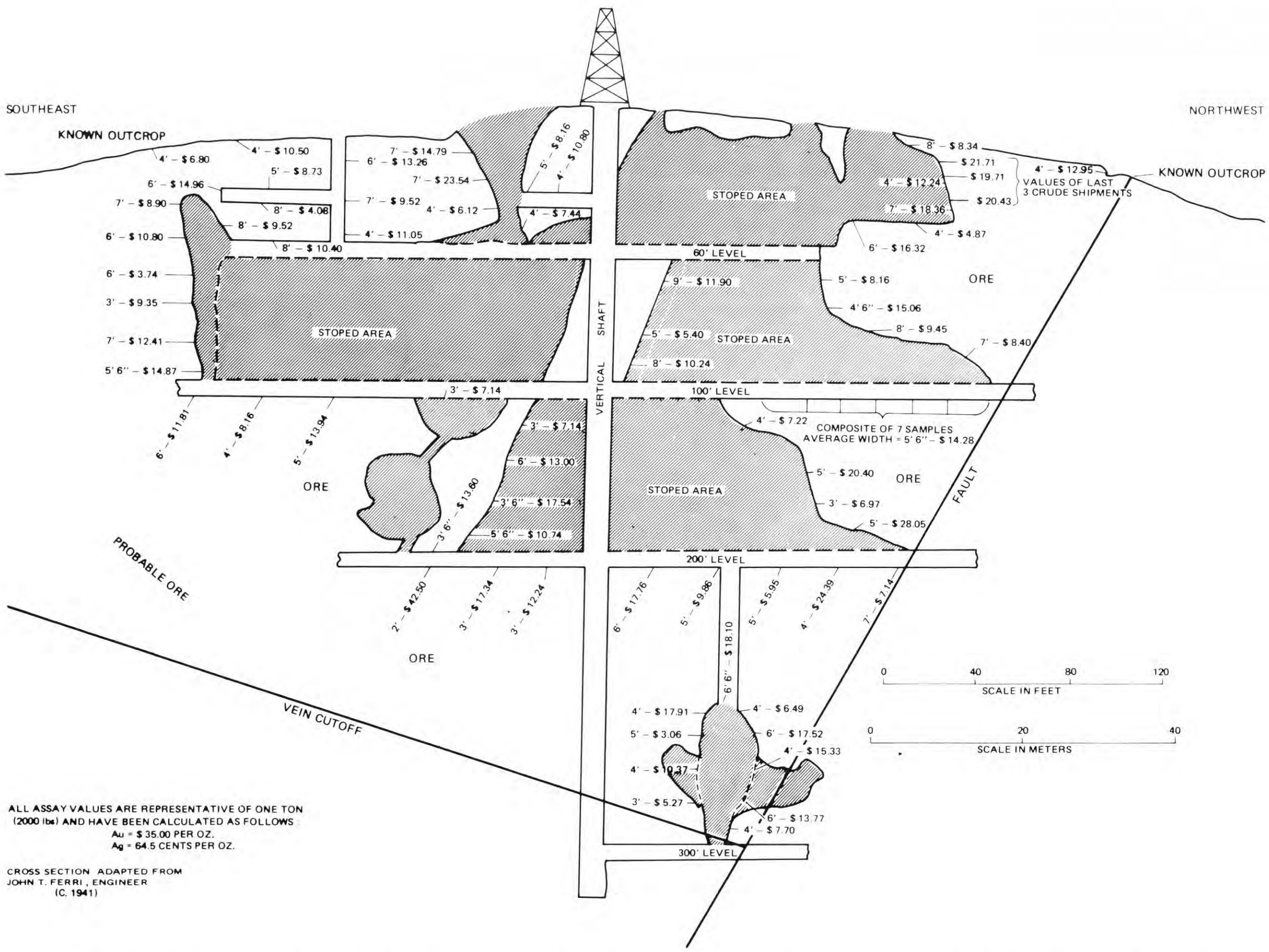


Figure 15. Inclined section of Jennie mine through B-B′ showing assay results (see figure 12), modified after Ferri (circa 1941).

Mining Review (1903) the shaft is 175 feet (53 m) deep. The shaft is inclined 72 degrees and has two small levels at 60 feet and 80 feet (18 m and 24 m) below the collar (figure 19). On the 60-foot level workings go northeast and southwest from the shaft. The northeast drift was not examined, but it had at least 40 feet (12 m) of working on the vein. The southwest drift was 50 feet (15 m) long. The 80-foot level has 45 feet (14 m) of drifting to the southwest along the vein. The vein has been stoped up about 10 feet (3 m) above the back of the drift. On the 80-foot level the vein is 6 to 8 inches (15 to 20 cm) wide and is composed of dark red hematite and quartz. The shaft is caved in at the 80-foot level and was not accessible below there. Four samples were taken; the results are shown in table 5. Sample 8-10-1 is a 6-inch (15 cm) cut in limonite 40 feet (12 m) southwest of the shaft on the 60-foot level. Sample 8-10-2 is a 2-foot (0.6 m) cut in a limonite-stained clay on the hanging wall of the vein, 40 feet (12 m) southwest of the shaft on the 60-foot level. Sample 8-10-3 is a 6-inch (15 cm) cut in hematite, 30 feet (9 m) southwest of the shaft on the 80-foot level. Sample 8-10-4 is a grab sample from dark red hematite that had fallen out of the back of the drift 25 feet (8 m) southwest of the shaft on the 80-foot level.

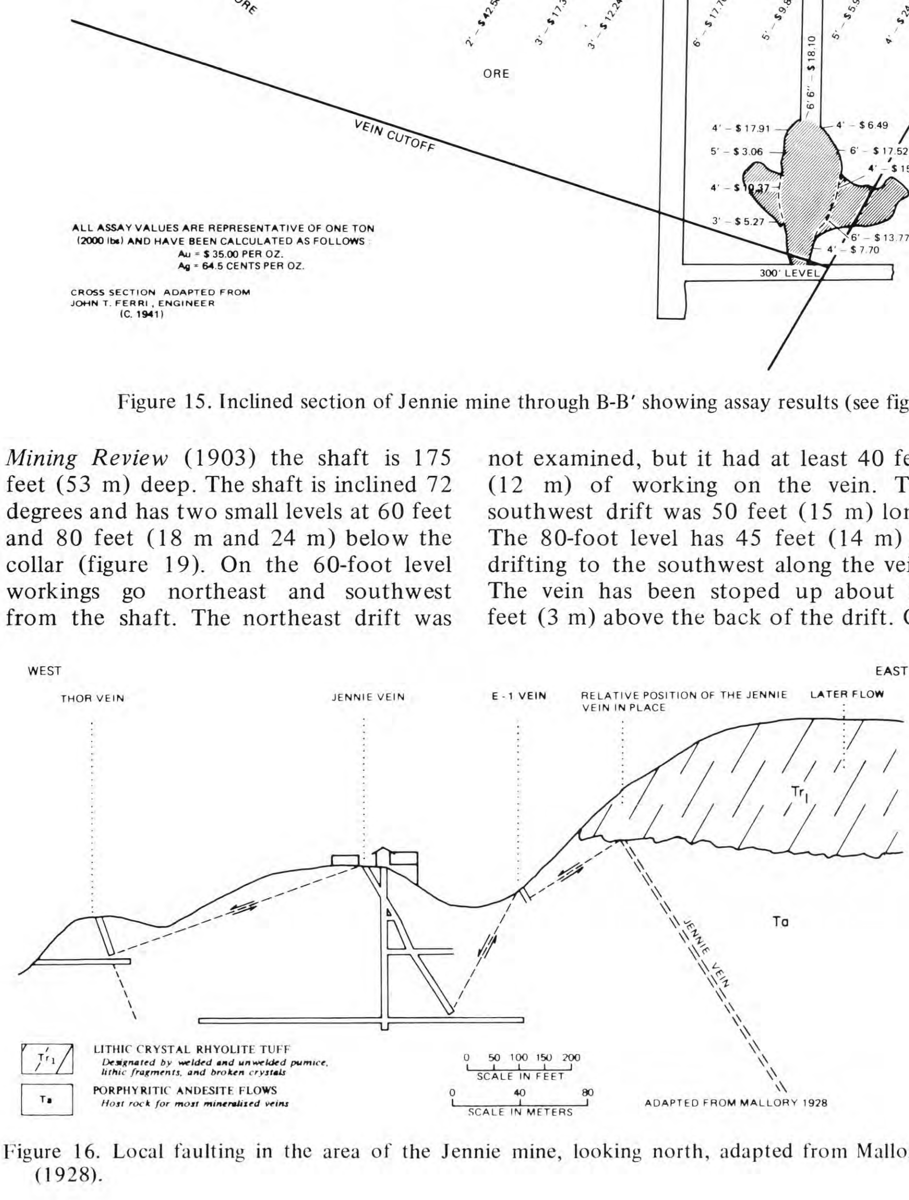


Figure 16. Local faulting in the area of the Jennie mine, looking north, adapted from Mallory (1928).

An adit was driven into the hill 400 feet (122 m) south of the Charley Ross shaft to look for the southern extension of the Charley Ross vein (figure 20). The adit cut and drifted along a fault zone accompanied by intense argillic alteration similar to that seen in the Charley Ross

Table 5. Assays of samples from the Charley Ross shaft.

Sample number	Width	Gold (ounces/ton)	Silver (ounces/ton)
8-10-1	6 inches	0.040	0.2
8-10-2	2 feet	0.005	none
8-10-3	6 inches	0.145	0.2
8-10-4	grab	0.040	0.2

shaft. The lack of stoping in the adit suggests that the metal value was not present in quantities of ore grade. After following the zone for 80 feet (24 m), the drifting continued to the northwest and failed to find minable rock. No samples were taken from this adit.

Snowflake Vein

The Snowflake, the largest vein complex in the district, is just over the Utah state line on the east side of Buck Mountain. Starting at Gold Springs Wash in sec. 4, T. 1 S., R. 71 E., Nevada, and going N. 15°-20° W. to the northern edge of sec. 32, T. 1 N., R. 71 E., Nevada, the strike of the complex can be traced about 6,800 feet (2,072 m). The Snowflake consists of several small veins or veinlets that range from 1-inch stringers to ones more than 20 feet wide (2.5 cm to 6 m). In places the complex is over 100 feet (30 m) wide but generally is around 50 feet (15 m) of stockwork-type mineralization. The veins are composed chiefly of calcite, quartz, and adularia and small amounts of limonite and pyrite. Boxwork derived from pyrite is common in the vein and suggests the presence of pyrite with depth (Asher, 1959). The presence of gold and silver is spotty and usually not in minable amounts. In the early days high-grade pockets and lenses were mined and shipped as smelting ore. The best concentrations of gold and silver seem to be where the main vein complex is cut by cross structures, which cause a swelling in the vein width. The Snowflake quarry was developed along several of these cross structures on the north end of Buck Mountain.

Several samples from different spots on the complex were crushed and panned, and gold was found in some. All of the gold seen was fine, and most was not visible to the naked eye. A sample taken from the open cut 100 feet (30 m) west of the Little Buck shaft was examined by Cather and was reported to be composed of quartz and small amounts of limonite. The gold present was up to 100 microns in diameter and was free from any gangue mineral. Some scattered pyrite was seen in the sample.

The principal workings on the Snowflake vein, listed from the north to

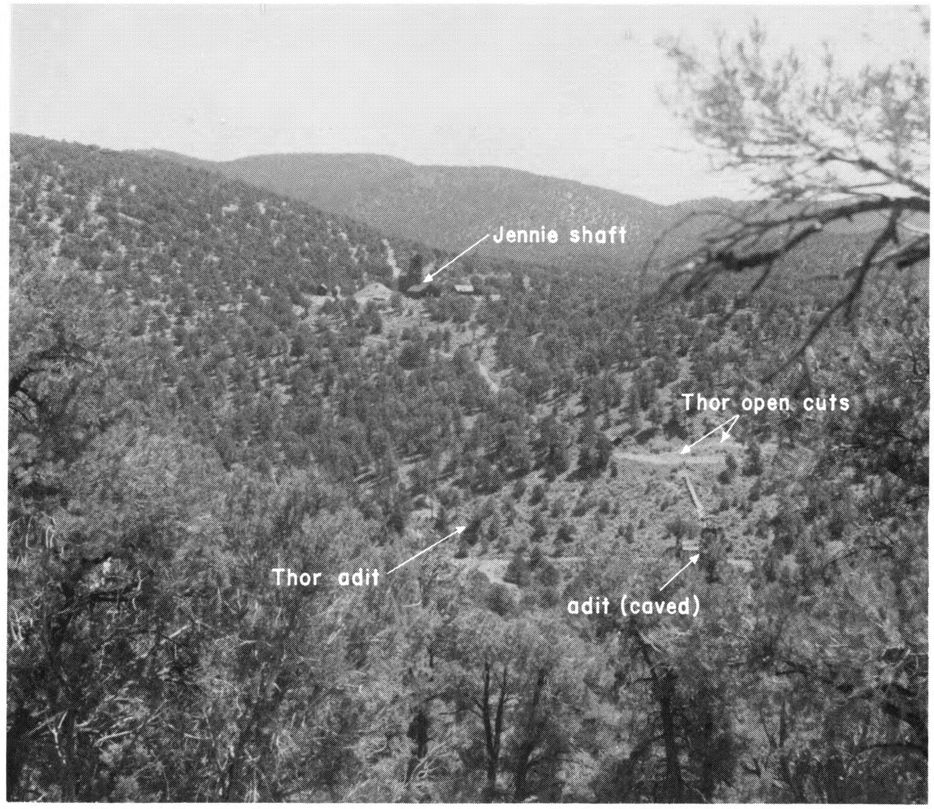


Figure 17. Workings on the Thor vein as seen from Buck Mountain, looking east.

Figure 18. Shaft on the vein on Bull Hill, looking southeast. The Jennie mine, indicated by arrow, can be seen in the distance.

Figure 19. Headframe of the Charley Ross shaft, looking south.

the south, are the Little Buck mine, Big Buck mine, Snowflake quarry, and the Red Eagle mine. Several other prospects are at various points on the complex.

Little Buck Mine

The Little Buck (plate 2e), the largest mine on the Snowflake vein, possibly rivals the Jennie as the largest producer in the district. It is on Winner No. 2 patented claim near the head of Midnight Wash in the NW¼ sec. 32, T. 1 N., R. 71 E., Nevada (plate 1). The shaft is located on an eastern strand of the Snowflake vein called the Little Buck vein. The Little Buck vein, according to Young (1934), ranges in width from a few inches to nearly 3 feet: "At some places [in the Little Buck mine] there is a splitting or feathering out of the vein, but after a few feet the average width again develops." The strike is N. 20° W. dipping 70 degrees east, varying locally 10 to 15 degrees.

The Little Buck shaft is inclined 70 degrees and has four levels developed from it. These levels are cut off the shaft at 70 feet (21 m), 135 feet (41 m), 185 feet (56 m), and 270 feet (82 m). Plate 2e is a reproduction of a composite map of the Little Buck mine by Jensen (1935) for the Andesite Mining Company. According to this map the mine contains 60 feet (18 m) of drifts on the 70-foot level and 340 feet (104 m) of drifts on the 135-foot level. The 185-foot level is the most extensive in the mine, consisting of 180 feet (55 m) of drifts south of the shaft and 340 feet (104 m) of drifts north of the shaft for a total of 520 feet (158 m). The 270-foot level consists of drifts 90 feet (27 m) south of the shaft and 330 feet (101 m) north of the shaft for a total of 420 feet (128 m). The total for the four levels is 1,340 feet (408 m). The ore body was developed and mined by raising from the levels and stoping the ore between the levels. According to Young (1934) most of the ore above the 185-foot level had been mined at that time, and the only remaining ore with any significant tonnage was below the 185-foot level. Jensen (1935) reported the reserves of the mine at 4,619 tons on November 1935, with an average grade of 0.20 ounce gold and 2.5 ounces silver to the ton. The mine was operating at the time of Jensen's report, and this ore was probably extracted.

There has been little faulting in the Little Buck mine to displace the ore body, but premineral faults have been a factor in the control of the Little Buck vein. According to Young there is a fault on the north end of the 135-foot level striking N. 50° W. and dipping 38 degrees northeast. This fault is picked up on the 185-foot level as shown in plate 2e; the drifts following the vein bend around to the west. Young describes this fault as "probably premineral with a small post-mineral movement." He also describes a fault in a stope above the 270-foot level south of the shaft with 5 feet (1.5 m) of displacement and with the north side of the fault shifted eastward. Other small minor postmineral faults are mentioned by Young, but the displacement is less than 5 feet (1.5 m) in all cases.

At the time of the author's visit, the workings of the mine were inaccessible because the shaft was caved in 20 feet (6 m) below the collar. The surface plant is almost gone with only a shop building, headframe, and ore bin standing. The steam boiler and hoist are still on the mine property and are reproduced in figure 21 as they appeared in 1975.

Big Buck Mine

The Big Buck mine is on Winner No. 2 patented claim near the head of Midnight Wash in the NW¼ sec. 32, T. 1 N., R. 71 E., Nevada (figure 22). The shaft collar is 650 feet (198 m) southeast of the Little Buck shaft. The Andesite Mining Company map by Jensen dated October 31, 1935, reproduced in figure 22, shows three levels at 30, 50, and 100 feet. The workings were examined by the author in 1974 but were not remapped. A sample was taken from the 50-foot level at the point designated in figure 22 as 5-1-1. This is a 1-foot cut across a calcite and quartz vein containing some limonite, its analysis showed 0.170 ounce of gold and 0.3 ounce of silver to the ton. The vein sampled appeared to be from a parallel or branch vein other than the one that was mined above the 50-foot level. The drifts on the 50-foot level are open with the exception of the N. 80° W. drift which was caved in. The 100-foot level was examined and appears as shown on Jensen's map. The drift going to the south from the shaft station is along a 3 to 6 inch (7 to 15 cm) vein; no stoping was done on this level south of the shaft. Extensive stoping has been done on and above the 50-foot level with stopes up to 20 feet (6 m) wide extending to the surface. The ore seems to have pinched out with depth, and the only evidence of ore on the 100-foot level is in the 3-inch to 6-inch (7 to 15 cm) vein. Jensen's map shows up to 2 feet of ore on the 100-foot level with 0.15 to 0.25 ounce of gold to the ton, but no samples were taken to verify this.

Just north of the Big Buck shaft is a postmineral fault that strikes N. 55° W. and dips steeply to the northeast. This fault offsets the northern end of the Snowflake vein complex a little over 100 feet (30 m) to the west. The Big Buck shaft is on a vein on the west side of the

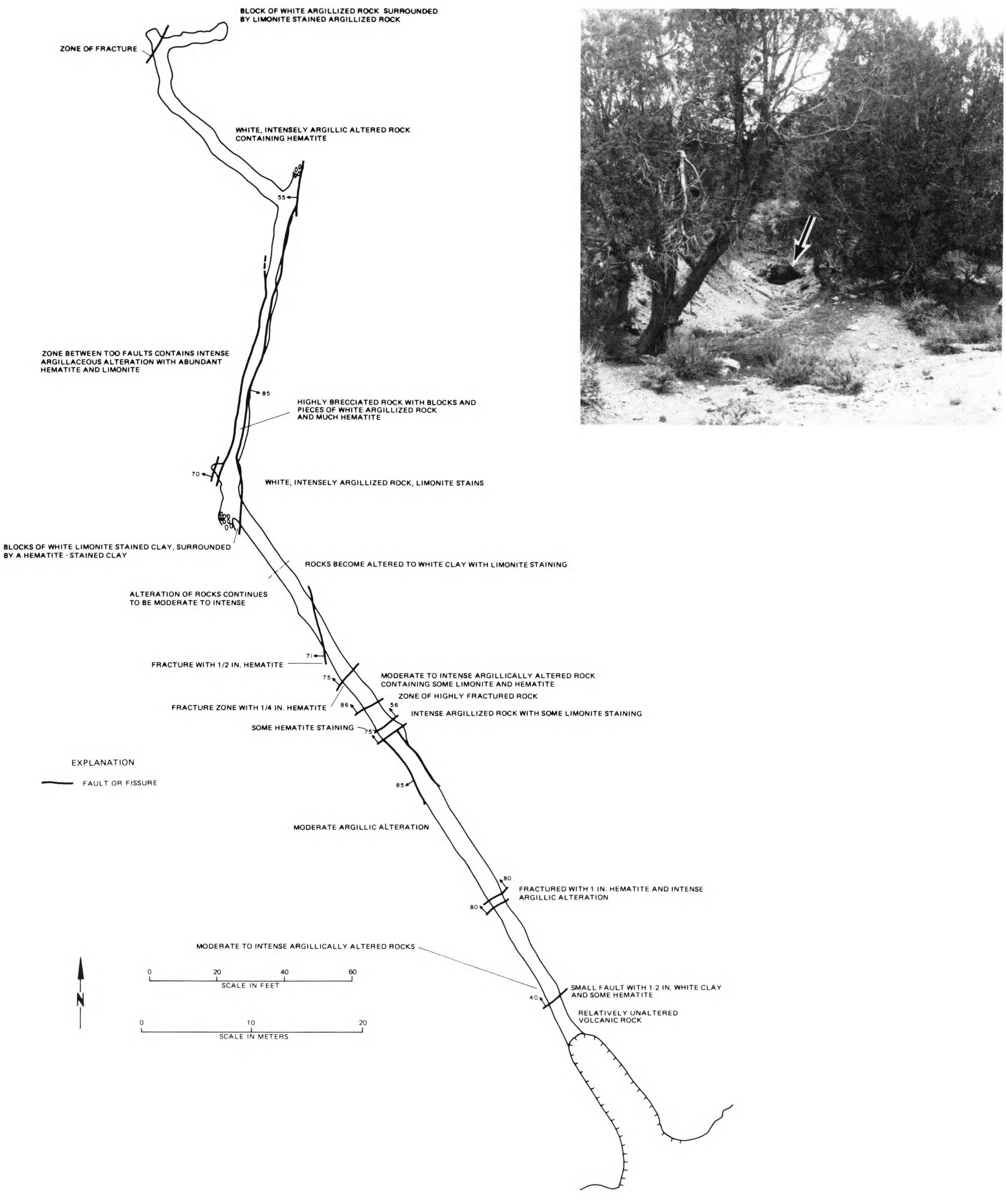


Figure 20. Map of Charley Ross adit, looking northwest. Photograph shows the partly caved in portal, indicated by arrow.

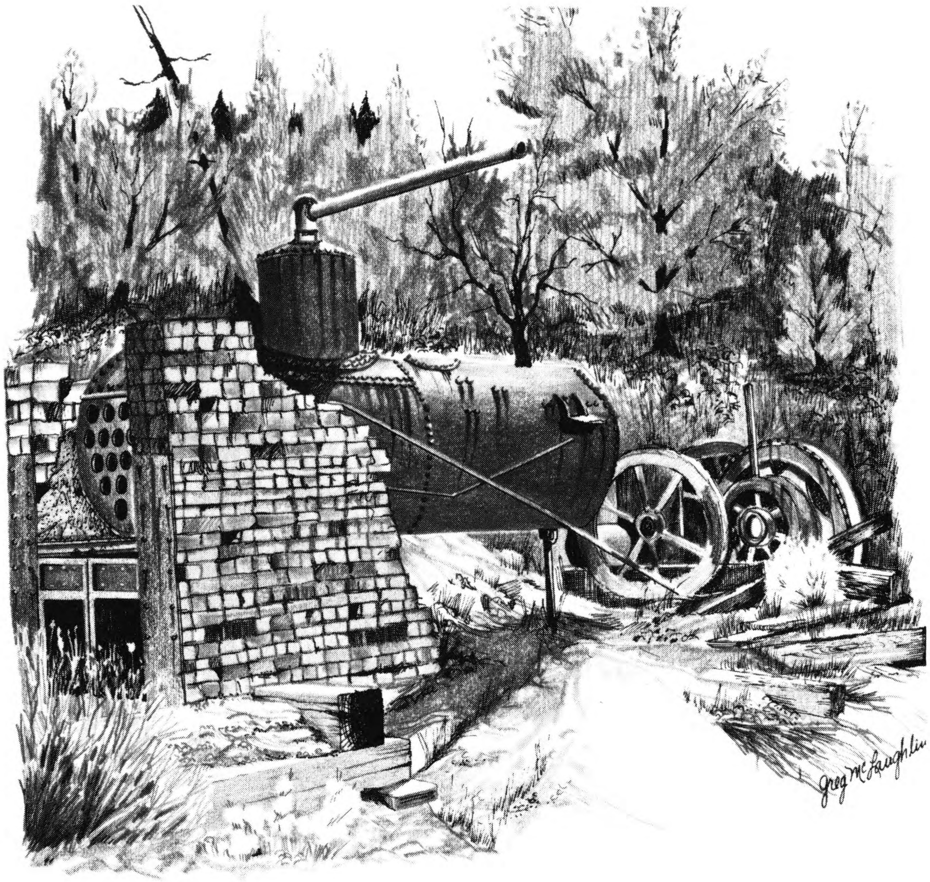


Figure 21. Steam boiler and hoist of the Little Buck mine as seen in 1974.

Snowflake vein complex, whereas the Little Buck is on a vein that is on the east side.

Snowflake Quarry or Glory Hole

The Snowflake quarry (figure 23) is in the W½ sec. 32, T. 1 N., R. 71 E., Nevada, on the Snowflake patented claim. The quarry is a large glory hole on the Snowflake vein complex where several quartz stringers crossing the complex cause an increase in vein width and value. According to Young (1934) several thousand tons of ore had been mined from the quarry prior to 1934. He reports 550 tons of ore taken from an underhand stope in the quarry that was milled at the Horseshoe mill in Fay, Nevada, and which returned $9.91 a ton (this ore was milled when gold was $20.00 an ounce). Young (1934) reported "a substantial tonnage of ore that will run about 0.185 oz. in gold and 2.2 oz. in silver" around the quarry. No samples were taken from the quarry for assay, although some samples were panned and showed color.

A tunnel was driven about 180 feet (55 m) vertically below the quarry to cut the vein complex at depth. Although the tunnel was driven below the quarry, the vein was not found. Young (1934) reported that "a flat northwest fault passes underneath the quarry and has displaced the vein." Figure 24 is a plan and cross section of the quarry and tunnel taken from Young's report to the Andesite Mining Company in 1934.

Red Eagle Mine

The Red Eagle mine is on the patented Snowflake No. 2 claim on the east slope of Buck Mountain approximately one-fourth mile southwest of the Jennie mine. It is driven into Buck Mountain to intersect the Snowflake vein and has about 200 feet of workings. The mine workings consist of several prospect holes and an adit that is driven S. 70° W. for 70 feet (21 m), crosscutting a 15-foot (5 m) zone of calcite approximately 10 feet (3 m) from the portal (plate 2f). The calcite is bladed and associated with quartz and much hematite. The workings follow the calcite S. 30° W. for 45 feet (14 m), along which some stoping was done. At a point 45 feet (14 m) from the portal, a drift is driven S. 45° W. for approximately 90 feet (28 m) and crosscuts a fault containing clay and hematite. On the hanging wall of the fault is a zone of massive calcite and some quartz. The calcite is brecciated along the fault and has been recemented with calcite. Some stoping has taken place in the calcite on the hanging wall of the fault. The stoping extends upward for about 20 feet (6 m) above the back.

Pope Mine

The Pope mine is in the SW¼ sec. 29, T. 1 N., R. 71 E., Nevada (figure 25). The Pope vein on which the mine is located is different from any other vein in the district in that it has a strike of N. 60°-65° E. and a southeast dip that varies from steep to vertical. The vein is narrow, averaging 2 to 6 inches (5 to 15 cm) in width, but is ore grade. The shaft is inaccessible, so the examination of the vein was restricted to the surface. Prospects and open cuts follow the vein outcrop for most of its 1,200 foot (366 m) strike length. The vein was sampled in three places and the results are shown in table 6. Sample 5-25-1 was taken 50 feet (15 m) west of the shaft in the east end of the open cut that crosses under the road. At this point the vein was 2 to 3 inches (5 to 8 cm) wide. Sample 5-25-3 was taken at the west end of the open cut 50 feet (15 m) east of the Pope shaft. The vein is 4 inches (10 cm) wide at the point of sampling. Sample 5-25-4 was taken in the open cut 100 feet (30 m) east of the Pope shaft. Some fine gold can be seen with a hand lens at this sample location. The vein was 4 to 6 inches (10 to 15 cm) wide at this sample location.

A sample was taken 50 feet (15 m) west of the shaft in the east end of an open cut and sent to Cather for examination. Cather (1975) reported the sample to be "mainly quartz with small amounts of limonite." Gold was found in the heavy fraction as "free grains up to about 50 microns. Gold up to 15 microns occurs locked with limonite. Tourmaline is a sporadic constituent of the sample." A single grain of chalcopyrite was also seen in the heavy fraction.

Miscellaneous Workings

Twelve hundred feet (366 m) west of the Pope mine in the bottom of the

Table 6. Assays of samples from the Pope vein.

Sample number	Width	Gold (ounces/ton)	Silver (ounces/ton)
5-25-1	2-3 inches	0.580	3.3
5-25-3	4 inches	0.270	1.1
5-25-4	4-6 inches	0.630	1.9

gully is a shaft and three adits. The shaft and one adit were caved in and inaccessible, but the other two adits were mapped. The adit going into the southeast side of the gully has 300 feet (91 m) of workings (figure 26). Two veins were found; the first vein was followed to the south for 70 feet (21 m) along which no stoping was done. The second vein has an inclined winze going down for at least 40 feet (12 m) on a 3-foot (1 m) calcite vein. Sample 5-25-5 is a 2-foot (0.6 m) cut across this vein; analysis showed 0.020 ounce of gold and no silver per ton.

On the northwest side of the same gully, 1,200 feet (366 m) west of the Pope mine, an adit is driven to the north for 180 feet (55 m) where it meets a vein containing calcite and quartz (figure 27). This vein was followed for 30 feet (9 m) before the adit was abandoned. No samples were taken from this working.

An adit has been driven into the north side of Gold Springs Wash, one mile (1.6 km) south of Buck Mountain to prospect a minor north-trending quartz vein up to 6 inches (15 cm) wide (figure 28). The vein was followed for 35 feet (11 m) before it was abandoned. Near the face of the adit, two fractures with up to 1 inch (2.5 cm) of limonite were found and followed for 10 feet (3 m). No samples were taken from this working.

One thousand feet (305 m) south of the Charley Ross shaft in the bottom of a gully, an adit was driven to the west (figure 29). Two hundred feet of workings are in the adit that crosscuts a 7-foot (2 m) vein in a portal. The vein strikes north and dips steeply to the west. The workings follow the vein to the south for 70 feet (21 m) and then turn sharply to the northwest for 20 feet (7 m). From the portal the workings extend 95 feet (29 m) west, crosscutting four small veins besides the main vein. These small veins contain quartz, calcite, and limonite. Two samples were taken from the workings, and analysis showed a trace of gold and 0.1 ounce of silver to the ton.

PRODUCTION OF MINES

Records from the early mining years are incomplete, which makes it impossible to determine the actual production, although the district is credited with mining 21,941 tons of ore and producing 9,335 ounces of gold, 40,279 ounces of silver, 12,031 pounds of copper, and 19,268 pounds of lead. On some mines there are no records at all, and on others only incomplete ones are available. The Jennie mine recorded the

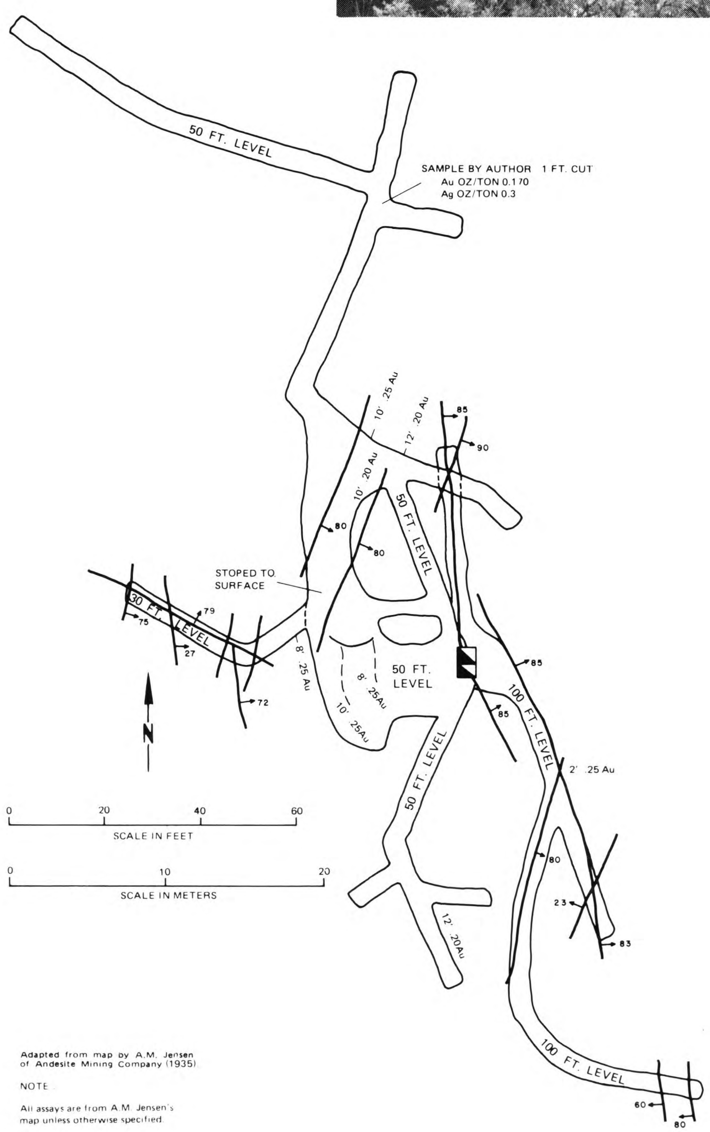


Figure 22. Composite map of the levels in the Big Buck mine, modified after Jensen (1935). Photograph shows the headframe of the Big Buck mine, looking southeast.

Figure 23. Part of the Snowflake quarry as seen from the dump, looking southwest.

largest production (table 7). No production is recorded for the Independence, Jumbo, or Thor mines. The workings of the open cut on the Independence vein alone probably produced several thousand tons of ore. In 1917 the production of Gold Springs and Stateline mining districts was combined and has been recorded this way since, making it hard to determine the production of Gold Springs district alone. Much of the recorded production of Stateline mining district during the 1930's came from the Jennie mine (tables 7 and 8). If the production of the Aetna were added to the Jennie's production, it would probably account for most of the recorded production for Stateline mining district.

Table 7. Recorded production of Jennie mine.

Year	Tons	Gold (ounces)	Silver (ounces)	Copper (pounds)	Lead (pounds)
1907	3,095	631.56	2,448		
1908	7,850	1,138.79	3,120		
1909	550	219.42	1,332		
1910	477	238.50	467		
1911	198	80.79	766		
1915	750	154.58	521		
1932	38	16.80	99	70	140
1933	110	43.01	341		
1934	1,800	665.16	6,505		
1936	1,162	333.00	4,604		
1937	361	126.44	1,322		
1948	[1]	1.22	10		
Total	16,391	3,649.27	21,535	70	140

Source: Compiled from records from U. S. Bureau of Mines.
[1] Not reported.

The mines on the Nevada side of the district have been recorded separately and show a production of 5,550 tons of ore containing 5,688 ounces of gold, 18,744 ounces of silver, 11,961 pounds of copper, and 19,128 pounds of lead (U. S. Bureau of Mines, written communication). These figures cannot represent the actual tonnage of ore produced, as the ore mined from the Snowflake quarry alone would probably exceed this figure. To this total could be added the production of the Little Buck mine, which was proabably as large or larger than the Jennie mine.

MILLS IN THE GOLD SPRINGS DISTRICT

Four mills were built in the Gold Springs mining district: two at the Jennie, one south of the Thor, and one at the Aetna mine. According to Snider (1927) the first Jennie mill was a 15-ton-a-day stamp mill. Later, the mill was replaced by a 100-ton-a-day mill (figure 30). Short (1909) described this new mill as an amalgamation mill with a cyanide plant to process the tails. He claimed that this process recovered 83 percent of the gold, 54 percent by the amalgamating plates and 29 percent by a cyanide leach. Snider (1927) described the milling equipment as a primary jaw crusher accompanied by a secondary gyrating crusher. After the ore left the crushers, it traveled by conveyor belt to a battery of 12 Nissen stamps of 1,350 pounds each. The ore moved from the stamps to a series of amalgamation plates, and the tailings were sluiced to a 100-ton-a-day cyanide plant for further processing (figure 31). Varley (1933) suggested that "from evidences still existing in the way of equipment and dumps, perhaps 50,000 tons or more of ore was treated in the mill." However, according to Snider, "the plant was only run, off and on, for thirty days, when operations ceased" owing to insufficient electrical power. Production figures in table 7 suggest that further milling must have been done in the late 1930's.

The Aetna mill was east of the collar of the Aetna mine (figure 32). According to Asher (1959) the mill was a 75-ton-a-day operation. The primary crusher was probably a jaw type with final crushing done in a small ball mill. Gold and silver were recovered by amalgamation and cyanide leaching of the tails. This mill was running in the mid-1930's and worked until the shutdown of gold mines during World War II.

The Herzog mill was constructed to process the ore from the surface workings

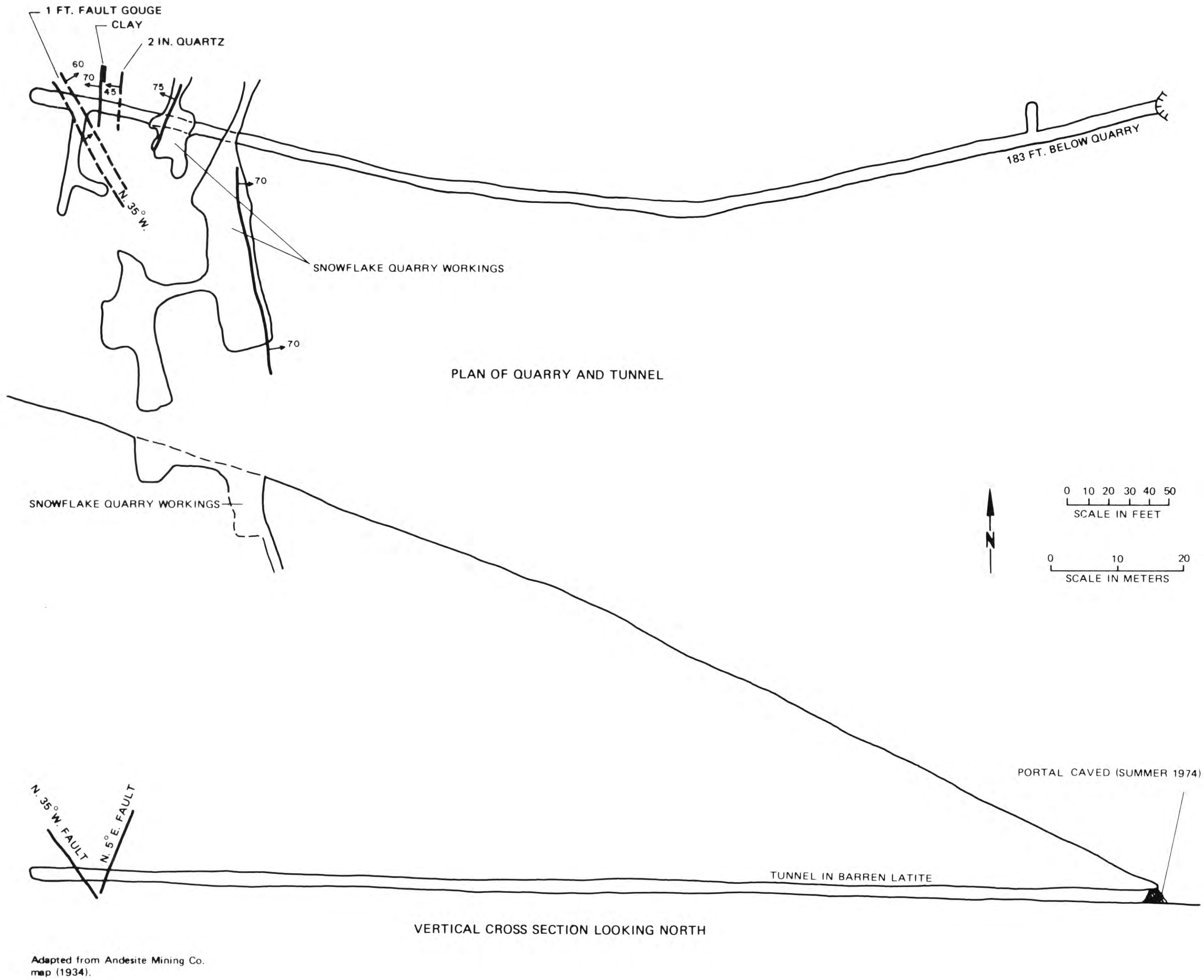


Figure 24. Plan and vertical cross section of the Snowflake quarry and the tunnel driven under it to intersect the Snowflake vein at depth; modified after a map of the Andesite Mining Company (1934).

Figure 25. Pope mine as seen from the road leading to the mine, looking northeast. Arrow indicates the shaft collar.

Table 8. Mineral production of Stateline mining district 1918-1973.
[Gold Springs mining district included in Stateline mining district's production since 1918.]

Year	Crude ore (tons)	Gold (ounces)	Silver (ounces)	Copper (pounds)	Lead (pounds)	Total value
1918[1]						
1919[1]						
1920	17	2.63	589			$ 697
1921[1]						
1922	5	2.00	10	1,498	2,120	370
1923[1]						
1924[1]						
1925[1]						
1926	21	11.86	64	16		287
1927[1]						
1928[1]						
1929[1]						
1930	120	22.01	31			467
1931	115	20.85	85			456
1932	38	16.83	99	70	140	384
1933	536	160.56	608			4,317
1934	2,842	1,231.70	11,340			50,379
1935	1,813	678.20	10,432			31,235
1936	4,138	1,596.60	16,284	185	717	68,543
1937	3,835	1,267.00	19,086	595	6,610	59,570
1938	1,255	562.00	4,902			22,839
1939	1,844	1,189.00	8,275	461	702	47,313
1940	889	275.00	3,292	425	9,200	12,475
1941	552	37.00	727			1,812
1942	1,445	209.00	1,018			8,039
1943[1]						
1944[1]						
1945[1]						
1946	60	12.00	99			500
1947	45	9.00	73			381
1948	1	1.00	10			44
1949 to 1973[1]						
Total	19,571	7,304.24	77,024	3,250	19,489	$310,108

Source: U. S. Bureau of Mines.
[1] No production.

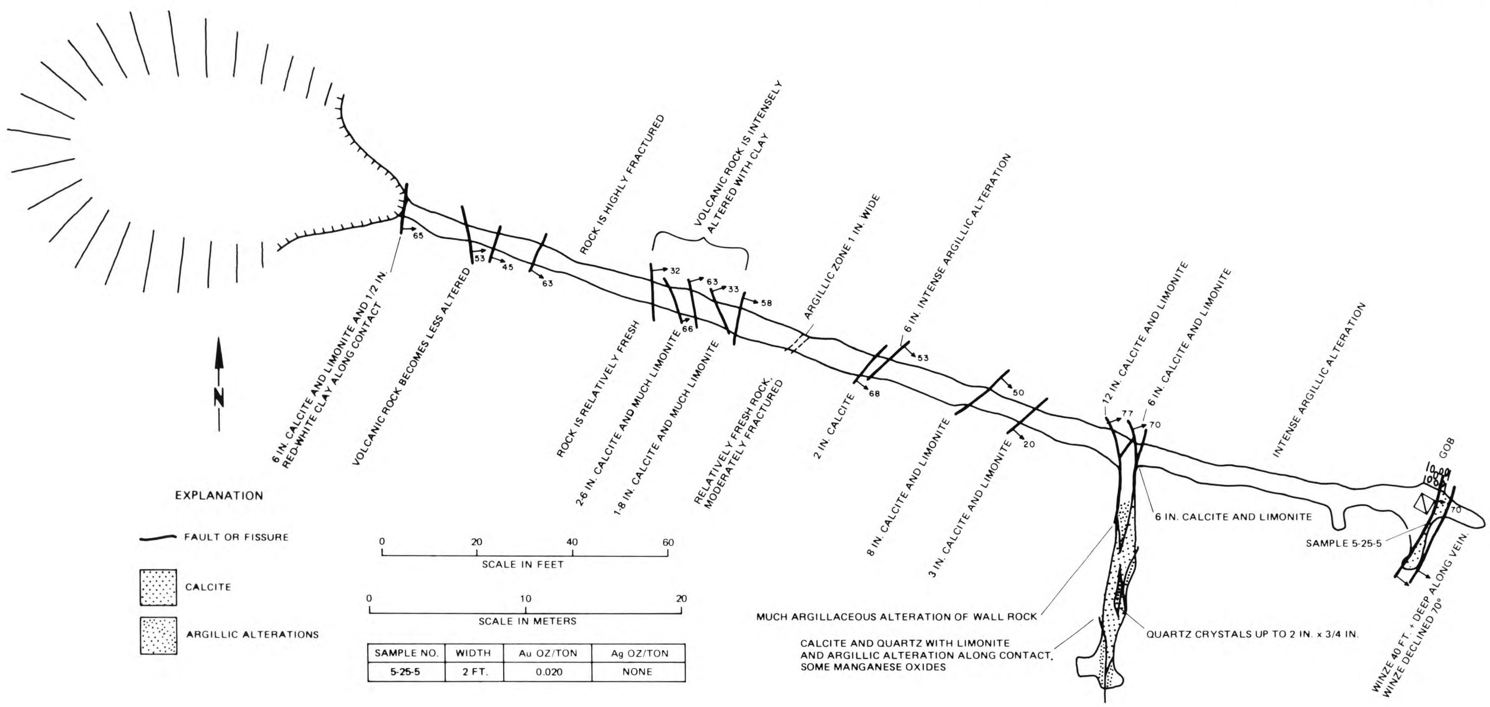
on the Thor vein. The mill site is approximately one-sixteenth mile west of the Utah-Nevada line. According to Ferri (1929) the mill had a daily capacity of 35 tons and consisted of two Agnew pulverizers, a pulsating screen, and amalgamation plates. The mill was powered by a steam boiler and a 25 horse-power engine (figure 33).

None of the mills remain intact today. The Jennie mill building is still standing, but all of the equipment has been removed. The Aetna building has collapsed, leaving only the ore bins. The Herzog mill has been torn down; the steam boiler and engine remain.

EXPLORATION POSSIBILITIES

The past production of the district and the tendency of the valuable minerals in the veins to be scattered suggest that any ore deposits found in the district will probably be small. Today's high metal prices make the grade of the ore attractive to low tonnage mining operations. There is a good possibility of finding concealed veins in the district, as alluvium and the postmineral lithic crystal tuff (Tr_1) cover large areas. The faulted parts of veins that have not been found such as the north end of the Jennie vein might be worth looking for. Some of the veins such as the Jumbo and Snowflake might produce a large enough tonnage to interest a limited mining operation.

The best prospects for low-grade deposits that might be mined with surface



SAMPLE NO.	WIDTH	Au OZ/TON	Ag OZ/TON
5-25-5	2 FT.	0.020	NONE

Figure 26. Map of unnamed adit 1,000 feet (305 m) west of the Pope mine. The portal of the adit is on the southeast side of the gully. Photograph shows the partly caved in portal as seen from the dump, looking east. Assay of ore sample is shown in table.

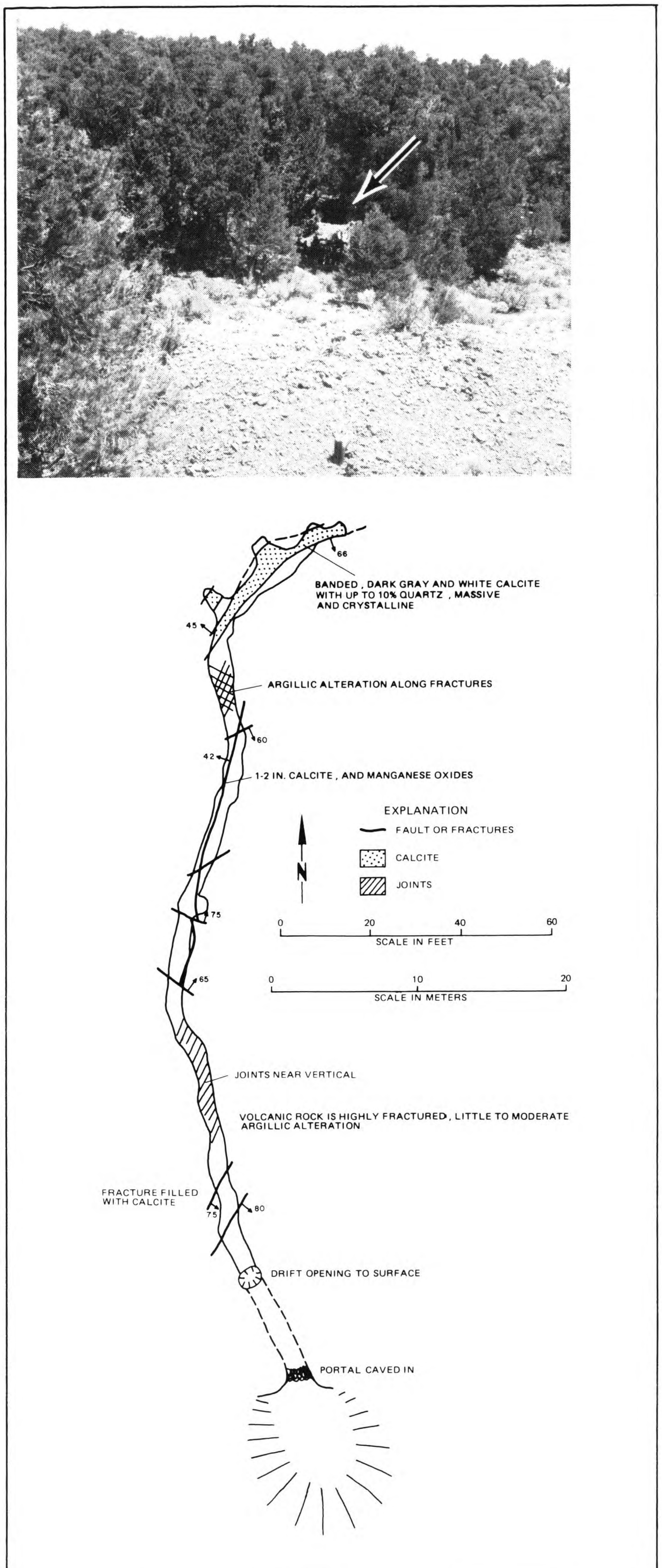


Figure 27. Map of unnamed adit 1,000 feet (305 m) west of the Pope mine on the northwest side of the gully. Photograph shows the caved in portal as seen from the dump, looking north, of the unnamed adit on the southeast side of the gully; arrow denotes portal.

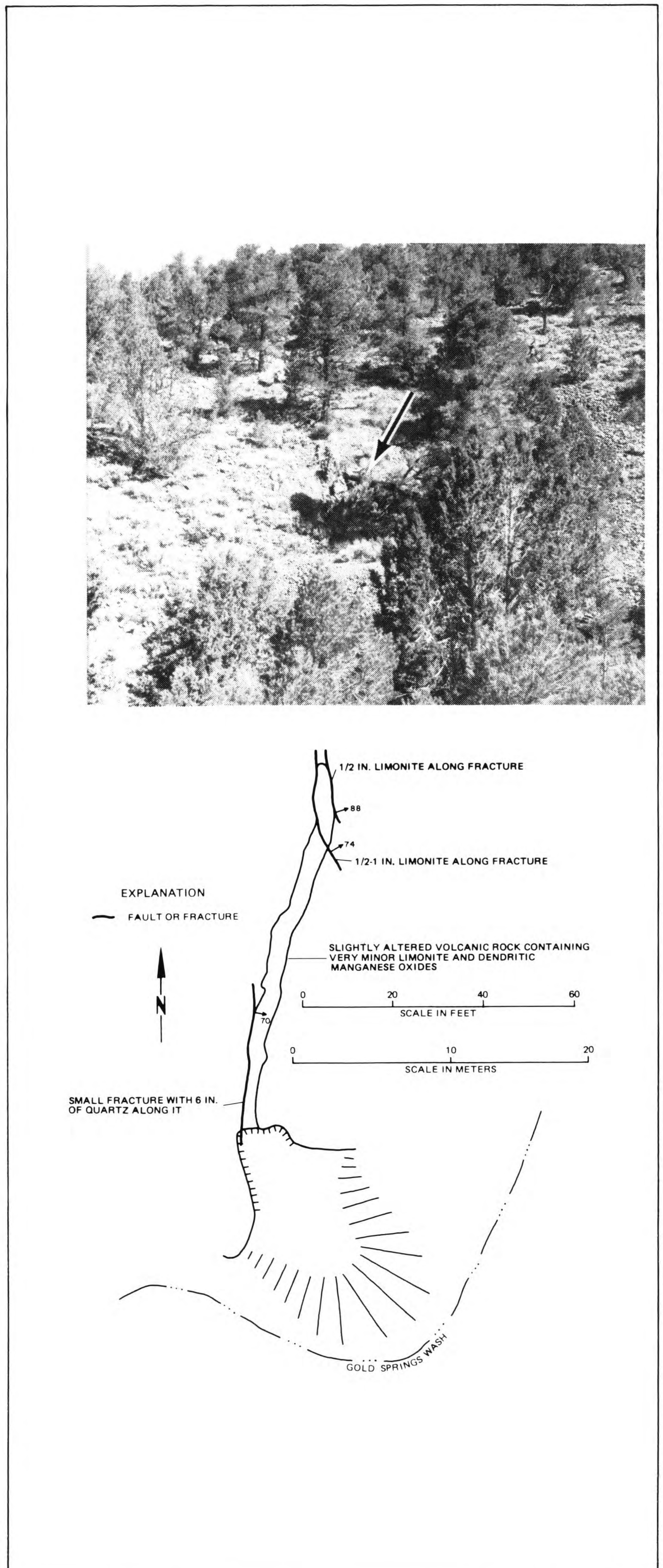
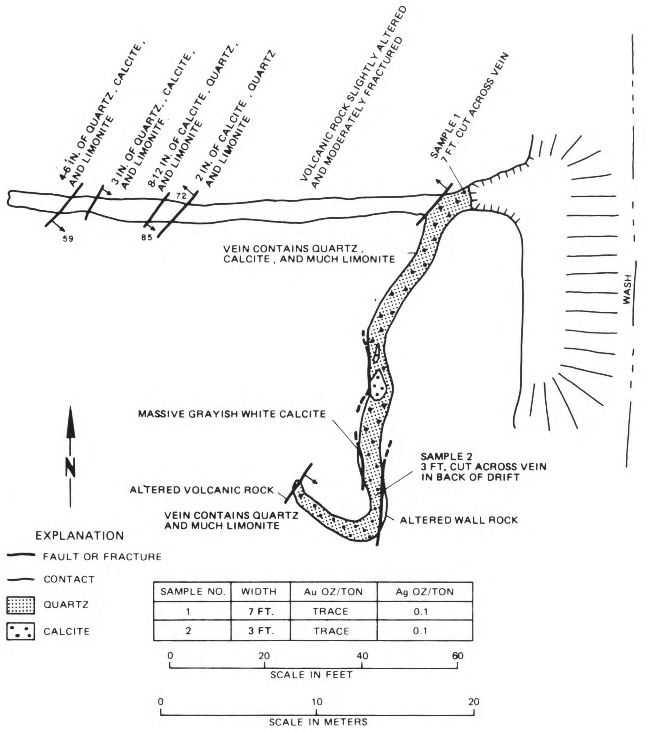


Figure 28. Map of unnamed adit on the north side of Gold Springs Wash. Photograph shows portal as seen from the south side of the wash, looking north; arrow denotes portal.



SAMPLE NO.	WIDTH	Au OZ/TON	Ag OZ/TON
1	7 FT.	TRACE	0.1
2	3 FT.	TRACE	0.1

Figure 29. Map of unnamed adit in the bottom of the gully south of the Charley Ross shaft. Photograph shows the partly caved in portal as seen from the east side of the gully, looking west; arrow denotes portal. Assays of ore samples are shown in table.

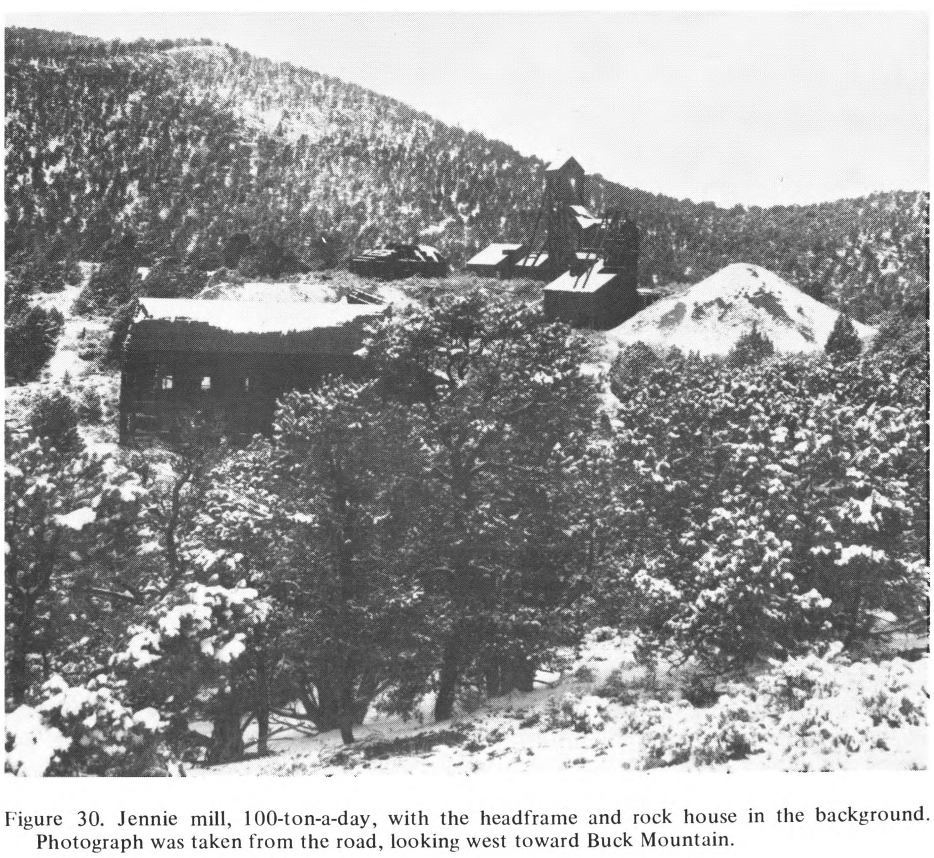


Figure 30. Jennie mill, 100-ton-a-day, with the headframe and rock house in the background. Photograph was taken from the road, looking west toward Buck Mountain.

Figure 31. Foundations of cyanide leach plant of Jennie mill as seen from across the gully, looking west.

Figure 32. Aetna mill as seen from across the gully, looking southwest.

excavations are the Jumbo and Snowflake veins. The Jumbo is wide enough to produce a sufficient tonnage for a small company. Much of this vein could be mined from the surface at a low cost per ton. However, further exploration would be necessary to determine if the grade is good enough to support the small operation. The Snowflake vein represents another prospect that could be mined from the surface. Jensen (1935) suggested that 119,000 tons of ore averaging 0.18 ounce of gold and 2.4 ounces of silver to the ton could be obtained from the Snowflake vein at a reasonable mining cost. A careful sampling of the outcrop along with the findings from several shallow diamond drill holes would be necessary to substantiate these figures.

The faulted north end of the Jennie vein could probably be found with one or two diamond drill holes. Mallory (1928) stated that the horizontal displacement of the Jennie vein is about 150 feet to the east of the north side of the fault. If the vein is in this position as suggested, it would be concealed by the lithic crystal tuff unit in the hill northeast of the Jennie mine. The possible presence of other concealed veins under this hill should not be overlooked.

The Independence vein might contain a small tonnage of minable ore and useful water below the old workings that could be tested with a couple of diamond drill holes. The *Salt Lake Mining Review* (1903) reported water at 135 feet (41 m) in the Independence shaft. At 200 feet (61 m) the flow was reported to be 3,000 gallons-per-day (11,355 liters-per-day). This water would be a valuable asset to any mining or milling operation in the area.

SUMMARY

The mineral potential of the Gold Springs mining district lies in the areas of the Jennie, Snowflake, Jumbo, and Independence veins. Most of the production has come from two veins, the Jennie and the Snowflake. These are probably the best two areas in which to concentrate future exploration. The Jennie property should be drilled to find the faulted north end of the vein. Drilling would require one or two diamond drill holes to locate the vein. Further drilling would depend on the grade of ore found. The Snowflake vein has a good potential for an openpit operation. A detailed sampling program including bulldozer cuts to expose the vein would be necessary to evaluate the outcrop. Diamond drilling could be used to substantiate surface findings.

The Jumbo and Independence veins should be looked at in more detail. The wide outcrop of the Jumbo vein might be mined from the surface by openpit methods. A detailed sampling program along with a few diamond drill holes would determine if further work was warranted. The Independence vein should be looked at for ore potential as well as for water that would be a necessary by-product of any underground mining on the vein. The lower parts of the vein could be tested with two or three drill holes to determine if further work would be fruitful.

ACKNOWLEDGEMENTS

The author acknowledges the help of Dee Burgess concerning the history and extent of some of the mine workings. William C. Block and Samuel S. Arentz allowed the use of Mr. Block's geologic map which has greatly assisted the

Figure 33. Remains of the steam boiler and engine of the Herzog mill as seen from the tailings of the Jennie mill, looking north.

author's work. Thanks is given to Paul Anderson and Larry Trimble who helped the author map the underground workings of the district. The illustrations of surface buildings and equipment were done by Greg McLaughlin.

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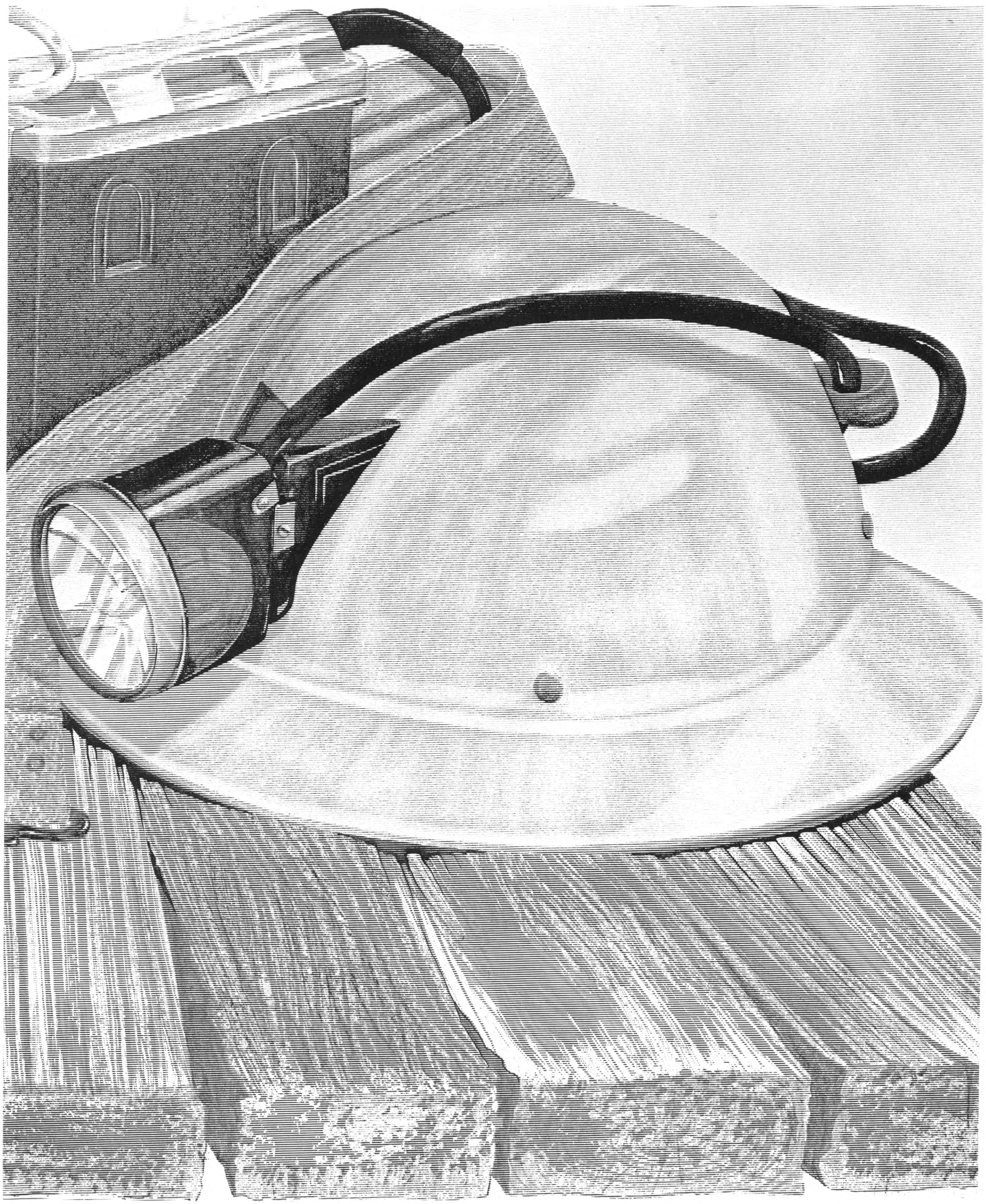

A SECOND NEW THEROPOD DINOSAUR FROM THE LATE JURASSIC OF EAST CENTRAL UTAH

by James H. Madsen, Jr.[1]

ABSTRACT

Marshosaurus bicentesimus (Reptilia: Saurischia), a new theropod dinosaur from the Late Jurassic Morrison Formation of east central Utah, is distinct from other Morrison theropods, *Allosaurus, Ceratosaurus,* and *Stokesosaurus,* of the Cleveland-Lloyd Dinosaur Collection in the unusual character of the type specimen, a left ilium, and in the referred materials, which include the tooth-bearing elements of the skull and jaw and the complete pelvic girdle. A relatively complete, articulated skeleton of *Marshosaurus* is unknown at this time.

INTRODUCTION

In addition to *Stokesosaurus* (Madsen, 1974) a second new theropod has been recognized in the Cleveland-Lloyd Dinosaur Collection of dinosaur bones from the Late Jurassic Morrison Formation of east central Utah. The late J. Leroy Kay had suggested to the writer that eventually many small generically distinct theropods would be recognized from the Morrison Formation. In confirmation of Kay's prediction, *Stokesosaurus* and *Marshosaurus* can be added to the existing list of small theropods from the Morrison, which includes *Ornitholestes hermanni, Coelurus fragilis, Coelurus agilis,* and the *nomina vana* proposed by Cope–*Tichosteus aquifacies* and *T. lucasanus* (Osborn and Mook, 1921, p. 272).

Skeletal remains in the Cleveland-Lloyd Dinosaur Quarry are usually found completely disarticulated. Although it might appear an unsatisfactory taxonomic procedure to include such an assemblage of elements in the description of a hypodigm, it is justified here for several reasons.

At this writing, only three published, theropod genera are recognized in the Cleveland-Lloyd Dinosaur Collection: *Allosaurus, Ceratosaurus,* and *Stokesosaurus.* Representative elements of *Allosaurus,* for example the femora, ilia, or dentaries, indicate a minimum of 40 individuals ranging from juvenile to adult in size. Other elements of the skeletons are recovered in approximately the same ratio. *Ceratosaurus* is represented by one large adult specimen; no duplication of elements suggests otherwise. A minimum of two individuals, one small and one large, of *Stokesosaurus* is indicated by the two ilia assignable to this genus.

The remaining unassigned, two right and two left theropod ilia in the collection are all about the same size (table 1) and, therefore, indicate a minimum of two individuals of approximately the same size. Likewise, there are three maxillae and three dentaries of subequal size, all of which confirm the presence of two theropods of approximately the same size. Using circuitous logic, it was concluded that since these theropod ilia and maxillae indicate individuals of about the same size, although not assignable to any of the other three recognized genera in the Cleveland-Lloyd Dinosaur Collection, they must represent a fourth genus.

It is suggested that these maxillae and ilia are assignable to a single genus. The interdental plates and the shape of the teeth in the maxillae are similar to those of an unassigned premaxilla and dentaries in the collection that are therefore assigned to the same genus. Since the articular surfaces of the iliac peduncles are exact matches to those of pubes and ischia in the collection, these are also assigned to the same taxon. The above elements form the hypodigm on which a new taxon is described.

One might question the sparse amount of original material in the description of this new genus, but the lack of funds make it impossible to complete preparation on the several hundred other elements of the collection that are generically suspect–bones that are clearly separable from the single *Ceratosaurus* because of its greater size. There is little chance of confusing juvenile *Allosaurus* material with similar elements of the new theropod because of consistant dissimilarities between them and the relatively well-known osteology of *Allosaurus*. In essence the problem is that the two new theropods and the larger of the Stokesosaurs represented in the Cleveland-Lloyd Dinosaur Collection are essentially the same size. Unfortunately, it is neither practical nor possible to do the fine preparation now that will be required eventually to taxonomically isolate all of the suspected materials.

Abbreviations used: USMN–United States National Museum, UUVP–University of Utah Vertebrate Paleontology Collection.

SYSTEMATICS

Class REPTILIA
Order SAURISCHIA Seeley, 1887
Suborder THEROPODA Marsh, 1881
Family INCERTAE SEDIS
Marshosaurus, n. gen.

Type species. Marshosaurus bicentesimus n. sp.

Type locality. As for species.

Age. Late Jurassic.

Distribution. Known only from the Brushy Basin Member of the Morrison Formation, Emery County, east central Utah.

Diagnosis. As for species.

Etymology. After Othniel Charles Marsh, a great student of dinosaurs.

Marshosaurus bicentesimus, n. sp.

Type. UUVP 2826, left ilium.

Hypodigm. The type and the following paratypes: UUVP 3266, right premaxilla; UUVP 1846, right maxilla; UUVP 1864, left maxilla; UUVP 4695, right maxilla; UUVP 40-555, 3454, left dentaries; UUVP 3502, right dentary; UUVP 1845, left ilium; UUVP 1882, 2742, right ilia; UUVP 40-295, 1867, left pubes; UUVP 4736, right pubis; UUVP

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Table 1. Measurements (in mm) of ilia, *Marshosaurus bicentesimus*.

	Holotype	Paratypes		
	UUVP 2826, left	UUVP 1845, left	UUVP 1882, right	UUVP 2742, right
Total length	375[1]	355[1]	330[1]	350[1]
Depth, anterior blade	100[1]	100[1]	110[1]	100[1]
Length across peduncles	183[1]	178[1]	130[2]	180[1]
Length at top of peduncles	145	138	113[2]	142
Depth, posterior blade	70[1]	65[1]	60[1]	70[1]
Greatest height, anterior blade	180[1]	175[1]	180[1]	185[1]
Height, anterior blade at peduncle	180[1]	175[1]	180[1]	185[1]
Height above acetabulum	180[1]	170	173	185[1]
Height of posterior blade	82	80	78	80[1]
Lateral width of pubic peduncle	43	18[2]	41	36[1]

[1] Estimated.
[2] Deformed.

2832, right ischium; UUVP 2878, left ischium.

Horizon. 150 feet (45.75 m) below the top of the Brushy Basin Member of the Morrison Formation (Stokes, 1952, p. 1770).

Type locality. Cleveland-Lloyd Dinosaur Quarry, east central Utah: NE¼NE¼ sec. 28, T. 17 S., R. 11 E., S.L.B.M., lat. 39° 19′ 00″ N., long. 11° 41′ 15″ W.

Diagnosis. A small- to medium-sized theropod, the adult probably five meters or less in length. Ilium heavy with long, low posterior blade; pubic peduncle stout, its articular surface rugose and divided into anterior and posterior concavities; ischiadic peduncle moderately long with a rugose, rounded surface truncated at apex; acetabulum deep and nearly symmetrical. And from referred specimens: interdental plates separated to their base; premaxilla loosely attached to maxilla; maxilla with a divided sinus having two openings in the usual position of the maxillary fenestra. Number of teeth in premaxilla, 4; maxilla, 16; and dentary, 22. Maxillary teeth with slightly expanded roots. Pubis long, slender, and anteriorly bowed with a rugose proximal end doubly convex for articulation with the pubic peduncle; the rugose ischiadic articulation crescent shaped and deeply notched on the underside; the bowed shaft of the pubis terminating in a posteriorly expanded foot or pedicle. Ischium shorter than pubis, its shaft relatively straight, grooved medially at midlength, and expanded distally; the pubic articulation crescentic and rugose; the iliac articulation concave and rugose; the proximoventral end expanded, striated laterally and medially to margin of medial contact.

Etymology. In honor of the bicentennial of the United States of America.

Description of type. UUVP 2826, a left ilium (figure 1), lacks part of the anterior blade, but the estimated total length is 375 mm. As restored from other specimens, the anterior blade (anb) is moderately high, extending at least 40 mm beyond the pubic peduncle. The anterior notch is open and moderately shallow. The dorsal edge of the ilium is a gentle uniform arch. There is no indication of the vertical ridge so apparent in *Stokesosaurus* (Madsen, 1974). The posterior blade (pob) tapers gradually backward and largely conceals the medial blade (meb) from lateral view. The posterior and medial blades roof a shallow trough (for the *M. coccygeofemoralis brevis, fide* Romer, 1923, p. 606). The posterior and medial blades are equally developed. The posterior blade fails to meet the supraacetabular hood and merges with the ischiadic (isc) peduncle just above and lateral to the inferior margin of the medial blade. The pubic peduncle (pu) is moderately long, stout, and directed anteroventrally. It is unusual in having anterior and posterior concavities on the articular surface separated by a heavy, median ridge. The rounded ischiadic peduncle is stout, its articular surface posteriorly truncated and pitted. The medial surface of the ilium is scarred at the points of attachment of the sacral ribs. The arrangement of the scars indicates at least four, and most probably five, sacral vertebrae. The medial blade is heavily striated posteriorly in the area of attachment of the fifth sacral rib; the striae parallel the trough formed at the intersection of the medial and posterior blades.

Description of referred specimens. UUVP 1845, a left ilium, though slightly crushed dorsoventrally with a resultant distortion of the pubic peduncle, has the medial blade meeting the posterior blade at an approximate right angle, continuing anteroventrally, and broadening to meet the ischiadic peduncle two centimeters above its articular surface. Owing to distortion, the acetabulum appears broader than natural as it grades into the laterally compressed pubic peduncle. The pubic peduncle is also incomplete, showing only the anterior concavity on its articular surface. Characteristic, prominent, narrow grooves appear above the medial margins of the articular surface of the pubic peduncle. Medially, the surface of the blade is decorated with a series of scars; the most anterior ones are paired for attachment of the second sacral vertebra. One scar is offset immediately above and behind the other, posterior to the angle between the anterior blade and pubic peduncle. The scar for the first sacral, if present, is not seen since part of the anterior blade is missing. The second pair of scars for the attachment of the third sacral are elongate anteroposteriorly, above, and slightly behind the acetabulum. The third pair are above the angle of the posterior blade and ischiac peduncle. They are both elongate anteroposteriorly; however, the lower one is on a broad pedestal. Attachment of the fifth sacral rib is indicated by a striated or grooved area covering much of the angle between the posterior and medial blades.

UUVP 1882, a right ilium, is distorted by anteroposterior compression, but it confirms most of the characteristics already noted for UUVP 1845. The pubic peduncle is representative in the development of two concavities divided by a strong ridge on the articular surface. The posterior concavity is indented on its posteromedial margin by a notch in the anterior surface of the acetabulum.

UUVP 2742, a right ilium, similar in character to those already described, but less complete, has an anomalous area developed on the posterodorsal margin of the blade, which grades into a ridge on the lateral surface. The deformity appears

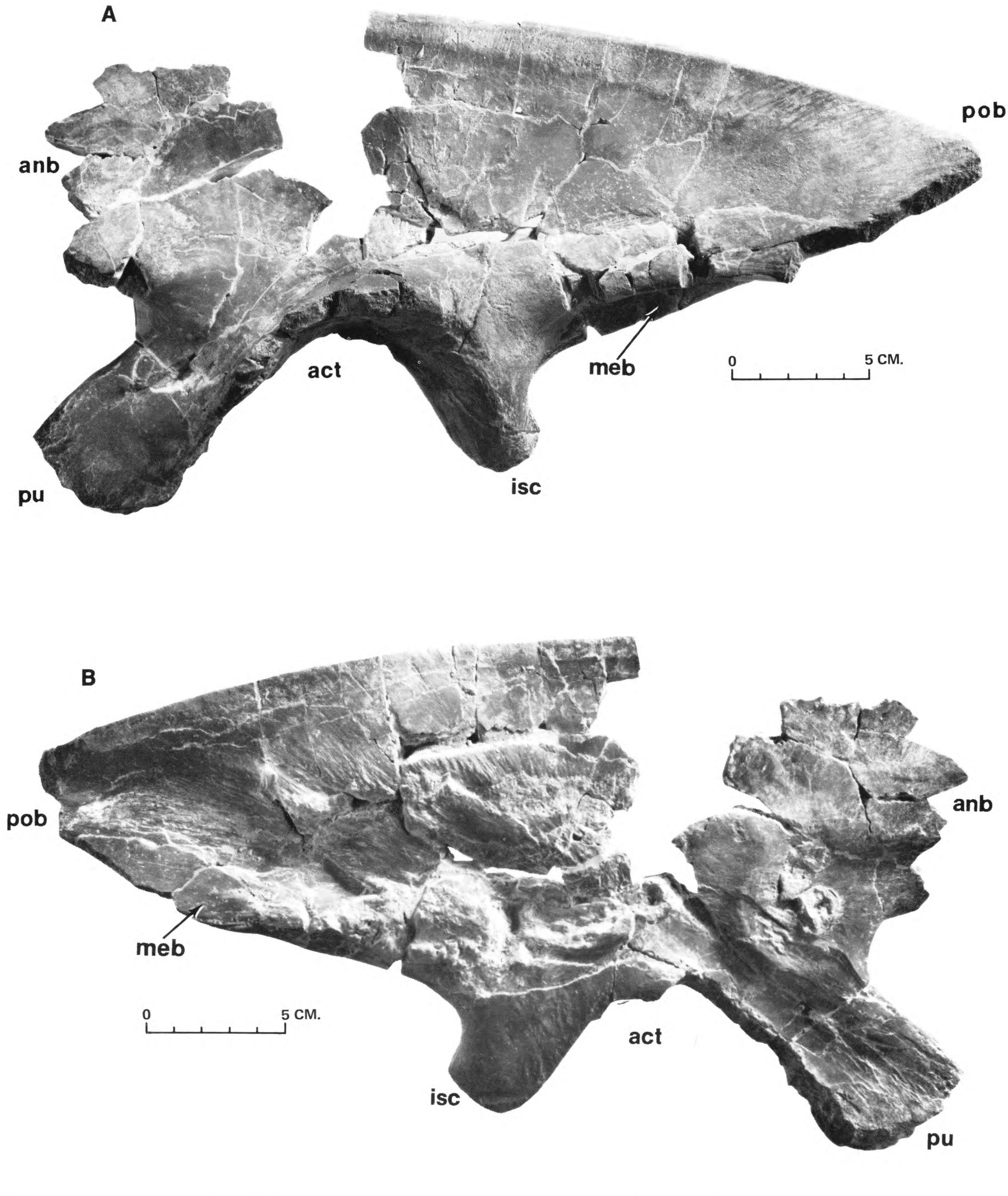

Figure 1. Left ilium of *Marshosaurus bicentesimus*, holotype (UUVP 2826) in lateral (A) and medial (B) views. Abbreviations: act—acetabulum, anb—anterior blade, isc—ischiadic peduncle, meb—medial blade, pob—posterior blade, pu—pubic peduncle.

to be traumatic in origin. Striae for attachment of the fifth sacral rib are particularly well developed at the angle of the posterior and medial blades.

UUVP 3266, a right premaxilla (figure 2), has a subrectangular body, which is noticeably longer than high (47 mm by 34 mm). It contains four alveoli. The nasal ramus (nr), though incomplete, indicates a rather large external naris (en). The maxillary ramus (mr) extends well back and over the vertical area of contact with the maxilla. The slightly grooved and pitted maxillary contact (mc) is restricted to a roughly triangular area lying on the outer surface of the premaxilla, which suggests a weak, squamous overlap by the maxilla. Medially, just below the margin of the external naris, there is a conspicuously large nutrient foramen (f). The teeth are laterally compressed, posteriorly curved, serrate, and terminate in sharp points. The teeth lie in planes parallel to the midline of the skull, although the alveolar margin is noticeably curved.

UUVP 1846, a right maxilla (figure 3 and table 2), has only 15 alveoli, but at least one more is possible since the posterior part is missing. The teeth are long and slender with slightly expanded roots. The tips of the teeth become more recurved from front to rear. The maxillary sinus is divided, having two lateral exits or fenestrae (mxf) below the nasal ramus. The anterior exit is smaller and subelliptical. It is just anterior to and slightly below the second exit, which leads into a sinus that appears to be separated from the first. The internal walls of both sinuses are less than one millimeter thick. The sinuses may have housed a specialized gland(s) such as an extension of Jacobsen's organ or may have served as additional surfaces for the development of sensory epithelium. The subnarial part of the maxilla is moderately low; the posterior part is extremely low and long. Above and anterior to the exits of the maxillary chamber, a ridge sweeps down and under, continuing posteriorly along the body of the bone. Along the lateral side, approximately one centimeter above the ventral margin of the maxilla, are unevenly spaced nutrient foramina. In medial view the anterior interdental plates (idp) are large, nearly vertical, and separated to their bases. They become very short posteriorly, and their backward slant increases. Their ventral border is zigzagged. A rounded ridge, the lingual bar, extends the length of the tooth row to terminate anteriorly in the anteromedial process. The vertical width of the bar is

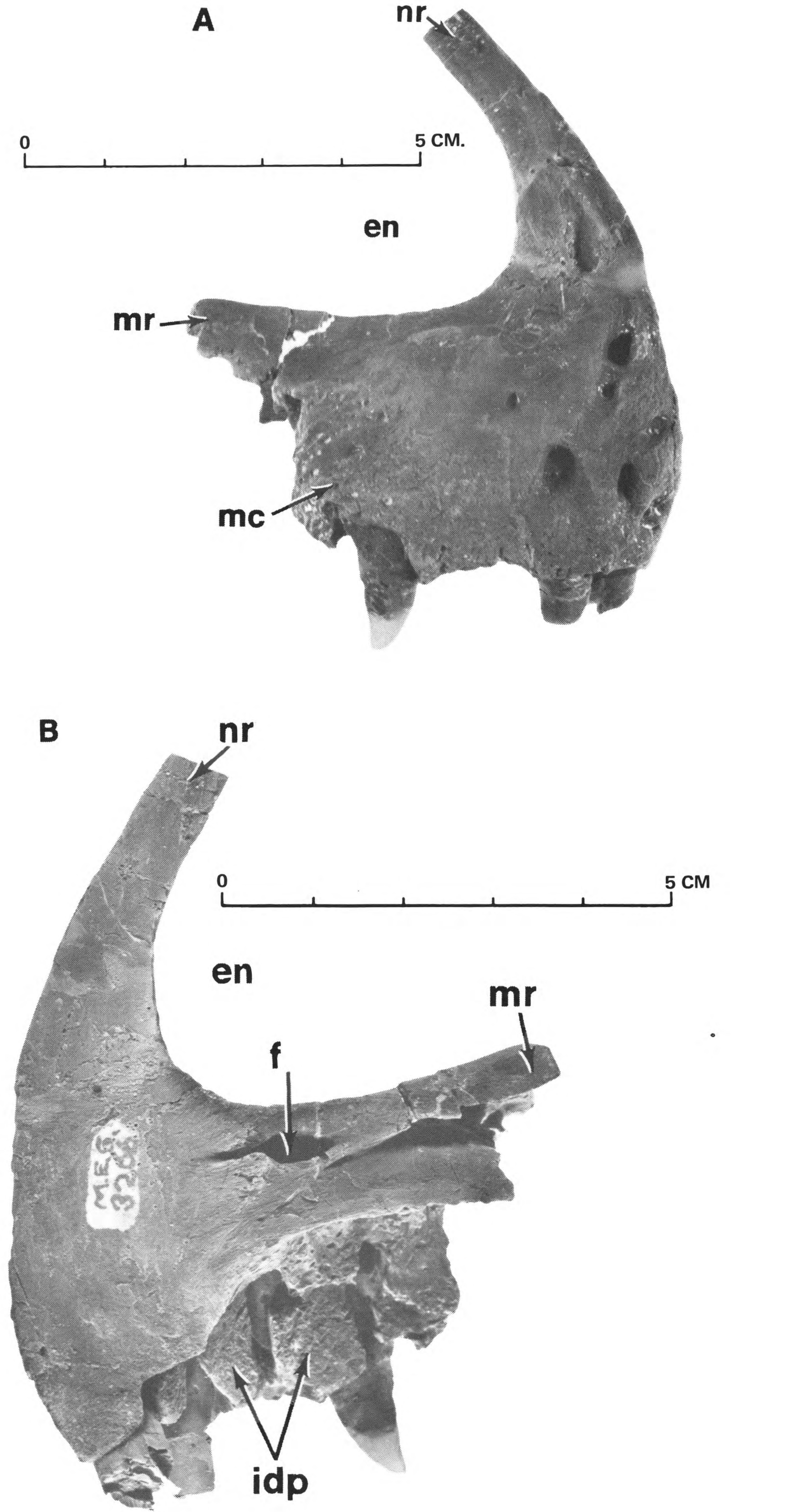

Figure 2. Right premaxilla of *Marshosaurus bicentesimus*, paratype (UUVP 3266) in lateral (A) and medial (B) views. Abbreviations: en–external naris, f–nutrient foramen, idp–interdental plate, mc–maxillary contact, mr–maxillary ramus, nr–nasal ramus.

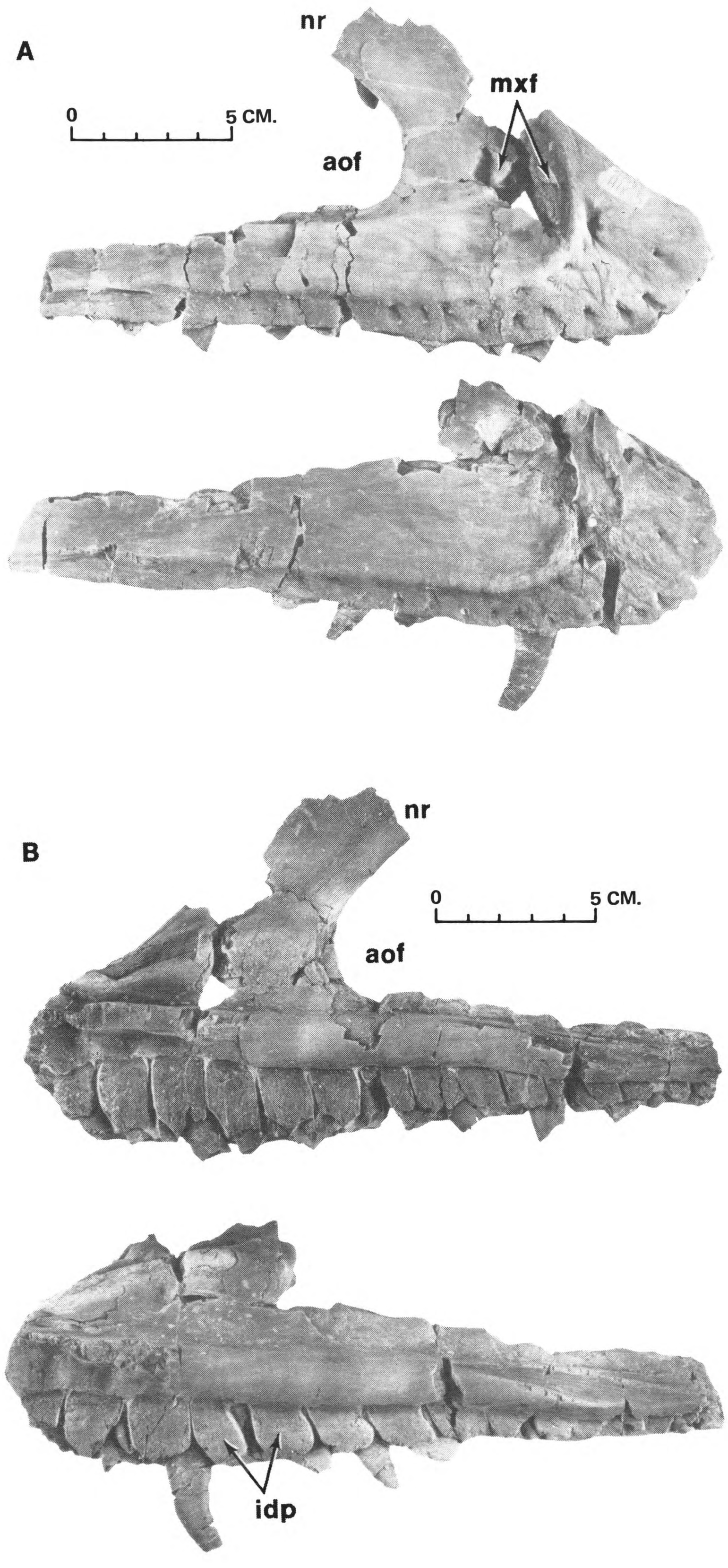

Figure 3. Right maxillae of *Marshosaurus bicentesimus*, paratype (UUVP 4695, above and UUVP 1846, below) in lateral (A) and medial (B) views. Abbreviations: aof–antorbital fenestra, idp–interdental plate, mxf–maxillary fenestrae, nr–nasal ramus.

about the same as that of the interdental plates. The anteromedial process is low, opposite the center of the front of the maxilla. The alveolar midline is unusually straight, exhibiting prominent septa that are continuous with the apices of the interdental plates throughout the tooth row.

UUVP 4695, a right maxilla, and UUVP 1864, a left maxilla, reveal little beyond the description of UUVP 1846. On UUVP 4695 are alveoli for at least 16 teeth. The posterior slant of the teeth increases towards the rear of the maxilla where it reaches an angle of almost 45 degrees. The anterior teeth are half again as wide as the teeth of the premaxilla. There is no evidence of a medial foramen leading to the maxillary sinus; however, there is a posterior exit at the angle between the nasal and posterior rami. UUVP 1864 is incomplete, having only four alveoli intact and a part of the maxillary sinus preserved.

UUVP 3454, a left dentary (figure 4 and table 3), has a transverse groove in the outer surface about 12 millimeters below the alveolar border. The groove is associated posteriorly, below the sixteenth and seventeenth alveoli, with a large foramen that opens medially just above and behind the Meckelian foramen (mc). The groove continues anteriorly to the vicinity of the fourth alveolus, where it turns upward and becomes indistinct. Nutrient foramina lie along the groove and in line with the groove's projection over the anterior surface, where the foramina are represented by six or seven deep pits. The medial surface of the dentary is grooved along the bases of the interdental plates from the symphysis back to the end of the tooth row, where the groove becomes shallow and lost. Below this groove the surface of the dentary bulges inward, though not as abruptly as in the lingual bar of the maxilla, and forms a gently rounded surface. Anteriorly this surface occupies the central third of the dentary, sweeping back and upward posterior to the Meckelian foramen. Below the rounded surface the dentary thins into a symmetrical groove, which extends from the symphysis to the Meckelian foramen, where it broadens and grades below into the sutural contact of the splenial. The anterior half of the dentary curves upward and becomes noticeably more narrow than in its posterior half. The interdental plates are separate, their upper border zigzagged. There are 21 alveoli in the complete tooth row.

UUVP 3502, a right dentary, has the maximum number of alveoli (22)

Table 2. Measurements of maxillae, *Marshosaurus bicentesimus*.

	Paratypes		
	UUVP 1846, right	UUVP 1864, left	UUVP 4695, right
Number of teeth	16[1]	[2]	[2]
Depth at 7th alveolus (mm)	45	36[1]	44
Length of tooth row (mm)	230[1]	[2]	220[1]

[1] Estimated.
[2] Incomplete.

represented. As viewed laterally, the natural, ventral bow of the alveolar margin is emphasized by the less curved central surface of the dentary. This contrasts with a slight, lateral bow of the dentary, as viewed from above. In articulation the dentaries form a narrow mandible, which is a fair indication that, similarly, the skull was narrow.

UUVP 40-555, a left dentary, has alveoli for 18 teeth; however, the anterior end is missing, and a diastema occurs two-thirds of the way back, so that I estimate a total of at least 21 teeth. The teeth are laterally compressed, curved, and terminate in sharp points that are more posteriorly directed toward the end of the tooth row, as noted in the teeth of the maxilla. The teeth of the dentary are subequal in size to those of the premaxilla, and similarly, are only two-thirds the width of the robust, anterior teeth of the maxilla.

Although few teeth of *Marshosaurus* are complete or well enough preserved to allow a detailed study, it is evident that: (1) posterior edges are more coarsely serrate, having fewer denticles per unit of length than the anterior ones in a ratio of about 3:4; (2) both edges are serrate to the tip, but the anterior edge only halfway to the root, and posterior edge almost to the root; and (3) the finer, anterior serrations appear to have worn faster than those on the posterior edge. Although beyond the scope of this paper, it may be useful to study the number of serrations per unit of length in *Marshosaurus* and other theropods, provided that teeth are all adjusted to a common size to allow for size differences between adults of different genera as well as between juveniles and adults of the same genus.

UUVP 40-295, a left pubis, has a long, anteriorly bowed shaft, which flares medially for half its midlength to form a thin apronlike symphysis (figure 5 and table 4). Proximally, there are two raised areas that match the concavities of the pubic peduncle. Distally, the shaft expands into a teardrop-shaped foot, which tapers posteriorly and extends only slightly beyond the anterior margin of the shaft. Laterally and anteriorly, the foot is roughened for muscle attachment. Medially, along the symphysis, an area of bone to bone attachment appears near the anteroventral margin. The remaining surface is covered with dorsoventral grooves.

UUVP 1867, a left pubis from a smaller individual than UUVP 40-295, lacks the distal foot but proximally has the rugose knobs preserved, as well as the acetabular border and part of the ischiadic peduncle.

UUVP 4736, a right pubis, is the most complete of the three referred pubes. The proximal surface is very rugose on the iliac and ischiac articular areas but less so on the acetabular border. The ischiadic peduncle, shaped as a broad crescent in proximal view, is vertically elongate, forming a deep obturator notch with the shaft (figure 4). On the anterolateral surface of the shaft, one-fourth the distance from the proximal end, is a conspicuously rugose area for the probable attachment of the ambiens muscle (amb) (figure 5). The medial symphysis or apron is half again as wide as the lateral diameter of the shaft and is concave posteriorly throughout its length.

UUVP 2878, a left ischium, is noticeably shorter than the pubis and has a relatively straight shaft terminating in an asymmetrical, moderately expanded distal end (figure 5 and table 5). Proximally, the shaft flares to the rugose and pitted articular surfaces of the iliac and pubic peduncles, which are separated by the uniformly concave and flattened inferior border of the acetabulum. The iliac peduncle is unevenly concave, being more deeply excavated on its medial surface. The pubic peduncle is crescent shaped and continuous below with an expanded plate that thins to an apparently straight margin of the obturator process (op). The medial and lateral surfaces of the obturator process are covered with fine grooves or striae oriented at a right angle to the ventral margin. The symphysis, at midlength of the shaft, is bordered by two deep grooves that merge distally and continue as a shallow, medial trough extending to the distal margin.

UUVP 2832, a right ischium, is the probable mate to UUVP 2878, since they were found less than 30 centimeters apart in the quarry. It is, however, three centimeters shorter, a difference that may be attributed to postmortem causes. Except for the difference in length, it is identical to UUVP 2878 in description.

COMPARISONS

A comparison of the tooth counts of *Marshosaurus* with those of some other theropod dinosaurs (table 6) indicates numbers in common with respect to individual elements. However, taken in combination, the tooth-bearing elements of *Marshosaurus* provide a formula unique to the species.

A disparity in the size and number of serrations on the anterior and posterior tooth margins exists in *Marshosaurus* as noted by Ostrom (1969, p. 37) for *Deinonychus* and *Velociraptor,* and as also noted by Woodward (1910, p. 113) for *Megalosaurus bradleyi.* In *Allosaurus* the number of serrations per unit of length are about equal.

The premaxilla of *Marshosaurus* in comparison with that of *Allosaurus* (Madsen, in press) is unusual in several respects: (1) the maxillary suture is weak and restricted to a slightly roughened area on the convex, posterolateral surface of the premaxilla, while in *Allosaurus* the contact is continuous along most of the posterior edge; (2) the teeth are laterally compressed, but in *Allosaurus* they are nearly circular in cross section; (3) interdental plates are present and separate, but they are fused in *Allosaurus*; and (4) there is little indication of the subnarial foramen, which is evident in *Allosaurus.*

The skull of the diminutive theropod *Velociraptor mongoliensis,* described by Osborn (1924) from the *Protoceratops* zone of central Mongolia, exhibits at least two characteristics important in a comparison with *Marshosaurus*: (1) a similar broad excavation of the external surface of the maxilla anterior to the maxillary fenestra(e) is bordered below by a sharp shelf that sweeps posteriorly under the antorbital fenestra; and (2) deep nutrient foramina are in conspicuous,

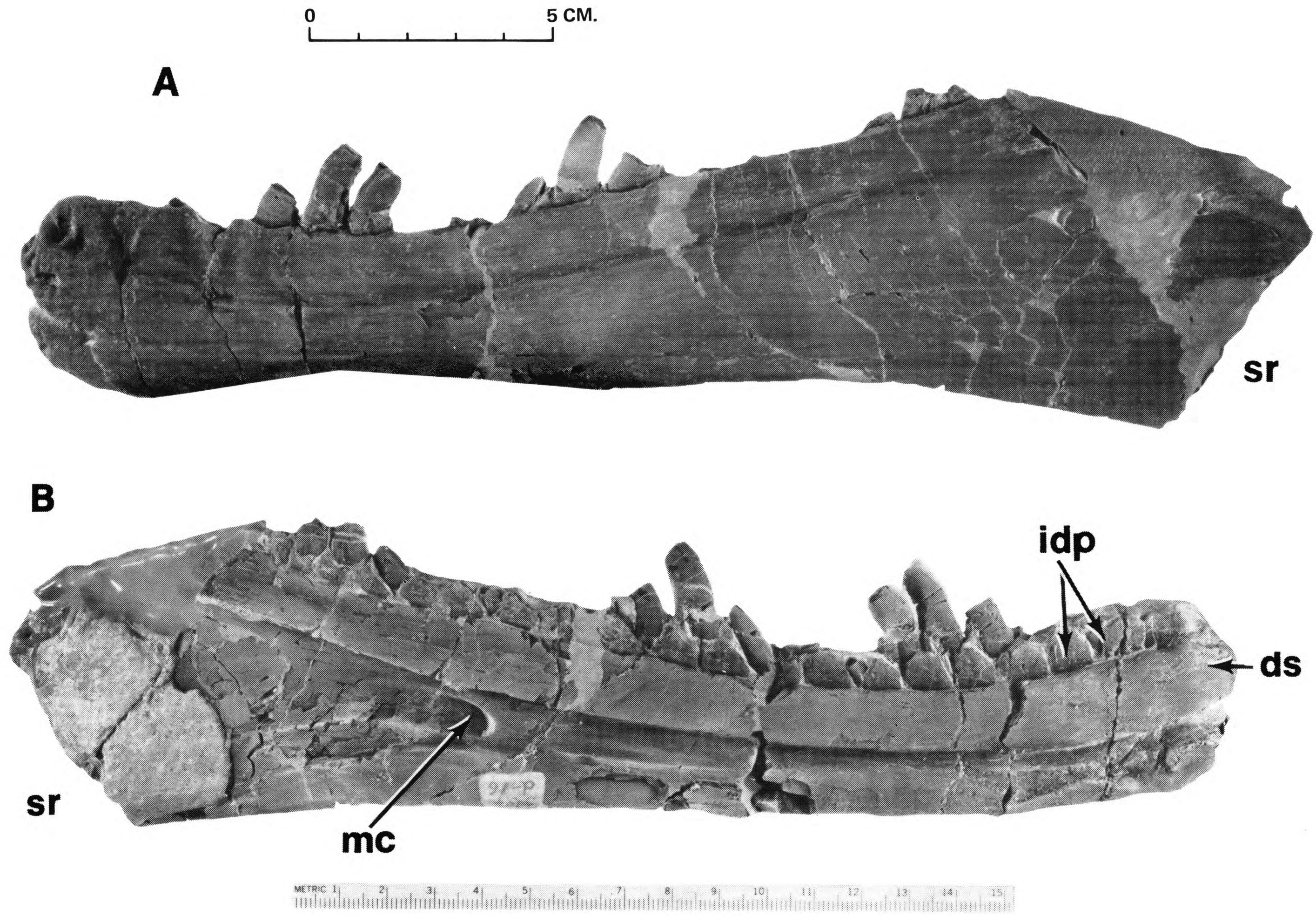

Figure 4. Left dentary of *Marshosaurus bicentesimus,* paratype (UUVP 3454) in lateral (A) and medial (B) views. Abbreviations: ds–dentary symphysis, idp–interdental plate, mc–Meckelian canal, sr–surangular ramus.

Table 3. Measurements of dentaries, *Marshosaurus bicentesimus.*

	Paratypes		
	UUVP 3454, left	UUVP 3502, right	UUVP 40-555, left
Number of teeth	21	22	21[1]
Depth at 7th alveolus (mm)	35	35	33
Length of tooth row (mm)	199	203	205[1]

[1] Estimated.

linear arrangement, parallel to the tooth margins of the maxilla and dentary. However, the difference in size and the significant stratigraphic separation indicate that *Marshosaurus* and *Velociraptor* are probably not closely related.

The maxilla of *Marshosaurus* is also similar to that of *Deinonychus* (Ostrom, 1969, p. 18) in having two exits from the maxillary sinus(es). Colbert and Russell (1969, p. 7) also note the occurrence of two openings in the maxilla of *Dromaeosaurus.* Variation in the development of chambers or sinuses in the superior rami of theropod maxillae, which may be of phyletic importance, warrants further study.

The dentary of *Marshosaurus* is long and narrow with a noticeable, downward bow in contrast to the straight dentary of *Deinonychus* (Ostrom, 1969, p. 29), but similarly it has a rounded anterior end terminating medially in a relatively weak symphysis. Additionally, the dentary lacks the marked lateral bow of *Allosaurus,* which indicates a relatively narrow, pointed lower jaw.

The significance of the diastema in one of the *Marshosaurus* dentaries (UUVP 40-555) is unknown, but it is curious that a similar abnormality is present on a dentary of *Ceratosaurus* (UUVP 158), on two dentaries of *Allosaurus* (UUVP 5289 and 5748) in the Cleveland-Lloyd Dinosaur Collection, and on the type of *Labrosaurus* (USNM 3215).

The pelvic structure of *Marshosaurus* is a generalized theropod design. The ilium of *Marshosaurus* is grossly similar in morphology to those of *Allosaurus, Ornitholestes, Ceratosaurus, Stokesosaurus, Deinonychus,* and *Tyrannosaurus* in having elongate, laterally compressed posterior and anterior blades that project beyond the ischiadic and pubic peduncles. The major characteristics of the ilium, which set it apart

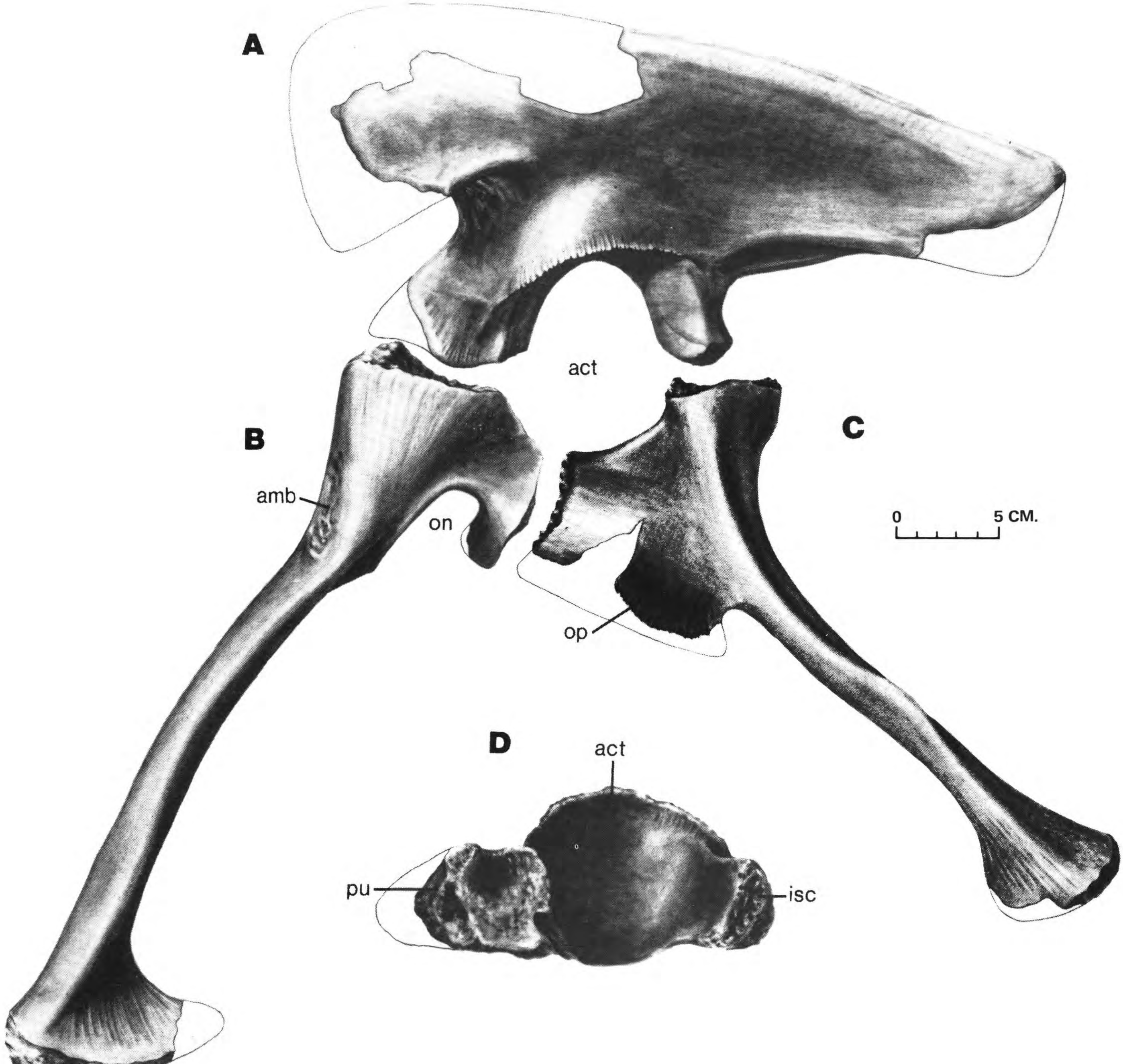

Figure 5. Left ilium (A), pubis (B), and ischium (C) of *Marshosaurus bicentesimus* in lateral view and acetabulum (D) in ventral view. Abbreviations: act–acetabulum, amb–probable origin of ambiens muscle, isc–ischiadic peduncle, on–obturator notch, op–obturator process, pu–pubic peduncle.

from that of other theropods, are the faceted ischiadic peduncle and the ventral concavities of the pubic peduncle (figure 5).

The pubis of *Marshosaurus* represents a slight departure in design from other theropods, but superficially it resembles Marsh's *Coelurus agilis* (1884), although it is approximately twice the length and, therefore, from a much larger individual. It differs from other Late Jurassic species in the unusual shape of the foot, the anterior bow of the shaft, and the knobs on the iliac articulation. The anterodistal expansion of the foot extends slightly beyond the anterior surface of the shaft. Additionally, the posterior extension of the pubic foot of *Marshosaurus* is also restricted, especially so in comparison with that of the tyrannosaurids and the Lower Cretaceous theropod *Microvenator* (Ostrom, 1970, plate 12).

The ischium of *Marshosaurus* is unusual primarily because of its relative shortness, which is approximately two-thirds the length of the pubis. The distal end of the ischium in *Marshosaurus* is asymmetrically expanded, more so than in *Allosaurus*. It is in sharp contrast with the thin shaft of the tyrannosaurid

Table 4. Measurements (in mm) of pubes, *Marshosaurus bicentesimus.*

	Paratypes		
	UUVP 1867, left	UUVP 4736, right	UUVP 40-295, left
Greatest length	390[1]	412	420
Greatest diameter of foot	[2]	105[1]	105[1]
Greatest width of foot	[2]	125	134
Greatest diameter, proximal end	100	120	[2]

[1] Estimated.
[2] Incomplete.

Table 5. Measurements (in mm) of ischia, *Marshosaurus bicentesimus.*

	Paratypes		
	UUVP 1870, left	UUVP 2832, right	UUVP 2878, left
Length from middle of acetabular border to distal end	325[1]	298	330
Greatest diameter, proximal end	130[1]	140	140[1]
Greatest diameter, distal end	[2]	65[1]	65[1]

[1] Estimated.
[2] Incomplete.

Table 6. Tooth counts for some theropod dinosaurs.

Taxon	Premaxilla	Maxilla	Dentary
Albertosaurus (Russell, 1970, p. 5)	4	13-15	14-16
Allosaurus (this paper)	5	15 ± 1	16 ± 1
Ceratosaurus (this paper)	3	12-15	15
Coelophysis (Ostrom, 1969, p. 156)	4-5?	21-22	25
Daspletosaurus (Russell, 1970, p. 17)	4	14-15	15-16
Deinonychus (Ostrom, 1969, p. 13)	4	15	16
Dilophosaurus (Welles, 1973)	3	12	17?
Dromaeosaurus (Colbert and Russell, 1969, p. 40)	4	9	11
Marshosaurus (this paper)	4	15-16	22
Megalosaurus bradleyi (Woodward, 1910, p. 112)	4	18	20?
Ornitholestes (Osborn, 1917, p. 734)	4	10	12
Saurornithoides mongoliensis (Osborn, 1924, p. 5)	4?	15?	?
Saurornithoides junior (Barsbold, 1974, p. 13)	4	19-20	33-35
Stokesosaurus (this paper)	4	?	?
Tarbosaurus (Maleev, 1955, p. 779)	4	12	15
Tyrannosaurus (Osborn, 1912, p. 26)	4	12	13-14
Velociraptor (Colbert and Russell, 1969, p. 40)	4	9	14

ischium, which is without distal expansion (Russell, 1970, p. 2), and the ischium of *Elaphrosaurus* (Janensch, 1925, figure 8), which is irregularly expanded.

Regrettably, the distal ends of the ischium and pubis of *Marshosaurus* cannot be compared in detail with those of *Ceratosaurus,* since as noted by Gilmore (1920, p. 108) they are missing in the type and may not have been available when Marsh (1884) made his original description.

A more complete comparison of *Marshosaurus* with other theropods of small size is impractical at this time. Although a significant number of dis-associated elements exist in the Cleveland-Lloyd Dinosaur Collection, some of which may be referrable to *Marshosaurus* forms, a comprehensive comparison must await preparation of all the materials.

ACKNOWLEDGEMENTS

I owe a special thanks to Samuel P. Welles and Robert A. Long at Berkeley, who also recognized the unusual character of this second new theropod and convinced me of it, as they did for my study on *Stokesosaurus* (Madsen, 1974). They also helped, together with Theodore E. White at Dinosaur National Monument, by reading the manuscript and providing scientific and editorial counsel.

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SMALL CHANNEL-FILL SEQUENCES IN THE DUCHESNE RIVER FORMATION NEAR VERNAL, UTAH: POSSIBLE EXAMPLES OF TRANSITIONS FROM MEANDERING TO BRAIDED STREAM DEPOSITS

by Ted A. Maxwell[1] *and M. Dane Picard*[2]

ABSTRACT

Small channel-fill sequences in the Duchesne River Formation (Eocene-Oligocene?) are especially well exposed between Roosevelt and Vernal, Utah, where they consist of discrete sandstone lenses set in silty claystone. Thicknesses of the channel deposits range from 5 to 10 meters. Widths are in tens of meters.

The channel sequences are divided into three vertically successive facies. Facies 1 is a trough cross-stratified, lag conglomerate or conglomeratic sandstone that is 0.5 to 1.0 meter thick. Facies 2 is fine- to medium-grained sandstone, 1 to 3 meters thick, with planar and trough cross-stratification, horizontal stratification, and ripple stratification. Near the top of facies 2, thinly bedded, discontinuous horizontal laminae of fine-grained sandstone and sandy siltstone are present in some sections. In about one-half of the sections studied, facies 2 is an upward-fining sequence from pebbly sandstone at the base to fine-grained sandstone or siltstone at the top of the facies. Facies 3 is a poorly sorted, medium- to coarse-grained, pebbly sandstone characterized by medium-scale, low angle (15-20 degrees), trough cross-stratification.

Together, facies 1 and 2 also form a general upward-fining sequence laterally confined within silty claystone. The lag conglomerate of facies 1 probably formed during the filling of scour pools during periods of high velocity flow. As the velocity decreased, the sand of facies 2 was deposited as small point-bar and possibly chute-fill deposits. The deposits of facies 3 resemble modern braided stream deposits, and our interpretation is that the transition from facies 2 to facies 3 represents a change from a meandering to a braided stream pattern. The transition from a meandering to a braided channel pattern in the Duchesne River Formation channels may have been caused by relatively minor climatic fluctuations affecting the discharge, by repeated uplift of the source area (Uinta Mountains) thereby increasing the gradient, or by changes in the drainage network (reoccupation of older channels or stream piracy). On present evidence it is difficult to evaluate these possibilities.

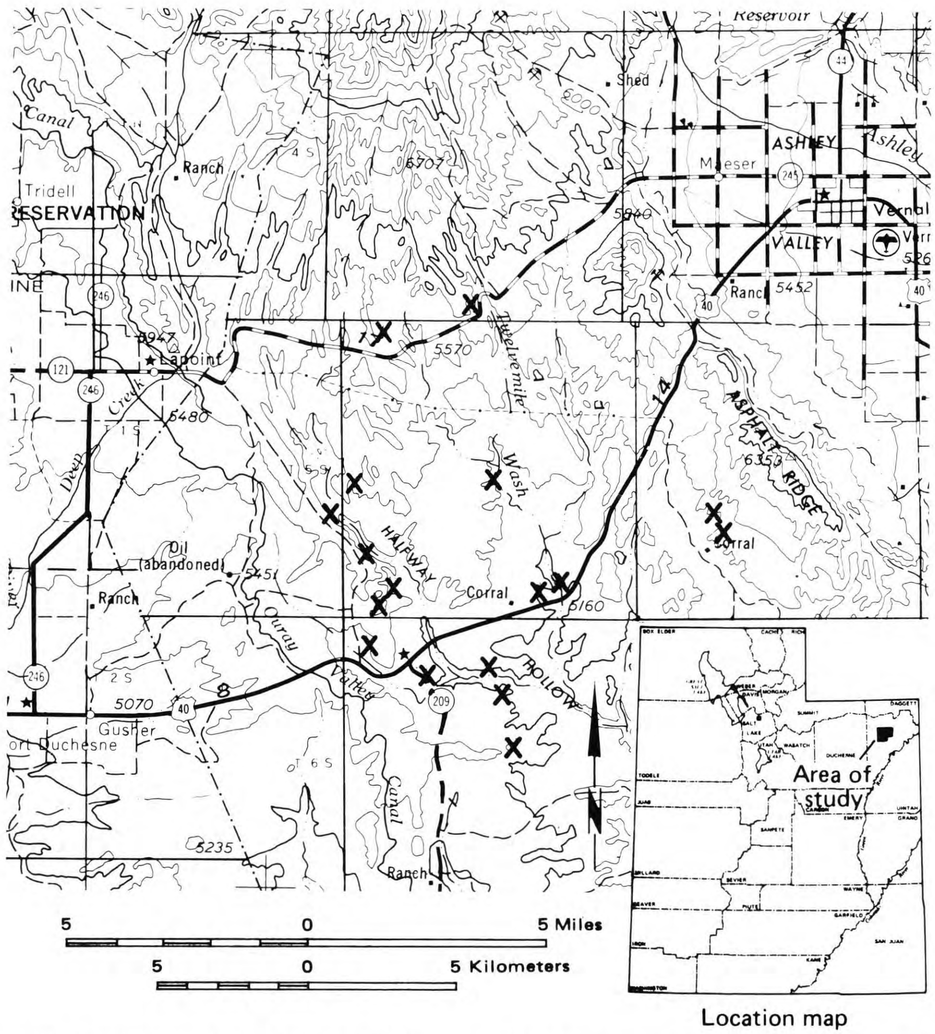

Figure 1. Index map of study area in northeastern Uinta Basin. Channel-fill sections (X) that were studied are well exposed along the valleys of modern ephemeral streams.

INTRODUCTION

The upper Duchesne River Formation of Eocene-Oligocene(?) age in northeastern Utah contains excellent exposures of fluvial sandstone, siltstone, and claystone. Recent work on the formation (Warner, 1966; Andersen and Picard, 1972, 1974; Picard and Andersen, 1975) provides a stratigraphic and petrographic framework that is useful for further analysis of the depositional environments.

Small channel-fill sequences are well exposed between Roosevelt and Vernal, Utah (figure 1). These channel deposits consist of discrete sandstone lenses, which average 5 to 10 meters in

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thickness and tens of meters in width, set in silty claystone. The basal contact of the sandstone with the underlying claystone is sharp, and relief generally is less than 10 centimeters. However, in outcrops perpendicular to the dominant paleocurrent direction (Picard and Andersen, 1975), some sandstone lenses are cut into the lower claystone as much as 3 meters. These lenses exhibit a troughlike cross section and are commonly 5 to 10 meters wide (figures 2a and 2b). The small channel-fill sequences of sandstone and conglomerate contain several primary sedimentary structures which, in conjunction with grain-size variations, provide useful information for interpretation of the depositional environments.

The few centimeters at the base of the channel deposits are characterized by poorly sorted lag conglomerate. Above the basal conglomerate, there commonly is a sequence of medium- to fine-grained sandstone (1 to 3 m thick), succeeded by a thick (up to 10 m) layer of trough cross-stratified, pebbly sandstone.

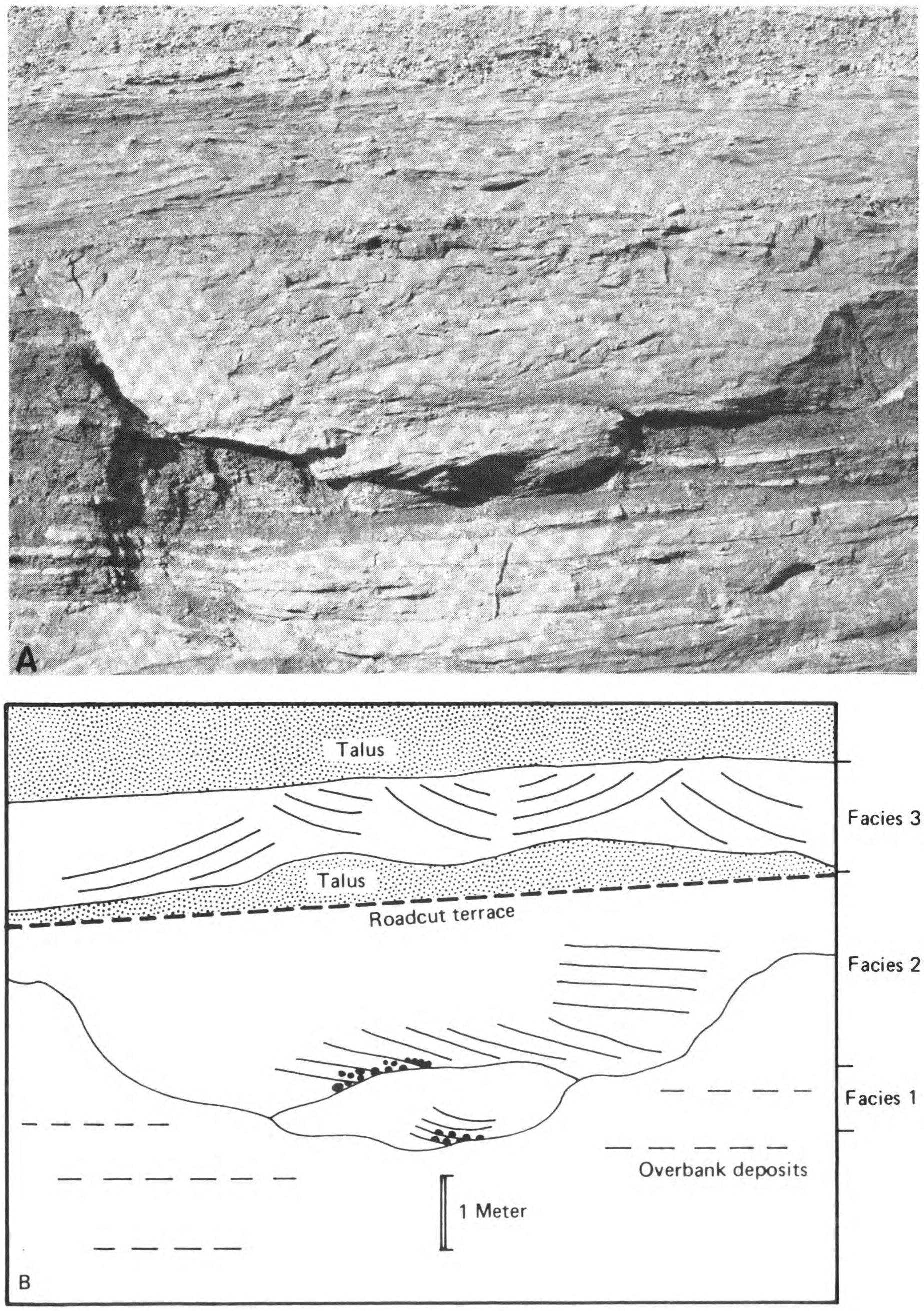

Figure 2. (a) Troughlike exposure of channel sandstone in roadcut west of Vernal, Utah. Meter stick directly below center of channel for scale. (b) Sketch of same area in photograph showing distribution of facies.

Vertical sequences of sedimentary structures and grain-size variations provide a means to distinguish between meandering and braided channels. Deposits of braided streams (Doeglas, 1962; Ore, 1964; Williams and Rust, 1969; Epstein and Epstein, 1972; Costello and Walker, 1972), fine-grained, mixed-load meandering streams (Bernard and Major, 1963; Moody-Stuart, 1966; Leeder, 1973), and coarse-grained, bed-load, meandering streams (McGowen and Garner, 1970; Oliver, 1971) have been recognized for both modern and ancient fluvial environments. The characteristics of these various types of streams are summarized in Shelton and Noble (1974, table 1).

We present here the succession of sedimentary structures and grain-size variations in some small channel-fill sequences of the Duchesne River Formation and from them interpret the depositional history.

TEXTURE

Thickness of cross-stratified units, inclination of bedding, and thickness of laminae were measured for 17 channel-fill sequences in the study area (figure 1). Point counts of 36 thin sections of channel sandstone (200 points per thin section) show the same modal composition as that reported by Andersen and Picard (1974). One-half of the samples are sublitharenite and the other half are litharenite, if named according to Folk's classification (1968).

The median grain size of samples averages 0.2 to 0.3 millimeter using thin sections. According to the classification of fine-grained rocks of Picard (1971), the samples are mainly clayey sandstone.

Samples show a pronounced skewness to the finer-size fraction (figure 3) because there is a substantial amount of silt-sized material. The median diameter of the grains measured was not corrected to sieve sizes (Textoris, 1971). The size analyses were made only for comparisons within the channel sequences studied.

CHANNEL-FILL SEQUENCE

Facies 1

The basal unit (facies 1) is a conglomerate with a disrupted framework that is infilled by fine sand- and granule-sized material. In most channel sections, clasts average 3 to 5 centimeters, with a maximum size of 15 to 20 centimeters.

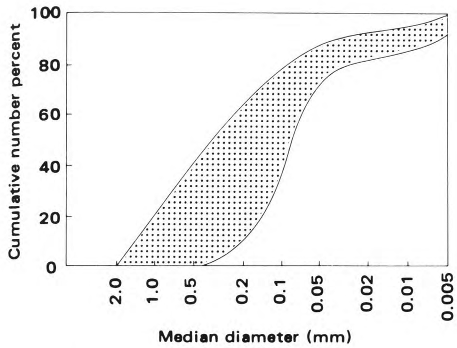

Figure 3. Representative grain-size distributions of channel sandstone. Note skewness to the fine-size fractions and poor sorting. Fine silt and clay-size material not included. Based on thin section measurements.

The conglomerate is poorly sorted, but locally it exhibits trough cross-stratification. Where troughs are present, angles of inclination of foresets are 15 to 20 degrees.

The contact of the conglomerate with the underlying silty claystone is uneven, and flute casts are present on the bottoms of some conglomerate beds. Clasts in the conglomerate are not imbricated, and there is not a well-defined upward-fining sequence within the conglomerate (figure 4). Isolated lenses of medium-grained pebbly sandstone with planar cross-stratification are also present within this facies; these lenses may show an upward-fining sequence (figure 5). Total thickness of the lower conglomerate facies is 0.5 to 1.0 meter, and the facies is present in most of the channel sections studied.

Identical facies of trough cross-stratified conglomerate or conglomeratic sandstone are commonly present higher in the channel sequence. In such instances, the sandstones display an unconformable lower surface against the fine- to medium-grained sandstone of facies 2.

Facies 2

Fine- to medium-grained sandstone above the channel lag deposits is commonly 1 to 3 meters thick and, together with facies 1, comprises the lower one-third of the channel sequence. Facies 2 is distinctive because of the absence of large amounts of pebbles and cobbles. However, some granule- to pebble-sized clasts, 2 to 3 centimeters in diameter, are present along bedding planes.

Facies 2 contains a varied assemblage of sedimentary structures. Planar cross-stratification and horizontal bedding are the most common bedding types. Medium-scale trough cross-stratification and ripple-drift stratification are rare to common (figure 6). There is no preferential vertical sequence of sedimentary structures within this facies, and the four principal bedding types vary laterally and vertically. Near the top of the facies, thinly bedded,

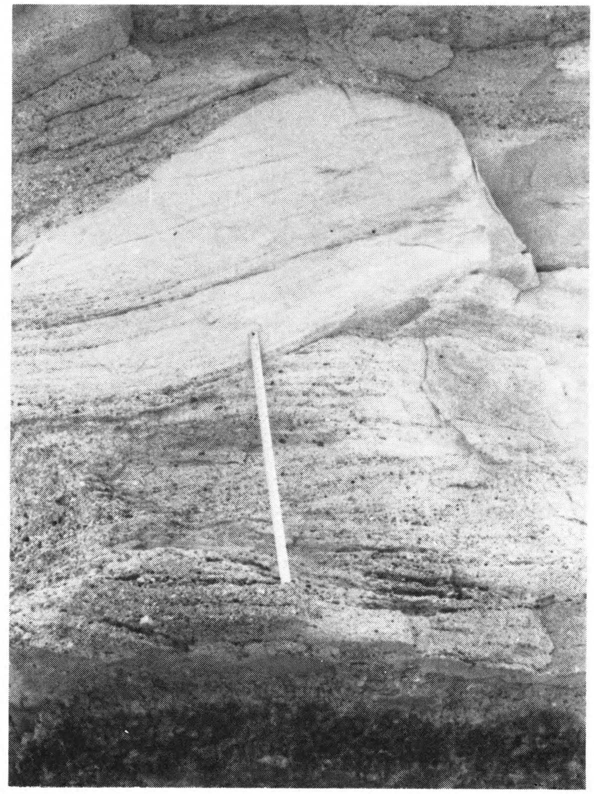

Figure 4. Lower, coarse pebble conglomerate with horizontal to trough cross-stratification (facies 1).

Figure 5. Isolated lens of planar, cross-stratified, pebbly sandstone within lower conglomerate unit (facies 1). Pencil at top is 13.5 centimeters long. Note upward-fining sequence within lower conglomerate and pebbly sandstone, especially in lower left corner of photograph.

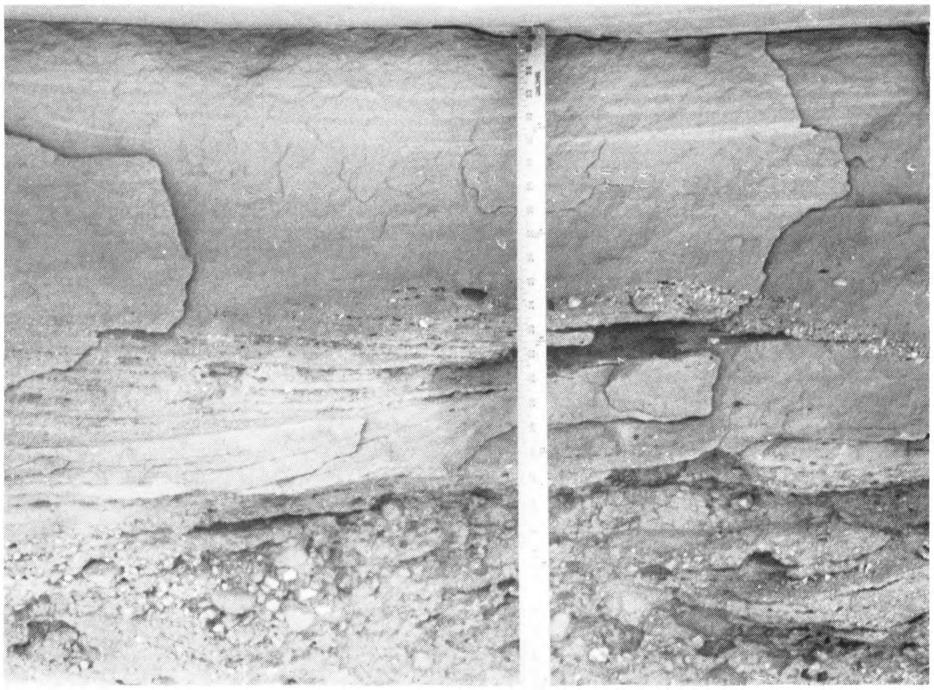

Figure 6. Conglomerate of facies 1 at base grading upward into ripple-drift stratification and discontinuous horizontal stratification of facies 2.

discontinuous, horizontal laminae of fine-grained sandstone and sandy siltstone may be present (figure 7).

The entire thickness of facies 2 comprises an upward-fining sequence in one-half of the sections studied. Pebbly sandstone at the base grades into medium- to fine-grained sandstone in the middle of the facies, which is overlain by fine-grained sandstone and rare siltstone. Secondary channel-fill sequences commonly are found in this facies and can be recognized by trough cross-stratification and lag conglomerate.

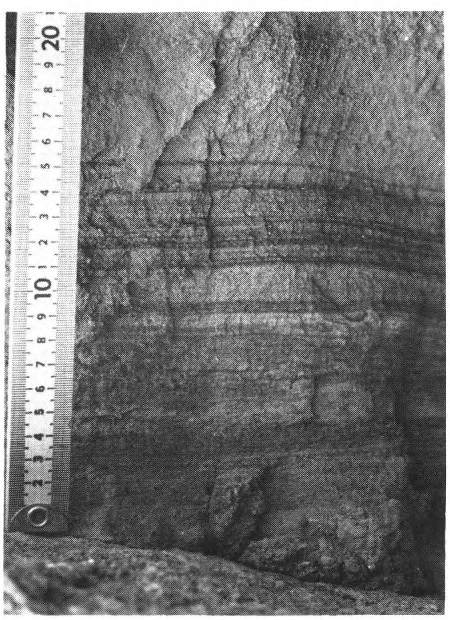

Figure 7. Thinly banded horizontal laminae of fine sandstone and siltstone in upper part of facies 2.

Facies 3

Poorly sorted, medium- to coarse-grained sandstone with abundant pebbles that average 5 to 10 millimeters in diameter overlies facies 2. Maximum grain size is about 15 centimeters.

Medium-scale low angle (15-20 degrees) trough cross-stratification (figure 8) is characteristic of facies 3. Beds of facies 3 may extend for several tens of meters laterally.

Facies 3 averages 7 to 10 meters in thickness and usually comprises more than one-half of the channel-fill sequence. Individual trough sets generally are 20 to 30 centimeters thick and do not show graded bedding within sets. No other sedimentary structures were observed within this facies.

The complete vertical succession of facies (figure 9) is present in 9 of the 17 channel-fill sections that were studied. There are two common variations from the complete sequence. Facies 1 may be composed of coarse-grained sandstone instead of conglomerate but is differentiated from facies 2 on the basis of stratification type. Secondly, the basal lag conglomerate may be completely absent. In addition, facies 2 may contain smaller lenses of trough cross-stratified conglomerate, probably formed during reoccupation of the stream channel. However, in all of the sections studied, the channel-fill sequences are overlain by the laterally extensive pebbly sandstone of facies 3.

DEPOSITIONAL ENVIRONMENTS

Depositional environments of the Duchesne River Formation have been summarized by Warner (1966), Andersen and Picard (1972, 1974), and Picard and Andersen (1975). The sandstone deposits have been interpreted to be representative of both meandering and braided streams. Andersen and Picard (1972) and Picard and Andersen (1975) found that the variability of paleocurrent directions is high for sandstones with low width-thickness ratios, although there is a considerable scatter of measurements. The small channel-fill sequences described here support these interpretations and provide sedimentologic information on what we believe is the transition from point-bar deposition of meandering streams to laterally extensive braided stream deposition.

The general vertical sequence reported here is not completely compatible with either fine-grained point-bar sequences (Bernard and Major, 1963) or with braided stream deposits (Ore, 1964; Costello and Walker, 1972). Its closest analogue may be the coarse-grained, meander belt sequence of McGowen and Garner (1970), but important differences are present in the upper part of the sequence.

Facies 1 and 2 form an overall upward-fining sequence laterally confined within the silty claystone. The lowermost trough-fill conglomerate probably formed during the filling of scour pools in the main part of channels during periods of high stream velocity. As velocity waned, finer-grained sand was deposited both as small point-bar and possible chute-fill deposits. Within some sandstone units, an overall upward-fining sequence and an upper layer of horizontal stratification (figure 7) is typical of point-bar sequences (Picard and High, 1973, p. 190). However, local trough-fill conglomerate and pebbly sandstone within the sandstone facies indicate repeated channel scouring and filling that may be the result of chute-fill deposition or reoccupation of the main channel.

Instead of the uppermost, large-scale, foreset cross-stratification

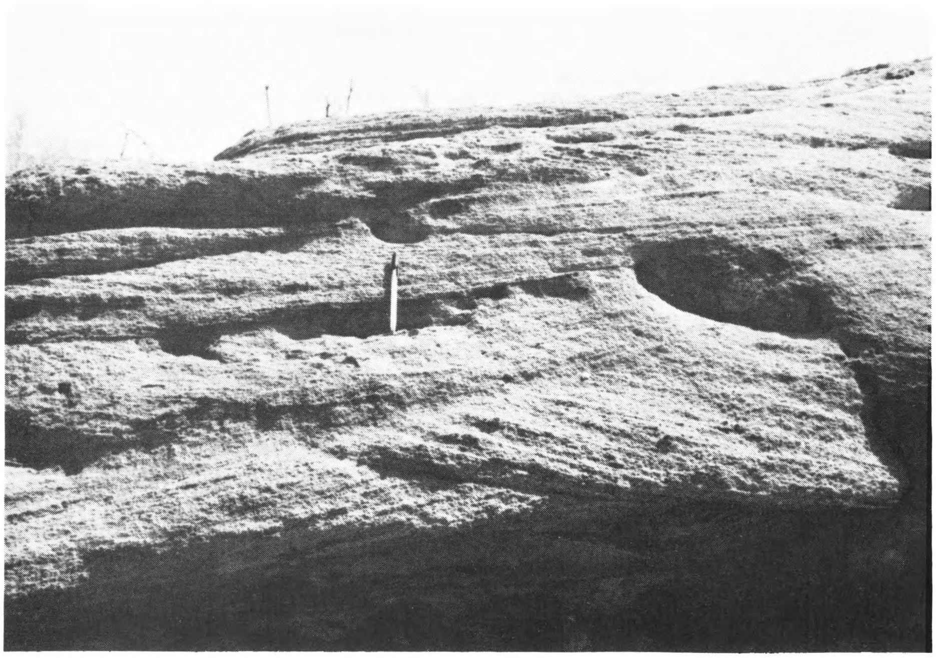

Figure 8. Medium-scale, low angle, trough cross-stratification at top of channel-fill sequence (facies 3). Unit is composed of pebbly sandstone and has greater lateral extent than lower channel deposits. Pen is 15 centimeters long.

(inclination of about 30 degrees) reported for the Simsboro Sandstone (Eocene) of Texas by McGowen and Garner (1970), the channel sequences in the Duchesne River Formation are capped by a thick, laterally extensive layer of pebbly sandstone with medium-scale, trough cross-stratification (inclination of foresets between 15 and 20 degrees). Facies 3 more closely resembles the trough cross-stratification reported by Ore (1964) for modern and ancient braided stream deposits. The uppermost trough facies resemble in part the chute-bar deposits of McGowen and Garner (1970), but the great lateral extent (in tens of meters) and different stratification type preclude that interpretation. Instead, we believe that the transition from facies 2 to facies 3 may represent a complete change in stream pattern, reflecting the change from a meandering to a braided channel pattern.

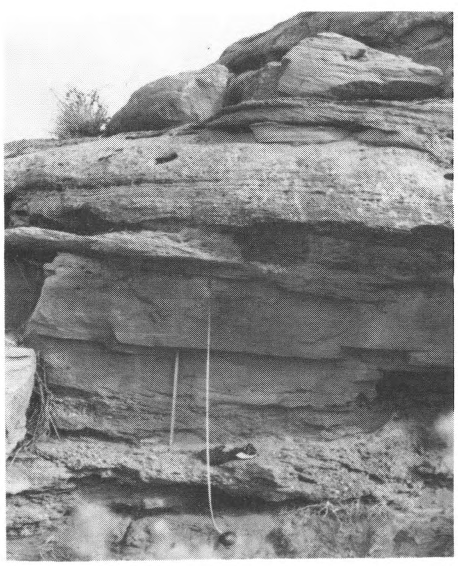

Figure 9. Typical vertical succession of basal conglomerate (facies 1), fine- to medium-grained sandstone (facies 2), and thick, trough cross-stratified pebbly sandstone (facies 3).

CONCLUSIONS

On the basis of grain size, geometry, and sedimentary structures, some small channel-fill sequences in the Duchesne River Formation suggest an upward decrease in flow velocity within the lower sandstone bodies. The fundamental genetic difference between streams of fine-grained and coarse-grained meander belts is the ratio of suspended load to bed load (McGowen and Garner, 1970). According to McGowen and Garner (1970, p. 106), upper point-bar sediments are deposited by mixed-load streams; suspended load streams also deposit upper point-bar sequences. The channel-fill sequences studied in the Duchesne River Formation are intermediate to the coarse- and fine-grained meander belts. Although a gross upward-fining sequence can be observed in facies 1 and 2, mud drapes and small-scale ripples are not present. If deposited, these features could have been eroded by later scouring and lateral migration of the streams. The upper facies of pebbly coarse-grained sandstone suggests that higher stream velocities were present following deposition of facies 2.

Characteristics of modern braided streams include high discharge, steep slope, and sporadic flow conditions resulting in initiation of longitudinal bars by deposition of lag gravel and dissection of transverse bars (Smith, 1970). For the same slope, Leopold and Wolman (1957) found that braided channels are associated with higher discharge than meandering channels. The transition from a meandering to a braided channel pattern in the Duchesne River Formation channels may have been caused by relatively minor climatic fluctuations affecting the discharge, by repeated uplift of the source area (Uinta Mountains; see Andersen and Picard, 1974) thereby increasing the gradient, or by changes in the drainage network (reoccupation of older channels or stream piracy). On present evidence it is difficult to evaluate these possibilities.

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EARTHQUAKE EPICENTERS IN UTAH
JANUARY-JUNE 1975

by Kenneth L. Cook[1]

EARTHQUAKES

Earthquake epicenters in and near Utah for January through June 1975, with dates of occurrences and approximate Richter magnitudes, are listed below. No attempt has been made to include events that were known blasts, but to discriminate man-made events from real earthquakes is often problematical; and a few events included in the list may in fact be artificial. All days are Coordinated Universal Time (UTC, same as Greenwich Mean Time, GMT), which is seven hours later than Mountain Standard Time (MST, in effect from 2:00 a. m. on October 27, 1974, MDT, until 2:00 a. m. on February 23, 1975, MST) and six hours later than Mountain Daylight Time (MDT, in effect from 2:00 a. m. on February 23, 1975, MST, until 2:00 a. m. on October 26, 1975, MDT). Therefore, some UTC dates are one day later than MST or MDT dates. All locations and magnitudes are preliminary determinations. Unless otherwise indicated, localities are in Utah. The final locations and magnitudes will be printed in the University of Utah Seismological Bulletins.

On January 1, 1975, ten new high-gain seismographs (supported by the U. S. Geological Survey and the National Science Foundation) were operational along the Wasatch Front in addition to the permanent Utah seismograph network. On June 30, 1975, the total number of such new stations that were operational along the Wasatch Front had increased to fifteen. Consequently, during the first half of 1975, a greater number of small-magnitude earthquakes were recorded and located in north-central Utah than were in southern Utah.

Other conditions affect the homogeneity of the seismicity sample below an approximate magnitude of 2.5. The skeletal seismograph network in southern Utah provided the only continuous information for locating small earthquakes in that part of the state. Malfunctions at a single station could preclude a reliable location for a small-magnitude shock. It should also be noted that the Uinta Basin Seismological Observatory (UBO) was not in operation during the six-month period of this listing.

January		Magnitude
2	7 km southeast of Richmond	1.3
2	14 km northeast of Salt Lake City	<1.0
3	22 km north-northeast of Vernal[2]	2.0
4	Stansbury Mountains (9 km east-southeast of Timpie)	1.2
4	9 km west-southwest of Clear Creek	2.2
5	13 km northwest of Huntington[2]	2.6
5	6 km west-northwest of Genole	1.2
7	15 km south-southeast of Indian Springs	1.7
8	Spring Lake area[2]	1.8
10	10 km west-northwest of Cove Fort	2.7
10	3 km northwest of Devils Slide[2]	1.3
11	12 km west-northwest of Wanship	1.0
11	8 km north of Lund	3.0
12	21 km south of Minersville	2.8
12	8 km east-northeast of Price[2]	1.8
13	11 km southwest of Lehi	1.4
13	8 km west-northwest of Huntington[2]	1.9
14	6 km west of Orem	1.6
15	13 km northwest of Huntington[2]	1.4
15	15 km northwest of Huntington[2]	1.6
15	7 km south of Clear Creek	1.6
18	5 km southwest of Pelican Point	<1.0
18	Devils Slide area[2]	1.0
19	22 km northeast of Salt Lake City	2.0
19	17 km northeast of Salt Lake City	<1.0
19	Bear River Range area (19 km east-southeast of Richmond)	2.0
22	Spring Lake area[2]	2.1
23	Near mouth of Parleys Canyon (16 km southeast of Salt Lake City)	1.4
23	5 km south-southeast of Porterville	1.6
24	West side of Lake Mountains (9 km west-southwest of Pelican Point)	1.1
24	5 km east-northeast of Randolph[2]	2.3
29	16 km west-northwest of Huntington[2]	2.7
29	14 km west of Huntington[2]	2.4
29	14 km west-northwest of Huntington[2]	2.5
29	4 km west of Scipio	2.0

February		Magnitude
3	13 km south of Levan	2.2
4	7 km west-northwest of Dugway	1.4
5	5 km west-northwest of Wattis[2]	2.1
7	16 km east of Snowville	1.9
7	Scipio	1.7
10	Spring Lake area[2]	1.9
12	13 km north of Devils Slide	1.6
12	9 km west of Orem	1.6
12	9 km west of Orem	1.6
18	7 km east-southeast of Lakeside	1.3
19	16 km north of Scipio; and 10 km south-southwest of Mills	2.6
19	7 km north of Scipio	2.1
19	Devils Slide area	1.4
19	Spring Lake area[2]	2.3
21	21 km west-northwest of Promontory Point	2.0
21	12 km west-southwest of Stockton	1.0
22	23 km north of Scipio; and 4 km south of Mills	1.3
23	8 km north of Castle Gate[2]	1.8
25	Rush Valley area (11 km south-southeast of St. John station)	1.7
25	9 km northeast of Holden	1.7
26	2 km northeast of Wallsburg	2.0
27	10 km northeast of Price[2]	2.2

March		Magnitude
1	Devils Slide area	1.1
4	Northern part of Thomas Range area (17 km northwest of Topaz Mountain)	1.8
7	Dugway Valley area (11 km north-northeast of Topaz Mountain)	1.5
8	4 km east of Morgan	1.7
10	16 km east-northeast of Randolph[2]	1.6
10	5 km east of mouth of Parleys Canyon (14 km east-southeast of Salt Lake City)[2]	1.8
10	18 km northwest of Scipio; and 10 km east of Oak City	1.5
11	Spring Lake area[2]	2.0
13	Dugway Valley area (23 km north-northeast of Topaz Mountain)	2.1
17	Dugway Valley area (14 km north-northeast of Topaz Mountain)	1.4
19	18 km east-northeast of Wendover	2.1
19	6 km east of Santaquin	2.3
21	South end of Dugway Range area (19 km north of Topaz Mountain)	2.2
24	15 km northwest of Promontory Point	1.6
27	South end of Dugway Range area (19 km north of Topaz Mountain)	1.5
27	In Idaho. Main foreshock of Pocatello Valley (Idaho-Utah	

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[2] Possible mine or quarry blast.

Magnitude

border) earthquake (18 km northeast of Snowville, Utah). Felt in epicenter area 4.2

28 In Idaho. Main shock of Pocatello Valley (Idaho-Utah border) earthquake (17 km northeast of Snowville, Utah, and 1-2 km south of epicenter of main foreshock on March 27). Felt widely in Utah (as far south as Delta), in Nevada (as far west as Elko), in Wyoming (as far east as Rock Springs), and in Idaho (as far north as Rexburg). Estimated damage: in excess of $1,000,000 .... 6.0

29 In Idaho. Main aftershock of Pocatello Valley (Idaho-Utah border) earthquake (17 km east-northeast of Snowville, Utah, and 6 km south-southeast of epicenter of main shock on March 28). Felt widely, as far south as Salt Lake City 4.7

29 7 km east of Paradise 2.3

29 6 km northeast of Paradise 1.0

30 6 km east-northeast of Paradise 1.5

31 6 km southeast of Richmond 1.6

April

2 Fish Springs Flat area (14 km west of Topaz Mountain) 1.5

7 4 km northwest of Orangeville[2] 1.6

7 Utah-Wyoming border (27 km east-northeast of Upton) 1.4

8 Fish Springs Flat area (15 km west of Topaz Mountain) 1.9

15 3 km east of Holden 1.7

15 Dugway Valley area (25 km north-northeast of Topaz Mountain) 2.3

15 Spring Lake area[2] 2.0

29 Near mouth of Parleys Canyon (12 km southeast of Salt Lake City)[2] 1.4

30 Spring Lake area[2] 2.1

May

6 Southern part of Thomas Range area (11 km north-northwest of Topaz Mountain) 2.1

7 Spring Lake area[2] 1.6

10 9 km southeast of Snowville 1.9

11 Southern part of Hansel Mountains (10 km east-northeast of Locomotive Springs) .... <1.0

11 23 km northeast of Salt Lake City ... <1.0

13 13 km east-southeast of Huntsville ... <1.0

13 24 km southeast of Snowville ...... <1.0

13 Dugway Valley area (13 km north-northeast of Topaz Mountain) 1.9

13 9 km northwest of Brighton .... <1.0

15 9 km southeast of Snowville 2.5

15 11 km southeast of Snowville 1.4

16 9 km southeast of Snowville 2.0

16 Devils Slide area 1.3

17 9 km southeast of Snowville 2.0

20 2 km west of Milton .... <1.0

20 3 km southwest of Adamsville 2.9

22 Cornish .... <1.0

23 2 km west of Lehi .... <1.0

23 3 km southwest of Lehi .... <1.0

Magnitude

23 Dugway Valley area (20 km north-northeast of Topaz Mountain) 1.8

28 Spring Lake area[2] 1.8

30 North tip of Oquirrh Mountains (3 km west of Garfield) .... <1.0

June

5 Spring Lake area[2] 2.1

9 24 km west-northwest of Promontory Point 1.6

10 Skull Valley area (11 km west of Iosepa) 1.2

10 Promontory Point 1.0

11 25 km north-northwest of Promontory Point .... <1.0

11 25 km southwest of Thatcher ...... <1.0

11 Southern end of Dugway Range area (15 km north-northeast of Topaz Mountain) 1.6

13 23 km west of Indian Springs 1.3

16 6 km north of Mills Junction .... <1.0

16 6 km northwest of the north end of Strawberry Reservoir 1.0

18 Near mouth of Parleys Canyon (12 km southeast of Salt Lake City)[2] 1.6

23 8 km southeast of Richmond 1.7

23 5 km south of Wallsburg .... <1.0

23 11 km southeast of Richmond ...... <1.0

24 2 km west of Midway .... <1.0

24 Spring Lake area[2] 1.9

26 Uinta Mountains area (20 km northeast of Kings Peak) 1.5

27 Logan Canyon area (9 km east-northeast of Logan) 1.1

27 Devils Slide area[2] 1.4

28 3 km west-northwest of Genola ..... <1.0

29 6 km west-southwest of Charleston .... <1.0

30 8 km west-southwest of Garden City .... <1.0

EARTHQUAKE SEQUENCE IN POCATELLO VALLEY (IDAHO-UTAH BORDER) AREA BEGINNING IN MARCH 1975

The earthquake sequence beginning in March 1975, which centered in Pocatello Valley on the Idaho-Utah border, is given in table 1 for all earthquakes of Richter magnitude 3.0 or greater.[3] The Richter magnitudes were determined from the Wood-Anderson seismographs in Logan (primarily), Dugway, or Price, Utah, or a combination of two or more of these stations. This earthquake sequence is the subject of a separate study (Arabasz, W. J., and others, in preparation for publication), and the listing of aftershocks in both the previous listing and table 1 is not complete. Several aftershocks with

[3] The Richter magnitude (M_L) is the magnitude measured using the long-period seismic waves recorded on the Wood-Anderson seismographs.

Table 1. Earthquake sequences in the Pocatello Valley (Idaho-Utah border) beginning in March 1975 with Richter magnitudes 3.0 or greater.

[all dates and times are UTC]

Date (1975)	Time		Magnitude
	Hour	Minute	
March 27	04	48	4.2 (felt)
March 28	02	31	6.0 (felt widely)
	02	36	3.8
	03	00	3.0
	03	06	3.2
	03	14	3.3
	03	15	3.1
	03	30	3.0
	03	38	3.0
	04	05	3.2
	05	19	3.1
	06	52	3.0
	11	22	3.0
	13	11	3.0 (felt)
	16	15	3.8 (felt)
	18	30	3.0
	21	33	3.0
	22	05	3.1
March 29	01	47	3.1 (felt)
	05	44	3.2 (felt)
	09	32	3.1
	13	01	4.7 (felt widely)
	14	32	3.0
	15	43	3.2
March 30	00	28	2.4[1] (felt)
	06	56	4.1
	06	57	3.7
	06	59	3.5
	07	32	3.4
	08	46	3.1
	12	56	3.2
	14	02	3.6 (felt)
March 31	01	55	3.6 (felt)
	08	52	2.8[1] (felt)
	10	31	3.5
	13	24	3.0
	13	46	3.2
April 2	21	06	3.2 (felt)
April 4	06	52	2.8[1] (felt)
April 5	01	08	3.1 (felt)
April 6	21	05	3.2 (felt)
April 7	08	22	2.8[1] (felt)
	13	42	3.1 (felt)
	14	01	3.1
	14	44	3.0 (felt)
April 8	03	48	2.9[1] (felt)
April 10	10	21	3.2
April 14	20	32	2.7[1] (felt)
April 20	08	56	3.1
April 23	04	05	2.6[1] (felt)
	04	28	2.7[1] (felt)
April 26	01	52	3.1
May 12	05	17	3.0
May 22	14	15	3.8
May 29	12	28	2.8[1] (felt)
June 5	20	47	2.4[1] (felt)
June 13	16	09	2.9[1] (felt)
June 30	03	26	3.0 (felt)

[1] Though the magnitude of this earthquake is less than 3.0, it is included because it was felt.

magnitudes slightly less than 3.0 were included in table 1 because they were "felt." The documentation of the "felt" aftershocks was obtained from answers to earthquake questionnaires filled out by residents in the epicentral area. Starting in mid-April 1975, when the farmers began moving into their homes in Pocatello Valley for the summer season, many small aftershocks (with Richter magnitudes of 2.5 or less) were reported as "felt" by the residents in Pocatello Valley; these are not generally included in the present summary report because they require confirmation and further study.

PROBABLE ROCKBURSTS

The seismic events (total of 284) during January through June, 1975, in the coal-mining areas of Carbon County, Utah—in particular, the Sunnyside-East Carbon City-Columbia region—are listed separately (table 2) in terms of the number of events each day. These events are interpreted as "probable rockbursts," although some may be earthquakes; no attempt was made to distinguish these two types of events. The interpretation of these events was based on the paper seismograms of the Price, Utah (PCU), seismograph station primarily and the Dugway (DUG) station secondarily, as the Uinta Basin Seismological Observatory (UBO) was not in operation during this report period.

Table 2. Number of probable rockbursts—January 1, 1975 through June 30, 1975.

Date	January	February	March	April	May	June
1	2	3	1		3	4
2					7	1
3	3	4	3		2	
4	7	2	1		1	2
5	3	3	1		2	5
6	1	1	1		1	4
7		3		2	1	3
8		1	2		4	3
9		4	1		2	2
10		1	2	1	4	1
11	1	1			2	1
12	3	5		4		3
13					2	5
14	7	3	2		4	13
15	4	2	3			4
16	3		1	2	2	
17	1	1				1
18	3	2			1	1
19	1				1	3
20		2	2		1	10
21	2		1		3	1
22			1			
23	1		1	2		2
24	3	2			3	2
25	3		2	4		3
26	1		1		3	2
27	1	1			3	2
28	3	1			1	2
29	4			6	1	
30				2	1	
31	1					
Total	58	42	26	23	55	80

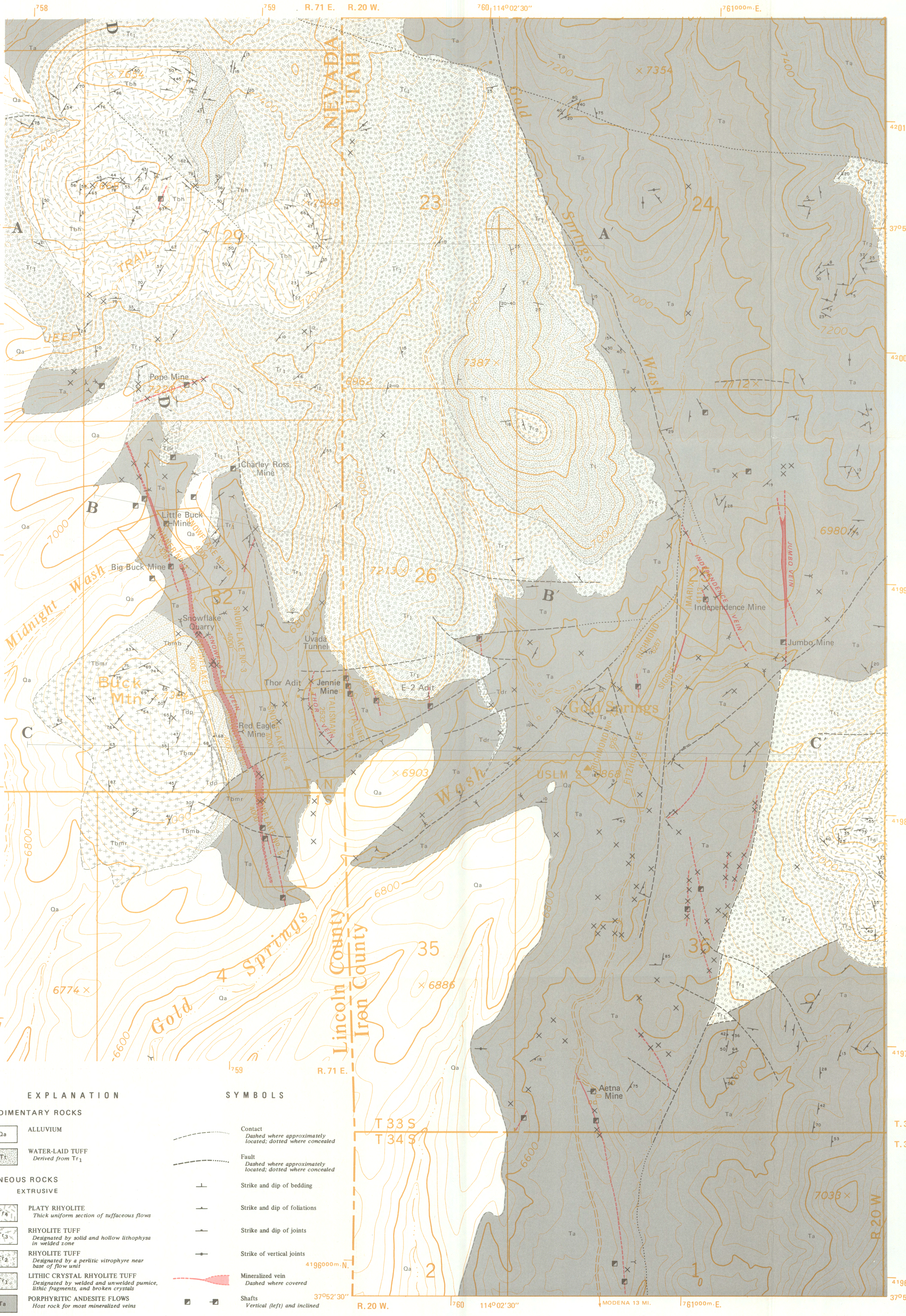
Table 2. *continued*

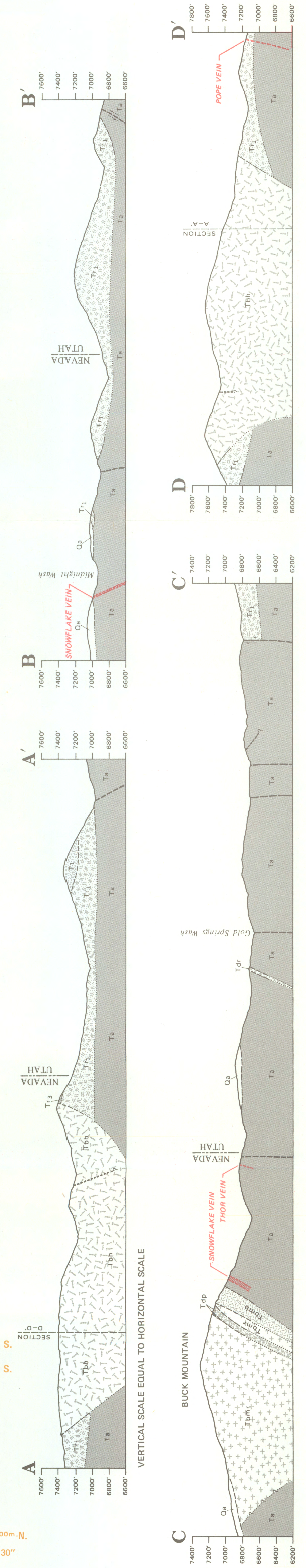
ACKNOWLEDGEMENTS

Efforts to monitor Utah seismicity involved the assistance of S. H. Ward, R. B. Smith, and several staff members of the University of Utah Seismograph Stations. Earthquakes during this report period were routinely located by W. J. Arabasz, W. D. Richins, A. J. Kastrinsky, and G. M. Hathaway. Financial support for the operation of the seismograph stations and the compilation of the data was provided by the National Science Foundation, the U. S. Geological Survey, the Utah Geological and Mineral Survey, and Utah state funds from the Utah legislature as a line-item budget to the University of Utah.

Information concerning the "felt" earthquakes was provided by people residing in the earthquake epicenter area, too numerous to mention individually, who filled out and returned the aftershock questionnaires circulated to them by the University of Utah Seismograph Stations.

Appropriations No. 01-61-03
Archives Approval No. 7600033





Geology and geologic sections adapted from William C. Block

EXPLANATION

SEDIMENTARY ROCKS

Quaternary

- Qa — ALLUVIUM

Tertiary

- Tt — WATER-LAID TUFF
  Derived from Tr_1

IGNEOUS ROCKS

EXTRUSIVE

- Tr_4 — PLATY RHYOLITE
  Thick uniform section of tuffaceous flows
- Tr_3 — RHYOLITE TUFF
  Designated by solid and hollow lithophysa in welded zone
- Tr_2 — RHYOLITE TUFF
  Designated by a perlitic vitrophyre near base of flow unit
- Tr_1 — LITHIC CRYSTAL RHYOLITE TUFF
  Designated by welded and unwelded pumice, lithic fragments, and broken crystals
- Ta — PORPHYRITIC ANDESITE FLOWS
  Host rock for most mineralized veins

INTRUSIVE

- Tbh — BULL HILL RHYOLITE PORPHYRY
- Tbmr — BUCK MOUNTAIN RHYOLITE
- Tbmb — BUCK MOUNTAIN BRECCIATED RHYOLITE
- Tdr — RHYOLITE DIKE
- Tdp — PERLITE DIKE

SYMBOLS

- Contact
  Dashed where approximately located; dotted where concealed
- Fault
  Dashed where approximately located; dotted where concealed
- Strike and dip of bedding
- Strike and dip of foliations
- Strike and dip of joints
- Strike of vertical joints
- Mineralized vein
  Dashed where covered
- Shafts
  Vertical (left) and inclined
- Adits
  Open (left) and inaccessible
- Prospect
- Quarry or glory hole

Base from U.S. Geological Survey topographic quadrangle: Deer Lodge Canyon, Nevada-Utah, 1972

1000-meter Universal Transverse Mercator grid ticks, zone 11. 1927 North American datum

Utah patented mining claims from records of U.S. Bureau of Land Management, 1974

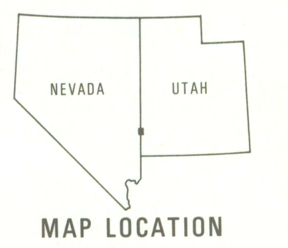
Nevada patented mining claims from maps of Andesite Mining Co. and Superior Gold Mining, Inc.

1" = 800'

½ 0 ½ Mile

1 0 1 Kilometer

CONTOUR INTERVAL 40 FEET



MAP LOCATION

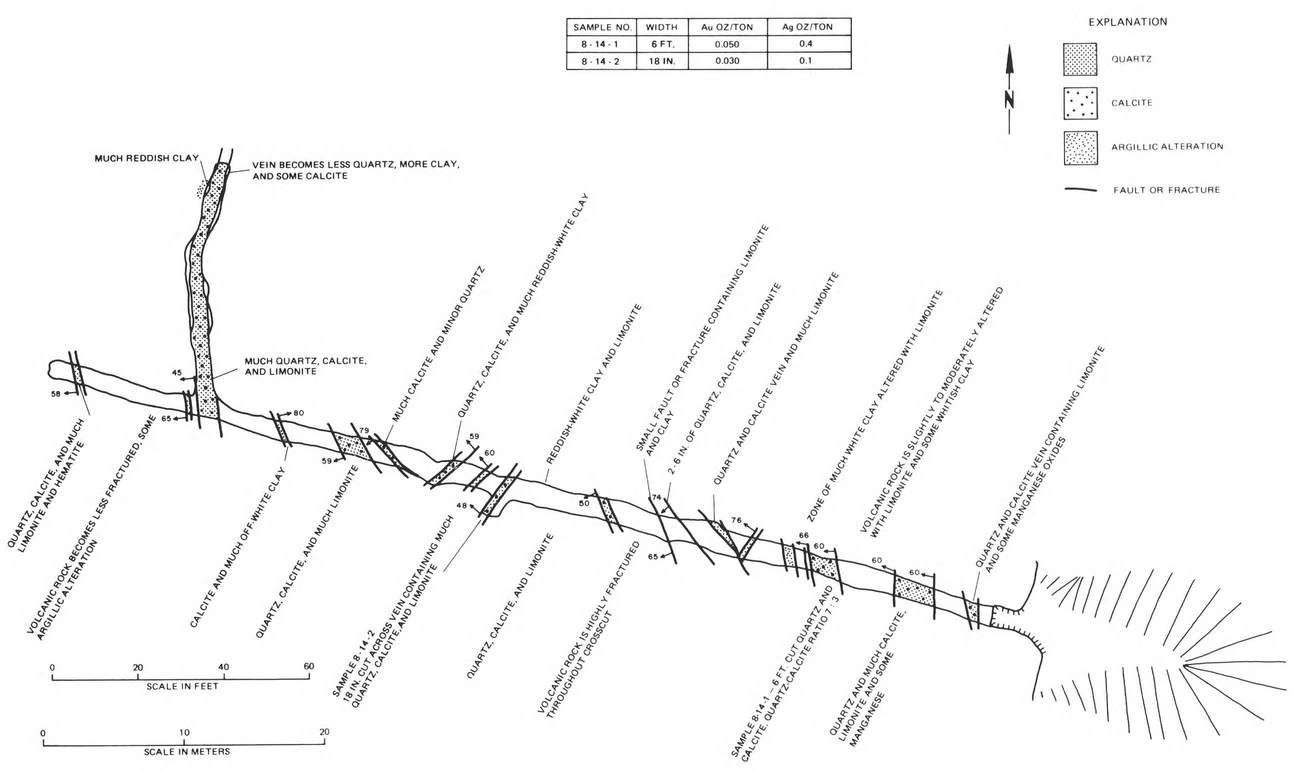
GEOLOGY OF GOLD SPRINGS MINING DISTRICT
IRON COUNTY, UTAH AND LINCOLN COUNTY, NEVADA

Compiled by Lee I. Perry

-1976-

PLATE 2

SAMPLE NO.	WIDTH	Au OZ/TON	Ag OZ/TON
8 - 14 - 1	6 FT.	0.050	0.4
8 - 14 - 2	18 IN.	0.030	0.1

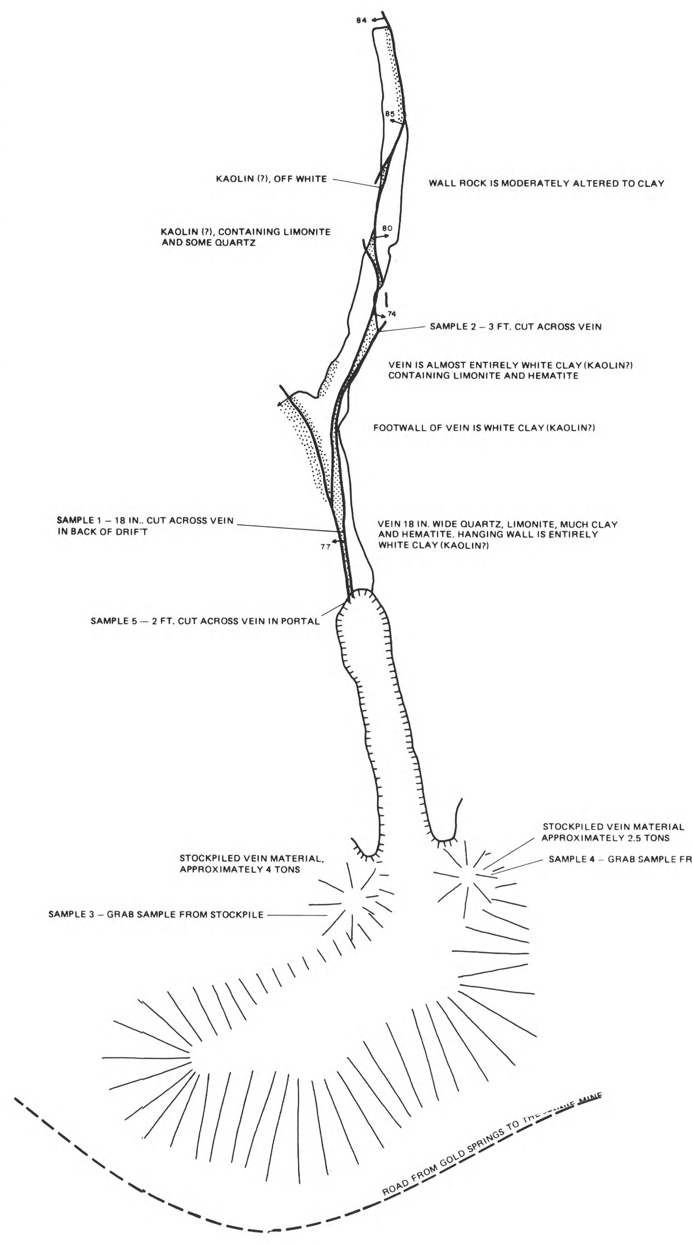


Unnamed adit on Aetna vein.

A. Map of unnamed adit on Aetna vein; assay of samples is shown in table. Photograph shows the portal, looking west.

E-2 adit.

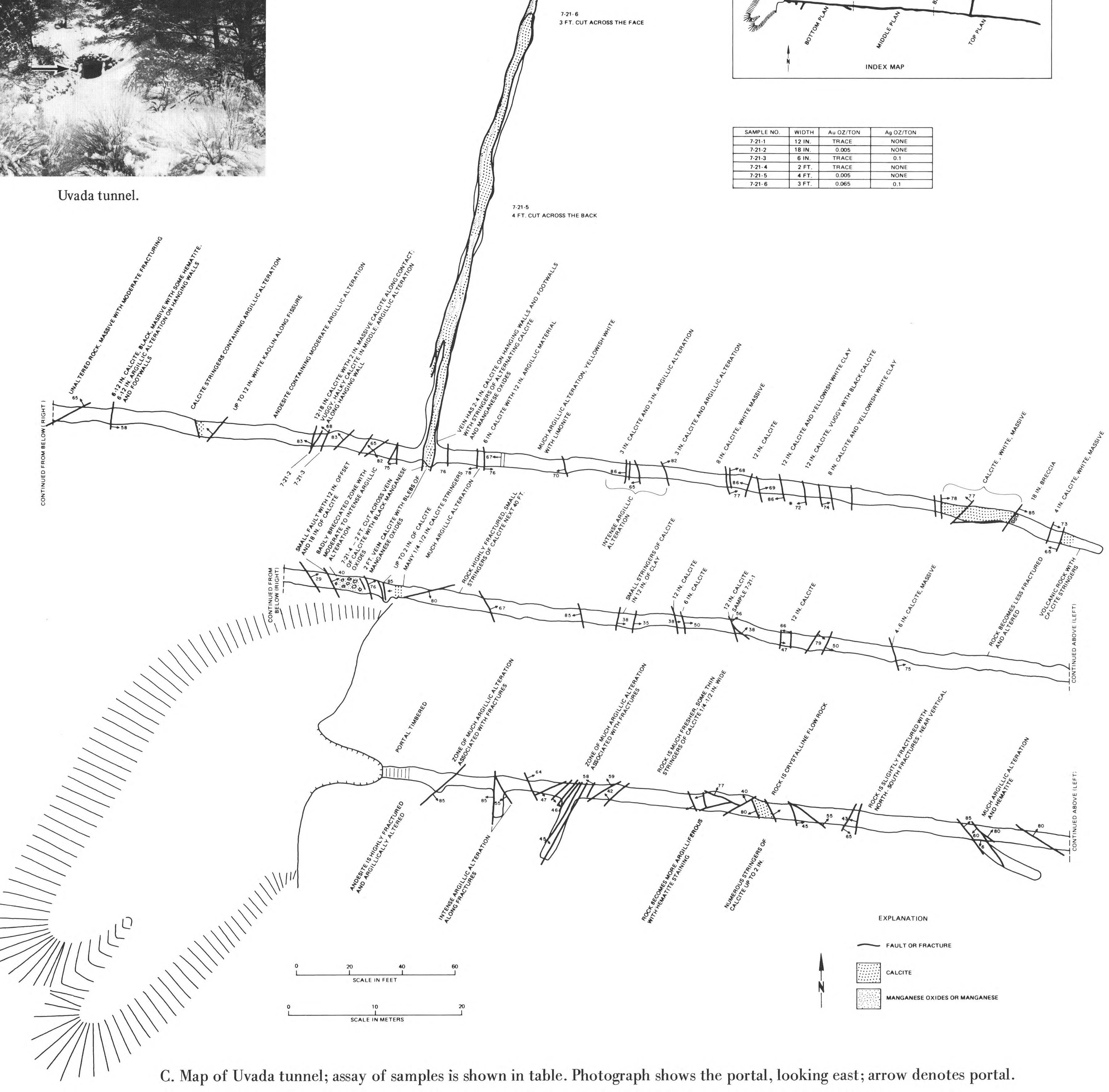
SAMPLE NO.	WIDTH	Au OZ/TON	Ag OZ/TON
1	18 IN.	0.070	1.4
2	3 FT.	0.010	0.2
3	GRAB	0.090	1.0
4	GRAB	NONE	0.3
5	2 FT.	0.020	3.4



B. Map of E-2 adit; assay of samples is shown in table. Photograph shows partly caved in portal, looking north.

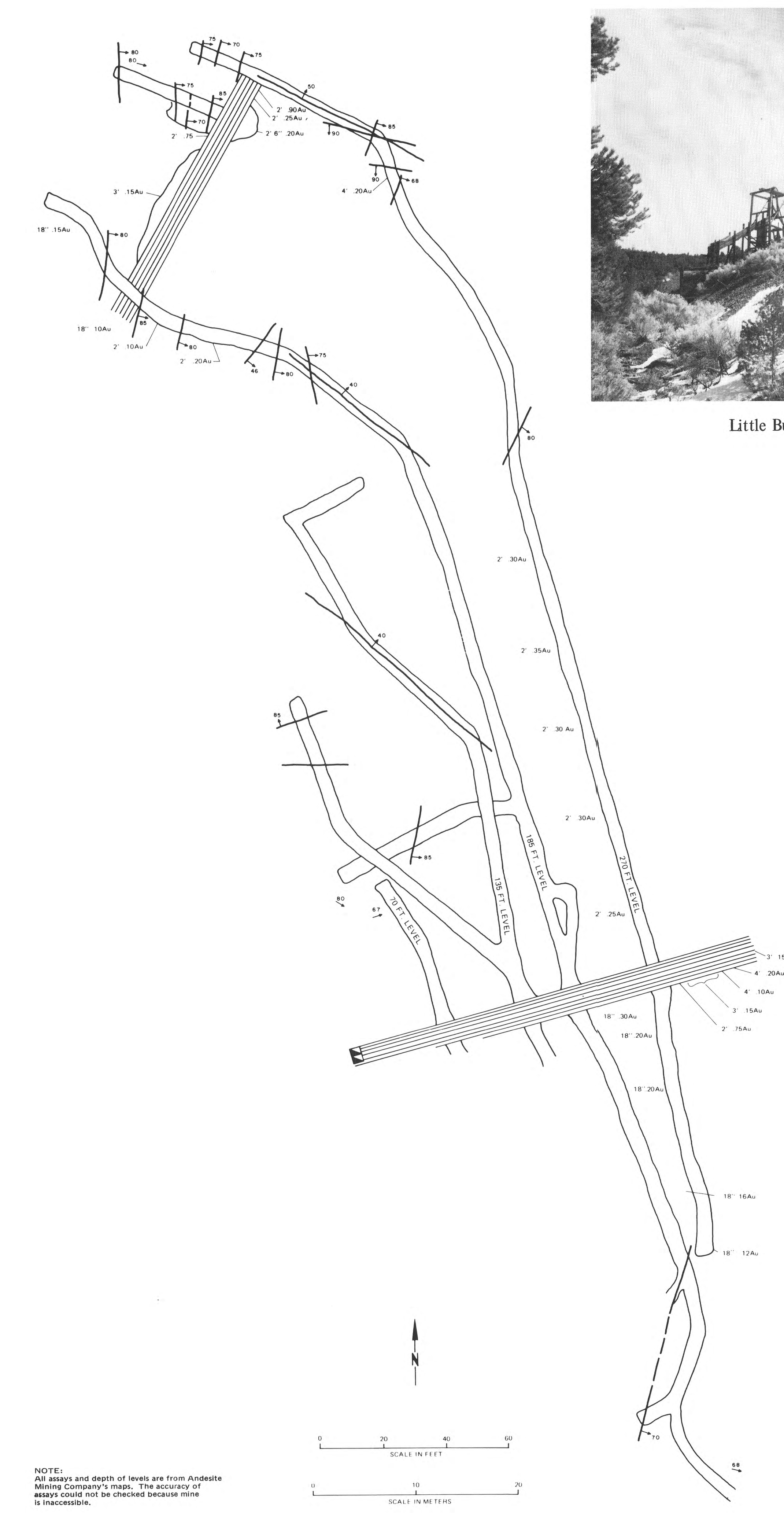
Uvada tunnel.

SAMPLE NO.	WIDTH	Au OZ/TON	Ag OZ/TON
7-21-1	12 IN.	TRACE	NONE
7-21-2	18 IN.	0.005	NONE
7-21-3	6 IN.	TRACE	0.1
7-21-4	2 FT.	TRACE	NONE
7-21-5	4 FT.	0.005	NONE
7-21-6	3 FT.	0.065	0.1



C. Map of Uvada tunnel; assay of samples is shown in table. Photograph shows the portal, looking east; arrow denotes portal.

Little Buck mine.

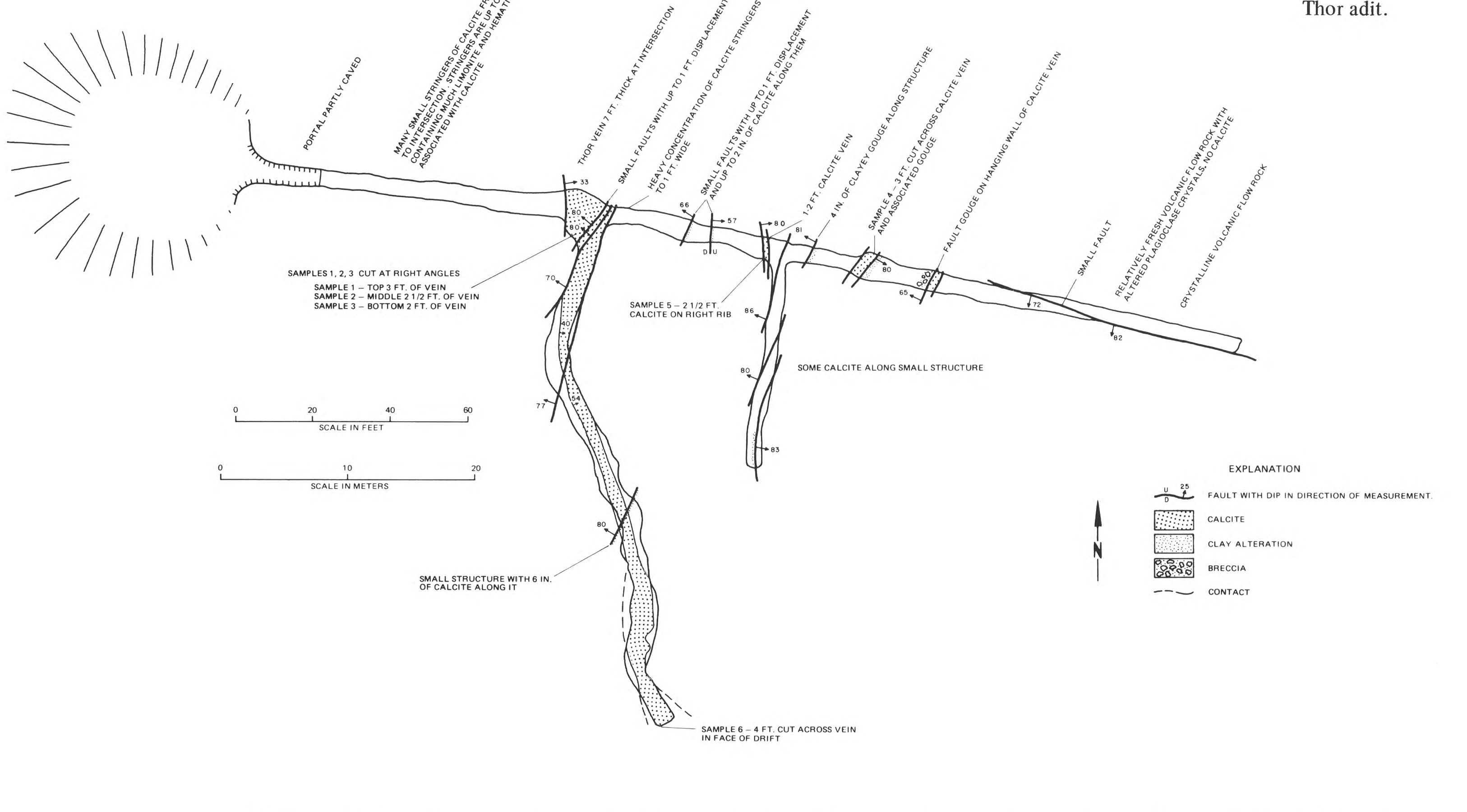


D. Map of Little Buck mine; adapted from map by Jensen (1935) of Andesite Mining Company. Photograph shows headframe and ore bin of Little Buck mine, looking north from Midnight Wash.

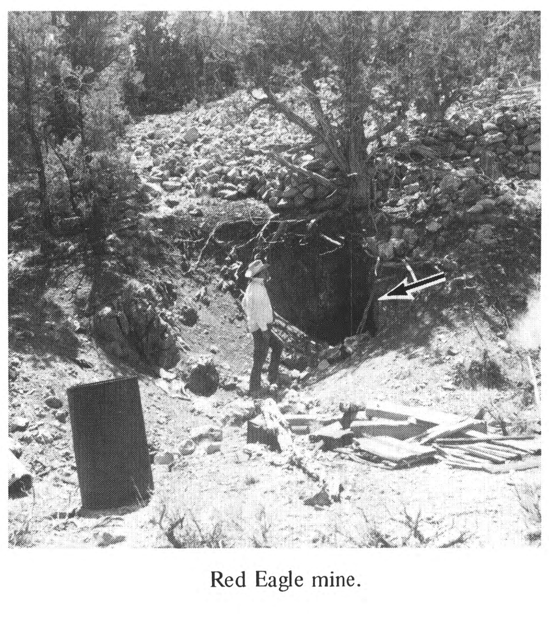
* SAMPLE NO.	WIDTH	Au OZ/TON	Ag OZ/TON
1	3 FT.	0.015	0.4
2	2 1/2 FT.	TRACE	NONE
3	2 FT.	0.010	0.3
4	3 FT.	0.005	NONE
5	2 1/2 FT.	TRACE	0.1
6	4 FT.	TRACE	NONE

* ALL SAMPLES CUT AT RIGHT ANGLES ACROSS STRUCTURE

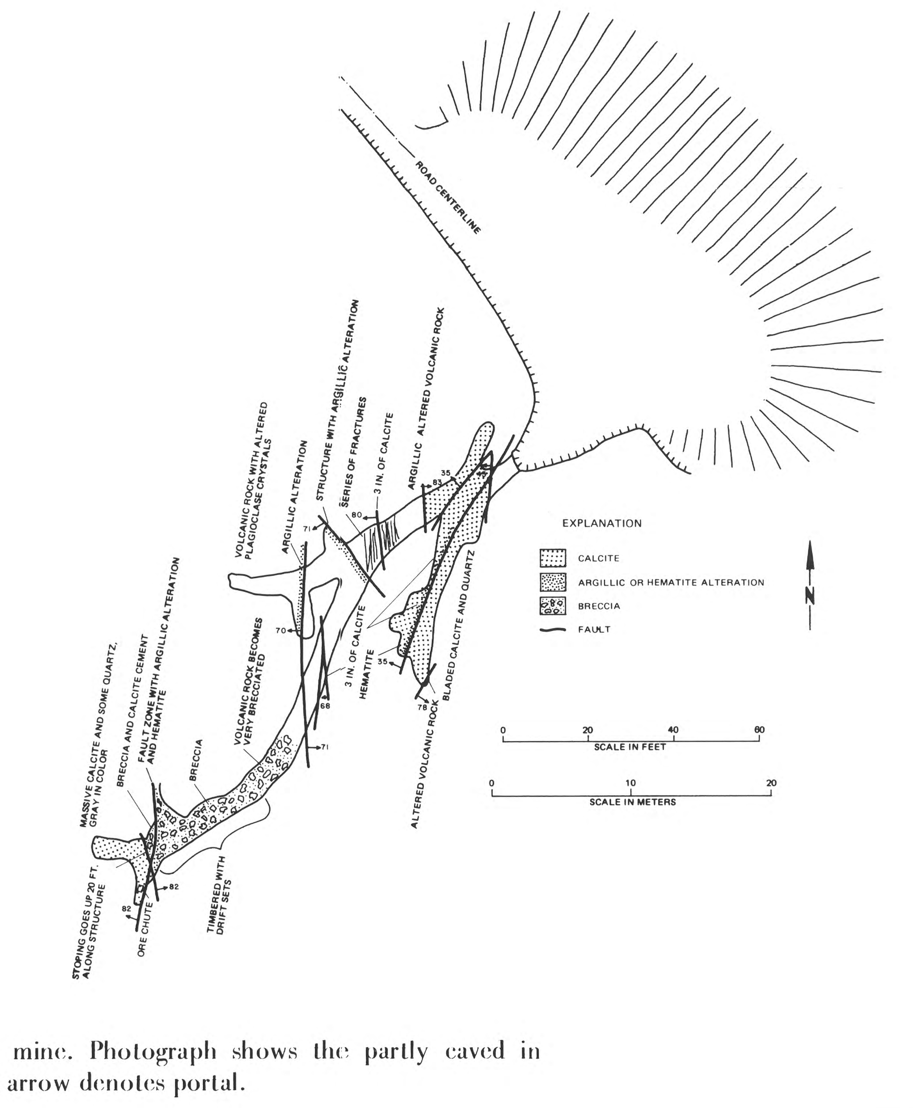
Thor adit.



E. Map of Thor adit; assay of samples is shown in table. Photograph shows the partly caved in portal, looking east.



Red Eagle mine.



F. Map of Red Eagle mine. Photograph shows the partly caved in portal, looking west; arrow denotes portal.

UTAH GEOLOGICAL AND MINERAL SURVEY

606 Black Hawk Way
Salt Lake City, Utah 84108

THE UTAH GEOLOGICAL AND MINERAL SURVEY, a Division of the Utah Department of Natural Resources, operates with a professional staff under the guidance of a policy-making Board appointed by the Governor of Utah from various representatives of industry and the public as specified by law.

The Survey is instructed to investigate areas of geologic and topographic hazards, to survey the geology and mineral occurrences, and to collect and distribute reliable information concerning the mineral industry and mineral resources, topography and geology of the state so as to contribute to the effective and beneficial development of all resources. The *Utah Code, Annotated, 1953 Replacement Volume 5, Chapter 36, 53-36-1 through 12,* describes the Survey's functions.

The Survey issues several series of publications and maps, *Survey Notes*—a quarterly newsletter, and *Utah Geology*—a biannual volume containing short papers on the geology of the state. It has also reprinted significant articles pertaining to Utah geology from other publications. (Write to the above address for the latest list of publications available.)

The Survey also sells the colored geologic map of Utah (Army Map Service base, 1:250,000, in four quarters), a project of the College of Mines and Mineral Industries from 1961 through 1964. It acts as sales agent for publications of the Utah Geological Association and its predecessor organizations, the Utah Geological Society, the Intermountain Association of Geologists, and the Intermountain Association of Petroleum Geologists.

THE SAMPLE LIBRARY is maintained to preserve well cuttings, drill cores, stratigraphic sections and other geological samples. Files of lithologic logs, electrical and other mechanical logs of oil and gas wells drilled in the state are also maintained. The Library's collections have been obtained by voluntary donation and are open to public use, free of charge.

THE SURVEY'S BASIC PHILOSOPHY is that of the U. S. Geological Survey, *i. e.,* our employees shall have no interest in lands within Utah where there is a conflict of interest deleterious to the goals and objectives of the Survey; nor shall they obtain financial gain by reason of information obtained through their work as an employee of the Survey. For permanent employees this restriction is lifted after a two-year absence; for consultants employed on special problems, there is a similar time period which can be modified only after publication of the data or after the data have been acted upon. For consultants, there are no restrictions beyond the field of the problem, except where they are working on a broad area of the state and, here, as for all employees, we rely on their inherent integrity.

Directors:
Donald T. McMillan, 1974-
William P. Hewitt, 1961-1974
Arthur L. Crawford, 1949-1961