GEOLOGY AND ORE DEPOSITS OF THE LUCIN MINING DISTRICT, BOX ELDER COUNTY, UTAH, AND ELKO COUNTY, NEVADA

by

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ABSTRACT

The Lucin mining district is in the northern third of the Pilot Range of western Utah and eastern Nevada. The district has produced since 1870 over three million dollars of low grade copper and iron ore primarily of malachite, chrysocolla, goethite and limonite. Mining operations reached a high point in the early nineteen hundreds but because of high percentages of alumina and silica, milling and metallurgical difficulties forced the gradual decrease in production until in 1955, operations were abandoned.

Ore bodies in the district are concentrated in two localities. At Copper Mountain they occur along north-south faults in the Devonian Guilmette Formation, and at Tecoma Hill they occur along east-west and northeast fractures in the Ordovician Fish Haven Dolomite, Silurian Laketown Dolomite and the Guilmette Formation. All of the major fault trends are pre-Late Tertiary, although the Tecoma Hill east-west and northeast fissures are younger than the Copper Mountain north-south faults. Intrusion of a monzonite stock accompanied the faulting but its relationship to ore formation is uncertain.

Ore deposits are classified as replacement and fracture fillings in favorable carbonate rock, particularly in the lower massive limestone member of the Guilmette Formation. Sulphide ores filled water-worn cavities in the host rock but

have since been almost completely oxidized to oxides, carbonates, sulphates, and other secondary minerals.

Both the Copper Mountain and the Tecoma Hill localities have experienced extensive post-Late Tertiary erosion accompanying uplift of the Pilot Range. Stripping of post-Devonian sedimentary rock has exposed the Guilmette and older formations to surface leaching allowing supergene enrichment to occur.

Rocks originally considered to be of Carboniferous age in the Lucin district range from Early Ordovician to Middle Permian. These revised ages are based on fossil zones in the immediate area, as well as in the entire Pilot Mountain area, on sequence of position, and on lithologic and paleontological correlation with the neighboring Silver Island and Crater Island Mountains.

The revised Paleozoic section is as follows:

Middle (?) Permian	unnamed formation	0 - 125'
Lower Permian (Leonard)	Pequop Formation	840 - 875'
Wolfcamp - upper Pennsylvanian undifferentiated (angular unconformity)		120 - 130'
Lower Pennsylvanian? - Upper Mississippian (angular unconformity)	Chainman - Diamond Peak undifferentiated	450 - 470'
Upper Devonian	upper shaly limestone (Pinyon Peak equivalent)	305 - 345'
Guilmette Formation	Middle quartzite (Victoria equivalent)	235 - 270'
Middle and Upper Devonian	lower massive limestone	850 - 900'

Middle Devonian (paraconformity)	Simmonson Formation	520 - 550'
Middle Silurian (paraconformity)	Laketown Dolomite	1055 - 1070'
Upper Ordovician (paraconformity)	Fish Haven Dolomite	370 - 395'
Middle Ordovician (paraconformity)	Eureka Quartzite	150 - 175'
Lower Ordovician	Pogonip Group (Lehman Formation)	0 - 150

At the southern end of the district as much as 2,000 feet of Proterozoic (?) - Cambrian Prospect Mountain quartzite is exposed and at the northeastern and western margin of the area 2,500 - 3,000 feet of Upper Miocene - Lower Pliocene Salt Lake Formation underlie a Pliocene, unnamed, vitric tuff deposit.

Igenous rock in the area, other than the monzonite, include a rhyolite flow or ignimbrite sequence and a basalt flow and associated diabase dikes.

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INTRODUCTION

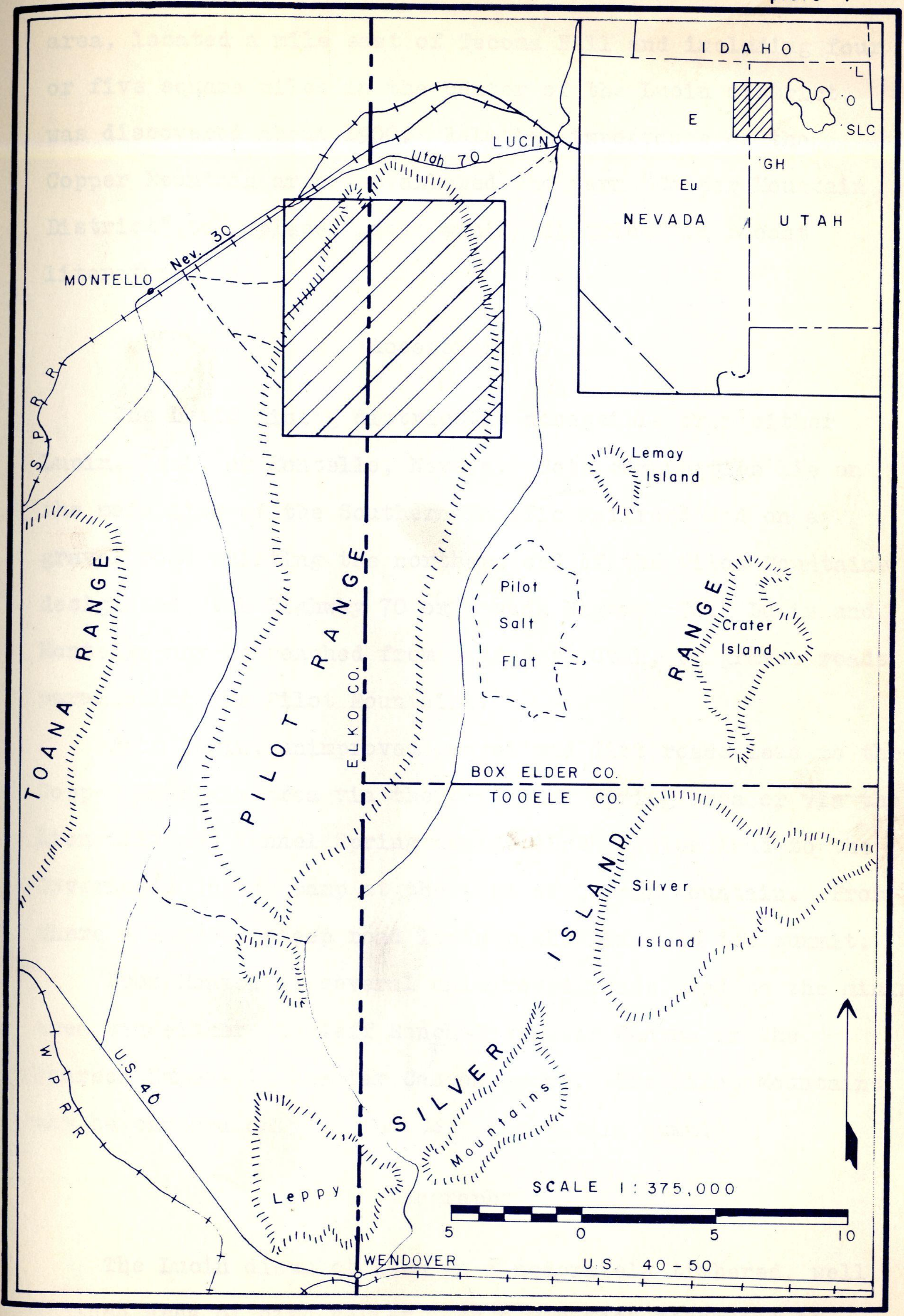
Location

The Lucin mining district lies in the northern third of the Pilot Mountain range of Box Elder County, Utah, and Elko County, Nevada. (plate 1) The mining district was organized and named in 1872 and, according to limits set in the nineteenth century, includes an area of 125 square miles and extends north of the Pilot Range. In this report, the Lucin mining district includes only the northern third of the Pilot Range in the immediate vicinity of Copper Mountain. Patterson Pass marks the southern boundary of the district.

The area covers about 65 to 70 square miles and includes all or part of Townships 6 and 7 North, Range 18 and 19 West, Salt Lake Base and Meridian and Townships 38, 39, and 40 North, Range 70 East, Mt. Diablo Base and Meridian.

Important mines of the district are at or near Copper Mountain and are eight miles southwest of Lucin, Utah, and 8.5 miles east of Montello, Nevada. Although situated on the Nevada-Utah boundary, the district's most valuable mines are in Utah in Box Elder County between one-half and 1.5 miles east of the state line.

The Lucin district includes two major areas of ore concentration. Tecoma Hill, located immediately east of the state line, was the first to be developed but has been of lesser importance than the Copper Mountain area. The latter



LUCIN DISTRICT INDEX MAP-EASTERN NEVADA-WESTERN UTAH area, located a mile east of Tecoma Hill and including four or five square miles in the center of the Lucin district, was discovered about 1900. Relative importance of the Copper Mountain area has allowed the term "Copper Mountain District" to replace "Lucin mining district" in recent literature.

Accessibility

The Lucin mining district is accessible from either Lucin, Utah, or Montello, Nevada. Both communities lie on the main line of the Southern Pacific Railroad and on a gravel road skirting the northern end of the Pilot Mountains designated Utah Highway 70 or Nevada Highway 30. Lucin and Montello may be reached from Wendover, Utah, by gravel roads paralleling the Pilot Mountains.

From Lucin, unimproved gravel and dirt roads lead to the Copper Mountain area via the Coal Bank Spring area or via the Lion Hill and Tunnel Spring areas. Both routes lead to the Governor's Spring camp at the base of Copper Mountain. From there a narrow, steep road leads to the mines at the summit.

From Montello, several unimproved roads lead to the mining area via either the Jeff Ranch-Regulator Canyon or the Pearson Ranch-Six Shooter Canyon areas. The Pilot Mountains may be crossed only at the Copper Mountain summit

Geography

The Lucin district lies in a moderately timbered, well drained area of high relief. An 8,026-foot recording at

Grassy Cairn, a U. S. Coast and Geodetic Survey triangulation station, is the highest point on the divide. Grassy Cairn is less than three quarters of a mile north of Copper Mountain. Copper Mountain is the lowest point on the divide within the district and has an elevation of about 7,300 feet. Patterson Pass, at the southern limit of the district, is the lowest point on the Pilot Mountain ridge and is little more than 6,800 feet above sea level. Areas between Copper Mountain and Patterson Pass attain altitudes of more than 7,800 feet and south of Patterson Pass the topography is more rugged with altitudes of more than 10,000 feet recorded. Tecoma Hill is a minor west-trending ridge between 6,200 and 6,800 feet above sea level.

The eastern side of the district is characterized by steep gradients where it is controlled by dip-slopes of the easterly dipping Guilmette Formation and younger rocks. The lower portion of the eastern slope has a lesser gradient than the upper part and is underlain by granitoid rock which extends eastward for about two miles beyond the Governor's Spring camp.

By contrast, the western slope of the district is characterized by a moderate slope. This slope is dissected by several east-west valleys separated by rounded ridges. The valleys are V-shaped except Fat Woman Canyon and are in the early mature stage of the fluvial erosional cycle. Fat Woman Canyon which is underlain by a northwest projection of the granitoid mass has a more open, rolling valley floor.

Because of the prevalent easterly dips the stratigraphic section from Lower Ordovician to Middle Permian is best exposed on the west side of the range.

North of Grassy Cairn the relief is less rugged and a more rolling topography prevails. East-west structural trends are less pronounced and ridges are capped by less resistant, post-Devonian rock.

The eastern flank grades into piedmont slopes that are modified only by sculpturing effects of Lake Bonneville, whereas on the western side a slight change in gradient exists between mountain slope and piedmont.

Vegetation and Rainfall

Rainfall in the district ranges from 10 to 15 inches at higher elevations, and on lower slopes and piedmont areas is less than 10 inches. On the alkali flats almost no precipitation is received. This distribution is based on few measurements and inferred from the distribution of the vegetation.

The higher slopes are moderately timbered with jack and pinon pine, juniper, aspen, and oak brush. Also typical of these slopes are patches of sagebrush and many species of shrubs and grasses. Prevailing westerly winds cause the western slopes to receive more moisture and as a result have larger pine and juniper growths as well as thicker soil cover.

On the higher slopes in the Patterson Pass area and in other areas underlain by granitoid rock, grasses and sagebrush are most common with small aspen groves associated with many springs. Grasses are also prevalent in areas that are underlain by Mississippian and Permian strata.

On either side of the main mountain ridge lower slopes and piedmont plains support an undergrowth of grasses at the upper fringe and sagebrush further down. The alkali flats are rimmed by greasewood and shadscale. Practically no moisture and poor drainage has favored the growth of these alkali-resisting plants.

Drainage and Water Supply

No perennial streams exist in the district although several canyons contain water until early summer. However, many permanent springs are present. Most occur on the eastern side where sedimentary rocks dip toward the east and provide natural channels for subsurface water.

Several spring areas on the eastern side, notable Coal Bank, Indian and Tunnel Springs, were originally dug as wells, then collected and piped to Lucin for railroad use. Others are gathered in shaded areas and used for stock watering. On the western side of the district spring water is collected for domestic and stock use. Governor's Spring and others in the Copper Mountain and Patterson Pass areas have been used in the mining operations.

Previous Work

Previous geological work in the Pilot Mountain area has been limited to brief and generalized reports concerning the

Lucin district. The first study was made in 1872 (Murphy, 1872) and described living and social conditions as fully as it did the mining operations at Tecoma Hill's copper and lead mines. In 1877, a general study was made by the Fortieth Parallel Survey (Hague, et al, 1877) in an attempt to unravel stratigraphic and structural relations in the Pilot Mountains as well as in other areas in the western states along the fortieth parallel. The Lucin district was mentioned only briefly in the Hague study. Much of the stratigraphic work completed by this group in the Pilot Range is now known to be error, although generalizations concerning structural relations appear to be nearly correct despite the lack of accurate stratigraphic control.

Huntley, (Huntley, 1885) wrote a brief description of variscite deposits five miles north of Lucin and this was followed in 1910 by D. B. Sterrett, (Sterrett, 1910) and in 1911 by L. J. Pepperberg, (Pepperberg, 1911) by reports concerning the variscite, but little was added beyond Huntley' original observations.

In 1914 the first detailed descriptive report on the Lucin ore deposits was compiled by G. H. Ryan, (Ryan, 1914). Ryan's study presented a geologic cross section and was concerned chiefly with the structural controls of the Copper Mountain ores. The report also briefly mentioned the Tecoma Hill ore. No attempt was made to amend the stratigraphic work of the Hague party.

In 1920, Butler, Loughlin and Heikes, (Butler, et al, 1920) reviewed the mining activity in the Lucin district and included a stratigraphic and structural description of the entire Pilot Mountains. Again, however, no revisions were made in the stratigraphic column.

In 1943, Crawford and Buranek, (Crawford and Buranek, 1943) wrote a brief description of the Copper Mountain area that was largely a summary of the Butler, Loughlin and Heikes report. This paper, however, was the first that treated the area as an iron property rather than as a copper property.

Since 1943 nothing has been published concerning either the Lucin district or the Pilot Mountains, although the Lucin ores have been studied by a mining company. Several oil companies have completed large and small scale stratigraphic and geophysical reconnaissance surveys in the area.

Method and Purpose of Study

Field work was done in the Pilot Mountain area during the summers of 1957 and 1958, and a more detailed study of the Lucin district was made during July, 1959.

Field investigation for this report included the correlation of measured sections in the Lucin district with sections observed elsewhere in the Pilot Mountains, mapping of stratigraphic units and structural elements on a broad scale and observing closely the relationship between ore bodies and stratigraphic and structural controls.

Aerial photographs used for the project were flown by the Jack Ammann Company and the U. S. Department of Agriculture at a scale of 1:20,000. The base map of the

Lucin district is part of the Pilot Mountain base map constructed by the writer from the aerial photographs by the slotted template method. Culture, and stream courses, as well as the geologic features, were transferred from the photographs to the base map by means of a radial planimetric plotter. Profiles used in constructing geologic cross-sections were obtained from Army Map Service sheets NK12-7 (Brigham City) and NK11-12 (Elko).

Laboratory studies at the University of Utah during the winter of 1957 and 1958 and August, 1959, included thin section study, X-Ray and infra-red analysis of host rock and ore alteration, and identification of fossils.

The Lucin report, a more detailed study of a portion of the Pilot Range, presents a descriptive summary of ore deposits including cross sections and plan views of the ore bodies. Also an attempt is made to unravel the genetic history of the ore deposits and to propose suggestions for future development. Major revision of the Paleozoic stratigraphy and minor revision of structural relations are made. Correlations with other parts of the Pilot Mountains is shown and correlations with stratigraphic units in neighboring ranges in the eastern Great Basin are proposed.

STRATIGRAPHY

Statement of the Problem

Rocks of the Lucin mining district range from Proterozoic (?) - Cambrian to Pleistocene in age.

Early reports (Hague et al, 1877) as well as more recent publications (Butler et al, 1920) point out that the Lucin district, as well as most of the Pilot Range, is underlain by strata of Carboniferous age, excluding Tertiary monzonitic rock and Late Tertiary lake beds. Little effort was made by these writers to subdivide the Carboniferous into the Mississippian or Pennsylvanian systems, nor is there mention of pre-Mississippian rocks or Permian strata.

Butler, (Butler et al, 1920, p. 490) briefly summarizes the stratigraphy:

> "Hague has provisionally correlated the quartzite with the Weber quartzite of the Wasatch range....the limestones at the southern end of the range are referred by Hague to the 'Upper Coal Measures'....the entire sedimentary series at the north end of the range is of Carboniferous age consisting of Pennsylvanian and probably upper Mississippian."

The Carboniferous age is based on several fossil zones reported in the southern part of the range, some twenty-five miles distant and on meager fossil evidence in the Copper Mountain vicinity. It would appear to this writer that original correlations in the Pilot Mountain were based largely on gross lithologic similarities betwee widely separated areas rather than on distinctive fossil zones or sequence of position within the Pilot area.

Early geologists are not to be severely criticized, however, for prior to the second half of the Twentieth Century little was known concerning Paleozoic sedimentary basins or geosynclines of the west. Because early surveys were necessarily pressed for time and because the area observed was restricted to a belt along the Fortieth Parallel, detailed reports on individual ranges could hardly be expected. It is for these reasons that early geologic surveys might have had the tendency to group thick, similar-appearing sections of carbonate and clastic material together as belonging to one time period. A few fossils of Carboniferous age collected at both ends of the Pilot Range might have induced early geologists to make sweeping correlations with little regard for structural complications or regional unconformities.

The following paragraphs present revised stratigraphic relationships of the Lucin district as determined by this writer, established by fossil assemblages found within the district and correlated with fossils found elsewhere within the Pilot Mountains. Also, lithologic similarities and sequence of position observed throughout the area, both in the Pilot Range itself and in the neighboring Crater Island and Silver Island Mountains, have contributed to the more complete understanding of the stratigraphic section. (Plate 4.)

General Statement

The oldest strata exposed in the Lucin district is an incomplete section of the Prospect Mountain Formation of Proterozoic (?) -Cambrian age. Above the Prospect Mountain is an incomplete section of the Lehman Formation of Early Ordovician age. The Lehman Formation, the upper unit of the Pogonip Group, consists of grey, platy limestones and is overlain unconformably by a 150- to 175-foot section of distinctive Eureka-Swan Peak Quartzite and 370 to 395 feet of black, massive Fish Haven Dolomite of Late Ordovician age.

Lying unconformably above the Upper Ordovician Fish Haven is approximately 1,060 feet of Middle Silurian Laketown Dolomite, an alternating light and dark grey resistant rock that caps much of Tecoma Hill as well as many ridges in the vicinity of Cook's Canyon and Hogan's Canyon. The Upper Silurian-Lower Devonian Sevy Dolomite is apparently absent from the entire Pilot Mountain area and, therefore, a hiatus spans considerable time between the Laketown and the Devonian Simonson Formation. The Simonson Formation is an alternating, banded dolomite and limestone unit of about 530 feet thickness in the Lucin district.

Above the Simonson, and providing the resistant cap-rock for the majority of ridges, is a 1,500-foot section of the Middle and Upper Devonian Guilmette Formation. The

Guilmette can be subdivided into three members in the Lucin district: an 850- to 900-foot section of massive dark grey and blue limestone, 235-270 feet of hematite stained, massive quartzite, tentatively correlated with the Victoria Quartzite, and 305-345 feet of grey, thin-bedded, platy limestone, tentatively correlated with the Pinyon Peak Limestone.

Diagnostic Mississippian fossils are absent from the Copper Mountain area but correlations from the southern end of the range and from the northern end where Mississippian cephalpods are recognized, show Mississippian rocks of probable Chester age lying with angular discordance on the Guilmette Formation. In the Copper Mountain area, the Mississippian is represented by 320 feet of medium and coarse sandstones and fine conglomerates of the very resistant Diamond Peak Formation. At the northern end of the range the Diamond Peak sandstones and conglomerates interfinger with thin lenses of the black, fossiliferous shales of the Chainman Formation. The cephalopod-bearing Chainman is only 50 to 100 feet thick and forms non-resistant, grass covered slopes.

Lying with unconformable relationship on the inter-fingering Diamond Peak and Chainman units is a 125-foot section of an unnamed clastic and carbonate sequence which represents the Virgil (?)-Upper Wolfcamp interval. It, in turn, is conformably overlain by 840-875 feet of platy, purple and grey limestones of Early Permian age, termed

Pequop by Steele (Steele, 1958). Fusulinid identification has placed the Pequop in the Lower Leonard-Lower Guadalupian interval.

Above the Pequop lies an incomplete section of unnamed cherty, productid-bearing limestones and dolomites that have been tentatively correlated with upper beds of the Pequop Formation at its type locality or with the lower units of the Park City Group, (Cheney, personal communication). Upper parts of the Park City Group have been removed by erosion in the Lucin district although they are exposed elsewhere in the range.

At the northern end of the range, on both east and west flanks, exposures of Miocene-Pliocene Salt Lake Formation are overlain by a younger vitric tuff unit reported by Van Houten (Van Houten, 1956).

PROSPECT MOUNTAIN FORMATION

At the southern-most limit of the map area, south of Patterson Pass, Prospect Mountain strata rise abruptly above the monzonite intrusive, and are also in fault contact with Paleozoic rocks tentatively correlated with the Permian Pequop Formation, and the post-Pequop unnamed beds.

Lithologic Description

The Prospect Mountain Formation is a fine- to medium-grained quartzite that is highly jointed and fractured. The rock is white or light grey to pink or light maroon on fresh surfaces and dark maroon or reddish-brown on weathered surfaces. Lower in the section, questionably below the Cambrian-Proterozoic (?) boundary, the units are more characteristically buff although light purple and green tints are not uncommon. In this lower section meta-limestones, phyillites, slates, argillites, and fine-pebble conglomerate are common, although quartzite remains the dominant rock type.

In describing the strata as a whole, the term massive or "heavy bedded" is applicable, although sometimes low angle, current cross bedding and partings of micaeous shale or argillite provide clues to ascertain the presence of bedding.

The Prospect Mountain Formation is easily distinguished in the field because of its massive habit, towering, blocky cliffs, and the presence of huge orange or brownish-red talus piles. Its resistant nature allows it to stand as the highest and most rugged ridges in the Pilot Range.

The Prospect Mountain section was not measured inasmuch as the section exposed in the area south of Patterson Pass probably represents but a small fraction of the section seen in the Pilot Range. Also the area in question is badly broken by faulting and it is suspected that much of the section has been repeated. A figure of 2,000 feet is suggested for the exposed thickness in order to estimate the amount of displacement on the Patterson Pass fault and this figure is probably conservative.

Age and Correlation

The Prospect Mountain Formation in the Lucin area is thought to be of Late Proterozoic and Early Cambrian age. It is correlated with the Prospect Mountain quartzite of the Silver Island Range where it is also thought to include time lies of both Proterozoic and Cambrian, (Schaeffer, 1960).

ORDOVICIAN SYSTEM

General Statement

Ordovician deposition is represented in the Lucin district by three formation which include 110 to 160 feet of the Lehman Formation of the Pogonip Group, 150 to 175 feet of Eureka-Swan Peak quartzite, and 370 to 395 feet of Upper Ordovician Fish Haven Dolomite.

ORDOVICIAN POGONIP GROUP

(Lehman Formation)

Rocks correlated with the Lehman Formation of the Pogonip Group are found in the Lucin area in three localities, within a horst structure on the eastern edge of Tecoma Hill, at the north of Quartzite Canyon, and on the Lucin-Montello road three miles west of Lucin.

Lithologic Description

The Lehman Formation is a thin-bedded, fine- to medium-crystalline, argillaceous limestone. Color ranges from dark blue-grey to blue-black with characteristic buff and lavendar mottling. The unit may be characteristically described as being platy, although surfaces are rough and edges angular.

Age and Correlation

No fossils except trilobite "hash" were found in the Lehman Formation in the Lucin area. It has been tentatively correlated with the Lehman Formation of the southern end of the Pilot Range and in the Silver Island Range. In both localities the Lehman rests conformably on the diagnostic Knosh shale, and in the Silver Island Range a fauna including *Leperditia* sp., *Cybelopsis* sp., *Eleutherocentrus* sp., *Helicotoma* sp. and orthid brachiopods is found in Lehman rocks. A similar assemblage is recognized in the southern Pilot Range. By lithologic similarity the Lehman of the Lucin district can be correlated with these areas, and by faunal assemblages identified in the Silver Island Mountains, placed stratigraphically in the Mohawkian Series of the Ordovician, and perhaps more closely within the upper part of the Chazyan Stage.

ORDOVICIAN EUREKA-SWAN PEAK QUARTZITE

The Eureka-Swan Peak Quartzite in the Lucin area is found only in Quartzite Canyon and at the mouth of a smaller canyon immediately to the north.

Lithologic Description

Strata thought to represent the Swan Peak-Eureka interval are massive, white, fine- to medium-grained, vitreous quartzite beds that have distinct orange or yellow-brown weathered surfaces. Typically, the beds are resistant and hence are recognized as cliff-formers. About 150 feet were measured, but it is suspected that the lowermost part of the unit is not exposed because of talus cover. Similarly, a carbonate slope is present below the massive cliffs and, because it also it covered, inference as to thickness or precise understanding of its lithology is difficult.

Age and Correlation

Eureka-Swan Peak beds probably include Early Bolarian to Late Trentonian time lines within the Mohawkian Series and the regional disconformity recognized by many writers between Middle Bolarian and Upper Trentonian is inferred in the Lucin area.

The problem of correlation and separation of the Eureka and Swan Peak beds is a complicated one that cannot be treated adequately in this report. The unit is best correlated with similar units in the Silver Island Range and Crater Island although in both localities the presence of Swan Peak is questioned.

ORDOVICIAN FISH HAVEN DOLOMITE

In the Lucin area, a complete section of Fish Haven Dolomite is exposed on east-west ridges near Quartzite and East Canyons, and partial sections are exposed in the vicinity of Regulator and Cook's Canyons. On the east side of the district north of Governor's Spring an unfossiliferous sequence of black and grey dolomites rises above the monzonitic rocks and has been tentatively mapped as Fish Haven.

Lithologic Description

Description of the Fish Haven Dolomite in the Lucin area resembles the outcrops reported in surrounding areas (Young, 1955; Cohenour, 1957; Anderson, 1957; and Schaeffer, 1960); that is, a massive, cliff-forming medium-grey to black, black weathering, medium- to fine-grained calcareous dolomite, and an upper unit consisting of thick-bedded, cherty, medium-grey and dark-grey arenaceous dolomites. The upper unit, about 100 feet thick, is characteristically a slope-former and often appears from a distance to be banded, the bands rarely exceeding twenty feet in thickness. The lower unit, about 275 feet thick, is typically a massive-appearing unit that stands as sharp ridges and bold cliffs. The presence of chert nodules and stringers is noted in both upper and lower units.

Age and Correlation

Few well-preserved fossils have been found in Fish Haven beds, although abundant dolomitized or partially dolomitized forms have been recognized. The principal fossils are Favosites sp., Halysites (Catinipora) gracilis and Streptelasma (?) as well as a very questionable specium of Palaeophyllum sp. Unidentifiable brachiopod fragments are also found but they afford no help in determining the age of the Fish Haven. The faunal assemblage listed above is similar to assemblages studied by Duncan (Duncan, 1956) and, therefore, is assigned to the early Late Ordovician or probably Richmond age. This designation is questionable inasmuch as the underlying Eureka quartzite is thought to have an upper age limit of Trentonian. If the upper Eureka limit is to be accepted, then rocks representing a considerable period of time (Edenian and Maysvillian) much be missing.

That the contact between the Eureka and Fish Haven is unconformable is not easy to demonstrate, for everywhere it appears to represent a faunal break rather than a structural discordance. In the Lucin area, the lower Fish Haven contact is placed at the top of the last sandstone of the Eureka at the base of the first dolomite cliff.

SILURIAN SYSTEM

General Statement

The Silurian is the least well represented of Paleozoic systems in the Basin and Range Province. In the Lucin district the Silurian is represented by but one formation, the well-known Laketown Dolomite of probably Niagaran age.

SILURIAN LAKETOWN DOLOMITE

Laketown rocks in the Lucin area are recognized in long continuous cliffs between Patterson Pass and Regulator Canyon. Laketown Dolomite is the conspicuous cliff-former in the vicinity of Tecoma Hill, and it have been tentatively mapped with Fish Haven rocks north of Governor's Spring camp. In the vicinity of Copper Mountain, 1,050 feet of Laketown was measured and about 1,100 feet is recognized in the southern part of the Pilot Range. These sections represent some of the thicker Laketown sections known in the eastern Nevada - western Utah area.

Lithologic Description

Laketown beds in the Lucin area consist chiefly of dolomite and calcareous dolomites. The texture is fine to aphanitic; bedding ranges from several feet to more than twenty feet in thickness. The formation is light- to medium-grey although when viewed from a distance the presence of three color zones is apparent. The lower zone, about 250 feet in thickness is light grey, the middle unit, about 400 feet thick,is dominantly dark grey to black, and the upper unit, 365-415 feet thick, is light- to medium-grey. The upper unit is characterized by its smooth weathering appearance and the absence of chert; the lower two units have rough weathered surfaces and chert is observed as nodules and in stringer and thin beds. The chert is usually brown weathering, black or dark grey.

Laketown rocks are recognized between Patterson Pass and Regulator Canyon as massive light and medium grey cliffs and underlie the distinctive Simonson Dolomite. The strata in this area probably represent the upper part of the Laketown section only, as the beds are almost void of chert and as a section only 450 feet thick could be measured. On Tecoma Hill, and on east-west ridges to the north in the vicinity of East and Quartzite Canyons, a more complete section was seen, the lower part of which was cherty and the upper part void of chert.

Age and Correlation

The age of the Laketown is generally regarded to be Niagaran and is based on coral and brachiopod identification in many areas. In the Lucin area, few fossils other than *Favosites* and *Halysites* and several unidentifiable coral specimens were found. In the southern part of the range, the Laketown is better exposed and a more complete collection was obtained, including *Favosites*, *Halysites*, *Coenites*, *Heliolites*, *Syringopora*, *Calopecia*, *Monograptus*, *Alveolites*, stromtoporids and pentameroid brachiopods. The age suggested by the above assemblage also points to the Niagaran Epoch, (Duncan, 1956), and hence the writer feels confident when correlating with neighboring areas.

In the Lucin district the Silurian-Devonian boundary is placed at the top of the Laketown Formation (Niagaran?) or at the base of the Simonson Formation (Middle Devonian).

The Sevey Formation, often containing the Silurian-Devonian boundary in the eastern part of the Great Basin, is absent in the Pilot Mountains.

DEVONIAN SYSTEM

General Statement

Devonian rocks in the Lucin district make up 1,950 to 2,050 feet of the stratigraphic column. Devonian formations recognized include the Simonson Dolomite (550') and the Guilmette Formation (1,400' - 1,500'). The Guilmette Formation can be subdivided into three members, a lower massive limestone (850 - 900'), a middle massive quartzite (235 - 270') and an upper platy, shaly limestone (305 - 345').

DEVONIAN SIMONSON FORMATION

In the Lucin district only the upper alternating member of the Simonson Dolomite, as defined by Osmond (Osmond, 1954) is recognized. It is best observed on the south-facing wall of Hogan's Canyon, but it also occurs in several canyons in the vicinity of Hogan's Canyon and on several ridges north of Fat Woman Canyon. No Simonson is recognized in the Cooper Mountain vicinity as it is omitted from that area by faulting.

Lithologic Description

The Simonson Formation consists of monotonous alternating light-grey to dark-grey and black, banded, calcareous dolomite beds. The formation is generally finely crystalline and weathers in step-like slopes, reflecting the thin to medium bedding. As a rule, the unit is non-resistant to erosion and as a result forms gentle slopes between cliffs of the underlying Laketown and overlying Guilmette. Commonly a poorly developed soil cover lies on the Simonson slopes which provides a foothold for vegetation that conceal the beds. The alternating nature of the unit, as well as its finely-laminated nature, tends to set the Simonson apart from other beds wherever it is present.

Age and Correlation

The Simonson is generally regarded to be of Middle Devonian age on the basis of well established faunal zones recognized throughout the eastern Great Basin. In the Lucin area, it is assumed that the part of the Simonson Formation exposed is of this age also because of the recognition of stromotoroid heads, Cladopora sp., Amphipora sp., Thamnopora sp. and assorted brachiopod fragments that could very well be forms of Atrypa and Stringocephalus (?).

In the northern part of the Pilot Range, the part of the Simonson recognized resembles on lithologic evidence the upper alternating member of the Simonson of east-central Nevada. It is, therefore, suggested that the Simonson Formation in the Lucin district represents only the upper part of the Simonson of east-central Nevada, and that the paraconformity between Laketown and Simonson rocks spans an interval from post-Niagaran to Middle Devonian time (Middle Erian).

The Simonson is easily correlated on lithologic similarity and sequence of position with the Silver Island Range and Newfoundland Range and with the type locality at Gold Hill. It is probably a time equivalent of the Nevada Formation at Eureka, Nevada.

DEVONIAN GUILMETTE FORMATION

General Statement

The Guilmette Formation is easily divisible into three mappable units, two of which are prominently displayed from almost any vantage point within the Lucin district. It is these two Middle and Late Devonian units, the lower massive limestone and the middle massive quartzite, that are frequently referred to by both Ryan (Ryan, 1914) and Butler, (Butler *et al*, 1920) when describing the Lucin ore deposits and considered by these writers, as well as by King (King, 1877), to be Mississippian and Pennsylvanian in age. The upper unit is a nonresistant, shaly limestone of probable latest Devonian age.

History of Nomenclature

The type locality for the Guilmette Formation is in Guilmette Gulch on the west side of the Deep Creek Mountains (Nolan, 1935, p. 20), where the formation is principally a fine-grained medium to dark grey dolomite with thick limestone beds and lenticular sandstones. The formation has since been recognized in many localities in the vicinity of the Pilot Range including the Newfoundland, Grouse Creek, Crater Island, and Silver Island Ranges. In these areas the unit is characteristically a limestone although minor quartzitic and shaly zones are commonly recognized in the upper parts of the formation.

Distribution

The Devonian Guilmette Formation, and particularly the lower two members, is widely distributed in the Lucin district. It forms long, continuous, resistant ridges extending from the northern side of Patterson Pass to Regulator Canyon, and discontinuous, blocky ridges north of Regulator Canyon.

The massive quartzite member is observed almost everywhere in the Lucin area to overlie the massive limestone member, the latter being the most prominent unit in the Guilmette Formation. The shaly limestone member is recognized in but a few localities, at the top of cliffs north of Patterson Pass, and in saddles in the area immediately south of Copper Mountain at the head of Hogan's and Cook's Canyons.

MASSIVE LIMESTONE MEMBER

Lithologic Description

The lower member of the Guilmette Formation is a dark-grey to blue-black, thick-bedded limestone with dolomite stringers near the base. The unit is very finely crystalline, and appears as smooth weathering, massive cliffs, as well as gentle slopes formed on less resistant limestone beds. The limestone unit in the Lucin area is 850 to 900 feet thick but becomes more clastic in nature upward in the section. Towards the top, and well displayed on the cliffs northeast of Governor's Spring Camp, sandy and even quartzitic beds, ranging from one to five feet in thickness, are present.

At the head of Hogan's Canyon the top of the lower massive limestone is characterized by a twenty-foot zone containing one- to three-inch black chert beds. Above the bedded chert unit, and within thrity feet of the contact with the quartzite member, the limestone beds contain elongated black chert nodules.

The massive limestone member has been referred to in early literature as the "favorable limestone bed" as it is the principal rock unit acting as host for copper and iron mineralization. It is suspected that the high lime content is in part responsible for replacement mineralization, whereas in dolomitic rocks lower in the section the magnesium content hindered replacement. In the area of mineralization the lower massive limestone is characterized by many white calcite and quartz stringers that give the overall appearance of the unit at that locality of being light- or medium-grey.

Age and Correlation

Fossil zones widely recognized in the Basin and Range Province are present in the Guilmette Formation and correlations with neighboring ranges are relatively easy.

At the base of the Guilmette Formation, a bed containing Helioites sp. is noted, as well as other forms that are often associated with that zone, including Favosites, Atrypa nevadensis (?), Syringopora and Prismatophyllum. The Helioites zone is overlain by the Stringocephalus zone, a distinctive guide from the upper part of the Nevada Formation (Merriam, 1940).

Above the Stringocephalus zone, Stromotopora- and Cladopora-bearing limestone cliffs are recognized and this horizon probably represents the lower parts of the Devils Gate limestone, of upper Middle and Late Devonian age (merriam, 1940).

The Late Devonian Spirifer argentarius zone is recognized above Stringocephalus-bearing strata and it is correlated with the upper part of the Devils Gate Formation. Associated with this form are Atrypa montanensis, Martinia sp., Stromatopora and Cladopora. Above the S. argentarius zone are species of Amphipora, but no Crytospirifer or Spirifer utahensis zone is recognized in the area.

The fossils suggest that an interval of Middle and early Late Devonian time is represented by the lower limestone member of the Guilmette Formation. It is also suggested that the upper two members of the Guilmette Formation span remaining Devonian time, normally recognized by Crytospirifer and Spirifer utahensis zones, and perhaps even bridge the Devonian-Mississippian boundary.

The boundary between the Simonson Formation and the lower massive limestone member of the Guilmette has been placed at the Helioites zone which lies more than 100 feet below the Stringocephalus zone. The Stringocephalus zone is often employed in the eastern Great Basin to locate the lowermost beds of the Guilmette Formation but this is not always a completely reliable guide. The boundary is correlated with the boundary in the Silver Island Range where a change from mixed dolomite and limestone to massive limestone cliffs is noted (Schaeffer, 1960).

Massive Quartzite Member

Lithologic Description

The massive quartzite member of the Guilmette Formation is a fine-grained, thick-bedded to massive orthoquartzite. In the Hogan Canyon area, it is granular but this is an exception and not the rule. On fresh surfaces, the unit appears as a light-grey to medium-grey vitreous rock that is characteristically tinted with light and dark blue shades.

The weathered surface, however, is perhaps the most diagnostic distinguishing feature of the unit, for the dark brown to reddish-brown, rounded but massive cliffs, are easily recognized even when most of the area is obscured by soil or vegetative cover.

The unit is thick-bedded to massive although bedding is indistinct except when viewed from a distance. Contacts with the underlying limestone and overlying shaly limestone are exceptionally sharp. The maximum thickness is 270 feet and towards the Patterson Pass area it thins to little more than 30 or 40 feet and north of Quartzite Canyon it apparently thins to a feather edge. The unit is not recognized south of Patterson Pass.

The unit everywhere exposed is extremely indurated and nowhere does it appear friable, nor are there any lithologies other than orthoquartzite represented.

Shaly Limestone Member

Lithologic Description

The shaly limestone member of the Guilmette Formation is recognized only in the area between Patterson Pass and Regulator Canyon. The unit consists of dark grey to black platy limestones that characteristically have mottled and finely-laminated appearance due to silty and argillaceous stringers that occur along bedding planes. Yellow and brownish-yellow shades, as well as purplish-red tints in the silty material, give to the entire member an overall mottled cast.

The member is non-resistant to erosion but at the head of Hogan's Canyon it is the ridge-former. To date no fossils have been found in this unit. The member, as measured at the head of Hogan's Canyon, is between 305 to 345 feet thick.

A sharp erosional contact with the underlying quartzite member is readily apparent, but the upper contact is covered. The contact between the upper Guilmette and the overlying Mississippian (?) Chainman-Diamond Peak Formation shows angular discordance.

Age and Correlation

The problem of establishing a precise age for the quartzite and shaly limestone members of the Guilmette Formation is the most troublesome stratigraphic problem in the Lucin area. Because of its clastic nature, no fossils of any kind have been found in the quartzite, and the overlying shaly limestone unit also appears to be unfossiliferous. Beneath the quartzite member the Spirifer argentarius zone is recognized in the massive limestone member of the Guilmette Formation, and this zone indicates an early Late Devonian age (Frasnian ?). It is known, therefore, that the quartzite member and the shaly limestone member are post-early-Late Devonian and it is suggested by this writer that the quartzite is equivalent to the Victoria Quartzite and represents a time interval spanning most of the remaining Devonian time (Famennian). Similarly, it is suggested that the shaly limestone unit is a Pinyon Peak equivalent and that it represents later Devonian time and possibly even earliest Mississippian time. These suggestions are based on lithologic correlation between the quartzite and shaly limestone and other Basin and Range units which are more definitely tied into the stratigraphic column by fossil evidence.

MISSISSIPPIAN AND PENNSYLVANIAN SYSTEMS

General Statement

Rocks of Mississippian and Pennsylvanian age are represented in the Lucin district by the Diamond Peak-Chainman Foramtions undifferentiated and by outcrops of Late Pennsylvanian rocks. The Missourian to Early Wolfcampian interval, although not clearly differentiated from the overlying Pequop Formation, is represented in the Coal Bank Spring area on the basis of fusulinid identification.

Mississippian and Pennsylvanian formations in Lucin district, have an aggregate thickness not exceeding 600 feet. These units are relatively insignificant when compared to the great thickness of rocks of the same ages in areas to both the east and west. (5,800 feet of Mississippian alone in the Stansbury Mountains plus another 16,000 feet of Pennsylvanian, and as much as 10,000 feet of the two systems in central Nevada.)

MISSISSIPPIAN DIAMOND PEAK-CHAINMAN FORMATIONS
UNDIFFERENTIATED

The current usage of the terms Chainman and Diamond Peak presents a considerable problem in nomenclature and correlation. This problem has been fully treated by Nolan (Nolan et al, 1956, pp. 56-61) and he states:

> "For the Eureka district we propose to use Diamond Peak Formation for the coarse clastic portion of the upper Mississippian sequence where it can be satisfactorily separated from the underlying black shales, and to adopt Spencer's name of Chainman shale for the lower unit, where it can be separately mapped. For those areas in the Diamond Mountains, where the two are gradational lithologically, we have grouped them in our mapping as "Diamond Peak-Chainman formations undifferentiated".... Our collections (marine faunas)...are believed to indicate a late Mississippian age for both formations."

In the Lucin district this writer believes it desirable to follow Nolan's usage, and thus the term Diamond Peak-Chainman Formations undifferentiated is used for mapping purposes except in localities where distinction is possible. For discussion purposes, however, it is desirable in part to present the data under separate headings.

Distribution

Strata of Diamond Peak-Chainman Formations undifferentiated are well exposed on the grassy hills immediately south of the Regulator Canyon transverse fault, and at the north end of the Pilot Range, north and west of Coal Bank Spring.

At the north end of the range the Chainman shale can be separated from the Diamond Peak Formation. This one locality affordsthe only view of the Chainman Shale, as a separate unit, in the entire Pilot Range. Elsewhere in the northern part of the Lucin district the black shales of the Chainman interfinger and are interbedded with the Diamond Peak clastics.

Lithologic Description - CHAINMAN SHALE

The Chainman Shale forms a steep slope and consists o very fine, fissile siltstones with some claystone at the base. Only 75 feet of Chainman lithology could be measured, although at the top of the unit the fissile shales are gradational with a thick sequence of brown quartzite and fine conglomerate. The shale is extremely hard and argillaceous and weathers to angular chips and fragments. Color of both the fresh and weathered surfaces is dark grey to black, although the slope appears to have a brownish cast.

Lithologic Description - DIAMOND PEAK FORMATION

The Diamond Peak lithology in the Lucin district is easily recognized because of its coarse nature. On the slopes south of Copper Mountain and the Regulator Canyon fault, the unit is a series of alternating slopes and low ledges of a highly indurated brown and tan sandstone and grit and fine pebble conglomerate. At the base of the unit there is a 150-foot section of brown weathering silty limestone which may be a facies of the Chainman lithologies recognized further north. Similar limestones are observed interbedded with the clastic material in the middle and upper parts of the unit, and hence the presence of a Chainman limestone facies is substantiated. The limestones are dark grey to black on fresh surfaces, thin bedded to platy, finely-crystalline and possess a medium brown weathered surface with a siltstone appearance. A thin surficial coat of silt covers the limestone.

The middle part of the sequence consists of about 135 feet of alternating slopes of fine sandstone, grit, and silty limestone and ledges of fine to coarse pebble conglomerate. The sandstones and grits are brown to yellow-brown weathering and have a light tan hue on fresh surfaces. The sandstones are well indurated, possessing a silica cement. Graded bedding is common in this unit, the range of grain size extending from a fine sand to coarse sand, and in some specimens to fine conglomerate. The conglomerate ledges in the middle unit are also brown-weathering, and, similar to the sandstones and grits, extremely indurated because of a silica cement. Pebbles in the unit range from one-eighth of an inch in diameter to more than three inches. Lithologies represented in the conglomerate include limestones and chert, the latter being largely a black or red variety. Green cherts are recognized in the Diamond Peak units at the northern end of the range, the size range of the fragments make it possible to refer to the unit in that locality as a coarse sandstone or grit.

The upper unit of the Diamond Peak sequence is largely composed of sandstone and minor amounts of fine pebble conglomerate. Limestones are absent from this part of the sequence.

The lower contact of the Diamond Peak-Chainman Formations undifferentiated with the Devonian Guilmette Formation is one of pronounced angularity in the area south of Copper Mountain. Elsewhere angularity is more difficult to demonstrate. The upper contact appears to be angular with younger rocks and a time span of much of the Pennsylvanian is thought to be represented at the contact.

Age and Correlation

Fossils identified by Steele from the Chainman shale north of Coal Bank Spring include the cephalopods Cravenoceras sp. and Eumorphoceras sp. This would place the age of the rocks as Chesterian and probably upper Chesterian. Inasmuch as the unfossiliferous Diamond Peak conglomerates and grits lie both above and below the fossil-bearing shales it is assumed that they also fall into a time range spanning the Chester epoch of the Mississippian, and perhaps into early Pennsylvanian epochs.

The unconformity between Diamond Peak-Chainman rocks and younger rocks spans an indeterminable amount of time as no upper age limit for the Diamond Peak can be assigned. The oldest rocks above the Diamond Peak lithology are Strathearn equivalents and are therefore placed in the

Missourian-early Wolfcampian interval. Middle and Upper Wolfcampian rocks and the Leonardian Pequop Formation rests unconformably on the Diamond Peak-Chainman Formation.

Correlation with neighboring areas is of some help in limiting the time interval represented by Chainman and Diamond Peak rocks, and determining the amount of time represented by the unconformity between Diamond Peak-Chainman rocks and younger rocks. In the Crater Island Mountains, Anderson (Anderson, 1957) mapped the Chainman and Diamond Peak Formations separately and assigned the Chainman to the Late Mississippian and Early Pennsylvanian and the Diamond Peak to the Early Pennsylvanian. Correlation of both units with their type localities is suggested by Anderson but conflicting opinions as to age designation of Nevada sections have complicated his conclusion.

In the Silver Island Range, Schaeffer (personal communication) has found relationships similar to that in the Lucin district; that is, black fissile shales of the Chainman Formation interfingering with clastics of the Diamond Peak Formation. Schaeffer suggests that the two units are actually facies of one another, and this belief is shared by this writer.

UPPER PENNSYLVANIAN-WOLFCAMPIAN UNDIFFERENTIATED

Lying with angular discordance on the Diamond Peak-Chainman Formation is a thin (120' - 130') limestone unit that has been tentatively placed in the Late Pannsylvanian-Wolfcamp time interval. The unit is best exposed at the crest of the ridge between Patterson Pass and Copper Mountain. Fossils from the Virgil-Wolfcamp interval have been recognized in the Coal Bank Spring locality but in this area it is impractical for mapping purposes to separate the beds from the overlying Pequop Formation.

Lithologic Description

The dominant lithology of the Upper Pennsylvanian-Wolfcamp interval is limestone. The unit is medium- to coarsely-crystalline. Stratification is difficult to distinguish and can be described as thick-bedded to massive. A very rough weathered surface is characteristic of the limestone. Fossil hash of crinoids, bryozoans, brachiopods, and fusulinids is scattered throughout the interval but only the fusulinids are useful in correlation.

The lower contact of the unit with the underlying Diamond Peak-Chainman Formation is structurally unconformable and the rocks are easily distinguished because of contrasting lithologies. The upper contact, however, is more difficult to place. In the area between Copper Mountain and Patterson Pass the unit lies at the top of the ridge, and hence erosion has stripped away an unknown amount of the limestone. At Coal Bank Spring there is no definite physical break between the Upper Pennsylvanian-Wolfcamp rocks and the overlying Pequop Formation. Virgil and Wolfcamp fusulinids give the only basis for separating the beds from the younger rocks and hence the entire sequence in this locality was mapped as Pequop Formation.

Age and Correlation

Fusulinids from the Coal Bank Spring area were identified by Grant Steele and he reports Schwagerina aff. cellamagnus and Schwagerina sp. These varieties indicate to Steele an Early and Middle Wolfcampian age, although he also reports the presence of the Virgilian time line (Late Pennsylvanian). Fusulinids from the area south of Copper Mountain area are Early Wolfcampian in age.

Lack of more faunal evidence and the small relative amount of the rock type exposed make the problem of correlation difficult. The following conclusions are offered until a more detailed study can be made: 1) The unit is tentatively correlated with the Strathern Formation, a term introduced by Dott (Dott, 1955, p. 2248) to include a sequence of limestone, siltstone and conglomerate in the north central Nevada area. The Strathern Formation overlies the Tomera Formation and underlies Wolfcampian siltstones near Elko. A Triticites zone in the lower part of the formation indicates to Dott a Missourian-Virgilian age whereas primitive Schwagerina in the upper part suggests an Early Wolfcampian age. 2) Another possible correlative is the "Ferguson Springs Formation," a term proposed by Steele (Steele, personal communication) to include fusulinid-bearing carbonate and clastic rocks, heretofore unnamed, lying between the Strathern and the Pequop Formations. At the type locality the "Ferguson Springs Formation" is a medium to massive bedded, fusulinid-bearing, limestone and siltstone overlying Middle

Pennsylvanian Ely Limestone and underlying the Pequop Formation of Leonard age. At the type section of the "Ferguson Springs Formation" the Strathern Formation is absent as a rock unit although Steele believes the Strathern time interval to be present (Steele, personal communication).

Thin deposits of Late Pennsylvanian and Early Permian rocks are recognized in the southern part of the Pilot Range, and a rather complete section of Pennsylvanian rocks including the Strathern Formation is present in the Silver Island Range, (Schaeffer, personal communication). In the Crater Island Mountains, Upper Pennsylvanian rocks are absent and the Permian section begins with Middle Wolfcampian rocks. The Lower Permian series of rocks, referred to as the Unnamed Formation by Anderson, (Anderson, 1957) is thought by this writer to represent the Upper Pennsylvanian-Wolfcampian interval.

PERMIAN PEQUOP FORMATION

The Pequop Formation named by Steele (Steele, 1959) is best exposed at Grassy Cairn, immediately north of Copper Mountain. From Grassy Cairn northward the Pequop Formation is exposed along most of the hills and ridges to a point at the northern end of the range where it disappears beneath alluvium fill and volcanic debris.

Lithologic Description

The Pequop Formation in the Lucin district consists of 840 to 875 feet of platy, irregular bedded limestones.

The unit is made up of a 310-foot section of silty limestone at the base, which grades into a 50-foot interval of limey siltstone and then into an upper 490-foot section of a thin-bedded, platy limestone. The entire unit may be described as being very fine grained. Color ranges from maroon- and lavender-tinted grey in the limestone intervals to light tans and yellow-browns where the formation is more silty. Throughout the Lucin area the Pequop Formation contains coquina zones spaced at irregular intervals which produce many specimens of fusulinids, corals, Pentacrinus sp., bryozoans, crinoid buttons and plates, and broken fragments of brachiopods and pelecypods. Only the fusulinids have been useful in correlation.

Whereas the unit as a whole can be described as being irregularly bedded, it is true that at Grassy Cairn the Pequop Formation is thin-bedded and platy and weathered fragments reflect a very even and uniform bedding over a wide vertical interval. The Pequop Formation is both a gentle and steep slope former and supports little vegetation other than grasses.

The lower contact of the Pequop Formation is placed at the top of the massively bedded Pennsylvanian-Wolfcamp Limestones, or if the contact zone is covered, at the point where the platy limestone fragments appear on the weathered slope. At localities where the unit rests on Diamond Peak-Chainman there is little difficulty in separating the clastics of the Diamond Peak-Chainman from the Pequop Limestones. The upper contact is also distinct, for lying conformably above slope-forming platy limestone is a massive-bedded, cliff-forming siliceous limestone. This younger unit to the writer's knowledge, is unnamed, although it possibly represents the lowermost beds of the Phosphoria or Park City Formation (Cheney, personal communication), or the uppermost beds of the Pequop Formation at its type locality.

Age and Correlation

The Pequop Formation of the Lucin district is correlated with the type section on the basis of fusulinid identification by Steele (Steele, 1959). Included in the collections are various species of Schwagerina and Parafusulina which, to Steele, indicate an Early to Late Leonard age.

No Guadalupian fusulinid specimens were recognized and thus it is possible to speculate that the massive, siliceous limestone above the Pequop, as designated in this report, are perhaps representative of the upper parts of the Pequop Formation as designated by Steele at Pequop Summit. Speculation results from the fact that the "post-Leonardian" lithologies in the Lucin area do not resemble closely any units in the Phosphoria or Park City Formation as described by Cheney (personal communication), nor do they approach the lithologies (massive dolomite) described by Steele to lie above the Pequop at the type locality. Similarly the "post-Leonardian" beds in the Lucin area are probably not lithologic equivalents of the 4,000 feet of silts, limestones and gypsiferous beds recognized separating the Pequop and the Phosphoria Formations in the northern Toana Range to the west. On the basis of negative evidence the "post-Leonardian" beds are best correlated with the upper parts of the Pequop Formation at the type locality, but with no faunal evidence, the correlation is little more than speculation.

POST-LEONARDIAN UNNAMED FORMATION

Distribution

Post-Leonardian rocks are best exposed at the top of Grassy Cairn and on the ridges branching from the summit. At the north end of the Pilot Range similar beds are recognized as cappings on the highest ridges and knolls.

Lithologic Description

The post-Leonardian unnamed formation consists of siliceous and cherty limestones and dolomites with argillaceous partings, and cherty and limestone breccia. The unit weathers in vertical cliffs and on weathered surfaces has a yellowish-brown color. Fresh surfaces exhibit a light yellow tint on a light- to medium-grey background.

Accurate measurement of the unit appears to be impractical inasmuch as the top of the unit is everywhere missing because of erosion. The maximum thickness recorded did not exceed 125 feet. The unit's lower contact, however, is distinct for the slope-forming, platy limestones of the Pequop are easily distinguished from the cliff-forming massive siliceous limestones of the younger unit.

Age and Correlation

The post-Leonardian unnamed formation is thought possible to be equivalent to the upper part of the Pequop Formation at its type locality at Pequop Summit or correlative with the lower members of the Park City or Phosphoria Formations. The former correlation is preferred by this writer. The U. S. Geological Survey is currently working on the Park City-Phosphoria problem and until that work is completed little more can be said.

TERTIARY SYSTEM

Tertiary rocks exposed in the Lucin district include a partial section of the Late Miocene-Early Pliocene Salt Lake Formation and a younger Early and Middle Pliocene (?) vitric tuff unit described by Van Houten (Van Houten, 1956). Neither Tertiary units play a role in ore deposition and hence little space need be devoted to them.

SALT LAKE FORMATION

Tertiary rocks are exposed on the northeast and northwest flanks of the Pilot Range, north of the Copper

Mountain area. Originally thought correlatives of the Eocene Green River Formation (Hague et al, 1877) they are now known to be of Late Miocene-Early Pliocene age and most probably equivalents of the Salt Lake Formation. The unit has been described more recently by Van Houten (Van Houten, 1956, p. 2810) as a part of the "eastern sedimentary sequenc that underlies or is a "lateral facies of the vitric tuff unit" in northeastern Nevada.

Lithologic Description

The Salt Lake Formation is a 2,500-to 3,000-foot aggregate of platy siliceous limestone and mudstone, tan and yellow-grey sandstone, cream-colored limestone and brown-stained pebble conglomerate. Tuffaceous shale and siltstone and minor amounts of carbonaceous shale are also characteristic of the unit. The formation is generally very fine-grained, and resistant to erosion. A brown and grey, coarse-grained, flaggy, greywacke sandstone provides an adequate marker bed for correlation purposes within the area, as does the conglomerate and interbedded sandstone near the top of the unit. The conglomerate beds consist primarily of quartzite, chert, and limestone pebbles up to one-half inch in diameter, cemented in a dense, siliceous matrix.

The lower boundary of the unit is uncertain for the beds are in fault contact with both Permian sedimentary rocks and the monzonite intrusive body. Where the Salt Lake Formation laps on the monzonite the contact is obscured by a soil and grass cover. The upper contact is likewise questionable as the formation dips steeply beneath piedmont gravels on both east and west flanks of the range.

Age and Correlation

Because of the nature of both the upper and lower contacts of the unit, it is uncertain as to how much of the Salt Lake Formation is present. Plant fossils near the top of the exposed beds could not be dated but mollucks, dated as Late Miocene or earliest Pliocene, were recovered within 450 feet of the exposed top. These fossils, identified by Dwight Taylor of the U. S. Geological Survey, include the freshwater clam Sphaerium indet. and the freshwater snail Viviparus of. V. Turneri Hannibal.

Nomenclature problems are complicated due to the present status of nonmarine Cenozoic deposits in this part of the Basin and Range Province. On the advice of Van Houten (personal communication) correlation with the Salt Lake Formation is proposed. Other possibilities are available although less desirable. The Late Miocene-Early Pliocene lake beds described herein, and possibly correlatives of the Payette beds of southern Idaho (Mapel and Hail, 1956), and the overlying vitric tuff could be given member status of one formation, either Salt Lake or Humboldt. The lake beds are time equivalents of the Payette Formation of southern Idaho but stretching that terminology as far as the Lucin area would be unwise. Similarly, the use of the term Humboldt (Sharp, 1939) is unwise becuase of the present confusion concerning its limits and its age. Van Houten hence suggests the separation of the lake beds and the vitric tuff unit into two formations, the former to be termed the Salt Lake Formation and the latter to be referred to as the vitric tuff unit until further work is completed in the northeastern Nevada and northwestern Utah area.

VITRIC TUFF UNIT

The most extensive and widely exposed sequence of Tertiary sedimentary rocks in northeastern Nevada is the vitric tuff unit described by Van Houten (Van Houten, 1956). In the Lucin district the unit is exposed in isolated patches on the eastern flank of the range and beneath Pliocene (?) lava flows at the northern end of the range. The beds were first described in the Pilot Range as Pliocene (?) volcanic products underlying Quarternary lavas and gravels, (Hague et al, 1877).

Lithologic Description

The vitric tuff unit in the Lucin District nowhere exceeds 500 feet in thickness and includes a sequence of white, light grey, lavendar and light green colored unaltered vitric tuff and ash interbedded with light colored calcareous siltstone, sandstone, and fine pebble conglomerate that appears to be water-lain. Stratification and cross bedding is present. At the northern end of the range the unit also contains subordinate amounts of welded tuff, glassy pumice- or lapilli-like material, and obsidian lenses. The unit stands out because of its light hues contrasting with the grey and drab-colored rocks on which it rests. The units is non-resistant to erosion and forms gentle slopes and low, rounded hills.

Age and Correlation

The vitric tuff unit, as described by Van Houten, is regarded as Late Miocene to Early Pliocene in age. In the Lucin area, however, the unit rests on the Salt Lake Formation which, on the basis of fossil evidence, is regarded to be as young as early Pliocene. Inasmuch as the vitric tuff unit lies stratigraphically above the Salt Lake Formation an Early Pliocene or slightly younger age can be assigned to it. That it be a lateral facies of the Salt Lake Formation is possible but in the Lucin area it appears as a separately mappable unit from the Salt Lake Formation and hence it is given separate status, but no formal name.

It has recently been suggested to the writer that the tuff unit may be in reality the lowest member of an ignimbrite sequence recognized in several localities in adjacent areas (Young, personal communication).

IGNEOUS ROCKS

Igneous rocks of the Lucin district include monzonite and monzonite porphyry intrusives, a basalt flow and a rhyolite flow (?) and associated diabase dike rock. The monzonite is the only igneous feature extensive enough to warrant a formal name and in this report will be termed the Patterson Pass stock. The Patterson Pass stock and monzonite porphyry are believed to be of Early Tertiary age whereas the volcanic rocks and the associated dike are possibly post-Early Pliocene age. Both the intrusive and extrusive rocks are similar to igneous sequences described by other workers in the northeastern part of the Basin and Range Province.

PATTERSON PASS STOCK

An area of about ten square miles in the Lucin district is underlain by a backward "L"-shaped Patterson Pass stock of monzonitic composition. The stock at its widest point is three and a half miles, but the average is less than two miles. The stock does not extend beyond Coal Bank Spring, nor southward more than a mile beyond Patterson Pass. The rock is far less resistant to erosion than are the surrounding sedimentary rocks which it intrudes, and hence the stock supports only gentle slopes with little relief. Characteristic erosional forms of the igneous body are numerous rounded knobs that protrude above the surrounding terrain. This is particularly true in the

Patterson Pass area where the stock forms the lowest point on the divide in the Lucin district.

The intruded sedimentary rock includes the Prospect Mountain Formation, Guilmette Formation, Diamond Peak Formation, Pequop Formation and the unnamed post-Leonardian rocks. Contacts with these units are generally obscured by talus slopes, as in the case of the Prospect Mountain Formation and by grass and soil cover as in the case of the other formations. The exact relationship betwe the igneous rock and the enclosing sedimentary units is, therefore, uncertain, although in several mine tunnels the igneous body definitely intrudes the older sequences with sharp contact. In the Patterson Pass areas contact silicates are noted at the margin of the stock.

Megascopic Description

The Patterson Pass stock is composed of monzonite that grades in areas west of Patterson Pass into quartz monzonite. The rock has a medium-grained (1-5 mm) phaneritic texture that is porphyritic with orthoclase phenocrysts, northeast of Copper Mountain. The rock is generally white or light grey although pink and reddish-grey mottling can be observed. Generally the rock has been deeply weathered and hence the weathered surface is quite friable.

In the Patterson Pass area many biotite-hornblende-rich inclusions are noted, none exceeding a foot in diameter. Also in this area are small aplite dikes and diabase dikes with glassy margins.

Microscopic Description

In thin section the Patterson Pass intrusive is holocrystaline and the fabric is granitic to panidiomorphic-granular. Much of the plegioclase is euhedral and most of the orthoclase and biotite crystals are subhedral and anhedral. Minerals include about equal amounts of white orthoclase and triclinic feldspar of andesine composition, black and brown-stained biotite, minor amounts of green hornblende, and quartz. Orthoclase crystals have developed to more than 10 mm in diameter. Orthoclase is clowdy with secondary kaolin whereas the plagioclase is altered slightly to sericite. Biotite and hornblende are partially intergrown and relatively fresh although biotite is partially altered to chlorite. Quartz is interstitial although a few medium (2 mm) anhedral crystals are present. Accessory minerals include magnetite, and minor amounts of zircon and apatite.

Age and Correlation

The Patterson Pass stock is similar to acidic, granitoid rocks described by workers in the Crater Island Mountain, Silver Island Range, Newfoundland Range to the east and the Toana Range to the west. Anderson (Anderson, 1957) describes several igneous occurrences in the Crater Island Mountains, the largest covering an area of two square miles. Its composition is quartz monzonite and monzonite that grades into syenite. Other stocks in the area include biotite and pyroxene-rich monzonite and granodiorite. In the Silver Island Range, Schaeffer (Schaeffer, personal communication) reports two small stocks of granodiorite composition. At the northern end of the Newfoundland Range (Paddock, 1956), a large quartz monzonite stock is exposed and microscopic study has revealed a rock rich in quartz, perthite, plagioclase, hornblende, and biotite. The Newfoundland stock is in sharp contact with the enclosing sediments with no gradation and little alteration. Small (¼ mile dia.) granodiorite and monzonite intrusives are recognized in the southern end of the Pilot Range and three separate but adjacent acidic plutons are recognized in the Toana Range (Stephens, unfinished thesis). North of the Lucin district there are similar stocks reported by Baker, (Baker, 1959) in the Grouse Creek Range and by Olsen, (Olsen, 1960) in the Delno district. In addition, several plutons have been described in the eastern Nevada area by Stringham and his associates at the University of Utah.

The Patterson Pass stock is thought to have been intruded in the Late Cretaceous-pre-Miocene time interval. Ages are based entirely on work done in surrounding areas, for within the Lucin district the only positive evidence for the stock's age is the relationship of the monzonite to the Late Miocene-Early Pliocene Salt Lake Formation. It can be demonstrated in the area south of Coal Bank Spring that the Salt Lake Formation lies nonconformably on the monzonite. Intrusives in the Ruby Range are thought to be of pre-Miocene age (Sharp, 1939), Late Eocene to Early Oligocene at Gold Hill (Nolan, 1935). Paleocene to Eocene generally in the Great Basin and east of the Idaho Batholith (Eardley, 1951), Oligocene in the Silver Island Mountains (Schaeffer, personal communication), pre-Miocene in the Crater Island Mountains (Anderson, 1957), and Late Cretaceous to Eocene in the Newfoundland Range (Gilluly, 1928; Paddock, 1956). Although few of these ages are in agreement they all fall within the broad time range of Late Cretaceous to pre-Miocene. In the light of existing evidence (or the lack of it) in the Pilot Range and particularly in the Lucin district, it seems best to this writer that the Patterson Pass stock be assigned an age in general agreement with plutons in surrounding areas.

MONZONITE PORPHYRY

A small monzonite porphyry stock, less than ¼-mile in diameter, is exposed at the head of Six Shooter Canyon. It intrudes the Laketown, Simonson, and Guilmette Formations and is in fault contact on the southern margin with the Fish Haven Dolomite and the Laketown Dolomite. It is believed that the monzonite porphyry and the Patterson Pass stock are genetically related. It crops out in Six Shooter

Canyon as low rolling hills and give the valley a more open appearance than the usual V-shaped canyons.

In hand specimens, the rock is white to light grey on fresh surfaces, yellow-stained on weathered surfaces, and a pink tint is afforded on some fresh surfaces by pink orthoclase crystals. The rock has undergone extensive erosion and the weathered material is extremely friable. The rock is fine-grained (0.5 - 1 mm) phaneritic but phenocrysts of orthoclase and plagioclase exceed 5 centimeters in diameter although the average diameter is less than 2.5 centimeters.

In thin section the monzonite is holocrystalline and the texture porphyritic with euhedral to subhedral crystals in the ground mass. The composition of the porphyry is identical to that of the Patterson Pass stock although the amount of biotite and hornblende is less in the smaller mass and there is a smaller percentage accessory minerals in the porphyry. Plagioclase phenocrysts are generally zoned with cores of andesine and rims of oligoclase. Groundmass material consists of a fine granular intergrowth of oligoclase and orthoclase. It has a microgranitic texture. Alteration of feldspar to sericite and biotite to chlorite is more intense in the Six Shooter Canyon area than at Patterson Pass.

RHYOLITE FLOW(?)

At the northern end of the Pilot Range an oval-shaped mass of rhyolite is exposed, once referred to as the Ombe Bluffs, (Hague et al, 1877). The feature is the most prominent topographic form at the northern end of the range and is more than a mile long and almost a mile wide, and stands in lavendar or light brown-colored cliffs about 300 feet high. At least two distinct units within the mass are recognized and these two, a partially welded rhyolite tuff and an underlying vitrophyre layer, may make up the middle two of four units in an ignimbrite sequence described by Roberts and Peterson (Roberts and Peterson, 1960). The vitric tuff unit, described under Tertiary Stratigraphy, may be the lowest unit of the four; the top unit, an actual flow rock, is not present in the Lucin district. Two hundred, twenty-five feet of welded rhyolite and welded tuffaceous material is exposed in an isolated area about a mile southwest of Indian Spring.

Lithologic Description - Megascopic

In hand specimens, the rhyolite is a lavendar to pink porphyry with glassy quartz phenocrysts and deeply weathered sanadine phenocrysts that weather as earthy white spots. The matrix material is aphanitic and has an earthy appearance. The vitrophyre is a black, glassy, brittle material about 20 feet thick with uniform structure. Black, red, and yellow bands of glass, woven together, can be seen in hand specimens.

Lithologic Description - Microscopic

In thin section the rock is a partially welded, porphyry of rhyolite composition. Texture is hypocrystalline to vitreous (eutaxitic). The rock consists of black, red and yellow contorted and alternating bands or streaks or dashes of glass that are intricately braided within the rhyolite. There are generally two types of glass, a red-yellow variety and a colorless variety, both quite brittle and with sharp division lines between them. According to Hague, they "look as if thin layers of red and colorless glass had been artifically laid on one another, thoroughly kneaded together and then drawn out longitudinally." (Hague, et al, 1877) Such a description suggests welding. The red-yellow glass contains long narrow cavities that are parallel to the banding, whereas the colorless glass is more compact and contains irregular tricites. At the base of the mass the glass approaches a true obsidian although still possessing the braided appearance.

Phenocrysts in the felsitic and glassy groundmass do not exceed 0.8 mm in diameter. They consist of sanidine and quartz that have inclusions of glass. Groundmass minerals include sodic plagioclase, sanidine, glass and minor amounts of biotite and magnetite that has been partially altered to hematite. Numerous drawn-out glass and air cells suggest flow structure, or if an ignimbrite, pseudo-flow structure.

The vitrophyre layer contains a completely glassy groundmass of flattened, compressed and squeezed glass particles, welded together to form a uniform mass. Glass takes the form of water-clear material with black glassy stripes, angular and rounded, black, opaque glass, and thin tricites.

Age and Correlation

The exact age of the rhyolite and vitrophyre is uncertain. It lies with slight angularity on the Early and Middle (?) Pliocene vitric tuff unit and below the basalt flow that is thought to be Late Pliocene or Early Pleistocene. The unit can be correlated with similar appearing rhyolites and vitrophyres in the southern Goose Creek Mountains, (Young, personal communication) and with lava flows (?) of Late Cenozoic age throughout the Basin and Range Province.

The origin of the rhyolite is uncertain for there appears to be no acidic volcanic centers in the vicinity. The possibility suggested above, that is, that the material is not a flow but rather an ignimbrite that formed by nuees ardentes, is the result of study made on similar appearing material described by Mackin in southwestern Utah (Mackin, 1960) and by Roberts and Peterson at Battle Mountain, Nevada, and Globe, Arizona, (Roberts and Peterson, 1960). Young (Young, personal communication) has shown by thin-section study that volcanic products in the Goose Creek Mountains is of the ignimbrite type.

BASALT FLOW

Immediately west of the rhyolite at the northern end of the range is a younger basalt flow and associated basalt dike. The flow has been broken into segments by erosion. The eastern segment is the most easily recognized for it takes the form of a well developed volcanic plug. The mass is flat-topped, slopes slightly to the south and the plug stands in vertical, columnar jointed walls of vesicular, scoriaceous basalt. The basalt dike extends northward from the northwest margin of the crater. The western segment is recognized as low rounded hills on which are superposed many well developed intermediate strand levels of Lake Bonneville.

Lithologic Description

The basalt is a tough, resistant variety that possesses a hackly fracture. In thin section the basalt rock possesses a holocrystalline, slightly porphyritic texture with phenocrysts of calcic plagioclase and minor opaline material. The aphanitic groundmass consists of lath-shpaed labradorite crystals and augite with interstitial glass; no olivine is present. Grains of magnetite and leucoxene are abundant in a groundmass that becomes more glassy and gobulitic towards the base. Cavities and druses (0.5 - 1 mm) are filled with secondary calcite.

Age and Correlation

The basalt flow and its associated dike are dated between Late Pliocene and the Wisconsin stage of the Pleistocene. This statement is based upon the fact that the basalt overlies the Late Pliocene (?) rhyolite and is masked by strandlines of Lake Bonneville between the Bonneville and Provo stage, thought to be Early Wisconsin age (Eardley *et al*, 1957). The basalt is probably correlative with Late Tertiary and Early Quaternary volcanics recognized by many writers in the Basin and Range Province. The eruption was evidently of a flow type, for no ash or cinder deposits are recognized.

DIABASE DIKES

Diabase dikes are recognized in several localities in the Lucin district. They are best displayed in the area immediately east of Copper Mountain where they intrude both the Guilmette Formation and the Patterson Pass stock. Within the stock they are best recognized on aerial photographs as darker colored patches and stringers for they are not readily apparent in the field. They do not stand as resistant ridges and their topographic expression is almost non-existant.

Lithologic Description

All of the dike rocks in the Lucin area have approximately the same diabase composition. In some instances the composition approaches a gabbroic or basaltic type. Textures are generally finely-phaneritic although aphanitic textures are not uncommon in the dikes of the Patterson Pass area.

Megascopically the rocks are black and dark green with a deep brownish weathered surface. Phenocrysts are not abundant in any of the dike material.

Thin sections reveal a ophitic to subophitic texture. The principal constituents are labradorite, partially altered to sericite, and both dark green and colorless augite. Biotite is partially altered to chlorite and chlorite also fills some of the interstitial space between the labradorite laths. Magnetite, leucoxene, apatite, and titanite (?) are recognized as accessory minerals. Secondary calcite is abundant in some of the diabase rocks.

Age and Correlation

Dike rocks in the Lucin district are thought by this writer to be associated with basaltic out-pourings recognized at the northern end of the range. They intrude Paleozoic rocks, following pre-existing fissures of probably Middle Tertiary age. They appear to be overlapped by the Salt Lake Formation of Late Miocene and Early Pliocene age although this relationship is not certain. Inasmuch as there are no other basic rocks in this area with which to correlate, other than the basalt flow, it would seem plausible to associate the flow and the dikes.

STRUCTURAL FEATURES

General Statement

Structural features in the Lucin district are complex due to regional folding, unconformable relationships between Middle and Late Paleozoic rocks that are masked by Late Mesozoic (?) and Tertiary normal faulting, and also due to the intrusion of the small monzonite stock.

The Lucin area is characterized by north trending Early Tertiary normal faults that are pre-intrusive, and by younger east and northeast trending normal faults that are questionably post-intrusive and transect the range. Both trends are truncated by Late Tertiary Basin and Range normal faults which caused tilting and accompanying uplift of the Pilot Range.

Folds in the Lucin district consist of asymmetrical synclines and anticlines. The axes of the folds strike a few degrees east of north. The folds plunge slightly to the north. Rocks involved in the folding include the Ordovician, Silurian and Devonian and Mississippian and younger rocks lie unconformably on the Devonian. These younger rocks have been warped by post-Devonian crustal forces. Post-Devonian folding has been on a minor scale and only broad, open folds are present. Their axes strike and plunge to the north.

Gravity slide phenomenon are questionably recognized in the Patterson Pass area, and numerous unconformities attest to several periods of deformation.

FAULTS

Copper Mountain Fault Zone

The most prominent fault zone in the Lucin district is a mineralized fault zone at the crest of Copper Mountain. The zone is more than 1,000 feet wide and includes several intersecting normal faults with a north trend within the Guilmette lower limestone member. Many smaller fractures cut this zone at various angles and the resulting junctions are mineralized.

The Copper Mountain fault zone consists of fault planes dipping to the west. Displacement along these is on the order of a few hundred feet with the west side down. Of the two major faults exposed at the crest of the hill within the Copper Mountain fault zone the western fracture is the older, for it is shown in the Bell and Green Carbonate Tunnels that the western fracture has been truncated by the eastern. It can also be demonstrated in these tunnels that faulting was both pre- and post-ore. A similar relationship is demonstrated several hundred feet to the east where the Copper Mountain diabase dike was forced into pre-existing fractures and subsequently off-set. The relation of faulting to intrusion of monzonite magma indicates the intrusion to be younger, as it can be shown that monzonite off-shots follow the fractures into the enclosing Guilmette limestone with only minor crushing or alteration.

The Copper Mountain faults were originally recognized on the basis of off-set ore bodies at the crest of the hill. Displacement could be estimated by projecting ore bodies in the subsurface and later checking the off-set when drifts were driven into the mountain. Without the aid of off-set ore bodies, the recognition of faults within the massive limestone would be difficult although brecciation and minor alteration of limestone can be detected.

South of the mining area the Copper Mountain fault zone veers to the southwest to a point where it is truncated by a younger east-west transverse fault. It has been suggested by Butler, (Butler et al, 1920, p. 492) that the Copper Mountain fault zone continues south of the east-west transverse fault, termed the Regulator Canyon fault, and is displaced 1,000 yards to the west. This relation is not clearly demonstrated. North-south faults occur in this area but the lack of mineralization of any kind, and the absence of a well developed breccia zone and accompanying alteration similar to that observed on Copper Mountain suggests that the zones are not the same.

Tecoma Hill Reverse Fault

West of the Copper Mountain fault zone, in a saddle between Copper Mountain and Tecoma Hill, is the trace of a north-south reverse fault that brings Silurian Laketown dolomite up on the west side into contact with the Guilmette Formation. Both stratigraphic units strike about N15W and dip 30 degrees to the east. The fault plane dips steeply to the west and displacement is estimated to be between 1,000 and 1,300 feet. It can be demonstrated that the displacement is at least 600 feet as apparently the whole Devonian Simonson Formation has been omitted. Upper limits on displacement are questionable, for the amount of Laketown and Guilmette missing cannot be accurately determined. Figures of 350 feet for the Laketown and 400 feet for Guilmette would be a close approximation and total displacement, including 550 feet of Simonson, therefore, does not exceed 1,300 feet. The Tecoma Hill reverse fault is not mineralized.

<u>Tecoma Hill Normal Faults</u>

West of the Tecoma Hill reverse fault are numerous north trending normal faults cut by east and northeast trending fractures. It is in these latter fractures, and particularly at the junctions of the various trends, that Tecoma Hill mineralization has occurred. The north-south trends are not mineralized except at points of intersection with younger displacements.

Immediately west of the reverse fault the trace of an easterly dipping normal fault is exposed that brings the Laketown Dolomite in contact with the Ordovician Pogonip Group, and in particular, the Lehman Formation. The Lehman Formation is actually present in a horst structure, for within a few hundred feet west of the one bounding fault is a westerly dipping normal fault that drops the Laketown Dolomite down into contact with the western edge of the Lehman Formation. It would appear from relationships observed south of Tecoma Hill in Regulator Canyon that the horst structure is older than the Tecoma Hill reverse rault, although this cannot be positively demonstrated.

Regulator Canyon Fault

Poorly exposed south of Regulator Canyon on the north-facing slope is the trace of an east-west transverse fault that displaces Guilmette limestone horizons for 1,000 yards. The movement on the fault has been strike-slip, with the north side being displaced to the east 1,000 yards and down less than 200 feet. The plane of the fault is nearly vertical although there may be steep inclination to the north.

A few hundred yards south of the mineralized zone of Copper Mountain the Regulator Canyon transverse fault cuts the ridge-line in a low pass. Here the upper shaly limestone unit of the Guilmette is brought in contact with the Diamond Peak Formation. Both formations abutt against the fault, and both dip to the east. Further west, in Regulator Canyon, Fish Haven and Laketown beds on the north side of the canyon strike into Simonson and Guilmette beds on the south side.

The Regulator Canyon fault appears to be younger than the monzonite intrusion for minor off-set in the igneous rock, at its contact with sedimentary beds, can be detected.

Brecciated and altered zones that might normally be expected in the monzonite along the strike of the fault have not been observed.

Grassy Cairn Fault

At the northern end of Copper Mountain a second transverse strike-slip fault crosses the ridge line and brings Guilmette strata in contact with Mississippian and Permian rocks. North of the Grassy Cairn fault is a possible extension of the north trending Copper Mountain fault zone. This northern extension has been off-set to the east for a distance of several hundred yards and brings Permian strata in contact with Ordovician, Silurian, and Devonian Formations. Only slight downward movement is apparent on the Grassy Cairn fault.

It is the Grassy Cairn and Regulator Canyon transverse faults that result in the topographic off-set nature of the ridge line between Patterson Pass and the northern end of the range, for both faults displace the north sides to the east.

Patterson Pass Fault

A transverse fault of probable large lateral and vertical displacement is recognized in the low divide termed Patterson Pass, at the southern end of the map area. The trace of the fault is not exposed at any point for it was into this zone of weakness that the Patterson Pass monzonite was intruded.

The reason for suspecting a fault with a large strike-slip component is readily apparent, for on opposite sides of the pass Prospect Mountain quartzite of Proterozoic (?) and Cambrian age strikes toward and approximately parallel to the Devonain Guilmette formation and undifferentiated Permian rock. The Prospect Mountain Formation dips steeply to the east and is itself complexly faulted by north-striking fractures. How much of the formation is represented in this area is uncertain because of possible repetition by north-south faulting and because of complex stratigraphic problems involved with Proterozoic-Cambrian boundary, but it would appear that several thousand feet would not be an ambitious estimate. If even the part of the formation exposed were taken to represent the very top of the Prospect Mountain and if 2,000 feet of the unit were exposed, a minimum off-set of 9,500 feet would be necessary to place the involved strata in their present positions.

Similarly, an almost equally large vertical displacement component is necessary, for the Guilmette strata are exposed at an elevation of 600 feet or more below the Prospect Mountain Formation, and all of the lower Paleozoic has still to be accounted for.

The Patterson Pass structure is the most impressive in the Lucin district and possibly in the whole Pilot Range. Its relation to other major faults in the Lucin district is not clearly understood, although it is definitely known to precede the implacement of the intrusive body. With only this one guide little can be said concerning relation to the Lucin structural features. That it is younger than the Copper Mountain north-south movements and older than or correlative to major east-west movements further north in the area is only a tentative suggestion, but perhaps the best possible in the light of existing evidence.

Other Faults

There are in the northern part of the Pilot Range many faults of minor significance when compared to the larger displacements mentioned above. Most of the minor faults, however, fall into the patterns established by the larger faults; that is, normal faults with north, east, or northeast trends. Most displacements in the area north of Copper Mountain bring into contact the Mississippian Diamond Peak and Diamond Peak-Chainmnan undifferentiated and Permian Pequop formations although several effect older strata. The displacements on the majority of faults is small, probably not exceeding 500 feet in any instance.

FOLDS

Folds in the Lucin district consist of broad, open, asymmetrical synclines and anticlines, broken by internal normal faults and marginal Basin and Range faults. Folding is recognized in two stages and represents two phases of deformation. The older folding is more severe than the younger and affects rocks of Ordovician, Silurian, and Devonian age, whereas the younger folding affects Mississippian and younger sedimentary rocks. Present dips of the Permian and older rocks are due in part to post-Permian tilting associated with Mesozoic and Cenozoic defomration.

The western limb of an open, pre-Mississippian syncline is exposed on the western flank of the Pilot Range, (plate 3, sec. D-D', E-E'). The synclinal axis approximately follows the ridge line of the range, south of Copper Mountain. The axis strikes between N5W and N15E and plunges slightly to the north. Western limbs dip between 35 and 55 degrees to the east whereas eastern limbs dip 15 and 20 degrees west. It is only postulated (plate 3, sec. E-E') that the westerly dip exceeds 35 degrees for Mississippian and younger rocks conceal much of the older rocks. The fold has been broken by marginal Basin and Range and hence the anticlinal extension to the west has been dropped down and partially buried by Tertiary and Quarternary sediments, (plate 3, sec. A-A', D-D', E-E').

Parts of the anticline can be observed, however, west and northwest of Copper Mountain, (plate 3, sec. B-B', C-C') and dips on either limb do not exceed 30 degrees. Anticlinal extension to the east is largely obscured by the monzonite intrusive body although shallow anticlinal folds are observed east and northeast of Copper Mountain, (plate 3, sec. A-A', and B-B'). North of Copper Mountain the folds are partially covered by Mississippian and Permian rocks that lie unconformably on their truncated edges.

Post-Mississippian warping is exhibited south of Copper Mountain, (plate 3, sec. D-D' and E-E') as a broad, shallow, asymmetrical syncline whose axis strikes N5W to N15E and plunges less than 10 degrees to the north. Dips on either limb do not exceed 30 degrees. North of Copper Mountain the fold is poorly exposed as a broad anticlinal warp, the dips of whose limbs average between 25 and 35 degrees.

Permian rocks in the southeastern margin of the district are intensely distorted and broken but this condition is believed to be the result of gravity sliding associated with monzonite intrusion, rather than regional compression. Permian rocks in the Grassy Cairn vicinity are tilted to the east at angles not exceeding 20 degrees and this is thought due to orogenic movement associated either with Mesozoic or Cenozoic disturbances.

UNCONFORMITIES

Regional unconformites observed throughout the Great Basin are recognized in the Lucin district. These include non-depositional or erosional breaks between the Lower Ordovician Lehman Formation and the Middle Ordovician Eureka Quartzite, between the Eureka and the Upper Ordovician Fish Haven Dolomite, between the Fish Haven and the Middle Silurian Laketown Dolomite, and between the Laketown and the Middle Devonian Simonson Formation.

In addition, a pronounced angular unconformity is recognized where Upper Mississippian Diamond Peak-Chainman Formation truncates the three members of the Devonian Guilmette Formation. Thae angular discordance is about 15 to 20 degrees and can be best observed south of the Regulator Canyon fault. The unconformity represents evidence for Paleozoic orogenic movements that have been postulated by Nolan (Nolan, 1928), Roberts (Roberts, et al, 1958), and Rigby (Rigby, 1959) to affect the northeastern part of Nevada and the northwestern and north-central parts of Utah during Late Devonian and Mississippian time, or the Wendover phase of the Antler Orogeny as postulated by Sadlick and Schaeffer to affect the Wendover area during Middle Mississippian time, (Sadlick and Schaeffer, 1959).

A minor angular unconformity exists between the Diamond Peak-Chainman Formation and the beds of Virgilian

(?) - Wolfcampian age in the area south of Copper Mountain. This discordance, with angularity of 10 degrees, suggests a post-Late Mississippian - pre-Middle or Late Pennsylvanian disturbance that correlates with a similar orogenic phase recognized in the Silver and Crater Island Mountains (Schaeffer and Anderson, 1959).

Post-Permian unconformities are recognized where Late Tertiary volcanic debris rests on Permian and older rocks, and where rhyolite and basalt flows rest on tilted Early or Middle Pliocene vitric tuff.

GRAVITY SLIDE PHENOMENON

It has been suggested to this writer by Wm. Lee Stokes that the isolated Permian Pequop Formation and the post-Leonardian beds in the Patterson Pass area are perhaps in their present positions due to gravity sliding as described by Mackin, (Mackin, 1960) in southwestern Utah. Although it was impossible to re-examine the field relationships in this new light it would seem appropriate to dwell briefly on this question.

Mackin suggests the possibility that block faulting has been the only type of regional tectonism in the Basin and Range Province in post-orogenic time, and that structures usually interpreted as orogenic thrust faults may merely be the result of emplacement of hypabyssal intrusions and gravity sliding from primary relief features raised by intrusion and block faulting. Mackin's study deals primarily with gravity slide relationships in Tertiary volcanic rocks but it may be applicable to the Permian rocks in the Patterson Pass area too. Although the position of the Permian rocks on the Patter Pass stock has not been regarded as a thrust relationship it does appear strange that they should be so isolated from the rest of the Paleozoic section. It is entirely possible then that the intrusion of the Patterson Pass stock caused the raising of the overlying relief features into unstable positions, perhaps causing slopes to exceed the angle of repose. It would then be possible and probable for the unstable mass, in this case the Permian sedimentary sequence, to slide down the slope into a stable position. Whereas the Permian rocks in the area are not brecciated, they are badly fractured and their dips far exceed structural dips of sedimentary beds elsewhere in the Lucin area. Similarly, the upper-most beds of the Pequop Formation, which is the lowest stratigraphic interval represented in the area, would provide material on which the mass would slide most readily. Since the time of intrusion, which is thought to be Late Cretaceous to Early Tertiary, there has been an inversion of relief, for the monzonite stock is topographically the lowest part of the area in question.

ORE DEPOSITS

HISTORY AND PRODUCTION

The deposits of the Lucin district were discovered in the summer of 1868 although the district was not organized and named until 1872. Native copper, red and black oxides, and blue and green carbonates were first discovered and ores were shipped largely from the Yellow Jacket, Waddell, Central Pacific, and First Extension claims. Native silver and lead sulphates, sulphides, carbonates, and molybdonite were subsequently mined from the Tecoma, Independence and Uncle Sam properties on Tecoma Hill.

The nearest station to the mines on the main line of the Southern Pacific Railroad was Tecoma, a settlement of about 200 people at the height of mining activity. Shipments of ore were made from Tuttle, a point at the base of the Pilot Range, to which a spur from the main line had been constructed. An aerial tram was employed after 1900 to transport ore from Copper Mountain mines to Tuttle, the terminal of the spur, but ore from Tecoma Hill has always been brought to Tuttle by wagon or truck.

In the Lucin district in early years the Tecoma property was the most prominent and in 1871 the mine shipped 400 tons of sixty percent lead and $60 to $140 silver ore. Murphy (1872) described the mining activity in the Tecoma area as follows:

> "The property, (Tecoma) has recently changed ownership, having been purchased by Buel and Bateman on the 4th of October, 1871,

for $125,000 gold. A town site was at once laid out and named Buel. Where previously there had been only four or five cabins occupied by some 25 or 30 quiet miners, in two or three weeks there sprang up two hotels, three restaurants, half a dozen saloons, stores for merchandise and a furnace of 20 tons capacity for each 24 hours.

"From 50 to 70 men are engaged in charcoal burning and about double the number in and around the mine, and putting up the smelting works, offices, and other necessary buildings, for the Buel company.

"A stage line has been established from Tecoma station to the town of Buel, a distance of 5 miles. A large accession to the mining population has been made since the erection of smelting works."

The Buel City smelter, erected by the American Tecoma Company to reduce lead ore, was subsequently sold to Howland and Aspinwall of New York in 1872; the latter firm shipped several thousand tons of 45 percent lead and 35 ounce silver ore between 1872 and 1876. The furnace was shut down in 1876 because of high operating costs, crude extraction methods and a small supply of ore. It has been idle ever since.

The English Tecoma Company owned several claims during this early period, and shipped about 1,000 tons of low grade ore, containing 30 percent lead and 10 to 25 ounces of silver to their company furnace at Truckee, California. In 1874, about 40 tons of horn silver ore, valued at $16,000 were collected from near-surface deposits at the Black Warrior claim on Tecoma Hill.

Records of mining activity are scanty; between 1876 and 1886, Box Elder County records show only a dozen new claims filed during that interval, compared to more than 25 filings prior to 1876.

Between 1886 and 1894, however, copper properties were vigorously worked and subsequently sold to the Salt Lake Copper Company. During this interval iron, although high in alumina and silica content, also was recovered and shipped to Salt Lake smelters for use as a flux. The most noted iron and copper property in the Lucin district was the "Glory Hole," at the summit of Copper Mountain. The original "Glory Hole" is now covered by waste from newer open pits.

The majority of claims recorded in the Lucin district were filed between 1886 and 1910 and worked intermittently by at least fifteen different mining and exploration companies. In 1902, variscite deposits were discovered on Utahlite Hill a few miles north of Lucin. Variscite, a gemstone well adapted for the making of craftsman or barbaric* jewelry, was recovered in minor amounts from the Utah Gem, Utahlite, Protection Lode, Greenback Lode and Sentinal claims. These deposits were never commercially important

* "...type of ornament consists of various precious and semiprecious stones and gem matrices worked into large and small settings of gold, platinum, silver or alloy material and built along the lines of quaint oriental and other designs."
(Pepperburg, 1910)

as gem stone producers, although interest was briefly revived in 1957 in search for lapidary material.

From 1870 to 1917 the following metal values were recovered from the Lucin district: (Butler et al., 1920, p. 489)

	Gold	Silver	Copper	Lead	Zinc	Total
1870-1905	$ --	$220,282	$ 237,835	$219,720	$ --	$ 677,837
1906-1913	563	12,387	1,767,346	7,973	--	1,788,269
1914-1917	1,595	20,815	697,077	67,063	34,680	790,087
	$2,158	$253,484	$2,702,258	$294,756	$34,680	$3,256,193

	Gold Fine Ounces	Silver Fine Ounces	Copper Pounds	Lead Pounds	Zinc Pounds
1870-1905	--	176,000	1,675,200	3,720,000	--
1906-1913	27.29	21,866	12,127,418	177,481	--
1913-1917	77.14	27,250	2,874,703	851,641	34,680
	104.43	225,136	16,577,321	4,749,122	34,680

Mining interest declined sharply after World War I although as many as fifty new claims were filed in the Copper Mountain area between 1920 and 1958.

The aerial tram, connecting Copper Mountain properties with the spur terminal, ceased operation in 1935. In 1941, the tram and the Buel City smelter were sold for scrap. In 1937, the Buel school, the one remaining vestige of the former town, was officially closed.

Zinc ore was recovered from the Black Warrior and Tecoma properties on Tecoma Hill until as late as 1943, but high shipping costs to a mid-western smelter forced their closure. Between 1945 and 1958 production has been meager with total recovery of iron, copper, lead and silver ore less than 10,000 tons. During the late 1940's and early 1950's the Copper Mountain Mining Company intermittantly mined low grade copper and iron ore from open pits near the "Glory Hole," and low grade lead-silver ore from the Walker Tunnel below Copper Mountain. Between 1945 and 1948 the England Brothers Company of Tooele, Utah, also attempted to revive the Copper Mountain workings but the venture proved unsuccessful. In 1950 and 1951 Church and Westover leased the open pits for copper and iron recovery and during this same interval local individuals shipped small quantities of copper, lead and silver ore from the summit's open pits and Walker Tunnel. Frazer and Fife continued the work in the Copper Mountain area in 1952 and 1953 but only small quantities of low grade copper carbonate and oxide ore was recovered.

The last major mining operation in the district was carried on in 1953 by MacFarland and Hullinger. In a period of several months almost 9,000 tons of low grade limonite valued at $50,000 was recovered from the "Glory Hole" area and shipped to Richland, Washington, for use by the Atomic Energy Commission.

The final shipment of low grade copper, silver, and gold ore was made in 1955 by Frazier and Killion to the American Smelting and Refining Corporation plant at Garfield, Utah, and to the Nevada Consolidated Copper Company at McGill, Nevada.

Copper Mountain was owned by the Lewisholn Brothers of New York City during the period from 1948 to 1955. Little mining has been done except by local prospectors since 1955. Copper Mountain was sold in 1955 to Uranium Petroleum Corporation, (Upetco), a Salt Lake firm but little development has been attempted because of prohibitive mining and milling costs and the low price now offered for domestic copper.

Production data for the Lucin district since 1917 are not available although it is probable that total production value from the Copper Mountain area alone may exceed five million dollars. Production from the Tecoma Hill properties since 1917 has been insignificant.

Claim maps for the Copper Mountain and Tecoma Hill areas are presented on plates 5 and 6.

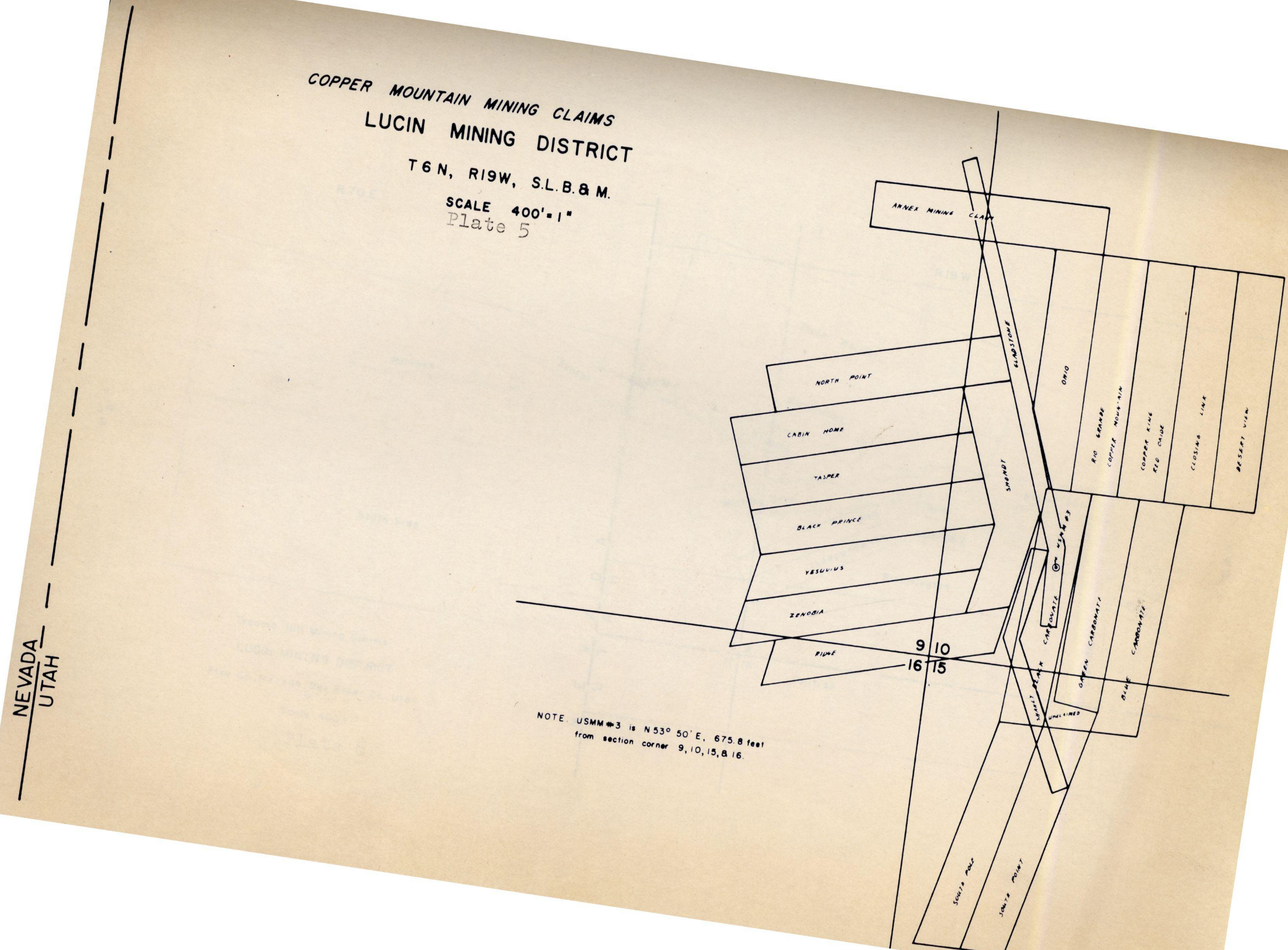
COPPER MOUNTAIN MINING CLAIMS

LUCIN MINING DISTRICT

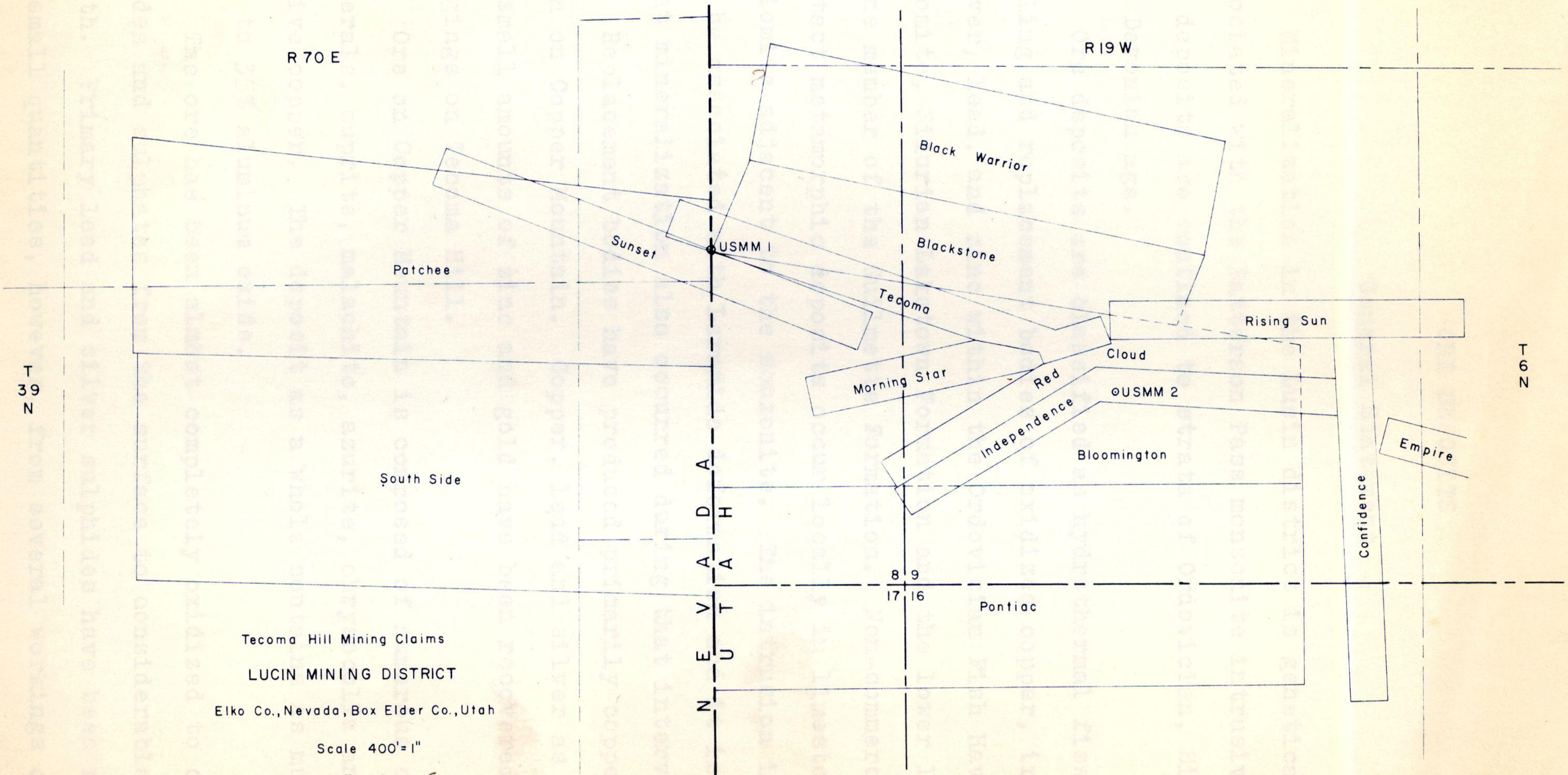
T 6 N, R19W, S.L.B.& M.

SCALE 400'=1"

Plate 5



NOTE. USMM #3 is N 53° 50' E, 675.8 feet from section corner 9, 10, 15, & 16.



Tecoma Hill Mining Claims

LUCIN MINING DISTRICT

Elko Co., Nevada, Box Elder Co., Utah

Scale 400' = 1"

Plate 6

ORE DEPOSITS

General Statement

Mineralization in the Lucin district is genetically associated with the Patterson Pass monzonite intrusive and ore deposits are confined to strata of Ordovician, Silurian, and Devonian age.

Ore deposits are classified as hydrothermal fissure-filling and replacement bodies of oxidized copper, iron, silver, lead, and zinc within the Ordovician Fish Haven Dolomite, Silurian Laketown Formation and the lower limestone member of the Guilmette Formation. Non-commercial contact metamorphic deposits occur locally in limestone and dolomite adjacent to the monzonite. The intrusion is thought to be associated with Laramide deformation and it is probable that mineralization also occurred during that interval.

Replacement bodies have produced primarily copper and iron on Copper Mountain. Copper, lead and silver as well as small amounts of zinc and gold have been recovered from diggings on Tecoma Hill.

Ore on Copper Mountain is composed of numerous clay minerals, cuprite, malachite, azurite, chrysocolla and native copper. The deposit as a whole contains as much as 30% to 35% aluminum oxide.

The ore has been almost completely oxidized to carbonates, oxides and sulphates from the surface to considerable depth. Primary lead and silver sulphides have been recovered in small quantities, however, from several workings on

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The ore has been almost completely oxidized to carbonates, oxides and sulphates from the surface to considerable depth. Primary lead and silver sulphides have been recovered in small quantities, however, from several workings on

Tecoma Hill and from the Copper Mountain pits, but no copper sulphide body has been encountered, nor have any secondary sulphides been observed either beneath Copper Mountain or Tecoma Hill.

Contact metamorphic silicate deposits in limestone and dolomite adjacent to the quartz monzonite have been prospected north of Tecoma Hill and only garnet, diopside and tremolite mineralization has been recognized. These pits have not yielded ore.

Alteration of the host carbonate rocks and monzonite is of little consequence although the monzonite shows traces of slight chloritization and sericitization. Bleaching and softening of carbonates, changes in grain size, and a slight increase in porosity and permeability are the only physical or chemical changes affecting the sedimentary rocks.

An extremely difficult problem of ore treatment has been encountered with Lucin copper deposits because of high percentages of aluminum oxide and silica. At present neither the clay type ore nor the cuprite is adaptable to milling and metallurgical processes for ores do not readily separate with flotation methods nor will they acid-leach or filter properly (Quigley, 1955). Problems with roasting of cuprite and crushing of native copper also exist thereby causing ore processing to be expensive, and in 1960 unprofitable. A summary of experimental ore treatment methods is presented in the appendix.

At the time of this study drifts and shafts were partially inaccessible because of caving. The Tecoma and Black Warrior claims are accessible, however, and of course, the open pits at the Copper Mountain summit are easily viewed.

Copper Mountain Mineralization

Copper and iron mineralization of commercial importance is located on Copper Mountain and worked by both open pit and underground operations. Ore occurs as oxidized replacement bodies of stratified copper and iron carbonates, oxides and sulphates. Ore minerals present and observed by the writer include the following:

azurite	$Cu_3(CO_3)_2(OH)_2$
malachite	$Cu_2(CO_3)(OH)_2$
native copper	Cu
cuprite	CuO
chrysocolla	$CuSiO_3 \cdot 2H_2O$
goethite	$FeO(OH)$
limonite	$FeO(OH) . nH_2O + Fe_2O_3 . nH_2O$
hematite	Fe_2O_3

Ore minerals reported by earlier writers but no longer present include the following:

native silver
lead sulphide (galena, ?)
lead carbonate (cerussite, ?)
lead sulphate (anglesite, ?)

Outcrops of gossan at the summit of the hill and at the margins of the open pits consist of soft, reddish-brown iron ore mixed with a gangue of soapy material of milk white to reddish-brown color, which Ryan (1914, p. 20) states contains as high as 27 percent alumina. The gangue material, as well as the ore itself, is stratified within the enclosing Guilmette Formation. Butler (Butler et al, 1920, p. 492) states that the ore consists of:

> "...hydrous oxides of iron, (limonite and goethite) oxide of copper, (cuprite) 'copper pitch', (a black substance containing copper and manganese), carbonates of copper, and a large amount of clayey material that is white to dark blue, according to the amount of copper it contains....Some specimens of the blue mineral approach the composition of chrysocolla ....Irregular masses of cuprite are in places enclosed in this material making a high grade ore."

X-Ray and infra-red analysis of this material confirms Butler's observation and points to the presence of other clay minerals as well. A complete list of the clay minerals and alteration products is as follows:

alunite	$KAl_3(OH)_6(SO_4)_2$
azurite	$Cu_3(CO_3)_2(OH)_2$
calcite	$CaCO_3$
chrysocolla	$CuSiO_3.2H_2O$
goethite	$FeO(OH)$
halloysite	$Al_2Si_2O_6(OH)_4 \cdot H_2O$
hematite	Fe_2O_3
kaolinite	$Al_2 Si_2 O_5 (OH)_4$
kaolin group undifferentiated	
limonite	$FeO(OH) \cdot nH_2O + Fe_2O_3 \cdot nH_2O$
malachite	$Cu_2CO_3 (OH)_2$
quartz and 6 Å quartz	SiO_2
sericite	$KAl_3Si_3O_{10}(OH)_2$

Minor amounts of native copper occur as small vugs within the copper carbonates. Minor amounts of silver and lead sulphide and aluminum silicates have also been reported, (Ryan, 1914).

There appears to be two phases of mineralization on Copper Mountain, one on the eastern side of the fault zone containing a high percentage of hydrous iron oxide.

with lesser amounts of copper, lead, and silver, and one on the western side of the fault zone containing a high percentage of copper carbonates with minor amounts of iron oxide and oxidized silver. Copper ore on the western side is surrounded by masses of porous limonite and goethite, or in some instances, a yellowish-brown iron-rich mud. Regarding the limonite and goethite deposits Crawford and Buranek (1942, pp. 16-17) state:

> "Limonite is common in other mines in the (Lucin) district, but none of them contain as large a body as that mentioned above," (Copper Mountain).
>
> "It is doubtful, however, if the Copper Mountain Mine will ever be worked primarily for its iron content, because although it is unusually large for a secondary deposit of its type, it is relatively small when compared with southern Utah iron deposits."

Copper Mountain ore samples analyzed by the Techmanix and Combined Metals Reducation Company in 1957 show the following composition:

Assay	Cu	Fe	SiO_2	CuO	MgO	Al_2O_3	CO_2	S	ignition loss
%	3.0	11.4	29.7	3.4	2.6	21.9	3.8	Tr	16.1

Assay	Zn	Pb	WO_3	Au	Ag
oz./ton	0.1	0.0	0.02	Tr	0.2

Other samples assayed for copper content showed 4.50% copper (Quigley, 1955) and composite samples taken at several points in the Bell and Green Carbonate Tunnels assayed 5.40% copper and 34.0% aluminum oxide. Quigley's assay figures for samples taken from the west side open pit (5- to 10-foot channels cut at 25-foot intervals) are as follows:

Sample No.	% Copper Content	Sample No.	% Copper Content
1-W	3.90	6-W	2.30
2-W	3.00	7-W	0.90
4-W	3.50	8-W	2.30
5-W	2.00	9-W	1.25

Average Copper Content..........2.40%

Copper Mountain Ore Distribution

Three ore bodies are exposed at the summit of Copper Mountain within a distance of more that 2,000 feet, but no connection between them has been observed. The main producing bodies, separated by a relatively barren zone, are the central and eastern, the central one being the largest and most important copper producer. (See appendix V for plan and section views.) It extends along strike for 150 feet at the surface and 300 feet down the western slope from the top. The central and eastern ore bodies are continuous faces of copper and iron mineralization for 250 and 220 feet respectively. The eastern-most ore body, with a greater concentration of the iron mineralization, has been truncated abruptly on the east side by the vertical diabase dike. Little ore has been recovered east of the dike.

The western ore body is the smallest of the three; it contains similar mineralization but is not noticeably affected by either north or east trending faulting.

South of the central ore body and approximately 50 feet below the western pit is the entrance to the Bell Tunnel. It extends into the mountain for 200 feet from the west. Seventy-five feet from the portal a drift turns south and joins the Green Carbonate Tunnel 475 feet farther south. Copper bodies and small veins were followed in these workings on three levels over a 60-foot vertical interval.

Ore similar to that at the summit of Copper Mountain was prospected at the west end of Tecoma Hill. The venture proved unsuccessful because the ore has been abruptly terminated at shallow depth by the quartz monzonite. Probably much of this deposit has been removed by erosion.

Structural Control of Copper Mountain Ore

The Copper Mountain fault zone plays a most important role in ore deposition. Of the two major structural trends in the Lucin district the north-south fracturing in the Copper Mountain area is the most significant in terms of ore control. The zone is about 1,000 feet wide and over one-half mile long and consists of normal fault planes that dip steeply to both the east and west. Faults are branching in nature and the intersections and junctions of the minor fractures show in pockets or cavities that were more favorable to ore deposition than were surrounding areas. Faulting in the zone is both pre- and post-ore although ore-bearing solutions followed pre-existing fractures. Drifts and raises into the central and eastern ore bodies show evidence of post-ore faulting but no further emplacement of ore is indicated.

Sedimentary Control of Copper Mountain Ores

Ore in the Copper Mountain area is confined to the favorable carbonate beds of the lower massive limestone member of the Devonian Guilmette Formation. For the most part, ore followed bedding surfaces in the limestone and, in its lower portions, contains re-deposited, leached material from the upper part of the deposit, "partially filling channels and crevices in the gangue and along the outer edge of the diabase," (Ryan, 1914, p. 21). Dolomite beds in the Copper Mountain area are not mineralized. Characteristic of the ore bodies is the lack of alteration other than disintergration between the ore and the Guilmette Formation. Walls generally are hard, unaltered limestones having the appearance of water-worn cavities, possibly representing an old erosion surface or even subterranean caverns.

Igneous Control of Copper Mountain Ores

Relationship of copper and iron ores to the Patterson Pass stock is uncertain. Because the stock is the only igneous body of any size or consequence in the area it is assumed that the ore and igneous material are genetically related. Sulphide-bearing solutions emmanating from the magma as it intruded the Guilmette Formation would percolate through the limestone and ore minerals could be precipitated by favorable carbonate horizons. Emplacement of the monzonite is post-north-south faulting for it can be demonstrated that the monzonite followed and intruded pre-existing fractures as did the ore solutions. In addition to the monzonite stock a diabase dike intrudes in the Copper Mountain area and truncates the eastern-most ore body. In regards to this dike, Butler (Butler _et al_, 1920, p. 492) states:

> "The strike of the dike corresponds in a general way with that of the fault zone, and the intrusion apparently followed this plane of weakness. The accessible workings at the time of visit did not furnish conclusive evidence of the relation of the dike to the ore, but indicated that it was intruded after the deposition of the ore. There has been movement along the fault zone, however, since the dike was intruded."

The dike is accompanied by little or no change other than crushing and minor brecciation.

Alteration at Copper Mountain

Alteration of sedimentary rock at Copper Mountain is minor. Little alteration is apparent other than occasional bleaching of dark grey sediments to light grey or white, slight softening and re-cementing of carbonates on a local scale and a minor porosity and permeability increase.

Little evidence of dolomitization of limestone is seen. Contacts between ore and carbonate rocks are generally sharp, and even the barren zones between the Copper Mountain ore bodies are free from alterations, other than minor limonite surface stain.

Similarly, contacts between monzonite and sediments are sharp where directly observed, and where brush or soil obscures the contact, rocks where last observed are fresh. The contact between diabase dike rock and sediment shows no effects other than crushing.

Origin of Copper and Iron Deposits

Several theories are advanced to explain the origin and the present form of the Copper Mountain deposits:

1) A larger or main sulphide body is located at depth but because of faulting has yet to be discovered, and only the upper oxidized portion of the mineralized body has been observed in open pits and tunnels; 2) Erosion has removed a greater portion of the mountain containing an original sulphide deposits, or 3) The ore body is the result of complete leaching and oxidation of sulphides as well as the re-deposition of minerals from waters percolating through a sulphide body in a position now occupied by the oxidized zone.

Only negative statements regarding the first suggestion can be made. Prospect tunnels driven from the east side encountered no downward extension of ore, in either oxidized or sulphide form, 1,000 feet below the summit, and in fact, encountered only unaltered quartz monzonite at that depth. It is known, however, that the Copper Mountain area is highly fractured and therefore, it is possible that a sulphide body in favorable limestone beds is located within a fault slice at depth, west of the monzonite body and hence away from the area actively prospected.

The relationship of ore and faulting, however, suggests more strongly that ore continuation is more likely contained in Guilmette Limestone beds that have been displaced up and to the east, and since eroded. Cross sections 1-4 (Appendix V) point out this relationship. Much erosion has taken place in the Copper Mountains area, in fact probably as much as 4,000 feet of Devonian, Mississippian, Pennsylvanian (?), Permian, and Triassic (?) rocks have been stripped, but probably the ore-bearing rock removed was only a lateral continuation of the Guilmette and not necessarily a downward extension of ore. Naturally no evidence remains to provide a clue as to the nature of eroded ore, i.e., whether it was in sulphide or oxidized form.

Because little pre-Devonian rock has been removed by erosion, and in fact is buried under younger sediment, it is highly inconceiveable that all traces of a sulphide body should be removed by erosive action. For this reason alone the possibility of finding ore in pre-Devonian rock or even a westward continuation in the Guilmette is not altogether remote.

It is likely that ore-bearing solutions filled the characteristic, water worn cavities in the lower member of the Devonian Guilmette Formation after the Paleozoic folding but before the strata were severely tilted and elevated to their present elevation. This conclusion is based on the sub-parallel stratification of ore compared to bedding planes within the Guilmette Formation.

Perhaps then, as Ryan (Ryan, 1914, p. 22) suggests, iron minerals filled the cavities or openings, and later copper minerals were precipitated from sulphide-bearing solutions emanating from the intrusive magma and rising along pre-existing fissures. If this is true, both iron and alumina could have acted as precipitants of copper in favorable carbonate beds, the copper to a large extent replacing the iron and the alumina remaining in the ore.

Descending supergene waters at some subsequent time, and probably after east-west faulting of strata and even tilting, could cause the almost complete oxidation of sulphides to the present form.

Weathering of now exposed surface deposits to deep-red iron-rich gossans probably occurred after the overlying strata were stripped and, therefore, after the range had been tilted and elevated.

It is difficult to imagine that oxidation and leaching were so complete as to obliterate all sulphides but in the light of existing evidence, no other conclusion is fully acceptable. It may seem presumptous to state that ore is genetically associated with the monzonite, and in fact that deposition is the result of precipitation from emanations from that body, when no connection to the monzonite is found, but again in the light of existing evidence, no other hypotheses seem reasonable.

Copper Mountain Reserves

Although total copper reserves have not been measured, it is apparent that they are large. Copper mineralization can be traced laterally for more than one-half mile; width and depth dimensions exceed 400 and 100 feet respectively. It is instead, problems of milling that raise the question as to whether Copper Mountain ores can ever be profitable. Proved, indicated and inferred ore reserves, (Quigley, 1955) are reproduced with the permission of Uranium and Petroleum Corporation and the economics and mining costs are listed in Appendix II and III.

In summary, proved ore reserves total 80,035 tons of 2.50% copper ore whereas indicated and inferred reserves total 130,240 tons of 2.50% copper and 3,000,000 tons of 2.50% copper ore respectively.

Tecoma Hill Deposits

Small commercial deposits of copper, lead, silver, and zinc and minor quantities of gold and low grade iron were worked on and in the vicinity of Tecoma Hill. Tecoma Hill properities, and particularly the Tecoma and Black Warrior mines have yielded fine specimens of galena, pyrite, and sphalerite. Sulphides are, however, limited in occurrence and the principle ore minerals are rather sulphates, carbonates and molybdenates. The ore also contains substantial quantities of hydrous iron oxides, especially limonite and goethite.

It has not been established by this writer what the silver minerals were, however, for no trace of them remains nor do ore shipment records indicate the variety. It is suspected on the basis of the associated assemblage of minerals that silver occurred as argentiferous varieties of galena as well as native silver, rather than sulfo-salts.

Native gold was found disseminated throughout the ores in minor quantities and only small values were recovered.

The molybdonate of lead, in the form of well-developed, exceptionally large wulfenite crystals, is described (Hague, 1887, p. 497) as follows:

> "The molybdonate of lead frequently forms so high a percentage of the ore as to interfere seriously with its treatment in the ordinary lead furnaces, rendering a modification of the methods employed very desireable. The crystallized wulfenite from the Tecoma mine occurs in large masses, the faces of individual crystals

> having been observed from an inch to 1½ inches in length. They possess a resinous luster, a lemon yellow color, and are frequently transparent and exceedingly brittle. In size and brilliancy the finest specimens far surpass the famous wulfenite crystals of Bleiberg in Carinthia. Associated with the wulfenite, adhering to the broad tabular faces, may occasionally be seen well developed crystals of cerusite and anglesite."

Ore minerals found in the Tecoma Hill area include the following:

anglesite	$PbSO_4$	limonite	$FeO(OH) \cdot nH_2O$
cerussite	$PbCO_3$	goethite	$FeO(OH)$
wulfenite	$PbMO_4$	hématite	Fe_2O_3
smithsonite	$ZnCO_3$	galena	PbS
hemiorphite	$Zn_4Si_2O_7(OH)_2 \cdot H_2O$	pyrite	FeS_2
plumbojarsite	$PbFe_6(OH)_{12}(SO_4)_4$	sphalerite	ZnS
native gold	Au	chalcopyrite	$CuFeS_2$
native silver	Ag		

Clay minerals and alteration products found in the Tecoma Hill area and identified by X-Ray and infra-red analysis include:

limonite	$FeO(OH) \cdot nH_2O$
goethite	$FeO(OH)$
alunite	$KAl_3(OH)_6(SO_4)_2$
halloysite	$Al_2Si_2O_5(OH)_4 \cdot H_2O$
sericite	$K\,Al_3Si_3O_{10}(OH)_2$
calcite	$CaCO_3$
kaolinite	$Al_2Si_2O_5(OH)_4$

Structural Control of Tecoma Hill Ore

Structures that control the deposition of the Tecoma Hill ores appear to be, for the most part, the east and northeast fractures, that is, normal faults with the planes of displacement dipping steeply to the south and southeast. The order of magnitude of displacement on these fractures is not large, for although dolomitization of carbonate beds has hindered the identification of Fish Haven, Laketown, and Simonson lithologies, it appears likely that on any one fault displacement is less than 500 feet. Fault planes and the relationship to the ore are well exposed in both the Tecoma and Black Warrior tunnels.

The largest lead-silver deposits are contained in the northeast trending fault zone, although east of the Tecoma property the fault is barren. A problem arises as to whether the northeast fault is actually the seat of ore deposition, or whether ore occurs in the main fracture only where it is intersected by smaller east-west fissures. The question is not fully answered although the latter suggestion seems more probable.

Tecoma Hill fractures are pre-ore, as are Copper Mountain fissures. It is apparent that fissure zones, as well as water-worn cavities, in both dolomite and limestone beds provided collecting areas for the mineralized solutions.

Sedimentary Control of Tecoma Hill Ore

The Tecoma Hill ores are fissure filling, replacement bodies in favorable carbonate beds and occur as irregular shoots and bunches. Ore minerals were precipitated in the lower member of the Devonian Guilmette Formation, and also in the Silurian Laketown Dolomite and Ordovician Fish Haven Dolomite. Simonson dolomite has been omitted by faulting at this locality.

Igneous Control of Tecoma Hill Ore

Tecoma Hill ore is controlled by presence of favorable carbonate beds in association with a monzonite porphyry intrusion, undoubtedly related to the Patterson Pass stock. The Black Warrior tunnel particularly shows the relationship of faulting to intrusion of monzonite porphyry dikes and it appears likely that the intrusion accompanied or even preceded the younger east-west and northwest movements, rather than succeeding them.

Alteration at Tecoma Hill

Alteration in the vicinity of Tecoma Hill is slight and of little importance as a guide to ore. Where the northwestern extension of the monzonite intrudes dolomite or where minor faults bring the monzonite in contact with carbonates, slight chloritization of magnesium-rich minerals has occurred. Similarly, at the contacts between sediment and monzonite, biotite and muscovite crystals have been altered to sericite. Minor contact metamorphism has occurred in this area although it is of local importance with no regional implication.

Along both north-south and east-west faults limonite and goethite has developed at the margins of mineralized fissures. Much of the limonite no doubt is the result of surfaces weathering and leaching, rather than alteration at the time of mineral deposition.

Origin of Tecoma Hill Ores

The genesis of Tecoma Hill copper, lead, silver and zinc ores probably follows a course similar to that of the Copper Mountain copper and iron deposits. It should be added, however, that Tecoma Hill ores are probably younger than Copper Mountain ores as they are controlled in part by east-west and northeast faults which cut, and are therefore younger than, Copper Mountain north-south faults.

Following the deposition of sulphides supergene solutions percolating through the carbonate beds could cause an almost complete oxidation of primary minerals to carbonates, sulphates, oxides and other secondary products.

Tecoma Hill Reserves

To the writer's knowledge the Tecoma Hill properties are almost completely mined out. No efforts have been made to recover ore in this area since 1943 and it is suspected that quantity of ore remaining is insufficient to support even small-scale operations. No figures concerning production are available since 1917, and no figures concerning reserves have ever been prepared.

Other Deposits

South of Tecoma Hill and Regulator Canyon, and southwest of Copper Mountain, many prospect pits have been dug in the Fish Haven and Laketown dolomites where surface limonite stains has exposed minor fissures. This area, called Mineral Mountain, has produced little mineral value, however, as deposits terminate at shallow depth.

Recently-worked claims in Hogan's Canyon have produced minor quanities of a galena sand from small fractures in the lower member of the Guilmette Formation. These sands also assay small values in silver, but little more than exploratory work has been done to develop the property.

Several tunnels have been driven into the lower member of the Guilmette Formation north of Patterson Pass and minor quanities of lead, silver, and copper were recovered from the Cunapah mine. At present only limonite-stained rock appears on the dumps. Both Hogan's Canyon and Patterson Pass operations are south of the Copper Mountain and Tecoma Hill mineralized areas and are separated from them by the Regulator Canyon fault.

Several miles north of Lucin are variscite deposits in the Permian Phosphoria or Park City Formation. These deposits have received considerable attention by Sterrett, Pepperberg and others and have been described as "green balls, nodules, and irregular masses of hydrous aluminum phosphate occurring in a cherty breccia containing fragments of limestone." The deposits have never been commercially important, and nothing is known concerning the relationship of these deposits to Copper Mountain and Tecoma Hill ores.

Relationship of Lucin Ores to Porphyry in the Basin and Range Province

A statistical report by Stringham, (Stringham, 1958) has classified the Lucin district as being one of a group of mining camps that have produced between three and five million dollars of metal value, and also as one containing intrusions of granitoid rock only, excluding small sills or dikes. Stringham's personal observation in the northern Pilot Range has revealed no significant intrusive porphyry in the vicinity of the Lucin ore bodies, although aphanitic intrusives could occur under immediately adjacent lava and sedimentary cover, (Stringham, 1958, p. 812). From detailed observation of the Patterson Pass intrusive by this writer, it would appear that the possibility of lava or sedimentary cover concealing an aphanitic intrusive is very remote indeed. Stringham's conclusions, based on the absence of a major porphyry body, would indicate that the Lucin district could never hope to be a large producer of metal values over a period of years. Such a statement is reinforced by analyzing the estimated reserves on Copper Mountain, (Quigley, 1955) listed in this report, (Appendix I, II, and III)

Summary and Sequence of Events of Lucin District Ores

Ore deposits of the Lucin district may be placed in chronological order and related to structural control and igneous features as follows:

1. During the early of middle phase of Laramide deformation, in Late Cretaceous or Early Tertiary time, the eastern Great Basin area was intruded by numerous acidic igneous bodies with monzonitic or granitic composition. One such body, of monzonitic composition, intruded the northern third of the Pilot Mountains in the Patterson Pass and Copper Mountain areas. The implacement of this body and others like it in adjacent mountains was controlled by pre-exisitng fault or fracture zones probably related to Laramide or even Late Nevadian deformation. Emanating from the igneous body were solutions and gases rich in sulphide compounds that were precipitated by iron and alumina compounds in water-worn cavities as well as in pre-existing, north striking fissures. In the Copper Mountain area deposition of ore minerals occurred in the lower limestone member of the Guilmette Formation.

2. Subsequent to early Laramide deformation and monzonitic intrusion mentioned in #1, were crustal disturbances that resulted in major east-west and northeast fault trends as well as minor movement on earlier faults. These trends are younger than the north-south trends at Copper Mountain but older than the major north-south

faults that parallel the margin of the range and resulted in its uplift. Associated with the east-west and northeast fissuring was the implacement of monzonite porphyry dikes in the Tecoma Hill area, dikes that are genetically related to the Patterson Pass intrusion and probably represent the last stages of the intrusive phase of the deformation. Emanating from the younger igneous bodies were sulphide-rich solutions from which precipitated copper, lead, silver, and zinc minerals in carbonate rock of Ordovician, Silurian, and Devonian age. Tecoma Hill ore, deposited in east-west and northeast fissures, is therefore younger than Copper Mountain deposits but older than Late Tertiary since their enclosing faults are truncated by range-elevating, Basin and Range faults.

3. During the last pulses of Laramide deformation, or associated with post-Laramide deformation, in probably Late Tertiary time, the Pilot Range was uplifted and sedimentary rocks were tilted to the east. Uplift and tilting were undoubtedly due to north-south Basin and Range normal faulting, particularly affecting the western flank of the range.

4. During and subsequent to the episode of uplift and tilting, the Pilot Range underwent considerable erosion, particularly in the Copper Mountain area. At Copper Mountain, Devonian Guilmette Formation is exposed along the crest of the Pilot Mountain divide. Younger rocks, namely the upper members of the Guilmette, the Mississippian Diamond Peak and Chainman, Permian Pequop and Phosphoria (?) Formations and perhaps Triassic rock were stripped away, allowing the sulphide deposits in the Guilmette to be attacked by weathering processes.
5. Oxidation and leaching of primary sulphides to carbonate, sulphates and oxides, as well as to other minor secondary forms by descending supergene solutions probably occurred after the tilting and uplift of the area and during the period of active weathering and erosion until the present. Formation of the Copper Mountain gossan and other minor limonite gossans probably occurred quite recently, or at least after the Guilmette was exposed by stripping of overlying post-Devonian strata.
6. During the Late Tertiary, and while the area was undergoing extensive erosion, basalt flows and rhyolite flows (?) were extruded in the Great Basin area including an area just north of the

Lucin district. This igneous activity may be related to uplift of the range although this relationship is not certain. That the extrusive rock is related to basic dikes at Copper Mountain is suspected, for certainly these dikes are post-ore and play no role in its deposition.

7. No attempt has been made by early writers or by this writer to determine how the variscite deposits north of Lucin are related to the above mentioned structural features or igneous intrusion.

APPENDIX

I. PROVED, INFERRED AND INDICATED RESERVES

The following material is the result of a special study made by W. Don Quigley (1955) for Uranium Petroleum Corporation.

Proved Ore Reserves

East Pit

Exposed face of copper ore - 10 ft. x 2-½ ft. x 20 ft. = 500 cu. ft. or about 35 tons of ore averaging 4% Cu.

Total Cu. content is...........1.40 tons.

West Pit

Exposed face of copper ore - 250 ft. x 50 ft. high x 208 ft deep (?) (The depth into the hillside is unknown, but mineralization is found in old workings on the east side - a distance of more than 400 ft. away) = 2,500,000 cu. ft. We must assume that half of this face will be waste, due to the lack of iron mineralized rock and fault breccia which will be encountered. Therefore, approximately 80,000 tons of ore are probable which may average 2.50% Cu.

Total Cu. Content is.......2000.00 tons

Totals - Total Cu. Content is....... 2001.40 tons

Indicated Ore Reserves

East Pit

Below the present workings, according to V. C. Frazier, the operator, is a good face of ore, some of which has been removed. This face may measure 40 feet long by 3 feet deep and 30 feet in width. This equals 3,600 cu. ft., or 240 tons or ore averaging about 3% Cu.

Total Cu. content is........7.20 tons

West Pit

According to the operator, the face of ore exposed in the pit continues on to the north for about 200 feet more to the edge of the old "Glory Hole." (This is now covered by waste material moved off the top and from the sides of the present pit.) This face is reported to be 60 feet high and my extend into the hill approximately 200 feet as above. This makes a total of 2,400,000 cu. ft.; but again, we must assume that half will be wate. Therefore, approximately 80,000 tons of ore are indicated, which may contain 2.50% Cu.

Total Cu. content is........2,000 tons

Old Mines

The Bell and Green Carbonate tunnels have considerable copper mineralization exposed along the sides of the drifts. The present workings are unsafe and the ore would have to be removed through open pit operations. It is entirely possible that another 50,000 tons of ore could be obtained. If we assume a 2.50% average copper content the

Total copper content is.... 1,250.00 tons

Totals - Total Cu. content is....... 3,257.20 tons

Inferred Ore Reserves

No deep or lateral drilling has been done on Copper Mountain. As previously stated, it is entirely possible that copper sulphide ores might be found below the oxidized zone. If so, the ore reserves could well be increased several times. The lateral extent of the copper mineralization on the surface is more than three times the distance considered in the above calculations for the proven and indicated reserves. Until more data is available, it is fairly safe to assume that the inferred ore reserves may be about 3,000,000 tons. If this averaged 2.50% Cu., the total Cu. content would be...7,500 tons.

II. COPPER MOUNTAIN ORE RESERVES AND VALUES (table 1)

The following figures are based on estimates compiled by W. Don Quigley (1955) for the Uranium Petroleum Corporation.

Proven Ore Reserves

East Pit	1.40 tons
West Pit	2000.00 tons
total Cu content	2001.40 tons
value at 43¢ per lb. (1955)	$1,721,204.00
value at 30¢ per lb. (1959)	$1,200,840.00

Indicated Ore Reserves

East Pit	7.20 tons
West Pit	2000.00 tons
Old Mines	
(Bell and Green Carbonate)	1250.00 tons
total Cu. content	3257.20 tons
value at 43¢ per lb. (1955)	$2,801,192.00
value at 30¢ per lb. (1959)	$1,954,320.00

Inferred Ore Reserves

total Cu. content	7500.00 tons
value at 43¢ per lb. (1955)	$6,450,000.00
value at 30¢ per lb. (1959)	$4,500,000.00

Total Proven, Indicated and Inferred Reserves

Cu. content	12,758.60 tons
value at 43¢ per lb. (1955)	$10,972,396.00
value at 30¢ per lb. (1959)	$ 7,655,160.00

III. COPPER MOUNTAIN RESERVES, ECONOMICS AND COSTS

The reserves and values listed in table 1 of the appendix should not be construed to indicate possible profit. Mining and milling costs included in this section will be necessarily high due to high percentages of alumina and silica in the ore and because of other chemical problems mentioned in section 4 of the appendix.

The cost of a specially designed mill to handle 200 tons of ore daily will be as much as $800,000 and the cost of processing one ton of ore will be approximately $3.00 (Quigley, 1955).

Because of the very porous and unstable nature of the mining area open pit recovery will be necessary at least until a more stable and even unoxidized ore body is discovered at depth. It is estimated by Quigley (1955) that mining costs may run as high as $10.00 per ton, especially when the cost of moving waste material is considered.

The folowing figures are based on estimates compiled by Quigley for the Uranium Petroleum Corporation, (table 2) and do not include the probable increase in mining and milling costs since 1955.

APPENDIX TABLE 2

		1955 (43¢ per lb.)	1959 (30¢ per lb.)
Proven Ore Reserve..................	80,035 tons		
Copper content and value	2,001.40 tons	$1,721,204.00	$1,200,840.00
Cost of Mining	$800,350.00		
Cost of ½ Mill Const.	$400,000.00		
Cost of processing ore	$240,105.00		
Total Cost....................................		$1,440,455.00......	$1,440,455.00
Profit or Deficit...........................		+$ 280,749.00....	-$ (239,615.00)
Indicated Ore Reserve...............	130,240 tons		
Copper content and value	3,257.2 tons	$2,801,192.00	$1,954,320.00
Cost of mining	$1,302,400.00		
Cost of ½ Mill constr.	$ 400,000.00		
Cost of Processing Ore	$ 390,720.00		
Total Cost....................................		$2,093,120.00......	$2,093,120.00
Profit or Deficit...........................		+$ 780,072.00....	-$ (138,800.00)

APPENDIX TABLE 2 (cont'd.)

		1955 (43¢ per lb.)	1959 (30¢ per lb.)
Inferred Ore Reserve	300,000 tons		
Copper content and value	7,500 tons	$6,450,000.00	$4,500,000.00
Cost of mining	$3,000,000.00		
Cost of processing ore	$ 900,000.00		
Total Cost		$3,900,000.00	$3,900,000.00
Profit		+$2,550,000.00	+$ 600,000.00
Total Ore Reserve	510,275 tons		
Copper Content and Value	12,758.60 tons	$10,972,396.00	$7,655,160.00
Total cost of Mining	$5,102,750.00		
Total cost of Mill constr.	$ 800,000.00		
Total cost of Ore Process	$1,530,825.00		
Total Cost		$7,433,575.00	$7,433,575.00
Total Profit		$3,539,821.00	$ 221,585.00

IV. SUMMARY OF MILLING AND METALLURGICAL PROCESSES

Because of the unusual nature of Copper Mountain ores, it was necessary to conduct experimental work to discover possible methods of extracting metals from ore. The following paragraphs are the conclusions of experimental work done by the Techmanix and Combined Metals Reducation Company for Uranium and Petroleum Corporation and are reproduced with their permission.

"The head sample on which our test work was done had the following analysis.

Assay	Cu	Fe	SiO_2	CaO	MgO	Al_2O_3	CO_2	S	Ignition Loss
%	3.0	11.4	29.7	3.4	2.6	21.9	3.8	Tr.	16.1

Assay	Zn	Pb	WO_2	Au	Ag
Oz./Ton	0.1	0	0.02	Tr.	0.2 Oz./Ton

"The following outline shows the various types of treatment procedures which have been partially investigated during the course of our work on this ore. A brief discussion of these procedures follows the outline.

I CONCENTRATION BY SIZING

II GRAVITY CONCENTRATION

III FLOTATION

(a). Flotation of Copper Minerals.
(b). Flotation of Gangue Minerals.

IV DIRECT LEACHING

(a). Sulfuric Acid.
(b). Ammonia, Ammonium Carbonate.
(c). Sodium Hydroxide.

V ROASTING AND LEACHING

(a). Dehydrating Oxidizing Roast Followed by Ammonia, Ammonium Carbonate Leaching.

(b). HCl Low Temperature Chloridizing Roast Followed by Both Water and Ammonia Leaching.

(c). Selective Sulfation Roasting Followed by Water Leaching.

(d). NaCl Chloridizing Roasting Followed by Water Leaching.

"I CONCENTRATION BY SIZING

"A screen analysis was run on the ore head sample after crushing through 8 mesh to determine the distribution of copper and gangue minerals. This test showed a remarkably even distribution of Cu, Al_2O_3, and SiO_2 in all the screen fractions and eliminated the possibility of making either a rejectionable product or a higher grade product by sizing alone. Iron, which is mostly present as hard limonite, does concentrate to some extent in the coarse size fraction. About 30% of the minus 10 mesh ore consists of minus 325 mesh slime with a copper content approximately the same as the head sample. This high slime content almost eliminates the possibility of using a direct leaching process which involves a filtration step. The slimes can, however, be readily flocculated with separan and other flocculating agents which might allow counter-current decantation to be used in place of filtering.

"II GRAVITY CONCENTRATION

Gravity concentration and heavy liquid tests on the sands show no appreciable concentration of copper in either the heavy or light products. Copper appears to be largely present as chrysocolla in the light gravity fractions while the heavy gravity fractions, which consist mostly of limonite, contains coarse malachite, copper oxides and a little native copper. Heavy media separation or some other gravity treatment procedure might possibly be of value in separating the light gravity chrysocolla from the native copper and other heavy copper minerals so that the different minerals could be treated by the most suitable procedures. Gravity treatment might also have some value in connection with the recovery of by-products such as scheelite.

"III FLOTATION

Numerous flotation tests have been conducted in which an attempt was made to either float the copper minerals away from the gangue minerals or the gangue away from the copper minerals. None of the straight flotation test work has been very encouraging although some additional work is probably warranted. Possibly some of the combination procedures, mentioned later, whereby copper minerals are reduced to native copper prior to flotation can be worked out.

"IV DIRECT LEACHING

(a). Sulfuric Acid

Direct sulfuric acid leacing tests have given copper extraction of around 80% with a consumption of around 400 pounds of H_2SO_4 per ton. The Al_2O_3 extraction in acid leaching is about 5.5%. The iron extraction varied from 2% on the coarse sand to 12% on the slimes. By use of counter-current leaching it may be possible to increase the copper extraction slightly and decrease the acid consumption. The acid leach pulps are practically impossible to filter without the use of flocculating agents such as separan. During acid leaching of +28 mesh, thoroughly washed, clean sand about 11% of the sand disintegrated into minus 325 mesh slime. This breakdown of the sands during acid leaching seems to eliminate the possibility of treating the sand fraction by conventional percolation leaching procedures.

The leach - precipitation - flotation or L. P. F. process is now in use at several plants. In this process the copper is first leached with acid and then precipitated in the pulp on finely divided metallic iron. The fine cement copper is then recovered by flotation from the slurry. Only the leaching step of this procedure has been investigated to date.

Before conducting more work on acid leaching, it would be desireable to find out if this ore sample is reasonably representative of the ore body with respect to its lime and other acid consuming constituents.

(b). Ammonia, Ammonium Carbonate

Test results on direct ammonia, ammonium carbonate leaching of raw UPTCO ore have produced low extractions and low grade solutions. Present information seems sufficient to rule out the possibility of direct ammonia leaching although it is quite likely that the product, after roasting with salt, can be successfully leached with ammonia solutions.

(c). Caustic Leaching

Test results with caustic leaching produced poor extractions and suffered from the same filtration difficulties experienced in the other raw ore leaching tests. This approach does not appear to warrant further consideration.

" V ROASTING AND LEACHING

On all tests where leaching has been preceded by any type of roasting step excellent commercial filtration rates have been obtained. Test results from dehydrating roasting and ammonia leaching, low temperature HCl chloridizing and leaching and selective sulfation roasting (a. b. c. of the outline) gave poor copper extractions and can probably be ruled out of future work.

"Test results with chloridizing roasting using sodium chloride have been very encouraging. Preliminary tests on this method of treatment have involved mixing the ore with NaCl, roasting at about 850° C. and water leaching of the $CuCl_2$. Water leach extractions of around 80% have been obtained by this procedure. During salt roasting the NaCl reacts with silicate gangue minerals and traces of water vapor to produce HCl as shown below.

$$2\ NaCl + SiO_2 + H_2O \longrightarrow Na_2SiO_3 + 2\ HCl$$

"This reaction is known to proceed rapidly at 700° C. and it would probably be possible to use a lower temperature than employed in our preliminary tests. The HCl gas liberated by this reaction then attracks the copper oxide minerals converting them to chlorides.

"Chrysocolla is also attacked by the HCl producing a copper chloride and free SiO_2. Since cuprous chloride, Cu_2Cl_2, has a relatively low water solubility, the principal product of the reaction under the test conditions was probably cupric chloride $CuCl_2$.

"Chloridizing roasting of oxidized copper ores using a chloride salt is not a new procedure and a number of process variations have been advocated over the past 50 years.

"The following represent some of these variations.

I Chloride Volatilization.

II Chloridizing and Water Leaching.

III Chloridizing and Ammonia Leaching.

IV Segregation Chloridizing and Flotation.

V Segregation Chloridizing and Ammonia Leaching.

In the chloride volatilization processes cuprous chloride is volatilized from the ore in the presence of salt at temperatures around 1000° C. and collected from the gas stream in cottrell precipitators. Although this procedure would probably give good metallurgical results on the UPTCO ore, the other procedures would seem to offer a better chance of being commercially successful. In procedures II and III, the salt roasting temperatures are kept below the volatilization temperature of copper chlorides which are subsequently leached from the calcine. Only cupric chloride can be successfully leached with water alone. Cuprous chloride requires the use of ammonia, brine, or some other solvent in the solutions. Chloridizing roasting and ammonia leaching might be successfully combined with resin-in-pulp ion exchange for metal recovery.

"In the segregation-process (Item IV and V) ore, salt, and coke or coal are heated together in a slightly reducing atmosphere at about 700° C. for a short time. The copper chlorides which are slightly volatile migrate to the surface of the carbon particles and are reduced to metallic copper with the regeneration of HCl gas. After cooling the calcine, out of contact with air, the metallic copper can be recovered by conventional flotation procedures or by ammonia leaching. Several small African plants operated successfully using the segregation-flotation procedure in the late 1920's but shut down in the early 1930's because of the very low price of copper. Copper recovery in these plants was about 90%. Pilot plant investigations by the Bureau of Mines on a number of oxidized ores from the Western

United States have given copper extractions ranging from 80 to 95% by the segregation-flotation procedure. On some of these ores it was possible to produce very high grade flotation concentrates but on many of them only low grade concentrates could be obtained because of activation of the gangue minerals during roasting. Conventional ammonia leaching of either the whole calcine or the low grade flotation concentrate could be expected to produce a copper oxide product containing nearly 80% copper. Ammonia leaching of the segregated product might have some advantage over flotation in that it would be capable of recovering copper chloride, oxides, and other compounds which might not respond to flotation.

"The salt requirement for the segregation process is reported to be from 10 to 50 pounds per ton or ore and the coke requirement is about 20 pounds per ton. A fairly recent cost estimate by the Bureau of Mines based on the segregation-flotation treatment of 1000 tons of ore per day indicates a direct operating cost of $3.30 per ton.

"CONCLUSIONS

"Preliminary tests with salt roasting have been encouraging. It seems likely that some form of salt chloridizing or segregation roasting could become the basis of a metallurgically sound process for the treatment of this ore. Additional test work will have to be done to evaluate this possibility and to determine what process variation would be best.

"Some form of sulfuric acid treatment such as the leach - precipitation - flotation process may also have merit if the lime content of the ore is not too high.

With a sizeable reserve of 3% ore and relatively low cost mining, it seems likely that an economical solution to this problem can be found."

V RECOMMENDATIONS FOR FUTURE DEVELOPMENT OF LUCIN DISTRICT ORES

Although the estimated reserves of the Lucin ores, and particularly the Copper Mountain deposits, are large, the problems of milling and beneficiation have recently made mining operations unprofitable. It is, therefore, imperative that primary copper sulphides, if present, be discovered and developed by underground workings. The latter condition is desireable because much of the already developed workings need be involved with the removal of waste before open pit expansion can be continued.

To locate the questionable sulphide body, it is suggested that an active drilling program be initiated in the area west of the Copper Mountain fault zone, but at the same time not more than a few hundred feet west of the northeast trending reverse fault. Drilling in this area may prove costly as depths of 600 to 700 feet may have to be reached in order to intersect possible ore-bearing horizons similar to those on Copper Mountain.

It will probably not be possible to intersect the Tecoma Hill ore continuation east of the hill, for besides its probable great depth (1200 - 2000 feet), structural complications at depth have undoubtedly played a part in ore location. Instead, a drilling program might be initiated a few hundred feet west of the Tecoma properties on the piedmont that extends toward Montello Valley. Such a program would be designed to intersect the Guilmette, Simonson, Laketown, and Fish Haven Formations that have been thrown down to the west and since covered with alluvial debris. The likelihood of encountering workable ore here would be uncertain for an undetermined amount of alluvium is piled on sediments perhaps as young as Permian or even Triassic. If the latter were the case, drilling would necessarily be required to depths of more than 5000 feet.

It should also be emphasized that before an active drilling program be attempted problems of beneficiation be solved. In this regard, Quigley (1955) states:

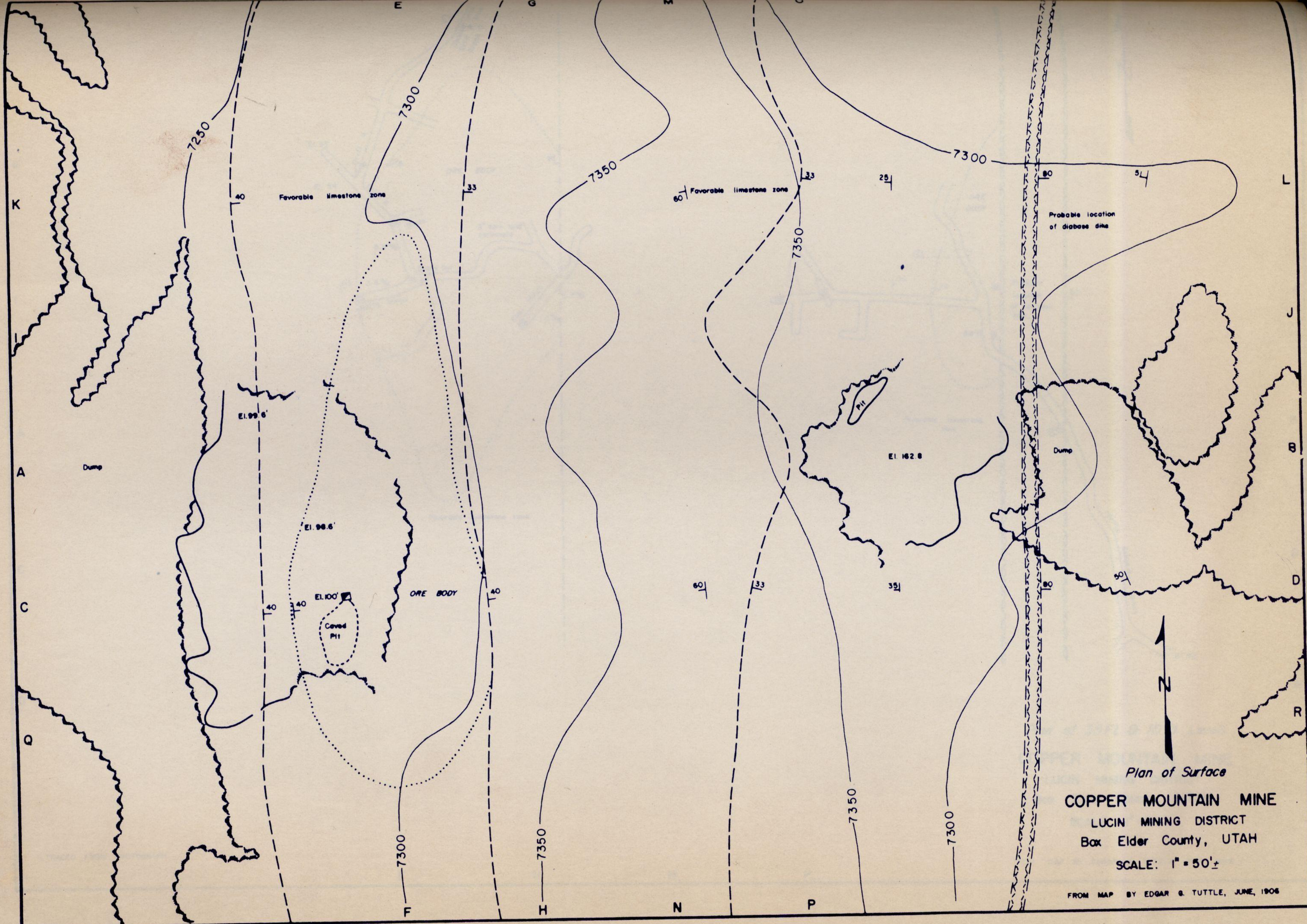
> "Along this line (an economical and satisfactory metallurgical processes for this special ore) it is suggested that the ore may first be separated into a light and heavy grade by gravity separation. The light grade could contain the clay-malachite ore, and the heavy would contain the cuprite and native copper. These two grades might then be processed differently. The lights could probably be treated by a caustic leach, rather than acid, because of the high lime content. The cuprite could also be leached, possibly by acid if most of the limestone gangue was removed in the gravity separation. It is possible that a mill designed to simply separate and concentrate would be sufficient. A cuprite concentrate should be marketable somewhere without further processing."

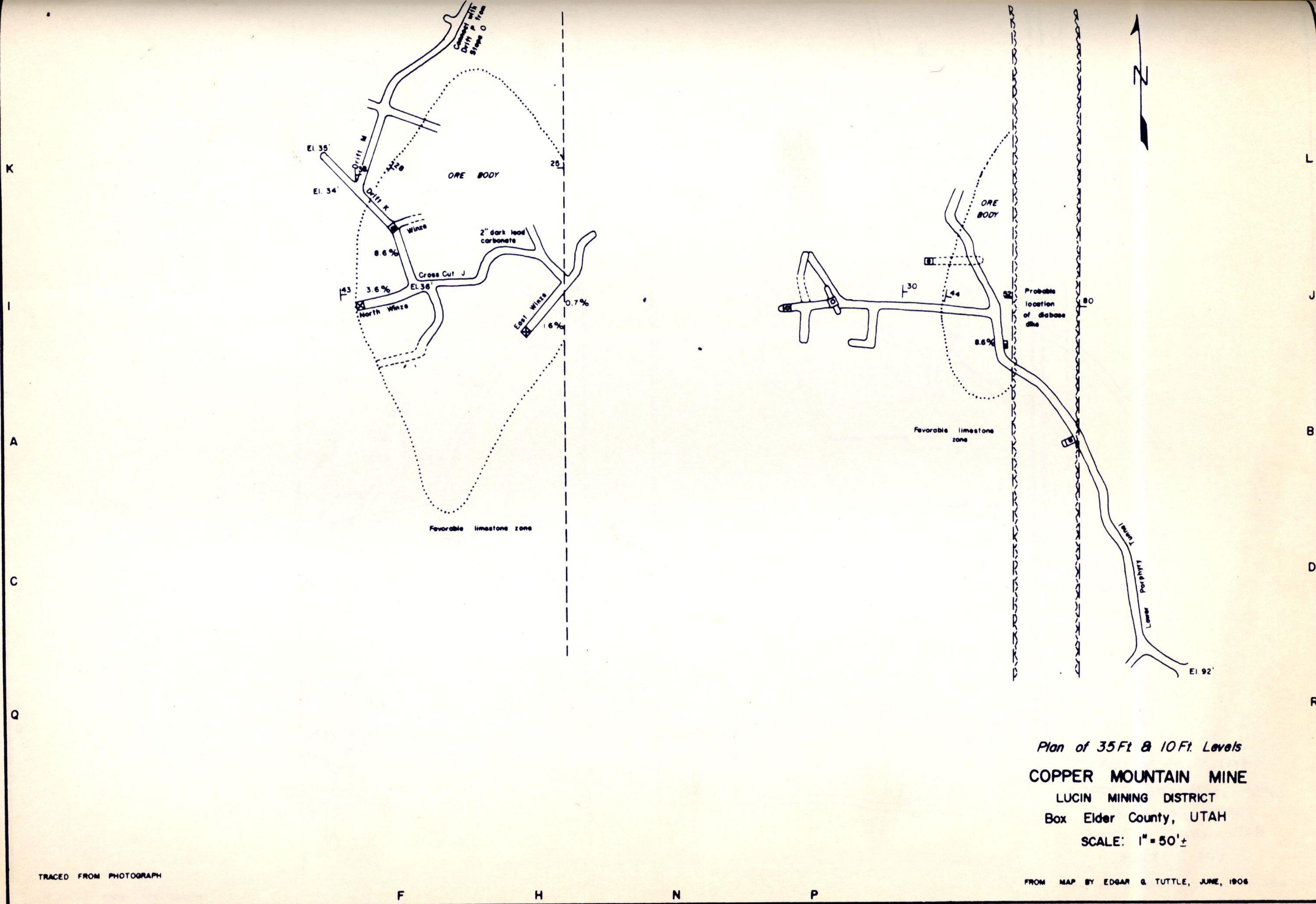
Also concerning the same problem, the Techmanix Corporation in 1957 reported as follows:

> "Preliminary tests with salt roasting have been encouraging. It seems likely that some form of salt chloritization or segregation roasting could become the basis of a metallurgically sound process for the treatment of this ore....Some form of sulfuric acid treatment such as the leach - precipitation - flotation process may also have merit if the lime content of the ore is not too high.

"With a sizeable reserve of 3% ore and relatively low cost mining, it seems likely that an economic solution to this problem can be found."

Finally, it is imperative that the mining claims in the Lucin district be re-surveyed inasmuch as all U. S. Mineral Markers have been destroyed and claim boundaries are uncertain.


E
G
M
7250
7300
7350
7350
7300
40
33
Favorable limestone zone
Favorable limestone zone
60
33
25
5
80
Probable location of diabase dike
K
L
J
I
El. 99.6'
El. 96.6'
El. 100'
Caved Pit
ORE BODY
Pit
El. 162.8
Dump
Dump
A
B
C
D
40
40
40
60
33
35
80
50
Q
R
N
7300
7350
7350
7300
F
H
N
P
Plan of Surface
COPPER MOUNTAIN MINE
LUCIN MINING DISTRICT
Box Elder County, UTAH
SCALE: 1" = 50' ±
FROM MAP BY EDGAR G. TUTTLE, JUNE, 1906



Plan of 35 Ft. & 10 Ft. Levels

COPPER MOUNTAIN MINE

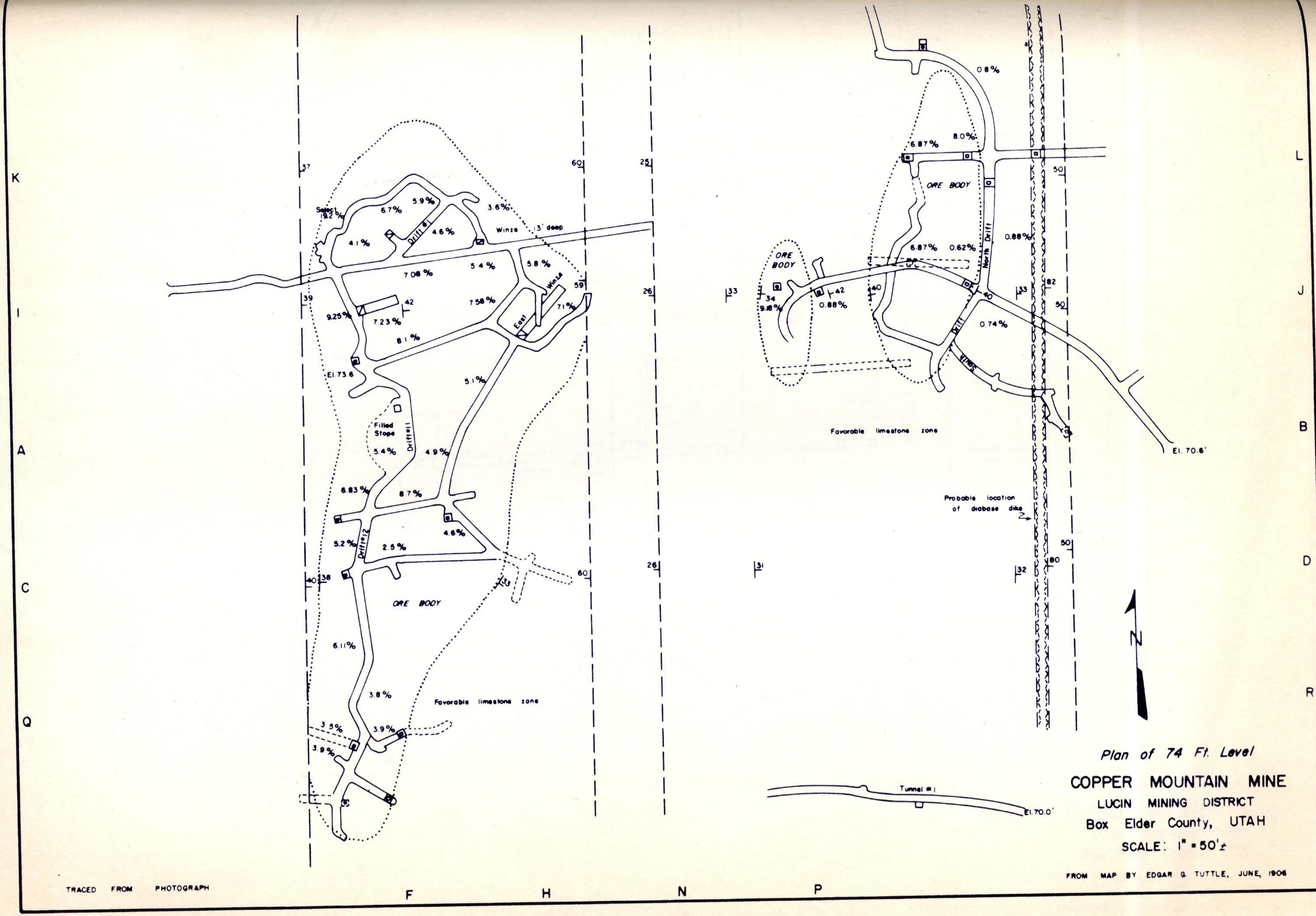
LUCIN MINING DISTRICT

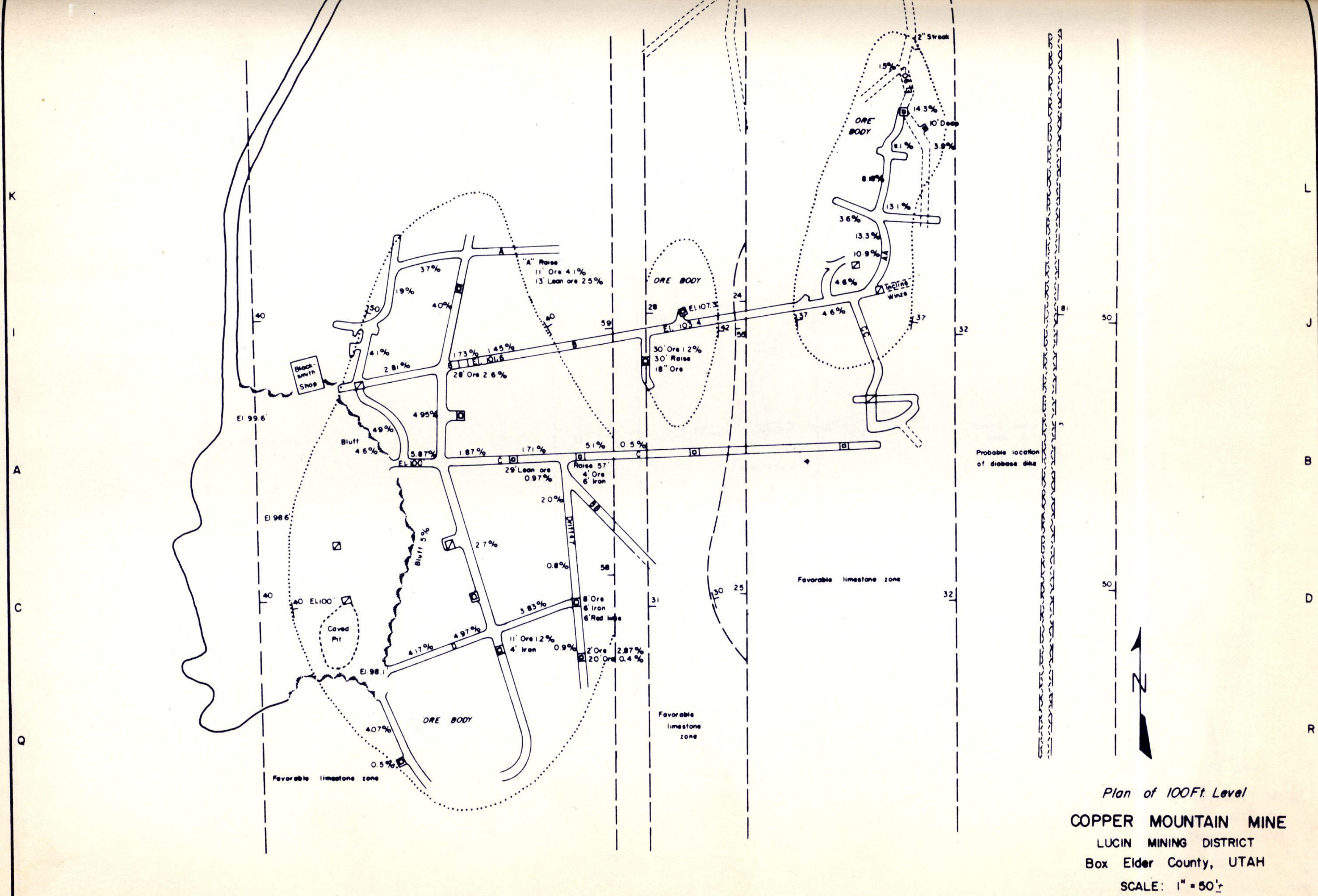
Box Elder County, UTAH

SCALE: 1" = 50' ±

TRACED FROM PHOTOGRAPH

FROM MAP BY EDGAR G. TUTTLE, JUNE, 1906


Plan of 74 Ft. Level
COPPER MOUNTAIN MINE
LUCIN MINING DISTRICT
Box Elder County, UTAH
SCALE: 1" = 50' ±
FROM MAP BY EDGAR G. TUTTLE, JUNE, 1906
TRACED FROM PHOTOGRAPH
ORE BODY
Favorable limestone zone
Probable location of diabase dike
Tunnel #1
El. 70.0'
El. 70.6'
El. 73.6
Winze 13' deep
Filled Stope
Select 19.2%
North Drift
Drift #1
Drift #2
Drift #11
East
K
I
A
C
Q
L
J
B
D
R
F
H
N
P



Plan of 100 Ft. Level

COPPER MOUNTAIN MINE

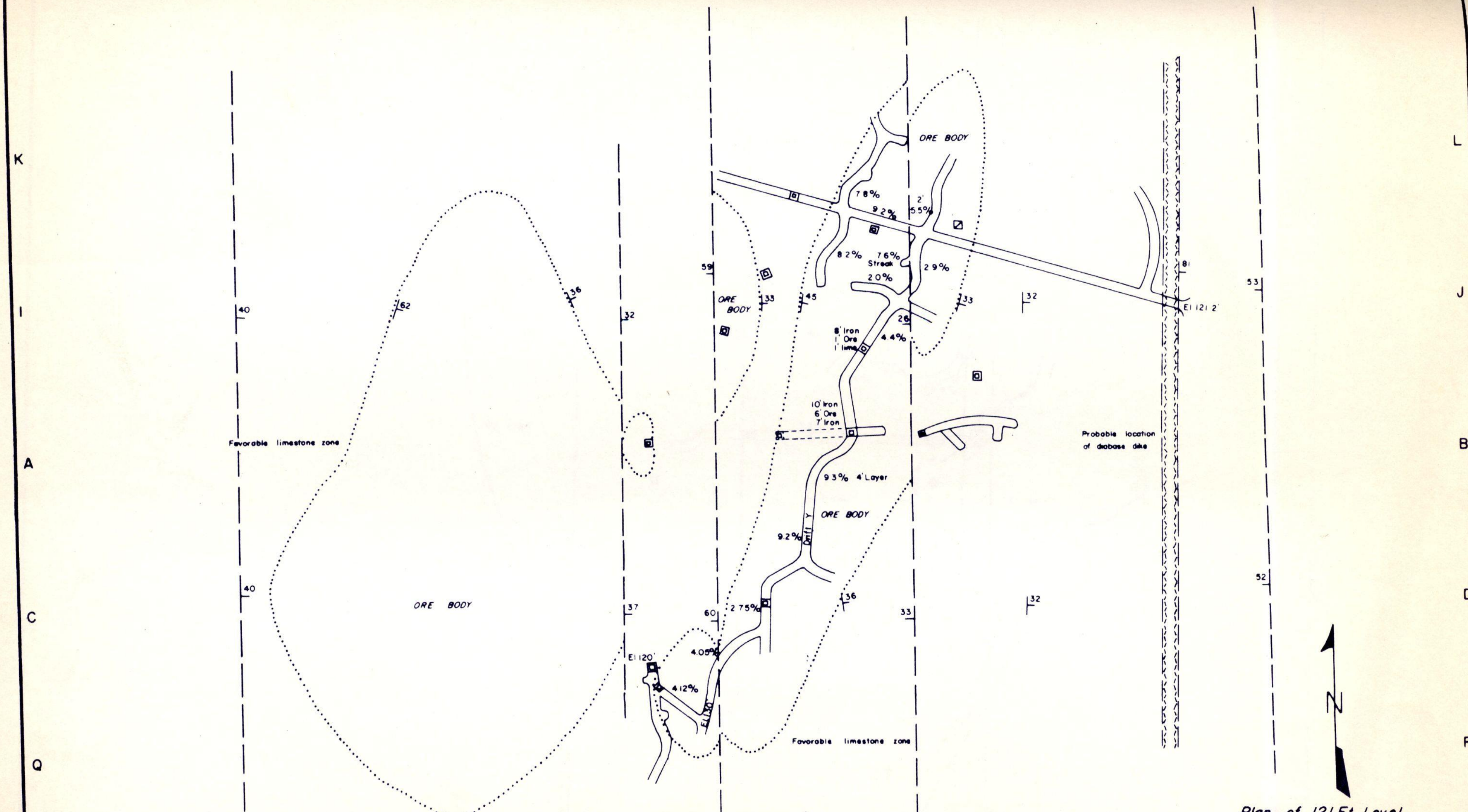
LUCIN MINING DISTRICT

Box Elder County, UTAH

SCALE: 1" = 50' ±

TRACED FROM PHOTOGRAPH

FROM MAP BY EDGAR G. TUTTLE, JUNE, 1906



Plan of 121 Ft. Level

COPPER MOUNTAIN MINE

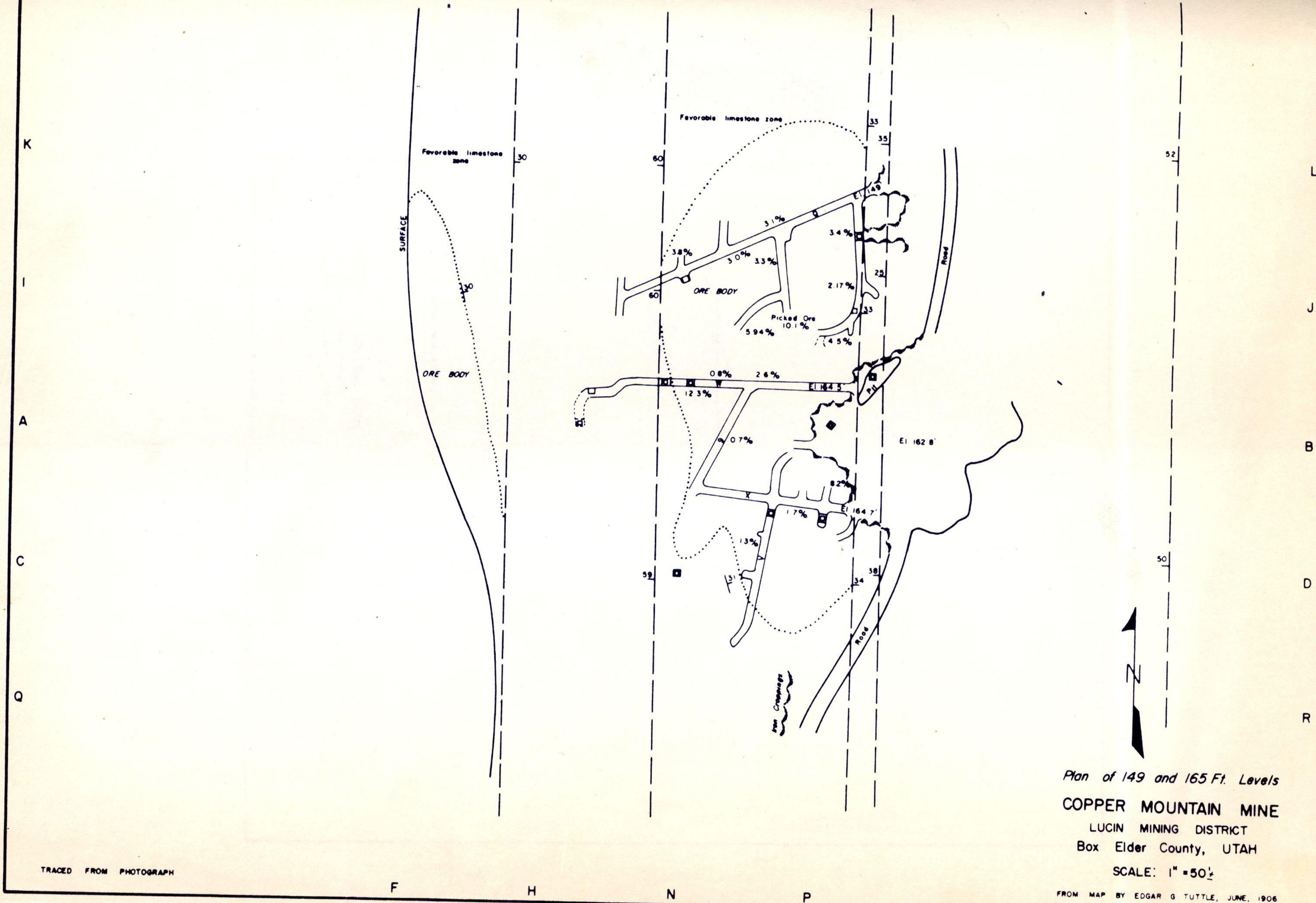
LUCIN MINING DISTRICT

Box Elder County, UTAH

SCALE: 1" = 50'±

TRACED FROM PHOTOGRAPH

FROM MAP BY EDGAR G. TUTTLE, JUNE, 1906



Plan of 149 and 165 Ft. Levels

COPPER MOUNTAIN MINE

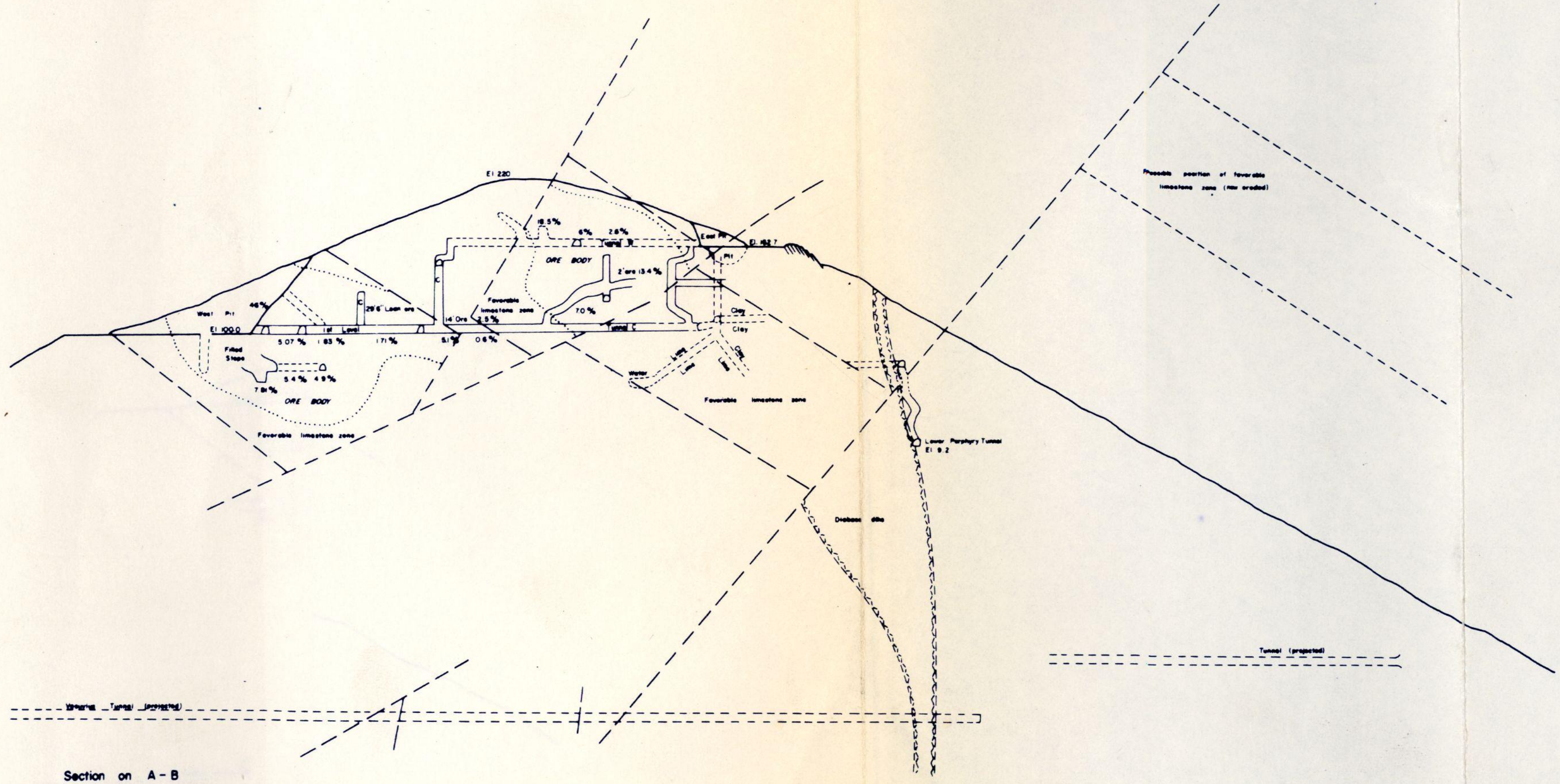
LUCIN MINING DISTRICT

Box Elder County, UTAH

SCALE: 1" = 50'±

FROM MAP BY EDGAR G TUTTLE, JUNE, 1906

E G M O



Section on A-B

COPPER MOUNTAIN MINE

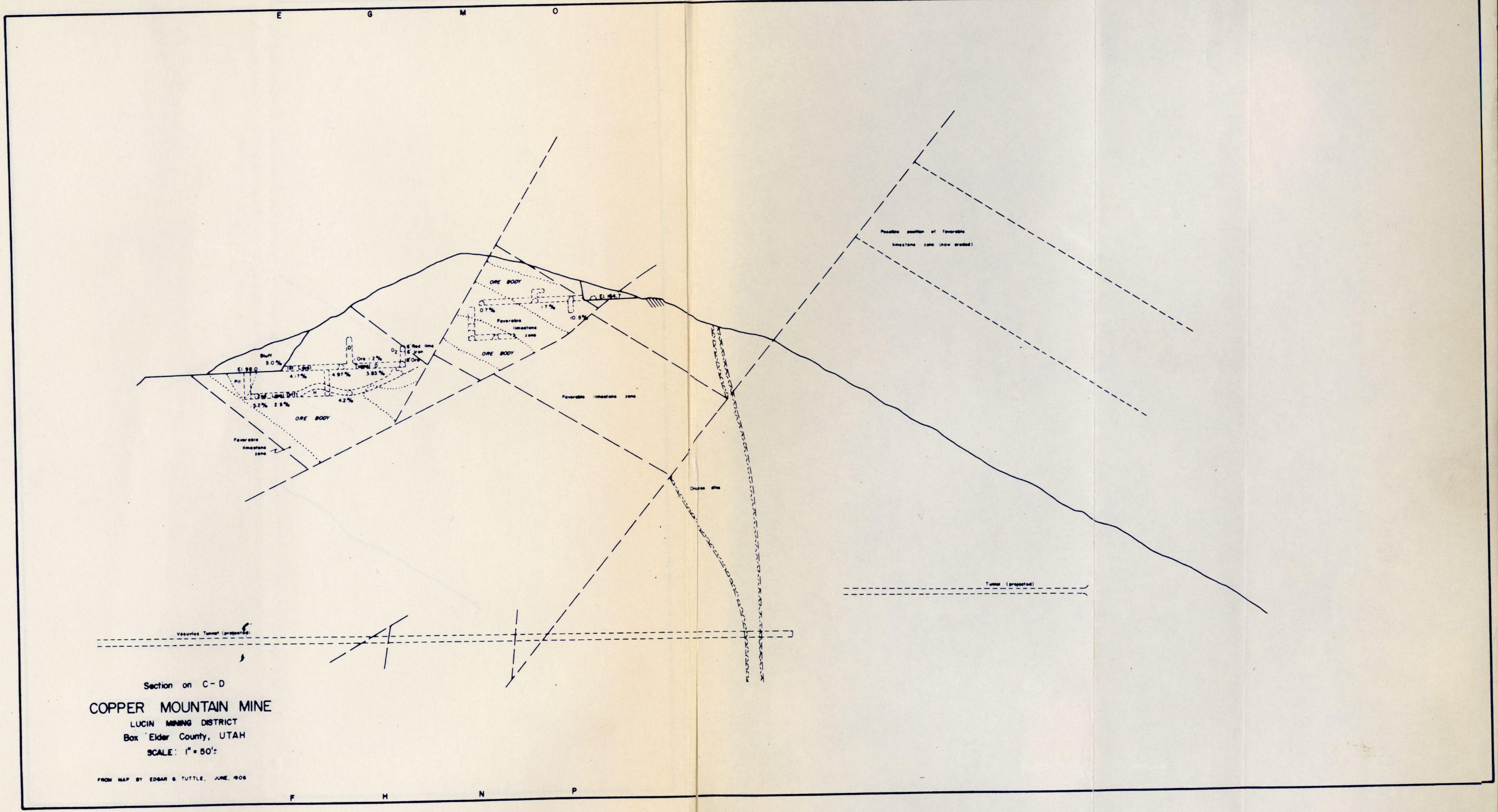
LUCIN MINING DISTRICT

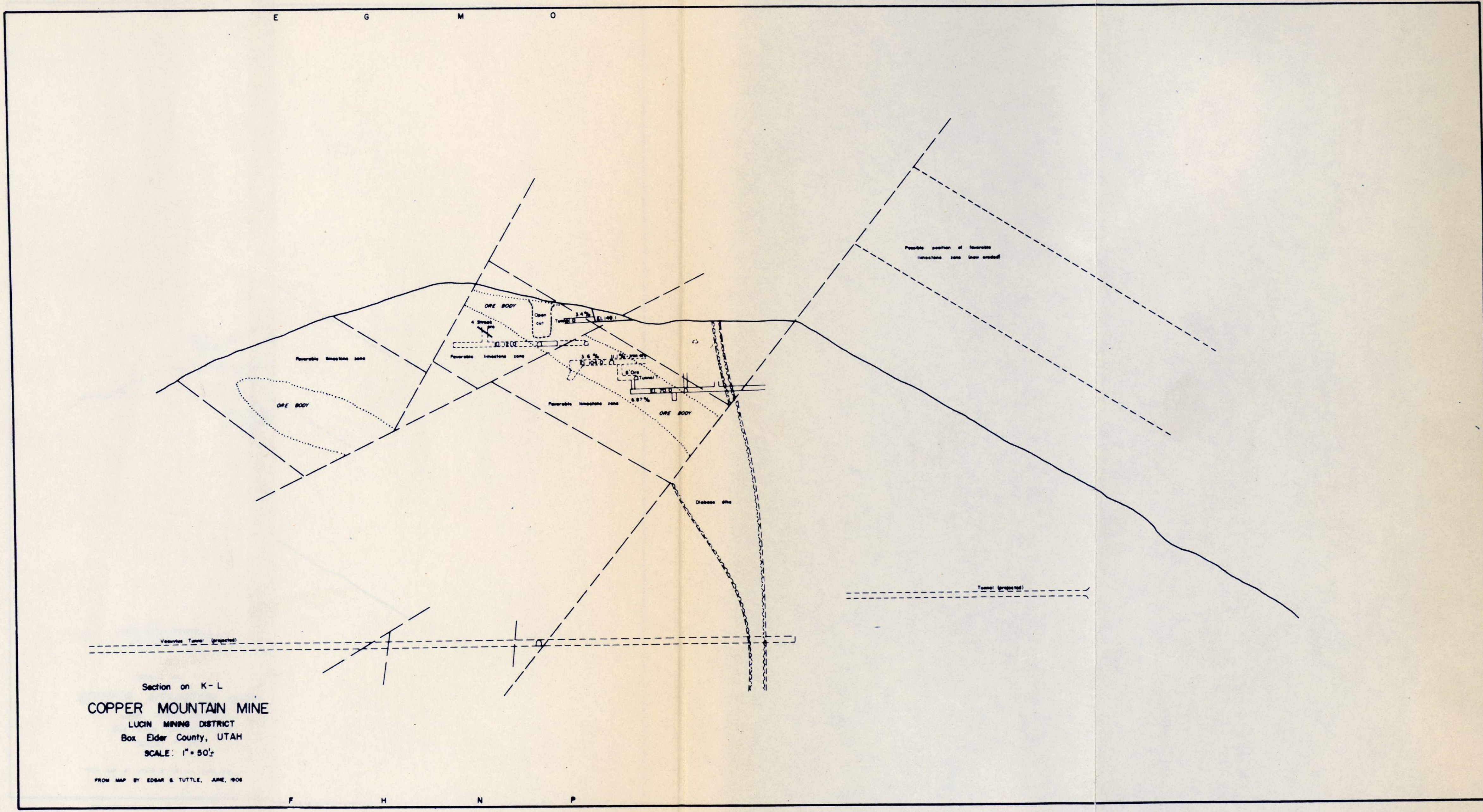
Box Elder County, UTAH

SCALE: 1" = 50'±

FROM MAP BY EDGAR S. TUTTLE, JUNE, 1906

F H N P


E
G
M
O
Possible position of favorable
limestone zone (now eroded)
ORE BODY
El 164.7
0.7%
17%
10.5%
Favorable
limestone
zone
ORE BODY
Bluff
5.0%
El 98.0
Ore 12%
D₂
6' Red lime
6' Iron
6' Ore
4.17%
4.97%
3.83%
Pit
4.2%
5.2%
2.5%
ORE BODY
Favorable limestone zone
Favorable
limestone
zone
Diabase dike
Tunnel (projected)
Vesuvius Tunnel (projected)
Section on C-D
COPPER MOUNTAIN MINE
LUCIN MINING DISTRICT
Box Elder County, UTAH
SCALE: 1" = 50'±
FROM MAP BY EDGAR S. TUTTLE, JUNE, 1906
F
H
N
P



Section on K - L

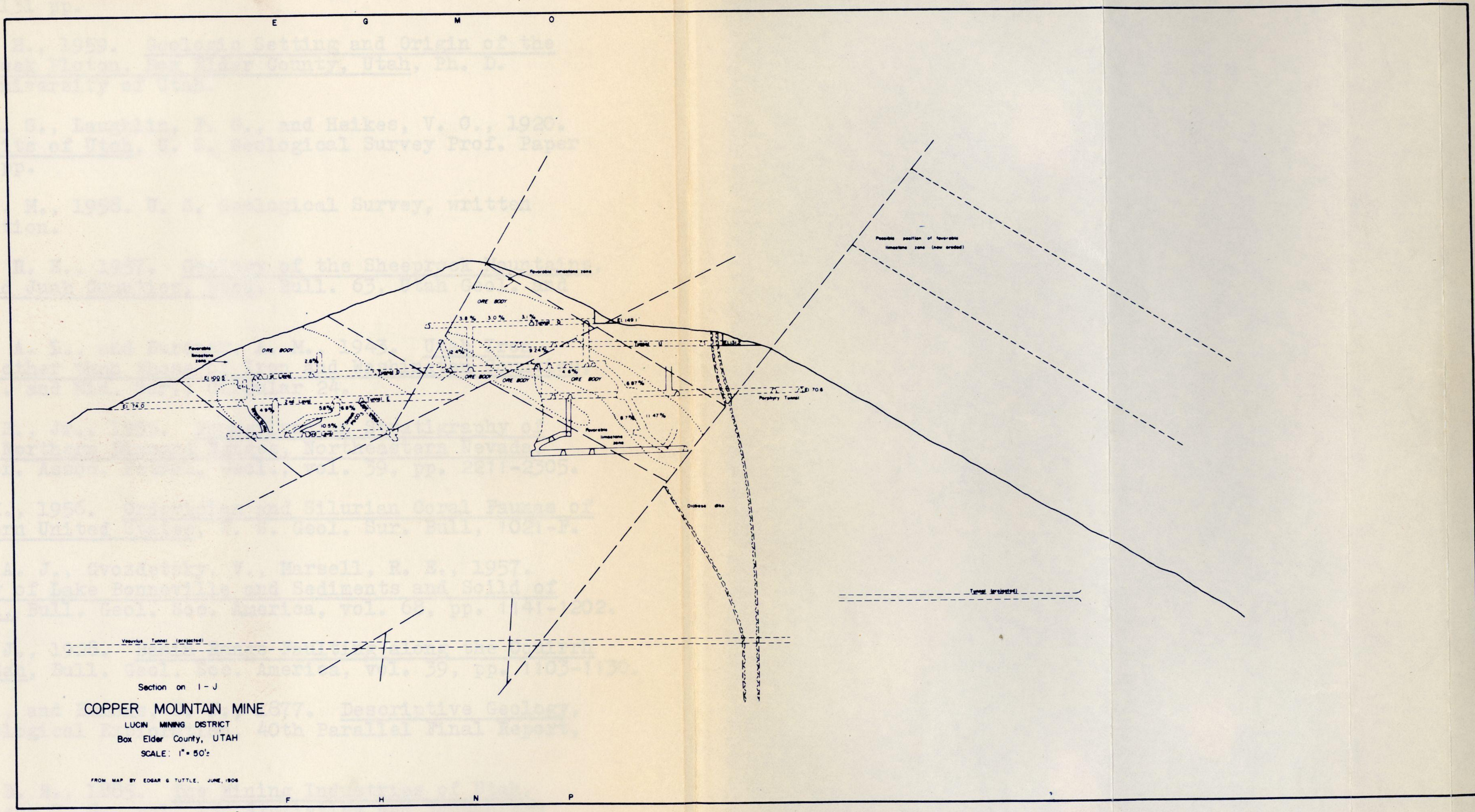
COPPER MOUNTAIN MINE

LUCIN MINING DISTRICT

Box Elder County, UTAH

SCALE: 1" = 50'±

FROM MAP BY EDGAR S. TUTTLE, JUNE, 1906



Section on I - J

COPPER MOUNTAIN MINE

LUCIN MINING DISTRICT

Box Elder County, UTAH

SCALE: 1" = 50'±

FROM MAP BY EDGAR G TUTTLE, JUNE, 1906

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