

NEVADA BUREAU OF MINES AND GEOLOGY

BULLETIN 57

**GEOLOGY OF THE WHITE PINE MINING DISTRICT,
WHITE PINE COUNTY, NEVADA**

By FRED L. HUMPHREY

MACKAY SCHOOL OF MINES
UNIVERSITY OF NEVADA, RENO

1960

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STATE OF NEVADA

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NEVADA BUREAU OF MINES

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FOREWORD

In 1868 rich silver ores were discovered at Treasure Hill, White Pine mining district. Within 10 years most of the high-grade ore had been removed; however, mining continued until World War II. Since then sporadic mining activities and exploration have occurred throughout the district. During the last decade the search has been chiefly for silver, lead, and copper but petroleum possibilities and building materials have received considerable attention.

In view of its past mineral production and future potential, the Nevada Bureau of Mines decided to prepare a geological report on the district. Dr. Fred L. Humphrey conducted field studies each summer from 1946 to 1949, when the field work was completed. About that time Dr. Humphrey became Professor of Mining Engineering, and later Assistant Dean, in the School of Mineral Sciences, Stanford University, and his duties prevented him from an early completion of his report.

Bulletin 57, "Geology of the White Pine Mining District, White Pine County, Nevada," contributes greatly to the understanding of the geology and mineral deposits of the area. Dr. Humphrey has deciphered the extremely complex geology of the White Pine district and has brought together much important data, so necessary to the future exploration for mineral deposits.

There have been a number of important changes in local stratigraphic terminology and geologic structural concepts, resulting from several recent geological investigations in the general area, since Dr. Humphrey did his field work. Attention is called to these changes by the editorial footnotes of Messrs. L. H. Beal and R. H. Olson, Mining Geologist and Economic Geologist, respectively, of the Bureau, who generously contributed their time to serve as technical editors of the report. Dr. A. R. Palmer, United States Geological Survey, kindly reviewed portions of the manuscript dealing with Cambrian and Ordovician stratigraphy and offered numerous constructive suggestions.

Dr. Humphrey did the geological field mapping on aerial photographs with the intention of plotting and publishing on a topographic base, then in preparation. However, he was unable to complete this part of the assignment. In 1959, Mr. L. H. Beal spent a few weeks in the area adjusting the manuscript geological map to the topographic base, and thus made it much more valuable and usable.

VERNON E. SCHEID, *Director*
Nevada Bureau of Mines

September 1960
Mackay School of Mines,
University of Nevada.

GEOLOGY OF THE WHITE PINE DISTRICT, WHITE PINE COUNTY, NEVADA

By FRED L. HUMPHREY

ABSTRACT

The White Pine district, at the north end of the White Pine Range about 35 miles west of Ely, Nevada, includes approximately 270 square miles. The oldest exposed rocks are Middle Cambrian, and the bulk of the area is underlain by Paleozoic rocks totaling approximately 18,000 feet in thickness. The Cambrian rocks are mostly shale and thin-bedded limestone, and the Ordovician, Silurian, and Devonian sedimentary rocks are dominantly limestone and dolomite. Mississippian rocks include a thick sequence of carbonaceous shale and sandstone which is overlain by Pennsylvanian limestone and sandy limestone. The Paleozoic section is overlain unconformably along the flanks of the ranges by Cretaceous (?), Eocene, and Miocene or Pliocene lake deposits. The most widespread Tertiary sediments are the Pliocene(?) bedded tuffs which surround the greater part of the White Pine Range. The southeast portion of the district was partially covered by late Tertiary basalt which was extruded after the deposition of the tuff beds.

Pogonip Ridge was subjected to pre-Eocene normal faulting followed by probable Late Cretaceous and early Tertiary orogenic disturbances throughout the district which formed folds and thrust faults. Eocene lake beds are disturbed along with the underlying Paleozoic rocks and furnish a partial dating for the folding and thrusting. Two small intrusions, one granodiorite and the other hydrothermally altered quartz monzonite, crop out on the west slope of Pogonip Ridge; they are post-thrusting in age. Normal faulting followed the period of compression.

Pogonip Ridge, a domed structure about 7 miles long and 1½ miles wide, is bounded by three faults. The structural outline of the ridge was established prior to the period of compression, but the greatest uplift, about 15,000 feet relative to the surrounding rocks, occurred later.

In 1868 rich silver ore was discovered on Treasure Hill, and from 20 to 40 million dollars worth of silver was recovered within ten years. The ore occurred in a fracture zone at the top of the Nevada limestone near the apex of an anticline on Treasure Hill.

Lead-zinc-silver ores occur in dolomitic rocks west of the silver zone and a small amount of chalcopyrite occurs close to the two intrusives. Folds in the Upper Paleozoic rocks surrounding Pogonip Ridge and Treasure Hill might furnish structures favorable for oil accumulation. The only oil observed occurs in cavities within goniatites in the White Pine formation.

INTRODUCTION

LOCATION

The White Pine district, Nevada (fig. 1), is about 30 miles east of Eureka, midway between Eureka and Ely. The area includes approximately 270 square miles and comprises essentially the southwest quarter of the Illipah quadrangle, the southeast quarter of the Pancake Summit quadrangle, the northwest quarter of the Treasure Hill quadrangle, and the northeast quarter of the Green Springs quadrangle in Tps. 15, 16, 17 N., and Rs. 57, 58 E., M.D.B.M.

PURPOSE AND SCOPE

The original purpose of the investigation was to prepare a geological map of the Hamilton area and Pogonip Ridge. After companies became interested in the petroleum possibilities of eastern Nevada in 1947, the study was expanded to include more of the Upper Paleozoic rocks in the vicinity. The author spent most of the summers of 1946, 1947, 1948, and 1949 working on this project.

HISTORY

The rich silver ore at Treasure Hill was discovered in 1868. A great influx of people took place after the discovery and it is estimated that between 10,000 and 25,000 people were living in the area in 1868. Hamilton (fig. 2) was, until a disastrous fire in 1885, the county seat of White Pine County. Within 10 years the silver ore was practically mined out, and the population steadily decreased. Since then there have been only sporadic mining operations west of Treasure Hill and on Pogonip Ridge in the lead-silver deposits.

The following is an excerpt from Lincoln (1923, p. 257) :

“Ore was discovered on the W. slope of White Pine Mt. by A. J. Leathers, Thomas Murphy, and other prospectors from Austin, in 1865. The Monte Cristo M. Co. was formed with Edward Marchand as superintendent and a mill was built and put in operation in 1867. An Indian gave Leathers a piece of rich silver chloride ore and was persuaded to show where he found it. Guided

by this Indian, Leathers, Murphy, and Marchand located the rich Hidden Treasure Mine on Treasure Hill on January 4, 1868. Shortly afterwards, T. E. Eberhardt discovered the remarkable silver chloride deposit known as the Eberhardt Mine on Treasure

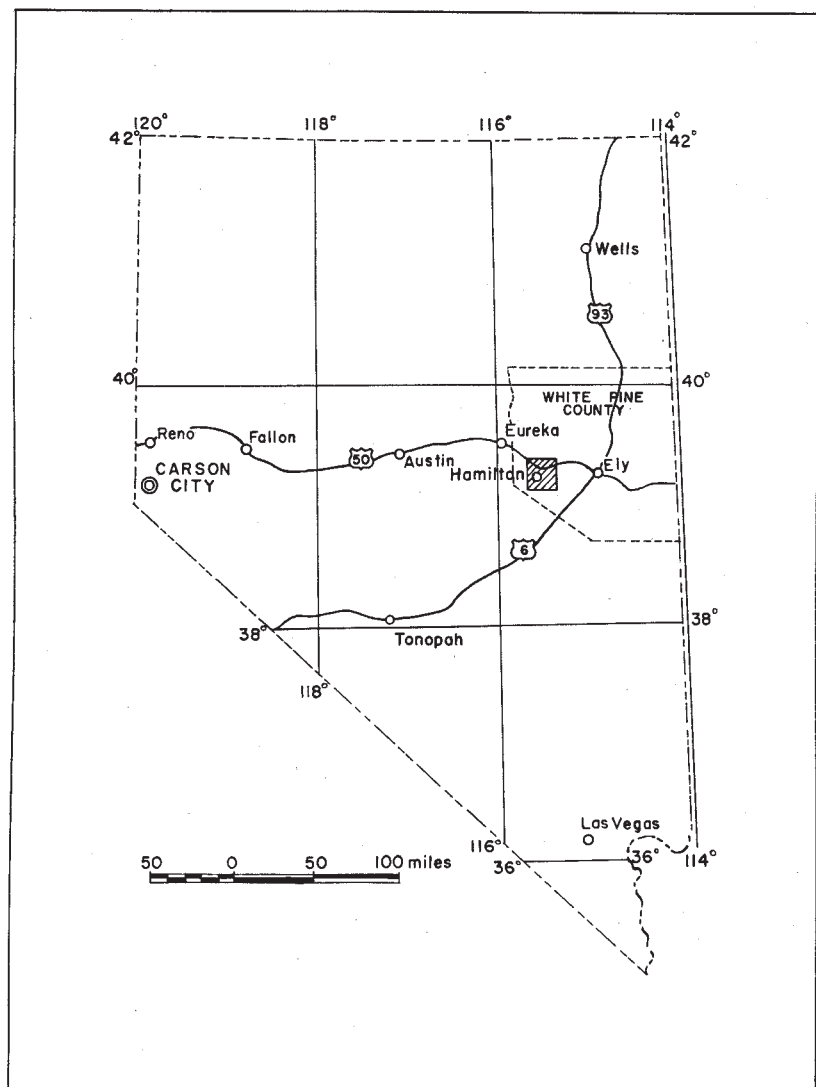


FIGURE 1. Index map of Nevada showing White Pine mining district.

Hill. Other rich properties were located and the great White Pine rush began. This sensational stampede continued and increased throughout the year, culminating in the spring of 1869. At that time Hamilton had a population of 10,000 people and 15,000 more

were living in smaller cities and towns in the district. There were 195 White Pine mining companies incorporated, and over 13,000 mining claims were recorded in the district in 2 years' time. The rich surface ores of Treasure Hill were soon exhausted, but silver ore continued to be mined from that section up to 1887, since which time most of the mining has been conducted in the lead-silver belt between Treasure Hill and Monte Cristo."

In 1865 the first mineral discovery in the district was made at the north edge of the Monte Cristo stock on the west side of Pogonip Ridge.¹ The ore was supposed to have been rich in gold and a British company built a brick smelter at Monte Cristo



FIGURE 2. Town of Hamilton, about 1915. Hotel (center) was built in 1869 when the population of Hamilton was approximately 10,000.

Spring. There is no evidence that the smelter was ever operated. The "ore" contained chalcopyrite but no gold.

According to Mr. Carl Muir, of Ely, Nevada, whose father came to Hamilton in 1869, the discoverers of the Treasure Hill ore, guided by an Indian, walked from Monte Cristo over Pogonip Ridge and camped the first night in some limestone caves near the present site of Hamilton. There were from 2 to 5 feet of snow along the route they followed. The next morning the party divided, one group going up the north slope of Treasure Hill and the other group skirting the east side of the hill and ascending the south slope where the sun had partially melted the snow. The first group, guided by the Indian, stopped to rest near the top of the hill and after clearing snow from an outcrop found heavy pieces

¹Called "White Pine Mt." by Lincoln (editors).

of rock that were almost pure cerargyrite and thus discovered the Hidden Treasure mine. The second party, ascending the south slope, found pieces of cerargyrite float which led them to the discovery of the Eberhardt mine. In the ensuing two years at least seven mills and five smelters were built. It is said that the mill for the Eberhardt mine, which was in Sherman Canyon about half a mile below Shermantown, recovered more than one million dollars worth of silver in the first three months of operation.

There was no water on Treasure Hill; therefore, the mills were built at or near springs around the base of the hill. In 1869 a water project was completed which brought water from Harris Spring in Harris Canyon about 3 miles east of Hamilton. A 12-inch pipe line was installed with five steam-powered pumping plants to pump the water to Hamilton and Treasure Hill. This operation involved a vertical lift of approximately 1,500 feet.

An ambitious but unsuccessful attempt to develop ore at depth was undertaken by the consolidated companies on Treasure Hill following the "working out" of the rich surface ores. The Eberhardt tunnel under Treasure Hill, about 6,000 feet long with two 1,000-foot crosscuts, failed to locate any deep ore.

The author found remains of five sawmills on Pogonip Ridge. No timber suitable for milling remains but literally thousands of rotted stumps, some as much as 3 feet in diameter, testify to the quantity of lumber that was produced. In addition, there are charcoal pits throughout the district and it is said that the hills were practically denuded of piñon and juniper to make charcoal for the mines and smelters.

Sixmile House, about 6 miles northwest of Hamilton, was a stage stop on the Eureka-Hamilton road where horses were changed for the steep pull into Hamilton. Likewise, Sixmile Spring, 6 miles southeast, was a stage stop on the Hamilton-Pioche road. The latter crossed the mountains southeast of Sixmile Spring to the headwaters of the White River, following it southward toward Pioche. The road to the east, which at that time was little traveled because of the railroad into Eureka, passed through Ely and later became a part of the Lincoln Highway. Until the present U. S. Highway 50 was constructed in 1929, the old Lincoln Highway passed through Hamilton and a store and post office were operated there. The town is now deserted and the buildings are in ruins.

ACCESSIBILITY

U. S. Highway 50 cuts diagonally across the northeast corner of the district. There are many unpaved roads, some of which

are graded annually, throughout the district so that it is possible to drive within two or three miles of any desired place.

CLIMATE AND VEGETATION

The climate is semiarid. Thundershowers contribute most of the rainfall during the spring and summer months. Winter snowfalls are occasionally heavy and the roads are at times impassable. Snow may remain in some of the high canyons of Pogonip Ridge until July. The total precipitation over the lowlands is 10 to 15 inches per year, and probably 25 or 30 inches at higher altitudes on Pogonip Ridge and Treasure Hill. The U. S. Weather Bureau records an annual average of 17 inches for Hamilton.

The summer temperatures sometimes reach 100 degrees at lower levels but decrease at higher altitudes. Above 9,000 feet the temperature seldom exceeds 80 degrees. Freezing temperatures may occur at night above 9,000 feet in early August. In winter the temperature sometimes drops to 20 or 25 degrees below zero. Wind is common in all seasons.

Altitude in the district ranges from about 6,000 feet in the southwest portion, near Green Springs, to approximately 10,700 feet on the summit of Mount Hamilton. The altitude of Hamilton is about 8,200 feet and that of Treasure Hill is approximately 9,300 feet.

Vegetation varies with the altitude. At the lower levels, around 6,000 feet, sagebrush is the principal plant, and the associated bunch grass furnishes good grazing. At about 6,500 feet, piñon pines and juniper trees are generally abundant, and together with the sage are found to about 8,000 feet. Above 8,000 feet white fir and pine are the principal trees, particularly on Pogonip Ridge, although on the east side of the district juniper trees and sagebrush are the most abundant plants, even above 9,000 feet. Aspen groves generally flourish near the springs.

Many flowering plants grow at the higher altitudes after the snow melts, and with favorable spring rains grow profusely at lower altitudes.

WATER SUPPLY

There are few springs in the limestone or dolomite and, since most of the area is underlain by carbonate rocks, surface water is not abundant. However, the three largest springs in the district occur on, or near, faults that cut carbonate rocks. Harris Spring, the largest, is in the upper part of Harris Canyon and feeds Illipah Creek, the only permanent stream in the district. This

spring has a fairly constant flow estimated to be in excess of 2,000 gallons per minute and supplied the water which was pumped to Hamilton and Treasure Hill. Green Springs occurs on a fault on the east side of Newark Valley, about a quarter of a mile south of the southern edge of the geologic map (pl. 1), and has an estimated flow of 500 gallons per minute. The spring at Monte Cristo, on the fault bounding the west side of Pogonip Ridge, flows between 10 and 100 gallons per minute. Its flow fluctuates with the seasons much more than the two previously mentioned springs.

There are four small permanent springs on the west slope of Pogonip Ridge. Emigrant Spring, situated about a mile north of the mouth of Mohawk Canyon, is related to the boundary fault on the west side of Pogonip Ridge. Seligman Spring is near the head of Seligman Canyon; another spring is about a mile south of Seligman, east of the Monte Cristo stock; and still another spring is in Hoppe Canyon about 3 miles south of Monte Cristo.

The most important aquifer in the district is the Diamond Peak formation, from which flow a great number of small springs. They are of particular value to cattlemen, and more than a thousand head of cattle usually graze in the eastern part of the district during the summer. An abundant water supply for agricultural purposes could probably be developed by drilling wells in Newark Valley.

PREVIOUS WORK

Little has been written or published on the geology of the district. Arnold Hague visited the area in 1868 and included a map and geologic description of Treasure Hill in the United States Geological Exploration of the Fortieth Parallel (Hague, 1870).

W. S. Larsh (1909), retired General Manager of the McGill Smelter, published a small geological map of the Hamilton area. The reports of the State Mineralogist of the State of Nevada for the years 1867 to 1878 contain information regarding the number of mines operating and ore production.

ACKNOWLEDGMENTS

The author is indebted to Dr. G. Arthur Cooper², Curator of Invertebrate Paleontology at the Smithsonian Institution, for his time-consuming work in identifying the fossils which were collected from approximately 250 localities. The collection is filed at the United States National Museum in Washington, D. C.

²All references to G. A. Cooper are by personal communication (editors).

Furthermore, Dr. Cooper has contributed much to the knowledge of the Paleozoic fauna of this part of the Great Basin. The author feels that without his help it would have been almost impossible to work out many of the complicated structures and facies changes.

Dr. Walter L. Youngquist kindly identified many cephalopod fossils from the White Pine formation. Dr. F. Stearns MacNeil and Dr. Teng-Chien Yen of the United States Geological Survey identified the Tertiary fresh water mollusks.

Dr. Cordell Durrell has been most helpful during field visits and in his careful and critical reading of the manuscript.

The author also wishes to express his sincere thanks to Drs. James Gilluly and T. B. Nolan, United States Geological Survey, for many helpful field visits and suggestions on critical problems.

Dr. Harry E. Wheeler, Professor of Geology at the University of Washington, and Dr. Vincent P. Gianella, Professor Emeritus of Geology at the Mackay School of Mines, University of Nevada, have both given freely of their personal knowledge of the geology of eastern Nevada. The author is grateful to Dr. Jay A. Carpenter, formerly Director of the Nevada Bureau of Mines, for making this work possible and for his cooperation in the project.

Mr. Carl Muir of Ely, Nevada, and Mr. and Mrs. Ed Halstead of Duckwater, Nevada, were generous in giving personal knowledge of the early history of Hamilton and the various mines in the vicinity. Millard and Son, an engineering firm in Ely, Nevada, has kindly permitted the reproduction of the mineral claim map of the Hamilton area.

The author was most fortunate in having the help of three excellent field assistants on this project: Thomas Morris, William Hughes, and Daniel Shawe.

STRATIGRAPHY

GENERAL STATEMENT

The sedimentary rocks of the White Pine district are for the most part Paleozoic, ranging from Middle Cambrian to Pennsylvanian. No doubt there are small exposures of Permian rocks but none were mapped as such because of the absence of diagnostic fossils. East of the district, however, there are more than 5,000 feet of Permian rocks, dominantly limestone and sandy limestone. The only younger sedimentary rocks that were recognized are Tertiary and Quaternary.

The Paleozoic stratigraphic sequence is as follows:

Age	Formation	Thickness (feet)
Pennsylvanian.....	Ely limestone.....	1,600
Mississippian.....	Diamond Peak formation.....	600-1,000
	White Pine formation.....	1,800-2,000
	Joana limestone.....	150-250
	Pilot shale.....	150-200
Devonian.....	Nevada limestone.....	1,600
Lower Devonian(?) and Silurian.....	Lone Mountain dolomite.....	2,100
Upper Ordovician.....	Hanson Creek dolomite.....	600-850
Middle Ordovician.....	Eureka Quartzite.....	250-400
Lower Ordovician.....	Pogonip formation.....	2,000
Upper Cambrian.....	Goodwin formation.....	1,500 +
	Dunderberg shale.....	350
	---Disconformity---	
Middle Cambrian.....	Secret Canyon shale.....	1,500-2,500
	Geddes limestone(?).....	100 + (base not exposed)

The combined thickness of the Paleozoic formations exceeds 18,000 feet (see fig. 3 for stratigraphic correlation).

MIDDLE CAMBRIAN

Geddes limestone(?)

A small exposure of dark-grey to black platy limestone, about a quarter of a mile south of Monte Cristo, resembles the Geddes limestone of the Eureka district. This formation, described by Wheeler and Lemmon (1939), is named from the Geddes mine in Secret Canyon. It underlies the Secret Canyon shale and is therefore the oldest exposed rock in the White Pine district. The formation is considered to be the Geddes limestone³ because of lithologic similarity and its position below the Secret Canyon shale.

Secret Canyon shale

The Secret Canyon shale, described by Hague (1892), is named from Secret Canyon in the Eureka district. With the exception of the small exposure of possible Geddes limestone, this is the oldest recognizable unit in the White Pine district. It is present only on the west side of Pogonip Ridge in an area 2½ by 4½ miles and is intruded by the Monte Cristo and the Seligman stocks. The greater part of the formation was metamorphosed by these igneous intrusions.

³A. R. Palmer, however, in a personal communication (1959) stated that the Geddes limestone(?) mentioned by Humphrey is not correlative with the Geddes limestone in the Eureka district owing to differences in age and lithology. Palmer found the trilobite *Holteria* of latest Middle Cambrian age in the upper part of the formation as described by Humphrey (editors).

The base of the formation is exposed only near Monte Cristo and the top of the formation is a disconformity. The fauna reveals that the Hamburg dolomite normally present between the Secret Canyon shale and the Dunderberg shale, is missing. At Eureka, only 30 miles to the west, the Hamburg dolomite is about 1,000

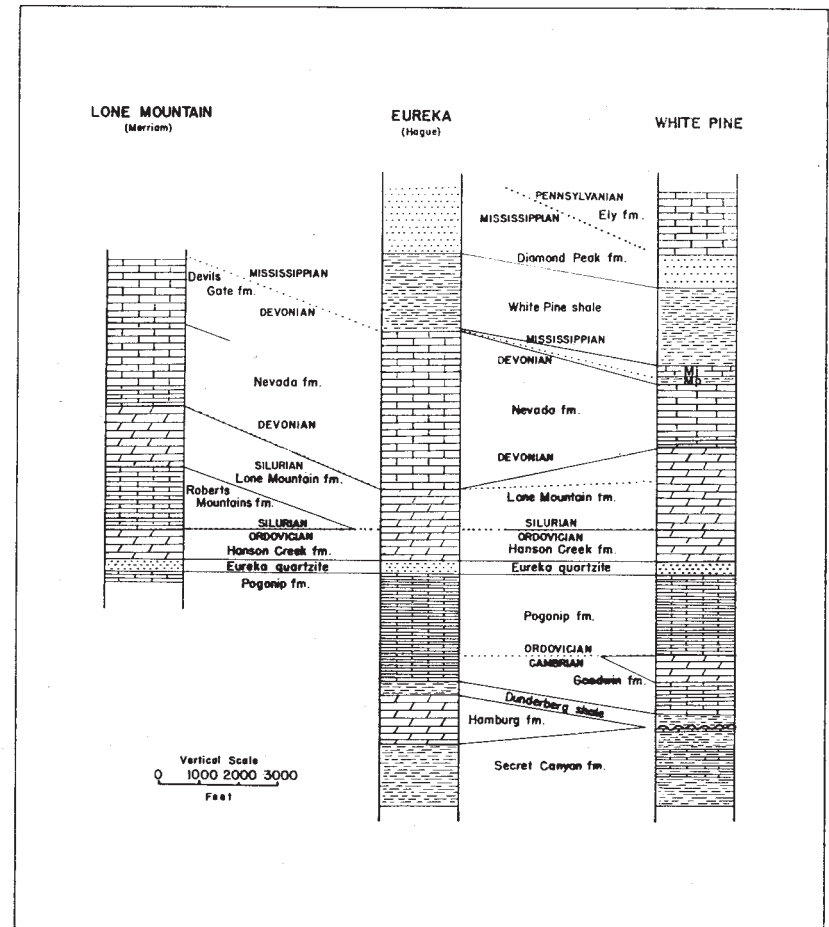


FIGURE 3. Correlation chart of Paleozoic formations in East-Central Nevada.

feet thick. The author unsuccessfully sought an explanation for the absence of the Hamburg dolomite owing to faulting.

Four distinct lithologic members comprise the Secret Canyon shale and the lower two correspond generally to the section at Eureka. The formation is at least 1,500 feet thick, and may be 2,500 feet thick.

Member 1 is a thin-bedded brownish locally micaceous shale. Its calcareous nature is indicated by the metamorphic mineral assemblage of diopside and zoisite in stratigraphically equivalent hornfels near the Monte Cristo stock. The hornfels is brownish on weathered surfaces and unweathered pieces generally have a pale-greenish hue.

Near the contact with the Geddes limestone(?) member 1 is about 400 feet thick, but near the Trench mine, a mile south, it is more than 800 feet thick with the base not exposed. The variation is probably due to compaction and squeezing plus repetition or omission by faulting.

Member 2 consists of about 1,000 feet of thin-bedded shale-parted limestone, as illustrated in figure 4. The shale partings, which range from less than $\frac{1}{8}$ inch to $1\frac{1}{2}$ inches thick, are calcareous and are locally interconnected (fig. 5), probably a result of compaction of the unindurated material before litification and the concomitant squeezing out of the limy ooze.

Member 3 consists of about 280 feet of greenish shale. The shale is thin-bedded and platy where well-weathered, but where not so well-weathered it resembles mudstone and forms massive outcrops. The locally massive character may be the result of metamorphism. Where metamorphosed to a high degree the shale is a massive fine-grained banded hornfels. The greenish bands are composed dominantly of fine-grained diopside and the white bands dominantly of zoisite. These thin mineral bands indicate an original thin-bedded shale which consisted of interbedded calcareous and dolomitic strata.

Member 4, at the top of the formation, consists of several thin-bedded limestone units, each separated by 3 to 20 feet of greenish shale. In the northern portion of the area containing exposures of the Secret Canyon shale (in Seligman Canyon), there are three such limestone units, each with thin shale partings. The lower two, each about 20 feet thick, are separated by about 20 feet of green, poorly bedded shale; the upper one, about 10 feet thick, is separated from the middle bed by about 15 feet of greenish shale. Farther south, just east and southeast of the Seligman stock, there are only two thin-bedded limestone units in this member; each is about as thick, respectively, as the lower two in Seligman Canyon and they are also separated by about 20 feet of shale. Although thoroughly recrystallized and bleached white, they still display their thin-bedded character. East of the Trench mine there are five thin-bedded shale-parted limestone units, each ranging from 5 to 10 feet in thickness and separated by 3 to 6



FIGURE 4. Member 2 of the Secret Canyon shale in Seligman Canyon showing thin interbedded limestone and shale.

feet of greenish shale. These beds cannot be traced laterally northward into the recrystallized limestone beds because of a wide talus slope, but the overlying Dunderberg shale-Goodwin formation contact may be traced almost continuously and shows little transverse faulting.

The Secret Canyon and Dunderberg shales were considered as one unit in the early stages of mapping because of their lithologic similarity and conformable attitudes. The presence of a disconformity between them was not recognized until the faunal



FIGURE 5. Member 2 of the Secret Canyon shale showing interconnected shale beds. This rock has been thermally metamorphosed. The shale beds are more resistant to erosion than the recrystallized limestone.

assemblages, identified by G. A. Cooper and his associates, indicated the absence of strata representing a distinct time interval. Fossils from member 4 in both the northern and southern exposures were correlated with the upper Middle Cambrian, while those from the overlying Dunderberg shale are Franconian in age; the lower Upper Cambrian is therefore absent. Only a few well preserved fossils were obtained in the northern exposures and none in the central exposures owing to the metamorphism. Characteristic trilobite genera are *Elrathia*, *Kochaspis*, and *Glyphaspis*. Numerous other trilobites were found but as Dr. Cooper wrote, "Miss Lochman . . . found quite a number of

unfamiliar things in the collection and she stated that in her opinion some of the material represented undescribed species and genera."⁴

Metamorphism of the Secret Canyon shale accentuated the differing lithologic characteristics of the interbedded sedimentary facies. The argillaceous members became fine-grained banded massive hornfels, and the thin-bedded shaly limestones formed either compact, recrystallized, differentially weathered rock or coarse-grained calc-silicate hornfels close to the intrusions.

UPPER CAMBRIAN

Dunderberg shale

The Dunderberg shale, named by Walcott (1908) after the Dunderberg mine in the Eureka district, was originally called Hamburg shale by Hague (1892).

The Dunderberg shale, which averages about 350 feet thick, overlies the Secret Canyon shale, and although they appear to form a continuous depositional sequence, they are apparently separated by a disconformity. The base of the Dunderberg shale overlies member 4 of the Secret Canyon shale, with no perceptible angular discordance. The basal 120 feet are greenish shale or mudstone, similar in appearance to member 3 of the Secret Canyon shale except that it contains a few thin limestone beds. Resting upon the basal shale or mudstone are 200 feet of interbedded shale and thin-bedded limestone with shale partings which are similar to the bulk of the formation at Eureka. About 30 feet of thin shale-parted nodular limestone overlies the shale-limestone sequence and forms the top of the formation. As shown in figure 6 this nodular member overlies a 10-inch bed of massive medium-grained medium-gray limestone.

Fossils from the formation have been determined as follows:

⁴Re-examination of Humphrey's collections from the "Secret Canyon" and re-collection of trilobites from the top of member 2 in 1959 show that all known trilobites of the "Secret Canyon" in the Hamilton district are Upper Cambrian forms. The earlier identifications of *Elrathia*, *Kochaspis*, and *Glyphaspis* by Lochman are in error. Trilobites from the top of member 2 and also some in Humphrey's collections represent species of *Aphelaspis* and *Olenaspella*. Member 2 is lithically like the Swarbrick limestone at Tybo, Nevada, and both have an *Aphelaspis* fauna in their upper beds.

The revision of the age of the "Secret Canyon" removes the need for an unconformity between it and the Dunderberg. As far as can be determined, the Cambrian section on the west face of Mt. Hamilton is without significant stratigraphic breaks (A. R. Palmer, written communication, 1960).

Dunderbergia, *Elvinia*, *Pseudagnostus communis*, *Pterosephaline bilobata*, *Acrotreta*, *Irvingella* sp., *Berkeia* sp., cf. *Ellipsocephaloides*. This faunal assemblage demonstrates the Franconian age of the Dunderberg shale which here immediately overlies the *Elrathia* zone of the Middle Cambrian.

In addition to the outcrops of Dunderberg shale in the "arc"



FIGURE 6. Nodular, shale-parted limestone at the top of the Dunderberg shale. Note the 1-foot thick massive limestone bed at base of nodular limestone.

around the Secret Canyon shale, there are a few outcrops in the upper plate of the Monte Cristo thrust. However, only the one at the mouth of Ophir Canyon is large enough to show on the map. Dunderberg shale is found on the dump of a shaft sunk in the base of member 1 of the Goodwin formation a short distance west of the Caroline claim in the canyon south of Ophir Canyon. Farther south, along the outcrop of the Monte Cristo thrust, there are two lenses of the upper nodular shaly limestone beds containing *Dunderbergia* and *Pseudagnostus communis*.

UPPER CAMBRIAN AND LOWER ORDOVICIAN

Mount Hamilton group

The Pogonip formation⁵ was first named by Hague (1877) from the rocks exposed in this area on Mount Hamilton (originally called Pogonip Mountain). Hague's "Pogonip" includes all the carbonate rocks between the Dunderberg shale and the Eureka quartzite, ranging in age from middle Upper Cambrian to about the base of the Middle Ordovician. The sequence is approximately 3,500 feet thick at the type locality and includes units of thin-bedded cherty limestone, massive limestone, and massive dolomite.

Hague (1892) also used the name "Pogonip" at Eureka for the limestones between the Dunderberg shale and the Eureka quartzite, and the name has been used throughout eastern Nevada for limestones of the same approximate age. Walcott (1923) proposed the name "Goodwin formation" for the lower part of Hague's Pogonip formation at Eureka and this name has been tentatively retained by Nolan et al. (1956). C. W. Merriam (personal communication) suggested that the name "Pogonip" be reserved as a group name for all the Upper Cambrian and Lower Ordovician sedimentary rocks in eastern and southern Nevada which lie between the Dunderberg shale or its equivalent and the Eureka quartzite. He notes that these rocks are generally limestone, but that they vary laterally in structure, composition, and appearance; consequently, individual units cannot be correlated throughout large areas. The author agrees with Merriam, but since the White Pine district is the type locality of the Pogonip formation it seems desirable to retain this name for a portion of the group sequence. The same name for a group and a formation is confusing, so the author proposes the name "Mount Hamilton group" to include all the rocks which Hague originally placed in the Pogonip formation.

The Mount Hamilton group in this area may be divided into two formations; the Goodwin formation is represented by two members, the Pogonip formation by four. The most pronounced lithologic change in the group sequence is between the second and third members, the second member being a massive dolomite and the third a thin-bedded, shaly nodular limestone. The author restricts the name "Pogonip formation" to the four upper members and has designated the two lower members as the "Goodwin formation." The members of the Goodwin formation are not

⁵Later workers (Nolan, T. B., et al., 1956) consider the Pogonip to be a group name. All references to this publication are the editors'.

strictly equivalent to the Goodwin limestone section at Eureka, since to the author's knowledge that section contains no dolomite and is dominantly thin-bedded limestone similar in lithology to the lower member in the White Pine district. Since they are partially similar in lithology and are approximately the same age it seems preferable to extend the name "Goodwin" to the White Pine district rather than to introduce a new name for the dolomite member.

The structure of the Mount Hamilton area is complicated and no complete stratigraphic section of the rocks of the Mount Hamilton group can be measured. The sequence presented here has been built up from a number of partial sections. In Blackrock Canyon, about 15 miles south of Mount Hamilton, there is an excellent and complete section of Paleozoic rocks ranging from the Upper Cambrian Goodwin formation to the Devonian Nevada limestone. The similarity of the stratigraphy in the two areas is striking; hence the author is confident that his interpretation at Mount Hamilton is correct.

*Goodwin formation.*⁶—The Goodwin formation conformably overlies the Dunderberg shale and is more than 1,500 feet thick. It forms the peak of Mount Hamilton and extends along the ridge from the Seligman thrust south to the Ophir fault. It also makes up the greater part of the upper plate of the Monte Cristo thrust.

Member 1 ranges from 700 to 1,000 feet thick, as measured in partial sections. The best section of member 1 is near the top of the west side of Pogonip Ridge, just north of Mount Hamilton. The lower 400 to 600 feet are bluish thin-bedded fine-grained flaggy limestone with no shale and very little chert. Faunal remains are not abundant, but *Eurekaia* sp. and *Lingulella* sp. are present and these are considered Upper Cambrian by G. A. Cooper. Resting upon the flaggy limestone are about 20 feet of buff thin-bedded shale-parted limestone which generally weathers red brown. Overlying the shale-parted limestone unit are about 400 feet of thin-bedded fine-grained limestone and interbedded chert. Common fossils in these beds are *Saukiella* sp., *Eurekaia* sp., *Lingulella* sp., *Irvingella* sp., and an undetermined spiny-tailed trilobite. Cooper places these fossils in the Upper Cambrian or more specifically in zone I as shown in figure 7, which illustrates

⁶Since the completion of the manuscript for this paper, the unit here called Goodwin has been named Windfall formation at Eureka by Nolan, Merriam, and Williams (1956), and Goodwin has been used by them for the basal formation of their Pogonip group (A. R. Palmer, written communication, 1960).

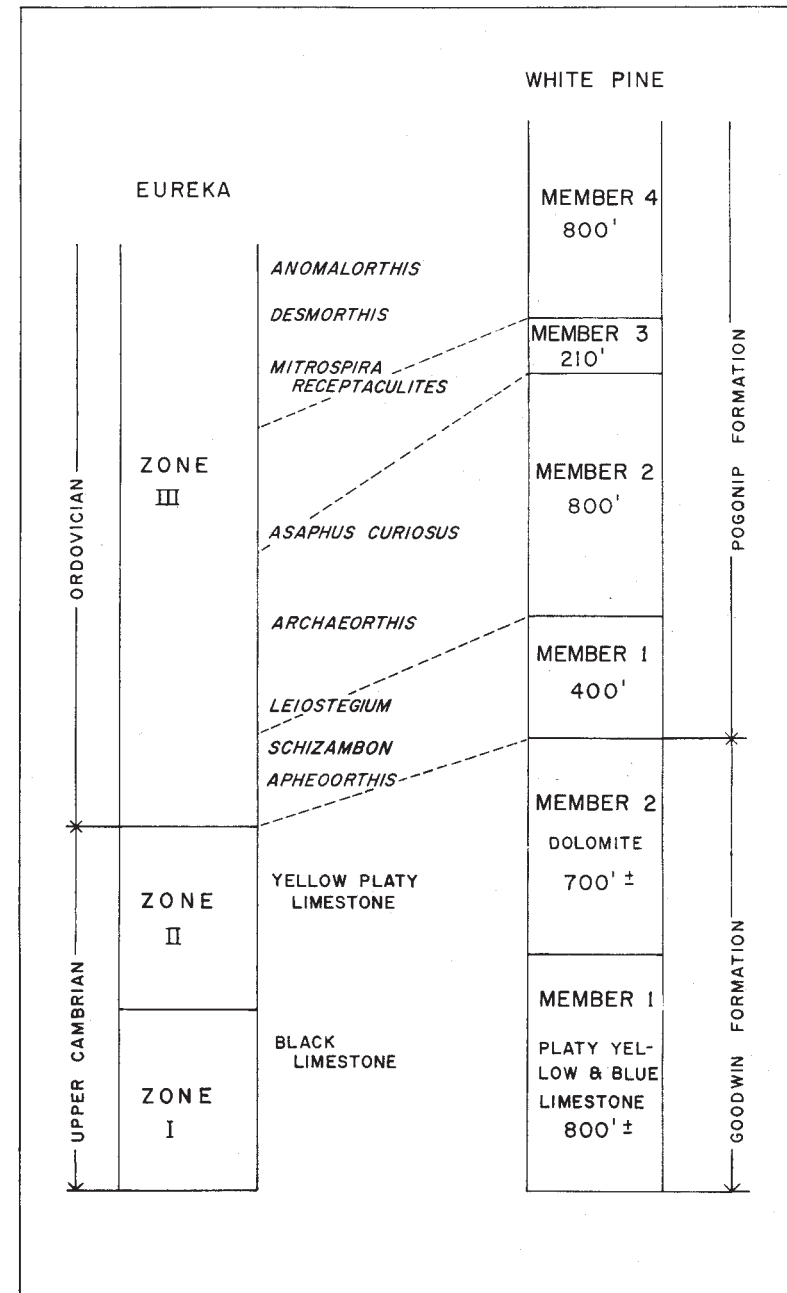


FIGURE 7. Faunal Zones of the Pogonip formation at Eureka, Nevada (after Dr. G. Arthur Cooper), compared to members of the Pogonip formation in the White Pine district.

the faunal zones of the Pogonip group at Eureka as established by G. A. Cooper. The small spiny-tailed trilobite which is common in these beds has eight spines, four on each side. The spines are about one-eighth of an inch long and are shaped like the cross section of a thin wedge. These trilobites are a distinct aid in mapping because they are entirely restricted to the upper portion of member 1.

Member 1 characteristically forms talus-covered slopes on the west and south slopes of ridges, but generally forms cliffs on the north sides of ridges.

The thickness of member 2, a rather massive dolomite, is unknown because of faulting, but it is not less than 500 feet thick. In Blackrock Canyon, where it is extremely well exposed, member 2 is about 1,250 feet thick. On Pogonip Ridge it varies from medium- to dark-gray in color. Near Mount Hamilton, where fracturing is intense, a zebra-like banding has been developed, consisting of irregular light and dark bands. The banding is undoubtedly due to differential recrystallization and bleaching owing to the proximity to the intrusion.

Member 2 is generally medium-grained and commonly has a sugary texture on weathered surfaces. It appears to be dolomite in this area, but in Blackrock Canyon the lower 600 feet are composed of a massive dark dolomitic limestone.

No faunal remains were found in the dolomite, but member 1 of the overlying Pogonip formation contains a "lowermost Ordovician or Uppermost Cambrian" fauna, according to G. A. Cooper.

A complete section of member 2 was not seen although the basal portion is present in Seligman Canyon and in the upper plate of the Monte Cristo thrust. The upper portion of member 2 is exposed for a short distance in the lower plate of the Monte Cristo thrust conformably underlying the Pogonip formation. Due to the uniform lithology of the unit it could not be determined if there is any overlap in these sections.

This formation apparently comprises the faunal zones I and II as established by G. A. Cooper for the Pogonip group at Eureka (fig. 7).

*Pogonip formation*⁷.—The time boundaries of the Pogonip formation, which is about 2,000 feet thick, coincide closely with those of the Early Ordovician epoch. The abrupt change in sedimentation from the massive dolomite of member 2 of the Goodwin

⁷The Pogonip formation of this paper equals the Pogonip group of Nolan, Merriam, and Williams (1956) (A. R. Palmer, written communication, 1960).

formation to the thin-bedded shaly unit at the base of the Pogonip formation suggests an important environmental change and may also represent a brief hiatus.

Member 1 comprises approximately 400 feet of alternating thin-bedded shale-parted limestone and massive medium-gray limestone beds from 1 to 3 feet thick. The massive beds are relatively coarse-grained and locally contain abundant fossil fragments. The shale partings in the thin-bedded limestone are as much as one-half inch thick; the limestone beds range in thickness from 1/2 inch to 2 inches. This distinctive member is found only in the footwall of the Monte Cristo thrust fault along its southern portion. The entire member is exposed only at the extreme south end of the Monte Cristo thrust. In the northern part of the district it is apparently faulted out by the Seligman thrust fault. This member contains near its base *Xenostegium* sp., *Aphoerthis melita*, *Acrotreta*, and *Nanorthis hamburgensis*, and is therefore considered by G. A. Cooper as "lowermost Ordovician or uppermost Cambrian," these forms are placed in the *Aphoerthis* horizon of zone III (fig. 7). The Cambrian-Ordovician boundary must approximate or coincide with the contact between the Goodwin and Pogonip formations.

Member 2 consists of more than 600 feet of thin-bedded reddish-brown weathered limestone, commonly with thin reddish, but locally buff, shale partings. Thin chert lenses elongated parallel to the bedding are common throughout the member. Characteristically the limestone has weathered more reddish brown than member 1 of the Goodwin formation. South of the Monte Cristo thrust, along the western edge of the range, member 2 is dolomitized. Faunal remains are not abundant, but those found indicate this member belongs in lower zone III, extending up into the *Archaeorthis* zone (fig. 7). The complete thickness cannot be ascertained, but it probably exceeds 800 feet. In Blackrock Canyon member 2 is about 800 feet thick.

Member 3 is fairly massive medium- to dark-gray medium-grained limestone. The thickness ranges from about 160 feet north of Mount Hamilton to a maximum of 210 feet near the southernmost exposures of the Pogonip formation. This member is in the middle portion of faunal zone III and extends upward to within about 30 feet of the *Receptaculites* zone (fig. 7). North of Mohawk Canyon, where it forms the dip slope into the next canyon to the north, the limestone has been locally dolomitized and somewhat resembles member 2 of the Goodwin formation.

However, it is recognizable as member 3 because it is concordantly overlain by member 4 of the Pogonip formation.

Member 4 is a thin-bedded limestone member which is about 800 feet thick in the southern part of the area and somewhat resembles member 2 except for the almost complete absence of chert. It is the most fossiliferous member of the group and may thus be distinguished from member 2 of the Pogonip formation. The presence of abundant *Receptaculites mammillaris* in a 10-foot bed about 30 feet above the base is of considerable aid in mapping. The *R. mammillaris* occurs in a thin-bedded gray limestone which is overlain by a bed of reddish-weathered thin-bedded limestone. *R. mammillaris* is found throughout the area in this one bed and associated *Receptaculites elongatus* may be found sparsely for 40 or 50 feet higher in the section.

The top of member 4 consists of from 10 to 20 feet of fine-grained, buff-weathered dolomite. This dolomitized bed varies in thickness from place to place, but it seems to be a diagnostic feature of the top of the Pogonip formation.

The following are G. A. Cooper's determinations of the fauna collected from the Mount Hamilton group. The corresponding locality numbers are shown on the geologic map (pl. 1).

Locality	
F4:	Zone III (upper) <i>Desmorthis nevadensis</i> U. and C., <i>Orthambonites</i> sp.
F13:	Zone III (upper) <i>Desmorthis nevadensis</i> U. and C., <i>Leperditia fabulites</i>
F21:	Zone III (lower) cystid plates
F34:	Zone III (lower) <i>Lingulella</i> , <i>Nanorthis</i>
F35:	Zone III (<i>Archaeorthis</i> zone) <i>Archaeorthis</i>
F36:	Zone III (upper) <i>Anomalorthis</i> , <i>Orthambonites</i>
F41:	Zone III (upper) <i>Desmorthis nevadensis</i> U. and C.
F45:	Zone III (middle) <i>Archaeorthis</i> sp.
F46:	Zone III (upper) <i>Anomalorthis</i> sp., <i>Leperditia fabulites</i>
F47:	Zone III (<i>Mitrospira</i> zone) <i>Receptaculites mammillaris</i>
F58:	Zone III (upper) <i>Orthambonites</i> sp.
F62:	Upper Cambrian—saukid tail (member 1, Goodwin formation)
F63:	Upper Cambrian— <i>Weeksina unispina</i> (member 1, Goodwin formation)
F66:	Upper Cambrian—saukid trilobite
F69:	Zone III (lower middle) " <i>Asaphus</i> " <i>curiosis</i> (Billings)

Locality	
F72:	Zone III (high) <i>Anomalorthis</i> sp., <i>Pliomerops barrandei</i>
F74:	Zone III (middle) <i>Archaeorthis</i> sp., <i>Pliomerops</i> sp.
F75:	Zone III (low in upper part) <i>Orthambonites</i> sp., <i>Maclurites</i> sp., <i>Orthidiella?</i> sp., asaphoid trilobite
F77:	Zone III (middle) <i>Goniruuus</i> sp., <i>Cybelopsis</i> sp., <i>Syntrophopsis</i> , <i>Pliomerops</i> sp., <i>Hesperonomiella</i>
F79:	Upper Cambrian— <i>Eureka</i> sp.
F84:	Zone III (upper) <i>Orthambonites</i> sp., <i>Anomalorthis?</i> sp.
F85:	Zone III (high) <i>Leperditia fabulites</i> , <i>Pliomerops barrandei</i>
F86:	Zone III (high) <i>Orthambonites</i> , coral, n. gen.
F100:	Upper Cambrian (Trempealeau)— <i>Richardsonella</i> cf. <i>R. megalops</i> (Billings), <i>Leiocorphe gemma</i> Clark
F101:	Zone III (middle) <i>Archaeorthis elongata</i>
F102:	Zone II <i>Lingulella</i> , <i>Idahoia</i>
F106:	Upper Cambrian— <i>Pterocephalina bilobata</i>
F107:	Upper Cambrian—(upper Zone II) <i>Lingulella</i>
F108:	Upper Cambrian— <i>Lingulella</i> , <i>Eureka?</i> , <i>Briscola?</i>
F110:	Upper Cambrian— <i>Acrotreta</i> , <i>Lingulella</i>
F111:	Upper Cambrian—cf. <i>Ellipsocephaloides</i>
F113:	Upper Cambrian— <i>Eureka</i>
F114:	Upper Cambrian or basal Ordovician— <i>Xenostegium</i> sp., <i>Apheoorthis melita</i> , <i>Acrotreta</i>
F115:	Zone III (upper— <i>Mitrospira</i>) cystid plates, <i>Orthidiella</i> sp.
F121:	Zone III (high) <i>Anomalorthis nevadensis</i> , <i>Leperditia fabulites</i> , bryozoa
F122:	Zone III (high) <i>Leperditia fabulites</i> , <i>Pliomerops barrandei</i> , bryozoa
F24B:	Zone III (upper) <i>Hesperonomia</i> sp., <i>Hesperonomiella</i> sp.?
F25B:	Base of Zone III (of Nolan) <i>Nanorthis hamburgensis</i>
F27B:	Upper Cambrian (Pogonip Zone I of Nolan) <i>Eureka</i> sp., <i>Irvingella</i> , sauکید trilobite

These determinations do not substantiate the statement made by Holliday (1940) that Pogonip rocks in the White Pine Range contain an Upper Ordovician fauna. The faunas listed above indicate that the upper part of the Pogonip formation in this area is Chazyan.

Blackrock Canyon section.—The Mount Hamilton group is well exposed in the upper part of Blackrock Canyon, about 15 miles

south of this district. This section is practically unfaulted in contrast to the extensively faulted section in the White Pine district. Member 2 of the Goodwin formation is about 1,250 feet thick; the lower part is massive medium- to dark-gray dolomitic limestone and the upper part is massive dolomite. Overlying the dolomite, but below the characteristic basal member of the Pogonip formation, there are about 150 feet of cherty thin-bedded (1 to 3 inches) dark-blue medium-grained limestone. The cherty limestone is the only unit in the Blackrock Canyon section that has not been recognized in the White Pine district.

The basal member of the Pogonip formation is about 450 feet thick and is typically thin-bedded, shale-parted limestone which alternates with massive beds, 1 or 2 feet thick, of medium- and coarse-grained limestone. Member 2 is about 800 feet thick and is similar in appearance to member 2 on Pogonip Ridge. Members 3 and 4 are also practically identical lithologically with these same units on Pogonip Ridge. The *Receptaculites* zone is present also at the base of member 4 and overlies the more massive and gray member 3. The buff dolomite comprising the top of the formation is about 30 feet thick instead of 10 to 20 feet as on Pogonip Ridge.

MIDDLE ORDOVICIAN

Eureka quartzite

The Eureka quartzite was named by Hague (1883) from a section in the Eureka district. Prior to 1883 this formation had been referred to as the Ogden quartzite by Hague (1877).

In the White Pine district the Eureka quartzite ranges in thickness from 250 feet at the north end of Pogonip Ridge to 400 feet at the south end. The formation consists of about 20 to 30 feet of basal pinkish sandstone interbedded with thin quartzite beds. This basal sandstone is overlaid by massive vitreous white or pale-pink quartzite. The basal portion of the Eureka quartzite is seldom visible because it is easily eroded and is generally covered with thick quartzite talus. The bedding has been partially obliterated by cementation and intense fracturing, but the gross aspects of bedding can be distinctly observed from a distance.

The age of the formation is probably Middle Ordovician but may be in part lower Upper Ordovician. The Eureka quartzite lies between the upper Pogonip formation of Chazyan age and the Hanson Creek dolomite, whose basal 100 feet contain Upper Ordovician fossils.

There is no angular discordance between the Eureka quartzite and the underlying or overlying rocks. The upper member of the

underlying Pogonip formation is of uniform thickness throughout the district. However, the 10- to 20-foot-thick buff fine-grained dolomite unit at the top of the Pogonip formation may be the result of penecontemporaneous dolomitization of the uppermost portion of the limestone due to changing environmental conditions in the depositional basin. There may be a hiatus, but there was probably little or no erosion prior to the deposition of the sand.

The variable thickness of the quartzite and its sharp contact with the overlying dolomite suggest a disconformity. Sharp (1942) found no Eureka quartzite in the Ruby Mountains, which are about 75 miles north of the White Pine district, and assumed that it was eroded prior to the deposition of the younger limestone. Merriam and Anderson (1942) measured a thickness of 500 feet in the Roberts Mountains, about 40 miles northwest of the White Pine district, and demonstrated that the formation thins southward toward the Antelope and Monitor Ranges. At Tybo, still farther south, Ferguson (1933) described a marked unconformity with the dolomite; here the Eureka quartzite is badly channeled and in some places missing. Thus, at least locally, an unconformity exists at the top of the formation.

The Eureka quartzite ranges between 250 and 500 feet in thickness in Nevada, southeastern California, and western Utah, where it has not been materially eroded. Such a widespread uniform sheet of sand differs remarkably from most near-shore sandstone facies. In the White Pine district and elsewhere, the Eureka quartzite is a relatively fine-grained practically pure quartz sand, generally cemented by silica. Deposition may have taken place in an extremely large but shallow basin. Apparently the wave action and currents were very active and able to distribute the sand more or less evenly over the entire basin. The purity of the sand demonstrates the concentrating or classifying ability of ancient ocean currents to remove completely any argillaceous or calcareous materials. The sand must have been continually shifting from place to place under the influence of the waves and currents, but at the same time it slowly accumulated until, with the closing of the seaway in the direction of the source or a change in direction of the currents through the basin, the deposition of sand ceased abruptly.

The source of this great amount of sand is unknown. Its purity, fine-grain size, and apparently equivalent age over the entire basin indicate that the Eureka quartzite is not a "basal conglomerate" type of deposit. Furthermore, the complete absence of any pebbles suggests that the sand may have been moved a considerable distance from its source.

UPPER ORDOVICIAN

Hanson Creek dolomite

The Hanson Creek dolomite, named by Merriam (1940) in the Roberts Mountains quadrangle west of Eureka, is equivalent to the basal member of the Lone Mountain formation named by Hague (1892) at Lone Mountain. Merriam restricted the Lone Mountain formation to the massive dolomite which is the upper part of Hague's Lone Mountain formation. The Hanson Creek dolomite and the Lone Mountain dolomite, as restricted by Merriam, are separated both at Lone Mountain and in the Roberts Mountains by a thick section of thin-bedded limestone. Merriam logically designated this as a separate lithologic unit and named it the Roberts Mountains formation. This formation apparently lenses out to the east and is not present in the White Pine district, nor to the author's knowledge is it present in the Diamond Range between the Roberts Mountains and the White Pine district. Since the Roberts Mountains formation is not present in the White Pine district, the Hanson Creek dolomite and the Lone Mountain dolomite could be considered as one formation. However, because the Hanson Creek dolomite is a distinct unit that may be easily differentiated from the members of the Lone Mountain formation the author deems it advantageous to apply Merriam's designation.

The Hanson Creek dolomite is confined to Pogonip Ridge, and with the exception of the basal beds of the Lone Mountain dolomite at the north end, it is the youngest sedimentary rock exposed within the Pogonip "dome."⁸

The formation is between 600 and 850 feet in thickness and is dominantly a dark-gray to black fine-grained dolomite which grades rapidly and distinctly into a light-gray coarse-grained basal dolomite of the Lone Mountain formation. About 100 feet above the base there are 30 feet of thin-bedded reddish-tinted dark limestone containing *Dinorthis* sp., which G. A. Cooper considers to be Upper Ordovician. The formation contains scattered small colonies of the coral *Streptelasma* which are white and therefore stand out distinctly in the black dolomitic matrix.

The lower portion of the formation is Upper Ordovician, but the age of the upper portion is not known and may be in part Silurian.

⁸A topographic dome, not a structural dome (editors).

SILURIAN AND LOWER DEVONIAN(?)

Lone Mountain dolomite

Overlying the black Hanson Creek dolomite and gradational with it through a thickness of about 25 feet is a light-gray coarse-grained dolomite which is overlaid in turn by four other distinct dolomitic members. Although no fossils have been identified in these beds, they are assigned to the Lone Mountain dolomite and are considered on stratigraphic evidence to be Silurian and Lower Devonian. The formation is about 2,100 feet thick.

The top of the Lone Mountain dolomite is placed at the base of a thin-bedded reddish fine-grained limestone which contains a Middle Devonian fauna, but these basal beds of the overlying Nevada limestone are locally dolomitized which renders an exact location of the contact difficult.

An excellent example of an unfaulted section of the Lone Mountain dolomite, about 2,000 feet thick, crops out in the upper part of Blackrock Canyon, about 15 miles south of the White Pine district. This section is mentioned because of its striking similarity to sections of the Lone Mountain dolomite within the White Pine district; in fact, it was only through examination of the Blackrock Canyon section that the stratigraphy of the Lone Mountain dolomite in the White Pine district could be satisfactorily worked out. No equivalent of the Roberts Mountains formation was noted in Blackrock Canyon.

Five members of the Lone Mountain dolomite have been differentiated. The basal unit, member 1, consists of about 450 feet of light-gray, coarse-grained dolomite which overlies the black Hanson Creek dolomite. Member 2, which is between 300 and 400 feet thick, consists of a lower dark fine-grained dolomite which weathers to a faint reddish tinge overlaid by 200 feet of mostly light-gray coarse-grained dolomite. These are regarded as one member because there are beds of the dark fine-grained dolomite in the light-gray, coarse-grained dolomite. Member 3, which averages about 300 feet thick, is a very fine-grained white porcelaneous dolomite. There is an unusual and significant series of thin (1 inch to 1 foot) quartzite beds in the upper part of this member, both in Blackrock Canyon and in the White Pine district. Member 4 consists of approximately 300 feet of coarse-grained sugary alternating medium- and light-gray dolomite beds. This member contains a few dark-gray beds, particularly in the upper part. Member 5 is dominantly a dark- to medium-gray, mottled dolomite

between 500 and 700 feet thick. It is gradational with member 4 over a stratigraphic interval of more than 100 feet, with alternating beds of coarse-grained light-gray dolomite and mottled dark-gray dolomite. The mottled appearance of this member is extremely distinct on weathered surfaces. Small medium- to light-gray lenses $\frac{1}{2}$ to 1 inch long are in a matrix of dark-gray fine- to medium-grained dolomite.

Member 1 is found only at the north end of Pogonip Ridge where it conformably overlies the Hanson Creek dolomite. Members 2, 3, 4, and 5 crop out on the west slope of Treasure Hill; however, due to faulting, no single complete section of these members can be measured. Member 1 is faulted out in this area by the Sherman fault.

The outcrops of Lone Mountain dolomite on Treasure Hill extend from the Eberhardt fault, near Shermantown, northward for about 3 miles. From the Rocco Canyon road northward to the Hamilton fault, the Sherman fault cuts diagonally across the formation and the members appear to be faulted out in sequence. The southern half of the contact with the Nevada limestone may be a normal sedimentary contact, but to the north the shear zone that makes up the west branch of the Hamilton fault obscures the exact relationship. There is little apparent displacement along this shear zone so that it probably approximately represents the normal sedimentary contact. The lowermost Nevada limestone may be dolomitized and both the Nevada limestone and Lone Mountain dolomite are commonly altered in appearance by mineralization.

In Rocco Canyon portions of members 2, 3, 4, and 5 are present. The older beds crop out at the south end of this dolomitic area and younger rocks progressively crop out toward the north end. The entire area is so complexly faulted as almost to constitute a dolomitic breccia.

The thin quartzite beds, previously referred to, occur at the top of the white porcelaneous member 3. Generally white and vitreous, the quartzite is strikingly similar in appearance to Eureka quartzite. There are commonly three of these beds within a stratigraphic thickness of about 40 feet. They generally range in thickness from 1 inch to about 1 foot, and one or the other may pinch out for a short distance. Where a quartzite bed lenses out, its place is taken by sandy cross-bedded dolomite. These quartzite beds are a great aid in solving structural-stratigraphic problems.

They are of particular economic significance because it is in this horizon that the faulted bedded ore deposits of the Rocco-Home-stake and Fay mines were formed.

The author believes that the uppermost Lone Mountain dolomite represents deposition during the Lower Devonian, because the lowermost portion of the overlying Nevada limestone in this district contains a Middle Devonian fauna. There is no evidence of angular discordance between the Lone Mountain dolomite and the overlying Nevada limestone, nor any suggestion that Lower Devonian rocks are missing in this area, or elsewhere in the region. The Lone Mountain formation of this district probably represents the entire time interval from Early Silurian to Middle Devonian.

There is a significant and widespread distribution of the aforementioned quartzite and sandy dolomitic beds. Not only are they present in the Blackrock Canyon section 15 miles to the south but the author has traced them as far south as the Worthington Mountains, about 100 miles distant, and as far to the southeast as the southern end of the Egan Range about 5 miles south of Sunnyside, some 65 miles away. In the Worthington Mountains there is one quartzite bed about 10 feet thick, overlaid by about 5 feet of sandy cross-bedded dolomite. Near Sunnyside there is one three-foot thick quartzite bed overlaid by 10 feet of sandy cross-bedded dolomite which, in turn, is overlaid by a one-foot thick bed of quartzite. In all cases the quartzite is at the top of a white fine-grained porcelaneous dolomite similar to that in the White Pine district. The author was told by William C. Bishop that near Hiko, about 60 miles south of Sunnyside, there are about 100 feet of sandstone which on faunal evidence is Lower Devonian and may therefore be a partial equivalent of member 3 of the Lone Mountain dolomite. In the Diamond Range, about 4 miles east of Eureka, T. B. Nolan and C. W. Merriam (personal communications) found about 100 feet of quartzite overlying a white fine-grained dolomite similar to that in the White Pine district. On scant faunal evidence they place the quartzite near the Silurian-Devonian systemic boundary.

MIDDLE AND UPPER DEVONIAN

Nevada limestone

The Nevada limestone, as originally named by Hague (1892) in the Eureka district, included all the limestones between the Lone Mountain dolomite and the White Pine shale. In the Roberts Mountains quadrangle this section of limestones represents practically the entire Devonian Period, although the term "Nevada

formation" was restricted by Merriam (1940) to the lower half of the section. He chose the *Stringocephalus* faunal zone as the line of demarcation, and renamed the upper portion of the section the Devils Gate formation; however, this is not a separate lithogenetic unit and thus does not conform to the accepted definition of a formation.

In the White Pine district fossils contained in the limestone immediately above the Lone Mountain dolomite are Middle Devonian, and insofar as the author could determine there is no *Stringocephalus* zone in the limestone. Consequently most of the limestone overlying the Lone Mountain dolomite must correspond to Merriam's Devils Gate formation and the restricted Nevada formation of Merriam is equivalent in age to the upper part of the Lone Mountain dolomite of this district.⁹ The author recognized no criteria that indicate a disconformity or hiatus between the Lone Mountain dolomite and the Nevada limestone and prefers to retain the term "Nevada" for all the limestone as originally defined by Hague; no division corresponding to that of Merriam (1940) can be made.

The formation is about 1,600 feet thick. The basal 250 to 350 feet consist of thin-bedded limestone with buff and reddish partings which lithologically resembles member 4 of the Pogonip formation. Although there is a distinct change in lithology from the massive Lone Mountain dolomite to this thin-bedded reddish limestone, the latter have been commonly dolomitized. This probably represents a continuation of the lithogenetic conditions within the basin that produced the Lone Mountain dolomite. Fossil localities F51, F52, and F55, on Ridgely in the southwestern part of the district, are in this thin-bedded limestone. These collections contain *Atrypa* sp., "*Martinia*" sp., and *Paracyclas* sp., and were designated Middle(?) Devonian by Cooper. The collection from fossil locality F18A, on the south slope of Treasure Hill, contains *Leiorhynchus* sp. and *Emanuella* sp., also determined as Middle(?) Devonian by Cooper. The collection from locality F19A, close to F18A, contains *Amphipora* sp. and is considered to be Middle Devonian. The collection from locality F20A, nearby but across a fault and slightly higher in the section, contains two specimens of *Atrypa* sp. which were classed as lower Upper Devonian. Fossil locality F17B, on the south side of Rocco Canyon, is in the thin reddish-parted limestone and, based on a

⁹The editors feel that the foregoing statements are not sufficiently substantiated by paleontological evidence, but that Dr. Humphrey's views should be presented intact.

species of *Amphipora*, is considered to be Middle Devonian. Consequently, faunal evidence indicates that the base of the Nevada limestone in this area is Middle Devonian, probably upper Middle Devonian in age.

Overlying the thin-bedded limestone there are between 1,250 and 1,350 feet of massive medium-gray to bluish-gray medium-grained limestone in beds 1 to 6 feet thick (fig. 8). The most accessible and spectacular outcrops of this portion of the formation are in Cathedral Canyon. There are two beds of thin-bedded

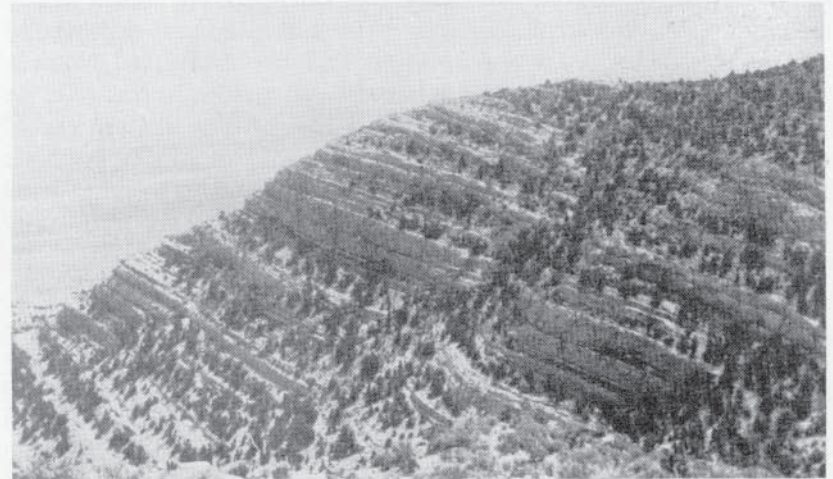


FIGURE 8. Upper part of Nevada limestone exposed on Ridgely.

buff limestone in this section, each a few feet thick, but they do not appear to be continuous throughout the area. The top of the Nevada limestone forms the crest of Treasure Hill and the formation's massive character is well displayed there. The best section of the formation may be seen on Ridgely in the southwestern part of the district. Except for repetition by an east-dipping fault, a good section crops out westward from the base of the ridge at the top of the Lone Mountain dolomite. A complete section, except for the basal 100 to 150 feet, is exposed west of this fault. Two small faults cut this section at the west end of section A-A' (pl. 1). The formation at this locality is about 1,600 feet thick.

Faunal determinations indicate that the massive limestone is mostly Upper Devonian, but fossil localities F15 and F16 in Cathedral Canyon were classed as Middle Devonian. Collections from these localities contain *Alveolites*, *Radiastraea*, *Atrypa*,

Spongophyllum, and *Amphipora* sp. Other fossils from the massive limestone in Cathedral Canyon and on Babylon Ridge include *Synaptophyllum* sp., *Cladopora* sp., *Atrypa* sp., *Oyrtospirifer* sp., *Thamnopora* sp., *Productella*, *Tylothyris* sp., *Schizophoria*, *Nervostrophia*, *Clathrodictyon*, *Alveolites*, *Ptenophyllum* sp., *Phillipsastraea verrilli* (Meek), *Atrypa* cf. *A. montanensis* Kindle. The upper 300 to 400 feet of the formation contain few fossils except for abundant *Synaptophyllum* (?), a spaghetti-like coral.

MISSISSIPPIAN

Pilot shale

Conformably overlying the Nevada limestone there are between 150 and 200 feet of shale which correspond stratigraphically and lithologically to the Pilot shale described by Spencer (1917) in the Robinson district. The shale is limy, thin-bedded, platy, weathers reddish brown, and fresh surfaces show alternations of buff and black. Locally the shale resembles the black shale of the White Pine formation, except that the Pilot shale has a platy habit and the black shale of the White Pine formation is thin and fissile.

No fossils were found in the Pilot shale, but it lies between the Upper Devonian Nevada limestone and the Lower Mississippian Joana limestone. The Devonian-Mississippian systemic boundary is probably within the Pilot shale.

The Pilot shale extends as far west as the Diamond Range but is not recognized in the Roberts Mountains. About 15 miles north of Eureka in the west-central part of the Diamond Range, the Pilot shale is about 150 feet thick.

Joana limestone

The Joana limestone is a massive limestone unit which ranges from 150 to 250 feet in thickness. The formation was named by Spencer (1917) in the Robinson district, where it lies between the Pilot shale and the Chainman shale. The Chainman shale is in part the age equivalent of the White Pine formation.

The Joana limestone is composed of light- to medium-gray, medium- or coarse-grained, recrystallized limestone which abounds with recrystallized crinoid stems. The most characteristic feature of the formation, in addition to the ubiquitous crinoid stems, is the abundance of chert nodules and lenses which parallel the bedding. Crinoid stems and brachiopods are commonly preserved in the chert and these cherty specimens are superior to those found in the limestone because the limestone

specimens are generally recrystallized. The replacement by chert probably took place prior to the recrystallization of the limestone because the fine structures of the crinoid stem plates are well preserved in the chert but are absent in the limestone.

Over the entire area the limestone is locally replaced by a dark reddish-brown jasperoid which resembles fine-grained quartzite but has a cryptocrystalline texture and is everywhere brecciated. The jasperoid is generally restricted to the upper portion of the formation but in some places may extend through the entire section.

This jasperoid, which is restricted to the Joana limestone, is generally associated with faults, indicating that faulting must have exercised some control over the formation of the jasperoid. However, it is not found in other limestone formations within the White Pine district, no matter how intensely they are faulted or mineralized. The jasperoid replacement is most abundant at the top of the formation which suggests the possibility that the silica may have been derived from the overlying White Pine shale. No original limestone structures or faunal remains are preserved in the jasperoid, which was undoubtedly formed later than the chert and generally later than the major faulting.

The formation is regarded as Lower Mississippian by G. A. Cooper. Fossil locality F27 at the north end of Treasure Hill contains *Centrocellulosum*?, *Hapsiphyllum*?, *Syringopora*, and crinoid stems. Fossil localities F97 and F119 near Cathedral Canyon have yielded a proetid trilobite, chonetid? productid?, *Spirifer*, and *Syringopora*.

On the west side of the Pancake Range, about 12 miles west of Mount Hamilton, the Joana limestone has a maximum thickness of about 75 feet and is lenticular along the strike. Locally it appears to lens out completely. About 2 miles north of Duckwater, 25 miles southwest of Mount Hamilton, the Joana limestone is missing. In the Newark Pass area of the Diamond Range, about 30 miles northwest of the White Pine district, T. B. Nolan (personal communication) found approximately 50 feet of dark crinoidal limestone at the base of the black White Pine shale. About 10 miles north of the Newark Pass area on the west side of the Diamond Range Nolan (personal communication) found about 100 feet of interbedded thin-bedded limestone and limy shale between the Pilot shale and the White Pine shale. The formation has not been found in the Roberts Mountains to the west of the Diamond Range. Thus it is well demonstrated that the thickness of the Joana limestone decreases appreciably to the southwest,

west, and northwest of the White Pine district. However, the "lensing in and out" of the limestone in the Pancake Range west of the White Pine district may be an erosional feature.

White Pine formation

The White Pine shale was first named by Hague (1877). The type locality is near Hamilton. Unfortunately the scattered shale outcrops east and north of Hamilton constitute a landslide area involving the White Pine formation, the Upper Mississippian Diamond Peak formation, and the Pennsylvanian Ely limestone. Portions of these formations slid over the shale and are intimately mixed with it. The surface is an excellent example of landslide topography and displays its characteristic hummocks and depressions (fig. 9).

The original term White Pine "shale" is misleading because of the several facies variations in the formation within the district. Consequently, for this area the author prefers the term White Pine "formation," designated to include all the beds between the Joana limestone and the Diamond Peak formation.

About 3 miles north of Hamilton an unfaulted area of White Pine formation furnishes a good section, although the outcrops are generally poor. The identity of the rocks in the unexposed areas was determined by surface characteristics, by float, and by digging shallow holes. The section in this area is about 1,900 feet thick, but this figure is only approximate because the dip varies considerably and the thickness was determined by employing the average dip between the underlying Joana limestone and the overlying Diamond Peak formation. The contact with the underlying Joana limestone is sharp but the contact with the overlying Diamond Peak formation is gradational, with the shale becoming more and more sandy. The upper contact is arbitrarily placed at the point of appreciable increase of slope because sandstone float obscures the actual contact. The change in slope is attributed to the topographic expression of the more resistant sandstone beds of the lowermost portion of the Diamond Peak formation.

The White Pine formation demonstrates alternating facies changes over short distances. Near Hamilton, and northward for several miles, the predominant lithology is black fissile carbonaceous shale with a few interbedded sandy layers toward the top. In the southern part of the district, east of Green Springs, most of the lower portion of the formation is composed of thin-bedded bluish fine-grained limestone. This is overlain by argillaceous beds which are sandy near the top. In Illipah Canyon,



FIGURE 9. Landslide topography north of Hamilton townsite.

along the east side of the district, the basal 700 to 800 feet of the formation are composed of thin-bedded, buff- and reddish-parted, bluish and gray limestone which resembles the upper Pogonip formation. The upper portion consists of several hundred feet of bluish and black fissile shale. The thickness of the shale could not be accurately determined but it exceeds 500 feet. In Sixmile Wash between these two areas of limestone facies the basal section of the White Pine formation is black shale similar to that north of Hamilton.

Just north of the mouth of Cathedral Canyon, the east-dipping Joana limestone forms a ridge about three-quarters of a mile long. Scattered outcrops of arenaceous limy beds apparently conformably overlie this massive limestone. The arenaceous limy beds contain pelecypods and brachiopods of Mississippian age and constitute still another facies of the lower part of the White Pine formation. The bluish thin-bedded lower White Pine limestone facies dips steeply to the west about 1,000 feet east of these outcrops. Between these two facies is one outcrop of west-dipping sandy shale which contains fossils considered to be "High Mississippian" and resembles the sandy shales near the top of the section south of Cathedral Canyon. Thus there may be a fault separating a lower White Pine sandy facies and a lower White Pine limestone facies.

South of Cathedral Canyon a bed of dense reddish-brown chert occurs in bluish thin-bedded limestone about 100 feet above the base of the White Pine formation. This silicified limestone resembles the jasperoid in the Joana limestone except that it lacks its characteristic brecciation. Similar reddish-brown massive chert beds occur in the White Pine formation north of U. S. Highway 50 on the east side of Little Antelope Summit and in the upper part of the White Pine limestone facies in Illipah Canyon. Massive cherts in the White Pine formation appear to occur in limestone beds stratigraphically close to shale.

No fossils were found in the lower part of the formation in the type section north of Hamilton. However, in the southern part of the district below Cathedral Canyon fossils in the basal member of the bluish thin-bedded limestone are definitely placed in the Lower Mississippian by G. A. Cooper. The fossils are considered equivalent to the Chouteau of the Mississippi River states.

Fossil collections from localities F98 and F99 contain:

Leptaena analoga
Chonetes sp.
Schuchertella sp.
Reticulariina
Orthotetes
Productina?
 echinoid plates

In the black shale facies in the upper half of the formation thin black limestone beds locally contain abundant fossil remains. This limestone is very fine-grained (almost lithographic) and breaks with a conchoidal fracture.

Locality F8A, about one mile south of Eberhardt, yielded:

Spirifer sp.
Linoproductus sp.
 "Aviculopecten"

Cooper placed these in "Mississippian (mid)." The fossil collection from locality F3A, within 100 feet of locality F8A, contained *Cravenoceras hesperium*, identified by Dr. Walter L. Youngquist. The fossil collection from locality F3B at the south end of the district, also identified by Youngquist, contains:

Mooreoceras sp.
Cravenoceras hesperium Miller and Furnish
Epicranites cf. *E. loeblichii* Miller and Furnish
Dimorphoceras humphreyi, n. sp.

This locality is within 200 feet of the top of the formation. In a personal communication dated May 31, 1947, Youngquist states: "In regard to the age of the White Pine . . . the fauna can definitely be correlated with that of the Caney shale of Oklahoma, and of course the White Pine shale (Girty, in Kirk 1918, p. 39) of southeastern California . . . the best estimate at present is that it is Meramec in age." There is agreement between Cooper and Youngquist that the upper half of the formation ranges between Meramec and Fayetteville in age. The White Pine formation in the White Pine district probably ranges in age from upper Kinderhook or Chouteau to middle Chester or Fayetteville. This indicates that the base of the formation is middle Lower Mississippian and the top is lower Upper Mississippian.

No volcanic rocks were noted in the White Pine formation in this district, although volcanic rocks of similar age are present in the Battle Mountain, Nevada area.

Diamond Peak formation

The Diamond Peak quartzite was named by Hague (1892) from the outcrops of sandstone and quartzite which overlie the black White Pine shale on the slopes of Diamond Peak, north of Eureka. There is no quartzite in this formation in the White Pine district (it is composed of sandstone and cherty conglomerates); therefore, it seems preferable to refer to it as the Diamond Peak formation.

The Diamond Peak formation conformably overlies the White Pine formation and is gradational with it. The Diamond Peak formation varies considerably in thickness throughout the district. North of Hamilton townsite, the complete section is about 1,000 feet thick. South of Cathedral Canyon, just beyond the south edge of the map (pl. 1), it is about 600 feet thick.

The Diamond Peak formation is dominantly a reddish-brown medium-grained sandstone which contains conglomerate lenses, but there are also scattered sandy shale beds which sometimes contain imprints of plant material. One good imprint of *Lepidodendron* bark showing the characteristic leaf scars was found. Conglomerate lenses are characteristic of the lower portion of the formation and some can be traced for several miles. The conglomeratic pebbles are dominantly green chert with lesser amounts of black, white, and reddish chert and a few small quartzite pebbles. The pebbles are generally less than 1 inch in diameter.

The origin of the chert pebbles in the Diamond Peak formation has not been determined. The abundant green chert pebbles may have had a source in the Ordovician Vinini shale in the Roberts Mountains area. According to Merriam and Anderson (1942), these rocks constitute the upper plate of a thrust fault and probably were originally deposited farther west.

Spencer (1917) does not mention sandstone between the Chainman shale (equivalent of the White Pine formation) and the Ely limestone, so it is presumed to be absent in the Robinson district. The author found between 50 and 100 feet of sandstone between the White Pine formation and the Ely limestone in the Connors Pass area about 20 miles southeast of Ely. Thus the Diamond Peak and the White Pine formations thin eastward from the White Pine district, which indicates a westerly source for the clastics. This source could well be the geanticline described by Nolan (1943) as present in west-central Nevada starting in late Devonian time.

No diagnostic fossil material was found in the Diamond Peak

formation, but its age can be inferred from its stratigraphic position between the base of the overlying Ely limestone which is Lower Pennsylvanian and the upper portion of the White Pine formation which is probably lower Upper Mississippian. The Diamond Peak formation is probably for the most part Upper Mississippian, but it may be in part Lower Pennsylvanian.

Several outcrops of white sandstone and chert-quartzite conglomerate immediately north of Sixmile House do not resemble Diamond Peak lithology. These rocks lie on characteristic Diamond Peak lithologies but the author believes that they rest unconformably on the Diamond Peak formation and are either Permian or younger. These outcrops of sandstone and chert-quartzite conglomerate are further described under "Permian (?) or Mesozoic (?)".

PENNSYLVANIAN**Ely limestone**

The name "Ely limestone" was first proposed by Lawson (1906) and later was used by Spencer (1917) in the Robinson district. The Ely limestone there comprises the lower massive member of a thick limestone section that overlies the Chainman shale.

The Ely limestone, exposed over about two-thirds of the eastern half of the White Pine district, is approximately 1,600 feet thick on Mokomoke Mountains. It conformably overlies the Diamond Peak formation and is gradational with it for nearly 100 feet. The basal contact is placed at the base of the first limestone beds above the noncalcareous sandstone; the lowermost 100 feet of the limestone contain variable amounts of sand which is more resistant to erosion and therefore readily visible on weathered surfaces. In addition, the basal 100 feet contain silicified fossils which help to differentiate the limestone from the sandstone. The remainder of the formation consists of massive beds of limestone from 10 to 100 feet thick, separated by 10- to 100-foot thick intervals of easily weathered, thinner bedded limestone. Normally, differential erosion of the beds results in a steplike sequence on the slopes. Chert nodules are a characteristic feature of the more massive beds. The massive beds are generally light gray to bluish gray and weather light buff; the intercalated, thin-bedded members are chiefly buff or light brown.

The formation is quite fossiliferous and, according to G. A. Cooper, is Pennsylvanian. Fossil localities F6A and F7A, within 200 feet of the base of the formation about three miles south of

Eberhardt, contain the following assemblage which is thought to be lower Pennsylvanian and the equivalent of Morrow:

Spirifer (rockymontanus—occidentalis type)
Composita
Cleiothyridina
Reticulariina
Eumetria
Dictyoclostus or *Marginifera* sp.

Fossil localities F15A, F16A, and F17A on Little Antelope Ridge, all within a few hundred feet of the base of the formation, were considered as "either High Mississippian or Morrow, probably the latter" by G. A. Cooper. They contain:

Composita
Linoproductus sp.

Spirifer (increbescens—rockymontanus type)

Spirifer (suggesting *striatus* type)
Dictyoclostus
Orthotetes sp.
Batostomella sp.
 productid sp.
 syringoporoid coral

Fossil localities F6B and F7B on Mokomoke Mountains, from near the top of the Ely limestone, are listed as "Pennsylvanian" and contain:

Composita sp.
Derbyia sp.
Cancrinella sp.
Wellerella sp.
Edmondia sp.
Neospirifer sp.
 productid sp.

These fossil assemblages indicate that the Ely limestone is probably entirely Pennsylvanian, although the basal beds may be uppermost Mississippian.

No shale was found in the formation within the district, but about two miles northward, in a highway cut at the western edge of Little Antelope Ridge, the lower part of the formation contains a 25-foot shale member which resembles the White Pine formation. A black shale member is exposed in the lower part of the formation by a man-made cut about seven miles north of this locality.

At the north end of Mokomoke Mountains several hundred feet of poorly exposed thin-bedded, shaly limestones overlie the intercalated massive and thin-bedded limestones. Although not differentiated on the geologic map, the shaly limestones possibly correlate with the Arcturus limestone named by Spencer (1917).

In the northeast corner of the district there is a one-foot bed of white sandstone overlaid by 10 to 20 feet of calcareous sandstone between the Ely limestone and the overlying thin-bedded, shaly limestone.

Between the junction of the Hamilton road with U. S. Highway 50 and Jakes Valley to the east, a thickness of more than 5,000 feet of limestone probably furnishes a fairly complete section from Lower Pennsylvanian to well up into the Permian. The basal 200 to 300 feet of the Ely limestone are missing because of the Illipah thrust and another thrust about 1½ miles farther east which probably cut out some of the section. Most of this limestone sequence within the area of the geologic map is Ely limestone; the outcrops of thin-bedded, shaly or marly limestone, which are probably Arcturus limestone, begin at about the east edge of the map (pl. 1). Fossils are scarce in the lower half of the Arcturus(?) limestone, but the upper half contains abundant fusulinids.

PERMIAN(?) OR MESOZOIC(?)

Interbedded conglomerates and sandstones are exposed on the two hills about half a mile north of Sixmile House and on a low hill about 2 miles north of this. These rocks were first mapped as Diamond Peak formation but differ from it in many respects.

The conglomerate is composed of chert and quartzite pebbles ranging from ¼ inch to 4 inches across, with a silicified or jasperized sandstone matrix. Many of the small chert pebbles, especially in the most northward exposure, are angular. A few silicified and rounded productid brachiopods were found in the conglomerate. The sandstone is white, fine-grained, and commonly jasperized, and has the same appearance as the jasperized matrix of the conglomerate. The silicification possibly resulted from silica being leached from overlying late Tertiary tuffs which have since been eroded.

A similar conglomerate, but one containing more angular chert fragments, unconformably overlies the partially jasperized Joana limestone and a limestone facies of the White Pine formation about 5 miles north of Round Spring Ridge.

Permian conglomerates of chert and quartzite pebbles are present at Tyrone Gap about 20 miles northwest of Eureka and in the

northern part of the Diamond Range about 25 miles north of Eureka. Rocks of this facies possibly were thrust from the west into the White Pine district. In addition, there are throughout east-central Nevada a number of outcrops of chert and quartzite conglomerate, limestone conglomerate, sandstone, shale, limestone, marl, and tuffs, which are considered by many geologists to be Cretaceous and early Tertiary. The author believes that the jasperized conglomerate and sandstone described above may be Cretaceous.

EOCENE

Illipah formation¹⁰

The name "Illipah formation" is proposed for the fresh-water sediments of Eocene age exposed in the northern part of the district. The name is derived from Illipah Creek where the formation is well exposed.

The formation includes two members; the lower member consists of limestone and chert conglomerate, calcareous sandstone, and vuggy limestone which resembles tufa, and the upper member contains well-bedded marl and fresh-water limestone with interbedded altered tuffs near the middle. The total thickness of the formation, as measured from partial sections, exceeds 1,500 feet, but the conglomerate and sandstone are lenticular and vary considerably in thickness.

Member 1.—The basal conglomerate generally contains abundant coarse limestone and chert pebbles, ranges in thickness from 5 or 10 feet to a maximum of approximately 100 feet, and commonly contains beds or lenses of calcareous sandstone and tufa-like limestone. The conglomerate has a pronounced red color, probably derived from the alteration and weathering of andesitic ash; purplish and reddish altered ash occurs locally at the base of the conglomerate. Overlying the conglomerate are from 10 to 350 feet of pinkish sandstone and calcareous sandstone with lenticular beds of marl and tufalike limestone and local conglomerate beds.

The best exposures of member 1 are on the west side of Little

¹⁰The name "Illipah formation" has been used by other workers for an Upper Mississippian formation which appears to be correlative with the Diamond Peak formation. The latter name, however, has stratigraphic priority, and usage of the term "Illipah formation" for this Upper Mississippian formation in eastern Nevada is becoming discredited. The U. S. Geological Survey does not recognize such usage.

The author's usage of "Illipah formation" for the oldest Tertiary formation in the White Pine district is retained here, even though it may cause minor confusion (editors).

Antelope Ridge between Sixmile House and the north edge of the district, on the east side of Round Spring Ridge, and near the intersection of the Hamilton road and U. S. Highway 50 on the east side of Illipah Valley.

Member 2.—Member 2 consists of white to cream-colored marl and fresh-water limestone with a number of thin tuffaceous beds near the middle. This limestone member exceeds 1,000 feet in thickness. The gray, fine-grained tuffaceous beds contain little quartz and range from 2 to 10 feet in thickness. The limestone for about 100 feet below the tuff beds contains chert nodules and silicified gastropods.

Member 2 is present only on the east side of Illipah Valley. A few small outcrops are present east of Round Spring Ridge but they are not mappable. Abundant marl float in the Belmont fanglomerate near Sixmile House indicates that this limestone member was deposited west of Little Antelope Ridge but has since been eroded.

The marl contains gastropods which were classified as Eocene by Dr. F. Stearns MacNeil of the U. S. Geological Survey. He identified the following genera: *Sphaerium* sp., *Lymnaea* sp., *Heliosoma* sp., and *Ancylus* sp. An outcrop of the marl which contains abundant gastropods is located half a mile north of the intersection of the Hamilton road and U. S. Highway 50.

Exposures of the contact between member 1 and member 2 are restricted to a few small outcrops east of Round Spring Ridge. About half a mile south of U. S. Highway 50 the marl appears to rest unconformably on Ely limestone. About 4 miles north of Illipah Valley the marl rests on pink sandstone, although at one place it rests directly on conglomerate.

Reddish conglomerate and calcareous sandstone similar to member 1 occur in an outcrop belt extending from Indian Springs, 10 miles northeast of the district, to the north end of the Diamond Range, 45 miles to the northwest. Northward of this, these rock types occur locally at the base of the "Humboldt" beds between the north end of the Diamond Range and the Humboldt River. At several of these local outcrops purplish and reddish altered volcanic ash, similar to that in the White Pine district, is present at the base of the conglomerate.

UPPER MIOCENE AND/OR PLIOCENE

Lake Newark formation

The name "Lake Newark formation" is proposed for a succession of bedded rhyolite tuffs and pyroclastics which were deposited over a large part of the area.

The formation includes both bedded tuffs which were deposited on a lake floor and subaerial pyroclastics which were deposited above the level of the lake. Although the materials in both types of deposit are of the same age and source, two members are differentiated because of the different depositional conditions which accompanied their formation.

Member 1.—Member 1 includes the bedded tuffs which in this district are present up to an altitude of about 7,400 feet. The unbedded pyroclastics are found above this elevation. Member 1 has a maximum thickness of about 350 feet and consists of three types of tuff. The oldest tuff beds are pale green and composed of about 10 percent small quartz crystals, 75 percent pumice and glass fragments and 10 to 15 percent pale-greenish clay. These beds, with an aggregate thickness of between 20 and 75 feet, are present only on the west side of Little Antelope Ridge and rest with only slight angular discordance on pinkish sandstone of the Illipah formation. Overlying the greenish tuff, or resting on Eocene or older rocks where the greenish tuff is absent, are from 50 to 250 feet of white to cream-colored tuff. This tuff is composed of from 20 to 50 percent of small euhedral quartz crystals or fragments of crystals in a matrix of pumice shards and glass fragments. Locally some of the tuff beds have as much as 10 to 15 percent sand grains and small limestone or chert pebbles. This is the most widespread of the three tuff units and well exposed on the west side of Little Antelope Ridge where it rests upon the greenish tuff and in the Illipah Creek area where it rests upon marl of the Illipah formation. The upper tuff, which is most common except north of the area on the west side of Little Antelope Ridge, ranges from 10 to 35 feet in thickness. This pumiceous tuff contains about 10 percent each of small quartz crystals and biotite with a small amount of ilmenite. Extremely porous pumice shards with a maximum length of 1 inch are present in this poorly bedded material. In places there are several feet of tuff and fine gravel between this and the underlying tuff.

About 20 feet of pinkish devitrified welded rhyolite tuff overlie bedded white tuffs about one-quarter mile south of Sixmile House. The rhyolite tuff contains both quartz and sanidine phenocrysts in a devitrified glassy groundmass. Outlines of glass shards are

visible in thin section with ordinary light. A similar welded tuff is present north of the area where it overlies the upper biotite tuffs.

The age of the Lake Newark formation, or more precisely the upper portion of the white to cream-colored tuff, is tentatively determined as "Upper Miocene or Pliocene" by Dr. Teng-Chien Yen. The fossil collection was made near Sixmile House and, according to Yen, contains the following genera of fresh-water mollusks: *Valvata*, *Amnicola*, *Ferrasia*, *Lymnaea*, *Planorbis*, *Sphaerium*. Yen states: ". . . the specimens consist of imperfect casts only . . . the containing rock . . . may be of late Tertiary age, possibly either Upper Miocene or Pliocene." No fossils were found elsewhere in the Lake Newark formation. Due to the poor condition of those fossils which were found, the author recognizes that the age determination is at best only an estimate. These fossils may not be indigenous inasmuch as they are in a bed containing sand grains and small limestone pebbles.

Member 2.—Member 2 is probably the age equivalent of the bedded tuffs but includes pyroclastics which were deposited above the lake level.

The pyroclastics apparently covered the entire area but only a few outcrops are preserved; these remnants have been protected by a cover of younger basalt. Outcrops of member 2 are invariably found under the basalt wherever basalt talus does not conceal the underlying rock.

Small doubly terminated quartz crystals constitute, in places, 10 to 15 percent of the pyroclastics. This is especially true near the southeast edge of the district. The quartz crystals in both members of the Lake Newark formation generally diminish in quantity and size from the east side of the district toward the west.

In the southern part of Illipah Canyon there is a gradation between the bedded tuffs of member 1 and the massive, nonbedded pyroclastics of member 2. The bedded tuffs are poorly bedded toward the top and at an altitude of about 7,400 feet they grade into a massive resistant pyroclastic unit about 80 feet thick. The subaerial pyroclastic material is more cemented and resistant to erosion than the bedded tuff.

The source of the pyroclastics is of considerable interest because of the enormous extent of tuffs over eastern Nevada. Such a wide distribution of similar material suggests that several contemporaneous vents extruded material of approximately the same composition.

In this district the source may have been from two vents now represented by two granite porphyry plugs about 4 miles east of the southeast corner of the district at the edge of Jakes Valley. The plug rock contains abundant corroded and fractured quartz phenocrysts. The corroded quartz phenocrysts in the porphyry are larger and unlike the euhedral, often doubly terminated, quartz crystals in the pyroclastic rocks of the Lake Newark formation. The corrosion may be a result of reaction between early-formed quartz phenocrysts and the slowly cooling portion of the magma in the vent.

PLIOCENE AND/OR PLEISTOCENE

Lampson formation

The name "Lampson formation" is proposed for bedded tuffs and gravels containing basalt pebbles and boulders which are exposed in the Lampson Canyon area and southward for several miles.

This formation is obviously younger than the Lake Newark formation because of the contained basalt and it is bedded and better consolidated than the overlying Belmont fanglomerate. The tuffs contain detrital sand and pebbles and probably were formed by deposition of pyroclastic material eroded from the surrounding area. It is impossible to determine accurately either the true thickness or lithologic sequence of the formation because its small outcrops are surrounded by fanglomerate. However, the section containing basalt boulders is probably near the base of the formation because it is topographically lower than the other outcrops and close to an outcrop of Ely limestone. This section is exposed in a gulch on the south side of Lampson Canyon about 1 mile southwest of Lampson Spring and contains basalt boulders up to 2 feet in diameter. Small outcrops of bedded and cemented gravels and sands occur on both sides of Lampson Canyon. These are at higher altitudes than the basaltic gravels and contain little or no pyroclastic material.

South of the district for a distance of 1 to 2 miles there are some larger outcrops of interbedded gravel and sand with intermixed pyroclastic material. In one of these outcrops the beds dip about 20 degrees to the southeast and are more than 300 feet thick.

Northeast of Cathedral Canyon there are two unmappable outcrops of bedded lime-cemented gravel and sand which may belong to this formation. One is in a gulch at the edge of the Ely limestone near fossil locality F5A and the other, farther north, is

exposed beneath the Belmont fanglomerate about 2,500 feet west of Shermantown. There are also several small exposures of bedded gravels underlying the Belmont fanglomerate north of Sixmile House. These deposits appear to be lacustrine, but they are younger than the Lake Newark formation and may be the equivalent of the Lampson formation. One outcrop is about 1 mile northeast of Sixmile House and another is approximately 4 miles N. 15° W. of Sixmile House.

The Lampson formation was not differentiated on the geologic map (pl. 1), but is included with the Lake Newark formation.

Belmont fanglomerate

The tentative formational name "Belmont fanglomerate" is applied to gravels and fanglomerates which presumably represent part of a rapid erosion cycle following the last uplift of the range, especially Pogonip Ridge.

The upper formational contact is arbitrarily placed because there is not a clearly defined boundary between the fanglomerate and the recent alluvium and reworked gravels.

The formation is composed of unsorted and generally massive limestone sand and pebbles, chert pebbles, and locally, quartzite and granitic debris. The best exposures of the Belmont fanglomerate, and the more characteristic according to origin, are on the west side of Pogonip Ridge where the high points of the fanglomerate are in front of the spurs of the ridge and where canyons have cut into the pediment surface as deeply as 80 to 100 feet. The author was told by Dooley Wheeler (personal communication) that a drill hole near Monte Cristo penetrated 1,200 feet of gravel without encountering bedrock.

North of Pogonip Ridge the Belmont fanglomerate has been dissected by intermittent streams originating in Belmont Canyon and the smaller canyons to the east. The terraces are about 50 to 75 feet high and are relatively flat. Near Pogonip Ridge the fanglomerate rests either on tuffs of the Lake Newark formation or on bedded gravels which possibly correlate with the Lampson formation.

IGNEOUS ROCKS

INTRUSIVE ROCKS

Monte Cristo stock

The Monte Cristo stock, located on the west side of Pogonip Ridge near Monte Cristo, is almost circular in plan and about half a mile in diameter. The stock was probably quartz monzonite

at the time of emplacement, but has subsequently been intensely hydrothermally altered with the introduction of abundant silica. The most outstanding feature of the rock is the presence of innumerable thin quartz stringers (fig. 10).

The rock is medium-grained and xenomorphic-granular. The anhedral form of the minerals is no doubt the result of intense hydrothermal alteration.

The mineral composition of a sample from the center of the stock is as follows:

Quartz:	40–50%. Corroded anhedral quartz grains constitute about 15% of the rock; the remaining 25–35% is later quartz.
Orthoclase:	15–20%. Generally cloudy and altered to sericite.
Plagioclase:	15%. Composition indeterminable. Zonally altered.
Muscovite:	4–5%. Some has very low 2V and is probably hydromuscovite.
Sphene:	Trace.
Zircon:	Trace.
Apatite:	Trace.
Rutile:	Trace. Needles in muscovite.
Hematite:	Trace. Generally in quartz stringers.
Sillimanite (?):	Trace. Curved needles in quartz.

The feldspars are cloudy and have been altered to sericite and clay. Crystals which are uniformly altered and from which optical properties could not be obtained are probably orthoclase. Others in which the core is much more altered than the rim are probably zoned plagioclase.

After its crystallization the stock was apparently thoroughly and unsystematically fractured and quartz-bearing solutions were introduced along the fractures. The alteration of the rock probably occurred during this period of quartz introduction.

In the central portion of the stock the only change in the rock, except for the quartz stringers, is the hydrothermal alteration to clay and sericite. Samples from the south edge of the stock are finer-grained, contain untwinned albite in granophyric intergrowth with quartz, and show minor sericitization.

Although the stock has been thoroughly fractured and the fractures have been subsequently filled by quartz, there is no increase in intensity of fracturing at or near the borders. The enclosing metamorphic rocks for a distance of several hundred feet from

the contact are fractured and filled by quartz in a manner similar to that of the stock. There is no evidence of differential movement between the stock and the surrounding rocks. The fracturing may

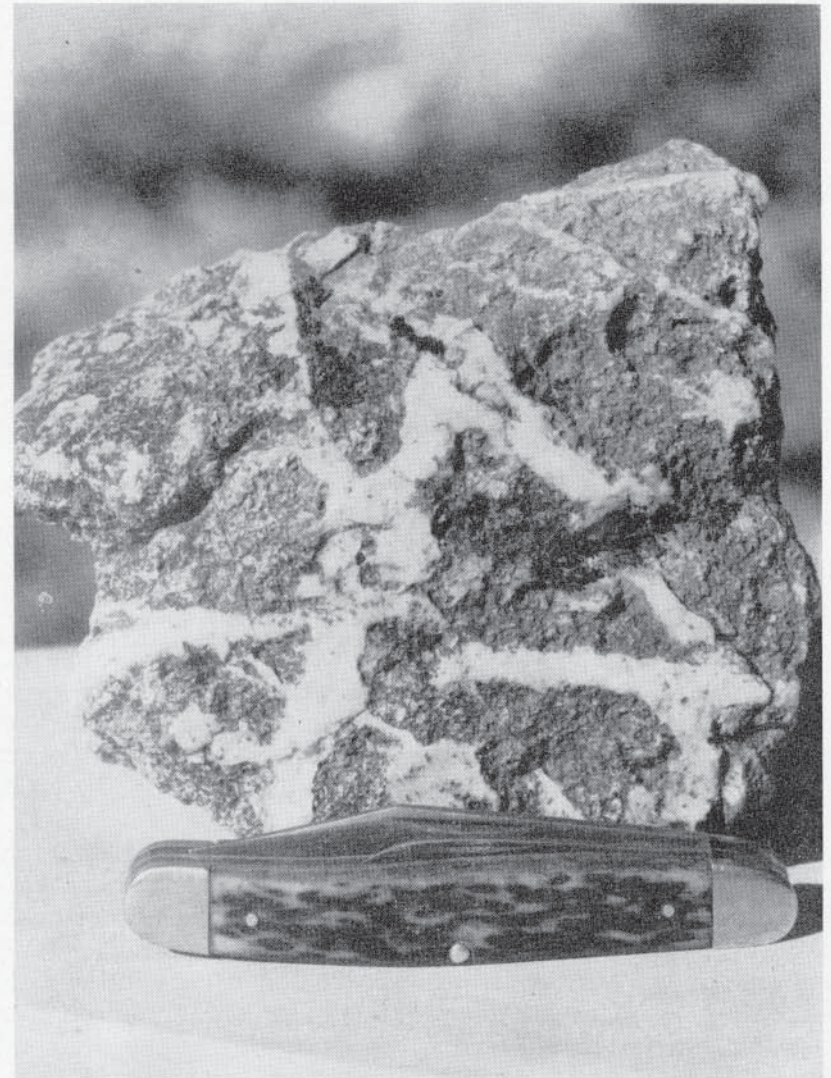


FIGURE 10. Quartz stringers in hand specimen from the Monte Cristo stock.

have resulted from a more or less uniform doming of both the stock and the enclosing rocks. This explanation is compatible with the theory of the doming of Pogonip Ridge which is discussed elsewhere.

Seligman stock

The Seligman stock is about three-quarters of a mile northeast of the Monte Cristo stock and is somewhat the larger of the two. The Seligman stock is elongated in a north-south direction and is about 4,000 feet long and 2,000 feet wide.

The rock is medium-grained subhedral granodiorite. The essential minerals are generally subhedral with the exception of the quartz which is anhedral.

The following minerals are present:

Quartz:	30-40%. Small anhedral crystals.
Andesine:	30%. Averages about An 45. Some crystals are zoned and range between An 30 in the outer rim and An 65 in the core. Commonly altered; contains epidote, clinozoisite, and sericite(?). Small amount of albite on cleavage planes or fractures.
Orthoclase:	10-20%. Generally sericitized.
Biotite:	10%. Locally partially altered to chlorite.
Hornblende:	1-2%. Unaltered. Pleochroic from light to dark green.
Muscovite:	1%. Probably an alteration product of biotite because of its association with iron oxide.
Pyrite:	Trace to 2%. Commonly oxidized.
Zircon:	Trace.
Apatite:	Trace.
Ilmenite:	Trace.
Leucoxene:	Trace. Whitish coating on small opaque ilmenite(?) crystals.
Rutile:	Trace. Needle crystals in biotite and quartz.
Calcite:	Trace.

The development of epidote and clinozoisite in the andesine probably resulted from deuteric alteration; the associated albite could have formed in a similar manner without the introduction of sodium.

Little silica has been introduced into the surrounding rocks, and even close to the intrusive the relatively pure limestone has merely been recrystallized. Only the impure shaly limestones which contained a considerable amount of silica were converted to calc-silicate hornfels. The sole element which definitely appears to have been introduced from the intrusive is manganese. Thulite,

the manganeseiferous zoisite, is common in the hornfels and is commonly concentrated along fractures where manganese-bearing mineralizing solutions could have easily percolated through the rock.

This stock is much more altered than the Monte Cristo stock. The alteration is probably a result of the oxidation of the pyrite, part of which is disseminated through the granodiorite with no apparent relationship to fractures or seams. The pyrite possibly crystallized from the magma together with the other minerals. Near the center of the stock a fracture zone contains a large amount of iron oxide and pseudomorphs of iron oxide after pyrite. The iron oxide undoubtedly resulted from oxidation of pyrite deposited along the fracture zone by hydrothermal solutions. The dump rock from a shaft sunk on this zone contains some unaltered pyrite and minor chalcopyrite.

Age relationship of the two stocks

The Monte Cristo stock is apparently older than the Seligman stock. Thulite, the manganeseiferous zoisite, is commonly present in the hornfels around the Seligman stock and is most abundant where it borders fractures in the hornfels, indicating that the manganese migrated along the fractures. There is a little thulite in the hornfels at the north end of the Monte Cristo stock which is about the edge of the thulite zone of the Seligman stock. A small dike, approximately three inches wide and within 50 feet of the north edge of the Monte Cristo stock, has had most of the feldspar altered to zoisite and thulite. This dike cannot be traced into the Monte Cristo stock because of talus covering, but its mineralogy indicates a close relationship between the two. The quartz phenocrysts are much larger than the quartz crystals in the Seligman stock and are rounded by corrosion. The original feldspars which have not been recrystallized to zoisite are mostly orthoclase; this relationship places the dike in closer affinity to the Monte Cristo stock. The fact that the thulite is concentrated only around the Seligman stock supports the idea that the manganese was introduced into the hornfels from that stock and was not residual in the sedimentary rocks; otherwise, the zoisite in the hornfels around the Monte Cristo stock would also contain manganese. The writer believes that the alteration of the dike is probably related to the emplacement of the Seligman stock. This would indicate that the dike and the Monte Cristo stock are older than the Seligman stock.

The geographic proximity of the two intrusive bodies suggests

a possible common genesis. However, the difference in mineral composition of the two stocks, the intense fracturing and hydrothermal alteration of the Monte Cristo stock, the great influx of silica into the adjacent metamorphic rocks from the Monte Cristo stock and the meager amount from the Seligman stock, the restricted relationship of manganese-bearing solutions to the Seligman stock, and an apparent age difference between the two stocks all limit the possibility of their having had the same magmatic source. They undoubtedly are genetically related, but due either to differentiation of the parent magma, or to assimilation, the composition was changed between the time of emplacement of the two stocks.

Rhyolite

A small rhyolite dike, the only one found in the district, occurs in the southwestern portion of the district on the north side of the mouth of Cathedral Canyon. It is about 8 feet wide and can be traced for a distance of about 300 feet.

This light-gray porphyritic rock has an aphanitic groundmass with quartz and orthoclase phenocrysts. The mineral composition is as follows:

Quartz:	6-10%.
Orthoclase:	5%.
Plagioclase (Oligoclase):	Trace.
Biotite:	Trace.
Zircon:	Trace.
Iron ore minerals:	Trace (euhedral, opaque).
Groundmass:	80-85%. Partly altered to sericite and limonite. Microcrystalline quartz and feldspar. Some glassy flow structure is evident.

EXTRUSIVE ROCKS

Basalt

The youngest igneous rock in the district is a basalt flow which rests upon unbedded pyroclastic rocks of probable late Miocene or Pliocene age. The unbedded member of the Lake Newark formation underlies the basalt everywhere, and it is assumed that the basalt was deposited soon after the pyroclastics. The basalt occurs in the southeastern quarter of the district and caps hills up to an altitude of about 9,300 feet. It undoubtedly represents the remnant of what was originally a continuous flow over most

of this area. The flow probably did not extend much farther to the north of the remaining outcrops because no basalt or basaltic float is associated with the tuffs or younger alluvium in the Illipah Creek area.

The basalt is porphyritic with plagioclase phenocrysts up to 2 mm. long and subordinate phenocrysts of hypersthene and augite. The groundmass is glassy with many plagioclase and pyroxene microlites. The plagioclase phenocrysts and microlites are chiefly calcic labradorite as determined by measurement of extinction angles. The rock has pronounced platy jointing; the joints are approximately horizontal and spaced 1 to 2 inches apart. The general occurrence of partially resorbed quartz crystals is characteristic of the basalt.

The average mineral composition is as follows:

Labradorite:	30%—calcic. Some phenocrysts corroded and zonally altered. However, the extinction angles of even the outer zones generally indicate labradorite.
Hypersthene:	2-3%.
Augite:	2%.
Quartz:	5%—corroded.
Magnetite and Hematite:	5-10%.
Apatite:	Trace.
Biotite:	Trace.
Groundmass:	50%. Glassy, with 10 to 50% plagioclase and pyroxene microlites. Glass commonly devitrified, giving an anisotropic wavy extinction.

The composition of the phenocrysts is characteristic of basalt. Contamination of basaltic magma by more silicic material after the labradorite and augite had crystallized may account for the porphyritic texture and corroded quartz. The corrosion of some of the labradorite phenocrysts indicates that they were no longer in equilibrium with the magma after they crystallized. The probable source of this contamination is the parent magma of the granite porphyry plug previously described. A 5 percent admixture of quartz would require the addition of about 20 percent of the granite porphyry magma. This could have materially changed the composition of the basalt toward andesite or dacite.

The quartz inclusions constitute, on an average, between 3 and 5 percent of the volume of the basalt. As stated above, the quartz

is considered to have resulted from a mixing of magmas. Certain beds of the underlying pyroclastic members abound with small well-formed, commonly doubly terminated quartz crystals. The basal part of the flow rock could easily have picked up and incorporated some of these crystals, but quartz crystals are as plentiful at the top of the basalt as at the bottom. The quartz grains are commonly larger (although rounded by corrosion) than the small quartz crystals in the pyroclastic rocks.

In most cases the quartz grains are enclosed by a rim of light brown glass with an outer rim of minute pyroxene crystals. The glassy rim may indicate that cold quartz grains were incorporated in the cooling basalt flow when their cooling effect was sufficient to cause a rapid chilling of the contiguous basalt liquid. The holohyaline portion of the groundmass of the basalt, however, is black; thus the light brown, transparent glass around the quartz was probably caused by solution of the outer surface of the quartz grains by combined action of heat and mineralizers.

METAMORPHIC ROCKS

Contact metamorphic rocks surround the two stocks. The degree of metamorphism decreases rapidly over short distances away from the intrusives and the metamorphic aureole ranges from 1,000 to 5,000 feet in thickness. The most intense metamorphism and recrystallization occurred on the east side of the Monte Cristo stock and extend eastward for a distance of about 2,500 feet, being found in the rocks close to the eastern and southern border of the Seligman stock.

Garnet, diopside, zoisite, clinozoisite, and thulite are the most abundant metamorphic minerals. Epidote occurs rarely and tremolite was not found.

Abundant silica was introduced into the rocks near the Monte Cristo stock but there is only meager evidence of silica introduction into the rocks adjacent to the Seligman stock.

East of the Monte Cristo stock, where the most coarsely grained calc-silicate hornfels occur, the original sedimentary rock was interbedded calcareous shales and limestones of member 2 of the Secret Canyon shale in which the beds average $\frac{1}{2}$ inch and 1 inch thick. The hornfels show both color and compositional banding, depending upon the nature of the original sediments (fig. 11). The metamorphosed shale beds are reddish-brown and the metamorphosed calcareous beds are green. The brown hornfels are dominantly garnet with subordinate diopside and a small amount

of zoisite and clinozoisite. The green hornfels are dominantly diopside, zoisite, and clinozoisite, with subordinate garnet.

The brown hornfels have the following mineral composition:

Garnet:	40-50%.	Some coarse crystals up to 5 or 6 mm.
		Some crystals show anisotropism with wavy extinction and common dodecahedral growth zoning.
Diopside:	15-25%.	
Zoisite:	4-5%.	Anomalous blue color.
Quartz:	20-25%.	
Chlorite:	3-5%.	



FIGURE 11. Garnet-diopside layers in metamorphosed member 1 of the Secret Canyon shale. Garnet layers, representing original shale beds, are dark and coarse-grained. Diopside layers, representing original limestone beds, are light and fine-grained.

Small diopside crystals are disseminated through the garnet and in lesser amounts in the quartz. The garnets are commonly corroded and embayed by quartz. Quartz occupies small cracks in and around the garnet and locally transects quartz grains. This later quartz contains no diopside but does contain all of the chlorite. These relationships indicate two periods of introduction of quartz.

The green hornfels have the following composition:

Diopside:	40-45%.
Zoisite and Clinozoisite:	40-45%.
Garnet:	5-15%.
Quartz:	1-4%.
Iron ore minerals:	1-2%.

The zoisite and clinozoisite in the green hornfels occur as a myriad of small grains forming a groundmass which is layered with thin diopside bands. The garnet is associated with the diopside bands.

The mineral composition of the brown hornfels suggests an original calcareous or dolomitic shale in which the diopside crystallized first, followed by the garnet and the quartz grains. The chlorite is confined to the thin seams of quartz which cut through the other minerals and is probably a result of retrograde metamorphism of the garnet or diopside during the second period of silica introduction.

The thin alternate layers of zoisite-clinozoisite and diopside in the green beds suggest an original interbedding of very thinly laminated limestone or magnesian limestone and shaly limestone. A small amount of quartz is present but no calcite remains, which indicates complete reaction of the original calcite with the contained argillaceous material and the introduced silica. In contrast, there is 20 or 25 percent quartz in the brown beds, probably because there was less calcite to react with it.

North of the Monte Cristo stock, near the western edge of the Seligman stock, these same interbedded shales and limestones characteristically form a differentially weathered banded rock, as shown in figure 5. Little or no silica was introduced into these rocks. The resistant beds are the metamorphosed calcareous shale beds composed dominantly of zoisite, clinozoisite, and diopside, with subordinate residual calcite. The less resistant layers are dominantly recrystallized carbonaceous limestone with a small amount of diopside. The carbonaceous material has been leached from the areas of most intense recrystallization.

A fine-grained white to faint-green hornfels, derived by metamorphism of member 3 of the Secret Canyon shale near the Seligman stock, contains the following mineral assemblage:

Zoisite:	40-60% (commonly thulite).
Clinozoisite:	5-10%.
Diopside:	20-40%.
Clay minerals(?):	5-10% (cloudy, opaque, cryptocrystalline).

Some beds of member 3 of the Secret Canyon shale also contain considerable phlogopite, muscovite, and subordinate biotite.

Diopside is generally considered to be indicative of high temperature contact metamorphic conditions and is commonly surrounded by a tremolite halo outward from the intrusive.

No tremolite was found at this locality, but diopside occurs as a product of recrystallization in the most distant limestone layers which have undergone metamorphism. In addition, in the beds distant from the intrusives the diopside occurs as long acicular crystals (up to 5 mm.) which megascopically resemble tremolite.

STRUCTURE

GENERAL STATEMENT

The White Pine district is divided into two major tectonic units by the Belmont fault. The eastern block is characterized by folds and thrust faults with a few large normal faults; the structure of the western block is dominated by the uplift of Pogonip Ridge which is bounded by the Belmont and White Pine normal faults.

Each of the major tectonic units is divided into smaller units by transverse faults which cut across the major north-south structures. The Cathedral fault is the southern structural boundary of Pogonip Ridge; the Eberhardt fault divides the eastern unit between the Belmont fault and the Lampson thrust fault.

The structural features are described in the order of their relative ages.

EARLY NORMAL FAULTS

The oldest faults which can be dated relative to other structural features are normal faults within the Pogonip "dome". The most prominent of these is the Center fault which is close to and parallel to the north-trending Belmont fault on the northeast side of Pogonip Ridge. The Center fault dips 45° to 50° to the east and its vertical displacement decreases northward from approximately 2,000 feet near the Seligman thrust to a few hundred feet

at the north end of Pogonip Ridge. The mineralization within the fault block between the Center and Belmont faults is younger than the Center fault but older than the Belmont fault. The dip of the Center fault was probably slightly affected by the northward tilting of Pogonip Ridge north of Mount Hamilton because the strike of the fault is approximately parallel to the direction of the tilting. The Center fault terminates against the Seligman thrust.

On the west side of Pogonip Ridge, in the upper plate of the Monte Cristo thrust, there are a few minor faults which are older than the thrusting. A minimum of 3,000 feet of normal fault displacement probably occurred along the west side of Pogonip Ridge previous to the thrusting. Evidence for this is the presence of Upper Cambrian rocks of the same stratigraphic position both on the summit of Mount Hamilton and in the hanging wall of the Monte Cristo thrust more than 3,000 feet lower. Such a relationship could have resulted if the involved rocks had been steeply tilted to the west previous to the thrusting, but there is no indication of such tilting in the rocks adjacent to the thrust outcrop. An early normal fault provides the most logical explanation. This supposed normal fault would now be concealed by the upper plate of the Monte Cristo thrust. Whatever vertical displacement was achieved by the thrust faulting must be added to the calculated minimum of 3,000 feet of normal fault displacement to give a measure of magnitude of the earlier faulting.

The east-west Ophir fault¹¹, which cuts across Pogonip Ridge southeast of Monte Cristo, is also pre-thrusting in age.

Evidently there are early normal faults on at least three sides of Mount Hamilton, and the general outline of the Pogonip "dome" was probably established prior to the period of folding and thrusting.

FOLDS AND THRUST FAULTS

A period of folding and thrusting, resulting from essentially east-west compression, apparently began in Cretaceous time and extended into early Tertiary. The dating of the upper limit of the period of folding is based on the Eocene age of the Illipah formation, which is tilted and folded along with the underlying Ely limestone.

It is not possible to state definitely when this tectonic episode

¹¹Both the Ophir and Eberhardt faults appear to have had right lateral movement with the southern block down-dropped (editors).

began, but it is clear that it continued until after at least a portion of the Eocene Illipah formation was deposited. The author assumes that this episode is related to one of the episodes of the Laramide revolution and that the inception of the orogenic disturbance in this area helped to create the lake basin in which the Eocene Illipah formation was deposited.

The Illipah anticline and the Little Antelope syncline are the folds of greatest magnitude. The Illipah anticline extends for a distance of more than 14 miles. The anticline plunges 3° or 4° to the north and progressively older rocks are exposed southward. The Round Spring thrust plate has overridden the anticline a short distance north of the district and the fold is concealed north of U. S. Highway 50.

Small areas of Diamond Peak formation crop out along the axis at the north end of the Illipah anticline. The White Pine formation crops out southward for a distance of about 11 miles, at which point the underlying Joana limestone crops out. For the next 3 miles to the south the Pilot shale and the Nevada limestone progressively crop out. To the south the identity of the anticline is lost in faulted and contorted Nevada limestone. The essentially symmetrical anticline has longitudinal dips of from 35° to 50° at the north end and from 10° to 30° south to Harris Canyon. South of Harris Canyon the dips again steepen, particularly near two transverse faults which cut the anticlinal axis and offset the south side to the west. South of the exposure of the Pilot shale the dips again become gentle, averaging from 10° to 20°. At the south end the Nevada limestone is badly contorted and the attitudes are erratic. The beds are essentially horizontal in at least three places along the axis.

The Little Antelope syncline about 4 miles west of the Illipah anticline may be traced from a point at least 2 miles north of the map area (pl. 1) southward along Little Antelope Ridge for about 6½ miles to where, due east of Sixmile House, a transverse tear fault offsets the southern extension of the axis to the east. The axis is traceable for about 1 mile south of the transverse fault in an arcuate course on to Mokomoke Mountains, where it is badly broken up by tear faulting. Several subsidiary synclines and anticlines occur on Mokomoke Mountains from this point southward for about 2 miles; at this point the single synclinal axis again becomes dominant and can be traced southward to the transverse Eberhardt fault. The structure, which exceeds 12 miles in length, is generally symmetrical and without plunge. South of the Eberhardt tear fault there are two synclines and

an anticline in the Ely limestone which are probably related to the Little Antelope syncline in the same manner as are the subsidiary folds on Mokomoke Mountains.

Two smaller folds are present between the Illipah anticline and the Little Antelope syncline. The Harris syncline, adjacent to the Illipah anticline, crops out near Harris Ridge and extends from its southern limit at Harris Canyon northward for about $3\frac{1}{2}$ miles, at which point it is lost in the thrust and overturned rocks of Round Spring Ridge. Near the trough of the syncline the rocks are broken at several places and offset by small west-dipping reverse faults. These probable thrust faults developed during the folding due to the incompetence of the limestone beds.

The unnamed anticline west of the Harris syncline is exposed in the Diamond Peak formation for a short distance near the north end of the Harris syncline. Although the crest is concealed by alluvium for some distance to the south, it is exposed in the same formation for a short distance just north of Harris Canyon. Both this anticline and the Harris syncline end abruptly at Harris Canyon, although there is no large structural feature in evidence to explain the termination of these folds. However, an enormous spring in the canyon, about half a mile west of the anticline, may be related to some structural break which is not evident at the surface. Both folds terminate to the north in the area of imbricate thrusting and overturning in the vicinity of Round Spring.

The northern tips of another anticline and syncline crop out at the south end of Sixmile Wash in the southeast corner of the district. These structures extend for several miles south of the district.

The Treasure Hill anticline is traceable for about $1\frac{1}{2}$ miles along the east slope of Treasure Hill. The west limb is cut by the Treasure Hill reverse fault and numerous smaller faults. North and south dips, at the north and south ends of the anticline respectively, indicate a domical anticline which, coupled with faulting, undoubtedly controlled the introduction and deposition of the silver ores of Treasure Hill.

The Emigrant anticline, north of Pogonip Ridge and west of the Little Antelope syncline, may be traced from the vicinity of Sixmile House northward to the Lake Newark beds at the north edge of the map (pl. 1). It probably extends further northward but there are no outcrops of Paleozoic rocks for several miles. The anticline generally plunges to the north, but near the north end its attitude appears to be approximately horizontal.

In addition to these folds, all of which are expressed in Upper Paleozoic rocks, there is a large "dome" in the Lower Paleozoic rocks of Pogonip Ridge. As shown on the geologic map (pl. 1), the strata at the north end of the ridge dip from 20° to 45° to the north and those at the south end dip from 20° to 40° to the south and southeast. Along the east central slope the rocks all dip to the east but on the west slope there are a number of minor folds and flexures, particularly within the area of metamorphosed sediments surrounding the two small stocks. The center of the elongated "dome" is not at the peak of Pogonip Ridge but appears to be near or a little to the south of the Seligman stock. This dome possibly resulted from differential vertical movements beginning during or prior to the time of the emplacement of the stocks.

Practically all of the folds are cut by west-dipping thrust faults. The Shellback thrust fault in the southeast corner of the district is clearly indicated by a small klippe of Joana and Nevada limestones lying upon Diamond Peak formation. There are two thrust plates about 2,000 feet west of Shellback Spring. The older one involves klippen of Joana limestone and Nevada limestone which overlie White Pine formation; the younger one, comprised of Nevada limestone has overridden these klippen and extends northward to form the eastern boundary of the Nevada limestone. The younger thrust is probably the Shellback thrust and the eastern klippe represents a remnant of it.

The Shellback thrust may compensate for the dying out of the Illipah anticline, with the crustal shortening compensated for by the thrust movement.

To the north the Shellback thrust is covered by either alluvium or basalt. A thrust fault, exposed on the east side of the basalt to the east of Aspen Spring, may be either a continuation of the Shellback thrust or, more likely, a branch of it. The vertical and overturned beds of Diamond Peak formation and Ely limestone and the outcrop of White Pine formation close to Ely limestone, about 2 miles north of Aspen Spring, may represent the continuation of the Shellback thrust. Two thrust plates are exposed for a short distance approximately 1 mile south of U. S. Highway 50. The Shellback thrust possibly connects with the Illipah thrust at the north end of Illipah Valley; if not, there is a zone of related thrusting between them. Thus the Illipah anticline for almost its entire length appears to be cut at fairly shallow depths by thrust faults.

An imbricate series of thrusts cuts the rocks at Round Spring Ridge where, in many places, the strata of the White Pine formation and Ely limestone are approximately vertical or overturned to the west. The Round Spring thrust overrides the Illipah anticline a short distance north of the district. South of Round Spring the thrust continues for about 3 miles between the axes of the Harris syncline and the anticline west of it. The thrust terminates about 2 miles north of Harris Canyon.

The Lampson thrust, whose northern extremity is near Sixmile Spring, extends southward beyond the district for a distance of at least 10 miles.

All previously mentioned thrusts cut fold axes at a relatively shallow depth (see cross sections, pl. 1).

The Green Springs thrust brings together different facies of the White Pine formation near the mouth of Cathedral Canyon. Only the Green Springs and Lampson thrusts show evidence of considerable horizontal displacement. The actual displacement cannot be determined from information available within the district but is probably in the order of magnitude of several miles.

The Green Springs thrust continues southerly for about 1 mile south of the district and then bends sharply back to the west into Railroad Valley. From the edge of the map (pl. 1) southward to the bend in the thrust the Nevada limestone of the upper plate successively overlies the White Pine formation, the Diamond Peak formation and the Ely limestone. Considering the generally flat westerly dips of the strata of the last mentioned formations near the thrust and assuming an average west dip of the fault of 30° , the Nevada limestone would have to have been moved a minimum distance of 20,000 feet in order to override the Ely limestone.

Another thrust fault, which lies chiefly west of the area mapped on pl. 1, is represented by a klippe of Joana limestone which overlies White Pine formation on the west slope of Ridgely. Only a thin sliver of this klippe is shown along the western margin of the geologic map (pl. 1). Still another thrust, in which Nevada limestone is thrust over White Pine formation, crops out about 4 or 5 miles west of Ridgely.

In a thrust at the mouth of Mohawk Canyon a small outcrop of intensely fractured Eureka quartzite and Hanson Creek dolomite is cut by many small reverse faults and surrounded by alluvium. A short distance to the east an outcrop of White Pine formation forms the hanging wall of the White Pine normal fault. In a normal stratigraphic section the dolomite and the White Pine

formation are some 5,000 feet apart. The present position of these two formations, coupled with the other structures which are present, strongly indicates that the dolomite and quartzite have been thrust into this area. Another small outcrop of Eureka quartzite is adjacent to White Pine formation about 2,000 feet north of this outcrop.

The Monte Cristo and Seligman thrust faults are both within the Pogonip "dome". The Monte Cristo thrust extends from the edge of the ridge about 4,000 feet south of Monte Cristo for approximately 3 miles to the south and is apparently cut at both ends by the normal fault which bonds the west side of Pogonip Ridge. The upper plate of this thrust is almost entirely composed of the Goodwin formation. North of the transverse Ophir fault the lower plate is Secret Canyon shale, and south of the Ophir fault it is Pogonip formation.

The Monte Cristo thrust dips from 35° to 65° to the west and this steep dip probably results in part from the tilting that accompanied the uplift of the Pogonip "dome". In the southern part of the Monte Cristo thrust the upper plate is mostly the thin-bedded member 1 of the Goodwin formation, and the rocks are very intricately folded (figs. 12 and 13). Similar structures occur along thrusts within the Pogonip "dome"; these rocks were buried more than 10,000 feet at the time of the thrusting. The rocks associated with thrust faults external to the Pogonip "dome" are upended or overturned and are broken and fragmented rather than plastically deformed.

North of Ophir Canyon, a small portion of another thrust fault crops out in the upper plate of the Monte Cristo thrust. In this small fault Eureka quartzite and Hanson Creek dolomite are thrust over the Goodwin formation. Farther to the south, portions of these two formations are thrust over the Pogonip formation. The trace of this thrust terminates against the transverse Cathedral fault.

Along the east side of the Belmont fault there are four thrust remnants which resemble klippen except that their west sides are bounded by the Belmont fault. One remnant is east of the Ophir fault, another is west of Babylon Ridge, another is southwest of the Belmont Mill and the last is about a mile north of the Belmont Mill at the north end of Pogonip Ridge. They probably represent the eastward extension of the Monte Cristo thrust which was cut by the Belmont normal fault.

The Seligman thrust, with a strike of about N. 50° W., cuts



FIGURE 12. Monte Cristo thrust fault surface. Main fault surface is from lower center to upper left of picture. Irregularities apparently are due to alternating massive and thin beds in the footwall rock (member 1 of the Pogonip formation). Fault dip is much steeper than average.

transversely across Pogonip Ridge along the north slope of Seligman Canyon and is the only east-dipping thrust in the district. The dip ranges from 15° to 45° to the northeast. The lowest dips are on the west side of Pogonip Ridge in Seligman Canyon where they average about 20° . The strata dip about 30° to 40° to the northeast and strike approximately parallel to the thrust. On



FIGURE 13. Folded limestone of the Goodwin formation in hanging wall of the Monte Cristo thrust fault. Hanging wall moved toward left.

the east side of Pogonip Ridge the thrust dips 35° to 45° to the northeast and the rocks dip from 40° to 60° to the northeast. The deformation of the rocks of this area is correlated with the uplift of the Pogonip "dome". The greater part of this uplift, however, is post-thrusting. There is some question as to whether the Seligman thrust may have originally conformed to the general west-dipping trend and was subsequently tilted by the uplift of Pogonip

"dome". If the strata involved were tilted back toward the horizontal, the Seligman thrust would then dip westerly and conform to the prevailing trend.

The presence of younger rocks in the upper plate of the Seligman thrust may be explained in at least two ways: (1) the rocks have been previously cut by a normal fault, at least with the younger beds dropped down beside the older and then thrust over them, or (2) the beds dip in the same direction as the thrust surface but more steeply. Approximately 500 feet of the lower Pogonip formation in the upper plate and about 200 feet of the upper Goodwin formation in the lower plate are cut out by the fault, so the fault displacement is probably not large. There is no evidence of a suitable older normal fault in either the upper or lower plate of the thrust; therefore, if the relative displacement was an eastward movement of the upper plate, the beds must have dipped more steeply to the west than the thrust surface. This relationship would not exist if the beds were tilted back to the horizontal, for the rocks now dip more steeply to the east than does the thrust. Consequently, the rocks must have had an eastward or northeastward dip component at the time of thrusting and the relative thrust movement was westward in the upper plate with the thrust surface flatter than the dip of the strata. The only apparent alternative would be an underthrust from the west, but this would be essentially the same condition that has been described. Both the thrust surface and the bedding have probably been further tilted to the northeast by later uplift of Pogonip "dome".

There are at least two major reverse faults in the district, both on Treasure Hill. The Treasure Hill reverse fault begins at the Eberhardt transverse fault, which is the southern limit of Treasure Hill, and extends north through Treasure Hill for a distance of at least 12,000 feet. The dip is steep, averaging about 75° to 80° to the west, and is locally about vertical. The maximum vertical displacement is about 900 feet at a point approximately east of the peak of Treasure Hill. At the north end of Treasure Hill the fault passes under the alluvium and the landslide area east of Hamilton townsite. Another reverse fault cuts Mokomoke Mountains east of Hamilton, about in line with the Treasure Hill fault. The fault can be traced northward for a distance of approximately 8,500 feet, at which point it bends abruptly to the west and becomes a tear fault across the ridge. It is concealed by the landslide area north of Hamilton.

The Hamilton reverse fault is exposed on the west slope of Treasure Hill about 3,000 feet west of the Treasure Hill fault. The relative displacement is down on the east side. It strikes approximately parallel to the Treasure Hill fault over its southernmost portion and displays increasing displacement northward. Northwest of the old town of Treasure Hill it changes directions and bears about $N. 20^{\circ} W.$ The Hamilton fault is obscured in a maze of faults approximately 1 mile northwest of Hamilton. Although it can be traced for nearly 18,000 feet, a reliable dip could not be found. The bend in the fault takes place at the apex, and the change in bearing of the fault trace indicates a steep westward dip, suggesting reverse movement. The vertical displacement reaches a maximum of about 1,000 feet over a distance of approximately 1 mile north of the bend, but decreases northward.

The Treasure Hill and Hamilton reverse faults were probably passageways for the mineralizing solutions which produced the ore minerals of Treasure Hill.

From the preceding discussion of the folds and thrusts it is apparent that the majority of the folds either have thrusts exposed within their limbs or are underlain by thrusts. Thus, at many localities the surface mapping represents a thin veneer of rocks which constitutes the upper plate of a thrust fault.

FAULTS ACCOMPANYING EMPLACEMENT OF THE STOCKS

A maze of small faults which crops out on Pogonip Ridge, Babylon Ridge, and Treasure Hill is probably related to the period of emplacement of the two granitic stocks. Small faults of this epoch commonly facilitated ore mineral deposition; this criterion serves to distinguish them from younger faults. The mineralization is assumed to be related to solutions emanating from the crystallizing magma.

The Monte Cristo stock and the metamorphic rocks surrounding it were thoroughly shattered, probably a result of doming shortly after the emplacement of the stock. The forces causing the doming and fracturing must have effected fracturing and faulting in the rocks which are now exposed on Babylon Ridge and Treasure Hill. The Eberhardt normal fault probably was formed during this period although later recurrent movement on it was mostly horizontal.

TRANSVERSE FAULTS

The two major transverse faults are the Eberhardt fault, south of Treasure Hill, and the Cathedral fault, north of Cathedral Canyon.

The Eberhardt fault extends from the Belmont fault, southwest of Rocco Canyon with a bearing of approximately S. 70° E. At its intersection with the Sherman fault it is offset about 3,000 feet to the south. The Eberhardt fault continues on the east side of the Sherman fault, a short distance northeast of Sherman-town, bears approximately S. 70° E. along the south end of Treasure Hill and extends eastward to the Lampson thrust fault. Near the Lampson thrust it turns sharply to the northeast. East of the Sherman fault, the rocks on the north side of the Eberhardt fault have been moved eastward between 5,000 and 8,000 feet relative to the rocks on the south side. The rocks on the north side of the fault, particularly near the east end, have been bent as much as 90° by drag folding. Where the Eberhardt fault bends north, it turns into a thrust fault due to the eastward movement on the north side and merges with the Lampson thrust. The merged Eberhardt and Lampson faults are covered by alluvium in Sixmile Wash but are undoubtedly cut by the Indian Garden normal fault.

The Eberhardt fault is younger than the Treasure Hill reverse fault and the Little Antelope syncline, and thus is probably younger than the period of thrusting and folding. The author feels that it originally formed as a normal fault during the faulting which accompanied the emplacement of the granitic stocks, possibly as a result of uplift or doming of Babylon Ridge and Treasure Hill. It later accommodated the horizontal displacement mentioned above; possibly (as discussed later) the block north of the Eberhardt fault was pushed eastward during the time of uplift of Pogonip Ridge.

The Cathedral fault cuts transversely across Pogonip Ridge north of Cathedral Canyon with a strike of about N. 60° W. It is cut on the east end by the southern extension of the Belmont fault and is covered by alluvium along the west edge of Pogonip Ridge. Where it crosses a canyon near the midpoint of its trace, the dip of the fault is about 42° to the south. The vertical displacement is calculated to be almost 8,000 feet, with about 12,000 feet of relative movement down the dip of the fault, and there is no evidence to indicate any important strike slip component. The Cathedral fault marks the southern structural limit of Pogonip "dome".

The Ophir fault, a transverse normal fault, cuts across Pogonip Ridge about 3 miles north of the Cathedral fault.

A transverse tear fault cuts the axis of the Little Antelope syncline about 4 miles north of Hamilton. The south side of this

fault has moved relatively eastward about 700 feet at the Ely limestone-Diamond Peak formation contact on the west side of Little Antelope Ridge. This transverse fault marks the southern geographic boundary of Little Antelope Ridge and the northern geographic boundary of Mokomoke Mountains. The stratigraphic relationships at the northeast corner of Mokomoke Mountains indicate that this fault bends to the south and becomes a thrust. The block between this fault and the Eberhardt fault has apparently been pushed eastward, more or less as a unit, relative to the rocks on the north and south.

LATE TERTIARY NORMAL FAULTS

An epoch of largescale normal faulting occurred in late Tertiary time, chiefly post-Lake Newark formation. The most striking of the normal faults are those which bound Pogonip Ridge. The coarse Belmont fanglomerate, which was deposited during and immediately following the major uplift of Pogonip Ridge, is a result of rapid erosion during and following this uplift.

On the western side of Pogonip Ridge the vertical displacement approaches a maximum of 15,000 feet in the vicinity of section A-A' (pl. 1) where Upper Cambrian rocks crop out on the summit of Mount Hamilton at an elevation of about 10,700 feet and Pennsylvanian rocks crop out in the valley to the west at an elevation of about 7,000 feet. Similar displacements occur along the west side of Pogonip Ridge as far south as the Cathedral fault. No single fault, however, can be traced along this entire distance. South of Mohawk Canyon, the boundary fault is concealed by the Belmont fanglomerate. North of Mohawk Canyon the White Pine fault is exposed in many places, possibly owing to minor recent movement which has placed the fanglomerate opposite older rocks. The White Pine fault curves to the east north of Mohawk Canyon and strikes almost east-west at the north end of Pogonip Ridge.

The Belmont fault (pl. 1) can be traced from the north end of Pogonip Ridge south to Cathedral Canyon, a distance of more than 9 miles. The displacement decreases to the south and the fault apparently terminates a short distance south of Cathedral Canyon. The Belmont fault splits about 1,000 feet north of Cathedral Canyon, and the east branch is traceable for 2 miles south of the split. The maximum vertical displacement on the Belmont fault is almost 8,000 feet near Babylon Ridge. Where exposed in mine workings, the fault dips approximately 60° to the east.

The Cathedral transverse fault, described previously, terminates against the Belmont fault, but the complex structure near their intersection indicates that displacement occurred on both of them more or less simultaneously. The Belmont fault was active later than the Cathedral fault since a branch of the former continues southward for a few thousand feet with no displacement at its contact with the Cathedral fault. The youngest fault in this vicinity is a small east-west fault which cuts both the Belmont and Cathedral faults.

Another east-west normal fault cuts the White Pine fault at the mouth of Mohawk Canyon. This fault, which dips steeply to the north and has a displacement of several hundred feet, probably represents one of the latest adjustments in the structural evolution history of the Pogonip "dome".

Pogonip Ridge ends abruptly on the north at the junction of the Belmont and White Pine faults and there is no evidence that either of these faults continues beyond this junction. Thus, the Pogonip "dome" is completely enclosed by the Belmont, White Pine, and Cathedral faults, none of which extends more than a short distance beyond the outline of the "dome" although their displacements are of the magnitude of several thousands of feet.

A series of normal faults forms the east boundary of Ridgely, about 5 miles west of Pogonip Ridge. This structure is typical of many Basin-Range type fault blocks in that there are at least three frontal faults. The total vertical displacement on these east-dipping faults is about 3,500 feet. The faults form the west boundary zone of the graben between Ridgely and Pogonip Ridge.

The Sherman and Indian Garden faults are the only large north-trending normal faults east of Pogonip Ridge. Both faults transect structures related to the period of folding. Along the Sherman fault south of Shermantown the thick Belmont fanglomerate appears to be in fault contact with the Nevada limestone, a relationship which would make this one of the younger faults in the district. However, isolated outcrops of White Pine formation south of the Sherman fault indicate that shale of the White Pine formation was faulted down against the Nevada limestone and the fanglomerate may have been subsequently deposited against the more resistant limestone in the footwall of the fault.

The southern extremity of the Sherman fault is located about half a mile south of Shermantown. The fault strikes almost north and extends for a distance of about 4 miles. The rocks on the west side are faulted down and the greatest displacement is about

1,400 feet near the middle of the fault trace. At its northern extremity the Sherman fault trends toward the Hamilton fault, then bends sharply to the west and ends abruptly. The canyon north of Shermantown over most of the distance to the top of the Treasure Hill ridge is a fault-line valley which has been excavated along the Sherman fault.

The Indian Garden fault trace coincides with the east side of Sixmile Wash from north of Sixmile Spring to the south edge of the district and probably extends at least 4 miles farther south. North of Sixmile Spring the fault disappears under the alluvium and its northward extension may be either of two faults which are shown on the map (pl. 1) along the south side of Harris Canyon. One of these faults cuts the axis of the Illipah anticline and the other, on the west side of the anticline, dies out near Harris Canyon. South of Sixmile Spring the fault has a maximum displacement of about 2,000 feet with the west side dropped down relative to the east side.

In addition to the major faults there are innumerable minor faults of various ages throughout the district, some of which are of economic interest.

Four structural epochs have been discussed: (1) early normal faulting, representing the first stage of uplift of the Pogonip "dome", with between 2,000 and 5,000 feet of normal fault displacement in Eocene or earlier time; (2) folding and thrust faulting, dated in part as Eocene on evidence concerning the age of the Illipah formation and assumed to be related to the Laramide revolution; (3) transverse tear faulting which is older than the late normal faulting but younger than at least some of the folding and reverse faulting; and (4) late Tertiary normal faulting, which took place after the deposition of the Lake Newark tuff beds. The outstanding feature of the last epoch was the extreme uplift of Pogonip "dome" with a cumulative displacement in excess of 10,000 feet.

The two stocks within the Pogonip "dome" are probably related to a phase of the Laramide revolution. However, on the assumption that the lead-silver-copper mineralization emanated from the intrusive magma, the final solidification was later than the Monte Cristo and Seligman thrusts. Thus, the history of the Pogonip "dome" appears to be complexly involved in all four recognized structural epochs.

In eastern Nevada the Cordilleran geosyncline was depressed during the Paleozoic era. In the White Pine district no unconformities are known within the Late Ordovician through Permian

interval. There appears to have been almost constant deposition in this part of the geosyncline during this time. Triassic limestones are present in northeastern Nevada and in western Utah; thus, the depression of the geosyncline continued until at least some time in the Triassic period.

The early normal faults in the district must relate to the period between the deposition of the Triassic sediments and the compressive period of the Laramide revolution. The tectonic forces which depressed this portion of the geosyncline must have diminished or ceased completely following the Nevadan revolution because no marine sediments younger than the Nevadan revolution are known in this part of the Great Basin. Isostatic compensation then became possible and as a result the uplift and early faulting of Pogonip Ridge began. Thus the Pogonip "dome" may have become partially outlined at this time. During the Laramide revolution strong regional compressive forces again became active. Regional isostatic uplift probably ceased and possibly further depression resulted, accompanied by folding and thrusting. During this period thick fresh-water sediments accumulated and some of these, at least locally, may have been deposited in basins formed by the folding.

TECTONIC UNITS OF THE DISTRICT

The district is divided into three tectonic units. Certain distinctive features characterize each unit.

Pogonip "dome"

The Pogonip "dome" is the most nearly independent tectonic unit in the district. It is bounded by three major normal faults which enclose a large, roughly lens-shaped area. The lens bows near the middle, has a maximum width of about 3 miles, and is about 9 miles long.

The Mokomoke Mountains are the northward extension of the White Pine Range; the Pogonip "dome" is a separate structural unit lying to the west. There is no structural evidence to indicate that the rocks in the White Pine Range were dropped several thousands of feet, by normal faulting, relative to a small static lens of rock comprising Pogonip "dome". The theory that the "dome" resulted from differential isostatic uplift is here proposed.

The presence of the two stocks within the Lower Paleozoic rocks of Pogonip "dome" lends support to the possibility that the inception of a magma played a part in the uplift of the "dome". The early normal faulting which originally outlined the Pogonip

"dome" may well have been caused by a magma underlying the "dome".

Treasure Hill unit

The Treasure Hill unit includes the area between the Belmont fault on the west side, the Eberhardt fault on the south side, and the transverse tear fault which cuts the Little Antelope syncline on the north side. This unit has apparently been moved eastward relative to the rocks to the north and south. Since the Eberhardt fault is cut off by the Belmont fault, the eastward movement probably took place prior to the displacement on the Belmont fault.

This area, particularly Babylon Ridge and Treasure Hill, was elevated only a few thousand feet during the uplift of Pogonip "dome". This is suggested by the lesser displacement on the Belmont fault than on the faults on the west side of the "dome", and the present high elevation of the Nevada limestone in the Treasure Hill unit relative to outcrops of the same formation to the south.

The maximum eastward movement of the Treasure Hill unit is almost opposite the widest portion of the Pogonip "dome", suggesting that the unit may have been pushed eastward to make room for the Pogonip "dome". This could have happened if the pushing took place during the cumulative displacement on the Belmont fault rather than prior to it. The compressive stress initiated by the upward wedging of the "dome" would certainly need to be compensated for in some such manner. This concept does not altogether agree with a previous observation that the Eberhardt tear fault displacement may be related to the later phase of the period of folding and thrusting because its eastward extension merges with the Lampson thrust fault. The inception of the eastward movement of this unit possibly began during the early normal faulting of Pogonip Ridge.

The oldest known structural features of the Treasure Hill unit are the Treasure Hill anticline and the two reverse faults on Treasure Hill. These may be related to the regional compressive stress which produced the regional folding and thrusting and to the early compressive stresses resulting from the beginning of the uplift of Pogonip "dome". Thus, the horizontal movement along the Eberhardt fault may have begun prior to or during the period of folding and thrusting as a result of compensation for possible early localized compressive stresses.

The rocks of Babylon Ridge and Treasure Hill are cut by a great

number of small east-west, north-south, and northeast-trending faults. Many faults and fractures parallel to these systems were not mapped because of their limited displacement. Many of the northeast-trending faults are reverse faults with the northwest side raised. The rocks on the south slope of Babylon Ridge, between the Eberhardt and Belmont faults, are so intensely fractured and faulted that they approach breccia texture. These rocks are cut off to the north and east by a southeast-trending post-normal fault with a northeast dip. The displacement of this normal fault is complementary to that of the Belmont fault.

Most of the east-west faults on Treasure Hill are pre-mineral, since they contain evidence of hydrothermal mineralization, and some of them were active during the period of ore mineral deposition. The greater number of the northeast-trending faults, which are most prevalent on Babylon Ridge, do not appear to be mineralized and are considered post-mineral.

The Sherman fault is the only fault within the Treasure Hill unit which is not compatible with the theory of a general uplift on the west side and with the eastward movement of the unit. It is a north-trending normal fault which dips to the west and cuts all other structures which it intersects. Lead mineralization occurs at one place close to this fault, but is related to an east-west fault which is cut by the Sherman fault.

East unit

The East unit comprises all of the area east of Pogonip Ridge except for the Treasure Hill unit. The structures of the East unit are dominantly folds and thrust faults. The folds and thrusts trend consistently north-south and a number are traceable for several miles beyond the confines of the district. They are related to a regional compressive period and do not appear to be in any way connected with the complex history of the Pogonip "dome". The folding is, in part, Eocene in age.

A rhombic block of Nevada limestone, about 8,000 feet long and 4,000 feet wide, is present in the hanging wall of the Belmont fault, about two miles southwest of the Eberhardt fault. The block appears to have been displaced eastward similar to the Treasure Hill unit, but on a much smaller scale.

The only normal fault of any size in the East unit, except for the southward extension of the Sherman fault, is the Indian Garden fault in Sixmile Wash. It is younger than any of the other structures in that part of the district.

GEOMORPHOLOGY

PHYSIOGRAPHIC FEATURES

Pogonip Ridge is a roughly lens-shaped mountain with a steep, abrupt western slope. This steep arcuate western front is a fault escarpment which rises from an altitude of 7,400 feet at Monte Cristo to 10,745 feet in a distance of 2 miles.

Newark Valley, on the west side of the White Pine district, is approximately 45 miles long, extending from Ridgely northward along the east sides of the Pancake and Diamond Ranges. Newark and Railroad Valleys are separated by Ridgely, a fault block ridge about 7 miles long. Railroad Valley is approximately 100 miles long and extends southward and southwestward from Ridgely.

Little Antelope Ridge and Mokomoke Mountains, its southern continuation, extend through the central part of the district east of Pogonip Ridge and form a ridge which is continuous with the White Pine Range to the south.

Babylon Ridge and Treasure Hill make up a high domelike area in the central portion of the district with an elevation of about 9,300 feet. They are separated from Pogonip Ridge by the Belmont fault and from Mokomoke Mountains by the deep Cathedral Canyon.

Between Little Antelope Ridge and Moorman Ridge, east of the district, the north-south Illipah Valley is superimposed upon the Illipah anticline. Illipah Creek, instead of following the valley northward beyond the district, cuts east through Moorman Ridge along the route of U. S. Highway 50 to Jakes Valley.

There are two principal drainage directions in the district, owing to an east-west divide or arch which extends from the north end of Ridgely on the west side, through Mount Hamilton, Hamilton townsite, and Mokomoke Mountains to the head of Cottonwood Gulch on the east side. South of this divide the drainage is southward to Railroad Valley, and on the north the drainage is northward to the Humboldt River.

CYCLE OF EROSION ON POGONIP RIDGE

The cycle of erosion in the vicinity of Pogonip Ridge has passed from the youthful stage into early maturity, as indicated by the steep slopes in the heads of the canyons and the absence of nearly all interfluves. The ridge top is sharp. Although the uplift of the ridge was probably gradual, erosion probably did not keep pace with it and near the close of the last major uplift the west and north fronts of the ridge must have been extremely steep. Erosion must have proceeded at a rapid rate until the slope was reduced,

resulting in the rapid deposition of a great amount of coarse alluvium along the east side of Newark Valley. This older alluvium is referred to as the Belmont fanglomerate.

The canyon bottoms now have slopes between 10° and 15° from the front of Pogonip Ridge and for about half the horizontal distance to the top of the ridge; upstream from this point they steepen abruptly. Where the steepening begins, the canyons fan into several branches which extend up the steep surface to the top of the ridge. This surface has an average slope of about 35° .

The headward fanning of the canyons has left prominent high spurs at the front of each ridge between the canyons. The spurs are steep in front, with gently sloping tops up to a line where the fanning of the streams begins. Above this line the ridge rises abruptly giving the impression that the part of the range occupied by the spurs had at one time been a terrace.

Tributary gulches from north and south meet at the line where the canyons fan out and are rapidly eroding the heads of the spurs along this line, thus indicating their ultimate isolation. In the case of the spur between Seligman and Mohawk Canyons, brecciation by faulting near the break in the slope has accelerated the erosion.

COALESCED ALLUVIAL FANS

Alluvial fans were deposited in the early stages of the last major uplift of Pogonip Ridge and have rapidly coalesced into a continuous slope of coarse alluvium extending from Cathedral Canyon to the north end of the ridge. As erosion proceeded the longer gulches were deeply incised, and with continuing erosion the streams cut into the previously deposited fanglomerate. The canyon floors are locally more than 80 feet below the alluvial surface. The dissected fanglomerate suggests apparent alluvial fans which have their highest points in front of the faceted spurs, rather than in front of the canyons.

PEDIMENTS

The surface of the fanglomerate on the west side of Pogonip Ridge is essentially a pediment, or what Howard (1942) calls a peripediment. It has a uniform slope between 8° and 10° , except where the intermittent streams cut it.

The continuity of the pedimented surface of coarse alluvium is lost south of Cathedral Canyon, where uplift of the ridge and consequent erosion has been slight compared to that of Pogonip Ridge north of the Cathedral fault. The south edge of the pedimented surface is being eroded by streams flowing south, which

have exhumed the low hill composed of Ely limestone southwest of Monte Cristo. The hill still contains abundant fragments of Cambrian and Ordovician rocks from Pogonip Ridge. The fragments are remnants of the old gravels which once covered the Ely limestone. During the rapid deposition of the old gravels, this hill apparently acted as a dam which helped to retard lateral movement of the alluvium. Current erosion is increasing the slope of the valley floor at the south edge of the hill.

North of Mohawk Canyon on the northwest side of Pogonip Ridge the fanglomerate area is narrower and its surface is much steeper than the pedimented fanglomerate to the south. This steepening has probably resulted from a relatively recent displacement on the White Pine fault. This fanglomerate is narrower, no doubt, because the northern part of Pogonip Ridge was not elevated as high as the central portion; therefore, less material was available for the formation of fans.

TERRACES

The north- and northwest-flowing streams of Belmont and Hamilton Canyons formed an extensive gravel terrace north of Pogonip Ridge which partially coalesced with the fanglomerate on the west and northwest sides of Pogonip Ridge. Belmont Canyon receives the drainage from a large portion of the east side of Pogonip Ridge. The top of the gravel terrace is at about the same level as the top of the pedimented fanglomerate. The drainage from Belmont Canyon formerly curved more sharply westward around the north end of Pogonip Ridge and at that time considerable gravel was deposited near Sixmile House. After the rapid deposition of this gravel terrace, the stream began to dissect it and subsequently the stream course changed northward to a confluence with Hamilton Canyon. This change in drainage direction probably occurred because of a slight uplift of Pogonip Ridge during the recent displacement on the White Pine fault. Between the old and new channels a high terrace exists, which is now isolated from the large terrace north of it. The terraces have been dissected to a depth of 75 to 100 feet, exposing Lake Newark tuffs beneath the gravel.

SUPERPOSITION

Cathedral Canyon is a good example of a superimposed stream which has succeeded in cutting down through approximately 600 feet of massive Nevada limestone to form a spectacular precipitous gorge. The large drainage area east of the head of the gorge is

composed chiefly of White Pine formation and Ely limestone. These formations are faulted against the Nevada limestone along the Belmont fault. The logical course for this drainage would have been southward in the White Pine formation. Instead, the stream flows directly through the massive Nevada limestone which is several hundred feet higher than the White Pine formation outcrops south of the gorge along the fault. Thus, the westward course of the stream was evidently established before the massive limestone was exposed by erosion, but the displacement on the fault was sufficiently slow to enable the downcutting of the stream to continue along the same course even when the more resistant rock was encountered.

LANDSLIDES

Landslide topography is characteristic of the area near Hamilton townsite. North of Hamilton and in Cathedral Canyon to the south, the shale of the White Pine formation is nearly covered by slides of Diamond Peak formation and Ely limestone. The surface north of Hamilton is characterized by more or less rounded hummocks and depressions (fig. 9). Some of the blocks of Ely limestone involved in the slides are 500 or 600 feet in diameter and a few have slid more than 2,000 feet across the shale.

About 2 miles north of Harris Canyon a large block of Ely limestone slid eastward and dammed the old course of Illipah Creek. Farther north, on the east side of Little Antelope Ridge, several small blocks of Ely limestone have slid as much as 4,000 feet eastward over Diamond Peak formation and White Pine formation.

STREAM DIVERSION

The eastern part of the district, east of Little Antelope Ridge and Mokomoke Mountains and as far south as the headwaters of Cottonwood Creek, drains into Illipah Creek and its tributaries. Illipah Creek which originates at Harris Spring, flows eastward past the south end of Harris Ridge and through the ridge which follows the axis of the Illipah anticline; it then merges with Cottonwood Creek and flows northward along the east side of the White Pine formation exposures. The creek originally flowed northward along the west side of Harris Ridge and cut diagonally through the ridge into Illipah Valley at the west end of a transverse alluvial ridge (see below). This original course was blocked by a large landslide of Ely limestone blocks and the present stream course through the White Pine formation was thus established around the southern end of Harris Ridge.

ALLUVIAL RIDGE ACROSS ILLIPAH VALLEY

A narrow alluvial ridge crosses Illipah Valley about one mile south of U. S. Highway 50. The gravel was deposited by the old Illipah Creek before its course was changed. The alluvial ridge begins on the west at the mouth of the old Illipah Creek Canyon in Harris Ridge and extends eastward across Illipah Valley. It terminates on the east at the head of the canyon where Illipah Creek bends eastward prior to cutting through Moorman Ridge. The appearance of height of the alluvial ridge has been accentuated because its south side has been incised by sporadic stream flow from the old Illipah Creek channel.

GEOLOGIC HISTORY

PALEOZOIC HISTORY

Every system of the Paleozoic era is represented in the White Pine district with only a few indications of interrupted deposition. This area is thus one of the most persistent parts of the Cordilleran geosyncline.

No marine sediments younger than Paleozoic are known in the district. The only water-laid sediments of later age are the fresh-water Tertiary deposits and possible Cretaceous rocks.

The earliest known faulting probably began in late Mesozoic time and faulting was fairly active throughout most of Tertiary time.

Cambrian

The Middle and most of the Upper Cambrian series consist of alternating argillaceous clastic rocks and thin-bedded limestone with local shale partings. Depositional conditions changed late in the Late Cambrian and the massive dolomite member of the Goodwin formation was deposited.

Limestone beds at the top of the Secret Canyon shale, in the Dunderberg shale, and in the Goodwin formation locally contain abundant fossil fragments. In some instances faunal fragments may constitute almost 50 percent of the rock. The fragmentation of the fossils was probably accomplished by wave or current action in shallow water. The closely spaced bedding planes of the thin-bedded limestone, with shale partings and raindrop imprints on bedding surfaces, indicate that there were frequent current variations and fluctuations of sea level in the basin. The massive Upper Cambrian dolomite was probably deposited in somewhat deeper water with less variation of currents and sea level.

The lack of sand in these sediments indicates a depositional environment some distance from the edge of the shallow basin.

There is one evident unconformity within the Cambrian rocks of the district. The Middle Cambrian Secret Canyon shale is directly overlain by the Upper Cambrian Dunderberg shale. More specifically, the Dunderberg shale, of Franconian age, immediately overlies the *Elrathia* zone of the Middle Cambrian.

The Hamburg dolomite is absent in the White Pine district, not as a result of faulting but because it was never deposited. There has been some erosion of the uppermost portion of the Secret Canyon shale; two or more thin limestone beds are locally absent. During the early part of the Late Cambrian epoch this area must have been fairly static relative to the continual depression of the area in the vicinity of Eureka and was probably slightly elevated as evidenced by erosion of the upper part of the Secret Canyon shale.

Ordovician-Devonian

During the Early Ordovician, while a thick section of thin-bedded limestone (Pogonip formation) was being laid down, depositional conditions were again similar to those of the Middle Cambrian; but early in the Middle Ordovician a change took place and the almost pure quartz sand of the Eureka quartzite was deposited over a large part of the geosyncline. The purity and wide areal extent of the sand implies that during this period the seaway must have been open to strong currents which could more or less evenly distribute the vast amount of sand and at the same time selectively remove any clay or calcareous ooze.

Important changes in depositional conditions within the geosyncline took place following Middle Ordovician time. The massive black Hanson Creek dolomite, which overlies the Eureka quartzite, is the basal member of a thick continuous sequence of dolomite extending through the Silurian into the Middle Devonian.

In the Lone Mountain and Roberts Mountains areas, about 50 miles west of the White Pine district, Merriam (1940) found about 1,500 feet of thin-bedded limestone between the Hanson Creek dolomite and the Lone Mountain dolomite. He named this stratigraphic interval the "Roberts Mountains formation". In the White Pine district the Hanson Creek dolomite grades into the Lone Mountain dolomite, indicating continuous deposition with no hiatus. Therefore, it is assumed that the Roberts Mountains formation lenses out east of the type locality.

During Middle Devonian time a change occurred in the conditions of sedimentation and the massive Nevada limestone was

deposited. The basal 100 to 300 feet of the Nevada limestone are reddish thin-bedded limestone. The thin-bedded limestone is locally dolomitic which shows that the conditions in the basin which caused dolomitization did not cease abruptly.

There is no evidence of an unconformity between the Pogonip formation and the Eureka quartzite, although there is a definite change in lithology. There may be an unconformity between the Eureka quartzite and the Hanson Creek dolomite, as occurs elsewhere in Nevada. The Eureka quartzite ranges in thickness from about 250 feet to more than 400 feet from the north end of Pogonip Ridge to the south end—a distance of about six miles. The contact between the quartzite and overlying dolomite is abrupt, indicating that a hiatus may exist between the quartzite and dolomite.

The author recognized no other unconformities within the Upper Ordovician, Silurian, or Devonian rocks of the district. There was probably continuous deposition throughout this time, although the thin quartzite beds and sandy dolomite beds between members 3 and 4 of the Lone Mountain dolomite indicate a brief period when conditions were again similar to those during the deposition of the Eureka quartzite. Beds of edgewise conglomerate, in addition to cross-bedding in the sandy dolomite beds associated with the quartzite, have been noted at other localities in eastern Nevada. Thus, there is local evidence of interrupted sedimentation during this period.

Mississippian-Permian

Lithogenetic changes occurred in the geosyncline in Late Devonian or Early Mississippian time with the deposition of thick sections of clastics interbedded with limestone. This sequence, particularly its Mississippian portion, is characterized by facies changes from limestone to shale to sandstone. While this area remained almost continually at or below sea level during this time, portions of the geosyncline to the west were uplifted and subjected to erosion (Nolan, 1943). During Pennsylvanian and most of Permian time this area remained depressed and a thick sequence of limestone and sandy limestone was deposited.

The deposition of the White Pine formation denoted the end of the relatively widespread uniform depositional conditions of early and middle Paleozoic time in eastern Nevada. The preponderant deposition of limestone and dolomite gave way to clastics, derived chiefly from westerly sources. Thick limestone sections accumulated locally up to the end of the Paleozoic and probably into the Early Triassic.

MESOZOIC HISTORY

No rocks of definite Mesozoic age are known within the White Pine district. During most of Mesozoic time there probably was gradual uplift accompanied by retreat of the sea, with erosion removing as much as 5,000 feet of Paleozoic sediments in some places.

The beginning of the uplift of Pogonip "dome" was prethrusting, probably during late Mesozoic. The earliest possible dating by stratigraphic evidence of the period of folding and thrusting is Eocene. But since the deformation was already underway when the Eocene lake sediments were deposited, it may have started in the Mesozoic.

Fresh-water sediments, which are considered on faunal evidence to be Cretaceous, are found north of Eureka and at Indian Springs, about 10 miles northeast of the district. These sediments near Eureka contain a thick section of coarse limestone conglomerate which probably has a tectonic origin. The chert-quartzite conglomerate and sandstone overlying the Diamond Peak formation north of Sixmile House are probably of late Mesozoic age and possibly represent fresh-water sediments deposited during the early portion of the thrusting and folding phase.

CENOZOIC HISTORY

The most pronounced unconformity in the district is that between the Upper Paleozoic sequence and the Illipah formation (Eocene). After regional uplift and erosion during late Mesozoic and early Tertiary time the fresh-water Illipah formation was deposited. The clastic rocks comprising the lower member of the Illipah formation are probably related to local uplift and tectonic activity in, or adjacent to, the district which may have been a continuation of the late Mesozoic tectonic conditions. The fresh-water limestone of the upper member of the Illipah formation contains little or no clastic material and, although it is folded along with the older rocks, there was apparently no differential uplift within the drainage area of the lake during deposition.

The Lake Newark formation (probably Miocene or Pliocene) is younger than the Illipah formation and lies unconformably on it. The Lake Newark formation is composed dominantly of volcanic tuffs; similar tuffs, probably of the same approximate age, are common in eastern Nevada and represent a distinct phase of widespread igneous activity.

There appears to have been no deposition of sediments within the district during Oligocene and most of Miocene time.

After the deposition of the tuffs the coarse Pliocene (?) Belmont fanglomerate was deposited around Pogonip Ridge and probably represents rapid erosion following the last major uplift of Pogonip Ridge.

In the southeast part of the district basalt flows were extruded shortly after the deposition of the tuffs.

DIASTROPHISM

With the exception of the Pogonip Ridge area, the major tectonic activity in the White Pine district was folding and thrusting. This activity is probably related to a phase of the Laramide revolution. No older deformation is recognized except the probable gradual regional uplift of the entire area throughout most of Mesozoic time.

Pogonip Ridge has had a long and complex history. It is a structural unit which was uplifted and deformed more or less independently of the surrounding rocks. The several tectonic phases, beginning with the pre-thrust normal faults, are summarized as follows: (1) an incipient "dome" was outlined by normal faulting prior to the thrusting, probably in Mesozoic time; (2) thrusting, with the displacement on the Monte Cristo thrust occurring at a depth of 10,000 feet or more; (3) emplacement of the two stocks followed by hydrothermal mineralization; (4) major uplift of Pogonip "dome" after the deposition of the Lake Newark beds, probably in Pliocene time; and (5) minor structural adjustments within the "dome", probably in Pleistocene time.

ECONOMIC GEOLOGY

MINERAL DEPOSITS

Mineral zoning

Three rather indefinite zones of mineralization occur within the district. A chalcopyrite zone lies within the two intrusive stocks and in their surrounding metamorphic aureole. A lead-silver-zinc-copper zone, farther from the intrusive bodies, more or less surrounds the chalcopyrite zone. The silver zone of Treasure Hill lies east of the lead zone and is farthest from the stocks.

The rock composition bears a definite relationship to the mineral deposition. The lead zone is confined almost entirely to dolomite rocks, except in the old Belmont mine where the ore occurs in quartzite. The silver zone is confined to the uppermost beds of the Nevada limestone. The north end of the silver zone, northwest of Hamilton, is closer to the intrusive outcrops than is the

lead mineralization on the west slope of Treasure Hill. The silver-bearing tetrahedrite ore south of Monte Cristo is also confined to the dolomite.

The silver zone

The small but rich silver zone on Treasure Hill was the most important ore deposit in the White Pine district. Between 20 and 40 million dollars worth of silver ore was mined from an area less than 1 mile long by half a mile wide. Most of the ore occurred in and near a fracture zone which begins at the Hidden Treasure mine on the north and extends south to the Eberhardt mine.

The ore on Treasure Hill consisted almost entirely of the secondary silver mineral cerargyrite (AgCl). Arnold Hague (1870) mentioned the presence of both silver bromide and silver iodide in the Treasure Hill ore. Polished specimens of the available samples failed to give any recognizable reaction to either a bromine or iodine test. Hague also mentioned "boulders" of cerargyrite which weighed as much as 2 and 3 tons. No evidence of secondary antimony or arsenic was detected in the samples and it is assumed that the primary mineral was argentite. Silver-bearing tetrahedrite, however, occurs in both the Trench and Caroline mines on the west side of Pogonip Ridge, south of Monte Cristo.

The mineralization on Treasure Hill is a replacement in the uppermost portion of the Nevada limestone just below the Pilot shale. The shale has been eroded from the greater part of Treasure Hill and the rich ore in the top of the Nevada limestone was exposed at the surface.

The richest and most extensive belt of mineralization extends from the Hidden Treasure mine S. 20° W. to the big dump of the Aurora mine. A definite gap in the mineralization extends southward for about 900 feet from the Aurora mine to the east-west fault which forms the north boundary of the rich Eberhardt mine. The Eberhardt mine is at the south end of the rich zone, although scattered mineralization in the Nevada limestone occurs southward for about 4,000 feet to the Eberhardt fault.

The rich ore is in an intensely brecciated zone with little fault displacement. The breccia (fig. 14) was cemented by silica and calcite when the ore was introduced. Black manganese oxide is generally present and seems to be associated with later calcite. Locally, where the brecciation is less intense, replacement deposits occur in favorable beds in the limestone. Subsequent to the introduction of quartz and ore minerals, brecciation took place accompanied by the deposition of an enormous quantity of secondary

calcite. Apparently no ore solutions were introduced during this episode.

In "Chloride Flat" along the west side of the Aurora and Ward Beecher mines (figs. 15 and 16) ore was mined in brecciated zones and along bedding planes. The mineralized zones occupy approximately the same stratigraphic horizon as the ore deposits along the main fracture zone.

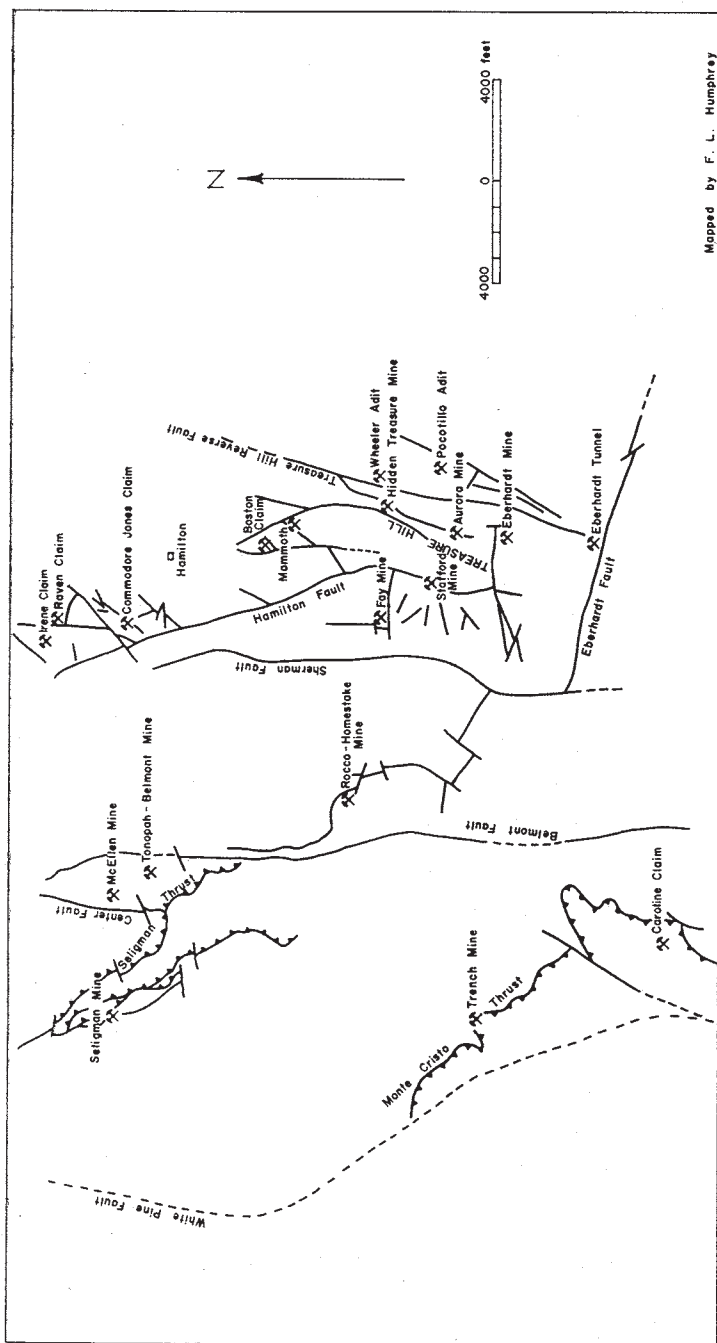
Both the north-south and the east-west fractures are mineralized and some of the widest stopes were excavated near intersections of east-west and north-south fractures. The north-south



FIGURE 14. Calcite-cemented limestone breccia from Treasure Hill ore zone.

fractures are locally offset by the east-west fractures; thus, movement on the east-west fractures continued after it had ceased along the north-south fractures. Recurrent movement and brecciation were the controlling factors in the introduction and localization of the mineralizing solutions in that they prevented the fractures from becoming sealed by the deposition of silica and calcite.

In the barren zone between the Hidden Treasure mine and the Second South Extension of the Hidden Treasure mine there is only a minor amount of brecciation and fracturing. The previously mentioned barren zone between the Aurora mine and the



Mapped by F. L. Humphrey

FIGURE 16. Principal mines in the White Pine district shown in relation to fault pattern.

A polished specimen of Hidden Treasure ore contains a calcite crystal surrounded by quartz, which in turn is surrounded by calcite containing a fine, disseminated, silver-bearing mineral thought to be argentite. This specimen was cut from a piece of limestone breccia which was partly surrounded by calcite and contained no discernible ore minerals. This relationship indicates that brecciation of the ore zone along with deposition of calcite continued after the silver deposition.

The main breccia zone along which the major portion of the ore formed strikes N. 20° E. on Treasure Hill and merges with the Treasure Hill reverse fault a short distance northeast of the Hidden Treasure mine.

North of the Hidden Treasure mine the Nevada limestone is generally covered by the Pilot shale and Joana limestone. The Joana limestone does not seem to be amenable to ore mineralization, although locally it is nearly replaced by jasperoid. The only known ore occurrence in the Joana limestone is in the drift running south from the Wheeler adit and at the surface over this drift. This mineralization is close to the Treasure Hill fault.

About 4,000 feet north of the Hidden Treasure mine two outcrops of the Nevada limestone are in fault contact with the Pilot shale. The Mammoth and Boston claims (pl. 2 and fig. 16) enclose these outcrops. Here, as on Treasure Hill, a considerable amount of silver mineralization with a later influx of calcite occurs in the top of the limestone.

Ore deposition may be assumed to have taken place in the limestone underlying the Pilot shale between these outcrops and the main ore zone on Treasure Hill. Several diamond drill holes were put down along the west side of the main ore zone and northwest of the Hidden Treasure mine in the middle 1920's, but ore was not encountered. Hence it appears probable that the intense fracturing and brecciation decreases north of the Hidden Treasure mine; thus, further exploration should be confined to the immediate vicinity of the faults cutting this area (pl. 1).

Northwest of Treasure Hill, beyond Hamilton townsite and east of the Hamilton fault, the upper Nevada limestone is exposed in several places. It is locally mineralized and in some places the size of the workings indicates that ore must have been mined. This mineralized zone extends as far north as the Irene and Raven claims (fig. 16). Little or no mineralization was observed north of these claims.

A thin wedge of Nevada limestone is exposed along a north-south fault on the Raven and Red Raven claims. A considerable

amount of rock was mined here over a distance of about 75 feet along the bedding from the fault. The stratigraphy is similar at the Boston and Mammoth claims in that the top of the Nevada limestone is exposed in the footwall of the fault and the overlying Pilot shale is in the hanging wall. Similar conditions occur on the Bon Homme Richard-Commodore Jones claims and at several places as far south as the road which runs west from Hamilton.

The structure north of Treasure Hill along the east side of the Hamilton fault is essentially an east-dipping homocline cut by faults and fractures. Where a single fault was the principal means of localization of the mineralizing solutions, as in the localities north of Treasure Hill, ore mineralization might be expected to be less intense, but this should not be construed to mean that these areas are unworthy of prospect. In fact, a substantial tonnage of rock was mined from five such occurrences. Studies of the ore zones north of Treasure Hill indicate that ore mineralizing solutions undoubtedly entered along faults and deposited ore in the Nevada limestone at or near its contact with the Pilot shale. At these localities the ore extended along the bedding away from the fault for not more than 50 or 60 feet, which is the present limit of the mining. Where ore occurs at the surface in the top of the Nevada limestone in the footwall of a normal fault or the hanging wall of a reverse fault, there is a reasonable possibility of its occurring at the same stratigraphic horizon in the opposite wall of the fault. Under such conditions, where the shale is in contact with the fault, the resulting fault gouge may be more impervious; therefore, the downthrown Nevada limestone could conceivably have had even more favorable conditions for mineralization than the upthrown Nevada limestone.

In the author's opinion, the area from the limestone-shale contact west of the Hidden Treasure mine north to the Irene claim furnishes the most favorable opportunities for successful exploratory work in the silver belt. Another zone of possible economic value is the limestone-shale contact in the vicinity of the Pocotillo claim on the east side of Treasure Hill in the footwall of the Treasure Hill reverse fault. The Nevada limestone on Treasure Hill south of the Hidden Treasure mine has been explored at depth by adits and surface drilling without success.

Eberhardt tunnel.—The Eberhardt tunnel (figs. 16 and 17), whose portal is near the large Eberhardt fault, was the most ambitious program undertaken to explore the hill at depth. This 8- by 10-foot adit was driven 6,000 feet under the east side of Treasure Hill by the consolidated properties of Treasure Hill in

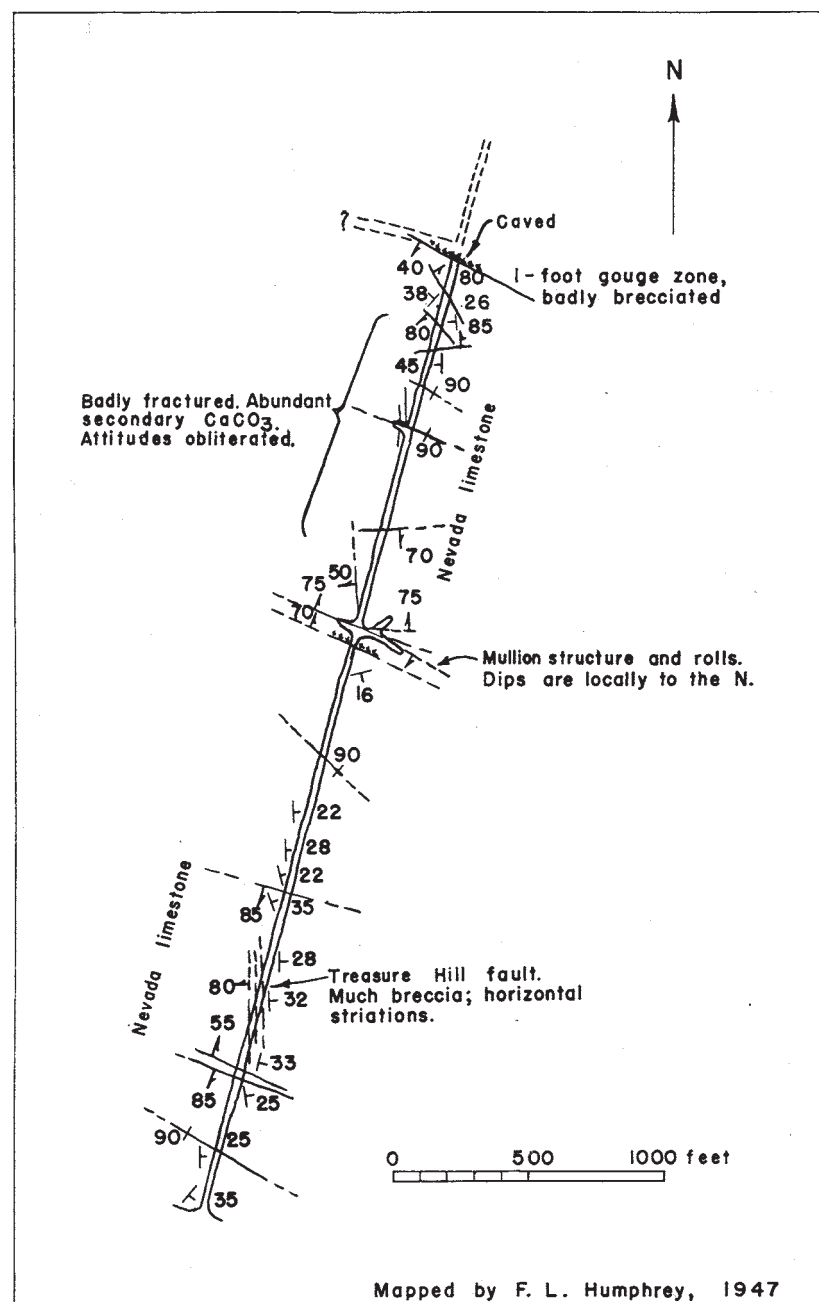


FIGURE 17. Geologic map of the Eberhardt adit.

the late 1870's. The portal of the adit is at an altitude of 7,666 feet and the altitude of the main ore zone on Treasure Hill is about 9,100 feet. The adit is caved at a fault intersection 3,000 feet from the portal and water is impounded behind the caved area. Apparently three crosscuts were run from the adit. One began at the fault where the adit is now caved, and was driven under the Eberhardt mine. This fault is probably the one which forms the north boundary of the Eberhardt mine. Two other crosscuts were apparently driven from the face, one under the Aurora workings and one under the Ward Beecher workings. Raises were driven to both the Aurora and Eberhardt workings. It is reported that little or no ore was developed by this exploration although minor amounts of argentite occurred along some of the faults which were intersected.

Unfortunately the adit parallels both the main structures of the hill and the strike of the beds. The adit cuts the Treasure Hill fault near the portal and remains in the footwall for the entire distance to the face. The dip of the beds changes from east to west at the fault zone about 2,000 feet from the portal; this is about where the adit should cut the axis of the Treasure Hill anticline. For a distance of approximately 1,000 feet the rocks are intensely fractured and the bedding planes obliterated (fig. 17).

Wheeler adit.—The Wheeler adit portal (figs. 16 and 18), as nearly as could be determined, is on the Silver King claim. It is 1,070 feet long on a bearing of N. 70° W. and the face is about 400 feet lower than the Hidden Treasure mine workings.

About 330 feet from the portal, the adit passes through a steep west-dipping fault zone that probably represents the Treasure Hill fault. About 160 feet farther, the adit cuts a fault. Fragments of Pilot shale in the footwall of the fault and Nevada limestone in the hanging wall suggest that this is a reverse fault. These two reverse faults probably represent an offset of the Treasure Hill fault by an east-dipping fault which cuts the adit about 380 feet from the portal. A 300-foot drift was run to the south along this east-dipping fault.

The Wheeler adit is in Joana limestone at the portal and appears to continue in it to the first reverse fault, where the wall rock then resembles the Nevada limestone. West of the south drift the wall rock of the adit strongly resembles Joana limestone as far as the second reverse fault. At this point the adit once again cuts Nevada limestone and remains in it to the face. This

repetition lends further support to the identity of the two reverse faults as indicated on the separate cross section shown on figure 18.

The fault in the south drift contains abundant calcite and minor iron oxide. A winze was sunk at the intersection of this fault and a mineralized south-dipping fracture. Water is standing at about the 200-foot level.

From 1 to 2 feet of ore were stoped for a short distance along the mineralized fracture at the winze. The ore is not offset by the fault and consequently must be younger than the fault. This apparent control of mineralization by east-west fractures is common throughout the district.

Near the face of the adit a winze and a raise were excavated along another east-west fracture zone which contains considerable iron oxide and calcite, but there are no indications that any ore was mined. The Nevada limestone contains innumerable calcite stringers along both the north-south and east-west fracture zones throughout its extent in the Wheeler adit.

Pocotillo adit.—The portal of the Pocotillo adit (figs. 16 and 19) is on the Pocotillo claim. The adit bears about N. 75° W. for 600 feet in the Nevada limestone where the Nevada limestone-Pilot shale contact is encountered. Development work was done on east-west fractures at several places in the limestone and some ore was mined. Beyond the Nevada limestone-Pilot shale contact the adit continues for approximately 400 feet on a N. 45° W. bearing. Had it continued on a more westerly bearing for the same distance, it would have cut the Treasure Hill fault; however, the adit is at least 90 feet above the projected limestone-shale contact at the fault.

This contact near the fault is a logical objective. There are sufficient indications of mineralization along east-west fractures in the limestone over 500 feet from the fault to indicate a possible increase in the amount of the mineralization as the fault is approached, but the position of the limestone sequence in the footwall of the fault may be objectionable. Possibly the reverse fault was one of the principal feeders for the mineralization; thus, the ascending solutions might have a greater tendency to penetrate the hanging wall of the fault than the footwall.

Diamond drilling on Treasure Hill.—In 1926 the Tonopah Mining Co. drilled several diamond drill holes on Treasure Hill. A study of their drill logs indicates that a great deal of time was spent in attempting to keep the drill water circulating. The overall core recovery was less than 40 percent and the bulk of

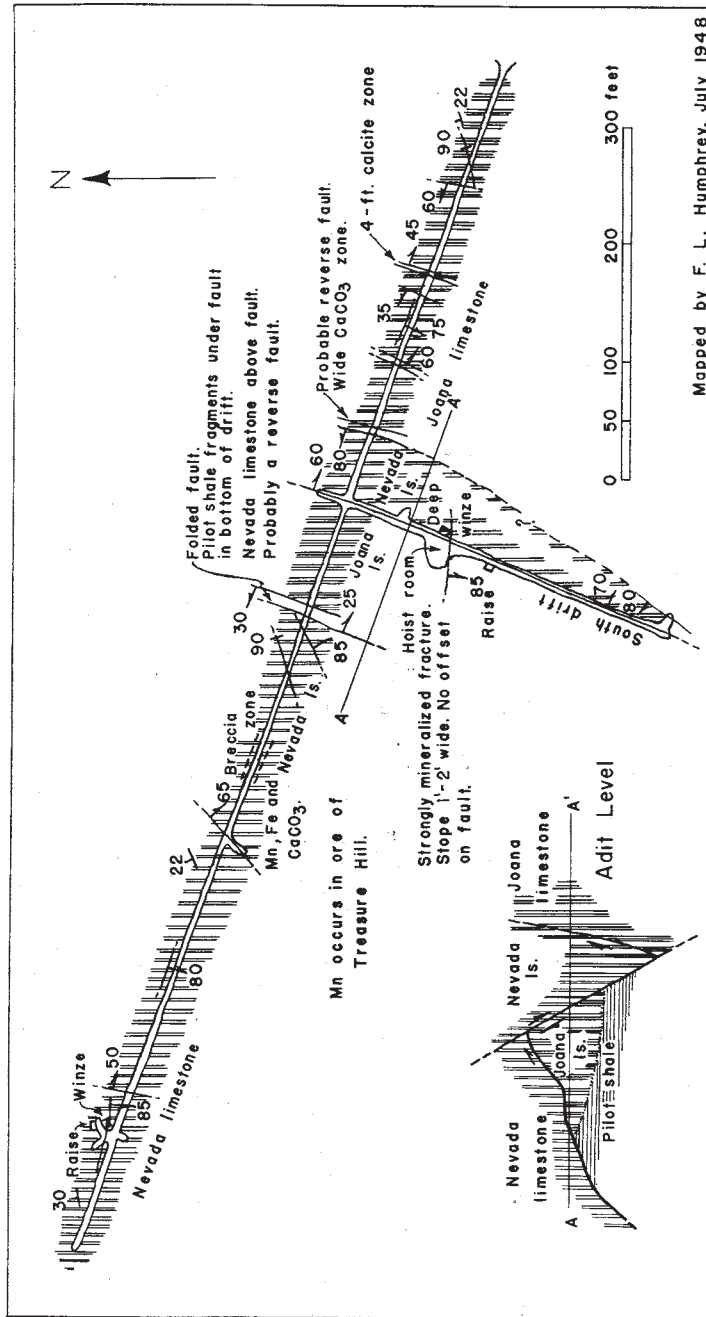


FIGURE 18. Geologic map of the Wheeler adit.

this is from the more solid unmineralized beds. The drilling in the limestone gave very inconclusive results; nevertheless, the possibilities are poor for finding any more rich ore south of the shale-limestone contact near the Hidden Treasure mine.

Sufficient exploration work was undertaken by the original mining companies, as well as several later ventures, to indicate that little silver ore occurs at depth in the Nevada limestone. Treasure Hill is honeycombed with shafts and adits, most of which produced no ore away from the main ore zones.

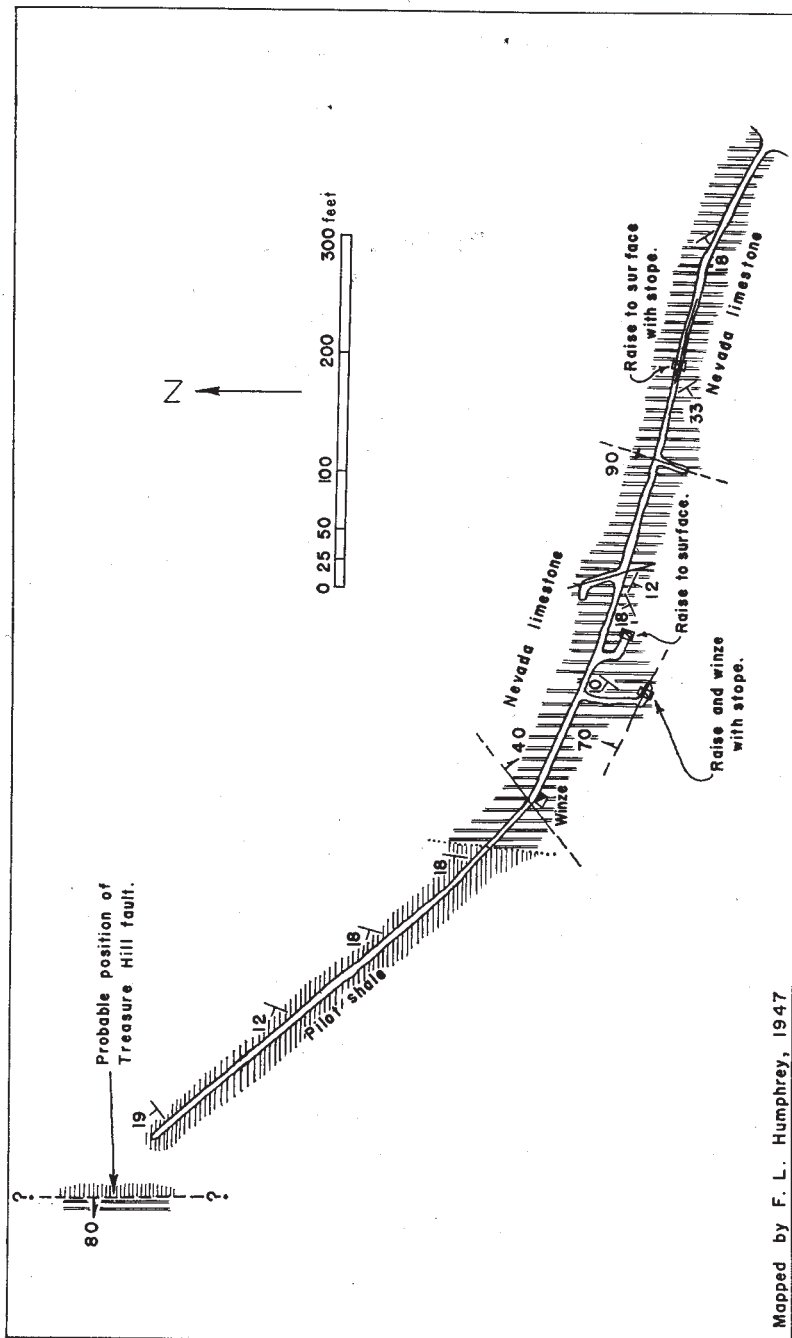
The Stafford mine (see fig. 16), near the west edge of the Nevada limestone on Treasure Hill, attained a depth of at least 400 feet in the limestone. This mine is near the Hamilton fault as well as on a system of east-west fractures and had a production of 2,674 tons with a gross yield of \$79,027. The deposits apparently occurred in erratic, disconnected lenses along the fractures. The "ore" returns did not repay the cost of the underground work.

The lead-silver zone

The lead-silver zone is west of the silver zone, generally closer to the intrusive bodies, and is confined almost exclusively to the dolomitic rocks. Member 2 of the Goodwin formation, the Hanson Creek dolomite, the Lone Mountain dolomite and the dolomitized areas of the lower portion of the Nevada limestone were susceptible to lead-silver replacement.

Galena is the only primary ore mineral which is preserved in the shallow mine workings. Upon oxidation, galena forms the relatively insoluble secondary sulfate, anglesite. Owing to the presence of calcium carbonate and carbonic acid in meteoric waters, the anglesite is slowly replaced or altered to the carbonate, cerussite. The enclosing rim of anglesite and cerussite partially protects the core of galena from further oxidation; galena nodules surrounded with anglesite and cerussite are common.

There may be some degree of secondary enrichment of the silver although the author was unable to determine the nature of either the secondary or primary silver mineral. The primary mineral may be argentite disseminated in the galena, but if so, it is too fine to be recognized on a polished surface. Most of the ore contains copper, generally as malachite, but less commonly as chrysocolla or cuprite. Sporadic zinc values, probably all as secondary smithsonite, also occur in most of the ores. The ores have generally been shipped to a lead smelter. Consequently, the zinc was of little value to the shipper and commonly drew a



Mapped by F. L. Humphrey, 1947

FIGURE 19. Geologic map of the Pocotillo adit.

penalty assessment. Jarosite is common in the secondary ores and some plumbo-jarosite is undoubtedly present.

The nature of the surface ores (in part oxidized lead, zinc, and copper minerals, and in part residual galena and jarosite) presents a difficult beneficiation problem. At the present time only ores of shipping grade are mined and are shipped directly to a smelter.

The lead ore occurs along fracture and shear zones, and irregularly along bedding planes. In the fracture and shear zones, at least near the surface, the ore values tend to be sporadic and rather unpredictable. The irregular lenticular nature of the ore shoots is a primary feature and not the result of oxidation and supergene migration. Where the ore has replaced dolomite along the bedding, particularly at the horizon of the quartzite beds in the Lone Mountain dolomite, it is much more continuous and uniform.

Lens-shaped ore bodies are particularly characteristic of the mineralization on Pogonip Ridge, and one of the most extensively mineralized areas is in the blocks of Hanson Creek dolomite on the north slope of Pogonip Ridge. Several shipments of ore, carrying from 20 to 40 percent lead, have been made from this area in recent years.

The sporadic lenses are commonly small and each must be prospected individually. The high-grade portions generally contain from a few tons to 20 or 30 tons, although a lens may contain as much as 50 tons of high-grade ore.

Most of the recent shipments from this area have been mined from the south end of the fault block of Hanson Creek dolomite between the Belmont and Center faults and from the Jenny A and Dog Star claims in the Hanson Creek dolomite near the top of the ridge. In the Jenny A claim the ore has irregularly replaced dolomite along bedding planes and along the shear zones. The greatest production in this area has been from the McEllen mine (shown on figure 16), including the Young Treasure adit. According to Couch and Carpenter (1943), ore worth \$210,000 was mined between 1887 and 1928. Lesars have made several shipments from the mine since 1940. The greatest part of this production was from the Young Treasure adit, where a series of high-grade lenses occurred along a north-south, east-dipping fracture in the dolomite about 150 feet east of the Center fault.

The Center fault and the Seligman thrust fault were probably the main feeders for the mineralization in this area. Lead mineralization occurs in the small block of Eureka quartzite in the Glory

and Quartz claims about a quarter of a mile south of the McEllen mine.

The small fault block of Hanson Creek dolomite on the west side of Pogonip Ridge, about one mile north of Mohawk Canyon, shows good indications of possible economic mineral occurrences. Furthermore, a small amount of ore occurs near the faults in the Eureka quartzite. This and the more extensive mineralization of the Eureka quartzite on the Glory mine and Quartz mine claims, worked by the Tonopah Belmont Co. constitute the only important lead-silver ore deposits which are not in dolomite.

On the north side of Seligman Canyon, along the zone of the Seligman thrust fault in the Goodwin formation, a belt of mineralization within dolomite extends to the top of Pogonip Ridge. This is a difficult zone to explore because the fault and the dolomite both dip to the northeast into the hill, and the west side of the ridge slopes about 30 degrees.

Where the hanging wall of the Monte Cristo thrust is composed of dolomite, it is mineralized. This ore consists of silver-bearing tetrahedrite in member 2 of the Goodwin formation, although the mineral is galena in the small wedge of Hanson Creek dolomite in nearby Ophir Canyon.

At the Trench mine, about $1\frac{1}{2}$ miles south of Monte Cristo, tetrahedrite apparently was irregularly disseminated in the dolomite along the bedding. A sample taken from an ore dump of 15 or 20 tons assayed 41 ounces of silver per ton. However, the dolomite outcrop at this locality is small and is immediately underlain by limestone.

On the Caroline claims south of Ophir Canyon (figs. 16 and 20), tetrahedrite occurred along a steep east-dipping fracture in the Goodwin formation and from appearances there must have been several hundred tons of high-grade tetrahedrite ore. An assay of rock from what was probably the sorting dump assayed 112 ounces of silver per ton.

Little or no mineralization is exposed on Pogonip Ridge south of the Caroline claims with the exception of several small pieces of barite float found near the base of member 4 of the Pogonip formation, about half a mile southeast of the Caroline claims. A portion of a specimen of *Orthoceras* collected at this locality was recognized by Dr. S. W. Muller as being replaced by barite.

In Rocco Canyon and on the west slope of Treasure Hill the Lone Mountain dolomite contains a number of lead prospects. These are of particular promise where they occur in the dolomite at the horizon of the thin quartzite beds. The dolomite at this

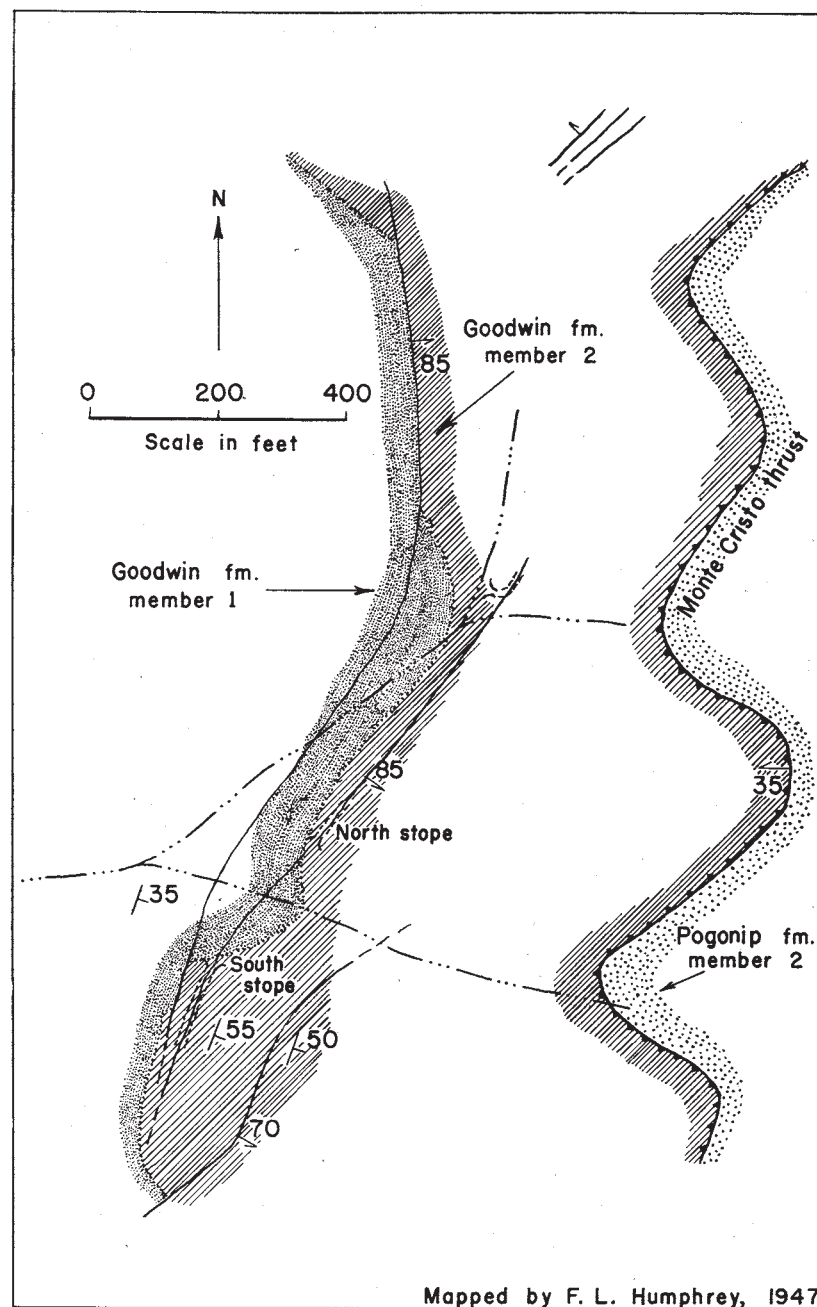


FIGURE 20. Geologic map of Caroline claims.

horizon is most amenable to replacement and in at least three mines yielded a considerable tonnage of bedded ore. Where these beds are in contact with mineralized faults or shear zones there are possibilities for ore occurrences.

It is not apparent why certain beds of dolomite or limestone are more susceptible to mineral replacement than others. Slight differences in chemical composition and relative permeability may be contributing factors. In this instance the presence of the sandy dolomite and quartzite beds probably increases the permeability. In the Fay mine the quartzite beds are not replaced but the ore occurs in the dolomite and sandy dolomite beds close to them.

The quartzite beds crop out along the west side of Treasure Hill, but their continuity is interrupted by faulting. They also crop out at several places in and near Rocco Canyon.

The Lone Mountain dolomite in Rocco Canyon is intensely faulted and consequently it is difficult to indicate the various outcrops of quartzite on the scale of the geological map. The quartzite may be most easily observed on the west side of Rocco Canyon, about 300 feet south of the Comanche adit, and on the east side of the canyon about 200 feet up the slope, across from the Comanche adit.

In the area between these outcrops the quartzite bed has been faulted down by two parallel north-south faults forming a small graben. The Rocco-Homestake and the Ne Plus Ultra mines are situated along this bed in the graben.

Rocco-Homestake mine.—The Rocco-Homestake mine (figs. 16 and 21) is situated in the small graben of Rocco Canyon. According to Couch and Carpenter (1943) the mine produced lead-silver ore worth \$349,000 between 1887 and 1905.

The mine map (fig. 21) was adapted from an old map loaned by Carl Muir of Ely, Nev. Portions of the mine were made accessible when the Hamilton Consolidated Mining Co. opened the Jackson shaft down to the 340 level. The old inclined shaft is caved to the surface and is inaccessible south of the marked drill hole and in most of the stoped area.

The graben was formed by four faults and is therefore a graben within a graben. The Rocco and East faults on the east side dip steeply to the west. The "step" on the west side of the graben is bounded by the Canyon and Comanche faults. The graben is cut off and dropped down to the north by the Jackson fault. The Muir fault forms the southern boundary of the Rocco stope and the rocks south of it are stratigraphically higher. The combined

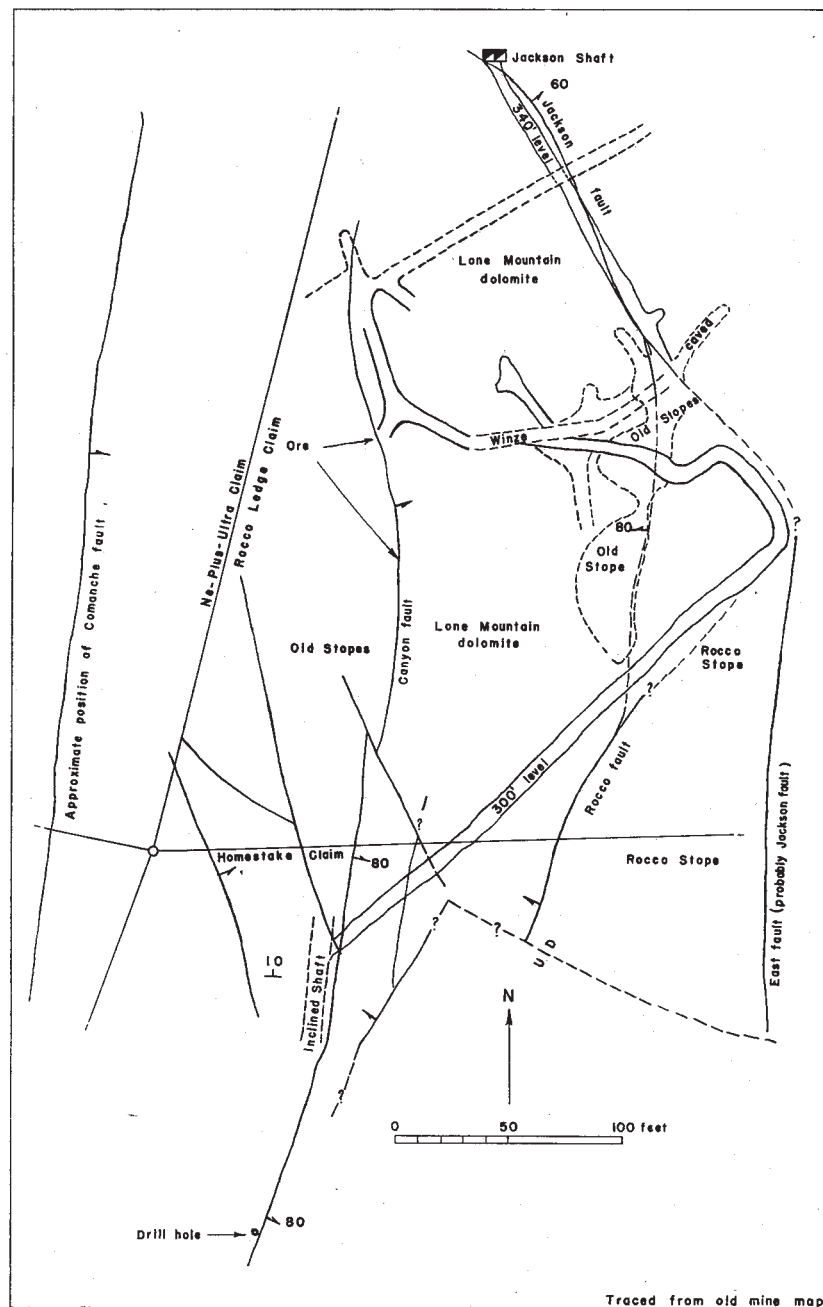


FIGURE 21. Map of the Rocco-Homestake mine shown in relation to fault pattern.

displacement of the Muir and Rocco faults has left the quartzite beds south of the Muir fault some 200 feet higher. The two large stopes are in the footwalls of the Canyon and Rocco faults at the horizon of the quartzite beds.

Exploration work, carried out by the Hamilton Consolidated Mining Co. in 1950, showed that the quartzite bed horizon in the central graben was mined from the 335 level of the Jackson shaft. The Jackson shaft has now been opened to the 440 level. A cross-cut running southward from this level is in the white porcelaneous dolomite member of the Lone Mountain dolomite, which underlies the quartzite horizon.

The northeast-dipping Jackson fault is exposed on the 335 level of the Jackson shaft and cuts off the ore zone at that level. This fault is again exposed in the crosscut from the 440 level. The rock in the hanging wall of this fault is that of the dark-colored uppermost member of the Lone Mountain dolomite. On the hill west of the mine the stratigraphic relationships indicate a vertical displacement of about 500 feet along the Jackson fault. Between 500 and 600 feet of vertical displacement are indicated along this fault on the 440 level of the Jackson shaft.

Because there are mineralized faults east of the Jackson fault at the surface and the mineralization at the 335 level of the mine was cut by this fault, mineralization could be expected at the quartzite horizon in the hanging wall of the Jackson fault.

Another possibility for replacement in the quartzite horizon exists in the vicinity of the Wolverine claim on the west slope of Rocco Canyon. West of the Comanche fault the quartzite beds project into the hill, dipping to the west or northwest. Near the top of the hill a strongly mineralized north-south shear zone crops out. A replacement ore body may be present at the intersection of the shear zone and the quartzite beds.

Fay mine.—None of the old claim corners of the Fay claim were found; thus, it is not certain that the Fay mine is on the Fay claim. However, if not, the north portal is very close to the claim and the south portal must surely be within it. This claim is on the west slope of Treasure Hill, about 3,500 feet N. 25° W. from the Stafford claim. The mine workings (figs. 16 and 22) are at the horizon of the quartzite beds of the Lone Mountain dolomite.

Couch and Carpenter (1943) list the production of the Fay mine between 1870 and 1893 at 287 tons with a gross yield of \$15,857. Rough calculations based on the approximate size of the stopes indicate that at least 1,200 tons of rock were mined.

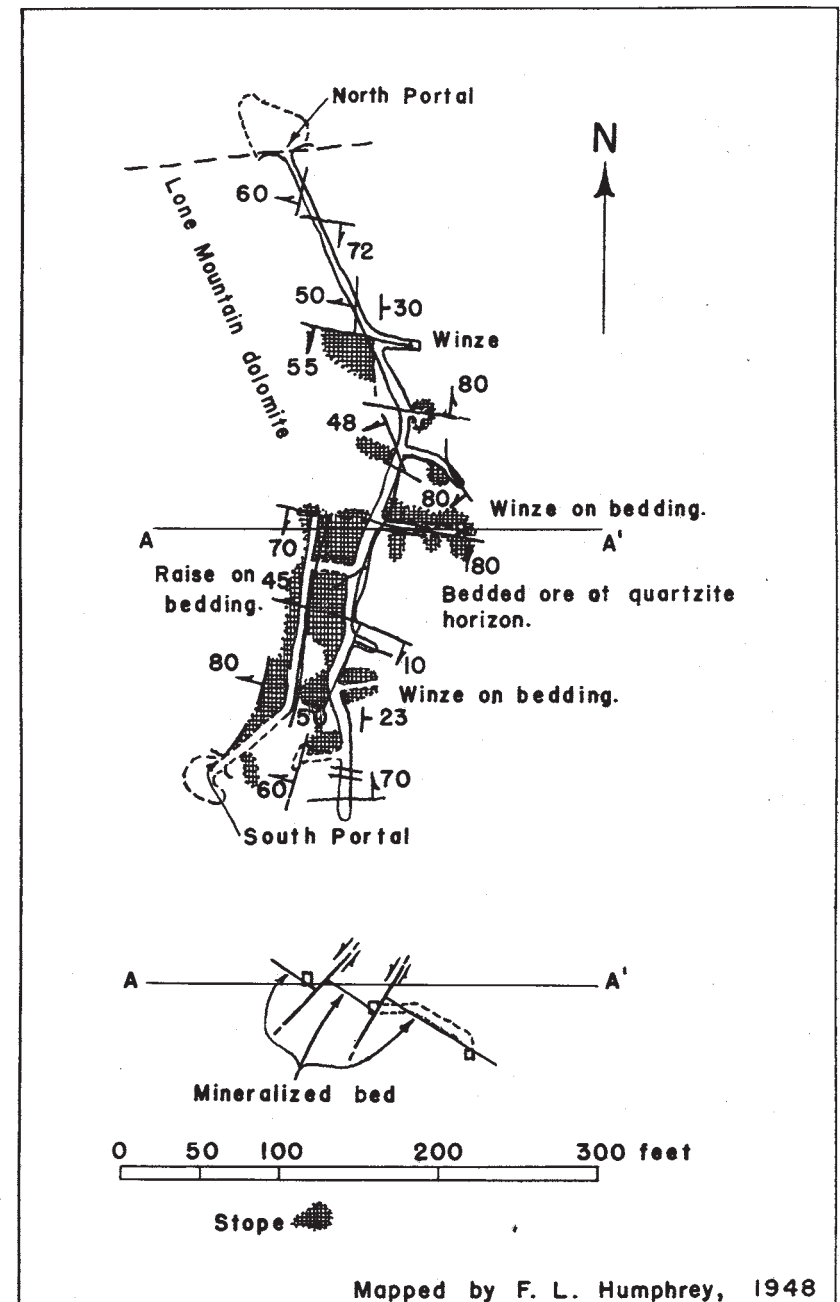


FIGURE 22. Geologic map and section of the Fay mine.

Since the lead smelters erected in this area in the 1870's were reportedly unsuccessful, it was apparently not until about 1890 that the base metal ores in the district were mined and treated profitably. The complex nature of the ore no doubt created a difficult metallurgical problem. Seemingly good ore was placed on the dump and most of it was later screened and shipped.

Three samples taken from the mine for assay yielded the following:

	Copper percent	Lead percent	Zinc percent	Silver ounces/ton
No. 1.....	8.0	5.2	9.4	20.20
No. 2.....	4.2	6.7	1.3	18.80
No. 3.....	25.2	Trace	8.1	0.80

Sample No. 1 was taken from a small stock pile on the dump. Sample No. 2 is from a pillar about 100 feet from the face of the main drift. Sample No. 3 was taken from approximately 15 feet below the collar of the winze shown on the cross section (fig. 22). The ore is a copper ore with subordinate lead and zinc. Apparently the silver is associated with the lead.

The beds dip approximately 25° E. The ore is cut by at least three west-dipping faults with 8 to 15 feet of displacement, but the ore control is primarily related to the south-dipping east-west fractures. The ore values diminish toward the face of the main drift, probably due to the lack of good mineralizing cross-fractures. The series of small north-dipping faults at the face cut off the remnants of the mineralization. The drag on the bedding indicates reverse movement along this fault zone.

Similar mineralization might be expected elsewhere on the west slope of Treasure Hill where the quartzite beds intersect zones of pre-mineral faulting and shearing.

Tonopah-Belmont Exploration Co. mine.—The Tonopah-Belmont Exploration Co. mine (figs. 16 and 23) is variously referred to as the Tonopah-Belmont, Tonopah Development Co., Nevada Belmont, or Belmont. It is now owned by Don Jennings of La Canada, Calif. The Tonopah-Belmont Co. acquired the Vulture mine in 1925 and the Cornell group, which includes the Glory mine and Quartz mine claims, in 1926.

A mill was built about 9,000 feet north of the mine and an aerial tram was installed. Water for the mill was piped approximately 2 miles from the old California Mill Springs northwest of Hamilton.

The ore was in the Eureka quartzite, about a quarter of a

mile south of the McEllen mine. Figure 23 shows the accessible workings. Near the portal the ore occurred as a replacement of the brecciated quartzite along a south-dipping fault. Some ore was also mined where the adit turned back toward the southwest along a northwest-dipping fault. The east-west fault was apparently cut by the northeast fault. The continuation should also be mineralized; it could be located by driving north in the hanging wall of the northeast fault.

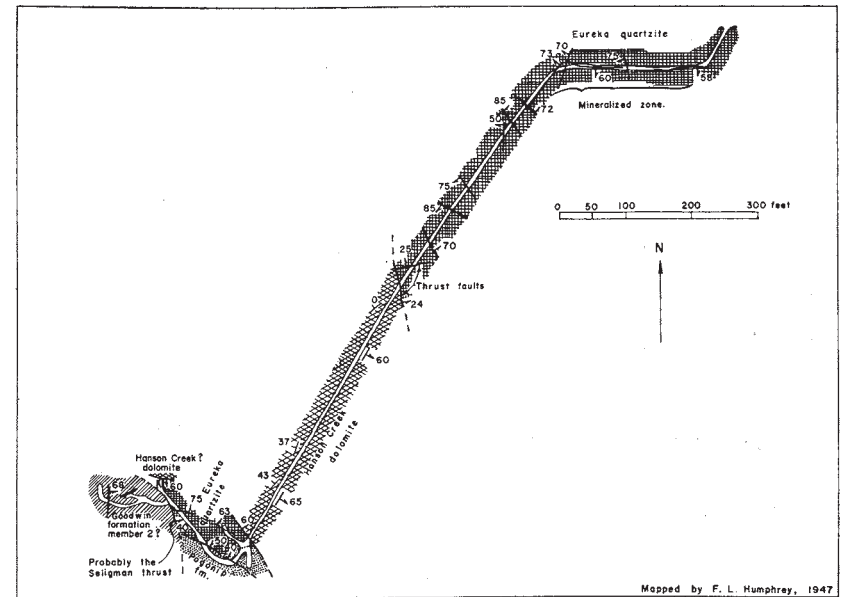


FIGURE 23. Geologic map of the Tonopah-Belmont Exploration Company mine.

There is a lower adit in the quartzite on the level of the upper end of the aerial tram and some ore was mined in it from the same south-dipping fault. The workings are inaccessible beyond the raise connecting to the upper adit.

Mineralized rock along the east-west fault was not mined apparently because of low recovery in the mill. According to the 1926 report of the company, there was a large percentage of slimes in the ore and the extraction was less than 50 percent. Owing to poor recovery and the drop in lead price, the mill was closed. Mine development, however, continued until January 1927.

According to Couch and Carpenter (1943), 3,588 tons of ore were treated in 1926 with a gross yield of \$63,697.

The upper adit (fig. 23) is approximately 1,400 feet long.

About 700 feet from the portal it cuts an east-dipping thrust fault, whose hanging wall is quartzite and whose footwall is Hanson Creek dolomite. This is probably the same small thrust which is exposed on the surface with Eureka quartzite thrust upon Hanson Creek dolomite. In the adit the Hanson Creek dolomite is exposed for 450 feet further to a northeast-dipping normal fault where Eureka quartzite has been faulted into place.

Little or no ore was found in the dolomite along the adit, although the southeast-dipping fracture, along which the adit was driven, contains numerous lenses of iron oxide. The north-dipping Eureka quartzite-Pogonip formation contact is present a few feet beyond the northeast-dipping normal fault and beyond this there is another northeast-dipping normal fault. The Eureka quartzite lies to the north of this normal fault. The Pogonip formation lies south of it up to a thrust fault, which is probably the Seligman thrust fault. The lower plate of this thrust fault is thoroughly brecciated and the rock is a light-colored dolomite which resembles member 2 of the Goodwin formation. The thin-bedded reddish and bluish limestone which is exposed in a raise near the face probably belongs to the Pogonip formation.

Ward Exploration Co. mine.—The northwest edge of Pogonip Ridge was explored by the Ward Exploration Co. Figure 24 has a map of the adit and a surface map of the area about 4,000 feet north of Mohawk Canyon. Mineralization is present at the surface along the fault between the Eureka quartzite and member 4 of the Pogonip formation and along the fault on the west side of the quartzite "lens" between the Eureka quartzite and the Hanson Creek dolomite. The projection of the first fault is shown on figure 24 about 50 feet east of the face of the adit. The second fault is the same as the one shown about 200 feet west of the face of the adit on figure 24.

There are two exploration possibilities for mineralization in this adit. The first is to continue the adit until the projected fault is encountered and then drift north through the quartzite into the Hanson Creek dolomite. The second is to drift north on the fault contact between the Hanson Creek dolomite and the Eureka quartzite at least to where these two faults intersect. Mineralization might occur in either the dolomite or quartzite; however, the more easterly fault appears to be much more heavily mineralized.

Seligman mine.—The Seligman mine (figs. 16 and 25) is situated on the north slope of Seligman Canyon, about 3,000 feet northeast of the north end of the Seligman stock. The majority

of the mine workings date back to the 1880's, at which time a mill was constructed and a small aerial tram was built to convey the ore down the steep slope from the mine. No doubt a considerable portion of the promotion funds was spent on surface installations because the underground workings are limited.

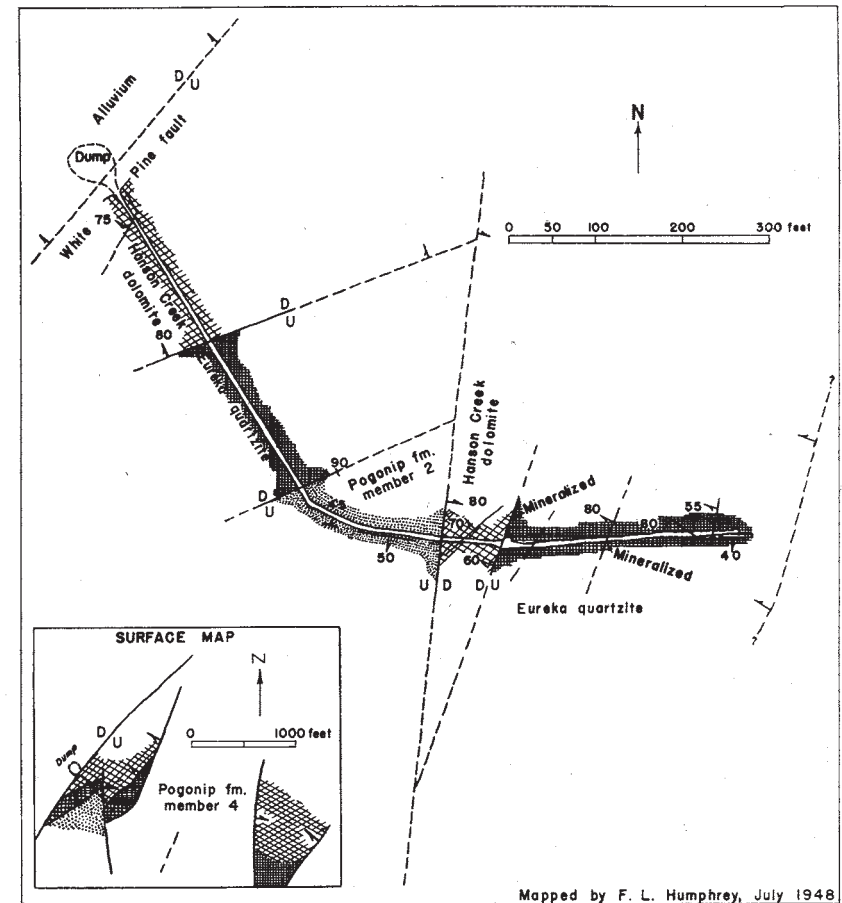


FIGURE 24. Geologic map of the Ward Exploration Company mine.

According to Carl Muir of Ely, Nev., whose father was foreman at the mine, several hundred tons of "good" ore were mined, but the low mill recovery discouraged the backers and the work ceased. The mill was a dry crushing process and apparently the "values" either accompanied the tailings or were scattered over the surrounding hills with the mill dust.

A narrow zone of mineralization may be traced, more or less

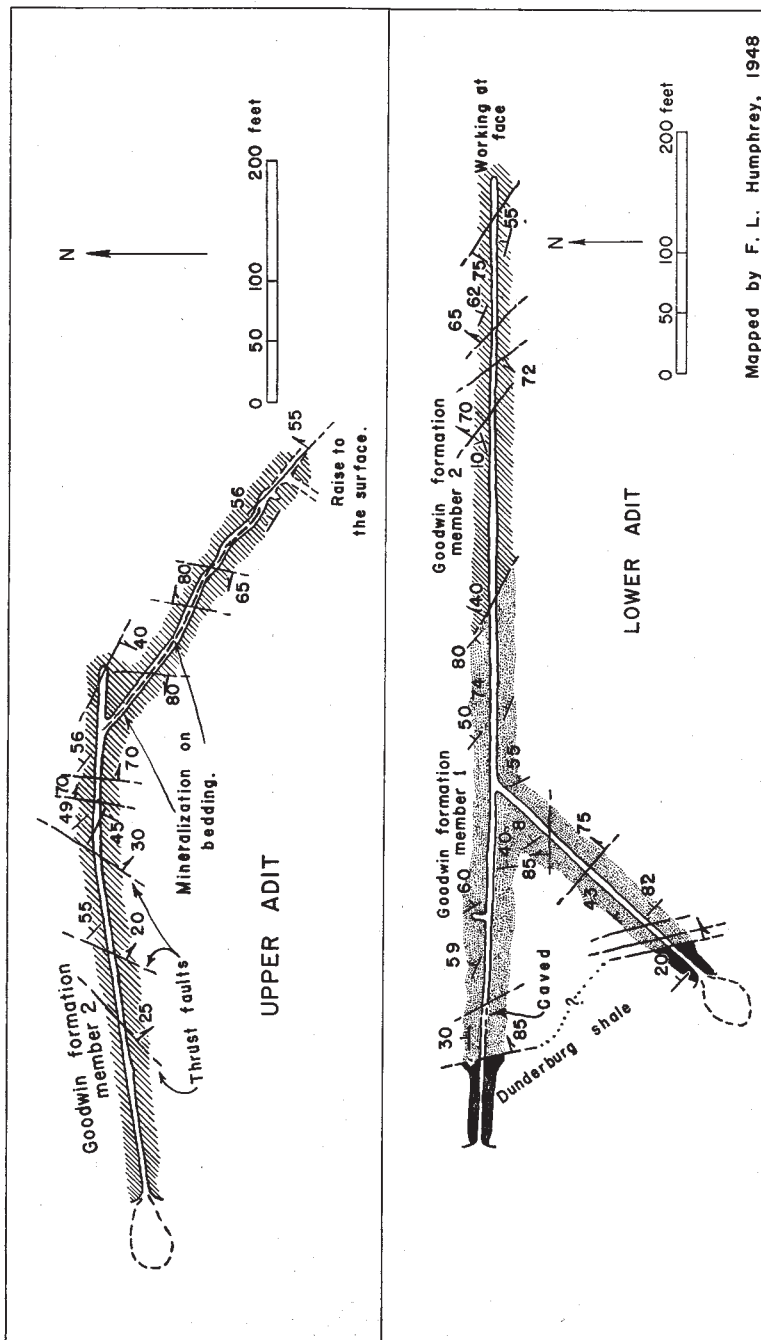


FIGURE 25. Geologic maps of the upper and lower adits of the Seligman mine.

continuously, for a distance of about 3,000 feet along the north-east side of Seligman Canyon. This zone is in member 2 of the Goodwin formation and is essentially parallel to both the bedding and the Seligman thrust.

Near the head of the old tramway there is an east-bearing upper adit (fig. 25) which crosscuts the dolomite for a distance of about 430 feet. At about 150 feet from the portal the adit cuts an east-dipping fault which is probably the middle of the three thrust faults shown in this vicinity on plate 1. About 400 feet from the portal the adit cuts a mineralized zone which parallels the bedding; it strikes approximately N. 55° W. and dips 55° NE.

The mineralized zone was investigated to the southeast for about 300 feet. A raise was driven to the surface near the end of this drift and presumably the ore which was milled was taken from this raise. Samples of the caved rock at the bottom of the raise contain megascopic grains of galena and cerussite.

Several shallow workings are located southeast of the upper adit along the same zone of mineralization. An ore sample from an inclined shaft parallel to the bedding, at the back of an old log cabin, assayed 24 percent lead, 3 percent zinc, and 7 ounces of silver. Another sample from the sump of a shaft farther to the southeast at an old board cabin, assayed 10 percent lead, 4 percent copper, and 7 ounces of silver. A third sample taken a short distance west of the second cabin assayed 2 percent lead, 20 percent zinc, and 1 ounce of silver. The silver seems to be associated with the lead and decreases as the zinc increases.

Northwest of the tramway and extending for a distance of about 1,000 feet along the same general trend, the dolomite has been generally bleached and contains many iron oxide lenses. Thin seams of galena and cerussite were noted at two localities, but samples taken for assay from the iron oxide lenses contain less than a few tenths of 1 percent of lead or zinc.

Unfortunately, the mineral zone is difficult and expensive to explore at depth. The slope of the ridge averages approximately 30° and the mineralization, being parallel to both the bedding and the thrusting, dips into the steep slope. In addition, it is a difficult terrain on which to move machinery or haul water for drilling.

Owing to many small imbricate thrusts in the dolomite below the main thrust, any possible bedding horizon which is amenable to ore replacement must be complexly faulted.

A lower adit (fig. 25) was begun in 1949 near the bottom of Seligman Canyon, where the old mill was located. The adit was

driven to crosscut the rocks and attempt to find the zone of mineralization at depth. It is between 400 and 500 feet vertically lower than the upper adit. By July 1949 this adit had been driven about 750 feet to the east. At about 475 feet from the portal it cut a fault dipping approximately 40° NE. The rock in the foot-wall of the fault is limestone of member 1 of the Goodwin formation and that in the hanging wall is dolomite of member 2 of the Goodwin formation.

The author estimates that the adit will need to be extended an additional 1,000 to 1,200 feet in order to contact the same dolomite beds which are exposed in the upper adit near the head of the tramway.

Caroline mine.—Exceptionally rich silver-bearing tetrahedrite ore was mined about half a mile south of Ophir Canyon on the Caroline claims (figs. 16 and 20). The ore was deposited along a steep east-dipping fracture above the base of member 2 of the Goodwin formation and was mined for a distance of about 150 feet along the fracture on each side of the gulch and above the base of the dolomite. The mineralized areas probably represent the remnants of one continuous ore shoot.

A sample of ore from a sorting dump on the north side of the gulch assayed 112 ounces of silver. A sample from a shallow pit about 50 feet south of the face of the south stope assayed only 12 ounces of silver. The ore does not occur in the underlying limestone and the deposit is undoubtedly mined out.

The Goodwin formation at this locality is in the upper plate of the Monte Cristo thrust which crops out about 500 feet east of the diggings. At its outcrop the footwall of the thrust is the middle portion of member 2 of the Pogonip formation. The displacement on the Monte Cristo thrust probably does not exceed 2,000 feet at this point.

According to Couch and Carpenter (1943) the Caroline mine produced 180 tons of ore between 1870 and 1875 with a gross yield of \$23,702. Obviously, a considerably greater tonnage than this has been mined from the two stopes but this figure would be the approximate tonnage from the north stope.

Extensive prospecting in this vicinity has developed a small amount of ore along the bedding in the dolomite between two west-dipping fractures about 1,200 feet to the north.

The chalcopyrite zone

The chalcopyrite zone occurs in and around the two small stocks on the west side of Pogonip Ridge. The metamorphic rocks on the north and east sides of the Monte Cristo stock contain a small

amount of disseminated chalcopyrite commonly localized along fractures.

There is little pyrite associated with the chalcopyrite, which probably accounts for its unoxidized condition. Thus, there seems little likelihood of an enriched copper zone below the surface near the Monte Cristo stock.

Disseminated pyrite, or more generally pseudomorphs of limonite after pyrite, occur sparingly in the granodiorite of the Seligman stock. This stock is much more weathered at the surface than the Monte Cristo stock, probably in part as a result of the oxidation of the pyrite. Near the center of the Seligman stock a fracture zone about 5 feet wide and over 100 feet long contains several percent of limonite.

A shaft has been sunk on this zone and rock from the dump shows a small amount of copper stain together with limonite and some limonite pseudomorphs after pyrite. The shaft is partially caved and was not examined, but judging from the size of the dump, it is probably 50 or 60 feet deep. An analysis of copper-stained rock from the dump gave 0.3 percent copper.

The rocks contiguous to the intrusives also contain minor scheelite. The area between the two intrusives, and particularly near the southwest edge of the Seligman stock, has scattered occurrences of scheelite concentrated along fractures in metamorphosed limestone beds. The occurrences are small and low grade; the richest sample cut contained less than 0.5 percent scheelite.

Limited prospecting has been done on two or three thin quartz seams in the hornfels about half a mile east of the Monte Cristo stock. This quartz reportedly carries gold. Where exposed in shallow workings the quartz stringers vary between 0.5 and 3 inches in width. Quartz stringers occur in the hornfels closer to the Monte Cristo stock, but no single stringer persists for more than 100 feet.

PETROLEUM POSSIBILITIES

Oil exploration

A shallow well¹² was drilled in the early 1920's about 4,000 feet east of Round Spring near the Hamilton road. The drill hole is in the White Pine formation about 1,000 feet west of the axis of the Illipah anticline. According to Carl Muir of Ely, Nev. (personal communication), the hole was drilled to a depth of

¹²Lintz (1957) lists six oil wells which were drilled in the Hamilton area; four are within the area covered by plate 1 and two are within three miles of this area (editors).

approximately 1,300 feet and at times sufficient gas escaped through the hole to be ignited.

Possible reservoir rocks

The rocks of the White Pine district include shales, sandstones, and limestones, all possible source and reservoir rocks for oil. A small amount of oil occurs in the upper half of the White Pine formation as droplets in some of the cephalopods in thin black limestone beds.

The Joana limestone, the Diamond Peak formation, and the tuff beds in the Illipah formation appear to be the most favorable reservoir rocks. The Joana limestone is characteristically extremely cherty and is also often replaced by jasperoid in faulted areas. The chert and jasperoid are easily fractured and consequently give the formation greater porosity and permeability than it normally would have. A surface sample of the Diamond Peak formation taken from an outcrop on the east slope of Little Antelope Ridge has a measured porosity of about 28 percent. The limestone and marl of the Illipah formation appear to be impervious but the tuff beds near the center of the formation are permeable.

In the deep mines of eastern Nevada the limestones and dolomites are commonly extremely permeable; water flows freely through these rocks when a pressure head is developed by pumping. Porosity is developed by the solvent action of ground water and by fracturing along faults and folds. Thus, most of the limestone and dolomite rocks in the district could be possible petroleum reservoir rocks.

Possible traps

Anticlinal traps.—The Illipah anticline, the longest and most prominent fold in the district, extends from the northeastern edge of the area southward along Illipah Creek for a distance of more than 12 miles. It plunges gradually northward but is sufficiently flat so that undulations of the axis might easily form small domes along the anticline. The White Pine formation crops out along the axis of the fold for the greater part of its length and any oil accumulations would have to be in the underlying limestones.

West of the Illipah anticline there is a shorter anticline between Harris Ridge and Little Antelope Ridge which probably extends as far south as Harris Canyon. The rocks at the surface of this anticline along its axis are dominantly Diamond Peak formation.

Another short anticline about a mile west of the south end of

the Illipah anticline has Ely limestone cropping out at the surface along its axis. At the north end the anticline plunges about 15° N. At the south end it flattens and appears to plunge slightly toward the south, thus forming a domical structure.

As shown on the geologic map (pl. 1), all three of these anticlines are apparently cut a short distance below the surface by thrust faults.

A south-plunging anticline has its northern boundary in the southwestern part of the district south of Cathedral Canyon. Good closure has been developed a short distance south of the edge of the geologic map (pl. 1).

The Emigrant anticline begins just north of the north end of Pogonip Ridge and its surface expression extends for at least 3 miles northward. The anticlinal axis is nearly horizontal as determined by the few reliable dips obtained in the Diamond Peak formation which outcrops along the axis.

In addition to the above-mentioned folds which might furnish favorable conditions for oil accumulation, the east-west arch which crosses the district is worthy of mention. If this arch is related to the uplift of the Pogonip "dome", it is probably a domical east-west fold. The arch extends westward from Monte Cristo Spring a little north of Ridgely. If the rocks which underlie the alluvium along this drainage divide in the valley are arched, this would represent one of the best possible oil structures in the district.

Fault traps.—Fault traps are another type of possible oil reservoir. The district abounds with faults; in fact, the area may be too intensely faulted for oil accumulations. Possible fault traps may occur along such normal faults as those bounding the graben between Pogonip Ridge and Ridgely, or the Indian Garden fault along the east edge of Sixmile Wash.

Pre-Tertiary structural traps.—Most of the structures which have been mapped in the White Pine district are probably post-middle Cretaceous; consequently, there is the problem of what happened during the Mesozoic era to both the Paleozoic rocks and any oil that they possibly contained. Major uplifts and downwarpings are known to have taken place in this general portion of the Cordilleran geosyncline during both the Paleozoic and the Mesozoic eras, but their complexity probably in no way compares to the complexity of structures which were generated during post-Cretaceous time. The location of the axes of these older uplifts is probably one of the most important keys to oil migration and accumulation in eastern Nevada.

Stratigraphic traps.—Facies changes (possible stratigraphic traps) are common in the Carboniferous rocks of the White Pine district and in the early Tertiary lake deposits of this part of Nevada. Many potential stratigraphic traps have been faulted and the rocks are dipping at high angles so that any oil which they may have contained was dissipated. Also, there are abrupt facies changes in the White Pine formation even within this district.

Effect of igneous activity

The intrusion of the two small stocks in Pogonip Ridge would undoubtedly have destroyed any oil which may have originally been contained in the sedimentary rocks within their immediate vicinity. Such intrusive bodies in eastern Nevada, however, are small and scattered, and they generally occur within areas where Lower Paleozoic rocks have been uplifted and the younger, potential oil-bearing strata have been removed by erosion. The extrusive rocks, mainly basalt and andesite, could have had no effect on the underlying sedimentary rocks except locally near the scattered flow vents.

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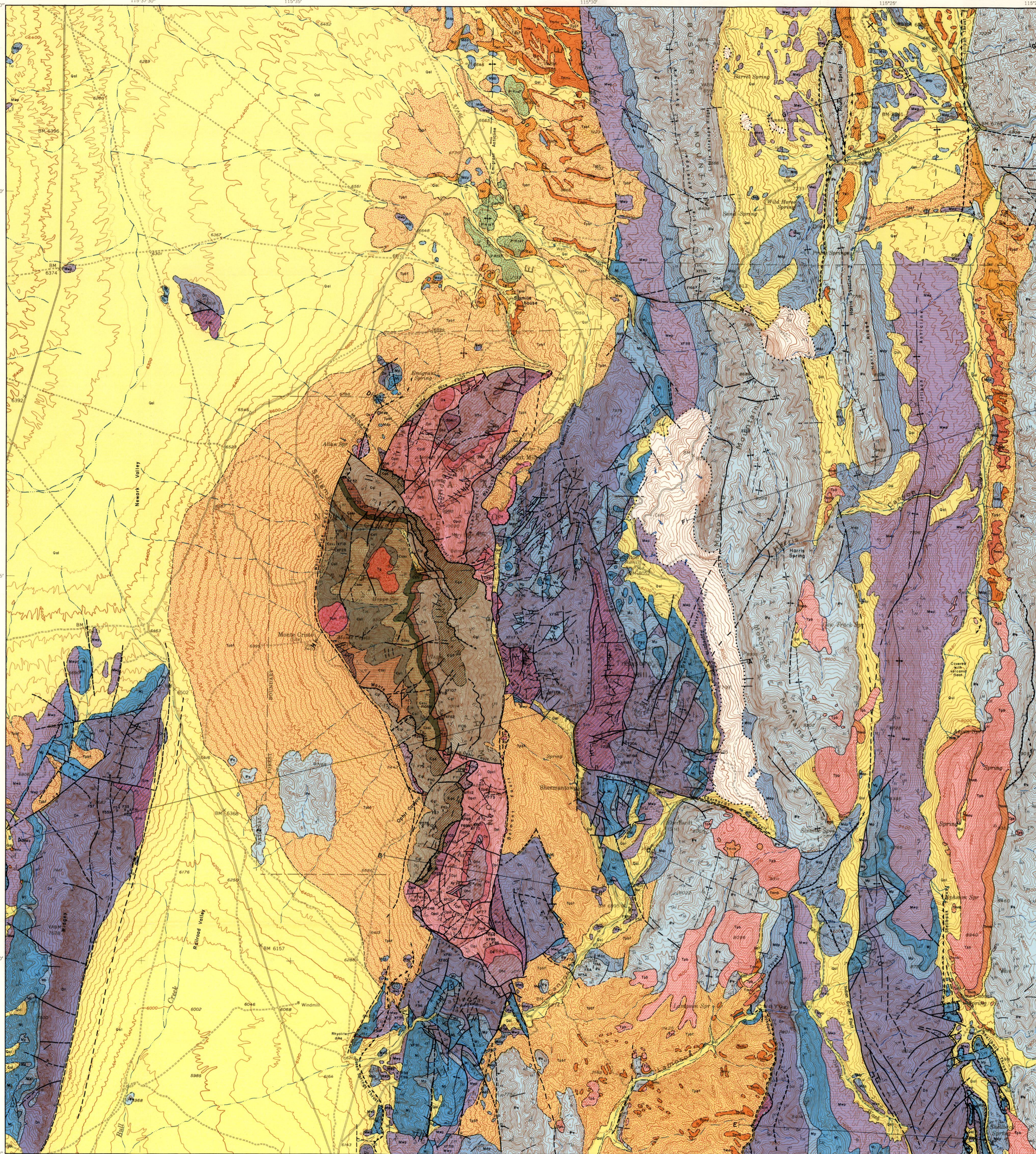
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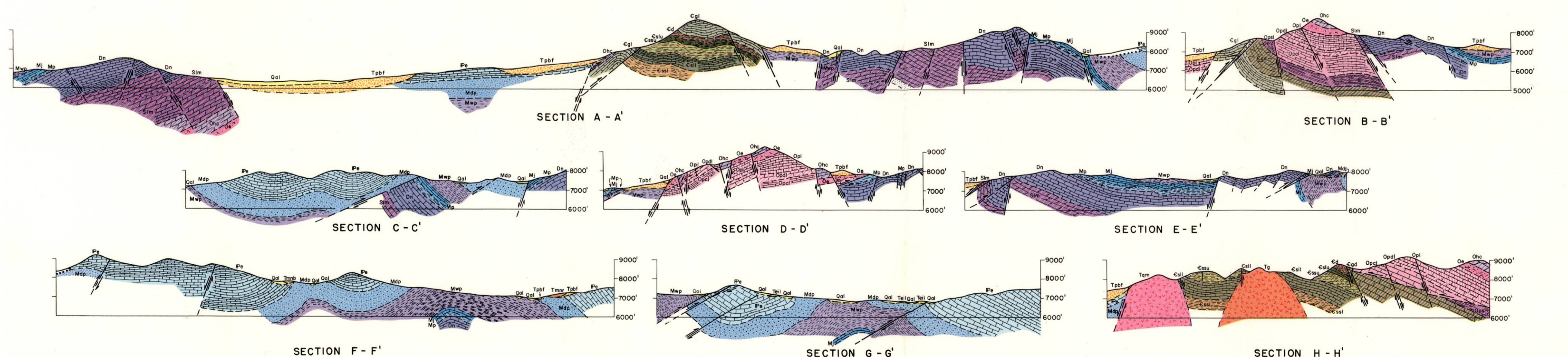
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EXPLANATION	
SEDIMENTARY ROCKS	
	Alluvium Includes unconsolidated sand, silt and gravel
	Tsft Includes unconsolidated sand, silt and gravel
	Belmont conglomerate Includes unconsolidated sand, silt and gravel
	UNCONFORMITY
	Lake Nevada formation Includes (Lacustrine) lacustrine rocks and gravels Includes (Lacustrine) lacustrine rocks and gravels Includes (Lacustrine) lacustrine rocks and gravels Includes (Lacustrine) lacustrine rocks and gravels
	UNCONFORMITY
	Iligh formation Includes (Lacustrine) lacustrine rocks and gravels Includes (Lacustrine) lacustrine rocks and gravels Includes (Lacustrine) lacustrine rocks and gravels Includes (Lacustrine) lacustrine rocks and gravels
	UNCONFORMITY
	Conglomerate and sandstone Includes conglomerate and sandstone Includes conglomerate and sandstone Includes conglomerate and sandstone Includes conglomerate and sandstone
	UNCONFORMITY
	Ely limestone Consists of shaly, gray to blue, medium to coarse grained limestone Includes (Lacustrine) lacustrine rocks and gravels Includes (Lacustrine) lacustrine rocks and gravels Includes (Lacustrine) lacustrine rocks and gravels
	UNCONFORMITY
	Diamond Peak formation Includes (Lacustrine) lacustrine rocks and gravels Includes (Lacustrine) lacustrine rocks and gravels Includes (Lacustrine) lacustrine rocks and gravels Includes (Lacustrine) lacustrine rocks and gravels
	UNCONFORMITY
	White Pine formation Includes (Lacustrine) lacustrine rocks and gravels Includes (Lacustrine) lacustrine rocks and gravels Includes (Lacustrine) lacustrine rocks and gravels Includes (Lacustrine) lacustrine rocks and gravels
	UNCONFORMITY
	Jobo limestone The Jobo limestone is light to medium gray, medium to coarse grained limestone Includes (Lacustrine) lacustrine rocks and gravels Includes (Lacustrine) lacustrine rocks and gravels Includes (Lacustrine) lacustrine rocks and gravels
	UNCONFORMITY
	Pilot shale Light gray to blue, shaly, commonly weathered to red-brown color
	UNCONFORMITY
	Nevada limestone The Nevada limestone is light to medium gray, medium to coarse grained limestone Includes (Lacustrine) lacustrine rocks and gravels Includes (Lacustrine) lacustrine rocks and gravels Includes (Lacustrine) lacustrine rocks and gravels
	UNCONFORMITY
	Lone Mountain dolomite Consists of thin bedded, light to medium gray, medium to coarse grained dolomite Includes (Lacustrine) lacustrine rocks and gravels Includes (Lacustrine) lacustrine rocks and gravels Includes (Lacustrine) lacustrine rocks and gravels
	UNCONFORMITY
	Hanson Creek dolomite Dark gray to blue, shaly, commonly weathered to red-brown color Includes (Lacustrine) lacustrine rocks and gravels Includes (Lacustrine) lacustrine rocks and gravels Includes (Lacustrine) lacustrine rocks and gravels
	UNCONFORMITY
	Eureka quartzite Consists of 20 to 30 feet of dark, pinkish quartzite Includes (Lacustrine) lacustrine rocks and gravels Includes (Lacustrine) lacustrine rocks and gravels Includes (Lacustrine) lacustrine rocks and gravels
	UNCONFORMITY
	Piggop formation The Piggop formation is light to medium gray, medium to coarse grained limestone Includes (Lacustrine) lacustrine rocks and gravels Includes (Lacustrine) lacustrine rocks and gravels Includes (Lacustrine) lacustrine rocks and gravels
	UNCONFORMITY
	Goodwin formation The Goodwin formation is light to medium gray, medium to coarse grained limestone Includes (Lacustrine) lacustrine rocks and gravels Includes (Lacustrine) lacustrine rocks and gravels Includes (Lacustrine) lacustrine rocks and gravels
	UNCONFORMITY
	Dundberg shale Cherty shale and interbedded thin bedded limestone Includes (Lacustrine) lacustrine rocks and gravels Includes (Lacustrine) lacustrine rocks and gravels Includes (Lacustrine) lacustrine rocks and gravels
	UNCONFORMITY
	Secret Canyon shale The Secret Canyon shale is light to medium gray, medium to coarse grained limestone Includes (Lacustrine) lacustrine rocks and gravels Includes (Lacustrine) lacustrine rocks and gravels Includes (Lacustrine) lacustrine rocks and gravels
	UNCONFORMITY
	Gadsden limestone (?) Dark gray to blue, shaly limestone
IGNEOUS ROCKS	
EXTRUSIVE ROCKS	
	Basalt Dark brown to black, fine grained
INTRUSIVE ROCKS	
	Rhyolite dike Light gray porphyritic, fine grained, 8 feet wide
	Granodiorite Medium to coarse grained, monzonitic
	Quartz monzonite Medium to coarse grained, granitic rock cut by diabase
	Strike and dip of beds
	Strike and dip of overturned beds
	Strike of vertical beds
	Horizontal beds
	Syncline
	Anticline
	F332 Fossil localities
	Contact Dashed where approximately located
	Fault Arrow is direction of slip; where known, dashed where approximately located
	Thrust fault The rock on the right, where present, dashed where approximately located
	Landslide area
	Intereformational beds



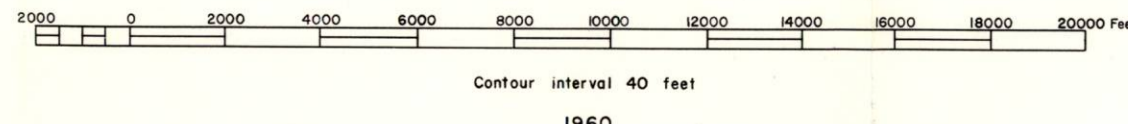
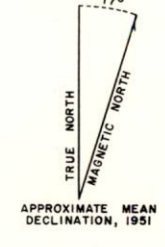
GEOLOGIC MAP OF THE WHITE PINE DISTRICT

WHITE PINE COUNTY, NEVADA

By F. L. Humphrey

Geology by F. L. Humphrey
Assisted by W. Hughes, T. Morris, D. Shawe

Topography by U. S. Geological Survey 1951
Geologic Cartography by B. Hamilton



Contour interval 40 feet

1960