The Geology of the

Northern Empire Mountains,

Arizona

by

Herbert Alberding

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Summary

The area is located about forty miles southeast of Tucson in the northern part of the Empire Mountains of Pima County, Arizona.

The dominant topographic features are three northeast trending ridges which stand between 600 and 800 feet above the surrounding country and have a maximum elevation above sea level of 5,389 feet.

The sedimentary rocks are divided into three principal stratigraphic units: The Pennsylvanian-Permian Cienega beds (4,690 feet thick), the Permian Snyder Hill formation (850 feet thick), and the Cretaceous series (3,170 feet thick). The Cienega beds and Snyder Hill formation belong to the upper part of Ransome's Naco limestone. The basal Lower Pennsylvanian limestone or Naco limestone sensu stricto is apparently missing. The total thickness is 8,710 feet.

The sedimentary rocks were folded and faulted and intruded on the west by the Sycamore quartz monzonite stock, presumably during the Laramide revolution.

The folding has resulted in a general dip of 35° to 45° to the east and southeast away from the stock.

The faulting was principally along the Cienega fault which is a steeply-dipping fault along which there is assumed to have been horizontal movement. Accompanying this movement, blocks of the Snyder Hill formation were dragged along the Empire fault which is assumed to be a subsidiary fault to the Cienega fault.

The intrusion of the Sycamore stock resulted in the metamorphism of much of the limestone, dolomite, and shale, of the Cienega beds.

In the southeast corner of the area is the Total Wreck mine. The deposits are almost entirely oxidized and consist of an argentiferous lead ore with copper in the deep part of the mine. The main production was in 1881-1882. The total production for the Empire district, with the Total Wreck mine the main producer, has been $1,050,000.00. The ore solutions may have been derived from the Sycamore stock.

INTRODUCTION

Acknowledgments

The writer wishes to acknowledge the assistance given him by the entire faculty of the Geology Department of the University of Arizona. Drs. B. S. Butler, G. M. Butler, F. W. Galbraith, M. N. Short, and A. A. Stoyanow, were very helpful in assisting with the field and laboratory work, and in proof-reading the thesis.

Dr. E. D. Wilson, of the Arizona Bureau of Mines, was also kind enough to accompany the writer into the field on various occasions and offer suggestions and criticisms.

I am also indebted to Mr. Stearns Cook and Mr. Melvin Willigman for the help given in making the topographic map of the area. This also applies to many of my students in Geology 1a and b who were kind enough to rod for me while I ran the instrument.

I also wish to thank Mr. E. D. McKee, Park Naturalist of the Grand Canyon National Park, for the assistance he gave me with the paleontology and stratigraphy.

Field Work

The field work was done over a period of a year and a half, starting in the fall of 1936 and ending in the winter of 1938. No work was done during the summer months.

The triangulation and topographic mapping were started in the fall of 1936. The work was done on Saturdays and holiday periods, and the topographic map was completed in the spring of 1937.

The triangulation and topographic mapping were done in the usual manner. On the north end of Eagle Bluff Ridge, the Empire triangulation station of the United States Coast and Geodetic Survey is located. All elevations were referred to this station.

The geologic mapping was begun in the spring of 1937 and resumed in the fall of 1937 after the summer. The work was done over week-ends and on holidays. The mapping was completed in the winter of 1938.

Location and Extent

The area is located in the northern part of the Empire Mountains of Pima County, Arizona. It is approximately forty miles southeast of Tucson and covers 4.62 square miles.

The area is seven miles from the way-station of Pantano which is located on the Southern Pacific railroad and the Benson Highway (U.S. 80) southeast of Tucson. A road leads from Pantano to the area, but at the present time (1938) it is in bad condition. The area is about as easily reached by taking the Sonoita Road (State Route 83) to a point eleven miles south of Mountain View Service station and walking the remaining three miles to the east.

Climate

No actual records for the climate of the northern Empire Mountain area are obtainable, but data do exist[1] from the stations of Pantano and Vail on the Southern Pacific railroad to the north of the area.

The average precipitation at Pantano is 12.37 inches per annum. The highest average precipitation at Pantano occurs in August and amounts to 3.16 inches. The lowest average precipitation occurs in May and amounts to 0.21 inches.

As is characteristic for all of southern Arizona, there are two periods of maximum rainfall: a primary period in the summer from July 1 to September 30, and a secondary period during the winter season. Little precipitation occurs during the autumnal and vernal seasons. The summer rains are local in character. The winter precipitation is the result of the general storm movement from the northwest, together with secondary movements induced by areas of low pressure that develop over the Gulf of California and the adjacent Pacific Ocean.[2]

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1 Climatic Summary of the United States: U. S. Dept. of Agriculture, Weather Bureau, Section 26, Southern Arizona, pp. 16, 23, and 24, 1930.

2 op. cit., pp. 1 and 2.

In the northern Empire Mountains, the precipitation is greater than at Pantano because of the higher elevation. At Pantano the elevation is 3,538 feet, whereas the elevation in the northern Empire Mountains averages 4,700 feet. The average precipitation must thus amount to over fourteen inches.[3] Some of the winter precipitation falls as snow.

This amount of rainfall is insufficient for dry farming, and irrigation is impossible because of the lack of any adequate supply of water. The nearest supply of water to the area is a spring at the north end of the Sycamore stock. This water supply is not quite sufficient for the horses, cattle, and goats, that are grazed in the Empire Mountains, and it would be totally inadequate for irrigation. Water was obtained at the Total Wreck mine, when the mine and mill were being worked, from a spring to the south of the mine. The water was pumped to the mine through a pipe over a distance of four miles.[4]

The average temperature at Vail (elevation 3,241 feet) is 66° F. for the year. The average minimum temperature at Vail occurs in January and is 46.8° F. The average maximum temperature occurs in July and is 85.1°F. The highest recorded temperature at Vail is 111° F. The lowest recorded temperature is 0° F.

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[3] op. cit., p. 1.

[4] Schrader, F. C., - Mineral deposits of the Santa Rita and Patagonia Mountains, Arizona: U.S. Geological Survey, Bull. 582, p. 144, 1915.

In the northern Empire Mountains, the maximum temperature is less then at Vail, and the minimum temperature is lower because of the higher elevation.

Topography and Drainage

The dominant topographic features of the northern Empire Mountains are three ridges which, in the course of this investigation, were named Eagle Bluff Ridge, Cienega Ridge, and Total Wreck Ridge (see Plate I). The general trend of Eagle Bluff Ridge is north 15° east. The trend of Cienega Ridge is north 25° east, and that of Total Wreck Ridge is north 35° east.

The name Eagle Bluff Ridge was given because of the eagles which are said to nest in the steep slopes of the west side of the ridge.

The name Cienega Ridge was given because Cienega Creek can be seen from the ridge. Cienega Creek and its tributaries drain the east slope of the Empire Mountains and the west slope of the Whetstone Mountains. The tributaries and Cienega Creek are dry except after heavy rains. The name Cienega is Spanish in origin and is derived from two words: "cien" - one hundred, and "agua" - water. The literal translation of the word is thus "a place of one hundred waters." The word is used to designate a swampy or marshy place, and such places did exist along Cienega Creek.

The name Total Wreck Ridge was given because the Total Wreck mine is located on the east slope of the ridge.

The highest point on Eagle Bluff Ridge is at triangulation station XI where the elevation is 5,389 feet above mean sea level. The highest point on Cienega Ridge is at triangulation station XIV with an elevation of 5,352 feet, and the highest point on Total Wreck Ridge is 5,379 feet.

The minimum elevation in the area is 4,180 feet; the relief 1,209 feet.

The average elevation of Eagle Bluff Ridge above the surrounding country is 800 feet. The average elevation of Cienega Ridge and Total Wreck Ridge above the surrounding country is 600 feet.

The slope of Eagle Bluff Ridge on its east side is 27°. On its west side, the slope of Eagle Bluff Ridge is much more precipitous. The slope of Cienega Ridge on its west side is 21°, and on its east side, 24°. The slope of Total Wreck Ridge is 30° on its northwest side, and 28° on its southeast side.

Between Eagle Bluff Ridge and Cienega Ridge is Eagle Pass. It is named Eagle Pass because of Eagle Bluff Ridge to the north of it. The highest point in the pass has an elevation of 4,842 feet. The drainage to the west of the pass is towards Davidson Canyon. This canyon and its tributaries drain the west slope of the Empire Mountains and the east slope of the north end of the Santa Rita Mountains. The canyon and its tributaries are dry except after heavy rains. The drainage to the east of the pass joins the drainage from Hilton Wash which joins Cienega Creek.

Hilton Wash, between Cienega Ridge and Total Wreck Ridge, is named after the Hilton Ranch which overlooks the wash to the south of the area mapped. The drainage of the wash is to the northeast towards Cienega Creek which is joined near Pantano.

Both Cienega Creek and Davidson Canyon are tributaries of Pantano Wash which is a tributary of Rillito Creek. Rillito Creek joins the Santa Cruz River to the northwest of Tucson, and the Santa Cruz River joins the Gila River southwest of Phoenix. The Gila River joins the Colorado River at Yuma, Arizona. The northern Empire Mountain area is thus in the drainage system of the Colorado River.

The foothill region of the area consists of a series of east-west trending spurs which originate on the east slope of Eagle Bluff Ridge and the southeast slope of Total Wreck Ridge. The slope of the spurs averages 18° to the east. In the foothill region to the east of Eagle

Bluff Ridge, the drainage joins that from Hilton Wash and continues to the northeast to Cienega Creek. In the foothill region to the southeast of Total Wreck Ridge, the drainage is to the east to Cienega Creek.

Flora

The vegetation of the northern Empire Mountains is typically that of the Upper Sonoran zone or belt, though it is markedly different from the flora of that zone in the northern part of the state. On the Colorado Plateau, the Upper Sonoran zone is marked by sagebrush, pinyon pine, and juniper. In the Empire Mountains, none of those plants are found. Instead, there are the following:

In the bottoms of the washes, the Arizona mesquite (Prosopis juliflora, var. velutina) is particularly abundant, and with it grows the catsclaw (Acacia greggii). Catsclaw is also abundant on the Sycamore stock where it forms an almost impenetrable, low thicket in places. The plant has short hooked spines on its branches, and if rubbed against, the spines will easily tear one's clothes to shreds. My dislike for the plant could never be overcome.

This feeling, incidentally, likewise applies to the spike-leaf agave (Agave schottii) which grows especially where there are quartzites or sandstones. Unlike its larger century plant cousin, Agave palmeri, which is somewhat abundant in the Empire Mountains, this smaller century plant does not grow singly, but as a dense covering on the entire area of outcrop of the sandstone or quartzite. Since the leaves average a foot in length, it is impossible to walk through the growth without being frequently stabbed in the leg by the sharp spine at the end of each leaf. The only remedy is to wear high boots or leather leggings.

Another plant to be wary of is the broad-leafed yucca or datil (Yucca baccata), whose common names, Spanish bayonet or Spanish dagger, make themselves known when the end of the leaf is encountered, for each leaf is provided with a sharp spine. Its saponaceous roots give it another name of soapweed, and its edible fruit that looks like a banana and turns purple in the fall, gives it the name, Indian banana. From the strong threads that can be stripped from the leaves comes another name - Needle and Thread.

The saw-tooth yucca or sotol (Dasylirion wheeleri) differs from the true yucca in being harmless to touch, and is likewise very common in the Empire Mountains. Its stalks make good stock feed, and the alcohol that may be derived from it gives it commercial value. In Texas, it is even cultivated for the alcohol that may be extracted.

Nolina microcarpa, or bear grass, is very common, and the same can be said of Fouquieria splendens - the ocatillo. I found the sharp spines that cover the sprawling branches of the ocatillo a continual nuisance and menace. This was particularly true when working on limestone, for the plant favors that rock.

Cacti types are very numerous. Hedgehog cacti (Echinocereus) abound, as do prickly pears and chollas (both of the Opuntia genus), pincushion cacti (Coryphantha and Neomammillaria), and the famed barrel cactus (Ferocactus wizlizeni). A few sahuaro (Carnegia gigantea) were observed.

In the washes, the Foothill palo verde, (Parkinsonia microphylla) grows, and with it is found the Evergreen sumac (Rhus choriophylla) and scrub oak (Quercus) trees. Buckthorn (Ceanothus gregeii) is especially abundant on the Sycamore stock, and the same is true of Mortonia scabrella and Aplopappus hartwegi - the burro weed or rayless goldenrod.

Various types of grasses are abundant in the lower regions.

Fauna

Of the fauna observed, the most interesting were a drove of peccaries, or Javalina pigs, that were seen on March 13, 1938, a mile to the east of the Total Wreck mine. These animals are called the Sonora or Yaqui peccary, and, like all of the New World peccaries, they are related to the wild boars of the Old World. They are quite large in size, have downward-pointed tusks, long gray hair, and a large musk gland in the middle of their backs. When disturbed, a liquid with a musky odor is secreted from this gland, and because of this odor, the peccaries are sometimes called musk hogs. Their flesh is edible, but the musk gland must be removed immediately after the animals are killed, or the secretions from the gland will taint the meat and make it unsavory.

The peccaries observed were busily occupied in digging up roots which provide them with their main food. In fact, the entire side of the hill where the peccaries were seen had been rooted over. Most of the plants dug up were the spike-leaf agave.

Due to the favorable wind conditions, the party I was with was able to approach to within fifty feet of the animals, but we were then observed by a large male, and the entire drove of ten made for the top of the hill. When we finally reached the top, the peccaries were far below on the other side and were last seen strung out in single file gingerly making for Cienega Creek to the east.

The fact that they made such an immediate and prolonged retreat is rather unusual, for peccaries are noted for their **ferocity.** There are any number of instances on record of people having been attacked by them without any apparent provocation. According to a published account, a man was turkey hunting in Sonora and was attacked by a single peccary. The man shot at the peccary and wounded it, but it persisted in its attack and the man was forced to climb a tree. Soon, peccaries came from all directions, and finally, about 200 were counted. Even when the man shot at them and killed some, the rest were undeterred and did their utmost to gnaw down the tree. After more than twelve hours they finally left.

In contrast with the redoubtable peccary is the slinking coyote which abounds in the Empire Mountains. The ranchers endeavor to take all precautions to keep the coyotes out, but are largely unsuccessful. The usual method is to plant prickly pear along the base of a barbed-wire fence so that the cacti reach the lower strand. This, however, usually means nothing to the coyotes for they will climb right over. In the fall and winter of 1937-1938, a new fence was built through the area I mapped, with meshed wire to supplant the prickly pear along the base. The ranchers also spoke of putting in batteries to electrify an additional strand. I was informed that the new fence cost about $7,000., and since its main purpose is to keep out coyotes, it can be seen that they are an expensive enemy. The ranchers also put poison in dead cattle and horses to try to kill the coyotes. However, the wary prairie wolf persists, and though rarely seen, I have noticed numerous coyote tracks in the bottoms of many washes throughout the Empire Mountains, and have been awakened early in the morning by their high-pitched yelps.

Another animal present, although by no means common, is the Mule deer. Its suspicious nature makes an approach difficult.

Among the smaller game are jack rabbits and cottontails which can be seen at almost any time.

In the sky, invariably some turkey buzzard is soaring about looking for carrion. In the fall of 1936, I observed as many as twenty of these scavengers eating a dead cow in the bottom of Davidson Canyon near Andrade's Ranch.

Other birds present include ravens, hawks, Gambel's quail, and the lizard-eating road-runners. A few eagles were observed.

Though I have never seen any Gila monsters in the Empire Mountains, one was killed near the Total Wreck Mine in 1935 by Mr. August Merz. I have never seen any snakes in the area, but others have reported rattlesnakes on the west side of the range.

Small lizards (swifts) are abundant everywhere throughout the area.

Centipedes are quite common and reach six inches in length, and black widow spiders are numerous enough to make one cautious about picking up pieces of rock without first turning them over.

GENERAL GEOLOGY

Sedimentary Rocks

The stratigraphy of southeastern Arizona includes rocks that range in age from Archeozoic to Cenozoic.[5,6,7,8,9] The oldest rock is the Archeozoic Pinal schist. Above it is the Proterozoic Apache group which is followed by the Middle Cambrian Bolsa (or Troy) quartzite and the Cochise (or Santa Catalina) formation. The Upper Cambrian is represented by the Abrigo formation and the Rincon limestone (or Peppersauce Canyon sandstone or Copper Queen limestone).

Ordovician strata are represented at Clifton and Morenci by the Longfellow limestone. Usually, however, the Upper Cambrian is directly overlain by the Upper Devonian.

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5 Lindgren, W. - The copper deposits of the Clifton-Morenci district, Arizona: U. S. Geol. Survey, Prof. Paper 43, 1905.

6 Ransome, F. L. - Geology and ore deposits of the Bisbee quadrangle, Arizona: U. S. Geol. Survey, Prof. Paper 21, 1904.

7 Ransome, F. L. - Description of the Bisbee quadrangle, Arizona: U. S. Geol. Survey, Geol. Atlas, Bisbee Folio, No. 112, 1904.

8 Ransome, F. L. - Some Paleozoic sections in Arizona and their correlation: U. S. Geol. Survey Prof. Paper 98-K, 1916.

9 Stoyanow, A. A. - Correlation of Arizona Paleozoic formations: Geol. Soc. Amer. Bull. 47, 1936.

The Upper Devonian strata are divided into three formations: the Picacho de la Calera formation, the Martin limestone, and the Lower Ouray formation.

Above these is the Lower Mississippian Escabrosa limestone which, in general, is overlain by the Lower Pennsylvanian Naco (or Galiuro) limestone. In the Chiricahua Mountains, however, the Upper Mississippian Paradise formation is between the Escabrosa and Naco limestones.

Overlying the Naco limestone sensu stricto are strata in the northern Empire Mountains which, in this report, are called the Cienega beds. The age of these beds is determined by their stratigraphic position between the Pennsylvanian Naco limestone sensu stricto and the Permian Snyder Hill formation.

Above the Cienega beds is the Permian Snyder Hill formation followed by the Chiricahua limestone.

The Mesozoic is represented in southeastern Arizona only by the Cretaceous, although at Bisbee there may be Jurassic.

The Cenozoic is represented by the Pliocene Gila conglomerate and Quaternary and Recent alluvium.

Of the mentioned stratigraphic units, the strata in the northern Empire Mountains include only the Cienega beds, the Snyder Hill formation, and the Cretaceous series, as well as alluvium of Recent age.

A generalized section of the formations is as follows:

Cretaceous	
Cretaceous series	3,170 feet
Unconformity	
Permian	
Snyder Hill formation	850 feet
Permian-Pennsylvanian	
Cienega beds	4,690 feet
	8,710 feet

Cienega Beds

In contact with the Sycamore stock are strata which, in this report, are tentatively called the Cienega beds, Their type locality is on the northwest side of Total Wreck Ridge, through Hilton Wash, and on Cienega Ridge. Along the line C-C' (see pls. I and II, and fig. 1), the exposed measured thickness of the beds is 4,690 feet, though the total thickness is not known, as the base of the beds has been cut off by the Sycamore stock. This relation to the stock also prohibits, in the area mapped, the determination of the true stratigraphic position of the base of the Cienega beds.

As measured along the line C-C' (see fig. 1), the lowest exposed beds in contact with the stock consist of

1,220 feet of alternating gray and white marbles of extremely coarse grain. These marble beds extend two-thirds of the way up the west side of Cienega Ridge. Observed from the Sonoita Road, at a distance of two and one-half miles, the white marble beds are conspicuous as regular horizontal bands. To the north of line C-C', west of Eagle Pass, and along the southwest side of Eagle Bluff Ridge, these marbles, in part, grade into their unmetamorphosed limestone and dolomite equivalents, as well as into metamorphosed and unmetamorphosed shales.

Along the southwest side of Eagle Bluff Ridge is 115 feet of marble adjacent to the Sycamore stock, and this is overlain by 95 feet of thin-bedded black shales (see pl. I). Immediately to the north of the area mapped, the marble disappears, the black shales are thicker, and are in contact with the stock. Close to the stock the shales contain layers of garnet that average one inch (25.4 millimeters) in thickness, and, in places, the shales have been metamorphosed into very hard resistant rock that weathers brown with large irregular pits on its surface. The appearance of these metamorphosed shales is characteristic of the metamorphosed shales that occur on Cienega Ridge, and those that are found two miles to the north and west in the California Mine area.[10] The unmetamorphosed

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[10] Gillingham, T., - Geology of the California Mine area, Empire Mountains: Master's thesis, Univ. of Ariz., 1936.

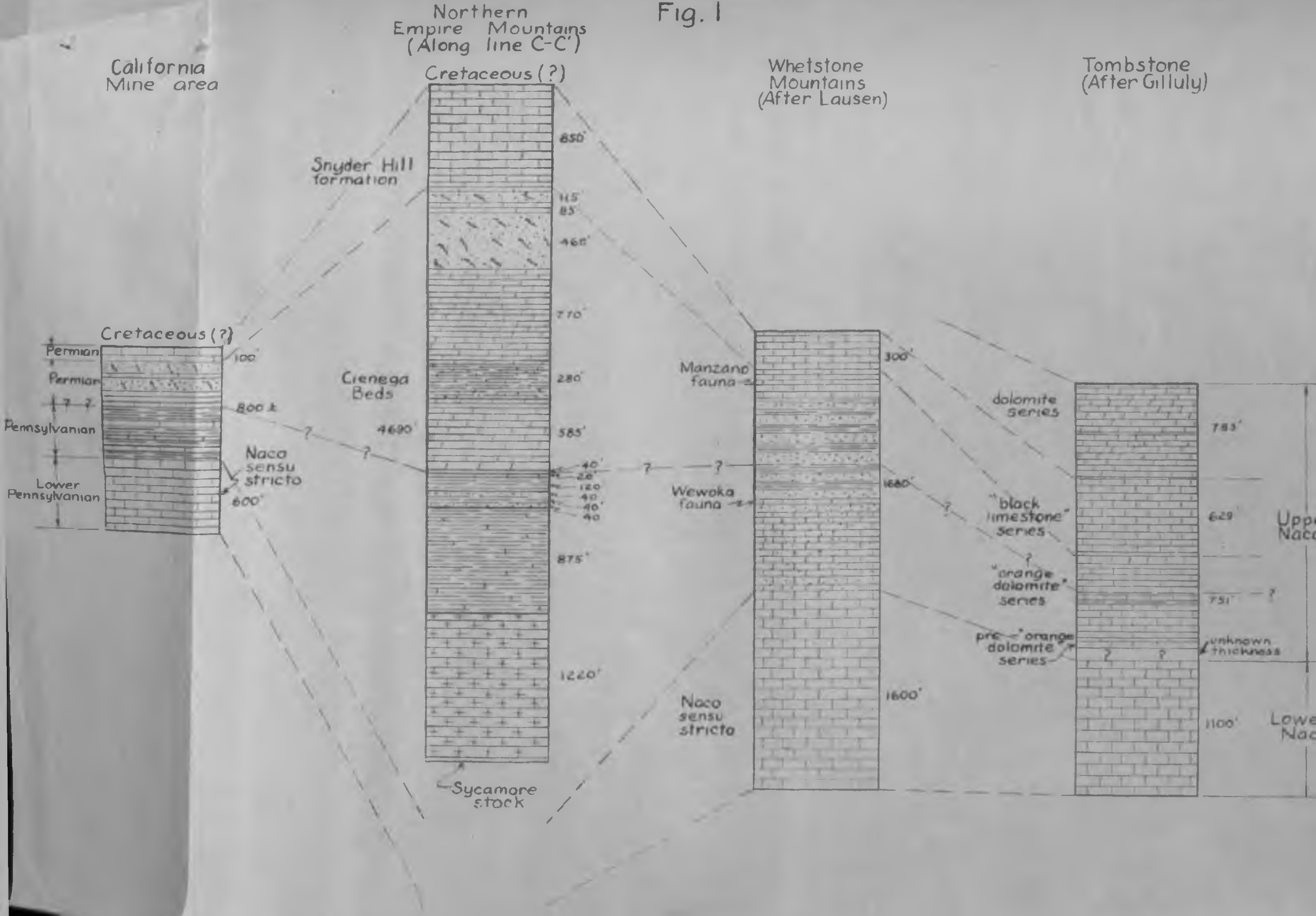
shales, though preponderantly black in color, in places have white shale beds alternating with the black (see pl. VI). The average thickness of the individual shale beds is from two to four inches, whereas the average thickness of the black and white layers is from four to twelve inches.

Above the black shales, along the southwest side of Eagle Bluff Ridge, is 395 feet of dolomite and limestone. The lower half consists of thin-bedded gray and white dolomite beds with occasional thin beds of gray limestone. The upper half is made up of thin beds of sandy buff limestone.

Immediately to the west of Eagle Pass, these limestones and dolomites grade into the marble which marks the base of the Cienega beds along line C-C'. In the pass itself, the marble alternates with thin beds of metamorphosed shales, and to the east, in a higher part of the section, the marble disappears, and all the rock consists of metamorphosed shales. Along the line C-C', the thickness of the metamorphosed shales above the marble is 875 feet (see fig. 1). Most of Cienega Ridge is composed of this type of rock. As mentioned before, the metamorphosed shales weather brown and have large irregular pits on their

CORRELATION CHART OF UPPER PALEOZOIC FORMATIONS OF NORTHERN EMPIRE MOUNTAINS AND ADJACENT AREAS

Fig. 1



surfaces. Furthermore, due to their very hard and tough character, they are particularly resistant to erosion, and outcrop as cliff-forming ledges, especially along the crest of Cienega Ridge. Though metamorphosed, their shaly bedding is apparent on weathered outcrops. To the east, along the east side of Cienega Ridge, the metamorphosed shales grade into their unmetamorphosed equivalents.

As mentioned, 875 feet of metamorphosed shales lie above the marble along the line C-C'. To the north, along the northeast end of Cienega Ridge, the metamorphosed shales change in part to beds of white marble, black unmetamorphosed shales, and hard buff sandstones. (see pl. I). One conspicuous conglomerate bed, two to three feet thick, is also present. Many of the black shales are slightly calcareous.

Above the metamorphosed shales, along the line C-C' and towards the base of the east slope of Cienega Ridge, is forty feet of hard buff sandstone, forty feet of black shale, forty feet of hard buff sandstone, and 120 feet of black shale (see fig. 1 and pl. II). All of these sandstones and shales thicken to the north of line C-C'.

Above the last-mentioned black shale is twenty feet of thin-bedded gray dolomite followed by forty feet of black shale. This is the highest black shale horizon in the section.

The next higher unit of the Cienega beds (see fig. 1) consists of 585 feet of predominantly thin-bedded gray dolomite with some white and black dolomite and gray limestone beds. No identifiable fossils were found in these beds, though small forms resembling sponge spicules are particularly abundant in the dolomite. These sponge spicules are altered to tremolite which also occurs in the dolomite in forms as long as one inch and grouped together in radiating fibrous masses. Most diagnostic of the dolomite, however, are small irregular geodes. They range in size from that of a pin head up to one-half of one inch in diameter. Many closely resemble fossil brachiopods in their external forms, but if they were fossils originally, they have been too altered for identification. Most of them consist of quartz or calcite.

The interbedded limestone is more susceptible to weathering and erosion than the dolomite and consequently forms topographically lower areas. The pitted and grooved weathered surfaces of the limestone are characteristic and appear in marked contrast to the usual smooth surfaces of the dolomite.

Above this dolomite unit are 280 feet of red sandy shales (see fig. 1 and pl. II) which form the bottom of Hilton Wash and extend slightly up the northwest side of Total Wreck Ridge. In most places in the wash these beds are covered with alluvium. The location of the wash can undoubtedly be attributed to the presence of the weak shales.

Lying above the sandy shales is 770 feet of gray dolomite with a few interbedded gray limestone layers. This dolomite and limestone is similar in lithologic character to the dolomite and limestone below the red sandy shales. At the base is some twenty to 25 feet of intraformational conglomerate composed of dolomite and limestone fragments that are oblong in shape and quite angular. The fragments average one inch in length.

Above this unit is 460 feet of quartzite, overlain by 85 feet of gray dolomite which, in turn, is overlain by 115 feet of quartzite (see fig. 1). The quartzite beds are light orange, very dense and hard, and on fresh fractures are quite vitreous.

The last quartzite marks the top of the Cienega beds as exposed along the line C-C'. Above this quartzite is the Snyder Hill formation (see pl. II). The contact between the two is considered to be a conformable one, though faulting of the nature of a bedding-plane slippage has occurred between the two formations.

Thus, the Cienega beds are known to lie below the Snyder Hill formation and to be 4,690 feet thick along the line C-C'. To the north of this line, through Eagle Pass and on to the southwest side of Eagle Bluff Ridge, the thickness is slightly greater, but measurements are untrustworthy because of the disturbed condition of most of the beds.

The general lithologic character of the Cienega group - dolomites, shales, intraformational conglomerates, quartzites derived from sandstones, and unaltered sandstones - is suggestive of deposition in shallow seas.

The true stratigraphic position of the Cienega beds is revealed if the beds are traced two miles to the south of the area mapped. At this locality, the top of the Cienega beds is in contact with the Snyder Hill formation, as in the area mapped, and the base of the Cienega beds is in contact with the Naco limestone sensu stricto as defined by Stoyanow.[11] Most of the basal marble unit of the Cienega beds in the area mapped cannot be directly traced to the south because of being cut off by the Sycamore stock. However, the upper part of the marble unit and the metamorphosed shales of the top of Cienega Ridge can be directly traced to the south where they lie at least 1,500 feet above the top of the Naco limestone sensu stricto. Since the marble unit of the Cienega beds is 1,220 feet thick along line C-C' in the area mapped, the base of the marble unit in contact with the Sycamore stock lies well up in the section of the Cienega beds above the Naco limestone sensu stricto.

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11 Stoyanow, A. A., - Correlation of Arizona Paleozoic formations: Bull. Geol. Soc. Amer., vol. 47, p. 523, 1936.

The true stratigraphic position of the Cienega beds is also shown two miles to the north of the area in the California mine area[12] where the beds overlie the Naco limestone sensu stricto and underlie the Snyder Hill formation (see fig. 1).

At this locality, on the west side of the highest limestone-capped ridge, is a series of red shales that are believed to be Cretaceous in age. Below the shales is the Snyder Hill formation which, in places, is thin-only three or four feet thick. Under the Snyder Hill formation is a group of sediments which are identical with the Cienega beds as exposed in their type locality, although the beds cannot be followed from one area to the other. The same quartzites, gray dolomites, buff limestones, and black shales - metamorphosed or not - which are so typical of the Cienega beds, in their type locality, are found in the California Mine area - the only difference being the thickness which, in the latter, is estimated to be at least 800 feet.

The contact between the Cienega beds and the Snyder Hill formation is well exposed in the California Mine area. The top of the Cienega beds is quartzite, and, in places, the quartzite has been brecciated for a thickness of one or two feet. This likewise applies to the basal part of

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12 Gillingham, T., - op. cit.

the Snyder Hill formation which is also brecciated in places. In these localities there can be no doubt that faulting is present. However, in other places, the contact between the two formations reveals no evidence of faulting and appears to be conformable. The relations suggest that faulting between the Cienega beds and Snyder Hill formation was of minor bedding-plane nature, and does not represent a major thrust movement. As bedding-plane faults are common throughout the Cienega group wherever exposed in the Empire Mountains, it would be anticipated that they would occur at the top of the Cienega beds along its contact with the Snyder Hill formation.

The Snyder Hill formation may thus be regarded as overlying the Cienega beds conformably. The Cienega beds overlying the Naco limestone sensu stricto conformably in the same area is shown by Gillingham.[13] The beds thus lie between the Naco limestone sensu stricto and the Snyder Hill formation.

Similar relations are present to the east and to the south of the Empire Mountains in the Whetstone Mountains (see fig. 1), where a series of limestones, sandstones, and shales, have been observed in the same stratigraphic position as the Cienega beds - that is, between the Snyder Hill form-

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[13] Gillingham, T., - op. cit., p. 19.

ation and the Naco limestone sensu stricto. This was observed by Lausen and reported by Stoyanow.[14]

A description of the sequence in the Whetstone Mountains is summarized by the writer as follows:

Lying conformably on top of the Naco limestone sensu stricto are from 400 to 650 feet of reddish arenaceous limestones. Above these is a white massive limestone, about thirty feet thick, underlain and overlain with white sandstones, and in this limestone a Lower Pennsylvanian fauna with a decided Wewoka aspect was found by Lausen. The fauna is characterized by numerous lamellibranchs and gastropods which form a large percentage of the species. Higher up in the section are sandstones and shales, about 750 feet in thickness, overlain by thin-bedded bluish-gray limestone, 250 feet thick. These upper limestone beds contain a characteristic Manzano assemblage.

Stoyanow also says: "Since the Manzano fauna is generally included in the Permian, and since in the Fort Apache Indian Reservation area, it is actually found within the Supai and above the Supai beds containing a Permian flora, the time interval between the Lower Pennsylvanian (Naco) and the Permian must be somewhere within the 750 feet of clastic rocks."[15]

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[14] Stoyanow, A. A., - op. cit., pp. 522-523.

[15] Stoyanow, A. A., - op. cit., p. 523.

Above the beds with the Manzano fauna are light-gray and black limestones which constitute the basal part of the Snyder Hill formation.

In the Whetstone Mountains there is thus a series of 1,680 feet of sedimentary rocks between the Naco limestone sensu stricto and Snyder Hill formation. The age of the lower part of the series, where the Wewoka fauna was found, is Lower Pennsylvanian. The age of the upper part of the series, where the Manzano fauna was found, is Lower Permian. An unconformity, representing the Upper Pennsylvanian, is within the series between its lower and upper parts.

The similarity in stratigraphic position, and the similarity in lithology of this series of rock and the Cienega beds suggests a tentative correlation. The age of the Cienega beds would thus be Pennsylvanian-Permian, and they would appear to change in thickness from 4,690 feet in the Empire Mountains to 1,680 feet in the Whetstone Mountains (see fig. 1).

Farther to the east and south, in the vicinity of Tombstone, Arizona, the equivalent of the Cienega beds appears to be present, though much thinner - only 751 feet thick (see fig. 1). As measured by Gilluly[16] along the ridge, including 5,352 B.M., southeast of Ajax Hill, approximately 1,100 feet of dense light-gray limestone constitutes the Lower Naco limestone or Naco limestone sensu stricto. Between the Lower Naco limestone and the next series is an unknown interval. As observed, however, the next series is 58 feet thick and is referred to as pre-"orange dolomite" limestones. The limestone is black in color. Above these limestones is the so-called "orange dolomite" series, 693 feet thick, consisting of gray limestones that appear pink or gray on fresh fractures, red shales, pinkish-gray dolomites that weather orange, and pink limestones.

Above the "orange dolomite" series is the so-called "black limestone" series, 629 feet thick, with Snyder Hill fauna, and above it is the dolomite series, 783 feet thick. Gilluly considers all of the 2,105 feet of the pre-"orange dolomite" series, the "orange dolomite" series, the "black limestone" series, and the dolomite series, as the Upper Naco, and refers to the 1,100 feet of the Naco limestone sensu stricto as the Lower Naco (see fig. 1).

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16 Butler, B. S., Wilson, E. D., and Rasor, C. A., - Geology and ore deposits of the Tombstone district, Arizona: Univ. of Ariz. Bull., Ariz. Bureau of Mines, Geol. Series, No. 10, Bull. 143, pp. 15-17, 1938.

He does not consider the 629 feet of the "black limestone" series with Snyder Hill fauna as a distinct formation (Snyder Hill formation), but includes it with his Upper Naco. Since Stoyanow's interpretation in regarding any rocks with Snyder Hill fauna as the Snyder Hill formation[17] is followed in this paper, the writer correlates Gilluly's "black limestone" series with the Snyder Hill formation, and suggests a tentative correlation between his pre-"orange dolomite" and "orange dolomite" series and the Cienega beds (see fig. 1). The stratigraphic position of the pre-"orange dolomite" and "orange dolomite" series, between the Naco limestone sensu stricto (Lower Naco) and the Snyder Hill formation ("black limestone" series), and their lithologic similarity to the Cienega beds, makes a correlation seem plausible. The lithologic similarity is in the presence of red shales, thin-bedded gray limestones that are pink or gray on fresh fractures, pinkish-gray dolomites, pink limestones, and black limestones.

It would thus seem that the Cienega beds diminish in thickness from 4,690 feet at their type locality in the Empire Mountains, to 800 feet in the California Mine area, 1,680 feet in the Whetstone Mountains, and 751 feet at Tombstone (see fig. 1).

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17 Stoyanow, A. A., - op. cit., pp. 530-532.

Snyder Hill Formation

As defined by Stoyanow,[18] the Snyder Hill formation is a rather empirical unit whose type locality is at Snyder Hill - an isolated hill about ten miles to the southwest of Tucson near the Ajo Road. Its exact thickness is unknown, but it is estimated to be between 200 and 500 feet.

The Snyder Hill formation is 850 feet thick in the area mapped and consists of thin beds of gray and black limestone and dolomite with some beds of quartzite. Chert is very abundant in many of the limestone and dolomite beds as lenticular and irregularly rounded masses. In general, the quartzite beds are quite persistent over distances of a quarter of a mile, but over greater distances they pinch out and disappear.

A list of the fossils found within the Snyder Hill formation is as follows:

Camarophoria deloi King
Composita mexicana (Hall)
Productus (Dictyoclostus) of _ivesi-bassi_ group
Productus occidentalis Newberry
Productus (Waagenoconcha) montpelierensis Girty

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[18] Stoyanow, A. A., - op. cit., pp. 530-531.

Squamularia guadalupensis (Shumard)

Chonetes subliratus Girty

Dielasma bovidens (Morton)

Euomphalus sp.

Murchisonia terebra (White)

Orthonema socorroense Girty

Bellerophon sp.

Worthenia (?) sp.

Dentalium mexicanum Girty

Archaeocidaris sp.

Axophyllum sp.

Lophophyllum sp.

One of the most characteristic and easily identified fossils of the Snyder Hill formation is the small brachiopod, Camarophoria deloi King. As described and pictured by King,[19] this form has a strongly biconvex shell with the pedicle and brachial valves about equal in depth, and with the pedicle valve depressed in the median anterior part of the shell to form an ill-defined sinus, which extends forward and upward as a tongue at the anterior margin. The brachial valve is elevated in the median anterior part as a low fold, and both fold and sinus are marked by four or five angular plications. In addition, each lateral slope bears four or five plications.

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[19] King, R. E., - The geology of the Glass Mountains, Texas: Univ. of Texas Bull. No. 3042, part 2, p. 110, pl. 34, figs. 24-27, 1930.

The most numerous specimens found were of another brachiopod named <u>Composita mexicana</u> (Hall).[20] As pointed out by King,[21] "there is a considerable variation in the configuration of this species. The convexity is variable, and the length may exceed the width. The development of the fold and sinus varies greatly - some shells have hardly any, and thus are indistinguishable from some small specimens of <u>Composita subtilita</u> Hall, while others are very strongly imarginate at the front, both the median fold and sinus and the bordering reflexions of the shell forming waves in the margin."

Brachiopods belonging to the <u>Productus (Dictyoclostus) ivesi-bassi</u> group are likewise very common in the Snyder Hill formation.

Another characteristic fossil of the Snyder Hill formation is <u>Productus occidentalis</u> Newberry. The same form has been reported from the Capitan formation of the Guadalupe Mountains by Girty,[22] and from the Leonard and Word formations of the Glass Mountains of Texas by King.[23]

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[20] Hall, J., - Emory's Report. U. S. and Mexican Boundary Surv., vol. 1, pl. 20, fig. 2, 1857.

[21] King, R. E., - op. cit., p. 129.

[22] Girty, G. H., - The Guadalupian fauna: U. S. Geol. Survey Prof. Paper 58, pp. 262-263, pl. 12, figs. 4-4C, 1908.

[23] King, R. E., - op. cit., pp. 72-73, pl. 14, figs. 10-14.

It is also found in the Toroweap formation of the Grand Canyon region.[24]

Only one specimen of Productus (Waagenoconcha) montpelierensis Girty[25] was found in the Snyder Hill formation.

A more common type of brachiopod is Squamularia guadalupensis (Shumard). The specimens collected conform exactly to those figured by Girty.[26]

Another fossil which is locally very abundant in the Snyder Hill formation is Chonetes subliratus Girty. All of the specimens of this species collected conform to those described and figured by Girty.[27] King reports this species as abundant in the Leonard and Word formations of the Glass Mountains.[28]

Another brachiopod collected is Dielasma bovidens (Morton).

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[24] McKee, E. D., - personal communication, March, 1938.

[25] Girty, G. H., - Fauna of the Park City formation: U. S. Geol. Survey Bull. 436, p. 30, pl. 2, figs. 5-6, 1910.

[26] Girty, G. H., - The Guadalupian fauna: U. S. Geol. Survey Prof. Paper 58, pp. 367-369, pl. 14, figs. 4-11a, 1908.

[27] Girty, G. H., - op. cit., pp. 228-229, pl. 20, figs. 4-7.

[28] King, R. E., - op. cit., p. 64 and 147.

The Snyder Hill formation also contains numerous gastropods.

The most numerous of these gastropods are various species of Euomphalus, both large and small. Murchisonia terebra (White) is also present.

Specimens identical with Bucanopsis modesta Girty, as described and figured by Girty,[29] were also found in the Snyder Hill formation. Specimens which resemble Orthonema socorroense Girty, which is also described and pictured by Girty,[30] were found in the same horizon.

Small specimens belonging to the genus Bellerophon, and small spirally-coiled forms resembling Worthenia specimens as figured by Girty,[31] are quite common.

In addition to brachiopods and gastropods, a species of scaphopod, identical with Dentalium mexicanum Girty, as described and pictured by Girty,[32] was found. Its longitudinal costae are characteristic.

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29 Girty, G. H., - The Manzano group: U. S. Geol. Survey Bull. 389, p. 103, pl. 11, fig. 1, 1909.

30 Cirty, G. H., - op. cit., p. 109, pl. 11, figs. 12-13.

31 Girty, G. H., - op. cit., pl. 11, fig. 5.

32 Girty, G. H., - op. cit., p. 95, pl. 11, fig. 10.

Echinoids, identical with the one pictured and described by Girty[33] under the generic name of Archaeocidaris, are also present in the Snyder Hill formation.

A specimen of coral was found resembling Axophyllum in its strong columella. Specimens of Lophophyllum are very common.

Colonies of bryozoa are numerous throughout, but no attempt was made to identify the genera or species.

Cretaceous Series

Resting unconformably upon the Snyder Hill formation are supposed Cretaceous strata. The age of these strata is not definitely known as no fossils were found within them.

Stratigraphically, the strata lie between the Permian Snyder Hill formation and the Pliocene Gila conglomerate. Outside the area mapped, Cretaceous fossils have been found in lithologically similar strata, and the conglomerate at the base of these strata is assumed to mark the base of the Cretaceous series as exposed. Whether the conglomerate is at the base of the entire Cretaceous system is not known.

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[33] Girty, G. H., - The Guadalupian fauna: U. S. Geol. Survey Prof. Paper 58, p. 110, pl. 27, figs. 18-18a, 1908.

In the area mapped, a conglomerate resting unconformably on the Snyder Hill formation is everywhere present at the base of the series. The size of the rock fragments which compose the conglomerate varies considerably, and many are as large as ten to twelve inches in diameter. Most of the fragments are quite angular (see pl. VII, A and B), and suggest short transportation from their source. The thickness of the conglomerate varies from 100 to 150 feet.

Above the conglomerate are 820 feet of thin-bedded alternating shales and sandstones, most of which are red, although some are gray. Included in these beds are a few beds of gray coarse sandstones. One-eighth of a mile to the south of the Total Wreck mine, and along the old road leading south from the mine to the Empire Ranch, is a bed of limestone three feet thick, interbedded with the shales. This was the only limestone observed in the entire Cretaceous series. It was not mapped as a separate unit.

Above the red shale and sandstone are 2,200 feet of alternating hard arkosic sandstones and shales. The arkosic sandstones reach 75 feet in thickness for individual units, but average about 25 feet. They weather buff, but are orange on fresh fractures. The hard layers form short ridges at right angles to the main spurs leading down from Eagle Bluff Ridge. The sandstones are composed of quartz and feldspar fragments so thoroughly cemented by silica that the entire mass is very hard. The dense hard texture and vitreous appearance of the rock suggests that much of the quartz may have been deposited in a gelatinous colloidal form.

Interbedded with the hard sandstones are shales that are preponderantly gray, but in places, black, red, and green. This series of hard arkosic sandstones and the gray shales continues to the east out of the area until it passes under the Gila conglomerate. Its exposed thickness adjacent to the area is approximately 2,000 feet, and thus the exposed thickness for the Cretaceous series on the east side of the Empire Mountains is approximately one mile. Within the area mapped the thickness for the series is 3,170 feet.

Igneous Rocks

Sycamore stock
(Quartz Monzonite)

The largest igneous body in the entire Empire Mountains is the stock that is, in part, within the west boundary of the area mapped (see pls. I, II, and III, B). I have named it the Sycamore stock after a growth of sycamore trees at its north end. It is approximately one and one-half miles across in an east-west line, and perhaps double that distance in a north-south line. I am not certain of the latter dimension, as I have never examined the south end of the stock, but have only observed it from the Sonoita Road. I am very familiar with the north end of the stock, however, since I have crossed it many times on foot in reaching my area.

The stock consists of a light-colored medium-grained rock that appears intermediate in composition because of the almost equal amounts of pink orthoclase and white plagioclase feldspar. On weathered surfaces and in the washes traversing the stock, these feldspar crystals, together with quartz grains, can be gathered by the handful. Weathered surfaces of the rock are stained brown, and spalling has produced rounded forms that are very typical (see pl. VIII, A and B).

Throughout the stock are numerous aplite dikes, and along its west border lamprophyre dikes are also present.

A detailed description of a specimen of the stock collected within the area about one foot from the northeast edge of the stock is as follows:

Megascopic

The rock is pink on fresh fractures, and is medium-grained. The pink color is due to orthoclase feldspar which can be recognized by its color and the lack of twinning lamellae on the conspicuous cleavage surfaces. A dark-colored ferromagnesium mineral appears to be biotite altered to chlorite. Rounded glassy grains of quartz are abundant, as are crystals of white plagioclase feldspar. Upon the application of cold dilute hydrochloric acid, a slight reaction on the surface of the rock takes place, proving the presence of calcite. Narrow streaks of limonite traverse the rock specimen.

Microscopic

Minerals

Essential	Accessory	Alteration
Orthoclase feldspar - 35% 2.7 mm by 2.00 mm to 0.01 mm in length.	Hornblende - 3% 3.4 mm by 1.6 mm to 3.0 mm by 0.4 mm.	Sericite 0.05 mm by 0.015 mm to less than 0.01 mm in length
Plagioclase feldspar - 28% (Andesine?) 5.5 mm by 2.9 mm to 0.01 mm in length	Apatite (trace) 0.08 mm by .035 mm to 0.01 mm in diameter.	Chlorite 0.8 mm by 0.6 mm to less than 0.01 mm in length
Quartz - 15% 1.2 mm by 0.8 mm to 0.01 mm in diameter.	Sphene - 1% 0.6 mm by 0.2 mm to 0.01 mm in diameter.	Kaolinite 0.01 mm in diameter and less.
Biotite - 10% 0.8 mm by 0.6 mm to 0.01 mm in diameter.		Limonite 0.01 mm in diameter and less.
		Leucoxene 0.01 mm in diameter and less
		Introduced
		Calcite - 8% 2.00 mm by 1.8 mm to 0.01 mm in diameter and less.

The section consists of an intergrowth of subhedral and anhedral feldspar crystals of both orthoclase and plagioclase. The plagioclase has been extensively altered to sericite, and the albite twinning lamellae have been destroyed to the extent that identification of most of the plagioclase by the method of maximum extinction is impossible. However, with two crystals of plagioclase, the lamellae were still present, and the maximum extinction angle measured on the albite twinning lamellae was $16\frac{1}{2}^{\circ}$. This corresponds to either albite or andesine. In both extinction positions its index exceeds that of Canada balsam, corresponding to andesine.

The orthoclase has also been sericitized, but not as extensively as the plagioclase feldspar.

In reflected light, the feldspars are milky white, due to the presence of kaolinite.

Intergrown with the feldspars is anhedral quartz.

Subhedral and anhedral crystals of biotite have been completely altered to chlorite, and the chlorite has been subsequently replaced by calcite. Some of the biotite contained titanium as evidenced by the presence of leucoxene as an alteration product.

Subhedral hornblende has also been completely altered to chlorite and leucoxene, and the chlorite has been in part subsequently replaced by calcite. The mineral appears as elongated "ghost" crystals with the hornblende outline barely preserved.

Other accessory minerals are sphene and apatite. The sphene is subhedral and typically diamond-shaped in cross section. It appears to have been completely altered to limonite, and in turn, the limonite has been partially replaced by calcite.

Small euhedral crystals of apatite are scattered throughout the section, but are especially abundant in the altered hornblende and biotite.

The proportion of the feldspars; orthoclase 35% and plagioclase 28%; the presence of 15% of quartz, and the texture, place the rock as quartz monzonite, following the Lindgren definition.[34]

The altered biotite I have considered as an essential mineral because it is usually present in quartz monzonites, though it is not essential to a quartz monzonite as defined.

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[34] Grout, F. F., - Petrology and Petrography: McGraw-Hill Book Co., New York, p. 47, 1932.

Quartz Diorite Dikes

Quartz diorite dikes were located in three places in the northern Empire Mountains, Schrader[35] reports what is undoubtedly the same kind of rock from the Total Wreck mine, though he refers to the rock as diorite.

Just to the west of Eagle Pass, a dike of quartz diorite has intruded marble of the Cienega beds exactly along the axis of a minor anticline. The dike is seven feet in width and exposed for approximately 250 feet (see pl. I).

To the east of this exposure, in Eagle Pass, is another outcrop of quartz diorite. (see pl. III, B). The rock occurs as a plug surrounded by alluvium. As exposed in the bottom of the wash draining to the east from Eagle Pass, it measures about 130 feet in length. Its true extent cannot be determined because of the alluvium. The rock is much decomposed, and one can dig into it one or two feet without striking unweathered rock.

Farther to the east, at the northeast corner of the base of Cienega Ridge, is another dike of quartz diorite (see pl. I). It outcrops along the slopes of a

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[35] Schrader, F. C., - Mineral deposits of the Santa Rita and Patagonia Mountains, Arizona: U. S. Geol. Survey Bull. 582, p. 145, 1915.

spur of Cienega Ridge and intrudes shales and sandstones of the Cienega beds (see pl. IX). The dike is from two to three feet in width and about 300 feet in length. The rock is fairly fresh.

A detailed description of the quartz diorite from a specimen of this last-mentioned locality is as follows:

Megascopic

The rock is non-porphyritic and phaneritic in texture, though fine-grained. It is grayish-green on fresh fractures and brown on weathered surfaces. Due to the fine-grained texture, the identification of individual minerals is impossible.

Microscopic

Minerals

Essential	Accessory	Alteration
Quartz - 15% 0.4 mm in diameter to less than 0.01 mm in diameter.	Ilmenite - 9% 0.13 mm in diameter to less than 0.01 mm in diameter	Chlorite 0.13 mm by 0.04 mm to less than 0.01 mm in length.
Orthoclase feldspar - 4% 0.16 mm by 0.03 mm to less than 0.01 mm in length.	Apatite (trace) 0.25 mm by 0.10 mm to less than 0.01 mm in length.	Leucoxene 0.01 mm in diameter and less.
Plagioclase feldspar - 31% $Ab_{64}An_{36}$ (Andesine) 0.22 mm by 0.11 mm to less than 0.01 mm in length.		Limonite 0.01 mm in diameter and less.
Hornblende - 20% 1.8 mm by 0.25 mm to less than 0.01 mm in length.		Epidote 0.02 mm by 0.01 mm to less than 0.01 mm in length.
		Sericite 0.12 mm by 0.01 mm to less than 0.01 mm in length.
		Introduced
		Calcite - 21% 0.7 mm by 0.5 mm to less than 0.01 mm in diameter.

The section consists of a fine-grained intergrowth of plagioclase feldspar (andesine), orthoclase, quartz, and hornblende. The feldspar laths are euhedral and subhedral in outline, and have been altered quite extensively to sericite. The plagioclase is andesine ($Ab_{64}An_{36}$), as determined by the method of maximum extinction measured in the zone normal to 010.

The quartz is anhedral. The subhedral hornblende has been completely altered to chlorite, and the chlorite has been replaced by calcite, so that only "ghost" crystals of the original hornblende remain.

Euhedral and subhedral ilmenite crystals are quite abundant throughout the section. The ilmenite has been quite extensively altered to leucoxene.

Subhedral and anhedral calcite has been extensively introduced throughout as a replacement mineral. One subhedral orthoclase crystal is almost entirely replaced by calcite, although the Carlsbad twinning of the orthoclase can still be discerned. The calcite has replaced much andesine and hornblende in addition to orthoclase. In places, the calcite is stained with limonite.

A few euhedral and subhedral crystals of apatite and epidote are visible.

The ratio of alkali to soda-lime feldspar (the orthoclase constituting 12.9% of the total feldspars), the presence of over 10% of quartz, and the phaneritic texture, places the rock, following Lindgren's classification, as quartz diorite.[36]

Syenite Porphyry Dike

On the west side of Total Wreck Ridge, about 100 feet vertically below the top and along the contact of the Cienega beds and the Snyder Hill formation is a syenite porphyry dike. Its width, as exposed on the side of the ridge, is about fifty feet and its length about 250 feet.

Its most conspicuous feature is the large hornblende crystals which attain forty to fifty millimeters in length.

A detailed description of a specimen of the dike follows:

Megascopic

The rock consists of large elongated prisms of

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36 Grout, F. F., - Petrology and Petrography: McGraw-Hill Book Co., New York, p. 47, 1932.

hornblende that occur as phenocrysts in a fine-grained phaneritic groundmass. The hornblende crystals are very conspicuous and one was measured as thirty millimeters in length by five millimeters in width. The groundmass is made up of gray feldspar with rounded green grains of epidote.

Microscopic

Minerals

Essential	Accessory	Alteration
Hornblende - 50% 6.00 mm by 0.8 mm to 0.03 mm by 0.01 mm.	Magnetite - (trace) 0.8 mm by 0.6 mm to 0.01 mm in diameter.	Antigorite (Serpentine) 0.025 mm by 0.02 mm to less than 0.01 mm in length.
Microcline - 30% 2.5 mm by 1.7 mm to 0.1 mm by 0.03 mm.		Epidote 1.2 mm by 1.2 mm to 0.20 mm by 0.04 mm.
Orthoclase - 20% 1.6 mm by 1.3 mm to 0.1 mm by 0.1 mm.		Actinolite 3.00 mm by 0.4 mm to 1.00 mm by 0.3 mm.
Plagioclase feldspar - (less than 1%) (Albite) $Ab_{94}An_6$ 0.5 mm by 0.2 mm to 0.1 mm by 0.03 mm.		

The section consists of an intergrowth of subhedral hornblende and subhedral and anhedral potash feldspars. The potash feldspars consist of both orthoclase and microcline - the orthoclase being either untwinned or twinned according to the Carlsbad law, whereas the microcline possesses its typical "gridiron" or"quadrille" structure from the lamellae of the albite and pericline twins combined. Some plagioclase feldspar is present in the form of albite. All of the feldspars have been extensively altered to epidote.

The hornblende crystals have been partially altered to actinolite and antigorite (serpentine).

A few subhedral crystals of magnetite are present.

From the presence of the potash feldspars and albite, the lack of quartz, the large abundant phenocrysts of hornblende, and the phaneritic groundmass, the rock is syenite porphyry. If the occurrence of the rock is taken into consideration, the fact that it is a hypabyssal dike confirms the use of the term "porphyry."

The igneous rocks intrude Permian strata and are thus post-Permian in age. Since most of the post-pre-Cambrian igneous rocks in southeastern Arizona intrude the Cretaceous and are assumed to be Laramide, the age of the igneous rocks in the northern Empire Mountains is assumed to be Laramide.

Metamorphic Rocks

Marbles of the Cienega beds

The greatest thickness of metamorphic rocks in the northern Empire Mountain area is at the base of the Cienega beds where 1,220 feet of marble occurs, as measured along the line C-C' (see fig. 1 and pl. II).

This marble outcrops along the west side of Cienega Ridge, and its gray and white alternating bands are very conspicuous. The bands average 100 to 125 feet in thickness, and the individual beds of marble in the bands average one or two feet in thickness. The marble is extremely coarse grained and most of it is composed of calcite. The remainder is of dolomite. The base of this marble unit of the Cienega beds is in contact with the Sycamore stock.

To the north of line C-C', just to the west of Eagle Pass and along the southwest side of Eagle Bluff Ridge, these marble beds, in part, grade into their limestone and dolomite equivalents, as well as into metamorphosed and unmetamorphosed shales.

Along the southwest side of Eagle Bluff Ridge is 115 feet of marble that is in contact with the Sycamore stock.

In Eagle Pass and on the northeast side of Cienega Ridge, marble beds alternate with beds of metamorphosed shales (see pl. III, B).

The relation of the metamorphosed rocks to the Sycamore intrusive indicates that they resulted from the intrusion of that body.

Metamorphosed shales of the Cienega beds

Above the basal marble of the Cienega beds is a thickness of 875 feet of metamorphosed shales as measured along the line C-C' (see fig. 1 and pl. II).

Farther to the north of the line C-C', along the southwest side of Eagle Bluff Ridge, the same type of metamorphosed shales is encountered.

These metamorphosed shales characteristically weather brown with irregular pitted surfaces. The rock is very tough and hard and is particularly resistant to erosion. Along the top of Cienega Ridge the rock outcrops as cliff-forming ledges.

The original nature of the metamorphosed shales is revealed by the shaly bedding, which is especially apparent on weathered surfaces, and the fact that the beds can be traced into their unmetamorphosed shale equivalents.

Specimens of the metamorphosed shales were collected from three localities: on the east side of Cienega Ridge about 200 feet vertically from the top, at the northeast corner of Cienega Ridge, and in Eagle Pass.

A detailed description of the specimen from the first-mentioned locality is as follows:

Megascopic

The rock is conspicuously banded with alternating grayish-green and white layers. The individual layers average four millimeters, though some bands are twelve millimeters in thickness. The fact that the rock cannot be scratched with a knife suggests the presence of quartz, though the texture is so fine-grained that accurate mineral identification is impossible. The presence of calcite is indicated, however, by the reaction that follows the application of cold dilute hydrochloric acid.

Microscopic

Minerals

Essential	Alteration
Quartz - 50%	Tremolite
0.08 mm by 0.04 mm to less than 0.01 mm in diameter.	0.12 mm by 0.08 mm to less than 0.01 mm in diameter.
Calcite - 50%	
0.15 mm by 0.08 mm to less than 0.01 mm in diameter.	

The section consists of a fine-grained mass of anhedral clastic quartz grains that are cemented by anhedral calcite. The bedding planes of the original sedimentary rock are visible and give the section a banded appearance. Much subhedral tremolite is present as an alteration product of the calcite and quartz.

It would thus appear that the original shale was made up of small anhedral quartz grains that were cemented by calcite. Due to the intrusion of the Sycamore stock, and the consequent development of heat and pressure, the calcite recrystallized to cement the quartz grains firmly and form a rock much harder and tougher than the original shale. Much of the calcite and quartz also combined, at the time of intrusion of the stock, to form tremolite.

The other two specimens of the metamorphosed shales: one from the northeast corner of Cienega Ridge, and the other from Eagle Pass, are so similar in their thin-sections to the specimen just described that detailed descriptions are not necessary. Both consist of small quartz grains cemented by calcite, and both reveal their original shaly bedding. In the specimen from the northeast corner of Cienega Ridge, a few small subhedral ilmenite crystals are present, and in the specimen from Eagle Pass, there are numerous lenses of calcite along the bedding planes (one lense was observed of an isotropic mineral which appears to be fluorite). These lenses average from one to two millimeters in length, and presumably are concretions. The calcite was probably introduced along the bedding planes and replaced some extraneous matter to form the concretionary lenses. The fact that the metamorphosed shales grade into black organic shales suggests that the replaced extraneous material in the concretions was organic.

In one locality, along the contact of the Cienega beds and the Sycamore stock, a mass of shales has been extensively replaced by silicates. The mass is approximately 400 feet in length and 250 feet in width, and forms a ridge fifty feet high (see pl. I). Immediately to the north of the area mapped and along the contact of the Sycamore stock, the same silicate zone in shales of the Cienega beds is encountered.

The silicates occur in thin layers (or bands) and lenses along the bedding planes of the shale.

A detailed description of a specimen of this rock from the above-mentioned locality in the area mapped is as follows:

Megascopic

The rock consists of a series of alternating green, black, and brown layers. The black layers are the original shale. The brown and green layers are metamorphosed shales. The black and green layers average four millimeters in thickness, and the brown layers and lenses average 1.7 millimeters in thickness. The brown layers are of garnet and the green layers appear to be of diopside. The rock reacts slightly with cold dilute hydrochloric acid in one or two places.

Microscopic

Minerals

Essential

Quartz

0.03 mm in diameter, to less than 0.01 mm in diameter.

Calcite

0.3 mm by 0.1 mm to less than 0.01 mm in diameter.

Alteration

Diopside

0.3 mm by 0.25 mm to less than 0.01 mm in diameter.

Garnet (Almandite)

0.6 mm by 0.3 mm to less than 0.01 mm in diameter

Hornblende

0.12 mm by 0.04 mm to less than 0.01 mm in length.

Tremolite

0.25 mm by 0.11 mm to less than 0.01 mm in length

Epidote

0.24 mm by 0.04 mm to less than 0.01 mm in length.

Sericite

0.025 mm by 0.02 mm to less than 0.01 mm in length

Magnetite

0.3 mm by 0.25 mm to less than 0.01 mm in diameter

The section consists of fine-grained anhedral quartz cemented by subhedral and anhedral calcite. The entire section has been extensively altered to metamorphic silicate minerals. Thus, the original ratio of the quartz to calcite cannot be determined.

The most conspicuous and abundant of the metamorphic minerals is subhedral and anhedral garnet. It occurs in lenses and bands along the bedding planes of the original shale. Since concretionary lenses of calcite are known to exist in the shale (see p. 58), the garnet probably represents the replacement of those concretions. The bedding planes bend around the garnet lenses, showing that as the garnet formed, it displaced the surrounding material and thereby distorted the bedding planes. The garnet has an index of 1.783 and thus is almandite.

The next most abundant of the metamorphic minerals is diopside which occurs as anhedral grains scattered throughout the section, but concentrated around the edges of and within the garnet. The diopside is thus later than the garnet and is an alteration product of it as well as of the original quartz and calcite.

Traversing the garnet are veins of subhedral tremolite and epidote. The diopside around the edges of the garnet is also traversed by these veins, and the tremolite and epidote are thus later than the diopside and garnet. The tremolite has probably formed from the alteration of the diopside and garnet. The epidote may have formed in a similar manner.

The garnet and diopside are also traversed by veins of sericite.

In one part of the section, subhedral prisms of hornblende are rather abundant.

Anhedral magnetite grains are found throughout.

The paragenetic sequence of the metamorphic minerals is as follows: garnet, diopside, and then all the rest. This includes tremolite, epidote, sericite, hornblende, and magnetite. Most of the latter minerals are not in contact with one another and their paragenetic relations cannot be determined. They all are later than the diopside.

Quartzites of the Cienega beds

At the top of the Cienega beds are two units of quartzite separated by gray dolomite. The quartzite unit below the gray dolomite is 460 feet in thickness, and the quartzite above the dolomite is 115 feet in thickness, as measured along the line C-C' (see fig. 1 and pl. II). The quartzite beds are light orange, very dense and hard, and quite vitreous on fresh fractures.

Along the west side of Total Wreck Ridge, the slopes in general are covered with broken weathered pieces of this rock and walking is very difficult. The quartzite appears to be quite susceptible to mechanical weathering, and surface exposures of the rock in situ are scarce. When it does outcrop, however, it forms ledges.

Whether the formation of these quartzites was the result of the intrusion of the Sycamore stock is difficult to say because of the great thickness of unmetamorphosed sedimentary rocks between the stock and the quartzites. If the stock underlies the area, the original sandstones of the quartzites may have been cemented by material set in circulation by the intrusive body.

Quartzites of the Snyder Hill formation

Within the Snyder Hill formation along the base of Total Wreck and Eagle Bluff Ridges are three, and in places, four, thin beds of quartzite (see pls. I and III, A). In general, the quartzite beds are quite persistent over distances of a quarter of a mile, but over greater distances, they pinch out and disappear. The average thickness of the beds is from twenty to 25 feet.

On the top of Eagle Bluff Ridge, are two beds of quartzite, one fifty feet, and the other ten feet thick (see pl. I).

These quartzite beds resemble the quartzites of the Cienega beds in being light orange, very dense and hard, and vitreous on fresh fractures.

The conditions under which the quartzites formed are unknown.

Structure

General Statement

The structure of the Empire Mountains is in general that of a large dome intruded by the Sycamore stock from which the rocks dip away in all directions.

The northern Empire Mountain area is on the east flank of the Sycamore stock, and the general dip of the strata is between 35° and 45° to the east and southeast (see pls. I, II, and III, A).

The steeply-dipping Cienega fault divides the area into two sub-areas (see pl. I). These sub-areas are designated the southern and northern. It is assumed that the strata of the northern subarea have been moved 8,000 feet horizontally along the Cienega fault from a position in which Eagle Bluff Ridge lay opposite and to the north of Total Wreck Ridge. Accompanying the movement along the Cienega fault, blocks of the Snyder Hill formation were dragged along the Empire fault which is assumed to be a subsidiary fault to the Cienega fault. By this movement, blocks of the Snyder Hill formation were brought in contact with Cienega beds of different horizons.

Southern Subarea

The southern subarea consists of the Cienega beds, the Snyder Hill formation, the Cretaceous series, and intrusive igneous bodies. On Cienega Ridge the strata strike in general north 45° east and dip in general from 35° to 45° to the southeast (see pls. I and II). On Total Wreck Ridge, the strike of the beds is more easterly, and in general is north 60° east. The general dip of the strata on Total Wreck Ridge is 30° to 35° to the southeast.

Variations are shown in the general strike at the east end of Total Wreck Ridge, where the strike of the Snyder Hill formation varies from north 75° west to north 40° east, with the dip to the northeast and southeast (see pl. I).

At the northeast end of Cienega Ridge and the north end of Total Wreck Ridge are a series of closely-folded pitching anticlines and synclines. The folds are especially apparent in the thin-bedded dolomite and limestone of the Cienega beds (see pl. X, A and B, and pl. XI). Eight anticlines and seven synclines, which alternate with one another, are located along the northeast end of Cienega Ridge (see pl. I). The pitch of the anticlines and synclines is 30° to the southeast. The general trend of the axes of the folds in north 30° west.

Minor bedding-plane faults are common in the closely-folded dolomite and limestone (see pl. I). In places, the faults are marked by three feet of gouge. The slippages along the bedding planes are assumed to have taken place when the rock was folded. Some alteration and mineralization has occurred along many of the faults, and the outcrops are stained a yellowish-brown by hydrous iron oxide.

A minor bedding-plane fault is along the contact of the Cienega beds and the Snyder Hill formation (see pls. I and II).

In places the gouge along the fault is three to four feet thick.

In most places, however, no gouge is apparent.

Total Wreck fault

On the southeast side of Total Wreck Ridge is the Total Wreck fault (see pl. I). The strike of the fault is north 70° east, and the dip is 32° and 33° to the southeast (see pl. II).

Where the fault disappears under alluvium, the hanging wall is of a quartzite member of the Snyder Hill formation, and the footwall is of limestone of the same formation. Farther to the southwest, the hanging wall and footwall are, in turn, of limestone of the Snyder Hill formation, and the Cretaceous series. At the southern boundary of the area, the hanging wall and footwall of the fault are of limestone of the Snyder Hill formation.

Mineralizing solutions have ascended along the fault throughout its length, but ore minerals are scarce.

The extent of the fault to the southwest out of the area is unknown.

On the southeast side of Total Wreck Ridge, a minor bedding fault is located along the contact of a quartzite member of the Snyder Hill formation and limestone of the same formation (see pl. I and II).

In the Total Wreck mine area, at the east end of Total Wreck Ridge, are a number of faults in the Snyder Hill formation (see pl. I).

Main vein (and fault)

The fault of greatest economic importance in the northern Empire Mountains is the so-called main vein (and fault) of the Total Wreck mine (see pl. I). Schrader also refers to it as Vein No. 3. [37]

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[37] Schrader, F. C., - Mineral deposits of the Santa Rita and Patagonia Mountains, Arizona: U.S. Geol. Survey Bull. 582, p. 144, 1913.

The strike of the fault is north 31° east and the dip is 85° to the southeast.

The downthrow side of the fault is the southeast side (hanging wall), and the movement has offset the north fissure (Vein No. 1) and the south fissure (Vein No. 2) of the Total Wreck mine (see pl. I).

Considerable ore mineralization has taken place along the main fault (see pl. V, A).

North and South fissures

The two fissures of greatest economic importance in the northern Empire Mountains are the north fissure (Vein No. 1) and south fissure (Vein No. 2) of the Total Wreck mine (see pl. I).

The strike of the fissures is east-west, and the dip is 86° to the north.

The fissures have been offset by the main vein (and fault) of the Total Wreck mine (see pl. I).

Considerable ore deposition has taken place along the fissures (see pl. V, B).

Northern subarea

The strata of the northern subarea consist of the Snyder Hill formation and the Cretaceous series. The general strike of the strata in the southern part, to the north of the Cienega fault, is north 55° east. To the north, the strike of the beds is more northerly, and in the northern part, the general strike is north 10° west. The general dip of the strata is from 35° to 45° to the southeast and east.

Cienega fault

Forming the southern boundary of the northern subarea is the Cienega fault (see pl. I). This fault is the longest in the northern Empire Mountains and extends unknown distances to the east and to the west out of the area. The writer has traced it as least one mile to the east out of the area.

The general strike of the Cienega fault is north 45° west. In Eagle Pass the general strike is east-west. The general dip of the fault is 85° to the northeast.

At the southeast corner of the northern subarea, the hanging wall of the Cienega fault is of the buff arkosic sandstone and shale unit of the Cretaceous series. This unit is in contact with the red sandstone and shale unit of the Cretaceous series which forms the footwall.

To the northwest along the fault, at the north end of Total Wreck Ridge, the footwall is of the basal conglomerate unit of the Cretaceous series. This unit is in contact with the buff arkosic sandstone and shale unit of the Cretaceous series which forms the hanging wall.

At the northeast end of Cienega Ridge, the red sandstone and shale unit forms the footwall and is in contact with the buff arkosic sandstone and shale unit which forms the hanging wall.

At the east end of Eagle Pass, the hanging wall is of the Snyder Hill formation and the footwall is of the Cienega beds.

At the west end of Eagle Pass, the hanging wall of the Cienega fault is of a quartzite member of the Snyder Hill formation, and the footwall is of limestone of the Snyder Hill formation.

At the southwest end of Eagle Bluff Ridge, the hanging wall is of the Snyder Hill formation and the footwall is of the Cienega beds (see pl. XII, A and B).

The general strike of the strata of the hanging wall of the Cienega fault is north 55° east, and the dip varies from 27° to 52° to the southeast.

The strike of the strata of the footwall of the fault shows a considerable variation. At the north end of Total Wreck Ridge and the northeast end of Cienega Ridge, the strike averages north 45° west. In Eagle Pass and on the southwest end of Eagle Bluff Ridge, the strike is more north-south. The dip of the strata varies from 25° to 73° to the north-east, east and southeast.

The Cienega fault is assumed to be a fault with a horizontal displacement. The hanging wall is assumed to have moved 8,000 feet northwest from a position in which the Snyder Hill formation of Eagle Bluff Ridge lay opposite and to the north of the Snyder Hill formation of Total Wreck Ridge.

Empire fault

Extending from the north end of Total Wreck Ridge to the west end of Eagle Pass is the Empire fault. Throughout its length, its strike is, in general, parallel to the strike of the Cienega fault (see pl. I). The hanging wall of the fault is of the Snyder Hill formation and the footwall is of the Cienega beds. The Empire fault is assumed to be a subsidiary fault to the Cienega fault.

The general strike of the Empire fault is north 55° west. Towards Eagle Pass, the fault strike is more westerly, and in Eagle Pass, the strike of the Empire fault is east-west.

The dip of the Empire fault at the north end of Total Wreck Ridge averages 25° to the north and northeast. In Eagle Pass, the fault dip varies from 0° to 15° to the north, and northeast (see pl. III, B).

The strike and dip of the Snyder Hill formation along the Empire fault show a considerable variation (see pl. I). At the north end of Total Wreck Ridge, the general strike of the Snyder Hill formation is north 25° west, and the dip is in general 35° to the northeast. The strike varies from north 75° east to north 65° west, and in one place, the strike is east-west. The dip of the Snyder Hill formation varies from 15° to 62° to the northeast, north, and northwest.

At the northeast end of Cienega Ridge, the strike of the Snyder Hill formation along the Empire fault varies from north 23° west to north 65° west. The dip of the beds averages 26° to the northeast.

In Eagle Pass, the strike of the Snyder Hill formation along the Empire fault varies from north 55° east to north 30° west. The dip of the beds varies from 53° to the southeast to 22° to the northeast.

The amount of brecciation along the Empire fault varies from 75 feet of brecciated limestone of the Snyder Hill formation in Eagle Pass to three feet of fault breccia along most of the length of the fault. The fault breccia is present along the entire length of the north side of Eagle Pass. In places in Eagle Pass, unbrecciated limestone of the Snyder Hill formation rests on the fault breccia, but in most places, the fault breccia alone outcrops (see pl. XIII, A and B). The breccia has been stained pink by hydrous iron oxide. The location of Eagle Pass can undoubtedly be attributed to the weak nature of the fault breccia and the ease with which it erodes.

The west end of the Empire fault is in contact with the Cienega fault at the west end of Eagle Pass.

The southeast end of the Empire fault is in contact with the Cienega fault at the north end of Total Wreck Ridge.

The movement along the Empire fault is assumed to have taken place at the time of the horizontal displacement along the Cienega fault. During the horizontal movement, blocks of the Snyder Hill formation were dragged along the Empire fault as a subsidiary movement to the main displacement along the Cienega fault.

At the south end of Eagle Bluff Ridge is a series of steeply-dipping faults in the Snyder Hill formation that have produced a conspicuous fault line scarp at the southwest end of the ridge (see pl. XIV, B). The faults strike and dip in all directions. The main faults of the series, however, have a general strike of north 50° west, and dip 80° to 85° to the northeast and to the southwest.

The east end of the fault line scarp is marked by a small pitching syncline (see pl. XIV, B). The pitch of this syncline is 25° to the southwest. The trend of the axis is north 40° east.

To the southwest, the pitching syncline grades into, and gives place to, a vertical fault (see pl. I). The strike of the fault is north 40° east.

In the north central part of Eagle Bluff Ridge is a block of limestone of the Snyder Hill formation that is essentially horizontal (see pls. I and III, A). The strike of the limestone beds averages north 10° east, and dip averages 5° to the east.

This block is probably surrounded on all sides by faults. The faults on the southwest and northeast strike north 45° west. The fault on the southeast strikes north 10° east. All of the faults dip from 35° to 72° in directions away from and towards the limestone block.

On the west, the limestone block is traversed by two faults eighty feet apart. The faults strike north 20° east, and dip from 11° to 20° to the west (see pls. I and III, A). The limestone between the two faults strikes and dips, in general, the same as the faults. In places, however, there are changes from the general strike. In one place, the strike is north 56° east, and the dip is 12° to the northwest. (see pl. I).

At the base of Eagle Bluff Ridge along line A-A' is a normal fault with a fault strike of north 5° east and a fault dip of 52° to the west (see pl. III, A). The hanging wall and footwall of this fault are in the Snyder Hill formation.

The age of the folds and faults throughout the northern Empire Mountain area is post-Cretaceous. It is assumed to be Laramide because most of the structures of southeastern Arizona are assumed to be of that age.

Geomorphology

The geomorphology of the northern Empire Mountains has been controlled by the varying resistances offered by the rocks and zones of weakness that have resulted from faulting.

Eagle Bluff Ridge and Total Wreck Ridge have their summits composed of the limestone and quartzite of the Snyder Hill formation. The summit of Cienega Ridge is composed of metamorphosed limy shales of the Cienega beds. It is the resistant nature of these rocks that has resulted in the formation of the ridges.

Between Cienega Ridge and Total Wreck Ridge is Hilton Wash. In the bottom of Hilton Wash and extending slightly up the northwest side of Total Wreck Ridge are 280 feet of red sandy shales of the Cienega beds (see p. 25). The shales are soft and easily eroded. The location of the wash can thus be attributed to the weak nature of the shales.

Between Cienega Ridge and Eagle Bluff Ridge is Eagle Pass. In the bottom of the pass is the Empire fault with its zone of fault breccia in places 75 feet thick. The location of the pass can be attributed to the weak nature of the fault breccia.

To the west of Cienega Ridge and Eagle Pass is a topographic basin underlain by the Sycamore stock. The stock is of quartz monzonite and thus of various minerals (see p. 43). The differences in the coefficients of expansion and contraction of the various minerals makes the quartz monzonite more susceptible to mechanical weathering than limestones and quartzites that are of one mineral.

The extensive alteration of the feldspars and biotite of the quartz monzonite (see p. 44) has also aided in the weathering of the rock which has permitted great erosion and the formation of a topographic basin.

To the east of Eagle Bluff Ridge and to the southeast of Total Wreck Ridge is the foothill region of the area. The foothills are of the shales and sandstones of the Cretaceous series. The weak nature of the shales has resulted in extensive erosion and the formation of a region lower than Eagle Bluff and Total Wreck Ridges.

Probably during the Cretaceous period, the area received clastic sediments now represented by 3,170 feet of sedimentary rocks in the northern subarea. The first of these sediments laid down was a conglomerate that was deposited on the Snyder Hill formation. The large size of the rock fragments of the conglomerate indicates that the transporting agent had a considerable velocity. The transportation was probably accomplished by rivers with large gradients. Above the conglomerate, the finer clastic sediments of the rest of the series were deposited. These sediments of quartz and feldspar sands, together with muds, were transported by rivers. Whether the sediments were deposited in seas or not is unknown.

Following the deposition of the probable Cretaceous sediments, the strata of the northern Empire Mountains were folded and faulted, and in part metamorphosed during the intrusion of the Sycamore stock. Whether the Sycamore stock was intruded before the strata were folded and faulted, or after, is not known. However, orogenic friction and release of pressure through diastropic uplifts are both important in generating magmas. It thus appears that the strata were folded and faulted, and that the orogenic friction and release of pressure from the diastrophic movements perhaps helped to generate the magma of the Sycamore stock.

Geologic History

The earliest geologic event of which there is any record in the area mapped is the deposition of the Cienega beds during the Pennsylvanian-Permian period. At that time the area was flooded by shallow marine waters and in these the calcareous oozes, calcareous muds, dolomitic oozes, quartz sands and intraformational conglomerates that now constitute the Cienega beds were deposited. The total thickness of the deposits was 4,690 feet.

The seas may have withdrawn from the area during the Upper Pennsylvanian epoch.

Following the deposition of the Cienega beds, the seas deepened and the calcareous oozes and quartz sands of the Permian Snyder Hill formation accumulated. The deposits reached a thickness of 850 feet. In these Permian seas, brachiopods, gastropods, corals, bryozoa, crinoids, echinoids, and scaphopods were abundant.

The seas in which the Snyder Hill sediments were deposited withdrew before the end of the Permian period and from then on until probably the Cretaceous period no deposition took place in the northern Empire Mountain area.

The ore deposits of the Total Wreck mine may have been derived from the stock.

All of the diastrophic movements and all of the igneous and metamorphic activity in the northern Empire Mountains are assumed to be Laramide in age.

Following the assumed Laramide activity, evidence is lacking for any deposition in the northern Empire Mountains until the beginning of the accumulation of Recent alluvium.

Throughout the Tertiary period and continuing to the present time, erosion was the rule instead of deposition. As a result of erosion, the northern Empire Mountains have assumed their present topographic form.

Economic Geology

Total Wreck Mine

The only ore deposit of any size in the northern Empire Mountains is at the Total Wreck mine which is located at the east end of Total Wreck Ridge (see pl. I). The mine may be reached by road from Pantano which is seven miles to the north.

History and Production

The Total Wreck mine was discovered in 1879 by John Dilden and was later relocated and acquired by the Empire Mining and Development Company, which installed a 70-ton milling plant.[38] Beginning in 1881, the mine and mill were operated for a year and a half on rich surface ore. In 1882, the manager reported 50,000 tons of ore in sight,[39] but after the production of 7,500 tons of ore, the mine and mill were closed. The mine was soon afterward sold for taxes and purchased by Vail and Gates of Tucson, Arizona. E. L. Vail and Company owns the mine at present (1938).

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[38] Schrader, F. C., - Mineral deposits of the Santa Rita and Patagonia Mountains, Arizona: U. S. Geol. Survey Bull. 582, p. 142, 1915.

[39] Blake, W. P., - Mining in Arizona: Report of the Governor of Arizona for 1899, p. 116, 1899.

The mine was idle until 1907, but was then worked by C. T. Roberts who found several thousand tons of low-grade ore remaining in old workings. He also discovered some new ore bodies and considerable ore was shipped until March, 1908.

In March, 1909, the property was bonded to E. P. Drew of Tucson, and work was resumed on a small scale. Some ore, in part high-grade lead-silver ore, was produced, but early in 1911 work was discontinued.[40]

From a Tucson newspaper clipping dated November 11, 1917, there is the following information:

> "The Total Wreck mine - after lying idle for a good many years, is again to be worked. In fact, it has been worked for the past four months, and while it is believed the silver-lead ore, which made it famous along in the '80's, has been exhausted, the molybdenum showing indicates the probability of a big paying output of that metal.
>
> "A new shaft is being sunk and is now down 70 feet with about 25 men at work mining and putting up buildings in the camp. The molybdenum ore is abundant ...."

A Tucson newspaper clipping dated April 15, 1918, states:

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40 Schrader, F. C., - op cit., p. 143.

> "One after the other of the molybdenum properties around Tucson are closing down and discharging their miners, owing to the impossibility of marketing the ore......
>
> "Among the important sources for wulfenite ore, the Total Wreck mine shut down last week ......"

From 1922 to 1925, the Total Wreck mine was leased by Tom Gardner. A Tucson newspaper clipping dated June 10, 1922, states that Gardner was developing the property at the time. A Tucson newspaper clipping dated October 21, 1925, states the following:

> ".... The Total Wreck mine was found being worked on a lease by Tom Gardner. About twenty tons of shipping-grade lead-silver ore has already been produced and the leaser expects to make shipment of a forty-ton carload before November 1. The old Total Wreck mine has a record of about $500,000. in production, mainly from high-grade silver production in the upper workings. It was equipped with the first Boss process of pan amalgamation in Arizona. The old mine has long been known to contain a large tonnage of low grade oxidized ore for which there has been no satisfactory process of concentration. The successful application of oil flotation to ores of this type at the Shattuck mine and many other properties suggests interesting possibilities for the low-grade ores of this old property."

At the present time (April, 1938), two Mexicans and a Yaqui Indian are working the mine for the wulfenite. They have not made any shipments.

Schrader reports[41] that the production from the Total Wreck mine was more than 10,000 tons up to 1915. Most of the production was prior to 1902, especially in 1881 and 1882. At that time, the mill was in operation, and a five month's run is said to have produced over $450,000. from about 7,500 tons of ore.[42]

The Total Wreck mine is in the Empire district and has produced most of the ore from the district. A summary of the production of the district from 1880-1930 is as follows:[43]

Copper (pounds)	Lead (pounds)	Gold (value)	Silver (value)	Total value
110,000	6,000,000	$15,000.00	$520,000.00	$1,050,000.00

The production of the Empire district from 1915-1933 is as follows:[44]

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41 Schrader, F. C., - Mineral deposits of the Santa Rita and Patagonia Mountains, Arizona: U. S. Geol. Survey Bull. 582, p. 143, 1915.

42 Hamilton, P., - The resources of Arizona, second edition: San Francisco, p. 131, 1883.

43 Elsing, M. J. and Heineman, R. E. S., - Arizona metal production: Univ. of Ariz. Bull., Arizona Bureau of Mines, Economic series 19, Bull. 140, p. 97, 1936.

44 Elsing, M. J. and Heineman, R. E. S., - op. cit., p. 74.

Year	Producers (lode)	Tons	Gold (value)	Silver (ounces)	Copper (pounds)	Lead (pounds)	Zinc (pounds)	Total value
1915	4	100	-	800	-	20,000	-	$2,144.00
1916	3	?	-	6,000	-	200,000	-	38,000.00
1917	5	1,528	$76.00	9,015	1,323	326,799	-	35,970.00
1918	4	469	64.00	2,725	1,371	165,093	50,864	19,478.00
1919	2	?	150.00	8,000	1,500	300,000	-	53,000.00
1920	2	?	60.00	1,000	1,500	130,000	-	14,000.00
1921	-	-	-	-	-	-	-	-
1922	7	746	620.00	7,988	9,310	178,188	-	19,720.00
1923	4	665	691.00	4,952	5,209	177,057	-	17,912.00
1924	5	466	157.00	2,352	2,262	183,215	-	16,686.00
1925	6	1,203	833.00	5,684	5,662	560,244	23,750	56,128.00
1926	7	3,461	2,764.00	24,983	32,066	1,566,272	-	148,144.00
1927	4	2,366	2,226.00	10,948	15,680	1,168,000	-	84,071.00
1928	6	1,435	1,662.00	5,770	14,825	645,641	-	44,619.00
1929	7	1,067	557.00	4,518	17,038	438,339	-	33,579.00
1930	5	356	262.00	2,243	6,804	164,852	-	10,254.00
1931	1	62	-	-	-	-	-	1,367.00
1932	-	-	-	-	-	-	-	-
1933	1	5	93.00	3	-	-	-	94.00
Total		13,929	$10,215.00	96,981	114,550	6,223,700	74,614	$595,166.00

Development and Equipment

The Total Wreck mine is well developed to a depth of about 500 feet by shafts, tunnels, drifts, inclines, winzes, and stopes, which aggregated about 5,000 feet of work in 1915.[45]

The workings have been only slightly extended since that time.

The principal shaft is the main inclined shaft which is 460 feet deep and is inclined 35^{o} to the southeast following the footwall of the main vein (and fault) (see pl. IV, A and B).

The adit through which most of the ore was taken out intersects the ore body on the 200 foot level.

The levels in general lie about fifty feet apart vertically. They trend northeast and have been driven several hundred feet from the main shaft in both directions.

Schrader mentions[46] that "the property comprises a

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[45] Schrader, F. C., - Mineral deposits of the Santa Rita and Patagonia Mountains, Arizona: U. S. Geol. Survey Bull. 582, pp. 143-144, 1915.

[46] Schrader, F. C., - op. cit., p. 144.

group of seven claims, some of which are patented."

"The principal equipment was a 20-stamp, 70-ton mill, and a 300-horsepower engine. The camp and mill were supplied with water pumped from a spring four miles to the south."

The mill and engine have since been dismantled and removed.

Geology

The Total Wreck mine is entirely within the Permian Snyder Hill formation which consists of thin beds of gray and black limestone and dolomite together with thin beds of quartzite (see p. 34). The quartzite in the Total Wreck mine is light gray.

On the surface, the basal conglomerate of the Cretaceous series (see p. 40) overlies the Snyder Hill formation over a considerable area (see pl. I).

The general strike of the beds is north 60° east and the general dip is 35° to the southeast (see pls. IV, B and V, A). This dip is approximately the inclination of the east and south slopes of the ridge in which the Total Wreck mine is located.

The rocks are much faulted, for the most part horizontally, somewhat folded, and contain a system of prominent east-west fissures. The principal fissures are the so-called north fissure (or Vein No. 1) and the south fissure (or Vein No. 2). These fissures have an east-west strike and dip 86° to the north (see pl. V, B). They are ninety feet apart.

The main fault is the so-called main vein (and fault) which strikes north 31° east and dips 85° to the southeast. The downthrow side is on the southeast, and the movement along the fault has resulted in the north and south fissures being offset (see pl. I).

The sedimentary rock is intruded by small dikes of what Schrader calls diorite[47] (see p. 46).

No water has been encountered in the mine.

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[47] Schrader, F. C., - Mineral deposits of the Santa Rita and Patagonia Mountains, Arizona: U. S. Geol. Survey Bull. 582, p. 145, 1915.

Ore Deposits

The ore deposits of the Total Wreck mine occur principally in three veins and replacement ore bodies. The veins and replacement bodies are in or near fissures, especially the east-west fissures, of which the most important are the north fissure (Vein No. 1) and the south fissure (Vein No. 2).

Another vein, with replacement ore bodies, is in the main vein (and fault) (Vein No. 3).

As mentioned before, the two east-west fissures are ninety feet apart and have a steep northerly dip (see p. 90). The ore bodies occur on their northerly or hanging wall side, mostly in the limestone and above beds of quartzite. Some of the deposits extend out from the fissures along the bedding planes of the limestone above and below quartzite beds, as blanket veins or ore beds (see pl. V, B).

In the main vein (and fault), the ore bodies are on either side of the vein and occur in the limestone, usually above beds of quartzite. Some of the deposits also extend from the main vein along the bedding planes of the limestone, above and below quartzite beds, as blanket veins (see pl. V, A).

The vein portion of the ore deposits, in the fissures and in the main vein (and fault), is more or less uniformly six or eight feet wide. The width of the zone comprising the vein and the replacement ore bodies in the adjoining limestone, is much greater (see pl. V, A), being in places 150 feet (excluding the blanket veins).

The deposits extend from the surface to the bottom of the mine where the lower limits have not been reached. Though some good-looking ore bodies have been reported from the deeper part of the mine, practically all of the ore which was profitably worked was found between the surface and the 350 foot level.[48]

The ore is an argentiferous lead ore which also carries a little copper in the deep part of the mine. The ore is in an altered and crushed limestone gangue with calcite and quartz in porous or honey-combed masses of various forms. The ore is stained reddish-brown, yellowish, greenish, or blackish, by oxides of iron and manganese, and carbonates of lead and copper.

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[48] Schrader, F. C., - Mineral deposits of the Santa Rita and Patagonia Mountains, Arizona: U. S. Geol. Survey Bull. 582, p. 145, 1915.

On the 450-foot level, forty to fifty feet of breccia was reported with the ore, and some light-colored argillaceous gouge-like material which is probably kaolin.[49]

The ore is practically all oxidized, scarcely more than a trace of sulphide having been found, even in the deepest parts of the mine.[50]

The principal ore minerals are cerargyrite or horn silver (silver chloride), cerussite (lead carbonate), wulfenite (lead molybdate), malachite and azurite (hydrous copper carbonates), chrysocolla (hydrous copper silicate), a little chalcopyrite (copper iron sulphide), and a little galena (lead sulphide). Gold is present but is not visible.

The associated minerals are hematite (iron oxide), "limonite" (hydrous iron oxide), vanadinite (lead-chloro vanadate), jarosite (basic hydrous sulphate of potassium and iron), and various manganese oxides (manganite, psilomelane, and wad).

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49 Schrader, F. C., - op. cit., p. 145.

50 Schrader, F. C., - op. cit., p. 145.

In the surface ore, much of which was very rich, the principal mineral was cerargyrite. In the lower part of the mine, however, silver is only sparingly present, or absent, and copper, principally in the form of carbonates, is more abundant. The main vein (Vein No. 3) is said to be five feet wide, to contain considerable wulfenite, and to average four percent copper, twelve percent lead, and twelve ounces of silver, to the ton.[51]

The early ore is said to have averaged in mill tests about $60.00 to the ton. The cost of mining and milling was reported to be about $8.00 a ton.[52]

The origin of the deposits of the Total Wreck mine is unknown, but the presence of the Sycamore stock, one and one-half miles to the west of the mine, suggests that the ore solutions originated from that igneous body. An extension of the Sycamore stock may underlie the Total Wreck mine.

Since the age of the Sycamore stock is assumed to be Laramide, the age of the ore deposits would then be Laramide.

Subsequent to the deposition of the ore deposits,

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[51] Schrader, F. C., - op. cit., p. 147.

[52] Schrader, F. C., - op. cit., p. 147.

they have become concentrated by percolation of meteoric waters in the oxidized zone.

During the formation and concentration of the ore, the quartzite beds of the Snyder Hill formation were important physical agents in aiding mineral precipitation. At the time of formation of the ore, the quartzite beds arrested the progress of the ascending solutions. During the time of concentration of the ore by meteoric waters, the quartzite beds arrested the progress of the descending solutions. The greatest concentration of the ore has been by the descending solutions as most of the ore is above the quartzite beds.

In 1915, Schrader reported[53] that the mine seemed to contain considerable good ore, but probably of low grade. Some of the leads were apparently lost on the lower levels, and Schrader suggested that the deeper part of the mine should receive detailed examination before operations are resumed on any large scale.

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[53] Schrader, F. C., - Mineral deposits of the Santa Rita and Patagonia Mountains, Arizona: U. S. Geol. Survey Bull. 582, p. 147, 1915.

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Plate VI

White and black shales of the
Cienega beds - southwest side
of Eagle Bluff Ridge. Strike
of beds is north 17° west, dip
is 85° to the east.
View looking north.

Plate VII

A.

Conglomerate at base of Cretaceous series - east side of Eagle Bluff Ridge. Strike of beds is north 68° east, dip is 35° to the southeast.
View looking west.

B.

Same as in fig. 1.

Plate VIII

A.

Sycamore stock - north end.

View looking southwest.

B.

Sycamore stock - north end.

View looking west.

Plate IX

Quartz diorite dike intruded into sandstones and shales of Cienega beds - northeast corner of the base of Cienega Ridge. View looking north.

Plate X

A.

Closely-folded pitching anticlines and synclines in dolomites and limestones of Cienega beds - northeast end of Cienega Ridge. View looking north. Pitch of folds is 30° to the southeast.

B.

Same view as above taken farther away and looking northeast.

Plate XI

Same view as in Plate X, A and B, taken farther away and looking northwest.

Plate XII

A.

Cienega fault - southwest end of Eagle Bluff Ridge. View looking northeast. Strike of fault is east-west, dip of fault is 30° to the north. Hanging wall is of the Snyder Hill formation. Strike of the Snyder Hill formation is north 70° west, and dip is 22° to the south. Footwall is of dolomite and limestone of the Cienega beds. Strike of the Cienega beds is north 20° east, and dip is 49° to the east.

B.

Same as above, taken farther away.

Plate XIII

A.

Pink brecciated limestone of
Snyder Hill formation along
Empire fault - Eagle Pass.
View looking northwest.

B.

Same as above.

Plate XIV

A.

West side of Eagle Bluff Ridge showing the Snyder Hill formation and Cienega beds. View looking northeast.

B.

Fault line scarp in the Snyder Hill formation produced by a series of steeply-dipping faults. Main faults of the series strike north 50° west, and dip 80° to 85° to the northeast and southwest. Small pitching syncline at east end of the fault scarp. View looking northwest.

2

In Pocket:
5 maps

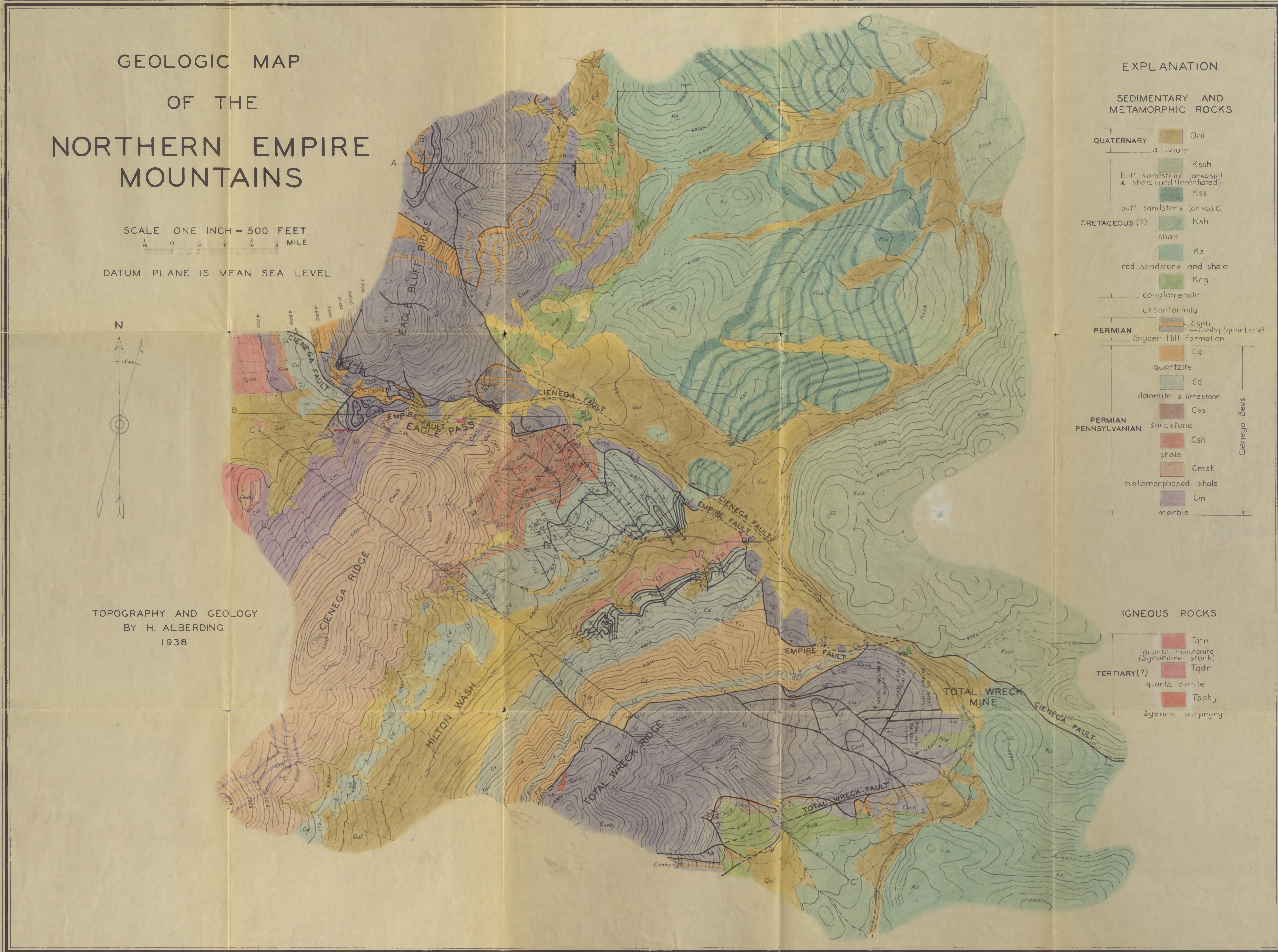

GEOLOGIC MAP
OF THE
NORTHERN EMPIRE
MOUNTAINS
SCALE: ONE INCH = 500 FEET
MILE
DATUM PLANE IS MEAN SEA LEVEL
TOPOGRAPHY AND GEOLOGY
BY H. ALBERDING
1938
EXPLANATION
SEDIMENTARY AND
METAMORPHIC ROCKS
QUATERNARY
Qal
alluvium
Kssh
buff sandstone (arkosic) & shale (undifferentiated)
Kss
buff sandstone (arkosic)
CRETACEOUS (?)
Ksh
shale
Ks
red sandstone and shale
Kcg
conglomerate
unconformity
PERMIAN
Csnh
Csnhq (quartzite)
Snyder Hill formation
Cq
quartzite
Cd
dolomite & limestone
PERMIAN
PENNSYLVANIAN
Css
sandstone
Csh
shale
Cmsh
metamorphosed shale
Cm
marble
Cienega Beds
IGNEOUS ROCKS
TERTIARY (?)
Tqtm
quartz monzonite (Sycamore stock)
Tqdr
quartz diorite
Tsphy
Syenite porphyry
N
EAGLE BLUFF RIDGE
CIENEGA FAULT
EMPIRE FAULT
EAGLE PASS
CIENEGA RIDGE
HILTON WASH
TOTAL WRECK RIDGE
TOTAL WRECK FAULT
TOTAL WRECK MINE

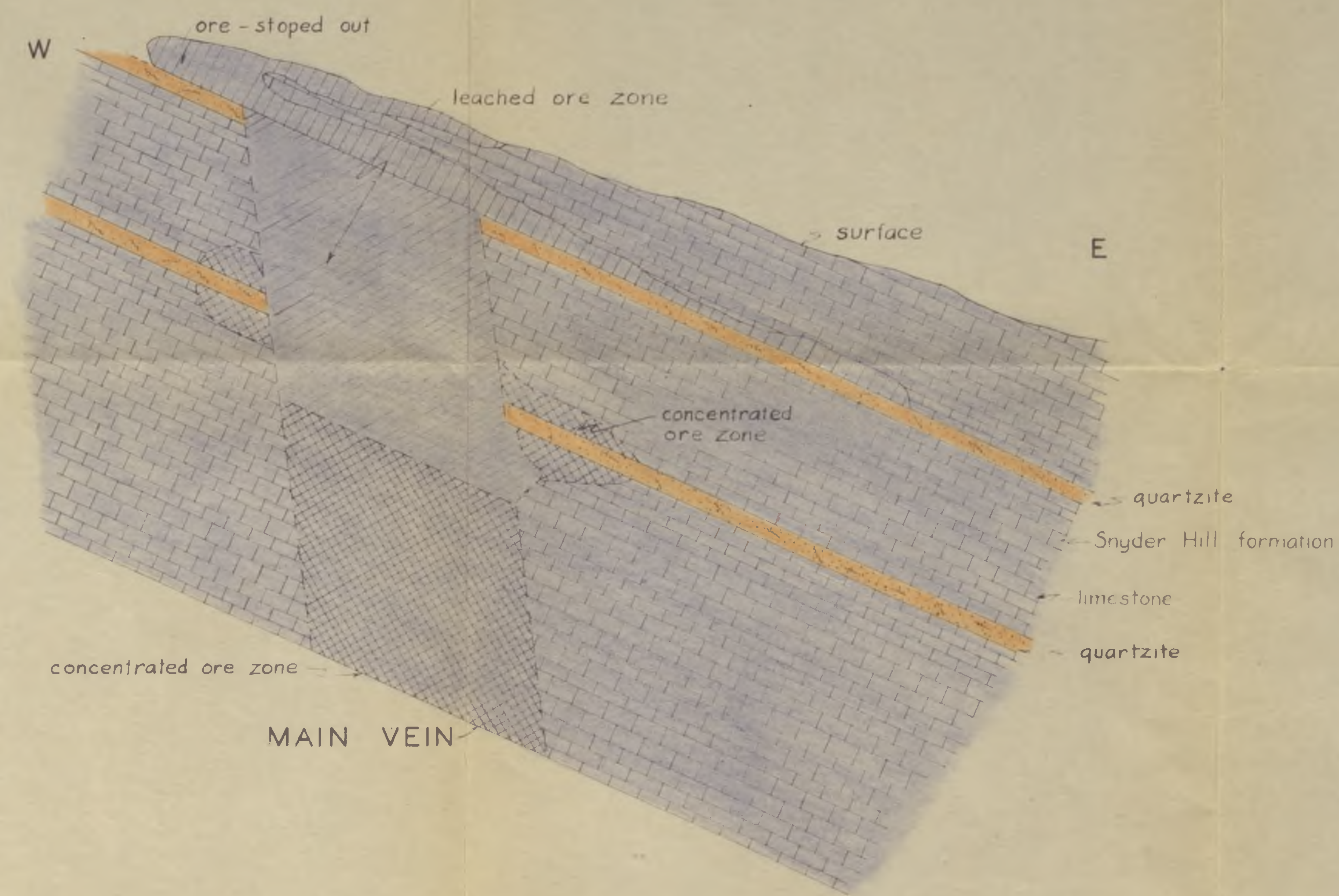
PLATE V

SECTIONS OF FISSURES AND ORE BODIES OF TOTAL WRECK MINE

MODIFIED AFTER F. C. SHRADER

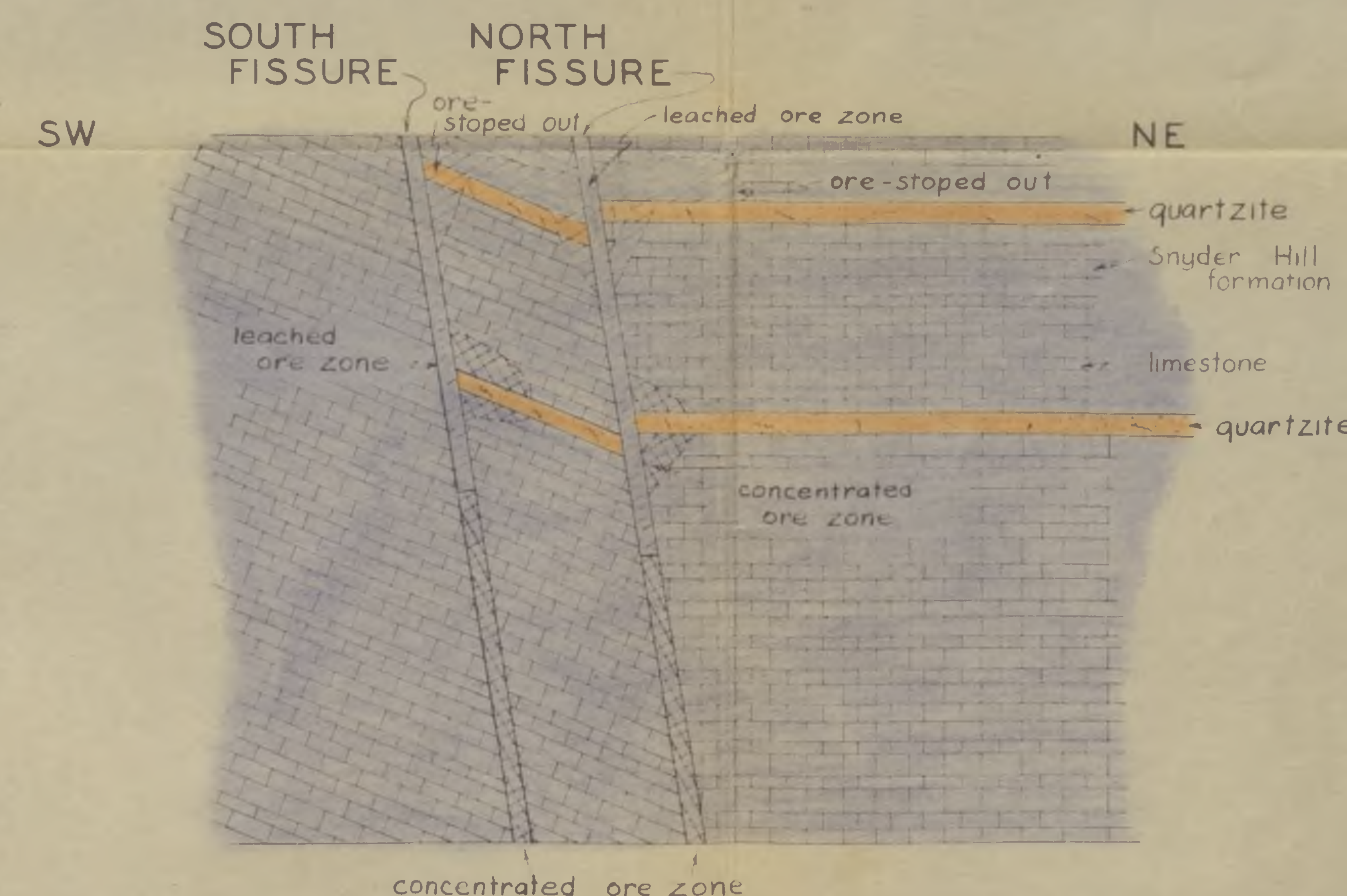
SCALE: ONE INCH = 85 FEET

A



OBLIQUE SECTION
OF MAIN VEIN NEAR SURFACE

B

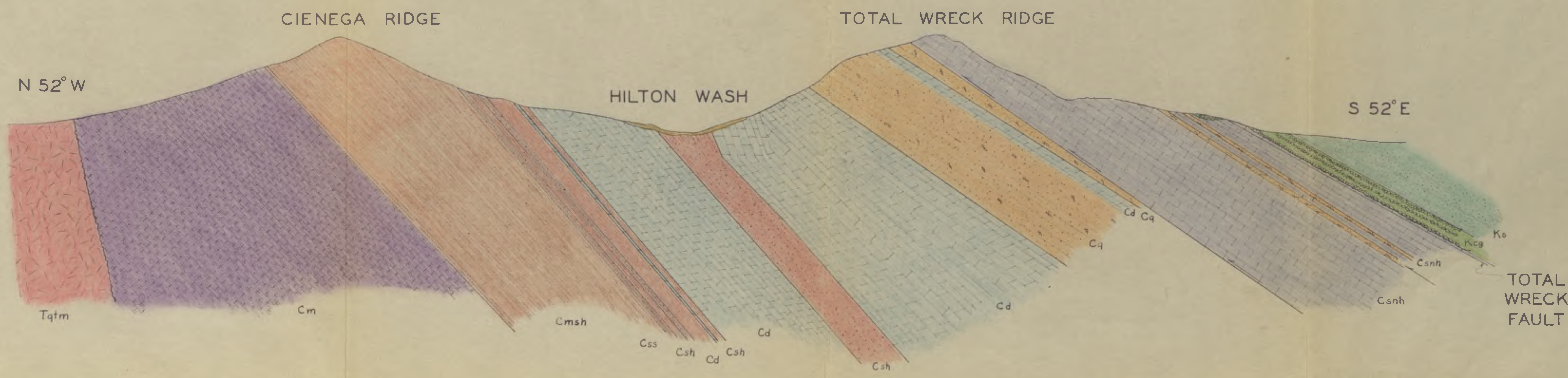


OBLIQUE SECTION
OF NORTH AND SOUTH FISSURES
ON 350 FOOT LEVEL

PLATE II

GEOLOGIC STRUCTURE SECTION

SCALE: ONE INCH = 500 FEET



SECTION ALONG LINE C–C′

EXPLANATION

IGNEOUS ROCKS

TERTIARY(?) — Tqtm — QUARTZ MONZONITE

SEDIMENTARY & METAMORPHIC ROCKS

CRETACEOUS
- Ks — RED SANDSTONES & SHALES
- Kcg — CONGLOMERATE

UNCONFORMITY

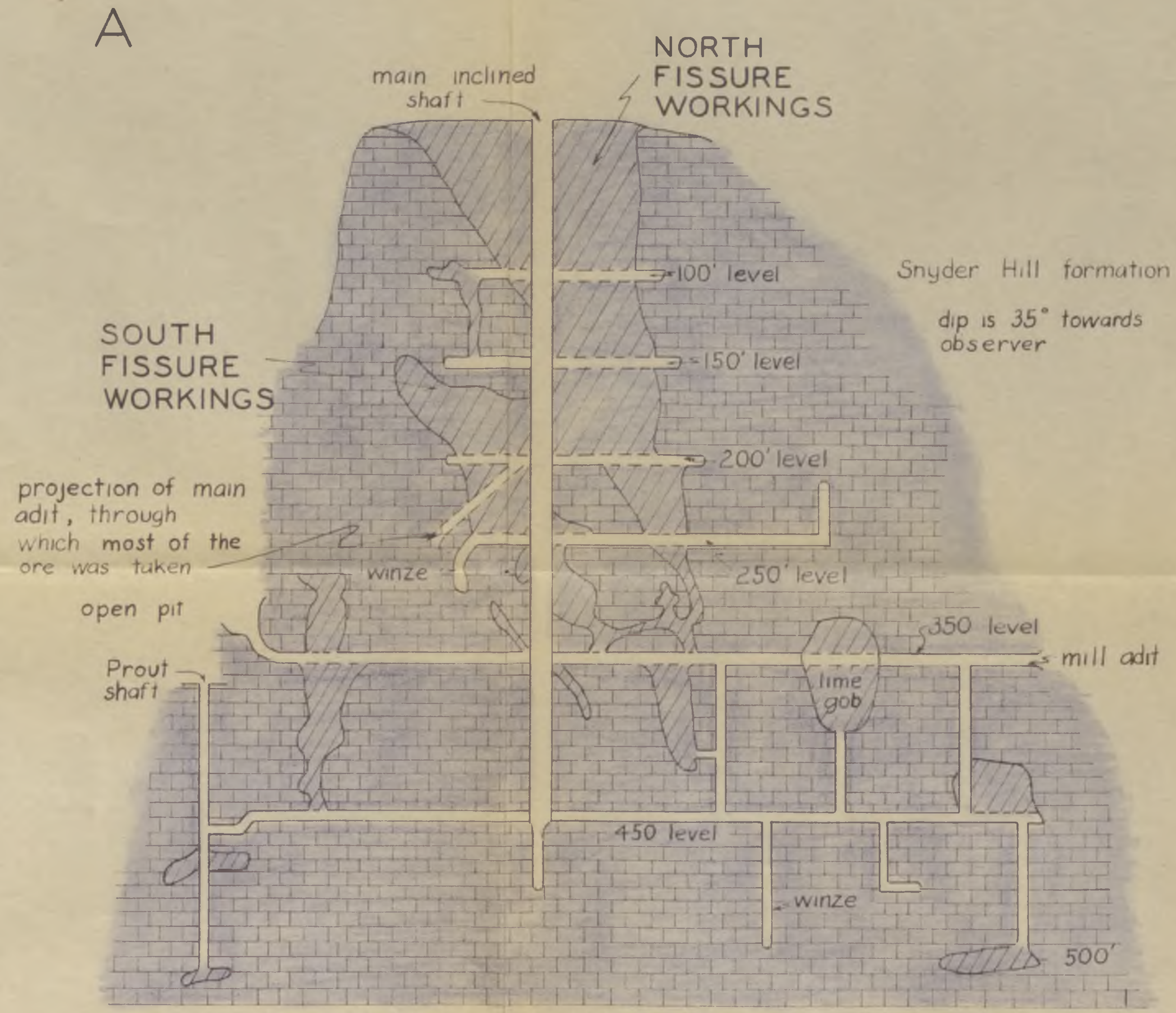
PERMIAN
- Csnh — SNYDER HILL FORMATION

PERMIAN – PENNSYLVANIAN (CIENEGA BEDS)
- Cq — QUARTZITE
- Cd — DOLOMITE & LIMESTONE
- Csh — SHALE
- Css — SANDSTONE
- Cmsh — METAMORPHOSED SHALE
- Cm — MARBLE

PLATE IV

SECTION AND PLAN OF TOTAL WRECK MINE

MODIFIED AFTER F. C. SHRADER



DIAGRAMATIC LONGITUDINAL SECTION
OF TOTAL WRECK MINE
ON DIP OF MAIN VEIN
DIP IS 85°

SCALE: ONE INCH = 80 FEET

PLAN OF UNDERGROUND WORKINGS
OF TOTAL WRECK MINE

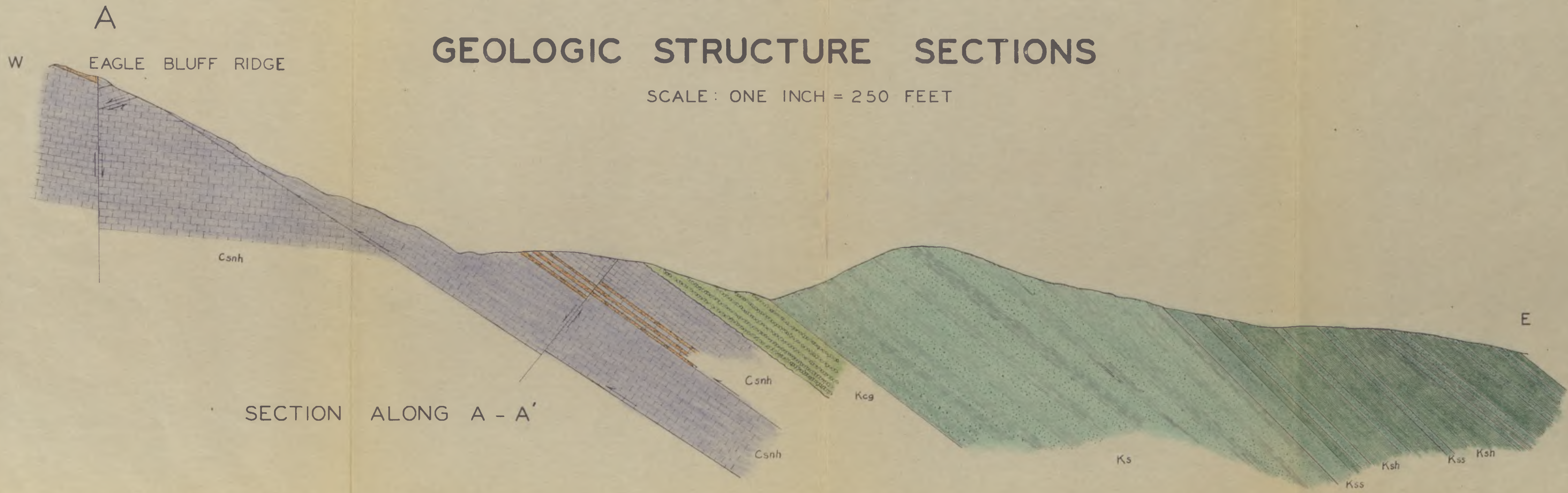
SCALE: ONE INCH = 70 FEET

Plate 4

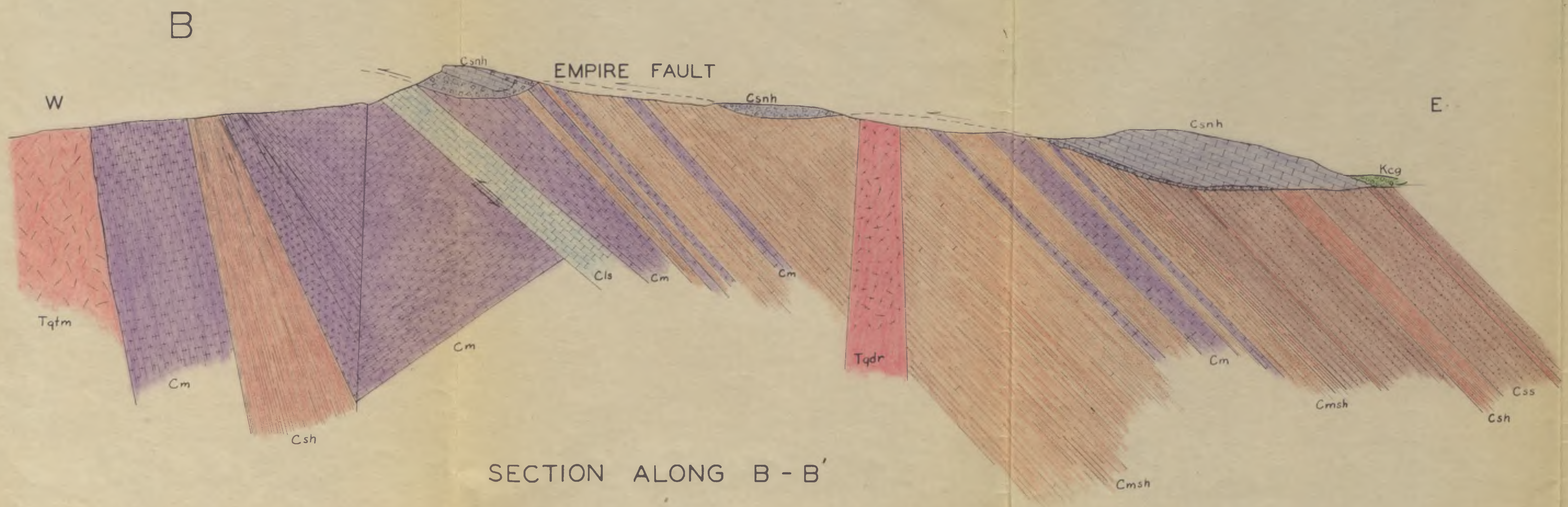
PLATE III

GEOLOGIC STRUCTURE SECTIONS

SCALE: ONE INCH = 250 FEET



SECTION ALONG A - A′



SECTION ALONG B - B′