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ARIZONA BUREAU OF MINES

GEOLOGY AND ORE DEPOSITS OF THE TOMBSTONE DISTRICT, ARIZONA

BY B. S. BUTLER, E. D. WILSON, AND C. A. RASOR

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PREFACE

Through the co-operation of the United States Geological Survey, the Arizona Bureau of Mines has been able to present this bulletin to the persons interested and to those who may become interested in further development of the old mining camp of Tombstone. If the Survey had not supplied the services of Dr. B. S. Butler and made available the data collected years ago by Dr. F. L. Ransome, the Bureau would have been unable to complete the project at this time. The Bureau is glad to acknowledge its indebtedness to the Survey for this splendid co-operation and for numerous courtesies extended in the past.

When a detailed investigation of an old mining camp is begun, it is always uncertain whether the report will be of any practical value. Too often such an investigation indicates that the ore deposits have been exhausted, and the report shows that further work in the camp is not justified by the conditions found.

Fortunately, that is not true of this report. The authors have demonstrated that the positions of the ore bodies are determined by definite structural conditions that are plainly set forth herein, and that numerous favorable areas remain unexplored. A good mining geologist who familiarizes himself with the geology of the district can, by following the suggestions offered in this bulletin, ascertain where new ore bodies are likely to be found, and it is confidently believed that the development of such ore bodies will eventually mean a great deal to the district and the state.

G. M. Butler

December 27, 1937.

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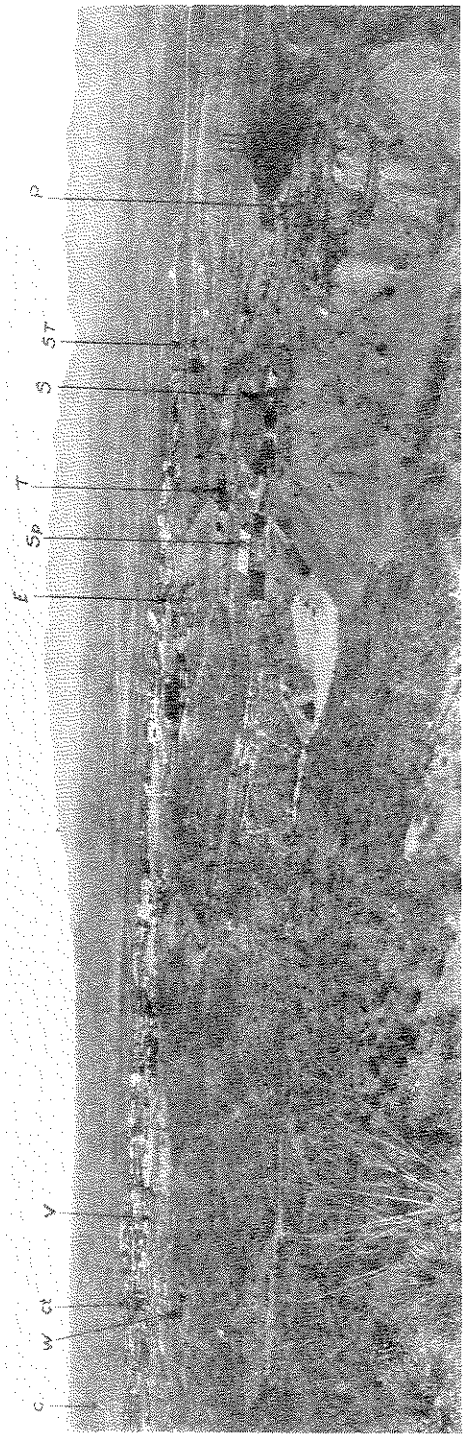

Plate I.—Looking east and north from Reservoir Hill at part of Tombstone district: *C*, Comstock Hill; *W*, West Side shaft; *Ct*, Court House; *V*, Vizina shaft; *E*, Empire shaft; *Sp*, Sulphuret shaft; *T*, Tranquility shaft; *S*, Sebring shaft; *ST*, Silver Thread shaft; *P*, Pump shaft. Dragoon Mountains in distance.

GEOLOGY AND ORE DEPOSITS OF THE TOMBSTONE DISTRICT, ARIZONA

INTRODUCTION

LOCATION, CULTURE, AND TRANSPORTATION

The Tombstone district (Fig. 1) is in western Cochise County, Arizona, 25 miles north of the international boundary. The area covered by the Tombstone special topographic map of the U.S. Geological Survey (Plate III) is bounded by meridians 110°02′ and 110°07′50″ W. and parallels 31°39″ and 31°43′30″ N.

Tombstone, the only settlement within the area, is on U.S. Highway 80, about 25 miles northwest of Bisbee. The old deserted mill town of Charleston is on the San Pedro River, 8 miles southwest of Tombstone and beyond the limits of the Tombstone special map.

The district is served by a standard-gauge branch line from Fairbank, a station on the Douglas loop of the Southern Pacific Railway, 7 miles west of Tombstone. For agricultural supplies, it has ready access to the farms of the San Pedro Valley.

PHYSICAL FEATURES

The Tombstone district is in the Tombstone Hills, a group of low, scattered mountains that extend northwestward from the Mule Mountains in which the Bisbee district is located. Tombstone is near the northwestern margin of the area, at an altitude of 4,530 feet or 670 feet above the San Pedro River at Fairbank. The Tombstone Hills rise to a maximum altitude of 5,339 feet or some 800 feet above the surrounding plain, which slopes westward to the San Pedro River. In the vicinity of the hills, this plain is a pediment, cut on hard rock.

Even slopes and rounded contours characterize the northern half of the area in contrast to the steep-sided, linear ridges that prevail in the southern half.

There are no perennial streams in the area. Drainage is westward to the San Pedro River through steep-sided gulches or arroyos that dissect the plain. Torrential rains flood these arroyos for short periods, but during most of the year no water flows at the surface.

Water is encountered in the mines of the eastern part of the district at an elevation of 4,120 feet above sea level. This mine water has been used for concentration of ores, but, according to analyses by H. V. Smith, of the University of Arizona, its fluorine content makes it unsuitable for drinking. Some water is obtained from shallow wells in the gulches, but the main supply for Tombstone is piped from springs in the Huachuca Mountains, about 25 miles southwest of the town.

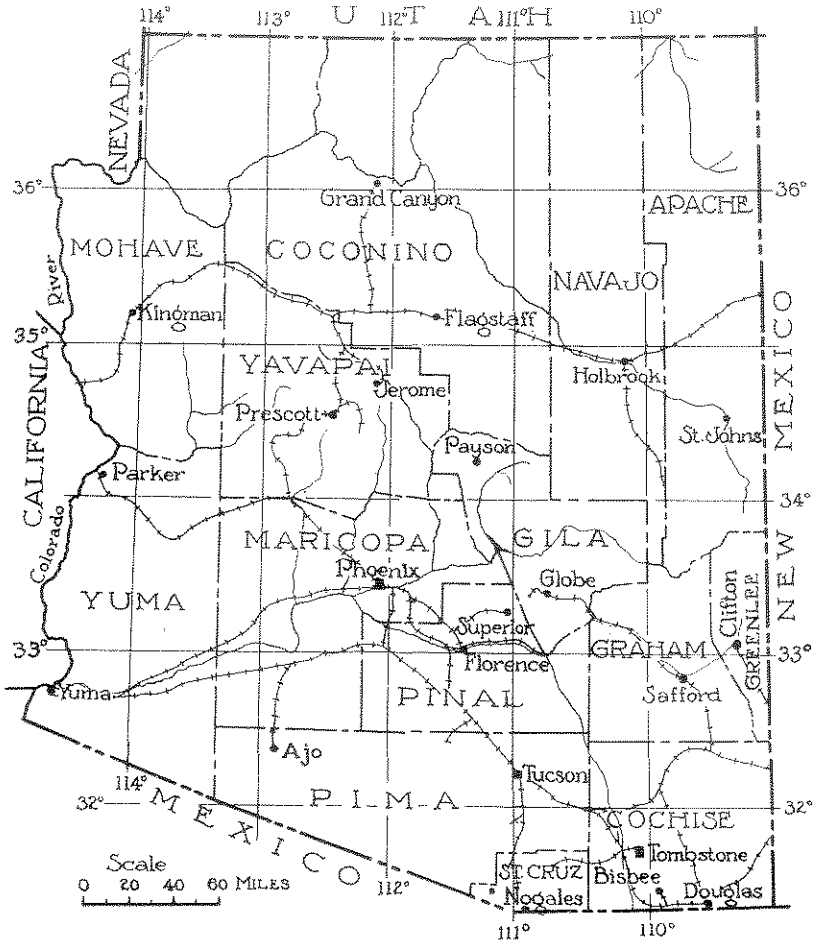

Figure 1.—Index map showing location of Tombstone district, Arizona.

CLIMATE AND VEGETATION

The climate of Tombstone is that of the intermediate altitudes of southern Arizona. The winters are characterized by moderate temperatures and only a few light falls of snow. In summer the days are hot, but the nights are comfortably cool. The average range in temperature for a twenty-seven-year period, prior to 1928,[1] was as follows:

[1] H. V. Smith, *The Climate of Arizona* (Univ. of Ariz., Agr. Exp. Sta., Bull. 130), 1930.

Month	Jan.	Feb.	Mar.	Apr.	May	June
Average extreme maximum	72.4	75	81.7	87.4	94.3	101.9
Average extreme minimum	20.8	24.8	28.6	33.8	40.8	50.4
Month	**July**	**Aug.**	**Sept.**	**Oct.**	**Nov.**	**Dec.**
Average extreme maximum	101	97	95.3	89.4	79	71
Average extreme minimum	58.7	58	51.6	37.9	29.8	22.6

The average annual precipitation for a thirty-one-year period prior to 1928 was 14.48 inches, distributed by months[2] as follows:

Month	Jan.	Feb.	Mar.	Apr.	May	June	
Average precipitation	0.84	0.87	0.79	0.34	0.24	0.46	
Month	**July**	**Aug.**	**Sept.**	**Oct.**	**Nov.**	**Dec.**	**Annual**
Average precipitation	3.52	3.41	1.69	0.66	0.78	0.88	14.48

As shown by this record, the main rainy season is from July to September, and the driest months are April, May, and June.

The vegetation of the district is likewise characteristic of the intermediate elevations of southern Arizona. It is above the altitudes favorable to abundant cacti and below those favorable to forest trees. Desert shrubs predominate. Cat's-claw and creosote or greasewood bush, together with some mesquite and ocotillo, form thickets on the foothill slopes and pediments. Several species of cacti are present, but prickly pear is most abundant. Mescal and yucca are sparingly present. Along gulches and arroyos mesquite, paloverde, and walnut are common. No trees in the district are suitable for lumber or for ordinary mine timber. On flats and slopes where soil and moisture are favorable, various grasses thrive.

PREVIOUS WORK

There are many references in the technical journals and the *U.S. Mineral Resources* to production and development in the Tombstone district, but few systematic descriptions of the geology and the occurrences of the ores have been published.

W. P. Blake[3] described the district in the early stages of its

[2] *Ibid.*
[3] "The Geology and Veins of Tombstone, Arizona" (Am. Inst. Min. Eng. Trans.), X (1882), 334-45.

development. J. A. Church[4] discussed the general geology and occurrence of the ores after the district was extensively developed.

F. L. Ransome[5] published a geologic map of the district and described the general geology with special reference to the occurrence of manganese ores.

In addition to the technical publications, the following books emphasize the history and human interest of this early mining camp of Arizona:

F. Becholdt,	*When the West Was Young*
Wm. M. Breckenridge,	*Helldorado*
W. N. Burns,	*Tombstone*
S. Lake,	*Wyatt Earp, Frontier Marshal*
A. H. Lewis,	*Wolfville Days*
L. D. Walters,	*Tombstone's Yesterday*
C. E. Willson,	*Mimes and Miners*

FIELD WORK AND ACKNOWLEDGMENTS

The Tombstone special topographic map, on a scale of 2,000 feet per inch and a contour interval of 50 feet, was prepared by R. H. Sargent of the U.S. Geological Survey in 1904-5. The Tombstone mining map, which covers the northeastern part of the district on a scale of 500 feet per inch and a contour interval of 10 feet, was prepared by E. R. Bartlett, also of the U.S. Geological Survey, in 1907.

F. L. Ransome, then of the U.S. Geological Survey, spent several months in the district at intervals during 1906, 1911, and 1912, making geologic maps of the surface and of part of the underground openings. Before Dr. Ransome had completed his work, however, other duties caused their postponement, and later he resigned from the Geological Survey.

The depression period following the "panic" of 1929, with the resultant decrease in copper production, resulted in increased interest in precious metal mining, and in consequence the U.S. Geological Survey and the Arizona Bureau of Mines in co-operation undertook the completion of the report started by Dr. Ransome. B. S. Butler for the Federal Survey and Eldred D. Wilson for the State Bureau worked in the district at intervals from September, 1934, to August, 1937. C. A. Rasor studied the mineralogy and petrography of the district for a doctorate dissertation submitted to the University of Arizona in 1937. The results of his work are incorporated, in part, in this report.

In 1936-37 James Gilluly, of the U.S. Geological Survey, mapped an extensive area including the Mule Mountains, the Tombstone Hills, and the southern part of the Dragoon Mountains. In this work he contributed to the mapping of the Tombstone area and also to the interpretation of the geological relations. He has

[4] "The Tombstone, Arizona, Mining District" (Am. Inst. Min. Eng. Trans.), XXXIII (1903), 3-37.

[5] "Deposits of Manganese Ore in Arizona" (U.S. Geol. Survey Bull. 710), 1920, pp. 96-103, 113-19, Pl. V.

generously allowed his work as related to the Tombstone area to be incorporated into this report.

During 1936-37 a group of engineers and geologists, including George M. Fowler, Joseph P. Lyden, Robt. Hernon, Neil O'Donnell, Chas. Higdon, and Walter Waidler, examined part of the area for the Eagle Picher Lead Company. Through the courtesy of Mr. Fowler, the writers were given access to many of the data thus collected.

The Tombstone Development Company and especially Ed. Holderness of that company furnished information, mine maps, assistance, and personal conveniences and donated numerous fine mineral specimens to the University of Arizona.

R. T. Walker and E. P. Jeanes of the United States Smelting, Refining, and Mining Company, C. M. d'Autremont and Harry Hasselgren, of the Tombstone Mining Company, Russell Kohlen, John Sebring, and the Giacoma brothers also generously gave information and mineral specimens.

J. H. Macia, former Superintendent of the Tombstone Consolidated Mines Company, was of great help to the writers and also to Dr. Ransome.

C. A. Rasor assisted in the mapping while obtaining data on the mineralogy of the district.

GENERAL GEOLOGY

GENERAL STATEMENT

The rocks involved in the structure of the Tombstone district range from pre-Cambrian to Quaternary in age. Their character and sequence are diagrammatically shown in the generalized columnar section of Plate II.

The oldest rock is fine-grained, greenish-gray schist, evidently pre-Cambrian and correlated with the Pinal schist of Bisbee. It is invaded by granitic and porphyritic rocks that have been tentatively regarded as pre-Cambrian, but may be younger.

Unconformably overlying the pre-Cambrian rocks is the Cambrian Bolsa quartzite, here about 440 feet thick. This is succeeded by the Cambrian Abrigo limestone, approximately 700 feet thick. Overlying the Abrigo with apparent conformity is the Devonian Martin limestone, about 340 feet thick, followed by the Mississippian Escabrosa limestone, estimated to be about 500 feet thick. It is not very distinctly separable from the overlying Naco limestone of Pennsylvanian and Permian age. As the upper limit of the Naco is a surface of erosion, the original thickness of this formation is unknown; its present maximum thickness exceeds 3,250 feet. The Naco limestone is intruded by a few dikes and sheets of quartzose porphyry, generally rather decomposed, that were probably erupted prior to the deposition of the Mesozoic sedimentary rocks.

Unconformably overlying the Naco is the Bisbee group, a series of conglomerate, sandstone, quartzite, shale, and limestone. These

beds, as shown by fossils in the limestone layers, are of Mesozoic, probably Comanche, age. The thickness of the Bisbee group is unknown, as no measurable section of the whole is available; it probably exceeds 3,000 feet.

After the deposition of the Tombstone formation, the rocks of the district were folded and faulted and, probably at the same time, were invaded by the mass of Uncle Sam quartz latite porphyry that crops out in the western part of the district. About the same time, but probably slightly later, they were intruded by an irregular body of granitic rock, the Schieffelin granodiorite. Southwest of the mapped area, near Charleston, the quartz latite porphyry is intruded into andesitic and rhyolitic extrusive rocks. It seems likely that the earliest volcanic activity was extrusion of lavas, followed by intrusion of quartz latite porphyry near the then existing surface, and this in turn was followed by intrusion of granodiorite.

After the intrusions, the district appears to have been subjected to long-continued erosion. Probably in late Tertiary time the low-lying parts of the district were covered by a fluvial deposit of rudely stratified, more or less firmly consolidated angular rock detritus with some layers of sand and silt. This material, which appears to be analogous in age and mode of deposition to the Gila conglomerate of central Arizona, occupies large areas in the broad valleys that separate the hills of the Tombstone district from the Huachuca, Whetstone, and Dragoon ranges. In most places it is overlain by a few feet of Quaternary gravel, sand, and silt. At least one basaltic eruption occurred during or after the accumulation of the valley fill, as shown in Walnut Gulch, about a mile northeast of Tombstone. Some faulting has taken place since the deposition of the valley fill, which has been deeply trenched by arroyos of the present erosion cycle.

PRE-CAMBRIAN ROCKS

The pre-Cambrian basement rocks of the Tombstone district are restricted in exposure to a narrow north-south belt west of the Summit of Ajax Hill, in the south-central part of the district. These rocks as a rule are rather decomposed and inconspicuous in outcrops. Consequently, and also because of their lack of known ore deposits, they entirely escaped the attention of Blake[6] and Church[7] who first described the geology of the district.

The Pinal schist is gray, fine-grained, brittle, and moderately fissile. Microscopic examination of a specimen from a shaft 0.7 mile south of Ajax Hill shows the rock to consist mostly of quartz and sericite with a very little biotite and green hornblende. Evidently it is a metamorphosed sedimentary rock.

[6] Wm. P. Blake, "The Geology and Veins of Tombstone, Arizona" (Am. Inst. Min. Eng. Trans.), X (1882), 334-45. "Tombstone and Its Mines" (New York, 1902). (A report to the Development Company of America.)

[7] John A. Church, "The Tombstone, Arizona, Mining District" (Am. Inst. Min. Eng. Trans.), XXXIII (1903), 3-37.

The granitic rock, which is best exposed on the west slope of Ajax Hill, beneath the Bolsa quartzite, is a granodiorite. Except at a few places close under the quartzite, the granodiorite is crumbly and decomposed. It is of medium grain, rather dark gray, and slightly gneissoidal. Under the microscope its principal constituent minerals are seen to be quartz, orthoclase, plagioclase, and biotite. The plagioclase, which is partly altered to sericite, is apparently a calcic oligoclase. The rock is classed as granodiorite, although chemical analysis might show it to be quartz monzonite.

As pointed out by Lindgren,[8] rocks of this composition are characteristic of the late Mesozoic or early Tertiary, rather than of the pre-Cambrian. The contacts of the granodiorite with the Cambrian Bolsa quartzite on the east and the Uncle Sam porphyry on the west do not reveal positive age relations. It has not been proved that the granodiorite is earlier than the Cambrian beds. As seen in a few shallow cuts, the lower contact of the Bolsa seems to be a fault plane rather than an erosional surface. Possibly the granodiorite of Ajax Hill is an intrusion akin to the Schieffelin granodiorite west of Tombstone (page 25), and its upper extent here was determined by a low-angle fault at or near the base of the quartzite. Its gneissoidal character may be due to flowage within the mass. A short distance southwest of the Oregon Mine, the granodiorite of Ajax Hill is separated from Naco limestone on the north by the Prompter reverse fault, which is believed to have been formed during the Laramide revolution between late Mesozoic and early Tertiary time.

The area of Pinal schist and granodiorite is traversed by a nearly north-south dike of a rock that is too decomposed for satisfactory determination, but which is provisionally termed granodiorite porphyry. Like the granodiorite of Ajax Hill, it is also of doubtful age.

CAMBRIAN ROCKS

Above the Pinal schist and the granodiorite is the Bolsa quartzite, about 440 feet thick. The actual base of the quartzite is very poorly exposed but where seen is marked by a layer of basal conglomerate generally about a foot thick. The formation consists of hard cross-bedded, fine-grained to pebbly quartzite in beds up to 6 feet in thickness, with small well-rounded pebbles up to the size of a pea common throughout. Its color on weathered surfaces is generally rusty brown.

Conformably overlying the quartzite is the Abrigo limestone, of which a complete section 700 feet thick is fairly well exposed east of Ajax Hill. It consists chiefly of thin-bedded, impure, and in part very cherty limestone, together with some beds of sandstone and shale. Sandy beds are more abundant in the upper than in the lower part of the formation. Some of them are flaggy

[8] Waldemar Lindgren, "Ore Deposits of the Jerome and Bradshaw Mountains Quadrangles, Arizona" (U.S. Geol. Survey Bull. 782), 1926, p. 22.

quartzite which contains thin streaks or layers of limestone and weathers rusty brown. At the top of the formation is a pure, vitreous, white quartzite, 4 to 5 feet thick, supposedly the same bed that marks its top at Bisbee. As at Bisbee, the Abrigo is sparingly fossiliferous.

Whether the Ordovician and Silurian are wholly without depositional record or are represented by some of the apparently unfossiliferous beds in the lower part of the Martin limestone is not known. The same hiatus in the record appears at Bisbee, in the Globe-Ray region, and at Jerome.[9]

DEVONIAN BEDS

The Martin limestone at its base, just above the white quartzite, consists of gray limestone with layers of soft gray shale. They probably are not over 10 feet thick and are succeeded by hard, dark gray limestone with a few intercalated sandy beds. As at Bisbee, the characteristic Devonian fossils occur in the upper half or upper two thirds of the formation. According to Dr. E. M. Kindle[10] the fauna is the same as that of the Martin limestone at Bisbee.

CARBONIFEROUS ROCKS

The Mississippian series of the Carboniferous is represented by the Escabrosa limestone which, like all of the rocks that precede it in the geologic section, is exposed in the south-central part of the district. It also crops out in the anticline in the east-central part.

Mississippian rocks crop out on the summit of Military Hill, the crest of the ridge for about a mile south of that hill, and irregular areas 1½ miles farther east. The formation consists of thick-bedded, light-gray limestone. Fossils are not very abundant, but a small collection from Military Hill was made up of species that occur in the Escabrosa limestone of Bisbee. No recognizable plane of separation appears between the Escabrosa limestone and the Naco limestone at Tombstone, and, as there is a considerable interval between the highest Mississippian and the lowest Pennsylvanian fossils, the line of separation as drawn in mapping is necessarily somewhat arbitrary. The thickness of the Escabrosa is taken as about 500 feet.

The overlying Pennsylvanian-Permian Naco limestone is in general thinner bedded and more compact than the Escabrosa. A few beds of hard pinkish limestone, as a rule fossiliferous, and of reddish, calcareous shale diversify the prevailing light-gray hue of the formation. Much of the upper part of the formation is dolomitic, as shown on pages 15-16. The Naco, in contrast to

[9] F. L. Ransome, "Some Paleozoic Sections in Arizona and Their Correlation" (U.S. Geol. Survey Prof. Paper 98), 1916, Pl. 25.
A. A. Stoyanow, "Correlation of Arizona Paleozoic Formations" (Bull. Geol. Soc. Amer.), XLVII (1936), 481.

[10] Written communication, March 11, 1912.

the older formations, is rather widespread as a surface rock in the Tombstone district. The largest occurrence is in the southeastern part of the district, where the beds as a whole are gently folded but are more closely compressed on the margins of the area. The limestone of Comstock Hill, northwest of Tombstone, is mapped as Naco, as is that west of the Lucky Cuss Mine and of an area east of the Three Brothers Hills. All of these smaller areas show considerable metamorphism due to the intrusion of Schieffelin granodiorite. The limestone southeast of Tombstone is cut by dikes and invaded by at least one sheet of rhyolite porphyry.

The following section of Naco limestone in the ridge 1 mile south of Ajax Hill was measured by James Gilluly and Edgar Bowles, of the U.S. Geological Survey.

Section of Naco Limestone South of Ajax Hill

Erosion surface overlain by Mesozoic conglomerate.

A. Dolomite member:

		Feet
1.	Limestone, thick-bedded, fine-grained, with a few pink beds that contain small silica nodules	103
2.	Limestone, blue to slightly green, interbedded with maroon dolomite. Thin-bedded, but some beds are up to 2 feet thick	26
3.	Alternation of dolomite and red to maroon shaly limestone and limy mudstone. The dolomite is somewhat sandy, in places conglomeratic, and forms ledges	159
4.	Dolomite, massive, red-brown and gray on fresh fracture, weathers brown-gray	14
5.	Concealed; probably maroon shale	6
6.	Dolomite, coarse-grained and massive, pink, weathers yellow-gray	25
7.	Alternating shale and dolomite, poorly exposed	10
8.	Dolomite, somewhat sandy. Massive, red-brown, weathers buff	8
9.	Red dolomitic breccia	2
10.	Concealed; probably shale and thin-bedded dolomite	26
11.	Dolomite, red-brown, weathers light cream to buff	6
12.	Mudstone, red, with fragments of dolomite. Exposures poor	33
13.	Dolomite, cream-colored, with mud cracks filled by red muddy breccia	5
14.	Concealed	8
15.	Limestone, massive, sandy bright red, weathers brown and buff	4
16.	Limestone, sandy, ranging to limy sandstone, with some thin dolomite and maroon shale. Very red. Poorly exposed, forms saddle	74
17.	Dolomite, beds 4 to 6 inches thick, weathers buff	58
18.	Sandstone, weathers yellow, forms saddle	11
19.	Dolomite, finely crystalline, black, weathers dark gray to yellow-gray and buff. Beds ½ to 2 feet thick. Carries many silica geodes and nodules 3 inches to 2 feet across	205
	(Total dolomite member 783)	

B. Black limestone member:

1.	Dolomite that blends into limestone	4
2.	Black limestone in beds 6 inches to 1 foot thick, thicker bedded toward the top. Sill of granite about 20 feet thick	173
3.	Same limestone as (2)	13
4.	Black limestone, massive, in beds 4 to 20 feet thick. Weathers gray	99
5.	Black limestone with some beds slightly yellow and dolomitic on top. Most beds less than 1 foot thick	74
6.	Black limestone in beds 2 to 12 feet thick. Some nodules and irregular masses of chert	81
7.	Black limestone, massive, weathers light to medium gray. Forms ledge	51
8.	Dense black limestone, slightly sandy. Somewhat shaly toward the top. Weathers dark gray. Beds 1 to 6 inches thick	30
9.	Like (8) but thicker-bedded	45
10.	Like (9) but with a few thin shaly and dolomitic layers in lower 40 feet. A little sandstone at top	59
	(Total black limestone 629)	

C. Orange dolomite member:

1.	Sandstone, pink and limy, weathering very dark brown	4½
2.	Concealed	5
3.	Dolomite, sandy, slightly cross-bedded near top. Pink, weathers brownish	3
4.	Sandy shale and dolomitic sandstone, poorly exposed	9
5.	Aphanitic limestone in beds ½ to 3 feet thick, weathering dark gray	13½
6.	Dolomite, dense, pinkish gray on fresh fracture, weathers orange. Slightly sandy	1
7.	Concealed	3½
8.	Dolomite, like (6)	4
9.	Limestone, mottled pink and gray. Forms conspicuous ridge	18
10.	Concealed; probably chiefly limestone with a little red shale	191
11.	Limestone, massive and pink, weathering gray	39
12.	Alternating red shale and pink limestone in layers of about 10 feet thickness	108
13.	Limestone, gray, mottled in places with red and orange. Beds 2 to 4 feet thick. Contains some thin shale beds and a shaly zone about 10 feet thick at base	53
14.	Limestone, gray to pink on fresh fracture, weathers light gray. Contains some nodular chert that weathers buff to red-brown. Beds average 1 foot in thickness	54
15.	Limestone, like (14) but with more chert. Beds 2 inches to 2 feet in thickness	100
16.	Thin-bedded, aphanitic, gray limestone, pink on fresh fracture. Very fossiliferous. Interbedded with a little red shale and sandy limestone	87
	(Total orange dolomite member 693½)	

D. Black limestone, weathering gray. Many crinoid stems. A little chert in 2- to 3-inch beds near top 58

E. Concealed by alluvium; unknown interval ..... ?

In the ridge east of Ajax Hill the following section was measured:

F. Dense light gray limestone, commonly mottled with pink on fresh fractures. Top not exposed ..... 1,100 approx.

Total Naco limestone ..... 3,263+

The upper portion of the Naco contains numerous large ore bodies. The Luck Sure and part of the Lucky Cuss deposits are in its upper dolomite, and the Oregon-Prompter bodies were in the limestone beneath the orange dolomite member.

The lower part of the Naco limestone is of Pennsylvanian age, and the upper portion, including the orange dolomite, black limestone, and dolomite members of Gilluly, is either Pennsylvanian or Permian. Regarding the age of the upper Naco, Dr. G. H. Girty, of the U.S. Geological Survey, wrote (November 18, 1936) as follows:

The Naco formation contains faunas of two distinctly different aspects and I understand that they occupy relatively higher and lower positions in the formation. The older fauna is related to that of the Magdalena limestone, the younger to that of the Hueco formation as now restricted.

To represent the younger fauna there is only one collection of sufficient size to be useful for purposes of correlation, and even so, the specimens are not in a good state of preservation, being rather coarsely silicified. They do not therefore show details of sculpture satisfactorily, a circumstance which is especially unfavorable to the identification of gastropods which constitute the major part of the fauna. The general character of the fauna is shown by the following list of this collection.

Faunal list of collection from 1¾ miles southeast of Military Hill, Tombstone District, Arizona.

Echinocrinus, several species
Productus ivesi Newberry var.
Composita subtilita Hall
Deltapecten vanvleeti Beede
Pleurotomaria? sp.
Bellerophon aff. Stevensianus McChesney
Euphemites subpapillosus White?
Omphalotrochus obtusispira Shumard
Turbo? sp.
Orthonema sp.

Two other collections contain some of the same species, but add little to the list that is significant. Mention may be made, however, of a small Rhynchonelloid resembling *Wellerella? Utah* Marcou, a Nucula resembling *N. anodontoides* Meek, a large Bellerophon resembling *B. mujusculus*, a Murchisonia resembling *M. terebra*, and a large Euomphalus. With regard to the species cited as Bellerophon aff. B. Stevensianus, the single specimen in the collection shows regularly arranged transverse imbrications, but it may also have fine revolving lirae, in which case it would be a rather large species of Bucanopsis. The facts are not clear.

Nearly all of the species mentioned above occur in the fauna of the Hueco formation, at least so far as the preservation permits the character of each to be determined. To this agreement there are two main exceptions, the form resembling *Productus ivesi* represented by two poor specimens and the form cited as *Pleurotomaria?* sp. which is rather abundant. Some of the species mentioned or species at present indistinguishable from them may occur in other faunas, but with no fauna is there so close a parallel, species by species, as with the Hueco fauna. As regards *Productus ivesi*, it is an outstanding species; it is almost characteristic of the Kaibab and San Andres faunas and it does not, seemingly, occur in the Hueco fauna. On the other hand, the large Omphalotrochus

is abundant in both the Hueco and Naco faunas and it seems to be highly characteristic of the Hueco fauna.

On the negative side, this Naco fauna, except for *Productus ivesi* var. is wholly unlike the fauna of the Kaibab limestone of Permian age and even more unlike the Guadalupian faunas. Some similar or identical species, however, occur in the faunas of the Manzano group.

If the upper Naco may be provisionally correlated with the Hueco formation its geologic age as Pennsylvanian or Permian is not definitely determined thereby for opinions differ as to the age of the Hueco formation, some writers referring it to the Permian, others, among them myself, to the Pennsylvanian. This does not seem to be a suitable place to argue the point.

MESOZOIC ROCKS

The name Bisbee group is in this report applied to a series of shale, sandstone, quartzite, conglomerate, and limestone that unconformably overlies the Naco limestone. These rocks occur within the district in two main areas. One, rudely circular and about 1¼ miles in diameter, lies south of Tombstone and contains many of the principal mines. A larger and very irregular area extends from the northwestern part of the district to and beyond the southwest corner of the area mapped in Plate III. This area in general lies between the large body of Uncle Sam porphyry on the west and granodiorite, pre-Cambrian, and Paleozoic rocks on the east. It contains the Randolph, Mamie, Bonanza, and other small mines that at one time were productive.

In most places the Bisbee group is not well exposed. It forms rather smooth, brown or rusty slopes that are littered with fragments of the harder beds. The most abundant rocks are sandstone, quartzite, red, brown, green, or black shale, and all gradations between shale or quartzite and impure limestone. Locally, metamorphism has not only converted the purer sandstone to quartzite but has produced abundant epidote in the calcareous sand or calcareous mud rocks and has converted some of the shale to brittle aphanitic hornstone or novaculite. The epidote is generally in little nests or aggregates which on exposed surfaces weather out so that the rock has a curious pitted appearance. In addition to the rocks mentioned, the formation contains some fairly pure limestone members. Lenticular beds of conglomerate, made up largely of pebbles of Carboniferous limestone and of siliceous rocks, are locally present in the lower portion.

Nowhere in the district is a complete section of the group available for study and measurement. Complexly folded, dislocated by faulting, and extensively metamorphosed by igneous intrusions, the Bisbee group has so far baffled attempts to discover the character and thickness of all its constituent parts, the total thickness of the whole, or its exact geologic age.

The following generalized section of the Bisbee group is a composite. Data for the lower 320 feet were obtained from mine workings, drill records, and surface exposures in the northern half of the Tombstone basin. The upper part is based upon measurements by J. P. Lyden, R. M. Hernon, Neil O'Donnell, and

C. E. Higdon in the Tombstone extension area, of the southeastern portion of the basin.

Generalized Composite Section of Bisbee Group

	Erosion surface	Feet
1.	Red to brown shale and brown to white quartzitic sandstone	1,040±
2.	Massive buff to gray quartzitic sandstone with some indurated shale	200
3.	Gray to green, hard siliceous shale with some sandstone	540
4.	Massive buff to white quartzitic sandstone with some shale and a few thin beds of limestone	422+
5.	Greenish and bluish shale with some conglomerate	58
6.	Massive blue to gray cherty limestone ("Joe" limestone)	20
7.	Varicolored shale	350
8.	Limestone bed	10
9.	Dark to greenish shale with some limestone	50
10.	Shale	55
11.	Limestone	4
12.	Gray, green, and black shale	80
13.	Yellow sandstone	10
14.	Reddish to black shale	80
15.	Blue-gray limestone with some shale	6
16.	Greenish to gray and brown shale with light-gray cherty beds	25-35
17.	Blue-gray fossiliferous limestone with some shale; lower 7 feet is massive limestone	10
18.	Gray to brown shale	25-35
19.	Blue limestone: blue-gray limestone, fossiliferous in upper portion	20-40
20.	"Novaculite": novaculite and fine-grained quartzite, with some limestone and limestone conglomerate in northern portion of Tombstone basin; in places contains lenses of conglomerate at or near base. Rests on Naco limestone	55-70
	Total	3,115+

The lower 55 to 70 feet of the Bisbee group constitutes a stratigraphic division that Ransome, in unpublished notes, termed "Novaculite." In the central part of the district it is referred to by the miners as the "white quartzite." Church,[11] who was the first to attempt a systematic account of the stratigraphy of the Tombstone district, refers to this division as the "Toughnut quartzite." His "Herschel quartzite," although he did not know it, is also the same division. This basal member is not a true quartzite and is far from homogeneous. In its least metamorphosed condition as exposed on the ridge southeast of U.S.L.M. No. 2, this member consists of hard, compact, banded epidotic shale interbedded with layers which on their rather rusty, weathered surfaces look like fine-grained quartzite, but in which the detrital quartz grains are cemented by calcite into a hard, tough rock. Such material grades rather irregularly across the bedding into dense, brittle rocks that closely resemble flint or true novaculite in texture. These rocks are light gray on fresh fracture, and, although so hard and flinty that they cannot be scratched with a knife, they effervesce with

[11] John A. Church, "The Tombstone, Arizona, Mining District" (Am. Inst. Min. Eng. Trans.), XXX (1903), 3-37.

acid, showing the presence of some calcite. They generally weather brown with a minutely, rough, sandy surface. Examined microscopically in thin section, the typical "Novaculite" is seen to consist largely of very fine, angular to rounded grains of detrital quartz together with considerable secondary quartz and abundant interstitial calcite. Associated with the novaculite are lenses of conglomerate in which nearly all of the rather angular pebbles are limestone. Most of these fragments, derived from the underlying Carboniferous limestone, are less than 6 inches in diameter, but some are 18 inches across. As the beds in this locality dip about 80 degrees southwest, they have been overturned and, although the conglomerate appears to have been deposited as small and relatively thick lenses in a generally fine-grained deposit of calcareous mud and sand, it is possible that the apparently lenticular character may be due, at least in part, to intense folding and compression. As seen underground in the mines near Tombstone the so-called "white quartzite" has evidently undergone more metamorphism than on Luck Sure Hill. Associated with material of novaculitic character is rock that would ordinarily be called a typical quartzite in which detrital quartz grains have been cemented by quartz. Such white granular quartz rock, however, in many places encloses residual masses of limestone or passes in the most irregular and disconcerting way into the dense novaculitic material or into limestone. The limestone conglomerates have been so altered as to be scarcely recognizable. They have become curiously blotchy rocks in which finely granular quartz, crystalline limestone, and vaguely bounded streaks or bunches of fibrous wollastonite are so combined as to make a rock that is unusually difficult to drill and break. Rock of this kind is exposed on the fourth level of the West Side Mine near the Girard shaft and is abundant in the West Side dump. Before pumping stopped, it could, according to Ransome, also be seen at many places in the lower levels of the Contention Mine. The lower part of the "Novaculite" contained large ore bodies, particularly in the Vizina, Quarry, and Girard rolls. Its middle portion has been productive notably in the Chino stope of the Quarry roll and in the Vizina roll.

Directly above the "Novaculite" is the Blue limestone, which contained some of the largest and richest ore bodies in the district. This member consists of 20 to 40 feet of medium to thin-bedded, blue-gray limestone that, where not metallized or otherwise metamorphosed, is very characteristic and readily recognizable. Not only is its color fairly distinctive, but its upper portion is in most places crowded with poorly preserved shells of a small undetermined species of oyster and of other genera. In the western part of the district, notably near the Randolph Mine and north of the Three Brothers Hills, are exposures of limestone similar to the Blue limestone near Tombstone and probably at about the same stratigraphic horizon. These exposures probably represent lenses, and they are not thought to have been actually continuous with the main Blue limestone that is exposed at the surface near the Toughnut and Ingersol mines and underground at many places in the maze of workings that extend from the surface near Tombstone down to the seventh level of the Contention Mine.

Overlying the Blue limestone is 25 to 35 feet of hard, brittle, gray to brown shale. Above this shale is a 10-foot member of blue-gray fossiliferous limestone with some shale. This member, which in the Tombstone basin is known as the "10-foot limestone," contained some important ore bodies. It closely resembles the Blue limestone in color and fossil content but can be readily distinguished by its stratigraphic sequence and relatively small thickness.

Overlying the 10-foot limestone is 25 to 35 feet of greenish to gray or brown shale with light-gray cherty beds. Above this shale is the "6-foot limestone" member, which consists of blue-gray limestone with some shale; in places it contained ore bodies.

Overlying the 6-foot limestone is a series, approximately 720 feet thick, of dark to light-colored shale, with some sandstone and a few beds of limestone (see section, page 19). Near the upper limit of this shaly series in the central Mesozoic area is a bed of gray, cherty limestone, generally about 20 feet thick, that has been traced on the surface from the Head Center claim just north of the Pump shaft of the Contention Mine, along the north slope of Reservoir and Hardup hills to near the Tribute shaft. Exposures are not continuous and in places the bed is plainly offset by faults. West of the Tribute Mine and on the west slope of Hardup Hill, what appears to be the same bed of limestone is much dislocated by faulting and is repeated in outcrop so that in traverses up and down the slope it may be crossed from two to four times. South of Hardup Hill, this limestone crops out almost continuously to a point about 900 feet northwest of the Bunker Hill Mine, where it is cut off by a fault.

Overlying the gray, cherty limestone and forming the upper portions of Hardup and Reservoir hills as well as the slopes near the southeast of the Contention Mine is a portion of the Bisbee group in which quartzite or hard quartzitic sandstone predominates (divisions 1 to 6 of section, page 19). Associated with it are beds of conglomerate, of impure, more or less metamorphosed limestone, and considerable red and green shale. These rocks are in many places rather conspicuously spotted with little segregations of epidote which weather out on exposure and leave the rock with a pitted surface. The total thickness of this member is not known. It probably is considerably over 1,800 feet.

The divisions of the Bisbee group just described have received local recognition in the mines near Tombstone and may be strictly applicable only to the central Mesozoic area—perhaps only to a part of that area. Farther west the rocks of the Bisbee group are in general less altered, the shale is less flinty, and sandstone takes the place of quartzite.

The geologic age of the Bisbee group is still rather uncertain. Fossils were collected from the Blue limestone at several localities

near Tombstone and from a lens of rather cherty, gray limestone, 2 to 3 feet thick, exposed 1½ miles southwest of Ajax Hill and about 375 feet southeast of the Huachuca Water Company's pipe line. All of the fossils collected were submitted to Dr. T. W. Stanton who reports that those from the Blue limestone are marine and are

evidently Mesozoic as they contain Ostreidae, but the fossils are very poorly preserved and do not include any recognizable characteristic forms which would indicate whether they should be referred to the Comanche series or to the Jurassic. The fact that the Comanche series is known to be present in the neighboring Bisbee district and that no marine Jurassic is recorded within a long distance make it more probable that they are of Comanche age. Comparisons have been made with Mr. Ransome's previous collections from the Bisbee district, but those collections do not include any from the Morita formation and there seem to be no identical species in the lots from the Mural limestone and higher formations from which fossils were obtained.

In various small collections made from the Blue limestone near the Toughnut shaft, just south of Tombstone, Dr. Stanton identified:

Ostrea sp.
Gryphaea sp.
Astarte (?) sp. a.
Astarte (?) sp. b.
Cyprina (?) sp.
Modiola (?) sp.

It will be noted that for only two of the forms was positive generic identification possible.

From the locality southwest of Ajax Hill Dr. Stanton recognized:

Planorbis veternus M. and H. (?)
Valvata scabrida M. and H. (?)

He states: "These are fresh-water shells and the two species to which they are provisionally referred occur only in the Morrision formation, the nearest locality at which they are known being Canyon City, Colorado. It should be said, however, that the Planorbis, which is the most abundant and best preserved form, does not differ greatly from a Tertiary species."[12]

The fresh-water shells in the Tombstone district are probably at a higher horizon stratigraphically than the marine fossils of the Blue limestone.

The Bisbee group of the Mule Mountains cannot be directly traced to the Tombstone district. The gap between the hills east of Sandy Bob Ranch where the Glance conglomerate passes below the alluvium at the most northerly point to which it can be traced from Bisbee and the low hills north of Government Draw where similar conglomerate appears is about 6 miles. There are many small outcrops of similar conglomerate between Government

[12] Written communication.

Draw and Tombstone. James Gilluly who has mapped this area believes that the conglomerate at the base of the Mesozoic section at Tombstone is the equivalent of the Glance, though it may be slightly younger inasmuch as the Comanche sea evidently overlapped this region from the south.[13]

The Mural limestone thins northward from Bisbee as far as it can be traced in the Mule Mountains, and it seems likely that it pinched out entirely, and the Cintura may have directly overlain the Morita with a few more miles to the north. The Cintura resembles the Morita very closely in lithology, and were it not for the intervening Mural limestone it is unlikely that the two formations would have been distinguished at Bisbee. The Mesozoic section above the basal conglomerate at Tombstone consists of rocks very like those of the Morita and Cintura, though the proportions of the several varieties cannot be closely matched. Mr. Gilluly therefore regards the Mesozoic rocks at Tombstone as equivalent to some part of the Bisbee group at Bisbee, an opinion that is shared by Dr. J. B. Reeside, Jr.,[14] who has examined the fossils in the field. Inasmuch as the several formations represented at Bisbee in the Bisbee group have not been discriminated at Tombstone, the Geological Survey classifies these rocks in the Tombstone Hills as the Bisbee group.

CENOZOIC DEPOSITS

The lower portions of the Tombstone district are mantled by deposits of more or less firmly consolidated gravel, sand, and silt. These deposits, which are locally termed "caliche," appear to be analogous to the Gila conglomerate. They are not deeply dissected in the district and consequently are not well exposed for study. Their material as a rule consists of very roughly bedded, rather coarse, more or less angular rock fragments and boulders from the neighboring hills. In some places the larger fragments are rather loosely held in a gravelly matrix; in other places they are firmly cemented by calcium carbonate.

The exposed thickness in the mapped area is not great, but the adjacent valleys are filled to an unknown depth by similar beds. A churn drill hole northeast of the town was discontinued in this material at a depth of 500 feet, which indicates a rather steep slope of the bedrock wall of the old valley.

A large part, at least, of the Gila conglomerate of Arizona has been shown to be of upper Pliocene age.[15] Kirk Bryan's original discovery of Pliocene fossils[16] within the formation was made a

[13] Written communication.

[14] Personal communication.

[15] M. M. Knetchel, "Geological Relations of the Gila Conglomerate in Southeastern Arizona," *Am. Jour. Sci.*, XXXI (1936), 81-92.

[16] J. W. Gidley, Preliminary report on fossil vertebrates of the San Pedro Valley, Arizona, with description of new species of Rodentia and Langomorpha: U.S. Geol. Survey Prof. Paper 131, pp. 119-31, 1922. "Fossil Proboscidea and Edentata of the San Pedro Valley, Arizona" (U.S. Geol. Survey Prof. Paper 140), 1925, pp. 83-95.

few miles north of Tombstone in beds beneath extensive pediments mantled by younger gravels.

In the Tombstone district only the upper portion of the formation is represented. In Emerald or Grand Gulch it is deformed by faulting (page 30), and in Walnut Gulch it is intruded by basaltic ring dikes (page 28). The formation is overlain in many places by a relatively thin alluvial cover of uncemented gravel, sand, and silt of Quaternary age.

POST-PALEOZOIC IGNEOUS ROCKS

Rhyolite porphyry

The Naco limestone and older rocks are cut by dikes and invaded by sheets of light-colored quartz-bearing porphyry. These intrusive rocks appear to have no connection with ore deposition. As they are generally more or less decomposed, it will be sufficiently accurate to characterize them in general as rhyolite porphyry.

Uncle Sam porphyry

Occupying an extensive area in the western part of the district and extending beyond the boundary of the area mapped (Plate III), westward toward Charleston, is a mass of rock that Blake and Church both called "rhyolite" and which Ransome also, in a brief report[17] on the manganese ores of the district, referred to as "rhyolite porphyry." Microscopic examination and chemical analysis (see page 25) show that this rock is not strictly a rhyolite but should be designated as quartz latite porphyry. It forms the Three Brothers and Uncle Sam hills and is the general country rock of the State of Maine, Merrimac, San Pedro, and Montezuma mines. In this report it is referred to as the Uncle Sam porphyry.

The Uncle Sam porphyry is buff or rusty brown where weathered but dark gray on fresh fractures. Its phenocrysts are small, generally less than a quarter of an inch in length, and are not conspicuous. The apparent order of decreasing abundance is feldspar, quartz, biotite, and hornblende. A characteristic feature of the rock is a blotchiness or unevenness of texture due to variations in the crystallinity of the groundmass. Under the microscope the porphyry shows a vitrophyric texture. The feldspars are plagioclase and range from andesine to labradorite; no potash feldspar was recognized. The quartz phenocrysts show the usual embayed outlines. Biotite, magnetite, a little hornblende, and small prisms of apatite are the other recognizable mineral constituents. The groundmass is a partly devitrified glass. A chemical analysis of the porphyry is given under 2, on page 25. It shows a rock more siliceous than the granodiorite, and with less alumina, iron oxides, magnesia, and lime. The quantity and relative proportion of the alkalies in the two rocks are almost identical.

[17] E. L. Jones, Jr., and F. L. Ransome, "Deposits of Manganese Ore in Arizona" U.S. Geol. Survey Bull. 710, 1920, p. 102 and Plate V.

The petrographic character of the porphyry suggests rapid crystallization. It is intrusive into the sandstone and shale of the Bisbee group west of Ajax Hill, and to the southwest toward Charleston it intrudes volcanic breccias and flows. The porphyry commonly shows numerous small inclusions of shale and other rocks, probably derived from the enclosing walls. It does not, however, appear to have brought about any pronounced contact metamorphism and the conclusion is that it represents the solidification of a magma that, at the time of solidification, had nearly reached the surface.

Schieffelin granodiorite

Granodiorite is exposed over an area about 2 miles wide that extends northwestward from the Lucky Cuss Mine, across Tombstone Gulch, and beyond the northern border of the area mapped as Plate III. Relatively weak in resistance to erosion, it forms a boulder-strewn pediment. It is termed the Schieffelin granodiorite from its typical occurrence in the vicinity of Schieffelin's monument, northwest of Tombstone.

The granodiorite has the general appearance of a rather fine-grained, light-gray granite and is locally known by that familiar rock name. In places it has a slightly reddish tint and passes into various porphyritic modifications along its contact with the sedimentary rocks into which it is intrusive. Under the microscope a typical specimen of the granodiorite from the roadside near Schieffelin's monument, a short distance north of the area included in Plate III, is seen to be composed of about equal quantities of plagioclase, ranging from andesine to labradorite, and orthoclase, with quartz, biotite, hornblende and a little colorless augite, magnetite, and apatite. A chemical analysis of this rock is given under column 1, in the following table:

CHEMICAL ANALYSES OF GRANODIORITE AND QUARTZ LATITE PORPHYRY, TOMBSTONE DISTRICT, ARIZONA (R. C. WELLS, ANALYST).

	1*	2†
SiO_2	62.33	68.04
Al_2O_3	16.92	15.82
Fe_2O_3	3.95	2.34
FeO	1.24	.84
MgO	1.97	.80
CaO	4.48	3.26
Na_2O	3.62	3.93
K_2O	3.36	3.32
H_2O, below 110°	.46	.37
H_2O, above 110°	.89	.77
TiO_2	.63	.42
ZrO_2	.02	none
CO_2	.04	.04
P_2O_5	.17	.15
S	.03	tr.

*Granodiorite, roadside by Schieffelin's monument, Tombstone district, Arizona.

†Quartz latite porphyry, 2½ miles west of Tombstone and ½ mile east of The Dome, Tombstone district, Arizona.

NiO	none	none
MnO	.07	.07
BaO	.10	.06
SrO	.10	.01
Li_2O	tr.	tr.
Cu	tr.	tr.
Zn	none	none
	100.38	100.24

The Schieffelin granodiorite mass, as indicated by the nature of its contact with Naco limestone and with beds belonging to the Bisbee group, east of The Dome, and by its contact with the Naco limestone west of the Lucky Cuss Mine, increases in size downward and would occupy a larger part of the area of the district were the general elevation of the surface reduced a few hundred feet by erosion; evidently it forms a stocklike body. During its intrusion and solidification it effected pronounced contact metamorphism, especially in the Naco and Blue limestones. Such metamorphism may be particularly well seen on Comstock Hill northwest of Tombstone and west of the Lucky Cuss Mine. In places the limestone is converted to marble; in other places there has been an extensive development of silicates in the limestone, particularly of vesuvianite, garnet, monoclinic pyroxene, and wollastonite. Wollastonite is particularly abundant in the metamorphosed Blue limestone and in some places has developed in association with sulphides at distances up to ¾ mile from any known exposure of the granodiorite. In addition to these more ordinary contact silicates there is an abundance of rarer complex hydrosilicates (see section on mineralogy).

As the Schieffelin granodiorite was nowhere found in contact with the Uncle Sam porphyry, there is no direct evidence of the relative age of these two rocks. A relatively coarse-grained rock similar to the granodiorite appears to be intrusive into the quartz latite porphyry in the flat south of the Three Brothers Hills, but its correlation with the granodiorite is not certain. Because of their similarity in chemical composition, the Schieffelin granodiorite and Uncle Sam porphyry are believed to have come from the same body of magma and to have been erupted at about the same time; probably the granodiorite was slightly the later. According to James Gilluly,[18] the Schieffelin granodiorite at Bronco Peak, a short distance west of the limits of Plate II, cuts off dikes that intrude the Uncle Sam porphyry, confirming this sequence.

Dikes

The central part of the Tombstone district is traversed by several dikes of granodiorite to dioritic composition. Although not noteworthy in their petrographic character, they are of exceptional interest because of their structural relation to ore deposition, their parallelism and persistency, and the manner in which some of them have been faulted. At least five such dikes

[18] Written communication.

traverse the central Mesozoic area with a general course of north 12 degrees east and a dip of 75 to 85 degrees west, except the Boss dike, which dips steeply eastward.

These dikes do not crop out prominently and as a rule are deeply altered. They are believed to have originated as a relatively later phase of the same magma that gave rise to the Schieffelin granodiorite and Uncle Sam porphyry.

Michigan Central dike.—The most easterly of these dikes passes through the Buffalo, Michigan Central, Cornell, and New Year claims. So far as known, no ore has been found in association with this dike and there are no extensive workings on it.

Grand Central-Contention-Empire dike.—About 1,000 feet west of the Michigan Central dike is the Grand Central or Contention dike, from which large quantities of ore have been mined. The most southerly outcrop of this dike is in a ravine on the Grand Dipper claim, 1,450 feet west-northwest of the Bunker Hill Mine. As the dike is traced northward through the south extension of the Grand Central and Sydney claims into the Naumkeag claim, it is seen (Plates IV and VII) to be offset successively to the east by cross faults. From the southern end of the Naumkeag northward through the Grand Central, Contention, Flora Morrison, Head Center, Yellowjacket, and Tranquility claims, it is displaced by curved faults that strike nearly parallel with the dike but which dip to the east. The effect of these faults has been to shift the upper portion of the dike to the east and, in places, to produce three or more nearly parallel outcrops of the same dike. All of the dike outcrops shown on the geological map (Plate IV) within the boundaries of the Grand Central, Contention, Flora Morrison, Head Center, and Yellowjacket claims are fault segments, and mining showed each of them to be cut off in its downward extension by a fault plane. The dike in place appears at the surface near the Tranquility shaft and can be traced northward through the Empire shaft to the point where it disappears under Gila conglomerate near the town of Tombstone.

Sulphuret dike.—About 400 feet west of the Grand Central dike is the narrower Sulphuret dike which can be traced from the margin of the Cenozoic gravels, on the Way Up claim just south of Tombstone, through the Little Wonder, Hawkeye, and Girard claims into the Sulphuret claim. A similar dike in nearly the same position relative to the Grand Central dike appears in the southern part of the central Mesozoic area, on the Sydney and Telephone claims, and probably occupies the same fissure as the Sulphuret dike. The actual presence of the dike itself, however, has not been established on the intervening Mayflower, Addie, Silver Dollar, Minuet, and Alps claims.

Boss dike.—From 500 to 700 feet west of the Sulphuret dike is the similar Boss dike which can be followed from the margin of the Cenozoic gravels south of Tombstone, through the Goodenough, Toughnut, Surveyor, Sulphuret, and Boss claims. The Toughnut and Boss shafts are both on this dike.

Tribute dike.—From 800 to 1,000 feet west of the Boss dike is the narrow but remarkably persistent Tribute dike which can be traced on the surface from the Vizina claim, just south of the railway station in Tombstone, through the Toughnut, Defense, Intervener, West Side, Tribute, Hard Up, Independence, C.O.D., and Luck Sure claims into the Prompter claim, where it is cut off by the Prompter fault.

Dike material that forms no persistent outcrop is present in the underground workings of the Lucky Cuss and Old Guard mines on a north-south fault.

Dikes in western part of district.—In the western part of the district numerous small dikes, generally less than 10 feet wide, invade the Bisbee group, Uncle Sam porphyry, and Schieffelin granodiorite. These dikes, some of which are mapped on Plate III, prevailingly strike northeastward, but a few show eastward trends. Most of them consist of a deeply altered, dark, greenish-black rock, probably of intermediate or ferromagnesian composition. Others, confined largely to the Uncle Sam porphyry area, appear to be rhyolitic or monzonitic.

Volcanic rocks

On the northwest side of the Huachuca Water Company's pipe line, about 2 miles southwest of Ajax Hill, is a small exposure of andesite breccia. This breccia is probably to be correlated with the far larger area of volcanic breccia exposed east of Charleston. The larger area is younger than the Bisbee group and probably of Tertiary age.

Basaltic rocks, probably of late Tertiary or Quaternary age, are present at two places in the district. Near the head of Grand Gulch, 1,100 feet northeast of the Bunker Hill Mine, a narrow dike of north-northeastward trend cuts the Bisbee group. This dike is of olivine basalt with numerous large phenocrysts of augite and a considerable percentage of magnetite. On the Gleeson Highway, ¾ mile northeast of Tombstone, an irregular mass of olivine basalt about ½ mile wide intrudes the valley fill. This mass appears to be of ring dike type, surrounding a core of altered, cemented conglomerate.

STRUCTURE

INTRODUCTION

The schistose character of the oldest rocks exposed in the Tombstone district indicates the operation of structural forces of first order in pre-Cambrian time, but the exposure of these rocks in the area is insufficient to reveal the pre-Cambrian structure. This oldest structure most probably influenced later structures.

The pre-Cambrian rocks had been deeply eroded and the surface reduced to a very mild relief, indicating a long period of quiescence, before the oldest Paleozoic sedimentary rocks were deposited.

This general quiescence seems to have continued throughout the Paleozoic, though the Tombstone area and most of southern Arizona were above sea level or were not receiving deposits through long periods of Ordovician, Silurian, and Early Devonian time. When marine deposition was resumed in Devonian time the sediments were laid down essentially in angular conformity with the Cambrian rocks. This conformity in attitude of beds continued to the close of the Paleozoic era.

The earliest rocks of Mesozoic age mark changed conditions of sedimentation from prevailingly marine limestone in the Paleozoic era to prevailingly conglomerate, sandstone, and shale in the Mesozoic, though some marine limestone was still deposited. This change in character of sediments was doubtless the result of structural changes. According to James Gilluly[19] the basal Mesozoic conglomerate rests upon variable horizons in the dolomite series of the Naco limestone, indicating an angular unconformity at the base of the Mesozoic.

At Bisbee, 25 miles southeast of Tombstone, Ransome[20] has shown that the Dividend fault with large displacement preceded the laying down of the Mesozoic rocks, and that the Paleozoic rocks were largely stripped from the upthrown side of the fault by erosion before the Mesozoic sediments were deposited.

Ransome[21] believed that the Sacramento Hill stock at Bisbee and the Juniper Flat stock north of Bisbee were intruded before the Mesozoic sedimentary rocks were deposited, but this conclusion as to the Sacramento stock has since been questioned.[22]

Earth movements and accompanying igneous activity are known to have been in progress in the Mesozoic in southern Arizona. They probably reached their climax in the Laramide revolution, between the close of the Mesozoic and the beginning of the Cenozoic eras but continued with decreasing vigor through the Tertiary period and perhaps even to the present. The structural history of the Tombstone district concerns the folding, faulting, igneous intrusion, and fissuring that took place principally during this revolution.

SEQUENCE OF STRUCTURAL EVENTS

A forerunner of the Laramide revolution in southern Arizona was volcanic activity in Mesozoic time, but this vulcanism was mild, if present, in the Tombstone area.

Next the Tombstone region was compressed in a general southwest-northeast to north-south direction with resulting folding of

[19] Written communication.

[20] F. L. Ransome, "The Geology and Ore Deposits of the Bisbee Quadrangle, Arizona" (U.S. Geol. Survey Prof. Paper 21), 1904; "Description of the Bisbee Quadrangle" (U.S. Geol. Survey, Geol. Atlas), revised 1914, folio 112.

[21] *Ibid.*

[22] J. B. Tenney, "The Bisbee Mining District" (16th Int. Geol. Cong., Guidebook 14), 1932; *Eng. & Min. Jour.*, CXXIII (1927), 837-41.

the rocks. Where the compression was great or the formations brittle, the rocks broke and slipped along the breaks, forming faults of steep dip. These folds and faults are prominent features of the Tombstone area.

Breaks with some displacement (dike fissures), at approximately right angles to the east-west folds and faults, were probably formed during the folding and faulting. The folding was followed by the intrusion of the igneous material that solidified to form the quartz latite porphyry and granodiorite bodies in the western part of the area and the dikes in the sedimentary rocks.

The principal intrusions were probably of one general period, within which the Schieffelin granodiorite is slightly later than the Uncle Sam porphyry. Some of the siliceous dikes in the Paleozoic rocks may have preceded the main period of intrusion, and basaltic dikes are present in the valley fill. The dikes show a considerable range in composition (pages 26, 28), and some dikes cut the larger intrusive bodies. Hence there was clearly an interval between the earlier and the later intrusions.

The dikes in general follow the trend of the earlier structures—namely, the north-south fissures and some of the east-west anticlines and faults. In the western part of the district, however, several dikes, some of which cut the larger intrusive bodies, have a northeasterly strike similar to the ore fissures. The Schieffelin granodiorite intrusive, which is bounded by Paleozoic beds on the south and Mesozoic rocks on the east and west, was for a part of its extent probably intruded along a north-south fault.

Following the emplacement of the larger intrusive bodies and the dikes, the region was broken by northeasterly trending fissures of very small displacement that cut all the rocks earlier than the Cenozoic gravels except some dikes that have the same trend as the fissures and were probably later. The northeasterly fissures were the main channels through which the mineralizing solutions were introduced.

Following the deposition of the ores, the eastern part of the district was cut by normal faults. Of these later normal faults, the best known are the Tranquility-Contention, of northeast to northward strike, and the Grand Central, of northwestward strike. The valley fill is displaced by a northward-trending fault that crosses Emerald Gulch 300 feet east of the Dipper shaft.

Basaltic rocks intruding the valley fill are exposed near Walnut Gulch northeast of Tombstone, and a basaltic dike probably of the same age is present in Grand Gulch, 1,100 feet northeast of the Bunker Hill shaft.

GENERALLY EAST-WEST STRUCTURES: AJAX HILL HORST

The Ajax Hill horst, named for the prominent hill near its western margin, is perhaps the most outstanding structural feature of the area. It is a block some 10,000 feet wide from north to south in its western part, bounded on its northern, southern, and western sides by faults. Along the northern or Prompter

fault, toward the western boundary of the block, Cambrian rocks abut against the upper part of the Naco limestone. Along the southern boundary pre-Cambrian rocks are in contact with the Naco limestone.

Along the western border, pre-Cambrian rocks, Bolsa quartzite, and Abrigo limestone lie against the Mesozoic rocks and the Uncle Sam quartz-latite-porphyry intrusive, indicating a fault with a vertical displacement of perhaps 6,500 feet or more.

Eastward the displacement decreases on both the north and south boundary faults, and Naco limestone forms both walls of the faults at the surface. In the western part of the block, the lower formations, from the pre-Cambrian to the Escabrosa limestone, strike nearly north-south and dip rather uniformly to the east at angles of 40 to 55 degrees. Near its western boundary the Naco limestone also has a similar attitude, but farther east the beds flatten, and folds with an east-west trend become prominent. Along the western border of the block, toward the northern boundary, the Bolsa quartzite and the Abrigo limestone dip westward as though turned down against the north-south fault. None of the boundary faults are simple breaks.

The northern or Prompter fault is of reverse type with a steep southerly dip. It consists of two main branches in its western part, with faults crossing between the main branches (Plates IV and VI).

The south boundary fault seems, in its western part, to be a simple normal fault with steep southerly dip, but eastward it sends off southeastward-trending branches that take up a large part of the throw. Its first and second branches bring Mesozoic conglomerate against upper Naco limestone.

The north-south fault that forms the western boundary of the block is poorly exposed. Its extension north of the north boundary fault brings Naco limestone against Mesozoic rocks, and, where exposed, it is of reverse type, with a dip of 70 degrees eastward. The extension of the north-south fault beyond the southern boundary fault is largely buried beneath surface wash. According to James Gilluly,[23] it crops out 1 mile south of Ajax Hill and also brings Naco limestone against the Mesozoic rocks. Where exposed along the main horst block the fault has a steep westward dip. Much of its displacement seems to be taken up by the north and south boundary faults.

These relations indicate that the displacement is due to a sharp eastward tilt of the western portion of the block. The synclinal axis of this fold is in Naco limestone where the easterly dips become flat or give place to low westerly dips, and the prevailing north-south structural trends give place to east-west trends. South of the Ajax horst the eastward tilting gives a sharp, eastward dip to the Naco limestone and a northerly trend to the structure. Eastward, however, the northerly trends give place to more easterly trends as in the Ajax horst.

[23] Written communication.

East of the main axis of tilting, the dominant structure is a series of rather open, east-west folds with accompanying faults.

The faults bounding the Ajax horst decrease in throw eastward, and their displacement in part is taken up by the folds of similar trend. It seems likely that movement on all of the faults bounding the Ajax horst was going on at the same time. The west boundary or north-south fault is offset to the west by the north boundary or Prompter fault and its several branches, which indicates very considerable movement on the north boundary fault after movement was well advanced on the west boundary fault.

THE TOMBSTONE BASIN

The Tombstone basin is north of the Ajax horst and includes the most productive portion of the Tombstone district. In its border features the Tombstone basin is an unsymmetrical synclinal fold that plunges southeasterly in its northern half and more easterly in its southern half.

The southern border adjacent to the Prompter fault is highly tilted Naco limestone and Mesozoic sedimentary rocks. Nearly vertical dips prevail in the Mesozoic rocks as far north as the Lucky Cuss and Grand Central gulches (see section, Plate V). Northward are open folds with variable dips.

The steeply dipping rocks swing northwestward through Luck Sure Hill and the Lucky Cuss Mine to form the western rim of the basin. The Naco limestone is exposed as far north as the Lucky Cuss Mine and may be largely cut out by the Schieffelin granodiorite intrusion to the north. Where the rim of the basin crosses Toughnut Gulch, basal Mesozoic rocks form the surface.

North of the basin the older rocks are covered by conglomerate and recent wash, and underground openings do not give much information about conditions there. Comstock Hill, northwest of Tombstone, is composed of highly metamorphosed rocks, probably the upper part of the Naco limestone, which suggests a rise of the rim from Toughnut Gulch.

Within the Tombstone basin the rocks have been folded into secondary anticlines and synclines with a general trend of N. 40 to 65 degrees W. They plunge gently southeastward in the northwestern part and more steeply in the southeastern part of the basin. They are best defined in the eastern part of the basin; in the western part they are more compressed and indefinite.

From northeast to southwest the folds have been designated, the Empire anticline, Sulphuret syncline, Sulphuret anticline, Boss terrace, Ingersol overturn, and Hardup syncline (Plate VI).

Excepting the Ingersol, which is closely oppressed and overturned southwestward, these folds are mostly rather open. The southwestern limbs of the anticlines are in general steeper than the northeastern limbs.

The Hardup syncline probably forms the lowest part of the basin and its northwestward extension forms the low part in the western rim near Toughnut Gulch. The Empire anticline is the highest part of the basin.

Rolls

Folds of a third order occur as corrugations on the secondary anticlines and synclines of the Tombstone basin. The anticlines of this order are locally termed "rolls," and within them are located many ore bodies. These third-order folds are more numerous on anticlines than on synclines and more numerous on steep anticlines than on more open anticlines. They have the features characteristic of drag folds produced by slipping of the beds during folding. Most of them are asymmetrical with a steep and a gentle limb. The steeper limb characteristically dips toward the axial plane of its superior anticline.

The shale and the relatively thin-bedded Blue limestone are folded into closer rolls than the massive Naco limestone. In general the rolls become sharper northwestward. Further details regarding the rolls are given on pages 84-97.

Bedding-plane faults

During the folding of the sedimentary beds, there was much slipping along bedding planes or along planes crossing the beds at a low angle. Such movements are designated bedding-plane faults.[24]

Bedding-plane faults are probably most numerous in the highly tilted rocks along the south rim of the Tombstone basin, but little is known of them there because of lack of adequate surface exposures or underground openings.

Faults of this general type are well shown in the steeply dipping rocks of the Lucky Cuss and Old Guard mines and the Oregon and Prompter mines. The Lucky Cuss fault occurs where the beds swing from a westerly to a northwesterly strike and flatten in dip. This fault cuts the beds at a low angle. There has been relative upward movement of the hanging wall which caused thickening or repetition of formations. Most of the movement was along the bedding and was a feature of the folding of the rocks. It may be classed as a bedding-plane fault though not strictly conforming to the bedding. The Oregon slip is a similar break in the steeply tilted rocks near the Prompter fault. (See description of Oregon and Prompter mines.)

Bedding faults associated with anticlines and rolls

Bedding faults are characteristically associated with the anticlines and rolls of the Tombstone basin.

As already indicated, the rolls have the characteristics of drag folds on the anticlines. The rocks, however, were not under sufficient pressure to flow, and the adjustments were made mainly by slipping along the beds or by bedding faults. The more common result of such faults is the apparent thinning or thickening of the formations. Thinning is characteristic of the steep limbs

[24] C. H. Behre, Jr., "Bedding Plane Faults and Their Economic Importance" (Am. Inst. Min. and Met. Eng.), *Mining Technology*, Jan., 1937, Vol. I.

of the rolls, and thickening is common in gently dipping limbs, sharp crests, and overturns.

Some of the larger faults of this character have displaced the rocks sufficiently to produce duplication of beds. Such faults characteristically dip toward the synclines, and the hanging wall has moved relatively upward. Essentially, they are drag folds that have broken and slipped toward the crest of the anticline.

Such faults have been found most numerous and with the largest movement in the rolls on the northeast limb of the Empire anticline where they duplicate the Blue limestone and "Novaculite" (see sections, Plate XXIV).

Tension fissures ("Hoodoo cracks")

Along the sharp crests of the rolls are fissures locally termed "Hoodoo cracks," which strike parallel with the rolls, dip steeply, and in places appreciably displace the beds. These breaks are present in varying degrees on all the rolls but are most numerous on the closer folds. They cut all the rocks but are most conspicuous in the "Novaculite" and limestones, particularly of the Quarry roll.

Saddle fissures

The sharp bending of the beds at the crests of the rolls has in many places produced openings parallel with the bedding that has added to the permeability of the top of the roll. This type of opening, where mineralized, produces the well-known saddle reefs.

The various types of fissures and faults produced in the folding of layered rocks has recently been discussed in detail by Behre[25] to whose paper those interested in further consideration are referred.

THRUST FAULTING

One half mile southwest of Ajax Hill is a block of Naco limestone, 3,000 feet long by 1,500 feet wide, completely surrounded by younger rocks (Plate III). On the northwest is a steep fault that brings Mesozoic rocks against the Naco limestone. The northeast and eastern boundaries are probably an intrusive contact. Along the southwestern boundary, which is a low-angle fault dipping 15 to 20 degrees SW., the Naco limestone rests on Mesozoic shale and sandstone. This contact has the appearance of a thrust fault but is not sufficiently exposed around the block to make the relations clear.

NORTH-SOUTH DIKE FISSURES AND FAULTS

Following the folding and faulting already described, the rocks were cut by a series of breaks that strike N. 10 to 15 degrees E. and generally dip 75 to 85 degrees W., except the Boss dike fault, which dips steeply eastward. Along most of these breaks there

[25] *Ibid.*

was little movement, but on the Empire dike fault the displacement amounted to more than 100 feet. The great north-south fault that bounds the Ajax horst on the west has this general attitude, and some, at least, of its displacement may have been of this period.

Into some of these breaks, aparently those on which there had been some displacement of the rocks, igneous material entered and solidified as dikes. In the Tombstone basin, from east to west, the Empire-Contention, Sulphuret, Boss, and Tribute dikes are the best known (Plates IV and VI). Dikes of similar trend are, however, present in other parts of the area and the dike-filled fissures represent but a small proportion of the fissures of this system.

EMPLACEMENT OF IGNEOUS BODIES

The main period of igneous intrusion closely followed or possibly in part accompanied the formation of the structures already described.

Igneous rocks occupy much of the western part of the area but are present only as dikes in the eastern part. The Uncle Sam quartz latite porphyry, which forms the surface over a large section of the western part of the quadrangle, seems to have been intruded largely as a stocklike body, but to the eastward it intruded the Bisbee group as sills or laccolithic bodies. In the State of Maine workings under Uncle Sam Hill, Mesozoic sedimentary rocks are present at essentially the level of those exposed on the surface 2,000 feet farther north and are probably continuous with them. This body of intrusive rock extends westward far beyond the boundaries of the area mapped. To the southwest it intrudes volcanic breccias and flows. A dike of the quartz latite porphyry appears to occupy the west boundary fault of the Ajax horst for a part of its extent, as well as some fissures in the Mesozoic rocks.

The Schieffelin granodiorite seems to have come in largely along the contact of Paleozoic and Mesozoic rocks and to occupy the northern extension of the great north-south fault. It extends as dikes and sills into the Paleozoic rocks of the Lucky Cuss Mine and of Comstock Hill.

In the eastern part of the district dikes occupy some of the north-south fissures, as described on pages 26-28, and east-west fissures or faults associated with the east-west folds.

It seems quite certain that the east-west folding, the major east-west faulting, and the north-south faulting, in large part preceded the introduction of the intrusive material, though there has been movement on all the faults since intrusion.

NORTHEAST ORE FISSURES

Fissures that strike N. 30 to 55 degrees E., cut all the rocks older than the Cenozoic gravels. These fissures prevailingly dip steeply southeastward in the Tombstone basin and northwestward in the western part of the district. The line of the great north-south

fault in general marks the boundary between southeasterly dipping fissures to the east and northwesterly dipping fissures to the west.

Most of the fissures, though by no means plane surfaces, nevertheless maintain rather uniform attitudes over long stretches. Fissure zones in which parallel fissures overlap, one fissure being strong where another is weak, are more persistent and regular than are the individual fissures. The notable exceptions to uniform strikes are where they cross dikes or faults.

The dikes and some of the faults strike at an acute angle to the ore fissures, and the ore fissures that meet them tend to warp into and follow them for a considerable distance before resuming their normal northeastward trend. This change in strike of the fissures in crossing the dikes and faults is similar to the refraction of fissures in passing from one formation to another, described by Knopf[26] for the Mother Lode veins. This relation of faults, dikes, and fissures is further complicated by later movement along the dike breaks. In general a fissure meeting a dike bends into the plane of the dike and crosses it at a lesser angle than it approaches it in the walls of the dike.

The stronger ore fissures within the Tombstone basin are rather uniformly spaced. Within the interval of 2,000 feet between the Intervener and the Arizona Queen fissures are eight large fissures rather uniformly spaced at intervals of about 300 feet (Plates IV and VI).

FAULTS OF UNCERTAIN AGE

The northeastern part of the area was broken by normal faults of which some have large displacement whose age is not certainly known.

Tranquility-Contention fault

The largest of these passes through the Silver Thread, Tranquility, Contention, and Grand Central workings. It is known as the Tranquility fault in its northern portion. With its southern continuation, it may be designated the Tranquility-Contention fault.

From the Silver Thread to the Tranquility Mine it strikes southwestward, nearly parallel to the Skip-shaft fissure but with considerably flatter southeasterly dip; the fault here dips 60 to 70 degrees, and the fissure 85 degrees SE. From a point near the Tranquility shaft the fault turns rather sharply and with eastward dip almost into the strike of the Empire-Contention-Grand Central dike which dips westward.

Northeast of the Tranquility shaft the displacement on the fault appears to be confined to a single zone 15 to 30 feet wide, whereas south of the Tranquility shaft it splits into several branches of similar easterly dip that successively drop the rocks down to the east. The Pump-shaft fault is such a branch.

[26] Adolph Knopf, "The Mother Lode System of California" (U.S. Geol. Survey Prof. Paper 157), 1929, p. 24.

The effect of the Tranquility fault system is to drop the hanging wall area to the east, perhaps as a single block in the northern part and as a series of slices or blocks in the southern part. The details of this fault so far as known are illustrated and discussed in the descriptions of the Contention-Grand Central ore zone.

The displacement on the fault is not known from direct measurement. Assuming that the Contention dike is a faulted portion of the Empire dike and that the movement was down dip, a displacement of 500 feet is calculated. The total displacement of the segments of the Contention dike, shown on Plate VIII, amounts to 590 feet.

Grand Central fault

Cutting the rocks in the southern portion of the Tombstone basin is a system of northwesterly striking faults of which the best known is the Grand Central fault. This fault offsets both dikes and fissures, but its age relation to the Tranquility-Contention fault is not known. Where the faults meet in the Little Joe workings, the rocks are greatly crushed, and there are not enough accessible openings to make a determination of the relations possible.

Date of the late faulting

The time of the late faulting is not definitely known. It was later than mineralization. On the Southern Belle claim, 300 feet east of the Dipper shaft, is a fault that lies in strike with the Tranquility-Contention fault, dips eastward, and displaces the Cenozoic deposits. It seems likely that a part, at least, of the movement on the Tranquility-Contention fault took place at the end of Tertiary or in early Quaternary time.

CAUSE AND RELATION OF STRUCTURAL FEATURES

The several structural features of the Tombstone district are perhaps the result of a single system of forces acting over a considerable period of time, but, if so, the character and direction of such forces have not been clearly determined or postulated. The earliest forces in the Laramide revolution seem to have been compressive and resulted in folding and reverse faulting. As judged by the nearly east-west Prompter reverse fault, the compression was in a north-south direction, but the folds in the Tombstone basin and in the southeastern part of the district indicate that the compression was in a northeast-southwest direction.

The early folding and reverse faulting were followed and perhaps in part accompanied by the nearly north-south fracturing. Displacement occurred on the stronger of these fractures, and the presence of dikes in some of them indicates that they were deep seated. They may be regarded as the results of shearing stresses that accompanied the folding.

The northeast ore fissures trend nearly at right angles to the folds in the Tombstone basin and are marked by very little displacement. They are more continuous as fissure zones than as individual fissures. These features suggest tension breaks rather than compression breaks.

The earlier structures might therefore have resulted from forces compressing the region in a southwest-northeast direction, with accompanying tension at right angles.

The later faults are normal, indicating extension rather than compression, and may be regarded as the result of the cessation of the compressive forces and the settling and readjustment of the region by gravity.

ORE DEPOSITS

HISTORY AND PRODUCTION

Summary

The Tombstone district proper was discovered by Ed. Schieffelin in 1877. By 1880 it was developed to large production with metallurgical plants on the San Pedro River.

By 1882 some of the mines had reached water level, and pumping was undertaken. The encountering of water in the mines led to the building of metallurgical plants at Tombstone and the abandonment of those on the San Pedro River.

By 1886 many of the large ore bodies had either been mined out or mined to water level, and production in the district fell off sharply.

During this early period to 1886 the district produced about one half of its total to the present. In 1881 and 1882 it yielded more than $5,000,000 worth of ore per year. From 1886 to the present the district has been a steady producer. Production has varied with conditions but has averaged more than a third of a million dollars per year. It was stimulated during the World War and subsequent years by the high price of manganese and silver and in recent years by the increased price of gold.

By 1900 many of the properties had been combined under one ownership, and during the next decade a serious attempt to develop the deposits below water level was made. This attempt did not prove profitable and was abandoned in 1911.

The value of metals produced to the close of 1936 is estimated at $37,000,000: $19,000,000 was produced from 1879 to 1886 and $18,000,000 from 1886 to 1936.

The accompanying table is a brief summary of the history of the district.

Detailed description[27]

Before its purchase from Mexico, the region that constitutes southern Arizona was largely controlled by Indians. Prospectors

[27] Based largely upon unpublished notes by J. B. Tenney and information furnished by J. H. Macia.

Period	Price of silver	Production	Remarks
1877-80	$1.15 -$1.20	$ 2,318,567	Discovery and early development. Mills built on San Pedro River.
1881-86	0.99 - 1.14	16,877,175	Active development and large production. Water encountered in mines in 1882, and mills built at Tombstone.
1887-96	0.63 - 1.05	4,564,650	Decreased production due to depletion of many of the large ore bodies above water level.
1897-1911	0.52 - 0.68	5,575,900	Consolidation of principal properties and attempted unwatering of district by a 1,000-foot pump shaft.
1912-14	0.553- 0.615	379,917	Lessee operations.
1915-17	0.507- 0.824	1,117,687	War period. Considerable production of manganiferous silver ore and concentrates.
1918-32	0.282- 1.12	5,150,789	Mainly lessee operations. Production of silver during 1918-22 stimulated by Pittman Act.
1933-36	0.35 - 0.77	1,118,325	Production stimulated by increased price of gold and silver.

did not venture far from the settlements that extended along the Santa Cruz and Colorado rivers for a hundred miles north of the present international boundary.

After the Mexican War and the Gadsden Purchase, American pioneers undertook more intensive exploration. In 1857 a mineral location about 5 miles west of the site of Tombstone was made by Frederick Brunckow, an engineer of the Sonora Exploring and Mining Company, of New York. He was later killed there by a Mexican employee. His old mine, commonly known as the "Bronco," was later relocated and finally patented as the Dean Richmond claim.

From the outbreak of the Civil War until the early seventies, no troops were left to guard against Apache and outlaw Mexican raids, and practically all mining and prospecting in the region ceased.

The Tombstone district proper was discovered in 1877 by Ed Schieffelin, a son of one of the forty-niners. An account furnished by Schieffelin to Bancroft for his history of the Pacific Coast is the basis for the following facts. Early in 1877, Schieffelin, after several years of fruitless prospecting in Nevada, Montana, and California, came to Arizona. As the Apaches, under Cochise, were then giving considerable trouble, he followed a troop of cavalry destined for Fort Huachuca, starting from San Bernardino, California, and traveling by way of Fort Mohave. He decided to go farther than Fort Huachuca and started alone down the San Pedro Valley. On this trip he visited the old Brunckow Mine, then owned by Tucson parties, and helped carry on its assessment work. He noticed the direction of the ledges, trending northeast, and made several trips along that trend to the site of Tombstone, where he found rich float. He finally staked the Tombstone and Graveyard claims on a small ledge of rich ore in the western part of the district and recorded them at Tucson, the county seat. As there was no assay office in Tucson at that time, the grade of the samples could not be determined, and Schieffelin was unable to raise money for further prospecting.

Maintaining faith in the value of his discovery, Schieffelin decided to find his brother Albert, whom he supposed to be at the Silver King Mine, 75 miles north of Tucson. With literally nothing but his pack outfit, gun, and ammunition, he journeyed to the Silver King but learned there that his brother had gone to the McCracken Mine at Signal, 165 miles farther northwest. After working at a mine near Globe to obtain money for an outfit, he continued on to Signal early in the winter of 1877. Albert and other miners there declared the Tombstone samples to be "leady" and of low grade, but Richard K. Gird, the company assayer, immediately recognized them as high grade and offered to go with the two brothers to prospect the ground. Ed demurred for several months, but, after the samples were assayed and proved to run from $40 to $2,000 per ton, he was persuaded to accept Gird as a partner and to return to the discovery. Gird financed an outfit, including some crude assay equipment, and the party started

with buckboard, saddle mules, and pack mules in February, 1878. As Gird was well known as a mining engineer and had been offered the superintendency of the McCracken Mine, his mysterious mission with the Schieffelins caused considerable comment.

The Schieffelins and Gird went directly to the "Bronco" cabin and started systematic work upon the Graveyard claim. As that locality proved to be disappointing, Ed prospected farther northeastward and, in two successive days, discovered the Lucky Cuss and Toughnut deposits.

Two other prospectors, Oliver Boyer and Henry D. Williams, arrived soon after the Schieffelin party and located the Grand Central ledge. Following a dispute with them regarding a share in its ownership, the Schieffelins and Gird relocated part of the Grand Central as the Contention claim. Shortly afterward, J. S. Smith, of San Francisco, bonded the Contention claim for $10,000, organized the Western Mining Company, and in the summer of 1878 started development work.

The fame of the rich discoveries brought many people to the camp. Among the earliest to arrive was E. B. Gage who bought the Grand Central claim and with C. D. Arms, N. Fairbank, Frank Struthers, and others, organized the Grand Central Mining Company.

Early in 1879, Governor A. P. K. Safford visited the camp from the capitol of the Territory, then at Tucson, and promptly offered to build a ten-stamp mill on the San Pedro River, the nearest water supply, for a quarter interest in the Toughnut claim. Together with Frank Corbin, of New Britain, Connecticut, he organized the Tombstone Mill and Mining Company and commissioned Gird to erect a stamp and amalgamating mill, which was completed in June, 1879.

Corbin then organized the Corbin Mill and Mining Company, and, for an interest in the Lucky Cuss claim, built a second mill of twenty stamps near the Gird Mill.

In March, 1880, the Schieffelin interest in the Tombstone Mill and Mining Company and the Corbin Mill and Mining Company was purchased for $600,000 by a syndicate of eastern capitalists consisting of the Corbin brothers, of New Britain, Connecticut; the Disstons, of Philadelphia; the Huling brothers, of Oil City, Pennsylvania; and Simmons and Squiers, of Boston. The two companies were merged as the Tombstone Mill and Mining Company. Gird retained his interest and for about a year was manager. When Gird later sold his interest for more than the Schieffelins had received for theirs, he divided with them. The three original locators thus realized handsomely on their discovery.

Ed Schieffelin remained in the Territory until 1882, when he went on a prospecting trip to Alaska. Returning in 1883 he married and settled in Alameda, California. He died in 1897 on a prospecting trip in Oregon. His remains were shipped to Tombstone and buried about a mile from the town, where a granite boulder monument was erected to his memory.

By the end of the year 1879, Tombstone was the most famous mining camp in the West, and capitalists, particularly from the newly exploited oil fields of Pennsylvania, were visiting it in great numbers. Several of them acquired claims from the Schieffelins, Gird, and other early pioneers.

T. E. Farrish and associates purchased the Head Center claim from Jerry Ackerson early in 1880. After developing the mine, they bought the Sunset ten-stamp mill on the San Pedro River in April, 1881. This company produced profitably until May, 1884.

In March, 1880, the Vizina claim, adjoining the Toughnut and covering part of the townsite of Tombstone, was purchased by H. Filkins of Bradford, Pennsylvania. The Vizina produced over a half million dollars' worth of ore in the three years of its active operation.

In 1880, the Boston and Arizona Smelting and Reduction Company, organized by Boston capitalists, erected a ten-stamp custom mill on the San Pedro River, about 4 miles below Charleston, at Emery City, to treat the ore of the Vizina and other small mines of the camp. Later, concentrating machinery and a patent roasting furnace were added. This plant stimulated production by furnishing an outlet to numerous small producers. In October, 1881, the company purchased the Stonewall (Oregon) Mine for $100,000 and mined on its own account, besides treating custom ore.

The Contention or Western Mining Company started building a mill in October, 1879, on the San Pedro about 2 miles below Fairbank. In 1880, the Grand Central Mining Company built their mill 1¼ miles below Fairbank. At the site of the Gird, Corbin, Boston, and Arizona mills, the settlement of Charleston was started. Several months later, Contention City grew up around the Contention mill.

The growth of the mining camp was rapid. In 1878, at the first miners' meeting, the district was christened Tombstone, from the first location. Schieffelin wrote that the name of the location was suggested to him by the soldiers at Fort Huachuca, who had said that he would find nothing but his tombstone. This name is retained in spite of many attempts to change it.

The *Arizona Weekly Star* of November 2, 1879, described Tombstone as a lively city of 1,000 to 1,500 people and Charleston as a town with a population of 600 to 800. The same issue of the *Star* stated that the incorporation petition of the city of Tombstone had been granted at a meeting of the Board of Supervisors of Pima County.

At the time of the discovery of the district, the Southern Pacific Railroad, building eastward from Los Angeles, had reached Casa Grande, which remained the terminal for several years. On March 20, 1880, the road was formally opened into Tucson and by the end of 1880 had reached the San Pedro River, where the town of Benson was started. In 1883 and 1884 the Santa Fe Railroad constructed a line from Benson to Fairbank, Nogales, and Guaymas. The Santa Fe holdings in the south were later bought by the Southern Pacific.

By the beginning of 1881, Tombstone, the largest city in Arizona, was reported to have 600 dwellings, two churches, schools with 100 pupils, and a population of 4,000. There were about 650 men working in the mines, and 150 in the mills at Charleston and Contention City. Most of the miners were American and Cornish. The wealth of Tombstone and the two mill towns had attracted numerous gamblers and undesirable characters from the old frontier towns in Kansas and Texas. There ensued stage robberies, cattle thieving, miscellaneous murders, and acts of outlawry, culminating in the Earp-Clanton feud. As the miners took very little part in the disturbances, the mines and mills continued operations without any serious interruption. By the end of 1882 the unruly element was subdued, and comparative quiet reigned. This period of lawlessness, spectacular though it was, has been given undue weight in popular belief. The effects, other than gaining a bad reputation with the rest of the country, were very slight.

The first water was encountered in July, 1881, at a depth of about 520 feet in the Sulphuret shaft. The seriousness of the water problem was not realized, however, until April, 1882, when the Grand Central shaft was stopped at water level. The first extensive pumping equipment of the camp was installed on this property. The pumps were of the old Cornish type. With one pump working at the Contention and one at the Grand Central shaft, some headway was made in sinking, but the flow proved too great for extensive drifting or stoping. Ore was proved to extend for at least 100 feet, and some stoping was done to a depth of about 50 feet below the water table. United pumping action was not achieved until many years later.

In 1881-82, after the finding of water in the mines, a Philadelphia company erected near Tombstone the twenty-stamp Girard mill which used water from the West Side Mine. This mill at first treated material from the Girard Mine, owned by the same company, but, as it proved to be below commercial grade, the mine was shut down in May, 1882. The mill continued to operate on low-grade Tranquility and other custom ores up to November, 1883. As expenditures exceeded receipts by $62,749, the company assets were sold by the sheriff to a Philadelphia syndicate. Early in 1884, after the new operators reopened the mine and developed a body of rich silver ore on the 200-foot level, the former owners redeemed the property.

The Benson Smelting and Refining Works was completed at Benson in October, 1881, for the treatment of silver-bearing lead ores. It operated until 1885.

In October, 1882, the Watervale Mill was completed near Tombstone. After a two months' run on custom ore it was closed.

In 1881, the old Corbin and Gird mills were modified and a small water-jacket furnace erected. Flux for this furnace was obtained from the manganese-silver ores of the Lucky Cuss and Luck Sure

mines, and some lead ore was supplied by the Hendricks and Atlanta claims, in Bisbee. As higher grade lead ore was found in the Toughnut Mine, the smelter discontinued buying lead ore.

The most productive year for the district was 1882, as shown in the table on page 49.

During 1883, production from the Contention and Grand Central mines was interrupted by the installation of pumping machinery. The Grand Central Company started developing the Emerald Mine, and the Tombstone Mill and Mining Company, which had not yet developed to water level, maintained normal ore extraction. During the year, operations were started on the Prompter and the Rattlesnake properties. The Prompter was financed by Arizona capital and operated by John Haley. The Rattlesnake Company, which owned the Rattlesnake, Bunker Hill, and Mammoth mines, shipped $10,000 worth of ore a month to custom plants. The Woronoco or San Diego Company built a 30-ton water-jacket furnace on its property 2 miles southeast of Tombstone, to treat silver-lead ore from the San Diego Mine and custom ores from the Luck Sure and other properties. The Way Up and Ingersol mines, operated by small companies and "chloriders," shipped ore to custom plants. A company did considerable development on the State of Maine vein and shipped a little high-grade ore from above the 200-foot level. The Head Center Mine continued production and operated its mill at Contention City during the year.

At the beginning of 1884 the prospects of the Tombstone district were very bright. The pumps were operating successfully, and ore was being developed below the water table at the Contention and Grand Central mines. Early in the year, however, the miners formed a union and struck for a raise from $3.00 to $4.00 a day. The strike was general, and all the mines closed, as the operators refused any advance until the pumping problems were more completely solved and additional ore proved below water level. The strike lasted four months, after which, the men voluntarily dissolved the union and returned to work at the old wage scale. All the companies except the Contention reopened their mines after the strike. During 1884 the Rattlesnake Company continued mining from the Rattlesnake and Bunker Hill mines. The Silver Thread Mine, which had been started in 1882, continued to ship high-grade ore to custom plants.

During the first half of 1885 the Contention and Grand Central companies attempted combined pumping, which was not completely successful. A large part of the Grand Central production came from the Emerald claim. In the latter part of the year the Tombstone Mill and Mining Company bought the Girard mill and treated all its ore, except stock-piled reserves, at Tombstone. The old Charleston mill was abandoned at the end of the year. The Boston mill had shut down at the end of 1884, leaving only the Grand Central mill operating on the San Pedro River at the end of 1886.

The year 1886 proved to be disastrous. In May the Grand Central hoisting house and pumping works burned, leaving only the Contention pumps to handle the water. The Contention Mine was closed during the early part of the year. The Head Center Company, reorganized as the Head Center and Tranquility Company, made a small production by treatment of tailings at the mill and developed additional ore. The Tombstone Mill and Mining Company operated only a part of the year and closed during the worst of the silver depression. The reorganized Bunker Hill Mining Company developed ore in the Bunker Hill Mine and built a five-stamp mill at Watervale where part of their ore was treated. The balance was shipped. Development continued at the Old Guard, State of Maine, and Silver Thread mines.

In 1887 only the Grand Central and Tombstone Mill and Mining Company mines produced. The Grand Central reported treating 14,500 tons, mostly from the Emerald, with a production in bullion and concentrates of $572,740, an average yield of $39.50 a ton. The Grand Central Mine closed in October, 1887, but the mill continued to operate for two years on tailings.

During 1888 the price of silver averaged 94 cents per ounce as compared with 98 cents in 1887. In July there were about 500 men at work in the camp, but by the end of the year their number had been reduced to 400. Water was encountered in the Emerald Mine at a depth of 700 feet, and no deeper stoping was attempted. The Tombstone Mill and Mining Company worked the West Side and Lucky Cuss mines during most of the year. The Vizina and Ground Hog mines were operated by lessees, who up to July treated their ore in the Fisher mill, the equipment for which had been moved from the Old Head Center plant on the San Pedro River. During the remainder of the year high-grade ore was shipped to custom plants at Socorro and elsewhere. The Bunker Hill Company sank a new vertical working shaft and shipped about 150 tons of high-grade ore per month.

The 1889 production came largely from the Bunker Hill Mine and lessees on the Vizina and Old Guard mines.

In 1890 the silver market showed marked improvement with an average price of $1.05 per ounce. Most of the mines resumed operations and shipped their better ore to reduction works but did not attempt to operate the mills. Freight concessions by railroads permitted more profitable operation. The Tombstone Mill and Mining Company, under the management of Geo. W. Cheyney, was the principal shipper. The Grand Central, Bunker Hill, and Vizina properties were also operated during the year.

The silver market continued strong during most of 1891, but the price declined to 87 cents in 1892, 78 cents in 1893, and 63 cents in 1894. The Emerald Mine was closed in 1892. The Comet Mine, which received a premium for its manganese ore, produced during 1893. The Tombstone Mill and Mining Company operated at a steadily reduced rate until the end of 1896, after which intermittent work was carried on by lessees. Most of the other mines had been turned over to lessees in 1892.

The Tombstone Mill and Mining Company ceased active operations in 1896. The value of its total production from 1879-96 amounted to approximately $10,550,000, of which $1,150,000 was paid in dividends prior to 1888.

For the remaining years of the century, lessees operated several mines, more notably the Tranquility, Silver Thread, and Telephone.

During the depression of the nineties, the Grand Central Company, through E. B. Gage, had gradually absorbed the principal independent holdings of the district. In 1901 the Tombstone Mill and Mining Company and Contention Company joined the Grand Central Company in a reorganization. The Tombstone Consolidated Mines Company was formed with Gage as manager, and the Development Company of America, which owned the Congress Mine and the Silverbell copper deposits, was induced to finance a program of pumping and prospecting below water level.

It was decided to sink a four-compartment pump shaft to a depth of 1,000 feet, install large pumps, and prospect the principal mines. The shaft reached water level in August, 1902, and large triple expansion Prescott steam pumps were lowered in November.

A branch of the El Paso and Southwestern Railway was built from Fairbank to Tombstone during 1902-3. Shaft sinking continued throughout 1903, and the old working levels of the Grand Central, Contention, Emerald, Lucky Cuss, Silver Thread, and other mines were reconditioned. Considerable ore was shipped to El Paso. By the end of the year, two 1,500-gallon pumps were installed on the 700-foot station, and 2,300,000 gallons of water a day were lifted.[28] The shaft was then sunk at the rate of 50 feet a month. The water in the outlying mines was lowered at the rate of 4½ feet a month. By the end of 1905, the shaft had reached a depth of 886 feet, and pumps were installed on the 800-foot level. A 125-ton cyanide mill was started during the year, and low-grade ore was stock-piled. Railroad lines were run to the principal shafts, and two or three carloads of silver-lead ore per day were shipped to El Paso. Independent companies started operating the Luck Sure, Old Guard, and Herschel mines, and the Slime Tailings Company attempted to treat the Grand Central mill tailings at Fairbank.

In 1906 the Pump shaft was completed to the 1,000-foot level, and drifting on that level was started. The mill, using stamps, Wilfley tables, slime cones, and cyanide tanks, ran the greater part of the year and attained a maximum capacity of 225 tons per day. The Old Glory Mining Company, operating the Luck Sure and Black Eagle mines, shipped ore regularly. The Herschel Mining Company developed to a depth of 325 feet and shipped two cars of ore per month to El Paso.

[28] The amount of water pumped during subsequent operations is shown on page 108.

In 1907 the Tombstone Consolidated Mines Company and the Herschel Mining Company continued regular shipments, and the concentrator operated during most of the year. The Old Glory Mining Company closed in December.

In 1908 the Tombstone Consolidated Mines Company produced lead and zinc concentrates beside silver and gold bullion. The Herschel Mine continued production.

The year 1909 proved to be disastrous. On June 1, due to a defect in the fuel supply for the boilers, the 1,000-foot-level pumps were submerged. Despite efforts to retrieve them by the aid of eight sinkers, the water raised to the 900-foot level. Due to overload, the six boilers of the power plant went out of commission simultaneously. Larger sinkers were installed, but the heat from the exhaust steam proved to be excessive, and in 1910 a 4,000-cubic-foot compressor was installed to run the sinkers by air. After installing new boilers, the pumps were recovered, and drifting on the 1,000-foot level was resumed by the end of the year. The amount of water pumped during this period is shown on page 108.

The concentrator was operated in 1909 and 1910, but in the latter year only lead-silver concentrates were made. The cyanide plant was not operated after 1908.

In 1909 the Phelps Dodge Corporation acquired the Bunker Hill Mine and shipped ore from it during 1909 and 1910.

As the extraordinary operating expenses proved too great for the Development Company of America,[29] pumping was discontinued on January 19, 1911. The pumps on the 1,000-, 800-, 700-, and 600-foot levels were left on the stations, where they remain to this day.

After unsuccessful attempts to refinance the Development Company of America in 1911, the mines were turned over to lessees who reworked the old dumps and upper-level stopes.

The Phelps Dodge Corporation, which had been one of the principal creditors, acquired the holdings of the Tombstone Consolidated Mines Company in June, 1914, and carried on operations at Tombstone under the name of the Bunker Hill Mines Company. This company made no attempt to regain the lost pumps but, after thorough sampling, prospected for ore in the upper levels above water. Shipments on company account began at the end of the year.

In 1915 the thirty-stamp mill, remodeled from the old Tombstone Consolidated concentrator, operated with cyaniding by percolation of the sands and agitation of the slimes. High-grade manganese concentrates of ores from the Escondido, Lucky Cuss, Oregon, and Prompter mines were shipped as chemical ore, and tails containing 10 ounces of silver per ton were sent to the smelter at Douglas. During the year the Old Guard and Solstice mines were reopened and produced small quantities of ore.

[29] A summary of the activities and financing of the Development Company of America was published in the *Engineering and Mining Journal* of July 8, 1911.

During 1916 and 1917 the Bunker Hill Mines Company shipped a large tonnage of smelting ore and milled nearly 40,000 tons, producing bullion, lead concentrates, a little wulfenite concentrates, chemical manganese, and silver-manganese tails. The Silver Bar, Solstice, Randolph, and Old Guard also produced small amounts.

In April, 1918, the mill was closed and the mines of the Bunker Hill Company were turned over to lessees. Most of the production of the district from 1918 to 1932 was by lessees on this property. Intermittent operations were carried on at the Ingersol, Herschel, Mellgren, State of Maine, Sunset, Old Guard, and Rocky Bar properties. Most of the output was smelting ore. Small local mills treated old gob and dump material and a little ore. The Grand Central Mining Company, headed by Lewis Douglas and Harry Hendrickson, treated tailings from the old Grand Central mill in a 150-ton flotation plant at Fairbank from June, 1924, to September, 1926.

The Tombstone Extension Mine, which started production in 1930, was the largest producer of lead ore in Arizona during 1932-33 and second in 1934. It was operated by the American Smelting and Refining Company during fifteen months in 1933-34 and subsequently by its original owners, the Tombstone Mining Company, and by lessees.

In June, 1933, the holdings of the Phelps Dodge Corporation in the Tombstone district were taken over by the Tombstone Development Company, with Ed. Holderness as Superintendent. This company and its lessees have since carried on the most extensive operations of the district and, to the end of 1936, produced $830,644 worth of ore. From early 1934 to May, 1937, the U.S. Smelting, Refining, and Mining Company did considerable underground work in the northeastern part of the district, on claims leased from the Tombstone Development Company, and shipped some ore.

The increased price of gold has led to development in the part of the district highest in gold. It has also encouraged lessees to treat old stope fillings and dumps in small local mills.

Production summary

The production of the Tombstone district prior to 1908 is not accurately known. According to estimates by John A. Church,[30] who was superintendent of the Tombstone Mill and Mining Company, the yield up to the end of 1901 amounted to about $25,000,000. Unpublished figures and estimates compiled by J. B. Tenney from old company reports and other sources indicate that the total to the end of 1907 was approximately $28,400,000 distributed about as follows:

[30] John A. Church, "The Tombstone, Arizona, Mining District" (Am. Inst. Min. Eng. Trans.), XXXIII (1902), 34.

Year	Total value
1879-80	$ 2,318,567
1881	5,040,633
1882	5,202,876
1883	2,881,900
1884	1,380,788
1885	1,320,976
1886	1,050,000
1887	600,000
1888	600,000
1889	250,000
1890	600,000
1891	674,650
1892	490,000
1893	450,000
1894	300,000
1895	300,000
1896	300,000
1897-1901	1,539,610
1902-1906	2,550,000
1907	550,000
Total, 1879-1907	$28,400,000

As recorded in the *Mineral Resources of the United States*, the production from 1908-34, inclusive, was as follows:

Year	Tons	Gold (value)	Silver (ounces)	Copper (pounds)	Lead (pounds)	Zinc (pounds)	Total value
1908	51,266	$ 84,866	357,414	7,608	1,770,794	173,313	$ 357,818
1909	27,123	47,119	201,700	27,706	1,535,637	713,116	260,145
1910	4,619	21,947	116,520	31,163	305,876	.....	102,285
1911	8,797	44,554	224,098	68,209	982,010	.....	216,042
1912	7,405	28,177	158,377	27,723	617,820	.....	157,956
1913	5,760	25,415	126,392	10,657	334,923	36,503	120,189
1914	6,063	28,532	108,868	14,217	234,345	39,324	101,772
1915	9,003	25,135	100,115	36,075	164,136	63,386	97,780
1916	57,200	81,654	343,453	131,546	983,983	.....	411,592
1917	57,474	69,721	444,139	229,488	1,278,754	.....	608,315
1918	19,507	28,719	283,412	41,503	457,183	.....	354,892
1919	27,445	40,220	450,366	290,182	289,424	.....	613,943
1920	28,946	36,953	456,855	144,010	243,946	.....	560,939
1921	18,594	31,141	423,688	132,688	678,946	.....	502,498
1922	44,347	48,005	613,700	196,740	744,529	.....	729,214
1923	32,770	63,924	495,943	195,485	465,914	.....	531,947
1924	15,448	50,820	247,642	72,836	465,323	.....	263,508
1925	27,760	55,328	241,381	77,340	1,527,019	32,592	369,157
1926	47,708	61,796	220,579	113,476	1,970,986	.....	373,003
1927	31,196	64,757	159,944	68,876	900,178	.....	221,179
1928	24,172	47,471	164,161	135,643	247,316	.....	177,382
1929	15,601	34,530	99,423	86,793	843,817	.....	155,959
1930	8,734	38,746	74,937	32,903	936,862	.....	118,717
1931	15,623	45,555	101,504	62,440	476,814	.....	98,315
1932	5,067	10,030	48,021	24,810	1,166,700	.....	60,136
1933	7,016	36,836	100,323	27,875	1,744,270	.....	138,261
1934	3,701	129,529	296,737	70,512	2,400,324	.....	415,627
Total	608,345	$1,281,480	6,659,692	2,358,504	23,767,829	1,058,234	$8,138,571

Subsequent production, as stated by the Tombstone Development Company and the Tombstone Mining Company, has been as follows:

Year	Tons	Gold (value)	Silver (ozs.)	Copper (lbs.)	Lead (lbs.)	Total value
1935	12,907	$120,581	243,087	103,574	2,228,288	$343,680
1936	9,305	102,234	147,218	53,962	969,017	220,757

The total production by the district to the end of 1936 is, therefore, as follows:

1879-1907	$28,400,000
1908-1934	8,138,571
1935-1936	564,437
Grand total	$37,103,008

MINERALOGY[31]

General statement

A detailed study of the mineralogy of the Tombstone mining district has shown a large number and wide variety of minerals. In addition to the minerals of the copper mining districts of the state, a great variety of lead, silver, and zinc minerals is found together with manganese, tellurium, molybdenum, and vanadium minerals. Some of the minerals are exceedingly rare. Tombstone is the only place in Arizona from which tellurides have been described. The contact zone formed by the intrusion of the granodiorite stock into the Paleozoic limestones is a source of rare calcium silicate minerals.

The arrangement in Dana's *System of Mineralogy* is followed in the following discussion of the minerals. An alphabetical list of the minerals is given for general reference.

Actinolite
Alabandite
Allanite (orthite)
Andesine
Andradite
Anglesite
Apatite
Argentite
Aurichalcite
Augite
Azurite
Barite
Beaverite
Bindheimite
Biotite
Bornite
Bournonite
Brochantite
Bromyrite
Calamine (hemimorphite)
Calcite
Cerargyrite
Cerussite
Chalcocite
Chalcopyrite
Chlorite
Chrysocolla
Clinozoisite
Connellite
Copper (native)
Covellite
Cuprite
Descloizite
Diopside
Embolite
Emmonsite
Epidote
Ettringite
Famatinite
Fluorite
Galena
Gold (native)
Grossularite
Gypsum

[31] Abstracted from C. A. Rasor, "Mineralogy and Petrography of the Tombstone Mining District, Arizona," unpublished doctorate thesis, University of Arizona, 1937.

Hematite
Hessite
Hessonite (?)
Hetaerolite
Hillebrandite
Hollandite group (?)
Hornblende
Hydrozincite
Iddingsite
Idocrase (vesuvianite)
Jarosite
Kaolinite
Labradorite
Limonite
Magnetite
Malachite
Manganite
Merwinite (?)
Microcline
Monticellite
Mottramite (cuprodescloizite)
Muscovite
Olivine
Oligoclase
Opal
Orthoclase
Pigeonite
Plumbojarosite
Polianite
Psilomelane
Pyrite
Pyrolusite
Pyromorphite
Quartz
Rhodochrosite
Rosasite
Serpentine (chrysotile)
Silver (native)
Smithsonite
Sphene (titanite)
Sphalerite
Stromeyerite
Sulphur
Tellurium (native)
Tenorite
Tetrahedrite
Thaumasite
Tremolite
Vanadinite
Wollastonite
Wulfenite
Zircon
Zoisite

Native elements

Sulphur (*S*).—Resinous yellow sulphur, somewhat resembling yellow sphalerite, occurs replacing anglesite and galena from the Skip shaft fissure on the fourth level of the Empire Mine.

Tellurium (*Te*).—Microscopic blebs of a silver-white mineral in tellurium-bearing galena are thought to be native tellurium.

Gold (*Au*).—Gold was most abundant in the Grand Central, Contention, Flora Morrison, Yellowjacket, Head Center, and Tranquility mines, all situated along the Empire-Contention dike. The Tribute and Herschel mines also yielded considerable gold. Native gold occurs as thin flakes and foils on fractures in altered shales and dike rock and as flakes resting on masses of horn silver. Some of the kaolinized dike rocks show innumerable small scales of gold on fractured surfaces. Such occurrences of gold indicate that it was deposited from supergene solutions.

Assays of hypogene sulphides show gold in varying quantities depending on the kind of sulphide. Pyritic ore from the Sulphuret stope close to the Arizona Queen fissure assayed 0.04 ounce in gold. Galena-sphalerite ore from the same stope assayed 0.38 ounce. Clean galena ore from the Skip shaft fissure on the fourth level of the Empire Mine assayed 2.46 ounces in gold. Quartz-bournonite ore from another fissure on the fourth level of the Empire Mine assayed 1.50 ounces of gold. These assays show that more gold is associated with the later sulphides than with the earlier. Galena probably owes its high gold content to the presence of gold tellurides which have not been positively identified.

Silver (*Ag*).—Small specimens of gougy slickensided material from the Empire Mine are heavy with disseminated flakes of

bright native silver. The silver appears to have been somewhat flattened along the slip planes. From the Flora Morrison Mine small masses of fine wire silver cling tenaceously to iron-stained drusy quartz. Included or intergrown with the silver are occasional black specks of argentite or hessite.

A polished section of hessite shows microscopic quantities of native silver in cracks and along the contacts with other minerals, suggesting that the silver may have resulted from alteration of hessite. Native silver in the ores associated with the "roll deposits" is generally near the bottom of the stopes.

Assays of hypogene sulphides show the presence of silver in varying amounts depending on the kind of sulphide. The same samples that were assayed for gold give the following assay for silver: pyritic ore, 4.18 ounces; galena-sphalerite ore, 21.86 ounces; clean galena ore, 237.84 ounces; and quartz-bournonite ore, 87.38 ounces. The silver is believed to occur as hessite and argentiferous tetrahedrite.

Copper (Cu).—Microscopic particles of native copper are sparsely distributed in specimens of cuprite from the Toughnut Mine. The irregular grains are grouped near the centers of cuprite crystals rather than along the boundaries.

Sulphides

Galena (PbS).—Some remnants of galena remain in the oxidized ores of the "roll deposits" and of fissure veins. Commonly the galena is coarse grained, but that from the Tombstone Extension Mine is fine grained with a gneissic texture that is due to shearing along the fissure.

Microscopic examination of polished sections indicates that galena is one of the latest sulphides, as it has replaced pyrite, sphalerite, and tetrahedrite, and possibly chalcopyrite. In contact with pyrite it oxidizes readily to form lead sulphate along cleavage cracks and around unaltered pyrite grains. Copper solutions acting on galena yield covellite as a replacement along the boundary grains and as feathery laths in anglesite.

Argentite (Ag_2S).—Argentite occurs only in the oxidized ore and part of it has formed from the supergene alteration of argentiferous tetrahedrite, a fairly common mineral in most of the hypogene ores. Some of it may have formed by the oxidation of hessite. The black material fills small fractures and honeycombed spaces in the quartzose ore. A specimen that contained supergene sulphides, malachite, and earthy hematite from the Empire Mine showed, on a polished surface, argentite closely associated with stromeyerite and chalcocite. Microchemical tests on argentite gave a copper reaction. Schwartz[32] has shown that chalcocite is soluble in argentite up to 20 per cent, but above 20 per cent stromeyerite is formed.

[32] G. M. Schwartz, "Relations of Chalcocite-Stromeyerite-Argentite" *Econ. Geol.*, XXX (1935), 128-46.

Chalcocite (Cu_2S).—Chalcocite has formed by progressive oxidation from the hypogene sulphide, chalcopyrite. Polished sections that contain galena, tetrahedrite, chalcopyrite, and sphalerite show the oxidation of chalcopyrite first to bornite, then the bornite to chalcocite. Chalcocite is best known from the Toughnut Mine where it is associated with argentite and stromeyerite.

Stromeyerite ($Ag_2S{\cdot}Cu_2S$).—Stromeyerite was identified in ore from the Empire and Toughnut mines associated with supergene chalcocite, covellite, malachite, and earthy hematite. Mineral associations suggest that some stromeyerite is supergene in origin; it also appears to be the result of unmixing from solid solution of argentite and chalcocite. Schwartz[33] has shown that argentite cannot replace chalcocite, but that, instead, it is soluble in chalcocite up to 15 per cent; beyond that limit stromeyerite will form and replace chalcocite. Stromeyerite is also replaced by feathery laths of covellite. The amount of stromeyerite is small, but it is probably an important source of silver in the oxidized ores.

Sphalerite (ZnS).—Sphalerite was rather abundant in ores from the Silver Thread and Sulphuret mines. Ores from the Lucky Cuss and Toughnut mines show small amounts with other minerals. The sphalerite in the district ranges from reddish-brown resinous varieties to black varieties and is mainly coarsely crystalline.

Polished sections of sphalerite show that some of it contains microscopic blebs of chalcopyrite along the borders of crystals. Sphalerite is later than pyrite. It rarely replaces pyrite but fills in and around the fractured pyrite grains. Sphalerite has been replaced by tetrahedrite, chalcopyrite, and galena.

Ore that has been acted on by solutions shows sphalerite replaced by covellite, and on complete oxidation the zinc minerals formed include smithsonite, hemimorphite, aurichalcite, and zinc-bearing descloizites.

Alabandite (MnS).—Alabandite from the Lucky Cuss Mine was described by Moses and Luquer[34] in 1892. It was found along the footwall of the Lucky Cuss fault fissure in a pure white, crystalline limestone. Moses described the massive alabandite body as gradually merging into spar and then into sulphides of iron, zinc, and copper, with small amounts of alabandite. Church[35] says that alabandite was under a tongue of minette on the 350-foot level, mingled with galena and pyrite.

Specimens of alabandite recently found on the dump of the Lucky Cuss Mine showed much oxidation on the surface to brown and black coatings indistinguishable from the common manganese oxides. On fresh breaks the alabandite appeared as brilliant black disseminations in a gray carbonate. Polished sections of alabandite from Tombstone in the mineralogical collections at the University

[33] *Ibid.*
[34] A. J. Moses and L. McI. Luquer, "Alabandite from Tombstone" *School of Mines Quarterly*, XIII (1892), 236-39.
[35] J. A. Church, "The Tombstone, Arizona, Mining District" (Am. Inst. Min. Eng. Trans.), XXXIII (1903), 29.

of Arizona show the mineral nearly free of other sulphides except for numerous triangular inclusions of chalcopyrite near the borders against other minerals. This relationship is similar to that often found between sphalerite and chalcopyrite.

Covellite (CuS).—A common occurrence of covellite is as linings of boxwork structures formed by the removal of primary minerals, and in this form it is easily mistaken for sooty chalcocite. It extensively replaces chalcocite and to a subordinate degree, galena and anglesite.

Bornite (Cu_5FeS_4).—Bornite occurs in ore collected from the "West Side roll." The one specimen showing this mineral consists of massive, slightly fractured chalcopyrite with bornite irregularly replacing chalcopyrite along these fractures. Bornite in turn is replaced by chalcocite along these same fractures.

Chalcopyrite ($CuFeS_2$).—Chalcopyrite is the most abundant of the copper minerals but is more widely distributed than are some of the secondarily concentrated copper minerals. At the Contact Mine it is rather abundant with sphalerite, but in general chalcopyrite is sparingly distributed with tetrahedrite and bournonite, as in the siliceous ore of the Ingersol, Empire, and Toughnut mines.

Polished sections of ores show chalcopyrite replacing sphalerite and filling fractures in pyrite and tetrahedrite, also as rounded blebs and triangular inclusions in sphalerite and alabandite.

Pyrite (FeS_2).—Pyrite, the most widespread and abundant sulphide mineral, is commonly present as granular masses in quartz and as isolated crystals in shale and other rocks.

In the veins pyrite occurs either massive with sphalerite and galena or as small, disseminated crystals in dark-gray quartz without other sulphides.

An assay of the gold and silver content of pyritic ore from the Sulphuret stope showed 0.04 ounce of gold and 4.18 ounces of silver. This ore has not been microscopically examined.

Tellurides

Hessite (Ag_2Te).—Hessite was described from the West Side Mine, Tombstone, by Genth.[36] According to his description the mineral occurred as bands and as disseminations in quartz where it was associated with cerargyrite, gold, and an unidentified bluish to siskin green mineral. From selected material he gave the following chemical analysis:

	I	II
Te	37.34	37.05
Se	trace	trace
Ag	62.87	62.34
Pb	0.28	0.30
	100.49	99.69

A polished section of hessite, made from a collection of Flora Morrison ores at the University of Arizona, shows a homogeneous

[36] J. A. Genth, "Hessite from the West Side Mine, Arizona" (Am. Phil. Soc.), XXIV (1887), 36.

mineral with only the borders altering to, or being replaced by, native silver. Its association with white crystalline vein quartz suggests that the mineral is hypogene, but its relation to the other sulphides is not known.

Sulpho-salts

Bournonite ($Cu_2S{\cdot}2PbS{\cdot}Sb_2S_3$).—Bournonite, a rare copper-lead sulphantimonite, occurs sparingly with other copper-antimony minerals and is frequently mistaken for tetrahedrite, which it resembles. Its luster, more brilliant than that of tetrahedrite, may help to identify it in the hand specimen.

Tetrahedrite [$5Cu_2S{\cdot}2(Cu, Fe)S{\cdot}2Sb_2S_3$].—Tetrahedrite is widely distributed in the district. As the tetrahedrite ores are high in silver, the mineral is probably argentiferous. Specimen ore from the Toughnut Mine is reported[37] to assay 85 ounces of silver to the ton. It is said to have been abundant in the ores from the Lucky Cuss and Ingersol mines where it is associated with quartz, chalcopyrite, and galena. As seen in polished section, the tetrahedrite was intensely fractured before being replaced by galena.

Famatinite ($3Cu_2S{\cdot}Sb_2S_5$).—Famatinite was found in ores from the Ingersol and Toughnut mines but can be identified only by examination of polished sections under the microscope. It is a rare mineral and a minor constituent of the sulphides.

Haloids

Some of the richest ore of the district contained considerable horn silver. This has always been considered as cerargyrite, but a chemical analysis of material collected during this study indicates that bromyrite is probably more abundant.

Cerargyrite ($AgCl$).—The silver chloride, cerargyrite, may be present in considerable quantities in the oxidized ores, but it cannot be distinguished physically from the other silver haloids. Only by chemical analysis are they determined.

Embolite [$Ag(Br, Cl)$].—In unpublished notes, Dr. Ransome mentions embolite in the ores from the State of Maine Mine.

Bromyrite ($AgBr$).—The detection of bromine in the silver ores led to the chemical examination of some unusually well crystallized masses of dark green horn silver that have not changed color since they were collected from the Skip shaft fissure on the fourth level of the Empire Mine, April, 1935. A carefully separated sample of about 3 grams was submitted to the Chemistry Department of the University of Arizona for analysis. The following percentages were determined by R. Carrillo under the supervision of Dr. R. L. Nugent.

Cl	0.6
Br	38.9
I	2.6
Ag	56.7
	98.8

[37] E. P. Jeanes, personal communication.

The analysis shows the mineral to be bromyrite that contains small proportions of iodyrite and cerargyrite, probably isomorphously.

Bromyrite occurs as individual crystals as well as irregular scales throughout limonitic material. Some of the richest silver ore from the "roll deposits" contains bromyrite associated with an unidentified green ferric tellurite (?), native silver, cerussite, limonite, and native gold. The presence of tellurites or tellurates suggests that much of the silver has been derived from the alteration of the silver telluride, hessite. An interesting fact is the occurrence of bromyrite with free gold in the midst of the Empire-Contention dike supposedly many feet distant from the portions that carry quartz stringers. The source of so much bromine has not been determined.

Fluorite (CaF_2).—Fluorite is an abundant mineral locally in some silicified areas, especially in the Empire Mine. In the "Quarry roll" most of the fluorite is green, though some is purple. It commonly cements the brecciated and fractured novaculite. In the Empire Mine small but well-developed crystals of fluorite line many of the drusy cavities. Veins of fluorite are reported to occur southeast of the district, but in the central mineralized area it is a minor mineral. Fluorite is one of the earliest minerals deposited in the first stage of mineralization.

Oxides

Quartz (SiO_2).—Quartz is an important constituent of most of the igneous rocks, particularly the rhyolite porphyry, granodiorite, and quartz latite porphyry. It also makes up a large portion of the sandstones and quartzites of the sedimentary rocks.

Quartz is a conspicuous mineral in many of the lead-copper sulphantimonite veins. It is highly vitreous and white, and so abundant that, locally, this type of ore is called siliceous. Some veins contain comparatively little quartz, particularly the Skip shaft vein exposed in the Silver Thread, Empire, and Sulphuret mines. Along the flanks of the "roll deposits" quartz occurs in druses as small, clear terminated crystals formed by crystallization in open spaces.

Opal ($SiO_2 \cdot nH_2O$).—Opal fills small seams in the ore from the Lucky Cuss Mine. From its mineral associations it is believed to represent a very late stage of the hypogene mineralization.

Cuprite (Cu_2O).—Cuprite, an uncommon mineral in the district, was observed as bright-red cubes, associated with connellite, brochantite, and malachite, lining small cavities in ore from the Toughnut Mine. In polished sections the cuprite shows replacement by native copper.

Tenorite (CuO).—Pitchy black melanochalcite, a mixture of tenorite, chrysocolla, and malachite, occurs with other copper minerals in the oxidized zone.

Hematite (Fe_2O_3).—Specular hematite is a primary mineral in one of the veins exposed in the granodiorite intrusive a few hundred feet west of the Lucky Cuss Mine. It occurs as radiating crystal aggregates that have replaced the wall rock that contains garnet, epidote, and calcite.

The less well crystallized, earthy red ferric oxide is a constituent of parts of the oxidized ore bodies.

Magnetite (Fe_3O_4).—Magnetite is present chiefly in the dark-colored igneous rocks and occurs as dusted particles in the light-colored igneous rocks. It has not been found with minerals of the contact metamorphic type.

Hetaerolite ($ZnO \cdot Mn_2O_3$).—Hetaerolite, a rare zinc hausmannite, has been described from but two other localities in the United States—Franklin Hill, New Jersey,[38] and Leadville, Colorado.[39] Hetaerolite from Tombstone has been identified in polished section only, principally with the aid of etch and microchemical reactions. Under the microscope it occurs as irregular veinlets and stringers in manganite and an unidentified manganese oxide.

Polianite and pyrolusite (MnO_2).—Polianite and pyrolusite occur in quantities of economic importance in the Oregon-Prompter, Lucky Cuss, Telephone, and Bunker Hill mines, and in minor quantities in the Luck Sure, Comet, and Dry Hill mines. The distinction between the two minerals is based upon hardness. In hand specimens the coarser-grained manganese dioxide generally has the greater hardness and is taken for polianite. Polished specimens examined under the microscope show a grain pattern that is typical of polianite. Mixed with the polianite is more or less psilomelane which has replaced polianite along grain boundaries and fractures.

Pyrolusite is a soft, sooty mineral that is easily gouged with a needle and which generally occurs as fine-grained, highly dispersed aggregates and elongated streaks in a fibrous manganese oxide identified as manganite. It is later than manganite and seems to have replaced that mineral as radial prismatic aggregates. Psilomelane, siliceous material, iron oxides, manganite, and an unidentified manganese oxide of unknown composition occur with pyrolusite. This aggregate of minerals probably came from the porous and siliceous centers of the manganese oxide ore bodies.

Manganite ($Mn_2O_3 \cdot H_2O$).—The prismatic crystals arranged in parallel groups of needles and soft fibers that line many druses and cavities are probably manganite, but they may be pyrolusite pseudomorphs after manganite, due to dehydration. In polished sections a certain manganese oxide has been identified tentatively as manganite. This determination is not positive since the etch reactions on manganese oxides are so indefinite that it is difficult to identify some of them exactly. Manganite appears to be replaced by both pyrolusite and hetaerolite.

Limonite ($2Fe_2O_3 \cdot 3H_2O$).—Limonite, referred to as mixtures of hydrated iron oxides, is common throughout the district, but is

[38] C. Palache, "The Minerals of Franklin and Sterling Hill, Sussex County, New Jersey" (U.S. Geol. Survey Prof. Paper 180), 1935, pp. 48-49.

[39] W. E. Ford and W. M. Bradley, "On Hetaerolite from Leadville, Colorado" *Am. Jour. Sci.*, 4th ser., XXXV (1913), 600-604.

most abundant in the completely oxidized lead ore bodies. The soft, yellow mineral is persistently associated with cerussite, jarosite, plumbojarosite, and quartz. Limonite occurs mixed with manganese oxides from the ore bodies of the manganese mines. The iron has resulted from the oxidation of pyrite.

Psilomelane [H_4MnO_5(?)].—Psilomelane is regarded as a manganate, H_4MnO_5(?), with the H replaced by various elements, chiefly iron, barium, and potassium. At Tombstone psilomelane is the most abundant and widespread of the manganese minerals. It is present in the mixed oxides as hard, compact masses, generally intergrown with polianite.

Carbonates

Calcite ($CaCO_3$).—Calcite is an abundant mineral in the district, occurring both as a hypogene and a supergene mineral in the ore deposits; as a primary constituent of the limestones; and as an alteration mineral of the igneous dikes and larger intrusives. As an early hypogene mineral in the ores from the Silver Thread, Sulphuret, and Northwest mines, it is generally coarsely crystalline and white. In the stopes of the "Quarry roll" it replaces fluorite. Coarser granular pyrite, sphalerite, and galena are the sulphides commonly associated with calcite.

Supergene calcite was deposited throughout the oxidation of the ores, but it is believed that the colorless and pure white calcite that forms coarsely crystalline aggregates and fills drusy cavities and "water courses" was a late deposition and probably is the latest mineral deposited. This type of calcite is common along the flanks of the "roll deposits" in caverns and water courses. Goodale[40] mentions that caverns in the widest parts of the manganese ore bodies were lined with snow-white, crystalline calcite.

A variety called "black calcite" also has two modes of formation: that believed to be supergene which occurs in caverns and water courses, and that believed to be hypogene which occurs in veins like the white variety. Thin sections of this hypogene black calcite indicate that the coloring is due to disseminated minute particles of manganese oxide replacing the calcite along the cleavage planes. Supergene black calcite owes its color to small rounded and angular particles of manganese oxide. The origin and relation of some of the calcite is uncertain.

Rhodochrosite ($MnCO_3$).—Rhodochrosite of hypogene origin has not been identified. In some of the oxidized alabandite ore from the Lucky Cuss Mine small grains of a reddish-brown carbonate were identified as supergene rhodochrosite after alabandite.

Smithsonite ($ZnCO_3$).—Smithsonite does not occur in sufficient amounts to constitute an ore of zinc. The few tiny rhombohedral crystals of smithsonite associated with crystals of azurite and hemimorphite from the Toughnut and West Side mines are only of mineralogic interest.

[40] C. W. Goodale, "The Occurrence and Treatment of the Argentiferous Manganese Ores of Tombstone District, Arizona" (Am. Inst. Min. Eng. Trans.), XVII (1889), 768.

Cerussite ($PbCO_3$).—All the large ore bodies mined during the early activities of Tombstone contained abundant cerussite mixed with iron oxides. Cerussite is still the most common lead mineral in the ores now being mined. Specimens of ore from the Tombstone Extension Mine retain centers of lead sulphide first altering to anglesite and then to cerussite. Most of the cerussite is associated with much limonitic material mixed with brown plumbojarosite, beaverite, wulfenite, and pyromorphite. Commonly the cerussite is granular and dark gray. A few small porcelain-white crystals were observed in drusy cavities.

Malachite [$CuCO_3 \cdot Cu(OH)_2$].—Malachite is sparingly present in all of the ore bodies that originally contained small amounts of copper-iron sulphide. The rosettes and radiating crystalline masses suggest that malachite was deposited from a bicarbonate solution rather than by replacing an earlier carbonate. These radiating masses commonly occur around the borders of ore bodies. In the Toughnut Mine, malachite fills fissures in chalcocite and small vugs in cuprite. Some malachite is believed to be pseudomorphic after brochantite where both are closely associated with cuprite.

Azurite [$2CuCO_3 \cdot Cu(OH)_2$].—Azurite is less common than malachite. Some specimens form dense earthy masses mixed with other copper and iron minerals. Other specimens show perfect crystals associated with smithsonite and hemimorphite. The Lucky Cuss and Toughnut mines furnished most of the specimens.

Rosasite [$(Cu, Zn)CO_3 \cdot (Cu, Zn)(OH)_2$].—A bright green mineral, commonly occurring in mamillary spherules from the Toughnut and Empire mines, has been tentatively identified as rosasite from physical and chemical properties. It occurs in the siliceous lining of quartz vugs and in the interstices between hemimorphite crystals.

Aurichalcite [$2(Zn, Cu)CO_3 \cdot 3(Zn, Cu)(OH)_2$].—Plumose aggregates of pale blue crystals of aurichalcite were collected from the west side of the Quarry roll. The specimens were taken from a small seam that also contained calcite, hemimorphite, and hydrozincite.

Hydrozincite [$ZnCO_3 \cdot 2Zn(OH)_2$].—Hydrozincite was identified with aurichalcite from the Quarry roll.

Silicates

Orthoclase ($K_2O \cdot Al_2O_3 \cdot 6SiO_2$).—Orthoclase is an important rock-forming mineral of the granodiorite stock, quartz-latite-porphyry stock, and rhyolite dikes and sills. It occurs as phenocrysts in the porphyritic rocks and as irregular grains in the granular rocks and the groundmass of the porphyritic rocks. A peculiar cloudiness is distinctive of the orthoclase in the granodiorite stock.

Microcline ($K_2O \cdot Al_2O_3 \cdot 6SiO_2$).—Microcline forms about 5 per cent of the granodiorite of Ajax Hill.

Plagioclase ($Na_2O \cdot Al_2O_3 \cdot 6SiO_2$—$CaO \cdot Al_2O_3 \cdot 2SiO_2$).—The rock-forming plagioclases range in composition from oligoclase to labradorite. Oligoclase and andesine occur as irregular grains and phenocrysts in the granodiorite, quartz latite porphyry, and in

light-colored dikes. Labradorite forms tabular and lath-shaped crystals in the diorite porphyry and basalts.

Pigeonite [$(Mg, Fe, Ca)O{\cdot}SiO_2$].—Pigeonite, a pyroxene, intermediate in composition between clinoenstatite and diopside, occurs somewhat abundantly as dark-green grains in the contact silicate zone exposed in the Lucky Cuss Mine. It is usually associated with abundant idocrase, calcite, and minor andradite.

Diopside ($CaO{\cdot}MgO{\cdot}2SiO_2$).—Small crystals of a pale green pyroxene (probably diopside) with clear vitreous luster occur in the contact zone of Comstock Hill.

Augite [$CaMg(SiO_3)_2$, $(Mg, Fe)(Al, Fe)_2SiO_6$].—Augite is an important constituent of the augite-diorite porphyries that traverse the district as narrow dikes. It also occurs as an important constituent of the basaltic rocks exposed northeast of Tombstone.

Wollastonite ($CaO{\cdot}SiO_2$).—Wollastonite occurs as radiating fibrous masses in the Silver Thread Mine with residual grains of quartz. The whole mass is partly replaced by sulphides of lead and zinc. Ransome, in unpublished notes, mentions wollastonite as occurring in the West Side Mine.

Tremolite ($2CaO{\cdot}5MgO{\cdot}8SiO_2{\cdot}H_2O$).—Tremolite occurs as long, fibrous masses that replace Blue limestone in the fourth level of the Toughnut Mine. It apparently was formed by the contact metamorphic effect of the Empire dike upon the Blue limestone.

Actinolite [$2CaO{\cdot}5(Mg, Fe)O{\cdot}8SiO_2{\cdot}H_2O$].—Actinolite occurs as reaction rims around altering augite crystals in the augite diorite porphyry. In most specimens of this porphyry the augite is completely altered to actinolite.

Hornblende [$Ca(Mg, Fe)_3{\cdot}Si_4O_{12}$].—Hornblende is a minor rock-forming mineral of the Schieffelin granodiorite stock. It occurs as long, prismatic crystals associated with biotite and orthoclase.

Grossularite ($3CaO{\cdot}Al_2O_3{\cdot}3SiO_2$).—Two varieties of calcium-aluminum garnet occur in the metamorphic zone. The more common of the two, the cinnamon-brown garnet, hessonite (?), is present in varying amounts in nearly all areas of contact alteration of the limestone. Some limestone beds on Comstock Hill are composed almost entirely of pure grossularite. At the Lucky Cuss Mine a fibrous undetermined calcium silicate and coarse crystalline calcite are intimately associated with grossularite. Also in the interstices of the crystals is a pale green mineral that appears to be merwinite.

Andradite ($3CaO{\cdot}Fe_2O_3{\cdot}3SiO_2$).—A few small black crystals of andradite were identified from the contact rocks exposed on Comstock Hill where it is associated with an amorphous, yellow-green mineral of undetermined composition.

Chrysolite (*olivine*) [$2(Mg, Fe)O{\cdot}SiO_2$].—Minerals of the chrysolite group are most abundant in the contact zone exposed at Comstock Hill and in the Lucky Cuss Mine, but they are also important constituents of the basaltic rocks.

Olivine is an important constituent of the basalts. It is an optically negative, iron-rich variety that alters to brown flakes of iddingsite.

Monticellite ($CaO{\cdot}MgO{\cdot}SiO_2$).—The comparatively rare calcium-bearing olivine, monticellite, occurs as narrow bands between bands of other silicate minerals on the fourth level of the Lucky Cuss Mine. It is distinguished by its light-gray color and greasy or vitreous luster. Closely associated with the monticellite are minor amounts of calcite, thaumasite, clinozoisite, and idocrase.

Idocrase (*vesuvianite*) [$Ca_6Al(OH, Fe)Al_2{\cdot}(SiO_4)_5$].—Idocrase (vesuvianite) has developed from the contact metamorphism of the limestone beds near the granodiorite intrusive. It is abundant in the contact zone of Comstock Hill where it occurs mainly as brownish to greenish crystalline masses. Excellent crystals of a deep-green variety occur with coarse, crystalline calcite in a bed on the north side of the hill. At the Lucky Cuss Mine it is associated with monticellite, grossularite, and the hydrothermal minerals, thaumasite and hillebrandite.

Zircon ($ZrSiO_4$).—Thin sections of many specimens of the light-colored intrusive rocks show microscopic grains of zircon, generally associated with plagioclase and biotite.

Zoisite ($4CaO{\cdot}Al_2O_3{\cdot}6SiO_2{\cdot}H_2O$).—Small grains of zoisite are observed in thin sections of the igneous rocks.

Clinozoisite ($CaO{\cdot}3Al_2O_3{\cdot}6SiO_2{\cdot}H_2O$).—Small grains of vitreous green mineral associated with idocrase, monticellite, thaumasite, and calcite were determined as clinozoisite from the indices of refraction.

Epidote [$HCa_2(Al, Fe)_3Si_3O_{13}$].—Epidote is a common mineral in the shale and quartzite of the upper portion of the Tombstone formation. Small amounts are present near the Lucky Cuss Mine associated with garnet and specularite, but it is not an important contact mineral in the district. It is also present in small amounts in the altered porphyry dike in the Contact Mine and in other igneous rocks.

Allanite.—Allanite, a complex silicate with small amounts of the cerium and yttrium metals, was identified in a thin section of the granodiorite stock.

Calamine (*hemimorphite*) ($2ZnO{\cdot}SiO_2{\cdot}H_2O$).—Calamine occurs sparingly in many of the ores that originally contained zinc sulphide. Small lumps of loosely coherent, colorless crystals were collected from the dumps of the Empire and Toughnut mines. It commonly occurs as radiating aggregates in drusy cavities and appears to have formed later than smithsonite.

Hillebrandite ($2CaO{\cdot}SiO_2{\cdot}H_2O$).—Tombstone is the second locality from which hillebrandite, a hydrous calcium silicate, has been recorded. It was first described by Wright[41] from Velardeña, Durango, Mexico, where it occurs with other unusual contact minerals such as gehlenite, spurrite, and merwinite. At Tombstone the mineral is associated with other silicates, chiefly monticellite. It was collected from the end of a drift directly west of the shaft on the

[41] F. E. Wright, "On Three Contact Minerals from Velardeña, Durango, Mexico," *Am. Jour. Sci.*, 4th ser., XXVI (1908), 545-54.

fourth level of the Lucky Cuss Mine. The snow-white color, faint silky luster, and delicate fibers are distinctive physical features. It seems identical with the mineral from the type locality. Positive identification was made by the indices of refraction.

Muscovite $[H_2KAl_3(SiO_4)_3]$.—Muscovite is present chiefly in the granodiorite on the west side of Ajax Hill. It occurs also as a contact mineral in the alteration and replacement of the limestone beds in the Lucky Cuss Mine. The fine, scaly variety, sericite, is commonly present in the hydrothermally altered rocks.

Biotite $[H_2K(Mg, Fe)_3(Al, Fe)(SiO_4)_3]$.—The dark mica, biotite, is one of the original constituents of the granodiorite. Under the influence of solutions it readily alters to chlorite.

Chlorite $[H_8(Mg, Fe)_5Al_2Si_3O_{18}]$.—Chlorite, an iron magnesium aluminum silicate of variable composition, occurs as a common alteration product of hornblende and biotite.

Serpentine $(3MgO{\cdot}2SiO_2{\cdot}2H_2O)$.—The fine, wooly, fibrous variety of serpentine called chrysotile is present on blue calcite from the fifth level of the Lucky Cuss Mine. Microscopic examination of limestones from the Lucky Cuss and Contact mines shows a fibrous serpentine replacing the limestone. Hydrothermal solutions are believed to have effected the pseudormorphic replacement of monticellite by serpentine. Serpentine associated with talc and calcite is abundant in the altered limestone in the south drifts of the Lucky Cuss Mine.

Iddingsite $(MgO{\cdot}FeO{\cdot}3SiO_2{\cdot}H_2O)$.—A thin section of the basaltic rock in the northeast part of the area shows iron-rich olivine altered completely to deep reddish-brown iddingsite.

Kaolinite $(Al_2O_3{\cdot}2SiO_2{\cdot}2H_2O)$.—Kaolinite (kaolin) is a common mineral in the Tombstone Extension and Toughnut mines where it has resulted from the alteration of aluminous minerals.

Chrysocolla $(CuSiO_3{\cdot}2H_2O)$.—Chrysocolla is widely distributed throughout the mines but is not abundant. It occurs chiefly with small quantities of the copper minerals, tenorite, malachite, and azurite, and with manganese and iron oxides.

Thaumasite $(CaO{\cdot}CO_2{\cdot}SO_3{\cdot}SiO_2{\cdot}15H_2O)$.—Thaumasite is a rare mineral that has been reported from but few localities. Butler[42] described it from the Old Hickory Mine, San Francisco region, Utah, where it occurs filling fissures that were formed later than the contact metamorphism. Foshag[43] has described another locality. He believes that thaumasite was derived from spurrite by the action of sulphated waters and was deposited as veins.

At Tombstone it was collected from the fourth level of the Lucky Cuss Mine where it fills small fissures and replaces altered limestone. Extensive collections were obtained from the dump. Some of the specimens indicate that thaumasite occurs as replacement veins that vary from 4 inches to microscopic widths. The thaumasite is believed to have resulted from the action of hypogene sulphated waters upon siliceous limestones or upon calcium silicates previously formed by contact metamorphism. Small amounts of barite from a near-by fissure and ettringite in an ore shoot in the white, crystalline limestone of the Lucky Cuss Mine just at the water level give other evidence of sulphates.

The snow-white, interlaced needles, the silky luster, and its lightness distinguish it from the altered and metamorphosed limestone and associated minerals, which include calcite, garnet, monticellite, and hillebrandite.

Sphene $(CaO{\cdot}TiO_2{\cdot}SiO_2)$.—Sphene (titanite) is an original constituent of the granodiorite and porphyries of the district. In these rocks it is associated with epidote, biotite, zircon, and apatite and has been detected only in thin sections.

[42] B. S. Butler and W. T. Schaller, "Thaumasite from Beaver County, Utah" *Am. Jour Sci.*, 4th ser., XXXI (1911), 131-34.
B. S. Butler, "Geology and Ore Deposits of the San Francisco Region, Utah" (U.S. Geol. Survey Prof. Paper 80), 1913, pp. 103-5.

[43] W. F. Foshag, "Thaumasite (and Spurrite) from Crestmore, California," *Am. Mineralogist*, V (1920), 80-81.

Phosphates

Apatite $[Ca(PO_4)_3(CaF)]$.—Apatite is an unimportant accessory mineral in many of the intrusive rocks but is not present in the augite diorite porphyries, the basalts, and the white rhyolite sills south of the Tombstone Extension Mine. It commonly occurs with epidote, chlorite, and magnetite near altered biotite grains.

Pyromorphite $(9PbO{\cdot}3P_2O_5{\cdot}PbCl_2)$.—Pyromorphite occurs rather abundantly as tiny crystals associated with much larger crystals of wulfenite in the outer borders of the oxidized lead deposits. The color ranges from white to grass green but is commonly bright lemon yellow.

Vanadates

Vanadates of lead, zinc, and copper have been identified from but few mines in the district. Specific determinations have been made on ores from the Tombstone Extension, Toughnut, Tribute, and Lucky Cuss mines. They are nowhere abundant and commonly form botryoidal crusts and minute crystals in drusy cavities.

Vanadinite $(9PbO{\cdot}3V_2O_5{\cdot}PbCl_2)$.—Vanadinite from the Tribute Mine forms white to gray, waxy, hexagonal prisms that rest on calcite. At the Tombstone Extension Mine small masses of tiny brown crystals fill a small fissure on the fourth level. Microscopic examination showed them resting on, and therefore later than, black resinous descloizite.

Descloizite $[4(Pb, Zn)O{\cdot}V_2O_5{\cdot}H_2O]$.—Descloizite has been identified from the Tombstone Extension Mine where it occurs in drusy cavities with vanadinite and from the Toughnut Mine where it occurs in honeycomb quartz. The color ranges through black and reddish brown to pale yellow and green.

Mottramite $[Pb(Cu, Zn)OH{\cdot}(VO_4)_3]$.—Mottramite (cuprodescloizite) from the Lucky Cuss Mine was first described by Hille-

brand.[44] He says that it occurs as incrustations, some half an inch thick, on quartz. The incrustations showed more or less botryoidal surfaces with dull greenish color. Other specimens from the Toughnut Mine show beautiful, mammilated crystalline groups of concentric crystals that have a brilliant black color. These indistinct, minute, fibrous masses fill drusy cavities in quartzose material and form coatings and crusts on fluorite.

Antimonates

Bindheimite (a hydrous antimonate of lead).—Microchemical tests on many of the yellowish-gray spots associated with the more siliceous ores gave distinct lead and antimony reactions, indicating that the mineral is probably bindheimite. It probably owes its formation to the alteration of tetrahedrite and bournonite.

Sulphates

Barite ($BaSO_4$).—White crystalline barite is present with quartz and manganese oxides in a vein exposed in a prospect pit about ½ mile west of the Lucky Cuss Mine. Pseudomorphs of limonite seen in polished sections of the ore indicate that pyrite may have been present. In one other locality, the Ground Hog Mine in the southwestern part of the district, there is exposed a vein of nearly pure, white barite from 1 to 3 feet wide. Quartz is a subordinate gangue mineral. Barite is sparse or lacking in most of the ore deposits of the district.

Anglesite ($PbSO_4$).—Anglesite is not an abundant mineral in the district. Ore from the Tombstone Extension Mine exhibits concentric layers of anglesite around galena centers. In the same specimens cerussite replaces anglesite. Polished sections of galena show that anglesite is the first stage in the alteration. It starts along the cleavage cracks and spreads until all the galena has been replaced.

Connellite [$CuSO_4 \cdot 2CuCl_2 \cdot 19Cu(OH)_2 \cdot H_2O$].—Connellite, a rare copper mineral of the oxide zone, was found when a large mass of copper ore from the Toughnut Mine was broken open, revealing deep-red crystals of cuprite lining a vug with brilliant dark blue, needlelike crystals of connellite projecting outward into the open space. Polished sections of the ore show connellite replacing cuprite. Brochantite, malachite, an unknown white crystalline mineral that gave a test for chlorine, and an unidentified pale to dark green, needlelike copper mineral are other minerals associated with connellite in the vug.

Brochantite [$CuSO_4 \cdot 3Cu(OH)_2$].—Brochantite, the green basic sulphate of copper, is a rare constituent of the ore and has been identified only from the Toughnut Mine where it occurs in small groups of radiating needlelike crystals lining vugs in cuprite. Other minerals associated with it are malachite, for which it is easily mistaken, black pitchy-looking copper oxide, chrysocolla, and connellite.

[44] W. F. Hillebrand, "Analyses of Three Descloizites from Three New Localities," *Am. Jour. Sci.*, 3rd ser. XXXVII (1889), 434-39.

Gypsum ($CaSO_4 \cdot 2H_2O$).—Gypsum was not recognized as a gangue mineral in the veins but occurs as small crystals and scales lining small fissures in the shales and on the walls and roofs of the stopes, where it has apparently been deposited from the action of sulphate solutions on limestone.

Beaverite ($CuO \cdot PbO \cdot Fe_2O_3 \cdot 2SO_3 \cdot 4H_2O$).—Beaverite was identified by microchemical tests upon a canary-yellow mineral from the Empire and Toughnut mines, where it is closely associated with cerussite.

Jarosite ($K_2O \cdot 3Fe_2O_3 \cdot 4SO_3 \cdot 6H_2O$).—Jarosite is common in the oxidized ores of the district and was abundant in ore from the Toughnut and Empire mines, where it occurred as "specimen ore." The finest specimens are golden-yellow, crystalline masses with only traces of quartz and iron oxides.

Plumbojarosite ($PbO \cdot 3Fe_2O_3 \cdot 4SO_3 \cdot 6H_2O$).—Plumbojarosite has been identified in the heavy, compact, brown oxide ore mined from the "Holderness roll." It is rather abundant. As seen in a hand specimen, the mineral is dark brown and massive, with a silky luster, but under the microscope it is distinctly crystalline. The miners call this type "chocolate ore" because of the deep-brown color. Besides being an ore of lead, Tombstone plumbojarosite yields considerable silver. An assay on a specimen from the Empire Mine yielded 58.92 ounces of silver, 0.48 ounce of gold, 8.50 per cent lead, and 26.10 per cent iron. Similar ore from the Toughnut Mine is reported[45] to have yielded as high as 200 ounces of silver per ton, which suggests that argentojarosite is present, although it has not been recognized as a distinct mineral.

Ettringite ($6CaO \cdot Al_2O_3 \cdot 3SO_3 \cdot 3H_2O$).—The rare mineral ettringite has been described from the Lucky Cuss Mine by Moses,[46] and, since specimens were not found by the writer, his description of the mineral is quoted:

> The mineral was found in an ore shoot in the white crystalline limestone of the Lucky Cuss mine, just at the water level. It occurs incrusting a massive silicate of lime and alumina from which it has apparently been produced by the action of sulphuric acid, as it frequently fills little veins and hollows in the silicate, and the latter is usually in these portions loosely coherent as if corroded. In appearance the sulphate resembles a fibrous pectolite, as it is made up of white, somewhat translucent, radiating fibers of a length up to one inch, or sometimes in little bunches of silky parallel fibers.

Bannester[47] has recently stated that a specimen of so-called ettringite from Tombstone, Arizona, in the mineral collection of the British Museum was identified by X-ray and optical methods with halotichite, the iron alum.

[45] E. P. Jeanes, personal communication.

[46] A. J. Moses, "Ettringite from Tombstone, Arizona, and a Formula for Ettringite," *Am. Jour. Sci.*, 3rd ser., XLV (1893), 489-92.

[47] F. A. Bannester, "Ettringite from Scawt Hill County, Antrim," *Mineralog. Mag.*, XXIV (1936), 324-29.

Tellurates and tellurites (?)

Tellurium-bearing minerals, which have not been identified but whose physical and chemical properties are somewhat similar, are grouped under the above heading.

A specimen of ore from the fourth level of the Little Joe Mine shows minerals not seen in any other ore from the district. A yellowish-green mineral that occurred as scales and plates between pyrite crystals and on white quartz was determined by microchemical tests to be tellurium bearing. It has the physical characteristics of emmonsite, a hydrated ferric tellurite, but the microchemical tests were negative to iron. The mineral may be a hydrous tellurium oxide.

A second tellurium mineral, probably also a hydrous tellurium oxide or tellurite, is sparingly present as bright, apple-green scales associated with white quartz and the previously described yellow mineral. It gave negative tests for iron and copper.

A third tellurium mineral with a characteristic greenish-yellow color occurs as small spherical masses in a highly oxidized ore that contains native gold, bromyrite, cerussite, and iron oxides. It gave microchemical reactions for copper, zinc, and tellurium. This mineral may possibly be a hydrous copper-zinc tellurite. Invariably associated with these yellow and green tellurium minerals is a black mineral at first mistaken for a tellurium sulphide but which seems to be a sulphate of lead and tellurium. Altaite, the lead telluride, has been sought for but has not been found on close examination of polished sections of tellurium-bearing ores.

Emmonsite.—Emmonsite, the hydrated ferric tellurite, has been reported[48] from near Tombstone.

Molybdates

Wulfenite ($PbMoO_4$).—Wulfenite is a common mineral, although not abundant in many of the mines at Tombstone. It is generally well crystallized and ranges from 1 to 25 millimeters in longest dimension. Many excellent specimens of wulfenite clusters and rosettes were collected from a stope on the fourth level of the Empire Mine. They were projecting downward and outward from the roof and walls into a slump cavity at the top of the ore body.

Wulfenite coats some specimens of oxidized galena from which it is separated by a thin film of anglesite or carbonate. More commonly, wulfenite occurs at the outer borders of the oxidized ore bodies where the rocks are porous and highly siliceous. Pyromorphite is generally the only other ore mineral present. Examination of many galena specimens has failed to reveal any trace of molybdenite as a source of the molybdenum. It is possible that molybdenite, having a higher temperature of formation, was deposited with the early quartz and pyrite and has been overlooked.

[48] E. S. Dana and W. E. Ford, *A Textbook of Mineralogy* (4th ed., New York, 1932), p. 770.

CLASSIFICATION OF THE ORE DEPOSITS

The ore deposits of the Tombstone district may be classified on several bases of which each has its value depending on the purpose desired. A classification on the metal content, as having the main value in gold, silver, lead, or manganese, or combinations of the metals, is of value, and such a classification together with a discussion of the distribution of metals is attempted in the section dealing with the zonal relations of the metals. The relation of the ores to structural features seems to have been the most useful guide in prospecting and development in the past and seems likely to continue to be most useful. In such a classification it is recognized that the different structures are interrelated, and that most of the deposits are associated with at least two structural features. The character of the associated rocks has also been an important factor in localization of mineralization and will be emphasized along with the structure.

The simplest structural type is the fissure in the intrusive rocks. Most of the deposits and the larger deposits in the sedimentary rocks are at the junction or crossing of a fissure with another structure, as a fold or fault, though some fissures are productive away from other structures. So large a proportion of the deposits is associated with northeasterly striking fissures that the relation may be assumed as general and the deposits classified, on the next most important or most obvious structural feature, into the following groups arranged in the approximate order of past productivity:

Deposits associated with north-south (dike) fissures
Deposits associated with faults
Deposits associated with anticlines and "rolls"
Deposits associated with northeast fissures only

FAVORABLE ROCKS

Before proceeding with a discussion of the structures, the importance of favorable sedimentary beds and dikes may be indicated.

Much of the ore in the Thombstone district has resulted from replacement of a few favorable formations that range from the lower Paleozoic to well above the base of the Mesozoic in the Bisbee group. The most productive sedimentary zones recognized are:

Beds of limestone above the Blue limestone in the Bisbee group
Blue limestone near the base of the Bisbee group
"Novaculite"
Upper portion of Naco limestone
Beds lower in the Naco: Lucky Cuss and Bunker Hill mines
Lower Paleozoic beds: Emerald Mine

In addition to the sedimentary beds the dikes in places, mainly within the Contention, Grand Central, and Head Center areas, were favorable to ore mineralization.

Upper part of Bisbee group

Along the stronger mineralized fissures there is some replacement in many of the beds of the Mesozoic shale-sandstone sequence, and mineralization may be continuous for considerable distances, as illustrated in the Skip shaft and West Side fissures. Mineralization tends to be most intense where fissure walls are limestone and to extend out farthest along limestone or limy beds. Several lenses of limestone near the base of the shale-sandstone series have been productive. The veins of the Tombstone Extension and neighboring mines are in the shale and sandstone of the Bisbee group.

Upper part of Naco limestone and lower part of Bisbee group

The largest production from bed replacement deposits has come from a group of strata that includes the upper part of the Naco limestone, the "Novaculite," the Blue limestone, and some higher limestone beds in the lower part of the Bisbee group. These beds may best be considered together, since the physical and chemical characteristics of the group produce the favorable conditions.

The Naco limestone is a strong, competent formation composed of rather uniform massive beds. The "Novaculite" is chiefly fine-grained and siliceous but contains some limestone lenses and some distinctly shaly and limy beds. The rocks are brittle and the formation relatively weak and incompetent.

The Blue limestone is composed of medium to thin beds of rather pure limestone that fractures readily but does not brecciate as extensively as the "Novaculite." The rock tends to break with some shattering near the faults rather than to brecciate over a wide zone. The Blue limestone is still less competent than the underlying "Novaculite." Overlying the Blue limestone are shale and sandstone with lenses of limestone. These are weak, incompetent rocks that folded readily.

This combination of physical properties has resulted in a rather systematic structural pattern. Faults and fissures have produced rather definite, clean breaks in the Naco limestone, strong zones of shattering in the "Novaculite," rather definite breaks in the Blue limestone, and generally tight breaks in the overlying shales. In many places the breaks in the limestones tend to be healed.

The different rocks also reacted differently during the folding. The massive Naco limestone bends to relatively broad open folds but with tension cracks on the crests of the folds.

The same folding produced brecciation in the "Novaculite," especially where the bending was sharp. The Blue limestone tended to fold into sharper crests or "pinches" than the Naco limestone. The adjustment to the sharp pinches is mainly in the incompetent shales above and the "Novaculite" beneath the Blue limestone, though the Blue limestone has thinned and thickened on different parts of the closely compressed rolls. On the sharp bends there was much tension fracturing ("Hoodoo cracks").

The shales of the Bisbee group above the Blue limestone are weak beds that in places are complexly folded, but for much of the area the details of this folding have not been determined. The most favorable beds on which to work out the general structure are those of the Blue limestone and the top of the Naco limestone. The brittle "Novaculite" lying between these strata presents a complexity due to adjustment that is difficult to understand until the main structure as represented by the more competent beds is determined. There is some suggestion, especially in the Empire area, where close folding has brecciated the "Novaculite" and dike fissures further broke it, that the entering dike tended to bulge into the brecciated areas, and the resulting adjustment further complicated the structure of this zone.

Dikes

Opportunity for observing structural features in the dikes has not been favorable in the Contention-Grand Central zone where mineralization along and in the dikes is greatest, since the mine workings in that area are largely caved. This dike fissure is a fault on which there has been considerable displacement, in contrast to most of the other dike fissures on which little movement has taken place. The deformation resulted in considerable brecciation in some of the beds cut by the fault, and the intrusion of the dike material into the fissure probably further brecciated the rocks along the walls. The walls of the fissure and the dike were further broken by movement on the fissure after the dike material had solidified. In general, faulting of the dikes resulted in gouge along the break rather than in breccia, but the mineralization in the Contention dike indicates that under some conditions permeable zones must have resulted from faulting along and in the dike. In general the dike fissures on which there was some faulting, such as the Contention-Empire dike fissure, have produced permeable zones along the dikes and to some extent in the dikes that have been favorable to mineralization. Prospecting along other dikes with less movement on their fissures has not revealed much ore. The northeast fissures, where they crossed the dike fissures, further broke the rock and completed the preparation of the ground for mineralization.

As described in the section on structure, the northeast fissures do not cross the dikes directly but tend to swing into the dikes for some distance in crossing.

The large ore shoots are at such crossings.

DEPOSITS ASSOCIATED WITH NORTH-SOUTH (DIKE) FISSURES

Contention-Grand Central ore zone

The Contention-Grand Central ore zone follows the Contention dike from the Tranquility fault southward through the Head Center, Contention, Flora Morrison, and Grand Central mines, past the Brady stope. In this length of 3,300 feet, it contained many large, rich ore bodies mainly between the surface and the

fourth level. As the Contention, Grand Central, and Head Center mines yielded more than $10,000,000 worth of ore prior to 1886, this ore zone has been the most productive one of the Tombstone district. Generally the rock was soft and the mining costs were low.

Water was encountered below the sixth level. During 1901-6, in an expensive effort to unwater the district, the Pump shaft of the Contention Mine was sunk to the tenth level. This project was abandoned in 1911, and subsequently the Pump shaft caved. The greater part of the Contention-Grand Central workings are now inaccessible.

Here the surface is composed of shale and sandstone of the Bisbee group, stratigraphically higher than the "Joe" limestone member (page 19). These beds prevailingly dip at low angles eastward and are intruded by the Contention dike. The Tranquility fault, swinging southward near the Tranquility shaft and separating into several branches, displaced the sedimentary beds and the dike in a complex manner (Plates IV and VIII). Some of these branches follow the bedding planes, and others dip more steeply. Due to their eastward dip, these faults displaced three or four segments of the dike successively downward and eastward, all above the fifth level (Plate VIII). At places the structure has been further affected by cross faults of east to northeast strike and relatively small displacement.

Ore occurs (1) in the faulted segments of the dike, (2) in brecciated footwall zones of these segments, and (3) in limestone beds of the shale sequence. Very little ore has been found below the fifth level where the dike is in place and unfaulted.

The ore bodies appear to have been genetically connected with northeast fissures, some of which are traceable on the surface (Plate IV). As stated on page 36, an ore fissure, upon intersecting the dike, tends to follow it for an interval before resuming the northeastward trend.

Two ideas as to the structural relations may be considered.

1. Prior to displacement by the postmineral Tranquility fault system, the upper portion of the dike, with steep, westward dip, and the sedimentary beds, with gentle easterly dip, formed a single northward-trending structure, like an inverted trough, that trapped the ore solutions. Within this structure, the rocks of sufficient permeability and favorable chemical composition were mineralized by the ore solutions from the northeast fissures.

Due, probably, to unknown conditions of fracturing, the portions of the dike above the fifth level were relatively permeable and susceptible to mineralization, whereas the dike on the seventh and lower levels was very little altered.

2. The Contention dike was faulted by the Tranquility fault system before the formation of the northeast mineralizing fissures, and the ground in the faulted block was well prepared for mineralization. The evidence does not warrant a definite selection of one of these but suggests the latter with the probability of renewed postmineral movement. According to Blake the dike is

laminated parallel to its walls, and large portions of it are strongly silicified. In the upper three levels, particularly, the dike and adjacent shale show extensive kaolinization.[49]

The ore was rich in silver, gold, and lead. Much of it was high in iron, and most of it was oxidized.

In the northern part of the zone were numerous large ore bodies, as shown on Plates IV and IX. South of the Grand Central shaft there were three large ore bodies in a faulted segment of the dike above the third level. No ore was found in the dike south of the southernmost or Brady stope. On the footwall side of the dike near the Brady stope, impure limestone in the shale sequence contained a sulphide ore body that was mined for 50 feet below the third level.

The Contention dike was followed on the third level for some 1,500 feet south of the Brady stope to the Dipper shaft but without finding any important ore bodies.

It may be noted that the intersections of the northeast fissures with the Blue limestone, "Novaculite," and upper part of Naco limestone have not been thoroughly prospected in this area.

Emerald Mine

The collar of the Emerald shaft is at the top of the Cambrian Abrigo limestone, which dips 35 to 45 degrees E. The mine workings connected with the 900-foot inclined shaft attain a vertical depth of approximately 880 feet and pass from Abrigo limestone into Bolsa quartzite at the eighth level. As these workings were inaccessible at time of visit, the following description of the underground features is based upon unpublished notes by F. L. Ransome, together with additional information furnished by J. H. Macia.

The ore deposit is mainly south of the shaft, within a fault fissure that strikes N. 20 degrees E. and dips about 76 degrees W. Replacing crushed material, the ore is narrow to absent where the fissure is tight. It is wider and of somewhat better grade in the Abrigo limestone than in the Bolsa quartzite. Although not of commercial width or grade throughout, the ore formed an essentially continuous shoot 1,100 feet long by ½ to 10 feet wide from the surface to below the deepest workings. According to Mr. Macia, an 80-foot winze from the ninth level, about 400 feet south of the Emerald shaft, showed a width of 6 feet of ore that contained 10 per cent lead, 8 per cent zinc, ⅔ per cent copper, 11 ounces of silver, and $2.00 in gold per ton. Discontinued because of water, this winze did not reach the bottom of the ore shoot. Mr. Macia states that the production from below the seventh or water level was worth $278,000.

The ore mined was partially oxidized sulphides. According to Ransome, considerable wulfenite was present in the oxidized material, and horn silver occurred in some of the solid galena.

[49] Wm. P. Blake, "Geology and Veins of Tombstone, Arizona" (Am. Inst. Min. Eng. Trans.), X (1882), 338-39.

Copper carbonate is reported to have been fairly abundant at the base of the Abrigo. Macia states that a carload of chalcocite ore that contained 40 per cent copper was shipped from the ninth level.

Little prospecting has been done in the southward extension of the Emerald fault fissure. Near the southern end of the Emerald workings, the Silver Plume shaft was sunk through the fault to a depth of 788 feet, but comparatively little drifting was done. At least two northeast fissures intersect the Emerald fault south of this shaft. West of the Silver Plume, the Abrigo limestone is cut by two northward-trending dikes whose faults have not been explored.

Tombstone Extension area

Deposits of lead ore associated with fault fissures of the general dike type have been worked by the Tombstone Extension, Carper, and San Diego mines southeast of Tombstone, in the east-central part of the district mapped on Plate III.

These mines are on the pediment, within a small area surrounded by Cenozoic conglomerate and outwash gravel. The rocks of this area consist of Mesozoic shale, sandstone, and quartzite (members 1-4, page 19) stratigraphically high in the Bisbee group, together with a small exposure of Naco limestone upfaulted on the east. On the south they are separated from the Naco limestone of the Ajax Hill horst by the eastward continuation of the Prompter fault system.

The Mesozoic beds of the Tombstone Extension area for the most part dip 45 to 50 degrees N., but in many places they are massive and do not reveal their attitude. In the mine workings the beds range in dip from 5 to 60 degrees N. and are displaced by several small faults that dip north to northeastward at low angles. The area is cut by at least three prominent fault fissures that strike N. 20 to 35 degrees E., dip steeply, and show marked horizontal and vertical displacement. In places these fault fissures contain thin masses of gouge and beccia that resemble altered dike material. The area is also traversed by several fissures that strike N. 45 to 60 degrees E. These fissures do not pass directly through the faults but follow them for short distances, in the manner described on page 36. The ore shoots, which are veinlike replacements in the fault zones, seem to be localized at the intersections of these northeast fissures with the fault fissures.

The Tombstone Extension workings, which reach a maximum depth of 550 feet or 35 feet below water level, are on a fault fissure that has an average strike of N. 24 degrees E. and a dip of 75 to 80 degrees N. (Plate III). As shown on Plate X, the main ore shoot, more than 800 feet long near the surface, separated into smaller branches downward. Its width, which ranged from 1½ to 5 feet, was generally greatest where shaly beds, rather than quartzite, prevail as wall rock, and also where the fault fissure changes in strike and dip. Movement on the fault has produced

Operator	Wet tons	Dry tons	Gold (ounces)	Value	Silver (ounces)
Tombstone Mining Co. (Jan. 1930 to Mar. 11, 1932)					
Yr. 1930	2,910.78	2,759.64	204.60	$ 4,229.08	21,996.64
Yr. 1931	311.66	299.69	44.21	913.82	5,800.71
Yr. 1932	2,482.88	2,348.69	225.56	4,516.21	32,392.00
Hayward & Richards (Begin Mar. 11, 1932 end Apr. 1, 1933)	795.00	747.31	60.27	1,202.70	9,093.00
A. S. & R. (From Apr. 1, 1933 to Dec. 31, 1933)	3,041.00	2,819.36	224.14	5,630.77	37,840.00
(From Jan. 1, 1934 to June 20, 1934)	2,018.00	2,006.20	116.38	4,090.24	19,836.00
Holt & d'Autremont (Lease June 21, 1934 to Nov. 10, 1934)	1,195.01	1,123.03	79.38	2,778.30	15,796.27
Hasselgren & d'Autremont (Lease Nov. 10, 1934 to Dec. 9, 1935)	2,308.64	2,164.36	79.86	2,795.58	27,055.81
Carper lease* (From Oct. 1934 to Oct. 1935)	196.71	183.35	8.14	298.60	2,421.26
Tombstone Mining Co. Dec. 1935	118.50	110.02	2.49	87.40	961.49
1936	80.78	75.93	2.36	82.73	648.74
1937	461.05	412.48	27.55	963.59	4,437.05
Macia lease* 1936	96.48	88.96	3.56	124.55	983.68
Gallagher lease 1936	65.37	56.63	4.14	140.92	1,228.01
Total	16,081.86	15,195.65	1,082.64	$27,854.49	180,490.66

* East vein.

PRODUCTION STATISTICS OF THE TOMBSTONE MINING CO.

Value	Silver (ounces)	Value	Lead (pounds)	Value	Fe + lime (pounds)	Value	Total gross value	Smelter chgs. + metal ded.	Net smelter value	Freight	Umpires	Net to shipper
$ 4,229.08	21,996.64	$ 8,524.90	887,952.45	$ 47,919.45	1,392,366.00	$ 4,177.10	$ 64,850.53	$ 40,328.29	$ 24,522.24	$ 1,842.59	$ 12.00	$ 22,667.65
913.82	5,800.71	1,783.86	232,098.67	8,336.40	81,772.00	245.32	11,279.40	4,967.67	6,311.71	473.19	9.00	5,829.52
4,516.21	32,392.00	8,871.40	1,226,722.00	37,702.90	1,150,456.00	5,752.28	56,842.79	33,428.23	23,414.56	4,133.77	91.72	19,188.97
1,202.70	9,093.00	2,355.88	336,810.00	10,377.04	425,322.00	2,126.59	16,062.21	9,456.30	6,605.91	1,481.20	18.95	5,105.76
5,630.77	37,840.00	15,643.39	1,145,565.00	49,653.14	1,669,500.00	8,347.77	79,275.07	36,793.48	42,481.59	6,288.26	89.45	36,103.88
4,090.24	19,836.00	12,660.50	726,559.00	29,120.67	712,107.00	3,574.11	49,445.52	20,312.33	29,133.19	4,661.91	101.31	24,369.97
2,778.30	15,796.27	10,129.36	553,991.48	21,897.29	618,071.00	3,090.36	37,895.31	16,731.81	21,163.50	3,084.84	54.38	18,024.28
2,795.58	27,055.81	20,167.22	842,762.11	33,785.72	1,082,035.00	5,405.64	62,154.16	27,268.87	34,885.29	5,298.83	59.38	29,527.08
298.60	2,421.26	1,805.93	88,951.82	3,652.76	102,854.12	514.27	6,271.56	2,473.28	3,798.28	566.72	2.56	3,229.00
87.40	961.49	740.34	39,143.48	1,761.35	52,174.00	260.87	2,849.96	1,347.76	1,377.53	228.13	3.04	1,271.03
82.73	648.74	489.52	21,970.27	1,010.63	37,895.00	189.47	1,772.35	857.23	915.12	148.27	3.04	763.81
963.59	4,437.05	3,416.53	167,949.24	10,498.94	.....	.....	14,879.06	5,022.38	9,856.68	1,280.42	17.42	8,558.84
124.55	983.68	756.33	36,054.90	1,658.53	45,772.00	228.86	2,768.27	1,144.86	1,623.40	262.22	.....	1,361.19
140.92	1,228.01	944.46	29,203.22	1,452.64	11,374.00	56.87	2,594.89	862.19	1,732.70	258.63	4.06	1,470.01
$27,854.49	180,490.66	$68,289.62	6,335,743.64	$258,827.46	7,381,698.00	$33,969.51	$408,941.08	$200,994.80	$207,946.28	$30,008.98	$466.31	$177,470.99

greater brecciation and greater permeability to ore solutions in such areas. The ore from the Tombstone Extension mine is mostly oxidized, but galena is relatively abundant below water level. The ore contained important amounts of gold and silver. Locally, considerable jarosite and iron-bearing carbonate are present in the gangue. The wall rock, particularly of the footwall, of the ore shoot is intensely kaolinized. Detailed figures of production are given in the accompanying table.

A horizontal diamond-drill hole indicated another mineralized fissure approximately 300 feet west of the Tombstone Extension workings. This fissure was sought by short drifts from a 70-foot shaft and prospected by a drift from the 250-foot level, but no ore has been found within it.

The Carper workings, northeast of the Tombstone Extension shaft, reach a depth of 150 feet. Here a fault fissure strikes N. 30 to 35 degrees E., dips 70 to 80 degrees W., and in places is occupied by altered, brecciated dike material. North of the shaft it is intersected by a northeast fissure that dips about 35 degrees southeastward. Along this intersection an irregular pipelike body of ore, 5 to 15 feet in maximum diameter, was mined from the surface to a depth of 90 feet. Other smaller bodies were found, both north and south of the shaft, where inconspicuous northeast fissures intersect the fault. The ore is oxidized and generally accompanied by jarosite. Some small masses were rich in gold. Detailed production figures are given in the accompanying table.

The San Diego Mine, southeast of the Tombstone Extension shaft, is 400 feet deep. Its workings follow a fault fissure that strikes parallel to the Tombstone Extension fissure and ranges in dip from steep westward near the surface to steep eastward below a depth of 250 feet. The workings were not accessible at the time of visit. According to J. H. Macia, the principal ore shoot is a short distance north of the shaft. It was mined over a length of 25 to 50 feet by a maximum thickness of 5 feet for a height of 140 feet above the fourth level. Some small bodies were mined from the fourth and third levels, 75 and 125 feet south of the shaft.

The major fault fissures of the area have not been thoroughly explored, particularly towards the south where limestone beds may be covered by the Cenozoic conglomerate.

Comet ore zone

Bodies of manganese-silver ore, locally with some lead, occur associated with the Comet dike in the southeastern portion of the area mapped on Plate IV. They have been opened in the Comet and Black Eagle mines.

Here the surface is composed of thick-bedded Naco limestone, stratigraphically low in the formation, though higher than that at the Bunker Hill Mine. These beds dip 20 to 30 degrees E. in the vicinity of the Comet Mine and eastward to northward at the Black Eagle Mine. Immediately south of the Black Eagle shaft they are cut by an east-west fault of small displacement. The

Comet dike strikes N. 10 to 15 degrees E., dips steeply westward, and is up to 50 feet wide.

The ore occurs as veinlike replacement bodies along the eastern or footwall side of the dike and to some extent within the dike. In general it was of low silver content but commanded a premium as smelter flux.

The mine workings have long been inaccessible. Nothing was learned of those of the Black Eagle, except that they were not very extensive or productive. The Comet workings, according to unpublished notes of F. L. Ransome, extend to a depth of 400 feet on a veinlike ore body that strikes N. 15 degrees E. and dips 70 degrees W. As shown by old maps of unknown origin, this ore body was stoped to a width of 2 to 10 feet for a maximum length of 1,375 feet (Plate XI and Fig. 2). J. H. Macia[50] states that 1,000 tons of this ore, shipped by the Tombstone Consolidated Mines Company, averaged 7 ounces in silver per ton. It extended below the fourth level, but its lower limit was not determined.

Mineralization associated with the Anchor or Coyote fault

The Anchor or Coyote fault is traceable from its junction with the Prompter fault, 1,275 feet east of the Prompter shaft, northward for some 3,000 feet, to a point where it disappears under alluvium in the gulch immediately east of the Lucky Cuss Mine. In its southern part it cuts northward across the essentially vertical beds in the rim of the Tombstone basin and dips 45 degrees E. Northward, in the gulch east of the Lucky Cuss Mine, it strikes parallel to the beds and dips 50 to 60 degrees E. In its southern part it is marked by ½ to 3 feet of breccia and in places is occupied by a thin, dense, dark-colored dike.

On the Anchor claim, some irregular pipelike bodies of manganese-silver ore have been found associated with the southern segment of the fault. These bodies as a rule are only a few feet in diameter and of medium to low grade. The largest and richest ones mined were relatively near the surface. The Anchor tunnel, which follows the Anchor or Coyote fault for some 300 feet, disclosed comparatively little ore.

DEPOSITS ASSOCIATED WITH FAULTS

Lucky Cuss fault zone

Ore deposits have been developed at intervals in a belt close to the Lucky Cuss fault zone from the Luck Sure Mine on the south through the several deposits of the Lucky Cuss and Old Guard to the Herschel on the north, a distance of about 3,000 feet. These deposits have many features in common, and the zone may be called, after the most productive mine, the Lucky Cuss mineral zone.

Rocks.—The sedimentary rocks in this belt include the same general zones that have been most productive in the bed replace-

[50] Oral communication.

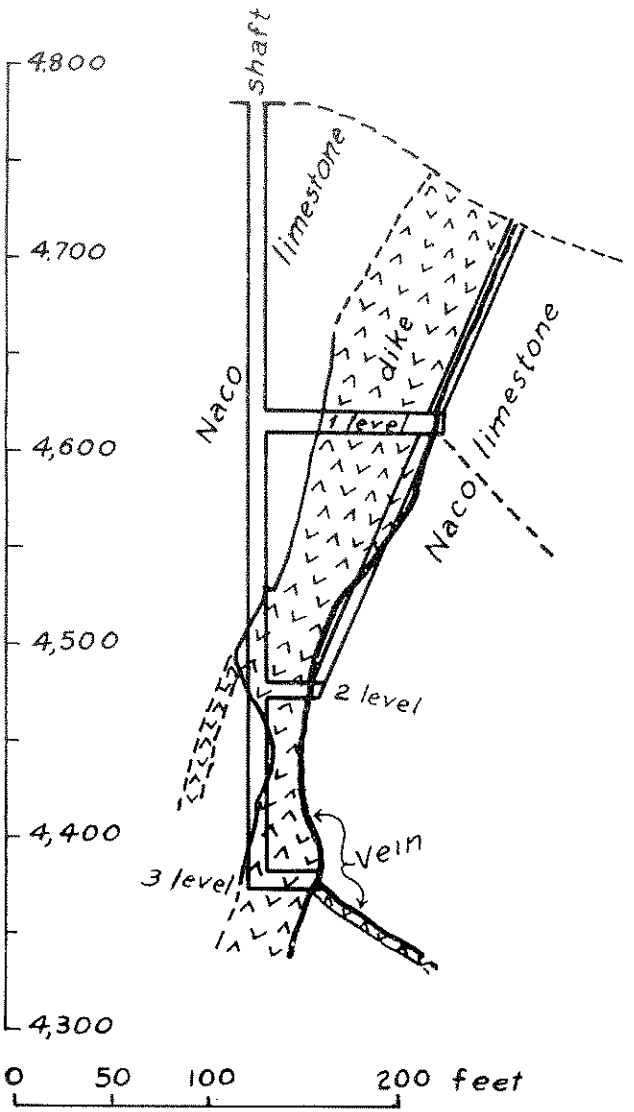

Figure 2.—Cross section through Comet shaft looking north.

ment deposits in other parts of the district—namely, from the upper part of the Naco limestone into the shale somewhat above the Blue limestone member of the Bisbee group.

The rocks, as exposed in Luck Sure Hill, differ somewhat in the Lucky Cuss belt from those near Tombstone. The most pronounced difference is the greater amount of conglomerate in the

Lucky Cuss area. Some of the conglomerate is made up largely of siliceous rocks rather than prevailingly of limestone, which is the principal component of the conglomerate where present near Tombstone. The conglomerate beds are, however, lenticular, for the thick lens of Luck Sure Hill thins before it reaches the Lucky Cuss Mine to the north and equally abruptly to the south. A second difference is the greater thickness over which siliceous novaculitic rock is interbedded with limestone. Crystalline, massive limestone resembling Naco limestone apparently is above "Novaculite." A third difference is that the first limestone above "Novaculite" and beneath the shale, in the position of the Blue limestone, is thinner than normal for the Blue limestone in the Tombstone area but otherwise resembles it.

The Lucky Cuss mineral zone is near the Schieffelin granodiorite intrusive. Sills and dikes of granodiorite, apparently offshoots of the main mass, are exposed in the mine. Alteration resulting from the proximity to the intrusive is pronounced. Much of the limestone is bleached and recrystallized, and some of it contains abundant silicates, mainly hillebrandite, thaumasite, monticellite, grossularite, and vesuvianite. In other areas the limestone has been replaced by a claylike material. Some of the limestone exposed on the surface, however, shows little alteration and contains fairly well-preserved fossils.

The stratigraphic differences of the mineralized beds in the Lucky Cuss mineral zone as compared with those nearer Tombstone may be summarized as follows: The thickness of strata between the lowest "Novaculite" and the shale above the Blue limestone is greater, due mainly to massive limestone above the "Novaculite." The Blue limestone is thinner. The rocks are more altered and less readily classified.

Structure.—The Lucky Cuss zone is located on the southwestern flank of the Tombstone basin where the strike of the formations swings from northwesterly on the southern rim of the basin to northerly on the western rim. Along this bow the dip of the beds changes from nearly vertical southeast of Luck Sure Hill to 40 to 45 degrees into the basin at the Herschel Mine.

Much slipping or faulting along the beds accompanied the folding. Some of the displacements were doubtless small and followed the bedding closely. The adjustment was taken up in considerable part, however, by larger faults, in general parallel to the bedding but cutting from one bed to another rather than following a single bedding plane. These larger faults are not simple but branch and unite in a complex manner.

The simple bedding faults are difficult to recognize, except by gouges or slickensides on the bedding planes, and still more difficult to evaluate as to amount of movement. The larger faults also present many of these difficulties.

These faults, where not parallel to bedding planes, show less range in dip than do the beds. To the north, where the beds flatten, the faults are steeper than the beds. To the south, where the beds steepen, the faults are flatter than the beds.

The movement on the faults resulted in slipping along the beds. Where the faults cut across the bedding, the movement resulted in an apparent thickening or thinning of the formations.

The Lucky Cuss fault is the most conspicuous zone of bedding faults on the sharp turn on the southwest rim of the Tombstone basin. This fault can be traced from about 1,000 feet south of Luck Sure Hill, where it strikes N. 30 to 35 degrees W., to north of the Old Guard Mine and probably through the Herschel Mine, a distance of about 3,500 feet, where the strike is N. 10 to 15 degrees E. Throughout this distance the fault maintains a rather uniform dip on the surface of 70 to 75 degrees. Similar dips generally prevail where the fault is exposed underground, though over limited areas the faults of this zone are much flatter.

The southern part of the fault is in Naco limestone, and the northern part is in the Blue limestone and overlying shale; it has not been definitely traced north of the Herschel Mine. It appears to have its maximum development where the formations are strongly warped in turning from the steep south rim of the basin to the flatter west rim.

The fault crosses at a small angle the favorable ore zones from the Naco limestone to the shales. It produces a complexity of structure in detail, but the known relations seem to be produced by a fault at a low angle with the beds, that gives an apparent thickening and duplication of the beds.

Similar bedding faults or near-bedding faults are doubtless present both above and below the Lucky Cuss zone. In the massive, recrystallized Naco limestone they are healed and difficult to recognize. In the poorly exposed shale sequence they are also difficult to recognize. There is, however, in the Herschel Mine at the north end of the belt a well-defined series of easterly dipping slips in the shale that may belong to this fault system, though they dip flatter than the Lucky Cuss fault.

Projections of several of the northeasterly striking ore fissures of the district cross this belt. Among the better recognized of these are the East Side, Blue Monday (West Side), Ingersol, and Intervener, as well as others less well developed. The East Side fissure has been followed for more than 1,000 feet northeastward from its junction with the Lucky Cuss fault. Numerous other northeasterly fissures have been opened on the hanging-wall side of the fault but have not been followed along their strikes. Their correlation with known fissures to the northeast is not now possible, though some of them are probably extensions of those fissures.

Where they meet the fault the fissures range in strike from N. 35 to N. 60 degrees E., and nearly all dip steeply southeastward. The fissures intersecting the fault from the east or hanging-wall side are not found on their projected strike on the west or footwall side. On the footwall side there are similar fissures of which the best developed are the Rat shaft, Wedge, and Luck Sure. It seems probable that the fissures on opposite sides of the fault are the same, but their definite correlation was not

attempted. The cause of the offset of the fissures on the fault is not certain. The fault is believed to have been initiated and largely formed during the folding of the rocks and is earlier than the northeast fissures. That the fault preceded ore deposition is indicated by ore along the fault. There was, however, post-ore movement on the fault, which would have displaced fissures crossing the fault.

Another cause for the offset of the fissures is the effect of the fault on the fissuring. The fault zone was clearly a zone of weakness. The fissures met this zone at an acute angle on the strike and a very acute angle on the dip. It would be natural for the later fissure to follow the earlier fault for a distance rather than cross it directly on the strike.

Ore deposits.—The ore deposits in and associated with the Lucky Cuss fault zone are of three types: veins in the Lucky Cuss fault, veins in the northeast fissures, and limestone replacement deposits associated with the northeast fissures.

Deposits in the Lucky Cuss fault.—From the Lucky Cuss shaft northward through the Old Guard Mine and possibly the Herschel Mine the ore was mainly in the Lucky Cuss fault. It was not, however, uniformly distributed but occurred in distinct shoots (Plates XII and XIII). The shoots in the Lucky Cuss and Old Guard mines seem to have been in the fault, near junctions of the fault with northeast fissures in the hanging wall. The junctions of fissures with the fault extend nearly down the dip of the fault, and the ore shoots likewise have this general trend.

Deposits in the Herschel Mine.—In the Herschel Mine the ore is in fissures of two distinctly different strikes. In the upper levels the fissure has essentially the strike of the Lucky Cuss fault, whereas in the lower levels the strike is essentially that of the northeast fissures (Plate VII). There was little opportunity for observation in this mine, but from the facts available it seems at least probable that the ore shoot was formed at the junction of the Lucky Cuss fault or a branch of it with a northeast fissure. The two breaks meet at an acute angle and possibly unite for some distance. The northeast fissure is mineralized, and the fault near the junction is mineralized. Within the fissure, mineralization was controlled by bedding slips, beneath which the ore shoots occur.

Deposits in northeast fissures.—Few of the northeast fissures in the shale of the hanging wall of the fault have been prospected. The East Side fissure has been followed for more than 1,000 feet on the third level where small shoots of ore that occurred between shale walls and small replacement deposits in beds of limestone were opened. This fissure was also productive near the surface for several hundred feet northeast from the fault where it cuts both shale and limestone. The extent of these deposits is not known.

Other hanging-wall fissures have been developed for short distances from their junctions with the faults and have yielded some ore.

The fissure deposits of the Herschel Mine have been mentioned above.

Replacement deposits in limestone.—Replacement deposits in limestone have yielded the main production south of the Lucky Cuss shaft and in the footwall of the fault. Above massive crystalline limestone that is definitely Naco is a series of interbedded siliceous novaculitic and crystalline limestone beds whose relation as determined in the limited accessible workings is uncertain. They may represent an alternation of siliceous and calcareous beds above the massive Naco limestone, or they may represent a part of the Lucky Cuss fault zone, with a duplication of beds by faulting nearly parallel with the beds. The latter quite certainly was a factor. The replacements occur where this series and the massive Naco limestone are cut by northeasterly fissures. Generally the deposits are irregularly pipelike or chimneylike, though some have a more tabular form. They follow the intersections of the northeast fissures and favorable limestone beds and bed faults.

A maze of irregular replacement deposits has been mined near the Lucky Cuss shaft where a group of northeast fissures, of which the Rat shaft fissure is the most conspicuous, cut the rocks in the footwall of the fault. A part of these bodies seems appropriately named the Rat Hole shoots. The deposits have been mined from the surface to below the eighth level. From the surface nearly to the fourth level the stope is between a massive, white crystalline limestone footwall and a "Novaculite" or shale hanging wall. Above the fourth level it meets the Lucky Cuss fault and continues in the footwall of that fault to the sixth level. From the fourth to the sixth level it is in massive white limestone. About 50 feet from the footwall of the Rat Hole shoot on the fifth level is a shoot that has been mined from above the fifth to below the eighth level. This body in general parallels the Rat Hole shoot and overlaps it from above the fifth to the sixth level (Plate XIII). This shoot is represented on old sections as in massive, white (Naco) limestone in the footwall of the main fault but approaching it with depth (Plate XIII).

The McCann shoots are on the Wedge fissure where it cuts the massive Naco limestone. The largest shoot is 150 feet from the footwall of the main Lucky Cuss fault on the fifth level. It is an irregular chimney perhaps 25 feet in diameter that has been mined from the surface to the fifth level. A smaller pipe 50 feet southwest on the fissure was mined from the fifth to the third level. A third pipe 150 feet farther southwest, on the third level, was mined from the surface to the third level. At the surface it nearly joined the largest shoot.

The Escondido shoots are on the Escondido fissure or fissures in the Naco limestone. The shoots appear to be in essentially the same stratigraphic horizon as the McCann shoots and are very similar in character, though in the upper levels, as indicated on old maps, they are very irregular. The stopes are inaccessible, and little of the detail of the occurrence of the shoots is known.

Luck Sure deposits.—South of the McCann are the Luck Sure deposits, which occur on the two Luck Sure northeast fissures in Naco limestone. These deposits, which seem to be similar in occurrence to the McCann and Escondido deposits, are reported to have been followed to a depth of 40 feet below the fifth level. The workings are inaccessible and no first-hand details of the occurrence were obtained.

Ores of the Lucky Cuss zone.—There was little opportunity for a study of the ores of the Lucky Cuss zone, and no authentic record of production is available. In general the ores in the Lucky Cuss fault and in the northeasterly fissures in the hanging wall of the fault had most of their value in silver with some gold and variable but small amounts of lead. In much of the ore, the lead, if present, was not recovered. Manganese was present in varying amounts, but except locally the ore was not highly manganiferous. W. F. Staunton[51] states that some of the Lucky Cuss ore near the shaft on the fourth level contained nearly an ounce of gold and 100 ounces of silver per ton. He also states that alabandite ore near the shaft on the fifth level was high in gold.

The chimney and pipe deposits in the limestone south of the shaft and in the footwall of the fault were essentially manganiferous silver ores.

Material low in silver and high in manganese was marketed as manganese ore.

The deposits are largely oxidized to the deepest workings, even below present water level, except in protected spots, as under the intrusive body on the fourth level west of the Lucky Cuss shaft.

Prompter fault system

Location.—Numerous bodies of manganese-silver ore are associated with east-west fissures of the Prompter fault system in the east-central part of the district. These deposits have been explored mainly in the Oregon-Prompter, Bunker Hill, Dry Hill, Rocky Bar, and Contact mines, representing a total linear distribution of 8,500 feet.

Stratigraphy and structure.—The Prompter fault system extends eastward across the central part of the district, as shown on Plate VI, and limits the Ajax horst block on the north (pages 30-32). At the Bunker Hill Mine the main fault is joined by the Rattlesnake branch fault. The area between the main Prompter fault and the Rattlesnake branch is crossed by several minor faults that resemble torsion breaks.

The Prompter fault dips steeply southward and is of reverse type. In its western portion, it brings the upper part of the Naco limestone on the north against Naco limestone, Escabrosa limestone, Martin limestone, Abrigo limestone, Bolsa quartzite, and granodiorite on the south, as shown on Plate III.

As determined by James Gilluly, of the U.S. Geological Survey, the Naco limestone beds on the northern side of the Prompter

[51] Personal communication.

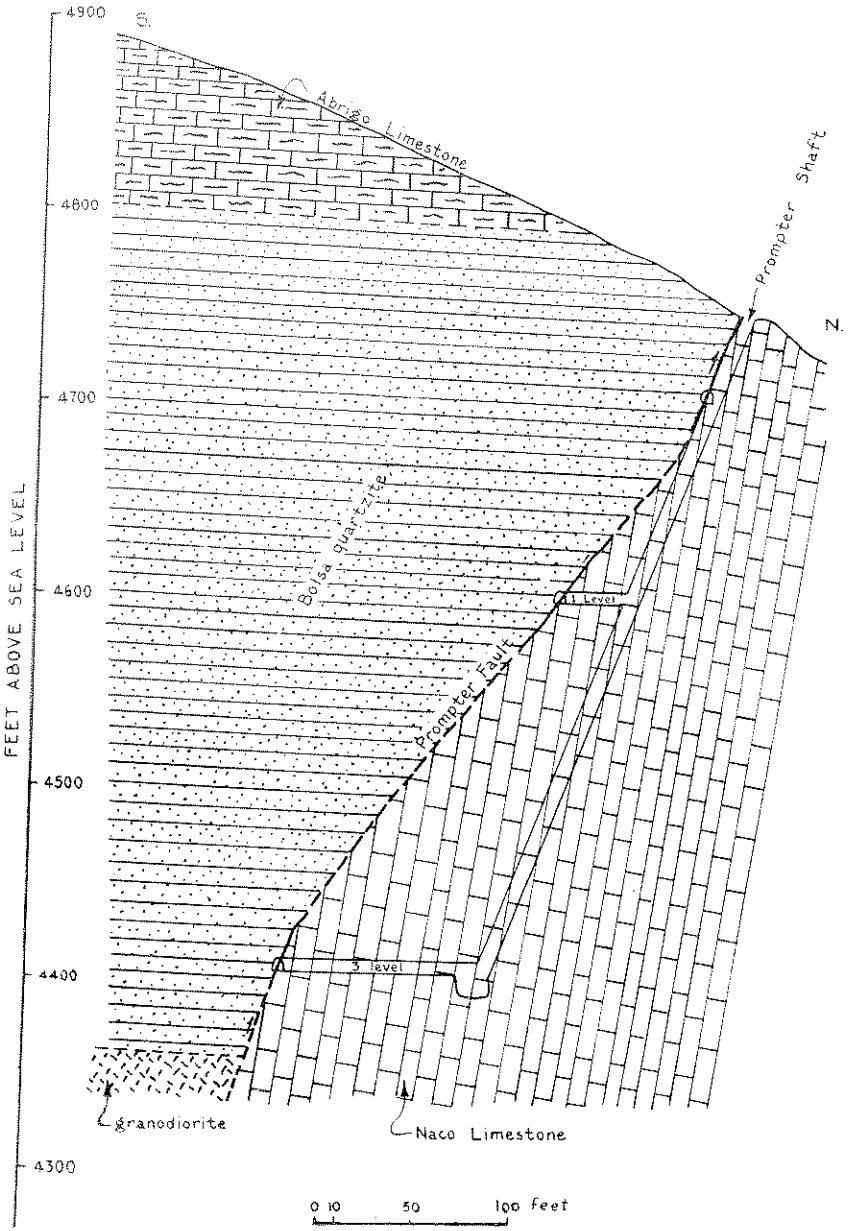

Figure 3.—Cross section through Prompter shaft, looking west.

fault, west of the Prompter shaft, are stratigraphically a short distance beneath the orange dolomite member (page 16); the

lower part of this dolomite here consists of rather siliceous hornfels that resembles novaculite. Eastward, still higher members of the Naco form the footwall of the fault.

On the northern side of the fault the Naco strata prevailingly dip steeply northward but in places are vertical or slightly overturned. There are numerous inconspicuous faults and slips parallel or at slight angles to the bedding.

Northeast fissures, mostly of steep southeastward dip, intersect the Prompter fault at many places (Plates IV and VI). These fissures, which are generally inconspicuous, appear to have been the channels through which the mineralizing solutions entered. The ore bodies associated with the Prompter fault system occur where northeast fissures intersect favorable beds and favorable structures.

Oregon-Prompter Mine.—The Oregon-Prompter workings (Plates VII and XIV) extend to water level, with a maximum vertical depth of 800 feet. The ore bodies exposed in these workings are irregular, pipelike to tabular replacement masses, of which at least twelve have been mined. They occur within certain favorable beds of the Naco limestone where the Prompter fault and bedding slips have localized ore solutions from the northeast fissures.

Associated with the Prompter fault were five separate ore bodies of which three occurred near the Prompter shaft between the surface and the fifth level, and one was 300 to 325 feet east of the Oregon shaft between the surface and the first level (Plates VII and XIV). The limestone beds that contained these bodies in general conformed with the footwall of the fault. This ore in general was of medium to low grade. Some 400 feet south of the Oregon shaft was the Massey-Williams ore body in vertical to steeply northward-dipping beds of Naco limestone beneath the Prompter fault. The stopes here are inaccessible, but according to maps and local information, the ore body extended, with medium to steep eastward plunge, from the fault, at a point approximately 125 feet above the third level, to water level. Throughout most of its vertical extent of 450 feet this ore was of high grade.

The ore bodies related to bedding slips in the Naco limestone are indicated on Plate XIV. In general they were very persistent, and one of them was followed for a length of 850 feet, from the surface near the Oregon shaft to water level. The most western one, the Giacoma ore body, occurs along the intersection of a northeast fissure with steeply northward-dipping limestone beds in the footwall of a bedding slip (Plate XIV). According to John Giacoma, this body yielded $175,000 worth of silver ore.

The Oregon-Prompter structures have not been thoroughly prospected. The favorable limestone beds and associated bedding slips, such as those of the Massey-Williams and Giacoma ore bodies, appear to be intersected by several other northeast ore fissures in unexplored areas. Other favorable beds and favorable structures may exist in the untested area north of the Oregon workings and south of the hornfels contact shown on Plate IV.

Bunker Hill Mine.—The Bunker Hill workings are within the acute angle of intersection of the Prompter and Rattlesnake faults and extend to a depth of 516 feet. These workings were inaccessible at the time visited, but some information regarding the underground features was obtained from the late John Pieroti and from mine maps.

Here the Prompter fault dips 50 to 70 degrees S. and brings the lower part of the Naco limestone on the south against the upper part on the north. The Rattlesnake fault, of vertical to steep southward dip, shows relatively small displacement, with its northern side thrown relatively downward and westward.

In the area of the mine workings, the beds are sharply folded into a southeastward-trending anticline. They are also broken by small faults and slips parallel to the Prompter and Rattlesnake faults and are intersected by at least two northeast fissures.

The ore bodies occur as irregular replacements in the lower part of the Naco limestone along the Rattlesnake fault and along the small faults and slips already mentioned. Most of the ore bodies are pockety, although some exceed 100 feet in length and 30 feet in width. In general the ore mined from them was of medium to low grade, worth less than $30 per ton in silver, lead, and zinc. The largest and richest ore bodies were found in or near the zone of the Rattlesnake fault, between the third and fifth levels. The ores are relatively more manganiferous in the western part of the mine.

The northern or footwall side of the Prompter fault in this area has not been prospected.

Contact workings.—On the Contact claim, the footwall of the Prompter fault has been explored for a distance of approximately 1,200 feet on a level some 35 feet below the third level of the Oregon Mine. This level extended to a point approximately S. 10 degrees W. of the Oregon shaft. The footwall has also been followed for short distances on upper levels. In this area the fault is intersected by several prominent northeast fissures in the vicinity of which some bodies of low-grade argentiferous manganese oxide were found. No commercial ore was developed.

Dry Hill Mine.—The Dry Hill Mine is on the Prompter fault system and 3,000 feet west of the Oregon Mine.

Here the Naco limestone is limited on the west by the great north-south fault described on pages 31-32, and the main Prompter fault gives way to two faults, 75 to 100 feet apart, that trend about N. 35 to 45 degrees E. and dip 70 to 80 degrees SE. The larger of these northeast faults brings Cambrian Abrigo limestone on the southeast against the upper part of the Naco limestone on the northwest and west (Plate III). The limestones have been strongly altered by contact metamorphism. As shown underground, this fault is paralleled by a zone of fissuring in the Naco limestone. This fault zone and the parallel fault that occurs 75 feet farther northwest are intersected by several fissures that strike N. 60 to 70 degrees E. and dip 60 to 80 degrees SE. Along these intersections are irregular pipelike to tabular bodies of

manganese-silver ore. The ore bodies range in size from small lenses to 20 feet wide by 5 to 25 feet long and 100 feet or more down the dip. Within a horizontal distance of 500 feet on the larger fault zone, three shoots have been stoped to a depth of about 100 feet, and one was followed from the 100 to the 200 level. On the parallel fault to the northwest, the ore bodies are of smaller size and lower grade.

Most of the production from this mine was made during the early days and is unrecorded. Recent production, by the Tombstone Development Company and lessees, has been as follows:

Ore shipped from Dry Hill Mine, 1933-37

Tons	Oz. gold	Oz. silver	Lbs. copper	Gross value
3,116	131	53,957	10,401	$34,075

Telephone Mine.—The Telephone Mine is 300 feet north of the main Prompter fault on a bedding slip parallel to that fault. In this vicinity the massive upper part of the Naco limestone strikes eastward and dips steeply to almost vertically. At the Telephone Mine the beds dip 65 to 70 degrees S. and are crossed by two closely spaced northeast fissures. These fissures show manganese mineralization at the surface, and the Telephone deposit is on the intersection of the fissures and the bedding slip in the limestone. The mine workings were inaccessible at the time visited, but an old company map shows eight levels with a maximum east-west length of 350 feet. The principal stopes are between the fourth level and the surface, and a small stope extends from the seventh level to a point midway between the fourth and third levels. The largest stope shown is 140 feet long by 1½ to 5 feet wide and extends from the surface to the first level.

Projected southwestward, the northeast mineralized fissures exposed at the Telephone Mine would intersect the Prompter fault, but this projected probable intersection has not been prospected.

DEPOSITS ASSOCIATED WITH ANTICLINES AND ROLLS

It has been shown in the section on structure that the formations within the Tombstone basin have been compressed into a series of rather broad southeastward-trending anticlines and synclines which have been designated, from northeast to southwest, as the Empire anticline, Sulphuret syncline, Sulphuret anticline, Boss terrace, Ingersol overturn, and Hardup syncline. On the larger folds are numerous minor folds or corrugations, the anticlinal portions of which are locally designated as rolls. They have the characteristics of drag folds. Some of them have been named after ore bodies that have been developed on them. The broader folds show a general parallelism between the massive Paleozoic and the thin-bedded Mesozoic rocks. In the minor folds or rolls the Mesozoic Blue limestone is generally more closely folded than the underlying Naco limestone.

The anticlinal areas have been much more productive than the synclinal areas. This generalization applies to deposits in shale along the strong fissures, like those shown in the West Side and Skip shafts, as well as to replacement deposits in the limestones. Bed replacement deposits are largest in the rolls and mainly in rolls on the anticlines as contrasted with those on the synclines.

Location of mineralization on the rolls

Location of mineralization on the rolls is determined by several structures and combinations of structures, so that prediction as to just where it will be found is somewhat uncertain. The several factors may be given in the following order, with due allowance for variation.

1. The overlying shale acts as a relatively impermeable cap.
2. The "Novaculite" is the most brecciated and the most permeable zone.
3. The upper part of the Naco limestone, the "Novaculite," and the Blue limestone are chemically the most favorable to replacement.
4. Brecciation is greatest and permeability generally greatest where the bends are sharpest. The folds are not symmetrical and the sharpest bends may or may not be at the crests of the folds. In some folds slipping along the beds has produced permeable zones on a limb of the fold, and mineralization extends far down the limb.
5. Following the folding, the north-south dike fissuring and intrusion of the dikes further brecciated the rocks and increased permeability.
6. The northeast fissuring completed the preparation of the ground for mineralization. These fissures were the channel through which the solutions rose and passed into the more permeable zones.

The resultant of the several controls has been variable, but some generalizations may be stated.

Mineralization is greatest in and near the northeast fissures and at or near the crests of the anticlines, but this is subject to many exceptions. Mineralization is least at or near the troughs of the synclines. Mineralization is also greatest near the base of the "Novaculite" and in the Blue limestone, but other zones in the "Novaculite" have yielded ore, especially where close to the northeast fissures. The limestone beds in the shale series above the Blue limestone have been mineralized along some of the strong fissures, as shown by the stopes on the West Side roll. Where the Naco limestone or the "Novaculite" is well mineralized, the Blue limestone may be poorly mineralized or the reverse, but this is not a generalization, and the fact that one is well mineralized does not mean that the other is barren of ore.

Description of roll deposits

The individual rolls plunge with the larger anticlinal structures with trends ranging from S. 60 to 70 degrees E. in the western

part of the area to considerably more southerly in the eastern part (Plate VI).

The rolls are crossed by the north-south dike fissures. Displacement on the Empire-Contention dike fault fissure has offset the rolls so that their correlation on opposite sides is not certain, and the areas east and west of this break may be considered separately. The horizontal offset is probably not great, but the folding on the east side of the dike is more complex than on the west.

Rolls east of the Empire dike

Jeanes roll.—The Jeanes roll (Plate XV), the most northeasterly that has been developed, is on the northeastern limb of the Empire anticline. The fifth level of the U.S. Smelting, Refining, and Mining Company lease encountered Blue limestone near the crest of the roll.

In the vicinity of a strong, northeast fissure, an ore body of irregular area was found on the crest and southwestern flank of the roll. This ore was of fairly high grade only near the fissure.

Farther northwest the Jeanes roll becomes a close fold, slightly overturned southwestward. A fourth level drift followed the Blue limestone near its axis northwest for 200 feet, to within a short distance from the Empire dike. In this interval the roll is crossed by four distinct northeast fissures in the vicinity of which the limestone is mineralized with abundant low-grade sulphide material. Near the end of the drift a pipelike mass of oxidized lead ore, 5 to 10 feet in diameter, occurred in the upper part of the Blue limestone on the southwestern, overturned limb of the roll. It was mined for a vertical distance of approximately 40 feet.

As shown by churn drilling, the limb of the Empire anticline northeast of the Jeanes roll dips steeply, carrying the Blue limestone far below water level.

Holderness roll.—The Holderness roll, southwest of the Jeanes roll but also on the northeastern limb of the Empire anticline, has been extensively developed. It is a broad, gentle arch, 250 to 300 feet across on the fourth level. The crest at the top of the Blue limestone where it meets the Empire dike is about 60 feet above the fourth level. The southeasterly plunge carries the crest nearly to the fifth level at the Skip-shaft fissure (Plate XXIII).

The gently dipping southwestern limb of the Holderness roll is separated by a high-angle fault from the almost vertical northeastern limb of the Silver Thread roll at about the fourth level near the Empire dike. On the northeastern limb at the fourth level the Blue limestone dips steeply below the fourth level and is next exposed to the northeast on the fifth level of the U.S. Smelting, Refining, and Mining Company lease near the crest of the Jeanes roll (Plate XV).

The northwestern part of the roll near the dike is crossed by two northeast fissures which, to the southwest, meet the Empire dike. Outward from these fissures the Blue limestone has been mineralized for a width of 50 to 100 feet in an irregular belt that

crosses the fold. From September, 1934, to February, 1935, this ore body, known as the "409," yielded 4,218 tons of ore with a gross value of $146,362.

The lower "Novaculite" zone, which lies below the fourth level, has not been extensively prospected on this roll, though a winze on the westerly fissure has been sunk to it, and some ore has been mined near the fissure. The "10-foot" and "6-foot" limestones in the shale sequence above the Blue limestone have not been prospected on the roll, but they are mineralized and have yielded ore in the U.S. Smelting, Refining, and Mining Company lease to the northeast along a northeast fissure on the northeastern limb of the roll.

Outside of this belt the roll has been prospected by drifts in the Blue limestone nearly to the point where it plunges below the fourth level. An irregular ore body was developed along a northeast fissure crossing the rolls about 100 feet southeast of the "409" stope. This ore extended along the fissure for a length of 160 feet and has a width of 5 to 100 feet and a thickness of 3 to 10 feet.

Where the Blue limestone at the crest of the roll is cut by the Skip-shaft fissure, just above the fifth level, it is mineralized and has been productive.

Silver Thread roll.—The Silver Thread roll is south of the Holderness roll. In contrast to the broad dome of the Holderness roll, it is a fold with both limbs steep. It corresponds, however, in having the northeastern limb the steeper, in places even overturned. Southeastward from the dike the fold becomes more open, but the northeastern limb continues to be the steeper. Near the Empire dike the Blue limestone crest is just below the Empire second level. Here it has a rather flat crest which bends sharply into a nearly vertical northeastern limb that drops about 200 feet to the fourth level where it flattens off sharply and rises into the fold to the northeast. The southwestern limb is not as clearly outlined by developments, but it is less steep and the top of the Blue limestone does not reach the third level before it flattens into the trough of the syncline.

The sharp bending has greatly brecciated the "Novaculite," and near the dike fissure it has been further brecciated. The adjustments in the breccia mass during the folding and subsequent intrusion of the dike have produced a complexity of detailed structure that is difficult to decipher. The roll plunges to the southeast as shown in Plate XVI. Where it meets the Skip-shaft fissure the Blue limestone crest is midway between the third and fourth levels.

Mineralization on the Silver Thread roll extends from the Empire dike to the Skip-shaft fissure, a distance of about 600 feet. It has been most productive near the Empire dike.

The Blue limestone has been more or less continuously mineralized along the crest of the roll 400 or 500 feet from the dike. There has also been mineralization that has yielded commercial ore on the steep northeastern limb of the roll.

The lower "Novaculite" zone has not as yet been widely productive in this roll, but there has been important production from the Benson and Albert ore body, mainly between the third and fourth levels in brecciated "Novaculite" and limestone close to the Empire dike. This is a thicker and more irregular ore body than most, evidently due to the replacement of the breccia, but otherwise does not differ from the replacements in the less-disturbed beds. The relation of mineralization to northeast fissures is not as clear in the ore bodies of the Silver Thread roll as it is in that of the Holderness roll.

The Benson-Albert ore body was nearly continuous with the ore body on the Holderness roll and probably is related to northeast fissures southeast of those that formed the Holderness ore body.

In the Silver Thread roll the Blue limestone has been most productive. The lower "Novaculite" zone has been prospected in several places and locally is strongly silicified and mineralized. Brecciated fault zones have been largely productive in the Benson-Albert ore body. The limestone beds in the shales above the Blue limestone have not been prospected on this roll except along the Skip shaft fissure, where they have been productive.

Macia roll.—The Macia roll, next southwest of the Silver Thread roll, is in general similar to the Silver Thread roll. Where crossed by the Skip shaft fissure, however, it is a very narrow "pinch." The limestone folds sharply in the pinch 70 feet above the third level, and the width of the Blue limestone across both limbs of the pinch on the third level is only 50 feet (Plate XXIII).

The Naco limestone below the pinch is in a rather open fold, and only the Blue limestone and beds above are involved in the sharp fold.

At the Empire dike the top of the Blue limestone at the crest of the fold is about 15 feet above the second level. At the Skip shaft fissure it is about 65 feet above the third level. About 50 feet farther southeast it is cut off by the Tranquility fault (Plate XVII).

The Blue limestone at the crest of the roll has been mineralized from the Empire dike nearly to the Tranquility fault. The mineralization has been most continuous on the crest, but it has also extended down both flanks of the fold.

The lower "Novaculite" zone has been prospected near the Empire dike on the third level and along the Skip shaft fissure on and below the fourth level. Some mineralization has been found and a little ore developed. The limestone in the shale series has not been prospected except at the Skip shaft fissure.

Roll southwest of Macia roll.—The second level of the Empire Mine exposes a small roll east of the Empire dike and 125 feet southwest of the crest of the Macia roll. Near the dike, where the roll is crossed by a northeast fissure, the "10-foot limestone" contained a small body of low-grade siliceous pyritic ore that was mined down the southwestern flank for approximately 45 feet below the second level. Immediately below on the third level, the roll is not represented; apparently it has been cut off by a steeply northeastward-dipping reverse fault. This displacement seems to diminish southeastward where the roll is exposed in the Skip shaft fissure workings and on the third level of the Tranquility Mine.

Empire anticline west of Empire dike

The Empire anticline has been extensively developed for a distance of about 2,000 feet between the Empire and Tribute dikes. Northwest of the Tribute dike there has been little development and production. The Blue limestone and the upper portion of the "Novaculite" were eroded from the top of the anticline over the northwestern part of the area before the Cenozoic conglomerate was deposited. On the section of the Empire anticline between the Empire and Tribute dikes are several rolls that tend to separate and join, so that a definite designation is not everywhere possible, and there are some differences in naming on local mine maps.

East of the Tribute dike two rolls—the Vizina and the Quarry—form, respectively, a northerly and a southerly crest of the Empire anticline. They are not, however, simple rolls throughout their extent southeastward to the Empire dike. The Vizina roll, which near the Tribute dike is composed of three subrolls, has not been developed throughout from the Tribute dike to the Empire dike, but the compound Goodenough roll near the Empire dike has a similar position on the Empire anticline and may be provisionally correlated with it. The Quarry roll branches southeastward into the Toughnut and Girard rolls. All have associated minor rolls.

This part of the Empire anticline is crossed by a series of northeast fissures of which many are mineralized and several have been mined as fissure deposits. From southeast to northwest the prominent fissures that have produced ore are the Tribute, Girard, West Side, Ingersol, and Defence fissures. These with many less prominent fissures appear to be the channels from which mineralizing solutions entered.

Vizina roll.—The Vizina is the most northeasterly roll that has been developed on the Empire anticline west of the Empire dike. At its northwestern extension near the Tribute dike it consists of three distinct rolls distributed over a width of 350 to 400 feet, which may be designated as the Northeast, Middle, and Southwest Vizina rolls.

Production from the Vizina roll has been mainly from the "Novaculite" and to some extent from the top of the Naco limestone (Plate XVIII and Fig. 4). In most of this area east of the Tribute dike, erosion prior to deposition of the Cenozoic conglomerate removed all the rocks above the "Novaculite." In places the conglomerate was laid down directly on ore that had been exposed by erosion. The area is crossed by many northeast fissures of which several are mineralized, but none sufficiently to encourage extensive development as fissure deposits. West of

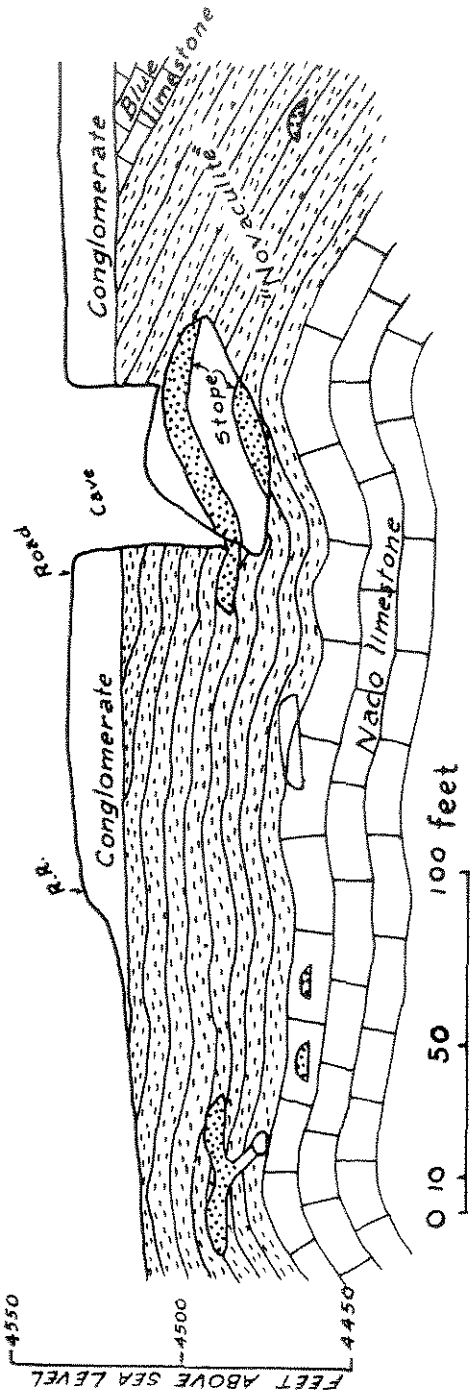

Figure 4.—Cross section of Vizina roll, looking northwest.

the Tribute dike the rocks are faulted down and less deeply eroded (Plate XVIII).

The Northeast Vizina roll has been developed for about 700 feet southeast of the Tribute dike. Near the dike the roll has been mined for a width of 150 feet. A width of 100 feet or more was mined for 400 feet southeast of the dike. Farther southeastward the mineralized zone narrowed and almost pinched out. The roll plunges southeastward gently in its northwestern portion and more steeply farther southeastward. The mineralization at several horizons, none of which is mineralized over more than a small fraction of the roll, has resulted in a complex maze of overlapping and branching ore shoots.

The Middle and Southwest Vizina rolls, where developed northwestward, are distinct and separated by a gentle syncline. They converge and appear to join southeastward. The Middle roll has been developed for a distance of about 350 feet, from the probable junction with the Southwest roll northwestward to the Tribute dike, and was productive throughout this area. The Southwest roll has also been developed from the junction to the dike but was not productive near the dike (Plate VI). From the junction southeastward nearly to the Ingersol fissure there has been little development along the projected extension of the roll.

As already stated the production from this area has been from the "Novaculite" and to some extent from the top of the Naco limestone. The Blue limestone has been eroded from all but the most southeasterly extension of the north Vizina stoped area.

Goodenough roll.—The Goodenough roll, east of the Boss dike, occupies a position on the Empire anticline similar to that of the Vizina rolls to the northwestward, but the slight development of the area between makes correlation uncertain. What is known as the Goodenough roll is made up of several rolls.

The development, almost entirely in Blue limestone, has extended from the outcrop near the collar of the Goodenough incline to the Empire dike, a horizontal distance of about 1,000 feet. In this distance the Blue limestone along the roll plunges from the surface nearly to the fourth level where it is cut off by the Empire dike fault. The structure in detail is complex with sharp pinches in the Blue limestone, some slight overturns to the southwest, and some reverse faults that have duplicated the formations (Plate XXIV, *A*). Southeastward some of the reverse faults give way to rolls; near the Empire dike the Red-stope roll to the north is separated from the Goodenough by a syncline. North of the Red-stope roll are two rolls that have not been prospected. The Goodenough roll is crossed by the Tribute, Girard, West Side, and Ingersol fissures as well as by many less prominent fissures that have not been named. Mineralization of the Blue limestone in some parts of this roll, particularly along the northeastern flank, has been practically continuous from the outcrop to the Empire dike. The Blue limestone has been extensively developed. The limestone members in the shale sequence above the Blue limestone

have been opened near the surface and have yielded some ore. The "Novaculite" in this area has been prospected but little.

Quarry-Toughnut roll.—The Quarry roll forms the southwestern crest of the Empire anticline where it is cut by the Defence fissure. Southeastward it appears to become two rolls of which the northeasterly one forms the crest of the anticline known as the Toughnut roll, and the southwestern one the Girard roll.

The Quarry roll has been developed almost continuously from the Defence fissure to a short distance west of the Empire dike, a horizontal distance of about 1,900 feet, and is perhaps the longest and most continuous ore shoot developed in the district (Plate XIX).

The top of the Naco limestone on the crest of the roll is near the surface where it meets the Defence fissure. The roll plunges southeastward, gently in its northwestern portion and more steeply farther southeastward. It crosses the Sulphuret dike below the third level and projected would meet the Empire dike at about 25 feet below the fourth level. Like most of the rolls it is not a simple fold throughout its length but is composed of overlapping parallel folds.

Production from the Quarry-Toughnut roll has been largely from the lower part of the "Novaculite." Higher zones in the "Novaculite" have been mineralized near some fissures, and considerable ore has been mined from them. The Blue limestone has been prospected to some extent on this roll, especially above the Chino stope in the southeastern part, but has yielded relatively little ore. The limestones above the Blue limestone have not been prospected.

Roll on southwestern flank of Quarry roll.—The second level of the Empire Mine has exposed a small, close roll in the shale series on the southwestern flank of the Quarry roll, west of the Empire dike. Where the roll is crossed by a northeast fissure 225 feet west of the Empire shaft, a small body of rich gold ore was developed in a thin bed of impure, shaly limestone. This ore was followed southeastward, down the plunge of the fold, to a depth of more than 40 feet below the second level and 100 feet west of the dike. In these lower workings the roll is tightly squeezed with almost vertical limbs. As it is not present on the third, fourth, and fifth levels, the structure is believed to represent a drag fold on the flank of the Quarry roll.

Girard roll.—The Girard roll is on the southwestern limb of the Empire anticline. Its trend projected northwestward would meet the Quarry-Toughnut roll at a point about 400 feet southeast of the Tribute dike (Plate VI). The Blue limestone, which has been developed on the southwestern limb of the roll, is cut off by erosion southeast of the projected junction with the Quarry roll. The northeastern limb of the roll dips gently toward the Toughnut roll and the crest of the Empire anticline. The southwestern limb drops steeply toward the Sulphuret syncline.

The crest of the roll at the top of the Blue limestone pitches southeastward from the surface west of the Toughnut shaft to

some 40 feet above the third level at a point about 900 feet farther southeast (Plate XX). Development of the southwestern portion of the roll as far southeast as the West Side fissure has been mainly on the Blue limestone. Where the West Side fissure crosses the roll, mineralization extends from the Naco limestone through the "Novaculite" and Blue limestone to the shale. The stopes on the shoot, known as the Vertical stopes, are 100 feet high. Southeast of the West Side fissure, development has been mainly in the lower portion of the "Novaculite." The limestones above the Blue limestone have not been prospected on this roll.

Rolls in Sulphuret syncline

A well-defined roll is exposed 250 feet west of the Girard shaft, on the second and third levels of the Toughnut, and the fourth level of the West Side Mine (Plate XXIV). There the top of the Blue limestone on the axis of the roll is approximately 25 feet above the third level of the Toughnut. It has yielded some small ore bodies where crossed by the Boss dike fissure. Elsewhere this roll has not been prospected. Projected southeastward, it would be intersected by several northeast fissures that are associated with ore bodies in the Girard and West Side rolls and would meet the Empire dike near the northeastward projection of the Arizona Queen fissure. At that place the Blue limestone of the roll should be well above water level.

On the fourth level of the West Side fissure workings, 150 feet southwest of the Boss dike, is exposed a sharp roll in the shale (Plate XXIV, *A*, *B*). So far as known, this roll has yielded no ore. Where intersected by the West Side fissure, the Blue limestone is probably below water level.

Sulphuret anticline

The Sulphuret anticline is southwest of and essentially parallel with the Empire anticline from which it is separated by the Sulphuret syncline. It plunges gently southeastward. Its crest is distinctly lower in elevation than that of the Empire anticline. The Sulphuret anticline along its trend varies in form more than the Empire anticline. In general the change from southeast to northwest is a closer compression of the structures, though the fold as a whole is much simpler and flatter than the Empire anticline. Along the Arizona Queen fissure the Sulphuret anticline has a gently dipping northeastern limb to the Sulphuret syncline which is here an open, flat fold. The southwestern limb drops steeply to the Boss terrace. Northwestward, along the line of the Eastside and Tribute fissures, the northeastern limb of the anticline has become steeper and the Sulphuret syncline a sharper fold, whereas the southwestern limb of the anticline dips more gently to the Boss terrace. Farther northwest, at the West Side shaft, the Sulphuret anticline nearly merges with the Boss terrace on the southwest but dips steeply to a well-defined syncline to the northeast (Plate XXIV, *A*, *B*).

West Side roll.—The crest of the Sulphuret anticline with associated minor folds is termed the West Side roll. It has been followed underground for 1,600 feet from the third level crosscut 175 feet northwest of the West Side shaft southeastward to the fifth level drift 50 feet southeast of the Sulphuret stope. As exposed in the West Side fissure workings, it is a double fold whose two rather sharp crests at the top of the Blue limestone are 125 feet apart horizontally and 35 feet vertically (Plate XXIV, *B*). In the Arizona Queen fissure workings, the southwestern or minor crest is 75 feet lower in elevation than the major crest. The axis of the roll is essentially horizontal from the West Side fissure to the Boss dike but pitches about 10 degrees southeastward between the Boss and Sulphuret dikes and at 15 to 20 degrees southeast of the Sulphuret dike. Southeastward the roll broadens from a sharp fold at the West Side fissure to a broad flexure at the Sulphuret stope (Plate XXII). Between the West Side fissure and the Sulphuret dike, at least, the Blue limestone in the northeastern flank of the roll has been duplicated by a bedding fault. Whether this duplication continues southeast of the Sulphuret dike, dies out, or gives way to a fold, is not known.

Development of the West Side roll has been very largely on its northeastern flank and northeastern major crest.

From the crosscut 175 feet northwest of the West Side fissure to the Boss dike, a third level drift near the northeastern axis of the roll encountered bunchy, high-grade ore in an impure limestone bed in the shale sequence. Diamond drilling by the Eagle Picher Company at a point 170 feet southeast of the West Side shaft showed this drift to be 88 feet above the top of the Blue limestone. The largest and richest ore body mined from the roll was accidentally discovered on the northeastern flank, between the fourth and fifth levels, where the Blue limestone is duplicated by a bedding fault. This ore body extended from the West Side fissure to the Boss dike. In its northwestern half it was 10 to 50 feet high by 5 to 20 feet wide and followed the zone of the bedding fault in the Blue limestone. In its southeastern half it transected the limestone beds to the shale along a northeast fissure. From this fissure to the Boss dike the ore occurred in the upper part of the Blue limestone and was 10 to 20 feet high by 30 to 60 feet wide. The production from this ore body is reported to have exceeded $500,000, and much of the ore was worth $100 per ton, predominantly gold. Mineralization of the ore body appears to have been accomplished by northeast fissures, of which two are mapped on Plate IV.

Between the Boss and Sulphuret dikes the West Side roll has been opened on its northeastern crest and flank by the third, fourth, and fifth levels which connect with the Boss and Sulphuret inclines. In this sector it is crossed by the Tribute and other northeast fissures as shown on Plate XXI. On the third level near the Boss dike two ore bodies were found in a thin, impure limestone member of the shale sequence, apparently at the horizon of the "6-foot limestone" (Plate XXI). The production from these stopes is reported to have been worth $125,000. Near the Boss incline ore was mined from the "10-foot limestone" along the main crest of the roll and from the Blue limestone at places along the northeastern flank (Plate XXI). The Sulphuret incline followed ore at the top of the Blue limestone along the main crest of the roll from the fourth level to the fifth level at the Sulphuret dike.

Southeast of the Sulphuret dike the roll has been opened on the fifth level, by the Sulphuret stope, and along the Arizona Queen fissure down to the seventh level of the Pump shaft workings. The Sulphuret ore body was a bed replacement at the top of the Blue limestone of the main part of the roll, which, southeast of the Sulphuret dike, was relatively broad. This ore body stope was 300 feet long by 25 to 100 feet wide and 3 to 8 feet high. According to J. H. Macia, it was mined in 1904-5 and made a gross production, largely of sulphide ore, worth $500,000. The central portion averaged $70 per ton, with a gold-silver value ratio of approximately 1:1. Its mineralization appears to have been accomplished by the Arizona Queen and other northeast fissures.

Along the Arizona Queen fissure, ore that, according to Mr. Macia, averaged $40 per ton was mined from the upper part of the Blue limestone southwestward from the Sulphuret stope down to the seventh level of the Pump shaft workings. At the 650 level, some 30 feet below water, the ore formed a body reported to be 25 feet thick on the southwestern or minor crest of the West Side roll and 5 to 30 feet wide by 80 feet long on the northeastern minor flank. At the seventh level was another body of similar size but higher grade.

In summary the West Side roll has not been thoroughly prospected southeast of the West Side fissure and practically not at all northwest of that fissure. Its southeastern crest and flank have been explored only along the West Side and Arizona Queen fissures and Boss dike. The "Novaculite" of the roll has been opened only in the West Side fissure workings and on the seventh level of the Pump shaft, and the Naco limestone only in the West Side fissure.

The Blue limestone on the main crest has been prospected for only part of the length of the roll, and the Blue limestone-shale contact along the northeastern flank has received comparatively little attention.

Northwestward from the West Side fissure to the Defence fissure, a distance of 1,000 feet, there has been little prospecting of the Sulphuret anticline and associated rolls, although this part of the anticline is crossed by the projected extension of the Ingersol and other fissures that appear to have been the channelways for mineralizing solutions that have produced deposits in other rolls.

Boss terrace

Immediately northeast of the West Side No. 1 shaft or some 550 feet southwest of the main (No. 3) shaft, the West Side fissure

intersects a roll on the Boss terrace. As these workings have long been inaccessible, little is known of the structure. According to J. H. Macia, the "10-foot limestone" reaches the fourth level, and the fifth level station of the No. 1 shaft is in the Blue limestone. Some 500 feet farther southeast, the top of the Blue limestone on this roll was opened by the sixth level.

On the seventh level of the Pump shaft workings, 250 feet south of the Boss shaft, a body of sulphide ore about 100 feet long by 75 feet wide, known as the "29" body, was stoped from the upper part of the Blue limestone. It appears to have occurred where a low flexure in the Boss terrace is intersected by a northeast fissure.

Ingersol overturn

Southwest of the Boss terrace the beds turn down in a sharp overturned fold (Plate XXII and Fig. 5). The most extensive developments on this structure are those of the Ingersol Mine, from which the name, Ingersol overturn, is taken.

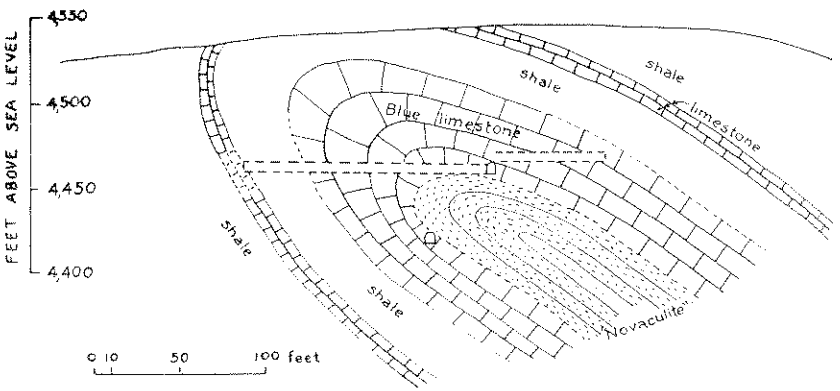

Figure 5.—Cross section of Ingersol overturn, looking northwest.

The overturn has been somewhat developed from northwest of the Ingersol Mine to the Arizona Queen fissure, a horizontal distance of about 2,000 feet. Most of this development has been in the Blue limestone, but the Tribute Mine workings on the Ingersol overturn, near the Tribute dike and Tribute fissure, are in the shale sequence above the Blue limestone. In the developed area the overturn is crossed by the Arizona Queen, Herald, Tribute, Blue Monday (West Side), Ingersol, and other less conspicuous fissures.

The crest of the overturn on the top of the Blue limestone is cut by the erosion surface near the collar of the Ingersol incline but is exposed on the southwestern side of the incline a short distance below the surface. The Ingersol workings in the Blue limestone extend southeastward to the Blue Monday (West Side) fissure.

Most of the production has been from the Blue limestone on the steep overturned limb of the fold where it is crossed by fissures, particularly the Ingersol and Blue Monday (West Side), and between these fissures. The flat-dipping upper limb has been little developed. The fissures contain ore where they cut the Blue limestone, but little ore has been found in the shale above the limestone. The "Novaculite" is exposed in the workings, but the Naco limestone has not been reached.

The ore, except in the lower workings, is oxidized, and so far as can be judged from material remaining in the stopes, is similar to other Blue limestone replacement deposits with perhaps more zinc and manganese present than in the more northeasterly deposits and less manganese than in those farther to the south and west. A stope tributary to the Ingersol incline, according to J. H. Macia, yielded ore that contained 0.08 ounce of gold and 40 to 80 ounces of silver per ton and 25 per cent lead. Small streaks of high-grade gold-silver ore were mined in places.

Farther southeast the Ingersol overturn has been developed on the Tribute fissure by the Tribute shaft to the fourth level in the shale sequence above the Blue limestone. The workings were not accessible at the time of the study, but the deposit is said to be in the Tribute fissure in and near the Tribute dike. The Tribute ore was particularly rich in gold and silver.

The seventh level of the Pump shaft was extended across the Tribute fissure near the overturn of the Blue limestone, but little ore was found. Still farther eastward, on the Arizona Queen fissure, the Blue limestone was cut in a winze below the seventh level of the Pump shaft and is said by Mr. Macia to have contained ore but not in sufficient amount to encourage further development. It may be noted that the sharp overturn of the fold was not opened where crossed by the Arizona Queen fissure.

FISSURE DEPOSITS

Several deposits of the district are confined to simple fissures. Other deposits consist of mineralized fissures closely associated with replacement deposits that extend outward from the fissures along favorable beds. The following descriptions include both types.

Skip-shaft fissure

The Skip-shaft fissure is a strong northeast fissure that crosses the northeastern section of the district. The Arizona Queen fissure is probably the southwestward continuation of the Skip-shaft fissure across the Empire dike. The North Point fissure has been considered the upward continuation of the Skip-shaft fissure that has been faulted down on the Tranquility fault. This assumes the Tranquility fault to be postmineral (page 70).

The Skip-shaft fissure has been productive for about 900 feet along the strike and for a maximum of about 600 feet below the

surface near the Silver Thread shaft where it has been mined below the water level on the Blue and Naco limestones. Stratigraphically it has been developed from a short distance below the top of the Naco limestone to perhaps 400 feet above the Blue limestone in the shale-sandstone sequence (Plate XXIII).

It cuts across the Empire anticline and the associated Macia, Silver Thread, and Holderness rolls.

On the anticline the Blue limestone rises for a vertical distance of about 470 feet, from below the sixth level near the Silver Thread shaft to 70 feet above the third level on the crest of the close Macia roll. Southwestward from the general crest the limestone drops about 300 feet to the Sulphuret syncline.

The fissure has perhaps been most productive along its intersection with the Blue limestone, where the ore makes out for considerable distance along the beds, and next most productive in limestone beds of the shale-sandstone series.

Most of the area mined in the shale sequence was not accessible to the writers, but from reliable information there seems no doubt that the fissure was mineralized and the vein mined over considerable areas regardless of the character of the wall rock (Plate XXIII). The fissure cuts the rolls on the Empire anticline, as already mentioned, and undoubtedly had some part in forming the ore bodies on the rolls. It may be noted, however, that although a strong fissure it seems to have been less effective in mineralizing large areas of the limestones than were some apparently less prominent fissures.

West Side fissure

The West Side fissure has been opened almost continuously from the Sulphuret dike on the northeast across the Empire and Sulphuret anticlines to the Grand Central fault. Across this fault it is probably to be correlated with the Blue Monday fissure, which can be traced to the Coyote fault. Beyond this fault it is probably represented by one of the fissures opened in the Lucky Cuss Mine, though the correlation here is questionable. Where opened to the greatest depth, the eighth level in the West Side shaft, it dips steeply southeastward, though where exposed over limited areas it commonly appears to be essentially vertical. The developments on the fissure cover a stratigraphic range from the Naco limestone to probably 500 feet above the Blue limestone.

The largest production from the simple fissure deposit has been from limestone beds in the shale sequence near the West Side shaft and southeast of that shaft (Plate XXIV, *B*). By far the largest deposit of this type is in the limestone beds in the shales on the Sulphuret anticline (Plate XXIV, *B*). As the workings here are largely inaccessible, information regarding the distribution of stopes, as shown in Plate XXIV, *B*, is mostly taken from old maps. Mineralization seems to have been essentially continuous over a large area but doubtless differed from place to place due to the character of rock and other conditions, as it is known to do in other fissures.

Where the fissure crosses the rolls of the Empire and Sulphuret anticlines the fissure deposit merges with the bed replacement deposits. In places, as along the crossing of the Girard roll, the favorable bed replacement horizons from the top of the Naco limestone through the "Novaculite" to the top of the Blue limestone have been replaced along the fissure, producing a large fissure ore body that merges with the bed replacement ore bodies. As mined in the Vertical stope it was 100 feet high (Plate XXIV, *A*).

A deposit probably of similar character has been opened where the Blue Monday fissure cuts the Blue limestone on the Ingersol overturn.

Arizona Queen fissure

The Arizona Queen fissure is probably the southwestward continuation of the Skip shaft fissure, offset about 150 feet south on the Empire dike. Exposures of the fissure at the surface on the Arizona Queen or Last Chance claim show a zone of shearing 4 or 5 feet wide that strikes N. 50 degrees E. and dips vertically or steeply northeast. Farther southwest the fissure ends at, or is probably displaced by, the Grand Central fault.

The fissure has been most productive at its intersection with the Blue limestone (Plate XXII). The Sulphuret bed replacement deposit, in the Blue limestone on the north limb of the West Side roll, is said to have yielded ore to the value of half a million dollars. A continuous shoot of ore, one of the long shoots of the district in the upper part of the Blue limestone, extends from the Sulphuret stope southwestward down the south limb of the West Side roll across the Boss terrace to the Grand Central fault, a distance of 1,150 feet (see structure section). Mr. Macia states that the ore west of the Sulphuret stope was confined to the fissure, with a width of 10 to 12 feet and a maximum thickness of 20 feet.

Southwest of the Grand Central fault an indistinct fissure appears in the proper location for the Arizona Queen fissure, but its correlation is uncertain. From the Arizona Queen drift of the seventh level, 170 feet west of the fault, a winze reached the top of the Blue limestone at a depth of 110 feet but exposed little ore. It is not known that this development was on the Arizona Queen fissure.

The fissure in the shale near the surface on the Arizona Queen or Last Chance claim has yielded some ore in narrow, irregular bodies that were developed to a depth of about 100 feet. The fissure in the shale was opened from the third level of the West Side shaft, but little mineralization was found there.

Defence fissure

The Defence fissure is the most northwesterly fissure within the Tombstone basin that has been productive as a fissure deposit. The main development has been where it crosses the Empire and Sulphuret anticlines. It has been most productive on the east

limb of the Quarry roll where mining along the fissure has been carried from the Naco limestone through the "Novaculite" and Blue limestone into the shale. Farther southwest the mineralization has been mainly in the shale. Northeast of the Quarry roll there has been production from the fissure near the surface in the Naco limestone and the "Novaculite."

The Defence fissure in its eastern part strikes distinctly more easterly than the prevailing direction of ore fissures. It seems probable that it is not a true ore fissure but an earlier fault fissure that has been mineralized by ore fissures that cross and perhaps join it.

Fissure veins in quartz latite

The Uncle Sam quartz latite porphyry occupies the western part of the district, including the Three Brothers Hill and Uncle Sam Hill, and extends westward toward Charleston beyond the mapped area. This quartz latite porphyry mass, in its eastern portion at least, seems to be a sill-like body intruded into the Bisbee group. Several mines and prospects, including the State of Maine, Montezuma, San Pedro, and Merrimac, have been developed in the quartz latite.

The mineralization is in a fissure zone of northeasterly trend. The individual fissures range in strike from N. 25 degrees E. to N. 50 degrees E. and dip 30 to 75 degrees NW.

The presence of gouge and striations on the walls of the fissures clearly show them to be faults, and faulting is also shown on some of the fissures that cross and offset the contact of the quartz latite with the sedimentary rocks. In general the fissure system is relatively simple, but some of the fissure zones, as in the State of Maine Mine, are complex in detail.

Alteration of quartz latite.—All of the rock in the fissured zone weathers brownish to reddish, apparently due to the oxidation of small amounts of pyrite. The wall rock of the fissures shows considerable range in alteration. The San Pedro vein and other near-by veins crop out several feet above the surrounding rocks through part of their length. The portions relatively resistant to erosion are characterized by silicified wall rock. Such outcrops commonly show rather strong stains of manganese. The wall-rock alteration of the State of Maine vein is to a soft claylike material that erodes readily, and the outcrop of the vein is inconspicuous. The alteration by the ore solutions appears to have been mainly sericitization, which was later modified by surface solutions. Intense alteration extended for not more than a few feet from the fissure.

Veins.—The ore in the State of Maine vein appears to be confined mainly to narrow stringers in the crushed and sericitized rock of the fault fissures. Vein quartz is present as a gangue mineral in small amounts in some of the stringers, but in much of the ore it is nearly or quite lacking. There was no opportunity to study the unoxidized ores of this type, but, from the oxidized ores that were seen, some suggestions as to the character of the primary

metallic minerals may be offered. The oxidized ores and vein material contain limonite, but except locally the veins do not appear to have been high in iron. Oxides of manganese are conspicuous in a few places in the State of Maine Mine, but manganese apparently was not abundant in the ore. Copper stains are present in places in the veins, but the assay maps show very little copper and little lead. The principal value of the ores is in silver; the assay maps of the State of Maine veins show from 0.01 to 0.02 ounce in gold per ton.

The silver in the oxidized ores is said to have occurred largely as horn silver. This character of oxidized minerals indicates a rather weak primary sulphide mineralization with the silver in some rich silver mineral. Developments in this type of deposit have nowhere been carried below the zone of almost complete oxidation of the sulphides. In the San Pedro Mine oxides of manganese appear to have been more general and abundant.

State of Maine Mine.—The State of Maine Mine has been the most extensively developed and most productive of the deposits in the quartz latite porphyry. Detailed figures of production are not available, but estimates range around $200,000.

The State of Maine vein has been opened by an inclined shaft 480 feet in length that reaches a vertical depth of 325 feet below the collar. The zone has been developed for a maximum distance of 900 feet along the strike, but most of the production has come from within an area 500 feet long.

The rock at the surface is all quartz latite porphyry, but the seventh or bottom level penetrates an area of shale 225 feet wide. Probably this shale is connected with the area of Mesozoic rocks that crop out 1,800 feet farther north.

The main or footwall vein has an average dip from top to bottom of the shaft of 40 degrees NW. but with a pronounced upward roll between the third and seventh levels (Plate XXVI). The hanging-wall vein, of somewhat flatter average dip, is 60 feet horizontally west of the footwall vein on the third level and 90 feet on the seventh level. The hanging-wall vein joins the footwall vein to the south and probably to the north. These two and other less developed veins are parts of a single fracture zone.

The fractures that have been cut by and developed from the seventh level crosscut lie west of the main producing fissures. Where developed, they show mineralization but little ore.

The extent and position of the stoped areas as recorded on available maps is shown on Plate XXV. The width of the vein in places amounts to several feet, but too little of the stoped areas could be seen for general estimates of it.

No record of the grade of the ore mined is available. Small stringers are said to have been very rich in silver, but the average as mined was probably of moderate grade.

The average of extensive sampling of the accessible workings in 1915 by the Phelps Dodge Corporation, since which time there has been but little development, is as follows:

ASSAY RECORDS, STATE OF MAINE MINE

Level	Number of samples	Average width (feet)	Average gold (ounces)	Average silver (ounces)
1st and 2nd	251	2.73	0.017	1.98
3rd	196	2.06	0.023	3.50
4th	199	1.80	0.019	4.35
7th	178	1.29	0.012	3.27
3rd (high-grade samples)	4			465.30

Why the ore is localized in parts of the fissure is not very evident. As already noted, the footwall and hanging-wall fissures join to the south and probably to the north. Most of the ore has come from the area where the fissure is split into the two branches, though ore has been mined to the south considerably beyond the junction. In the north end of the mine the most extensive mineralization was in the hanging-wall fissure. Only a small part of the production has come from below the fifth level on either hanging-wall or footwall branches. The footwall fissure is a warped plane that below the fifth level steepens distinctly to 55 to 60 degrees. The most productive area is in the flatter part of the vein.

San Pedro Mine.—The San Pedro vein, which is entirely in the quartz latite porphyry, strikes N. 30 degrees E. and dips steeply northwestward.

Silicification of the wall rock has been pronounced along parts of the fissure, and these parts crop out prominently. The mine was inaccessible at the time of the visit, but the size of the dump indicates considerable development, which is known to extend to the third level. The mine yielded some ore, but neither the amount nor the grade is known.

From the outcrop and from the material on the dump, it appears that the vein contains more manganese and quartz than the State of Maine vein, but otherwise the ore may not have been greatly different.

DISTRIBUTION OF METALS AND MINERALS

Tombstone is essentially a precious-metal district. Of the production by value from 1879 to 1933,[52] silver amounted to about 81 per cent and gold about 14 per cent of the total. The remaining 5 per cent was mainly lead with some copper, manganese, and zinc.

The ores in different parts of the district range greatly in content of the different metals, and whether they were recovered or not depended somewhat on the degree of oxidation. Zinc has been recovered only from sulphide ores, and the distribution of oxidized zinc minerals is little known. Manganese, on the other hand, has been recovered only from oxidized ores.

[52] Morris J. Elsing and Robert E. S. Heineman, *Arizona Metal Production* (Arizona Bureau of Mines, Bull. No. 140), 1936, p. 91.

The distribution of metals suggests an area of most intense mineralization in the northeast section of the district with a rough zoning outward. The most definite of the metal zones are the central gold zone and the marginal manganese-silver zone. The gold zone is characterized by abundant quartz and fluorite, and the manganese-silver zone by manganese.

Silver

Silver is the most widely and uniformly distributed of the metals that have been recovered. It is present in nearly all types of ore from those chiefly valuable for gold to those chiefly valuable for manganese, but ores extraordinarily high in gold are not uniformly high in silver, and some of the ores very high in manganese contain but little silver. Ores high in lead may or may not be high in silver. Some ores have practically all their value in silver.

Gold

Gold is more restricted than silver in distribution, both geographically and as to the minerals and metals with which it is associated. Geographically, ores with important gold are restricted to the northeastern part of the district, part of the Lucky Cuss-Herschel zone, and the Ingersol and Tribute deposits.

The deposits in the outlying parts of the district, as those in the quartz latite porphyry intrusive rock and Mesozoic sedimentary rocks of the western part of the district, contain little gold. The Tombstone Extension and neighboring deposits east of Tombstone are mostly low in gold. Even the Vizina deposits contain but little gold.

Within the gold producing areas the gold content is greatest in or near the northeast fissures as contrasted with replacement deposits extending outward from the fissures.

No satisfactory record of the metal content of individual shoots is available for the district as a whole, but a few records show the decided range in gold content.

The ores from the "409" stope on the Holderness roll in the gold area had a silver-gold value ratio of about 1.48 to 1, as compared with 6 to 1 for the production of the district.

The ore produced by the Tombstone Extension Mine, in the eastern part of the district, averaged approximately 0.071 ounce in gold per ton.

Lead

Lead occurs widely distributed but less so than silver. It is low in the fissure deposits in the western part of the district and low in the deposits that are high in manganese.

Manganese

Manganese in small amounts is widely distributed, and manganese minerals are present in all parts of the district. It is abundant, however, only around the margins of the more produc-

tive parts of the district, particularly in the mines on the Lucky Cuss and Oregon-Prompter ore zones and in some of the mines in the western part of the district. Very locally it is abundant in the Vizina deposit. In the gold area it is present in small amounts, largely in "black calcite," which is a late mineral and possibly supergene, at least in part.

Silver is present with much of the manganese, and a large amount of silver-manganese ore has been mined.

Copper

Copper is also widely distributed but in small amounts, and its distribution is not well known. It seems to be most abundant in and near strong northeast fissures.

Copper carbonate stains in the fissures are generally regarded as good indications of ore near by.

The Emerald Mine probably contained the largest body of copper ore.

Zinc

The distribution of zinc is not well known. Probably the largest body mined was in the Silver Thread area.

Molybdenum

Molybdenum occurs in the ores as wulfenite, the lead molybdate. It is present over a considerable part of the district but is most abundant in the gold areas particularly of the Silver Thread roll. Like the gold it is most abundant in and near the northeast fissures. The wulfenite is, however, a secondary mineral not closely associated with gold, and the material high in molybdenum is not generally high in gold. Wulfenite rather commonly occurs around or beneath an ore body, and although conspicuous, it nowhere forms more than a small percentage of the larger bodies of ore.

Iron minerals

Iron minerals that have resulted from oxidation of iron sulphide are widely distributed. They are mainly hydrous ferric oxide that may be called limonite and basic ferric sulphates, members of the jarosite family. Although widely distributed, iron does not form a large percentage of most of the ore. It has resulted mainly from the oxidation of pyrite and probably no large bodies of massive pyrite were present in the primary ores.

Iron seems to be most abundant in and near the gold area. The silver-manganese ore shoots and the fissure deposits in the western part of the district are low in iron.

Nonmetallic minerals

Of the nonmetallic minerals, quartz and fluorite are of most interest.

Quartz is widespread but is most abundant in the gold areas. There are numerous types of occurrence, but two are particularly

conspicuous: a fine-grained, cherty type that has largely replaced earlier rocks, and well-formed crystals from very small size to as much as 2 inches in length that project from the walls of cavities.

Silicification of the rock has extended for a considerable distance from some of the fissures. The silicified material is largely fine-grained, cherty quartz that in places contains disseminated pyrite. In the process of silicification open vugs or cavities were formed, some of which are lined with layers of fine-grained quartz. From the walls of the cavities project well-formed quartz crystals.

Fluorite, like quartz, is rather widely distributed, and is most abundant in the areas that are relatively rich in gold. It is not, however, closely associated with gold or with other metals. Rocks rich in fluorite are generally not ore. It is most closely associated with intense silicification where it forms a filling of silicified breccia and seems to have formed mainly during or after a late stage of the silicification.

FUTURE OF THE DISTRICT

In the discussion of the different deposits and areas in preceding pages, the extent to which they have been prospected has been indicated where known. In the following paragraphs it is intended to point out some of the more general features to be considered in development.

In the Tombstone district, as in many others that have been extensively mined, several lines of development must be carried out before its full potentialities are tested. The results of some of them can to some degree be predicted, whereas others can not yet be evaluated. They are discussed in what is regarded as the order of their predictability.

Deposits in the eastern part of the district above water level
Deposits in the eastern part of the district below water level
Deposits in the western part of the district

DEPOSITS IN THE EASTERN PART OF THE DISTRICT ABOVE WATER LEVEL

Deposits in the eastern part of the district include several types that may be considered separately, though two or more would be prospected together.

Deposits in northeast fissures
Deposits associated with faults
Deposits associated with dikes
Deposits associated with rolls

Deposits in northeast fissures

Deposits in the northeast fissures are the simplest of the group and except for some of the stronger fissures have perhaps been the most thoroughly prospected. It is not a simple matter, however, to determine from a few outcrops or a few openings what importance is to be assigned to a certain fissure.

Over a considerable area a fissure may seem unfavorable and especially so if seen where it cuts unfavorable rocks. The same fissure in another place and in favorable rock may be promising and productive. It is certain that some of the known productive fissures will prove nonproductive in other places and equally certain that some fissures that have not been productive where opened will prove to be productive elsewhere.

The area between the main Tombstone district and the Tombstone Extension Mine is largely covered by recent sediments and is little known. There may be productive veins in this area.

The fissure deposits have been most productive where they cut favorable rocks, such as the favorable limestone beds or favorable structures, and such intersections offer the greatest promise. The northeast fissures, however, are associated with all the types of deposits and, for much of the area, can best be prospected along with other types.

Deposits associated with faults

Some of the large deposits of the district are associated with faults. Bed faults or closely allied faults such as the Lucky Cuss fault and secondary faults associated with the Prompter fault have been most productive. These faults have broken the rocks and in some places duplicated favorable beds.

Deposits have formed where northeast fissures cut such faults or fault zones. The intersections of fissures and favorable beds and faulted sections of favorable beds in such zones offer promise. The old stopes in this type of deposit are not sufficiently accessible to make it possible to determine whether any faulted sections of favorable rock have been missed or neglected, but it seems possible that some have been missed.

Deposits associated with dikes

Some of the largest deposits of the district have been developed at the intersection of the Empire-Contention-Grand Central dike and northeast fissures. This belt, except for the Empire area, was so inaccessible to the writers that no clear idea was gained as to how thoroughly it has been prospected. The mine maps, however, indicate rather thorough prospecting of the sections downfaulted to the east.

Too little is known of conditions along the unfaulted portion to justify prediction of its possibilities for ore.

Deposits associated with rolls

In the deposits associated with rolls, there are several favorable horizons that are known to be mineralized on different rolls and in different parts of the same roll. An examination of the maps and sections of the different rolls will show that in none have all the favorable horizons been thoroughly prospected. On some of the rolls one or more of the favorable horizons have not been opened over considerable areas. In this type of deposit there is no doubt that additional deposits remain to be developed.

The best place to test these undeveloped areas is at the intersection of northeast fissures with the favorable beds on the bends of the anticlines. This will, at the same time, prospect the fissures.

Remaining deposits of this type may not be the largest in the district, but they are probably the easiest and the cheapest to find. In the last two years development has been extended northward to the Jeanes roll, previously known from diamond drilling and slight development by shaft and drifts, and it has been found productive near the fissure that was followed in its development. Churn drilling by the Eagle Picher Company indicated that any rolls that might be present north of the Jeanes roll will have their productive zones below water level. There has been practically no development in the rolls below the top of the Naco limestone. The possibilities in beds at lower horizons is therefore speculative.

DEPOSITS IN THE EASTERN PART OF THE DISTRICT BELOW WATER LEVEL

Some of the ore shoots yielded good ore below water level.

The amount of water raised from the Pump shaft from 1903 to 1909 is shown in the following table. Increased flow was due to increases in depth of shaft and increase in openings.

Water Raised at Pump Shaft
(Gallons per day)

Jan. 1, 1903 to Mar. 31, 1903	1,207,465
Apr. 1, 1903 to Mar. 31, 1904	2,180,341
Apr. 1, 1904 to Mar. 31, 1905	3,345,477
Apr. 1, 1905 to Mar. 31, 1906	3,164,079
Apr. 1, 1906 to Mar. 31, 1907	4,223,550
Apr. 1, 1907 to Mar. 31, 1908	4,824,642
Apr. 1, 1908 to Sept. 30, 1908	4,915,900
Oct. 1, 1908 to Sept. 30, 1909	5,008,808

Oxidation is known to extend well below present water level, but the deeper ores were in general less altered, and, since in the main, oxidation has improved the grade of the ores, it is probable that the deeper ore, on the average, will be of lower grade than that above present water level.

Mining has been carried on below the water level in the Lucky Cuss zone, in the Silver Thread, West Side, and Sulphuret areas, in the Contention-Grand Central belt, and in the Bunker Hill and Emerald mines. In several of the areas, development below the water level is a matter of necessary pumping and following known ore shoots downward. In two important areas, however, this simple process is complicated by faulting.

In the Contention-Grand Central belt, the productive shoots are cut off by faults, and their continuations must be located across the faults.

The rolls in the northwestern part of the district are also dropped down to the southeast of the productive area by the Tranquility fault. Most of them have been developed nearly to this fault, and any extensions must be located across the fault at greater depth.

Lowering the water to the tenth level in the Pump shaft is said to have lowered the water level over a wide area in the district. This fact indicates that long-continued pumping at one locality will drain a large area, but it is not necessarily true that the same result would be secured everywhere in the area. The water could be lowered rapidly and held for short periods in some localities without completely draining large, adjacent areas. It should be recognized that if mining is to be continued for long periods below the present water level, draining of the area to the depth of development will be necessary. Ore extraction below the water level, to be profitable, must be on a scale commensurate with the cost of pumping.

The elevation of the San Pedro Valley at Fairbank, 3,859 feet, is approximately 260 feet lower than the water level at Tombstone, 4,120 feet. As that is the lowest point in the area, it is not possible to drain the area to any considerable depth by tunnel. It must further be recognized that the water level at Tombstone is not very different from that in the adjacent sediment-filled valleys. If the level is lowered in the district, there may be some seepage into the area from the adjacent valleys.

DEPOSITS IN THE WESTERN PART OF THE DISTRICT

Fissure deposits in the Mesozoic sedimentary rocks and in the quartz latite porphyry in the western part of the district have not been largely productive but are of some prospective interest. Some of the veins are persistent and strong, and contain enough metal, mainly silver, to have encouraged considerable development and mining.

The quartz latite porphyry, in part at least, appears to be in sill-like bodies intruded into the Mesozoic rocks. So far as is known, no fissure in the latite or in the Mesozic sedimentary rocks has been followed downward to the Paleozoic rocks or through the main ore zone of the eastern part of the district. The position of the Paleozoic rocks in most of the western part of the district is not known. Whether the basal portion of the Mesozoic rocks and the top of the Paleozoic rocks may be mineralized, as in the eastern part, remains to be determined.

The water table has been reached in some of the shafts, and deeper exploration other than by drilling would necessitate pumping. Water in this part of the district, however, is encountered at higher levels than at Tombstone and apparently at different levels in different openings. This suggests that local water tables have been struck rather than the general water table of the region.

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