Mineralogy and Petrography of the Tombstone Mining District, Arizona

by

Charles Alfred Rasor

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## Contents

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abstract</td>
<td>iii</td>
</tr>
<tr>
<td>Introduction</td>
<td>1</td>
</tr>
<tr>
<td>Location</td>
<td>1</td>
</tr>
<tr>
<td>Previous work</td>
<td>2</td>
</tr>
<tr>
<td>Acknowledgments</td>
<td>3</td>
</tr>
<tr>
<td>Brief history</td>
<td>4</td>
</tr>
<tr>
<td>General geology of the district</td>
<td>4</td>
</tr>
<tr>
<td>Mineralogy</td>
<td>7</td>
</tr>
<tr>
<td>General statement</td>
<td>7</td>
</tr>
<tr>
<td>List of minerals</td>
<td>8</td>
</tr>
<tr>
<td>Native elements</td>
<td>10</td>
</tr>
<tr>
<td>Sulphides</td>
<td>13</td>
</tr>
<tr>
<td>Tellurides</td>
<td>19</td>
</tr>
<tr>
<td>Sulpho Salts</td>
<td>20</td>
</tr>
<tr>
<td>Haloids</td>
<td>23</td>
</tr>
<tr>
<td>Oxides</td>
<td>25</td>
</tr>
<tr>
<td>Carbonates</td>
<td>34</td>
</tr>
<tr>
<td>Silicates</td>
<td>38</td>
</tr>
<tr>
<td>Phosphates</td>
<td>50</td>
</tr>
<tr>
<td>Vanadates</td>
<td>50</td>
</tr>
<tr>
<td>Sulphates</td>
<td>53</td>
</tr>
<tr>
<td>Tellurates; Tellurites (?)</td>
<td>58</td>
</tr>
</tbody>
</table>
Mineralogy - Continued.

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Molybdates</td>
<td>60</td>
</tr>
<tr>
<td>Petrography of the Igneous Rocks</td>
<td>62</td>
</tr>
<tr>
<td>Pre-Cambrian quartz diorite</td>
<td>62</td>
</tr>
<tr>
<td>Rhyolite porphyry</td>
<td>63</td>
</tr>
<tr>
<td>Quartz latite porphyry</td>
<td>64</td>
</tr>
<tr>
<td>Granodiorite</td>
<td>67</td>
</tr>
<tr>
<td>Monzonite porphyry</td>
<td>70</td>
</tr>
<tr>
<td>Augite diorite porphyry</td>
<td>71</td>
</tr>
<tr>
<td>Basalts</td>
<td>72</td>
</tr>
<tr>
<td>Paragenesis</td>
<td>74</td>
</tr>
<tr>
<td>Hypogene vein minerals</td>
<td>74</td>
</tr>
<tr>
<td>Supergene minerals</td>
<td>77</td>
</tr>
<tr>
<td>Gold and silver mineralization</td>
<td>79</td>
</tr>
<tr>
<td>Manganese mineralization</td>
<td>85</td>
</tr>
<tr>
<td>Lead mineralization</td>
<td>86</td>
</tr>
<tr>
<td>Contact metamorphism</td>
<td>101</td>
</tr>
<tr>
<td>Introduction</td>
<td>101</td>
</tr>
<tr>
<td>Field Occurrence</td>
<td>102</td>
</tr>
<tr>
<td>Mineralogy</td>
<td>104</td>
</tr>
<tr>
<td>Bibliography</td>
<td>112</td>
</tr>
<tr>
<td>Figures</td>
<td>115</td>
</tr>
<tr>
<td>Plates</td>
<td>117</td>
</tr>
</tbody>
</table>
Abstract

This report presents a study of the mineralogy of the Tombstone mining district. A large number and variety of lead, silver, copper, and manganese minerals, in addition to some exceedingly rare zinc, tellurium, molybdenum, vanadium, and silicate minerals are described.

The greater number of minerals were formed by supergene processes. Hypogene sulphides are relatively few. They include the more common minerals, pyrite, sphalerite, tetrahedrite, chalcopyrite, and galena, and the rarer minerals, alabandite, bournonite, and famatinite. Hessite from Tombstone is believed to be the only known occurrence of a telluride from Arizona.

Rare supergene minerals are, bromyrite, silver bromide, the only known and described occurrence in the United States; hetaerolite, a rare zinc hausmannite, the third recorded locality in the United States; connellite, a rare hydrous sulphate and chloride of copper; and beaverite and plumbojarosite, which are hydrous lead-iron-copper sulphates.

The contact zone in the Paleozoic limestone adjacent to the granodiorite, especially where it is crossed by fissures, is a source of rare silicate minerals, as, thaumasite, a
hydrous carbonate, sulphate, and silicate of calcium; hillebrandite, a hydrous calcium silicate, the second locality ever recorded; and ettringite, a rare calcium-aluminum sulphate.

The igneous rocks petrographically described are; the pre-Cambrian quartz diorite, post-Cretaceous quartz latite porphyry, granodiorite, monzonite and augite diorite porphyry, and late Tertiary basalts.

Deposition of hypogene vein minerals is grouped in four main stages; (1) early gangue minerals: quartz, barite, fluorite, and calcite, in order of deposition; (2) early sulphides: pyrite, sphalerite, tetrahedrite, bourbonite, famatinite, and chalcopyrite; (3) renewed movement along vein fissures, and introduction of quartz and galena; (4) a possible fourth stage of late sulphides and tellurides, which include alabandite and hessite.

Manganese oxides are believed by the writer to have been formed by the oxidation of alabandite. The manganese was dissolved by acid sulphate solutions which, upon hydrolysis with reduction of acidity, precipitated oxides of manganese.

Field relations indicate that the lime silicates of the contact zone have resulted largely from the recombin-
atation of impurities present in the limestones with little if any introduction of silica and alumina from igneous sources.
Mineralogy and Petrography of the Tombstone mining district, Arizona

by C. A. Rasor

Introduction

This investigation represents the combined results of field and laboratory study on ores and rocks collected from the Tombstone mining district. The collecting of specimens and other data pertaining to the investigation was done during the summers of 1935 and 1936, and the laboratory study of these specimens was carried on throughout the college years of 1935, 1936, and 1937. The problem as presented will include a detailed description of the minerals, their paragenetic relationships, and the petrography of the igneous rocks.

Location

The Tombstone mining district (Plate XIV, A) is on Highway 80, about twenty-six miles northwest of the Bisbee mining district and seventy-four miles southeast of Tucson. It is a matter of only two hours drive from Tucson to visit this once famous mining camp for the purpose of collecting specimens.
Previous work

Previous work on the mineralogy has been done principally by investigators who were interested in describing rare and unusual minerals without giving much attention to the more common minerals; or by mining men who merely mentioned some of the minerals in connection with reports on the mining and milling methods used at Tombstone. One of the first articles on the district to mention the character of the mineralization was by Blake. He says that the ore consisted of pyrite, galena, lead carbonate, silver, gold, and horn silver (with probably some iodide). Later, Church mentioned tellurium as a constituent of especial interest in the ore, and stated that it probably occurs in combination with lead, silver, and gold. Goodale was the first to describe the manganese oxides from

the mines in the west part of the district. Descriptions and chemical analyses of individual minerals have been recorded by Genth, Hillebrand, and Moses. The latest report on


the district describes mainly the manganese mineralization.

Acknowledgements

The writer is indebted to Dr. B. S. Butler for guidance both in the field work and in the preparation of this thesis, to Dr. M. N. Short and Dr. F. W. Galbraith for their criticism and advice, and to Mr. E. D. Wilson, Geologist for the Arizona Bureau of Mines, for many helpful suggestions. Acknowledgements are expressed to the mining operators in the district, especially Mr. Ed. Holderness, Superintendent of the Tombstone Development Co., and Mr. E. P. Jeanes, Superintendent of the Bunker Hill lease for the U. S. Mining, Smelting,
and Refining Co., for many valuable mineral specimens. Also, the writer wishes to thank the Department of Chemistry of the University of Arizona for analyses of minerals, and Mr. J. Fritz, assayer for the Tombstone Development Co., for assays of ores and minerals.

Brief History

The following paragraph is quoted from "Structure at Tombstone, Arizona," by Butler and Wilson. They say:


"Tombstone, Arizona, was the best known mining camp in the southwest from the discovery of its mines by Ed. Scheiffelin in 1877 through the eighties. During this period it produced the larger part of the approximately $36,000,000 worth of metals that it has yielded. Since those boom days it has been a consistent producer in a small way, and during the depression years, 1930 to 1936, has yielded more than a million dollars worth of metals."

General geology of the district

The geological history of the district has been summed up briefly by Butler and Wilson. They state:

9 Butler, B. S. and Wilson, E. D., - op. cit.

"Rocks ranging in age from early pre-Cambrian to present are exposed at Tombstone. The exposure of pre-Cambrian
rocks is too limited to reveal much of the pre-Cambrian history, though the schists intruded by granitic rocks indicate the long period of sedimentation, igneous intrusion, and metamorphism common to the early pre-Cambrian of the southwest.

"Between the early pre-Cambrian and the Paleozoic the area was deeply eroded, and on this erosion surface of little relief was deposited a thick series of Paleozoic sediments, prevailingly limestone. There were long periods during which sediments were not deposited, notably the Ordovician, Silurian, and Early Devonian, but there is little angular discordance in the Paleozoic rocks.

"From Paleozoic to Mesozoic there is a notable change in sediments from prevailingly limestones in the Paleozoic to prevailing sandstone and shale with subordinate limestone in the Mesozoic. Ransome has shown that there was faulting and extensive erosion between the deposition of late Paleozoic and Mesozoic rocks in the neighboring Bisbee district.

"This change is recorded in the Tombstone district by a change in the character of sediments, but with no notable angular discordance.

"The presence of volcanic material in the basal beds of the Mesozoic rocks indicates igneous activity in the interval between the deposition of the two series of sedimentary rock, but igneous rocks of this age have not been recognized within the Tombstone area.

"Following the deposition of the Mesozoic sedimentary rocks there was a period of deformation and igneous activity whose age is not closely known, but which may be essentially the same as that of the Laramide revolution in the Rocky Mountain region.

"It is with the folding, faulting igneous intrusion, and fissuring of this period that the ore deposits are associated.

"The earliest prominent structures of the period were generally east-west folds and steep angle faults represented by the Promptor fault and the folds to the south and the Tombstone basin and accompanying folds to the north. Following or accompanying the east-west folding and faulting was north-south fissuring with steep westerly dip and with small displacement on most of the fissures but large displacement
on the fault bounding the Ajax Hill block on the west. Next was igneous activity. To the southwest of the district a large area of volcanic breccias and flows is intruded by quartz latite porphyry. Within the Tombstone area the quartz latite porphyry intrudes the Mesozoic sedimentary series and rocks of similar composition occupy some of the north-south faults.

"In the northern part of the district an intrusive mass of granodiorite intrudes along the contact of the Mesozoic and Paleozoic rocks, probably guided by a fault.

"The relative age of the different intrusive bodies is not clear as they have not been found in contact. They were probably of one general period, but it seems likely that the granodiorite is the latest except for some late dikes that intrude the quartz latite porphyry, granodiorite, and basaltic rock that is later than the late Tertiary sediments of the valley fill."
Mineralogy

General Statement

No systematic description of the mineralogy of Tombstone has been published. Previous descriptions have been mainly of the rarer varieties which were collected and analysed when the mines were first opened over fifty years ago.

In the years following the early active period, the stopes were stripped by lessees of all accessible ore and the valuable minerals were thus removed. This has made the collection of typical ores and the study of their relationships difficult. However, the old mine dumps, accessible stopes, and new mining operations, have yielded much information on the character of the primary mineralization and many excellent specimens of oxidized ore.

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.

List of Minerals

<table>
<thead>
<tr>
<th>Alabandite</th>
<th>Covellite</th>
</tr>
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<tbody>
<tr>
<td>Allanite (see Orthite)</td>
<td>Cuprite</td>
</tr>
<tr>
<td>Andesine</td>
<td>Descloeizite</td>
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<tr>
<td>Andradite</td>
<td>Diopside</td>
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<td>Anglesite</td>
<td>Embolite</td>
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<tr>
<td>Apatite</td>
<td>Emmonsite</td>
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<tr>
<td>Argentite</td>
<td>Epidote</td>
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<tr>
<td>Aurichalcite</td>
<td>Ettringite</td>
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<td>Augite</td>
<td>Famatinite</td>
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<tr>
<td>Azurite</td>
<td>Fluorite</td>
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<td>Barite</td>
<td>Galena</td>
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<tr>
<td>Beaverite</td>
<td>Gold (native)</td>
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<tr>
<td>Bindheimite</td>
<td>Grossularite</td>
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<tr>
<td>Biotite</td>
<td>Gypsum</td>
</tr>
<tr>
<td>Bornite</td>
<td>Hematite</td>
</tr>
<tr>
<td>Bournonite</td>
<td>Hemimorphite (Calamine)</td>
</tr>
<tr>
<td>Brochantite</td>
<td>Hessite</td>
</tr>
<tr>
<td>Bromyrite</td>
<td>Hetaerolite</td>
</tr>
<tr>
<td>Calamine (Hemimorphite)</td>
<td>Hillebrandite</td>
</tr>
<tr>
<td>Calcite</td>
<td>Hollandite group (?)</td>
</tr>
<tr>
<td>Cerargyrite</td>
<td>Hornblende</td>
</tr>
<tr>
<td>Cerussite</td>
<td>Hydrozincite</td>
</tr>
<tr>
<td>Chalcocite</td>
<td>Iddingsite</td>
</tr>
<tr>
<td>Chalcopyrite</td>
<td>Idocrase (Vesuvianite)</td>
</tr>
<tr>
<td>Chlorite</td>
<td>Jarosite</td>
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<tr>
<td>Chrysocolla</td>
<td>Labradorite</td>
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<td>Clinogozosite</td>
<td>Limonite</td>
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<tr>
<td>Connellite</td>
<td>Magnetite</td>
</tr>
<tr>
<td>Copper (native)</td>
<td>Malachite</td>
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</tbody>
</table>
List of Minerals (cont'd)

Listed in order of increasing atomic number:

- Manganite
- Microcline
- Monticellite
- Mottamite (Cuprodesclzoizite)
- Muscovite
- Oligoclase
- Olivine
- Orthite (Allanite)
- Orthoclase
- Pigeonite
- Plumbojarosite
- Polianite
- Poroustita
- Psilomelane
- Pyrite
- Pyrolusite
- Pyromorphite
- Quartz
- Rhodochrosite
- Rosasite

Listed in order of decreasing atomic number:

- Serpentine (Chrysotile)
- Silver (native)
- Smithsonite
- Sphalerite
- Sphene (titanite)
- Stromeyerite
- Sulphur
- Tellurium (native)
- Tenorite
- Tetrahedrite
- Thaumasite
- Titanite (see Sphene)
- Tremolite
- Vanadinite
- Vesuvianite (see Idocrase)
- Wollastonite
- Wulfenite
- Zircon
- Zoisite
10.

Native Elements

Sulphur, S

Resinous yellow sulphur occurs in oxidized lead ore. This somewhat resembles yellow sphalerite. In polished sections of this ore the relations indicate that the sulphur has resulted from the oxidation of galena to anglesite, (Plate I, A and B). Possibly the sulphur has resulted from the oxidation of galena by ferric sulphate according to the following reaction:

\[ \text{PbS} + 2\text{Fe}_2(\text{SO}_4)_3 \rightarrow \text{PbSO}_4 + 2\text{FeSO}_4 + \text{S} \]

The photographs show galena oxidizing to anglesite and both partly replaced by sulphur. This ore is from the Skip Shaft fissure on the 4th level of the Empire mine.

Tellurium, Te

Microscopical blebs of a silver white mineral in galena are thought to be native tellurium. Microchemical tests of the galena and associated oxidized material gave tellurium. Definite tests on the blebs were not feasible.

Gold, Au

Gold was most abundant in the Grand Central, Contention, Flora Morrison, Yellow Jacket, Head Center, and Tranquillity 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 the presence of gold in varying quantities depending on the kind of sulphide. Pyritic ore from the Sulphuret stope close to the extension of the Skip Shaft 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 4th level of the Empire mine assayed 2.46 ounces in gold. Quartz-bournonite ore from another fissure on the 4th 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 clung tenaciously to iron stained drusy quartz and 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 "rolls deposits" is usually near the bottom of the stopes. There is a general opinion among the miners that when native silver is encountered in ore it is approaching its lowest limit. This, locally at least, seems to be true. Oxidized ores in the "Jeanes roll" contained rather abundant native silver at the bottom of the stope, but upward the silver seemed to give out.

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 assays 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 come from 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 replaces pyrite, sphalerite, and tetrahedrite (Plate VII, A and B) 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. Similar
relations prevail where chalcopyrite is in contact with galena.

**Argentite, Ag₂S**

Argentite or "petanque", as the Mexican lessees call the mineral, occurs only in the oxidized ore and has formed from the supergene alteration of argentiferous tetrahedrite, a fairly common mineral in most of the hypogene ores. It may also owe its formation to the oxidation of hessite. The black material fills small fractures and honey-combed spaces in the quartzose ore. A specimen containing supergene sulphides, malachite, and earthy hematite from the Empire mine showed on a polished surface argentite closely associated with stromeyerite and chalcocite, (Plate II, A) though not replacing either. Microchemical tests on argentite gave abundant copper reaction. Schwartz has shown that chalcocite is soluble in argentite up to 20 percent, but above 20 percent, stromeyerite is formed.


**Chalcocite, Cu₂S**

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 (Plate IV, A and B). Chalcocite
is best known from the Toughnut mine where it is associated
with argentite and stromeyerite. (Plate II, A, B, and C)

**Stromeyerite, \( \text{Ag}_2\text{S},\text{Cu}_2\text{S} \)**

Stromeyerite was identified in ore from the Empire
and Toughnut mines associated with supergene chalcocite,
covellite, malachite, and earthy hematite. The writer be­
lieves that stromeyerite is supergene in origin; this be­
lief is based on its mineral associations. Stromeyerite
also appears to be the result of unmixing from solid solu­tion
of argentite and chalcocite. Schwartz\(^{11}\) has shown that

\(^{11}\) Schwartz, G. M., - op. cit.

argentite cannot replace chalcocite, but that, instead, it
is soluble in chalccite up to 15 percent; beyond that limit
stromeyerite will form and replace chalcocite. Stromeyerite
is also replaced by feathery laths of covellite (Plate II, A).
The amount of stromeyerite is limited, 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, now closed. 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 instead, fills in and around the fractured pyrite grains. Sphalerite has been replaced by tetrahedrite, chalcopyrite, and galena.

Ore that has been subjected to the action of acid 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 in 1892. It was found along the foot-

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wall 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 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 mine showed much oxidation on the surface to brown and black coatings indistinguishable from the common manganese oxides. Upon breaking to a fresh surface, the alabandite appeared as brilliant black disseminations in a gray spar. Polished sections made of alabandite from the mineralogical collections at the University of Arizona show the mineral nearly free of other sulphides except for numerous triangular inclusions of chalcopyrite near the contact borders with other minerals (Plate III, A and B). 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 (Plate II, A and B) and to a subordinate degree, galena and anglesite.
Bornite, \( \text{Cu}_5\text{FeS}_4 \)

Bornite occurs in ore collected from the "Westside roll." The one specimen showing this mineral consisted of massive chalcopyrite slightly fractured with bornite irregularly replacing chalcopyrite along these fractures (Plate IV,A and B). Bornite in turn is easily replaced by chalcocite along these same fractures.

Chalcopyrite, \( \text{CuFeS}_2 \)

Chalcopyrite is the most abundant of the copper minerals, but is more widely and sparingly 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 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, \( \text{FeS}_2 \)

Pyrite, the most widespread and abundant sulphide mineral, is commonly present as granular masses in quartz
and as isolated crystals in shales and other wall rocks of the ore bodies. Porphyry rock from the Oregon mine is extensively impregnated with pyrite alteration, from the influence of the atmosphere, to greenish yellow coatings. During rainy weather the smell of oxidizing sulphides may be detected. Silicified porphyry rock from the Silver Thread mine contains sparsely disseminated crystals of pyrite.

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. Microscopic examination of this ore has not been made, therefore the possibility of argentiferous galena filling minute fractures is not eliminated.

Tellurides

Hessite, $\text{Ag}_2\text{Te}$

Hessite was described from the West Side mine, Tombstone, by Genth. It occurred in specimens from the West Side mine.

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According to his description the mineral occurred as bands and as disseminations in quartz. In the latter occurrence
it was associated with cerargyrite, gold, and an unidentified bluish to siskin green mineral. From selected material he gave the following chemical analysis:

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<th></th>
<th>I</th>
<th>II</th>
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<tbody>
<tr>
<td>Te.</td>
<td>37.34</td>
<td>37.05</td>
</tr>
<tr>
<td>Se.</td>
<td>trace</td>
<td>trace</td>
</tr>
<tr>
<td>Ag.</td>
<td>62.87</td>
<td>62.34</td>
</tr>
<tr>
<td>Pb.</td>
<td>0.28</td>
<td>0.30</td>
</tr>
<tr>
<td></td>
<td>100.49</td>
<td>99.69</td>
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A polished section of hessite made from a collection of Flora Morrison ores at the University of Arizona, shows a homogeneous 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, $\text{Cu}_2\text{S}.2\text{PbS}.\text{Sb}_2\text{S}_3$

Bournonite, a rare copper-lead sulph antimonite, 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.

Polished sections of ores containing bournonite show,
under the microscope, that it is closely associated with quartz, chalcopyrite, and galena, and is quickly identified by its characteristic polarization colors and twinning, as described by Short.\textsuperscript{15} Some specimens show the first stages of oxidation along fractures to an unidentified mineral, probably a complex sulphate of copper and lead. (Plate VI, A and B). Small grains of galena have remained unaltered when in contact with bournonite. Possibly like tetrahedrite it oxidizes before galena.

Proustite, $3\text{Ag}_2\text{S}\cdot\text{As}_2\text{S}_3$

Proustite has been reported\textsuperscript{16} as occurring in small crystals on calcite with alabandite, but has not been identified by the present writer.

Tetrahedrite, $5\text{Cu}_2\text{S}\cdot2(\text{Cu,Fe})\text{S}\cdot2\text{Sb}_2\text{S}_3$

Tetrahedrite is widely distributed in the district. Tetrahedrite ores are high in silver, and it is probably argentiferous. Specimen ore from the Toughnut mine is


\textsuperscript{16} Moses, A. J. and Luquer, L. McI., - op. cit. p. 238
reported 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, (Plate VII, A and B) tetrahedrite is light gray in contrast to the white of galena, and was intensely fractured before being replaced by galena. The tetrahedrite is broken, but the galena is free of fracturing, which suggests movement on the fissure between the formation of tetrahedrite and galena.

Tetrahedrite oxidizes much more readily than galena when the two minerals are in contact. The oxidation mineral has not been identified.

Famatinite, $3\text{Cu}_2\text{S}\cdot\text{Sb}_2\text{S}_5$

Famatinite was recognized in ores from the Ingersol and Toughnut mines and can be identified only by examination of polished sections under the microscope. It is a rare mineral and a minor constituent of the sulphides. Its decidedly pink color distinguishes it from bournonite with which it is closely associated. Schwartz identified

famatinit from the Campbell ore body at Bisbee, Arizona, with other copper minerals, but did not give its sequence. Famatinite, like tetrahedrite and bournonite, alters readily to some unidentified mineral. (Plate V, B)

**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 differently.

**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 separated.

**Embolite, Ag(Br,Cl)**

In unpublished notes, Dr. Ransome mentions embolite as the principal silver mineral 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 and irregular masses of dark green horn silver that have not
changed color since they were collected from the Skip Shaft fissure on the 4th 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 Mr. R. Carrillo under the supervision of Dr. R. L. Nugent.

<table>
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<th></th>
<th>Cl.</th>
<th>Br.</th>
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<th>Ag.</th>
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<tr>
<td></td>
<td>0.6</td>
<td>38.9</td>
<td>2.6</td>
<td>56.7</td>
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The analysis shows the mineral to be bromyerite containing 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 bromyerite 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 bromyerite with free gold in the midst of the Empire-Contention dike supposedly many feet distant from the portions carrying quartz stringers. The source of so much bromine has not been determined.
Fluorite, CaF$_2$

Fluorite is not an abundant mineral except locally in some silicified areas, especially in the Empire mine, where it is plentiful. In the "Quarry roll" it was a fairly common gangue mineral, and also in some veins in the Empire mine that are now inaccessible. 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 around the center of mineralization 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 a mineral of varied occurrence. It is an important constituent of the various igneous rocks, especially the pre-Cambrian quartz diorite, rhyolite porphyry, quartz latite porphyry, and granite and quartz monzonite porphyry dikes. Quartz forms rounded glassy phenocrysts in the porphyries. The quartz phenocrysts in the quartz latite porphyry are clear or faintly smoky. It occurs in irregular
fragments, rounded grains, or well-developed bi-pyramids, many of which are corroded or embayed. (Plate XVII A and B). Quartz was one of the last minerals to crystallize in the quartz diorite and granodiorite; consequently, it usually fills the interstices between the other constituents.

In the sedimentary rocks, the Bolsa quartzite of Cambrian age, the numerous sandstones and quartzites of Cretaceous (?) age, and the novaculite ore horizon, consist essentially of fragmental quartz grains.

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." Assays of this type of ore are usually high in silver. 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.

\[ \text{Opal, } \text{SiO}_2\text{nH}_2\text{O} \]

Opal fills small seams in the ore from the Lucky Cuss mine. From its mineral associations it is believed to represent the dying out stages of the hypogene mineralization.
Cuprite, Cu$_2$O

Cuprite was observed as brilliant red cubes lining a small cavity in ore from the Toughnut mine. A copper-stained clay-like material enclosed the cuprite protecting it, as well as the brilliant blue needles of connellite and tuffed masses of brochantite and malachite. In polished section, cuprite shows replacement by native copper. It is a very uncommon mineral in the district.

Tenorite, CuO

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

Hematite, Fe$_2$O$_3$

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 containing garnet, epidote, and calcite.

The less well crystallized red earthy ferric oxide is a constituent of parts of the extensively oxidized ore bodies.
Magnetite, Fe$_3$O$_4$

Magnetite is present chiefly in the dark colored igneous rocks. It varies in amount from two to three percent in the diorite porphyries to twenty-five percent in some of the basaltic rocks. It occurs as dusted particles in the acid igneous rocks. It has not been found with minerals of the contact metamorphic type.

Hetaerolite, ZnO.Mn$_2$O$_3$

Hetaerolite, a rare zinc hausmannite, has been described from but two other localities. It was first described from Franklin Hill, New Jersey, by Palache.\textsuperscript{19} The occurrence at Leadville, Colorado, was described by Ford and Bradley.\textsuperscript{20} Hetaerolite from Tombstone has been identified in polished section only and 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. (Plate X and XI, A and B) Dark gray color, high relief, four extinctions per revol-
ution under polarized light, and a decided reddish-brown internal reflection, are characteristic of the mineral. Etch reactions for hetaerolite were determined as follows:

Conc. HNO faint etch which rubs off easily, probably negative.

Conc. HCl etches instantaneously, turning the mineral reddish-brown.

Conc. SnCl etches instantaneously, turning the mineral reddish-brown.

KCN negative.

FeCl₃ negative.

HgCl₂ negative.

H₂SO₄ negative.

H₂O₂ effervesces.

These etch reactions agree closely with those given by 

Orcel and Pavlovitch.

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Romanachite(?), chiefly a manganate of manganese, barium, and ferric iron.

Romanachite is listed in Dana-Ford "Textbook of Mineralogy" under the mineral hollandite which comprises manganates of manganese, barium, and ferric iron. Orcel and Pavlovitch describe it separately from hollandite.
Specimens of a long fibrous manganese oxide that occur with barite, quartz, and other manganese oxides, (Plate VIII, A) in a vein exposed in a prospect pit one-half mile west of the Lucky Cuss mine, look very much like manganite, but gave etch reactions for romanachite. Identification is not considered certain.

Polianite and Pyrolusite, MnO₂

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 separation of 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 (Plate IX, A and B). Mixed with the polianite is more or less psilomelane which replaces polianite along grain boundaries and fractures (Plate IX, B).

Pyrolusite is a soft sooty mineral that is easily gouged with a needle and which usually occurs as fine-grained, highly dispersed aggregates and elongated streaks in a fibrous manganese oxide identified as manganite. (Plate X, A and B, and Plate XIII, B) It is later than manganite and seems to replace that mineral as radial prismatic
aggregates. Psilomelâne, 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.

Under the microscope pyrolusite is distinguished in ordinary light by its brilliant white color, and under crossed nicols by its characteristic polarization colors.

**Manganite, Mn₂O₃·H₂O**

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. (Plate X and XI A and B) This is not positive since the etch reactions on manganese oxides are so indefinite that it is difficult to determine some of them exactly. Manganite appears to be replaced by both pyrolusite and hetaerolite.

**Limonite, Fe₂O₃·nH₂O**

Limonite, referred to as mixtures of hydrated iron oxides, is common throughout the district, but is 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. Complete oxidation extends in some mines several hundred feet below the water level.

Psilomelane, $\text{H}_4\text{MnO}_5$ (?)

Psilomelane is regarded as a manganate, $\text{H}_4\text{MnO}_5$ (?), with the $\text{H}$ 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. The mineral, when examined in polished section under the microscope, is so variable in reflecting power and hardness that it is difficult to describe. Some of the more typical psilomelane is that illustrated. (Plate XII, A and B, and Plate XIII, A) The photographs show the botryoidal or reniform masses of psilomelane concentrated as replacements. Part may have been deposited in nodular form, as it shows irregular contraction cracks filled with a later generation of the same mineral. Some of the cracks are filled with psilomelane of a greater hardness which takes a better polish and is therefore conspicuous.

Psilomelane (?) shown by Plate XI, B has a bluish color in
contrast to the brilliant white of polianite, and at first was mistaken for hausmannite. The mineral, however, is isotropic, seems slightly softer than polianite, and takes an excellent polish. The etch reactions obtained for this mineral differ somewhat from that generally given for psilomelane. The following etch reactions were determined for this mineral:


Negative - HNO₃, KCN, H₂SO₄, KOH, HgCl₂.
Positive - Conc. HCl etches gray.

Conc. SnCl etches gray; in oblique light the mineral appears reddish-brown.

FeCl₃ etches light brown.
H₂SO₄ slight etch, may be negative.
H₂O₂ effervesces vigorously; leaves a brown stain.

Microchemical tests indicate more than a trace of antimony. The reddish-brown color of the mineral is much like that shown by hetaerolite, but instead of a zinc reaction, there was antimony. This may be a new mineral, but for lack of material suitable for analysis, a name is not suggested for it.
Carbonates

Calcite, CaCO₃

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. It is an early hypogene mineral in the ores from the Silver Thread, Sulphuret, and Northwest mines, is usually coarsely crystalline and white, and is usually the primary gangue mineral of the ore. In the stopes of the "Quarry roll" it replaces fluorite. Coarse granular pyrite, sphalerite, and galena, are the usual sulphides 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

24 Goodale, C. W., - op. cit., p. 768.

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. (Plate XX, A and B) 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 as yet uncertain, but is further discussed under manganese mineralization.

Rhodochrosite, MnCO₃

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, ZnCO₃

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.
Cerussite, $\text{PbCO}_3$

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, $\text{CuCO}_3\cdot\text{Cu(OH)}_2$

Malachite is sparingly present in all of the ore bodies that originally contained small amounts of copper-iron sulphide. The few 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, $2\text{CuCO}_3\cdot\text{Cu(OH)}_2$

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, $(\text{Cu},\text{Zn})\text{CO}_3.(\text{Cu},\text{Zn})(\text{OH})_2$

A bright green mineral, commonly occurring in mamillary spherulites 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, $2(\text{Zn},\text{Cu})\text{CO}_3.3(\text{Zn},\text{Cu})(\text{OH})_2$

Plumose aggregates of pale blue crystals of aurichalcite were collected from the west side of the "Quarry roll." It was taken from a small seam that also contained calcite, hemimorphite, and hydrozincite.

Hydrozincite, $\text{ZnCO}_3.2\text{Zn}(\text{OH})_2$

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, quartz monzonite dikes, and rhyolite dikes and sills. It occurs as phenocrysts in the porphyritic rocks, and as irregular grains in the granular rocks and groundmass of the porphyritic rocks. A peculiar cloudiness is distinctive of the orthoclase in the granodiorite stock. (Plate XVI, A)

Microcline, $K_2O\cdot Al_2O_3\cdot 6SiO_2$

Microcline, instead of orthoclase, occurs as a rock forming constituent of the pre-Cambrian quartz diorite. It forms about 5 percent of the rock. The typical plaid structure of microcline is an aid in separating the pre-Cambrian rocks from later intrusives.

Plagioclase, $Na_2O\cdot Al_2O_3\cdot 6SiO_2-CaO\cdot Al_2O_3\cdot 2SiO_2$

The rock forming plagioclases vary in composition from oligoclase to labradorite. Oligoclase and andesine occur as irregular grains and phenocrysts in the pre-Cambrian quartz diorite, post-Cretaceous granodiorite stock, quartz latite porphyry, and in various light-colored dikes. Labradorite forms tabular and lath-shaped crystals in the diorite porphyry and basalts.
Pigeonite, \( (\text{Mg,Fe,Ca})_0.\text{SiO}_2 \)

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. Its indices of refraction were determined as: \( \alpha = 1.690, \beta = 1.691, \gamma = 1.700. \) The higher index is somewhat low for the determined pigeonite, but otherwise the mineral corresponds to pigeonite. It is usually associated with abundant idocrase, calcite, and minor andradite.

Diopside, \( \text{CaO}_0.\text{MgO}_0.2\text{SiO}_2 \)

Small crystals of a pale green pyroxene with clear vitreous luster occur in the contact zone of Comstock Hill.

Augite, chiefly \( \text{CaMg(SiO}_3)_2 \) with \( (\text{Mg,Fe})(\text{Al,Fe})_2\text{SiO}_6 \)

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, \( \text{CaO}_0.\text{SiO}_2 \)

Wollastonite, calcium silicate, has been recognized in but one locality in the district. It occurs as radiating fibrous masses (Plate XXIV, B) in the Silver Thread mine with
residual grains of quartz. The whole mass is partly re-
placed by sulphides of lead and zinc. Ransome, in un-
published notes, mentions wollastonite as occurring in the
West Side mine.

Tremolite, $2CaO \cdot MgO \cdot 0.8SiO_2 \cdot H_2O$

Tremolite in long fibrous masses replaces "blue lime-
stone" exposed on the 4th level of the Toughnut mine. (Plate
XXIV, A) It apparently was formed by the contact meta-
morphism of the Empire dike upon the "blue limestone."

Actinolite, $2CaO \cdot 0.5(Mg,Fe)O \cdot 0.6SiO_2 \cdot H_2O$

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, chiefly $Ca(Mg,Fe)_{3} \cdot Si_{4}O_{12}$ with $CaMg_{2}(Al,Fe)_{2}Si_{3}O_{12}$

Hornblende is a minor rock-forming mineral of the
granodiorite stock. It occurs as long prismatic crystals
associated with biotite and orthoclase (Plate XVI, A).
Phenocrysts of hornblende in an andesite porphyry exposed
six miles east of the district show excellent zonal struc-
tures. (Plate XVI, B)
Two varieties of calcium-aluminum garnet occur in the metamorphic zone. The more common of the two, the cinnamon-brown garnet, probably 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. Determination of the index of refraction of the garnet gave:
\[ n = 1.760 \pm 0.003. \]

A white, nearly pure, calcium garnet occurs as metamysts that etch out in the weathering of limestone. The crystals show subadamantine luster and excellent octahedral faces modified by small cube faces. Crystals from the contact zone on Comstock Hill gave an index of refraction of
\[ n = 1.752 \pm 0.003, \] on the weathered fragments.

Andradite, \( 3\text{CaO} \cdot \text{Fe}_2\text{O}_3 \cdot 3\text{SiO}_2 \)

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 undeter-
mined composition.

Chrysolite (Olivine) $2(Mg,Fe)O.SiO_2$

Minerals from 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.

A pale green variety from the contact zone varies in texture from loosely coherent coarse-grained masses to compact fine-grained aggregates, and is closely associated with coarse cleavable calcite. It is optically positive with $2V$ close to $90^\circ$. The determined indices of refraction, $\alpha = 1.680 \pm 0.003, \beta = 1.692 \pm 0.003, \gamma = 1.710 \pm 0.003$, indicate that there are optically positive olivines with higher indices than those given by Larsen and Berman.\(^{25}\)


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

Monticellite, $CaO.MgO.SiO_2$

The comparatively rare calcium-bearing olivine, monticellite, occurs as narrow bands between bands of other
silicate minerals on the 4th level of the Lucky Cuss mine. It is distinguished by its light gray color and greasy or vitreous luster. The indices of refraction, $\alpha = 1.639 \pm 0.003$, $\beta = 1.652 \pm 0.003$, $\gamma = 1.657 \pm 0.003$, are close to those determined by Schaller on specimens from California.


Closely associated with the monticellite are minor amounts of calcite, thaumasite, (CaO,CO$_2$SO$_3$,SiO$_2$1.5H$_2$O), clinozoisite, and idocrase.

Idocrase, $\text{Ca}_6(\text{Al(OH,F)})\text{Al}_2(\text{Si}_4\text{O}_{15})$(?)

Idocrase, (vesuvianite), has resulted 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. Determination of the indices of refraction on an especially large crystal gave: $\varepsilon = 1.704$ and $\omega = 1.708.$
Zircon, $\text{ZrSiO}_4$

Thin sections of many specimens of the light colored intrusive rocks show microscopic grains of zircon usually associated with plagioclase and biotite.

Zoisite, $4\text{Ca}_0.3\text{Al}_20_3.6\text{SiO}_2.\text{H}_2\text{O}$

Small grains of zoisite are observed in thin section of the igneous rocks.

Clinozoisite, $\text{Ca}_0.3\text{Al}_20_3.6\text{SiO}_2.\text{H}_2\text{O}$

Small grains of a vitreous green mineral associated with idocrase, monticellite, thumasesite, and calcite, were determined as clinozoisite from the indices of refraction.

Epidote, $\text{HCa}_2(\text{Al,Fe})_3\text{Si}_3\text{O}_{13}$

Epidote is a common mineral in the shales and quartzites of the upper portion of "shale series." 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. Thin sections show epidote replacing, principally, altered plagioclase feldspars, but also to some extent chlorite after biotite. (Plate XVI, A)
Allanite (Orthite), $4(Ca,Fe)O.3(Al,Fe)2O3.6SiO2.H2O$

Allanite, a complex silicate with small amounts of the cerium and yttrium metals, was identified in a thin section of the granodiorite stock. (Plate XVI, A)

Hemimorphite, $2ZnO.SiO2.H_2O$

Hemimorphite occurs, but not abundantly, 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, $2CaO.SiO2.H2O$

Tombstone is the second locality from which hillebrandite, a hydrous calcium silicate, has been recorded. It was first described by Wright$^{27}$ 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 4th level of the Lucky Cuss mine. The snow-white
color, faint silky luster, and delicate fibers are distinctive physical features. Compared with the mineral from the type locality, the two seem identical. Positive identification was made by the indices of refraction ($\alpha = 1.604$, $\beta = 1.610$, $\gamma = 1.613$) which check closely those determined on the type mineral. Larsen\textsuperscript{28} regards foshagite from Crestmore, California, as identical with, or closely related to, hillebrandite. Its relation to other calcium silicates is given under the subject of contact metamorphism.

\textsuperscript{28} Larsen, E. S. and Berman, H., - op. cit. p. 167.

Muscovite, $\text{H}_2\text{KAl}_3(\text{SiO}_4)_3$

Muscovite, a minor rock-forming mineral from the district, is present chiefly in the pre-Cambrian quartz diorite. 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 much more common and is always present in the hydrothermally altered rocks.

Biotite, $\text{H}_2\text{K(Mg,Fe)}_3(\text{Al,Fe})(\text{SiO}_4)_3$

The dark mica, biotite, is one of the original constituents of the quartz diorite and granodiorite. Under the influence of solutions it readily alters to chlorite.
Chlorite, $\text{H}_8(\text{Mg,Fe})_5\text{Al}_2\text{Si}_3\text{O}_18$

Chlorite, an iron magnesium aluminum silicate of variable composition, is a common alteration product of hornblende and biotite.

Serpentine, $3\text{MgO} \cdot 2\text{SiO}_2 \cdot 2\text{H}_2\text{O}$

The fine wooly fibrous variety of serpentine called chrysotile is present on blue calcite from the 5th level of the Lucky Cuss mine. Microscopic examination of limestones from the Lucky Cuss and Contact mines shows a fibrous mineral replacing the limestone. The optical properties of the fibrous mineral are probably those of serpentine. Hydrothermal solutions are held responsible for the pseudomorphous replacement of serpentine after monticellite (Plate XXIII,B). Serpentine associated with talc and calcite is an abundant mineral in the altered limestone exposed in the south drifts of the Lucky Cuss mine.

Iddingsite, $\text{MgO} \cdot \text{FeO} \cdot 3\text{SiO}_2 \cdot \text{H}_2\text{O}$

This section of the basaltic rocks exposed in the northeast part of the area shows iron-rich olivine altered completely to deep reddish-brown iddingsite.

Kaolinite, $\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2 \cdot 2\text{H}_2\text{O}$

Kaolinite (kaolin) is a common mineral in the Tomb-
stone Extension and Toughnut mines resulting from the alteration of aluminous minerals.

**Chrysocolla, CuSiO$_3$2H$_2$O**

Chrysocolla is widely distributed throughout the mines, but is not abundant. It occurs chiefly with small quantities of the copper minerals tenorite, malachite, azurite, and with manganese and iron oxides.

**Thaumasite, CaO$_2$,CO$_3$,SO$_4$,SiO$_2$,15H$_2$O**

Thaumasite, a hydrous carbonate, sulphate, and silicate of calcium, is a rare and unusual mineral that has been reported from but few localities, especially mining districts. Butler described it from the Old Hickory mine, San Francisco region, Utah, where it occurs filling fissures that were formed later than the contact metamorphism. A complete bibliography of the mineral is also given. Foshag has described one other locality. He believes that thaumasite was
derived from spurrite \((\text{CaO}.\text{CO}_2.2\text{SiO}_2)\) by the action of sulphated waters, and was deposited as veins.

Its identification at Tombstone makes that locality the fourth in the United States. At Tombstone it was collected from the 4th 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 varying from four 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. Other evidence of sulphates is at hand in the presence of small amounts of barite from a near-by fissure and the presence of ettringite \((6\text{CaO}.\text{Al}_2\text{O}_3.3\text{SO}_4.33\text{H}_2\text{O})\), not identified by the writer, in an ore shoot in the white crystalline limestone of the Lucky Cuss mine just at the water level.

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, \(\text{CaO}.\text{TiO}_2.\text{SiO}_2\)

Sphene (titanite) is an original constituent of the
granodiorite, quartz diorite, and quartz monzonite porphyries of the district. In these rocks it is associated with epidote, biotite, zircon, and apatite, and has been detected only in thin sections of the rocks.

**Phosphates**

**Apatite, \( \text{Ca}(\text{PO}_4)_3(\text{CaF}) \)**

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, \( 9\text{PbO}.3\text{P}_2\text{O}_5.\text{PbCl}_2 \)**

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 varies considerably from white to grass green, but the most common color is 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 usually form botryoidal crusts and minute crystals in drusy cavities. Some vanadates are difficult to distinguish from other minerals, but when dissolved in concentrated hydrochloric acid the solution turns green, which, upon the addition of hydrogen peroxide, turns red, thus proving the presence of vanadium.

**Vanadinite, \(9\text{PbO}.3\text{V}_2\text{O}_5.\text{PbCl}_2\)**

Vanadinite from the Tribute mine forms white to gray, waxy hexagonal prisms resting on calcite. At the Tombstone Extension mine small masses of tiny brown crystals fill a small fissure exposed on the 4th level. Microscopic examination showed them resting on, and therefore later than, black resinous descloizite.

**Descloizite, \(4(\text{Pb,Zn})\text{O}.\text{V}_2\text{O}_5.\text{H}_2\text{O}\)**

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 varies through black, reddish-brown, to pale yellow and green.

31 Bannester has shown that descloizite and all similar-

ly related copper-zinc vanadates represent an isomorphous series; descloizite representing the zinc-rich end and mottramite the copper-rich end. The name mottramite has displaced cupro-descloizite on grounds of priority.

**Mottramite**, Pb(Cu,Zn)OH.(VO$_4$)$_3$

Mottramite (cuprodescloizite) from the Lucky Cuss mine was first described by Hillebrande. 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. The chemical analysis on this material by Hillebrande is quoted:

<table>
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<tr>
<th>Element</th>
<th>Analysis</th>
</tr>
</thead>
<tbody>
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</tr>
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</tr>
<tr>
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<td>4.19</td>
</tr>
<tr>
<td>V$_2$O$_5$</td>
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<td>P$_2$O$_5$</td>
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<tr>
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<tr>
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<tr>
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</tr>
<tr>
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</tr>
<tr>
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</tr>
<tr>
<td>CO$_2$</td>
<td>0.82</td>
</tr>
</tbody>
</table>

Specimens of this material are not available, but other specimens from the Toughnut mine show beautiful
mammililated crystalline groups of concentric crystals that give a brilliant black sheen. These indistinct minute fibrous masses fill drusy cavities in quartzose material, and form coatings and crusts on fluorite.

**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 one-half mile west of the Lucky Cuss mine. Pseudomorphs of limonite seen in polished sections of the ore indicate that pyrite may have been present. (Plate VIII, A and B) One other locality, the Ground Hog mine in the southwestern part of the district, exposes a vein of nearly pure white barite from one to three feet wide. Quartz is a subordinate gangue mineral. Barite is sparse or lacking in most of the ore deposits of the district.
Anglesite, PbSO₄

Anglesite is not an abundant mineral. Ore from the Tombstone Extension mine exhibits concentric or colloform-like structures 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, CuSO₄·2CuCl₂·19Cu(OH)₂·H₂O

Connellite is a rare copper mineral of the oxide zone. The specimens from Tombstone represent the second locality in Arizona from which it has been described. It was identified previously by Palache and Merwin in specimens from Bisbee, Arizona. At Tombstone it 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 needle-like 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
needle-like copper mineral, are other minerals associated with connellite in the vug.

Spangolite, \( \text{CuAlClSO}_6 \cdot 9\text{H}_2\text{O} \)

This highly basic sulphate of aluminum and copper has been mentioned as occurring in the neighborhood of Tombstone.  

Brochantite, \( \text{CuSO}_4 \cdot 3\text{Cu(OH)}_2 \)

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 needle-like crystals lining vugs in cuprite. Other minerals associated with it are malachite, for which it is easily mistaken, black pitchy-looking copper oxide, chryso-colla, and connellite.

Gypsum, \( \text{CaSO}_4 \cdot 2\text{H}_2\text{O} \)

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, $\text{CuO.PbO.Fe}_2\text{O}_3.2\text{SO}_3.4\text{H}_2\text{O}$

Beaverite was identified by the use of microchemical tests upon a canary yellow mineral from the Empire and Toughnut mines where it is closely associated with cerussite. When observed under high magnification it appeared to consist of minute crystals of indistinct hexagonal outline. Other yellow minerals have been grouped tentatively with beaverite until material suitable for analysis is collected. Preliminary tests show that one sulphate, associated with cerussite, contains only lead and iron; that it is not plumbobjarosite; and that the mineral is amorphous. Another yellow mineral, essentially a copper and iron sulphate, replaces chalcocite. The chalcocite appears to alter first to a green mineral, probably some copper sulphate, which, in turn, gradually becomes yellow with the addition of iron.

Jarosite, $\text{K}_2\text{O.3Fe}_2\text{O}_3.4\text{SO}_3.6\text{H}_2\text{O}$

Jarosite was abundant in ore from the Toughnut and Empire mines where it occurred as "specimen ore." The most beautiful specimens are golden-yellow, well-crystalline, with only traces of quartz and iron oxides. Its crystal form is well brought out under the microscope. A chemical analysis is being made of four samples to see if there is any indication of isomorphism between jarosite and plumbobjarosite. The results will be given later.
Plumbojarosite, PbO$_{0.5}$Fe$_2$$O_3$.4SO$_3$.6H$_2$O

Plumbojarosite, hydrous lead-iron sulphate, has been identified in the heavy, compact, brown oxide ore mined from the "Holderness roll." It is rather abundant. As seen in the hand specimen, the mineral is dark brown, has a silky luster, and is massive, but, under the microscope, it is distinctly crystalline. Locally, the miners call this type of ore "chocolate ore" because of the deep brown color. Besides being an ore of lead, 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 percent lead, and 26.10 percent iron. Similar ore from the Toughnut mine is reported to have yielded as high as 200 ounces of silver per ton which suggests that argentojarosite

35 Jeanes, E. P., - personal communication.

is present, although it has not been recognized as a distinct mineral.

Ettringite, 6CaO.Al$_2$O$_3$.3SO$_3$.33H$_2$O

The rare calcium-aluminum sulphate, ettringite, was described from the Lucky Cuss mine by Moses, and since


specimens were not found by the writer, his description of the mineral will be 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."

A chemical analysis on 0.2235 gram yielded the following proportions:

\[
\begin{align*}
\text{CaO} & \quad 26.615 \\
\text{Al}_2\text{O}_3 & \quad 10.157 \\
\text{SO}_3 & \quad 17.675 \\
\text{H}_2\text{O} & \quad 35.109 \\
\text{H}_2\text{O} \text{ at red heat} & \quad 10.872 \\
\text{SiO}_2 & \quad 1.901 \\
\end{align*}
\]

\[
\frac{99.329}{100}
\]

Bannester\(^{37}\) has recently made the statement 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.


Tellurates; 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 4th level of the Little Joe mine shows minerals not seen in any other ore from the district. A yellowish-green mineral occurring as scales and plates between pyrite crystals and on white quartz was determined by microchemical tests as tellurium-bearing. It has the physical characteristics of eumonsite, a hydrated ferric tellurite, but the microchemical tests were negative to iron. The mineral dissolves slightly in hot 1:1 nitric acid, but readily in hot 1:1 hydrochloric acid, leaving a white tellurous acid residue. A slight amount of water is given off when the powdered mineral is heated in a closed tube. Random fragments of the mineral, when examined under the microscope, indicate high indices of refraction and show high interference colors. The mineral may probably 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 containing native gold, bromyrite, cerussite, and iron oxides. Microchemical tests gave character-
istic reactions for copper, zinc, and tellurium. The powdered material, when heated in a test tube, changed to dark-brown, indicating that it gave up water. 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 it has not been found on close examination of polished sections of tellurium-bearing ores.

Emmonsite

Emmonsite, the hydrated ferric tellurite has been reported from near Tombstone, but has not been identified by the present writer.

Wulfenite, PbMoO$_4$

Wulfenite is a common mineral, although not abundantly present in many of the mines at Tombstone. It is usually well crystallized and varies from 1 to 25 millimeters in longest dimension. Many excellent specimens of wulfenite clusters and rosettes were collected from stope A on the 4th
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 often, wulfenite occurs at the outer borders of the oxidized ore bodies where the rocks are porous and highly siliceous. Pyromorphite is usually the only other mineral present. Examination of many galena specimens has failed to reveal any trace of molybdenite, a source of molybdenum. It is possible that molybdenite, having a higher temperature of formation, was deposited with the early quartz and pyrite, and has been overlooked.
Igneous rocks in the Tombstone district are of few types and are not extensive except for the quartz latite porphyry intrusion which lies chiefly outside the mineralized area. The igneous rocks are intrusive, range in age from pre-Cambrian to late Tertiary, and occur as stocks, dikes, and sills. Most of the dikes are porphyritic, and range in composition from granite to diorite.

Pre-Cambrian quartz diorite

Pre-Cambrian igneous rock occurs as an irregular strip about one-fourth mile wide and one and one-half miles long on the west slope of Ajax Hill ridge. It crops out between the schist and the Bolsa quartzite. The rock weathers to a loose friable soil which forms smooth slopes and obscures the contacts with other rocks. A fairly fresh sample from north of Ajax Hill is medium to coarse grained, and is composed essentially of pearly white feldspar, quartz, and biotite. The rock is mottled white and black. Other minerals recognizable in the hand specimen are epidote and, rarely, muscovite.

The rock in thin section is typically hypidomorphic-granular (Plate XV, A) in which the plagioclase feldspar shows its crystal outline surrounded by later quartz and microcline. Minerals recognized with the microscope, other
than those seen in the hand specimen, are andesine, microcline, sphene, apatite, magnetite, zircon, chlorite, and minute flakes of secondary white mica. Quartz ordinarily comprises about 25 percent of the rock, the andesine 56 percent, and the microcline about 5 percent. Biotite is the most common dark mineral and forms nearly 12 percent. Sphene, apatite, magnetite, and zircon, are minor accessory constituents, though sphene is notably more abundant than the others. It forms about 1 percent.

Andesine, composition Ab$_{59}$An$_{41}$, one of the first minerals to crystallize, shows a marked tendency to assume its own crystal shape, though its edges are corroded by later crystallizing minerals. The tabular crystals average about 3 millimeters in length. Zonal structures, so characteristic of tabular feldspars, are lacking, but, like the albitic twinning, may be obscured by nearly complete seritization.

Muscovite flakes, epidote, and sphene, are consistently associated with the altered andesine.

Microcline, the potash feldspar, is one of the last minerals to crystallize in the final consolidation of the igneous rock.

Rhyolite porphyry

Rhyolite porphyry dikes and sills intrude the Naco
limestone of Pennsylvanian and Permian (?) age in the southwest part of the Tombstone area. The main mass crops out in an area about one-half mile wide and more than a mile long at the base of the cliff-forming limestone (Plate XIV, B). Narrow dikes or sills are exposed in the anticlinal ridge south of the Tombstone Extension mine and east of Military Hill. The two outcrops are about one-half mile apart, separated by limestone of Pennsylvanian age. Along the crest of the hill the porphyry body is of irregular form and breaks across the bedding.

The rock varies slightly in appearance, but commonly has an aphanitic texture. It breaks with a platy or conchoidal fracture and is generally white or pale buff. Visible minerals are quartz phenocrysts of moderate grain.

The microscope has helped but slightly in the identification of other minerals, chiefly because of the intense alteration that has apparently accompanied the intrusion. Besides the quartz phenocrysts which constitute about 12 percent of the rocks, the microscope reveals the faint outlines of feldspar phenocrysts. Their short stubby form suggests orthoclase. The groundmass is microcrystalline, tending toward spherulitic.

**Quartz latite porphyry**

Quartz latite porphyry occupies the greater portion
of the western part of the district, including the Three Brothers Hills, Uncle Sam Hill, an area extending nearly to Charleston, and irregular areas that extend as far east as the Ground Hog mine. (Plate XVIII, A and B) The mass is intrusive, with sharp contacts with the Mesozoic shales and conglomerates. Fragments of shales and fine-grained igneous rock in the quartz latite porphyry were probably from the wall-rock.

The quartz latite porphyry is greenish-gray to light reddish- or purplish-brown with conspicuous phenocrysts of white feldspar from 1 to 3 millimeters in size that give the rock a "birds-eye" effect. Quartz phenocrysts are not conspicuous, but ordinarily comprise from 15 to 25 percent of the rock. A few small specks of altered biotite are visible. The groundmass is usually dense or felsitic, and in some parts of the area near Charleston, shows a weakly developed flow banding.

Microscopically, the groundmass exhibits a well-developed flow structure between the phenocrysts of feldspar and quartz. (Plate XVII, A and B) The phenocrysts consist of feldspar, both orthoclase and plagioclase, quartz, and biotite, many of which are broken and fragmental. Some are rounded or corroded by the reaction with the viscous groundmass. Biotite grains invariably are altered to chlorite and epidote. Magnetite, zircon, and apatite, are minor accessory
minerals.

An analysis of the quartz latite porphyry collected by Ransome and analysed by R. C. Wells, is shown below, together with an analysis of average quartz latite porphyry (granodiorite porphyry) as given by Johannsen.


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<tr>
<th></th>
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<th>II</th>
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<tbody>
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<td>SiO₂</td>
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<td>FeS₂</td>
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<tr>
<td>Zn</td>
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</table>

I. Quartz latite porphyry Tombstone.
II. Average quartz latite porphyry (granodiorite porphyry) Johannsen.

The norm of the quartz latite porphyry from Tombstone
based on the C. I. P. W. classification of igneous rocks is:

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<tr>
<th>Mineral</th>
<th>Mol. %</th>
</tr>
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<td>33.00</td>
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<td>an.</td>
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<td>di.</td>
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<td>hy.</td>
<td>1.90</td>
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<td><strong>Total</strong></td>
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</table>

**Granodiorite**

A granitoid rock, mainly of granodiorite composition, is stock-like in its proportions, and occupies an area of about two square miles in the northwest part of the district, but extends an undetermined distance beyond the mapped area, where it disappears under the gravel of the late Tertiary sediments.

The rock is light gray to nearly white, mostly even-grained with the individual minerals. About 1.5 millimeters in diameter. Biotite and hornblende are sparingly present in the rock which consists essentially of feldspar. Quartz grains are rarely visible. On exposed surfaces the rock has a distinct pinkish cast from hematite formed by weathering.

The granodiorite is characteristically a non-resistant rock occupying low areas. It weathers in place into blocks and masses, forming a bouldery topography (Plate XIX B), which is slightly elevated above the general level. The
weathering of the granodiorite, a process of granular
disintegration, has further assisted in reducing the rounded
boulders to a coarse feldspathic soil. (Plate XIX, A)

Minerals of the granodiorite are andesine (Ab$_{60}$An$_{40}$),
orthoclase, biotite, hornblende, and a little quartz.
Additional accessories are sporadic grains of sphene, apatite,
and zircon. Biotite and hornblende are always visible,
though not separable, except in thin section, where it is
seen that the clusters are made up of prismatic grains of
hornblende and rounded grains of biotite usually altered to
chlorite. (Plate XVI, A) The dark minerals range between 5
and 7 percent. Biotite is generally the more abundant,
usually near 4 percent.

The calcic andesine normally forms about 63 percent of
the rock and shows a marked tendency to assume its own crystal
shape, though its edges are slightly corroded by later crystal­
lizing minerals. (Plate XVI, B) Quartz generally forms less
than 5 percent of the rock.

Orthoclase ordinarily comprises about 25 percent of the
rock. It exhibits visible cleavage planes through a cloudiness
that is not an alteration of the mineral, but a feature that
is characteristic of orthoclase in Tertiary intrusives.

A chemical analysis by R. C. Wells of a typical
specimen of this rock from near the Scheiffelin monument is
reproduced from the unpublished notes of Ransome, together with an analysis of an average granodiorite as given by Johannsen.\(^4\)

\(^4\) Johannsen, A., op. cit. p. 344.

<table>
<thead>
<tr>
<th></th>
<th>I</th>
<th>II</th>
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<tr>
<td>SiO(_2)</td>
<td>62.33</td>
<td>65.41</td>
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<tr>
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<td>15.72</td>
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<td>Fe(_2)O(_3)</td>
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<tr>
<td>FeO</td>
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<td>MgO</td>
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<tr>
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<tr>
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<td>SrO</td>
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<tr>
<td>Li(_2)O</td>
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<td>F, Cl</td>
</tr>
<tr>
<td>Cu</td>
<td>trace</td>
<td>Cr(_2)O(_3)</td>
</tr>
<tr>
<td>Zn</td>
<td>trace</td>
<td>FeS(_2)</td>
</tr>
</tbody>
</table>

100.38 100.06

I. Granodiorite from Tombstone
II. Average granodiorite, Johannsen

The norm composition calculated from the chemical analysis is as follows:

<p>| | |</p>
<table>
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<tbody>
<tr>
<td>quartz mol.</td>
<td>16.55</td>
</tr>
<tr>
<td>or.</td>
<td>20.10</td>
</tr>
<tr>
<td>ab.</td>
<td>30.40</td>
</tr>
<tr>
<td>an.</td>
<td>20.00</td>
</tr>
<tr>
<td>di.</td>
<td>1.73</td>
</tr>
<tr>
<td>hy.</td>
<td>4.20</td>
</tr>
<tr>
<td>ap.</td>
<td>1.32</td>
</tr>
<tr>
<td>iron ores</td>
<td>4.34</td>
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</table>

\[98.64\]
Although quartz is much more abundant in the calculated composition than was estimated in the hand and thin sections, the chemical analysis agrees closely with the average chemical composition of basic granodiorite.

**Monzonite porphyry**

A series of five parallel dikes cross the area in which mineralization has been most intense, striking N 12°E and generally dipping steeply 75° to 80° west. The dikes are named from mines in which they are prominently exposed. Because extensive ore bodies were mined in parts of these dikes, it was believed at one time that all the ore deposited was associated with them, and consequently, they have been developed on many levels.

The monzonite porphyry is represented by the Empire-Contention dikes, and possibly some dikes exposed east of the Tombstone Extension mine, though they appear to be granite porphyry. Underground, the monzonite porphyry is exposed extensively in the Empire, Tranquility, Head Center, Yellow Jacket, Contention, and Grand Central mines where it is complexly faulted and fissured.

On the surface it is exposed as far south as the Oregon-Prompter fault where it disappears. Northward beyond the Empire mine it is covered by alluvium. This dike ranges in width from a few feet to 50 feet, which also includes the narrow borders of diorite porphyry.
The monzonite porphyry is light gray to light pink with dull white feldspar phenocrysts ranging in size from 2 to 5 millimeters in length embedded in an aphanitic light pink groundmass. Other visible minerals are sporadic grains of biotite chloritized and rarely a rounded quartz grain.

Microscopically, the groundmass consists of plumose or spherulitic feldspar, probably orthoclase. (Plate XX, A) Feldspar phenocrysts are chiefly oligoclase, though in parts of the dike, orthoclase becomes fairly prominent. Quartz phenocrysts rarely exceed 3 percent of the rock. This rock is usually considerably altered, the feldspars sericitized and the biotite altered completely to chlorite and large grains of epidote.

Augite diorite porphyry

The Sulphuret, Boss, and Tribute dikes, all west of the Empire-Contention dike, and the border facies of the Empire-Contention dike, are classified on the basis of texture and mineralogy as augite diorite porphyry. These narrow dikes appear to represent undifferentiated rocks from the magma, as wider dikes show differentiation to monzonite.

The augite diorite porphyry is dark gray to nearly black, lacks visible phenocrysts, and is dense or felsitic. In a few places the texture of the rock is slightly porphyry-
itic, although rarely noticeable except under the microscope. (Plate XX, B). The minerals of the augite diorite porphyry are plagioclase, augite, magnetite, usually a little quartz, and the accessories apatite, actinolite, and pyrite.

Plagioclase phenocrysts, generally about 72 percent of the rock, show zonal growths of variable composition ranging from An$_{47}$ to An$_{50}$. The individual minerals range from 2.5 to 3 millimeters in length.

Augite generally forms about 22 percent of the rock, and occurs as phenocrysts, roughly tabular, with an average diameter of about 2.5 millimeters, but these have been largely altered to actinolite. Some magnetite grains are as much as 2 millimeters in diameter.

The fine grained groundmass consists essentially of feldspar, augite, and magnetite.

Basalts

Basaltic rocks are of very minor extent in the district. A small dike crops out in a gulch east of the Emerald mine, and a much larger mass occurs one mile northeast of Tombstone on the highway to Gleeson. Both are olivine basalts.

The small dike east of the Emerald mine is a typical dark gray to black vesicular basalt with many of the vesicules filled with calcite. Micaceous flakes of iddingsite, 1.5
millimeters in diameter, give to the rock a brown mottled appearance.

In thin sections the rock may appear somewhat porphyritic because of the scattered olivine grains a little larger than the lath-shaped feldspars. The plagioclase laths, generally 0.5 millimeter in length, are haphazardly arranged in a fine grained groundmass of needle-like plagioclase and magnetite to give the typical basaltic texture. (Plate XXI, A)

The plagioclase laths are essentially labradorite which comprises about 55 percent of the specimens examined. Magnetite comprises about 35 percent, and olivine 10 percent. Most of the olivine grains are completely altered to iddingsite; some show the process partly finished; but a few are unaltered, well-shaped, and as large as 0.5 millimeter in diameter.

The basalt mass northeast of Tombstone appears to be intrusive into the late Tertiary sediments that fill the valley between Tombstone and the Dragoon mountains. The occurrence of the mass appears to be that of a ring dike with the center portion consisting of altered cemented conglomerate. Surrounding this inner core there is a variable thickness of black, dense, basaltic rock without vesicles.
Still another ring of red oxidized rock surrounds the whole and grades into the unaltered late Tertiary sediments, chiefly conglomerate. The outer border of the basalt is platy and laminated, and weathers to a peculiar white spotted rock. (Plate XX, C) The inner border of the basalt is massive and weathers smooth.

This basalt differs mineralogically as well as texturally from the one previously described. The texture is very fine grained and is not typically ophitic, (Plate XXI, B) but this may be due to the microscopic size of the feldspars. The minerals of the basalt are labradorite (55 percent), olivine (10 percent), augite (30 percent), magnetite (2 percent), and an unidentified mineral, possibly nephelite, (2 percent). Under high magnification, short, stubby, pale-green augite crystals may be seen interstitial with the feldspar laths. Most of the olivine has a fresh appearance with only the borders altering to iddingsite.

**Paragenesis**

**Hypogene vein minerals**

The sequence of the hypogene vein minerals differs somewhat in detail from place to place, but the general sequence shown in Figure 1 holds for most of the veins. Some unusual minerals that occur in only one mine have not been placed definitely in the general sequence.
Four main stages of ore deposition are; (1) vein gangue minerals which are quartz, barite, fluorite, and calcite, in the greater number of veins, and thaumasite, ettringite, and hillebrandite, in addition to some of the others, in the Lucky Cuss mine; (2) deposition of early sulphide minerals, pyrite, sphalerite, tetrahedrite, bournonite, famatinite, and chalcopyrite; (3) renewed movement along the vein fissures brecciating previously deposited sulphides, introduction of more quartz which has healed the fractures, and deposition of galena; (4) deposition of the later sulphides and tellurides, alabandite and hessite, with some deposition of opal in the Lucky Cuss, and possibly other mines.

The general order of early minerals is thought to be quartz, barite, fluorite, and calcite, though this order is not invariable. The rare sulphates, thaumasite and ettringite, and the silicate, hillebrandite, are thought to be hydrothermal minerals and have been placed after barite, though there is no definite evidence for this assumption except that hydrothermal sulphates usually occur together. Vein quartz of the early stage ranges from blue-gray to white. The earlier blue-gray is commonly fine grained, though, in vugs, it is coarser, whereas the later white quartz is fairly coarse grained. The white quartz has commonly extended into the later sulphide stages, particu-
larly in the Lucky Cuss ore where it cements brecciated sphalerite and tetrahedrite. Barite is believed to have followed quartz at the Ground Hog mine and in a fissure exposed in a prospect pit one-half mile west of the Lucky Cuss mine. Fluorite occurs in few veins in the district, but is locally abundant in the Empire mine. It is later than quartz and earlier than calcite in the "Quarry roll." Deposition of calcite has, in general, closed the first, or barren, stage of mineral deposition. In some veins, calcite is the only gangue mineral, and is generally very coarsely crystalline.

The early stage sulphide minerals show a distinct succession. Pyrite was first, and was largely deposited before the fracturing that followed the first stage. It does not comprise a large part of any of the veins, but is most commonly present with blue-gray quartz and coarsely crystalline white calcite. Sphalerite and tetrahedrite generally heal the fractured pyrite. Bouronite, famatinite, and chalcopyrite, deposited in minor amounts, close the second, or early sulphide, stage.

Movement along the fissure veins that brecciated earlier sulphides, (Plate VII, A and B) particularly noticeable in sphalerite and tetrahedrite, opened the third, or lead sulphide, stage. Deposition of quartz and galena healed the brecciated sulphides. During this stage, galena was de-
posited in abundance and replaced all previously deposited minerals, including both gangue and sulphide, but showed preference for quartz, calcite, sphalerite, and tetrahedrite.

The deposition of galena was followed by the fourth, or final, stage of mineral deposition. As the minerals of this stage are rarely associated with previously deposited sulphides and are never found together, a definite mineral sequence cannot be given. Alabandite has been identified only in the Lucky Cuss mine where it has replaced all previously deposited sulphides and some calcite. Ruby silver minerals were reported from the Lucky Cuss mine, but were not identified by the writer. Hessite occurs in white quartz from the West Side and Flora Morrison mines.

Hypogene mineralization ceased with the deposition of opal in the remaining open spaces in ore from the Lucky Cuss mine.

Supergene minerals

The more important phases of supergene alteration are discussed under the several metals.

Supergene sulphide enrichment of copper consists in the replacement of chalcopyrite by bornite, and bornite by chalcocite. Covellite is observed replacing galena, anglesite, sphalerite, chalcocite, and stromeyerite. Stromeyerite replaces both argentite and chalcocite. Copper is not an im-
portant metal.

Supergene gold and silver are later than the silver haloids, as many specimens of bromyrite show fine flake gold and wire silver resting on it. Native copper replaces cuprite.

Supergene zinc minerals are smithsonite, partly replaced by hemimorphite (calamine). Probably between the deposition of smithsonite and hemimorphite, or after hemimorphite, aurichalcite, $2(Zn,Cu)CO_3 \cdot 3(Zn,Cu)(OH)_2$, rosasite, $(Cu,Zn)CO_3 \cdot (Cu,Zn)(OH)_2$, and hydrozincite, $ZnCO_3 \cdot 2Zn(OH)_2$, were deposited in open cavities around the borders of the ore bodies.

Supergene iron minerals are jarosite, "limonite", chiefly a mixture of hydrous iron oxides, and red earthy hematite. "Limonite" is the more abundant and stable mineral.

The supergene lead minerals are given diagrammatically in Figure 2 and discussed under lead mineralization. Copper minerals are also diagrammed. Galena and chalcopyrite are the two hypogene minerals altered by surface waters to show the succession of supergene minerals.

White crystalline calcite in caverns and porous boxwork structures is usually the last supergene mineral deposited.
Gold and Silver Mineralization

The rich gold and silver ores in the district were mined from the surface to depths of about 400 feet in the first 20 years of mining activity, and but few specimens representative of that zone remain. Descriptions of the early mined gold and silver ore are meager and confined to general mineral associations discussed in the early reports on the district. Blake mentions that the ore, in 1881, assayed $70 per ton in gold and silver. The gold was free, and the silver occurred chiefly as chloride with probably some iodide in crusts and films. Later, Church mentions the ore as composed almost entirely of horn silver enclosed in a gangue of quartz, containing lead carbonate, manganese, and iron oxides, and some silver sulphide. The ore assayed 60 ounces of silver and 0.83 ounce of gold.

Later, Church made some comparisons of the ratio of gold to silver in the ore from the various mines, which he assayed $70 per ton in gold and silver. The gold was free, and the silver occurred chiefly as chloride with probably some iodide in crusts and films. Later, Church mentions the ore as composed almost entirely of horn silver enclosed in a gangue of quartz, containing lead carbonate, manganese, and iron oxides, and some silver sulphide. The ore assayed 60 ounces of silver and 0.83 ounce of gold.

Later, Church made some comparisons of the ratio of gold to silver in the ore from the various mines, which he...
found to vary greatly. The Contention and Grand Central mines had about 1 ounce of gold to 80 ounces of silver. The mines that belonged to the Tombstone Mill and Mining Co. had about 1 ounce of gold to 180 ounces of silver. Also, he found that the ratio of gold to silver was greater in the fissure veins than in the anticlinal deposits. The Lucky Cuss mine, which had little more than a trace of gold at the surface, produced ore containing $12 per ton in gold below the ground water level.

On the silver content of the manganese ores Goodale


says:

"All of the chimneys (principally from the Oregon mine) yielded ore assaying from 30 to 50 ounces of silver per ton near the surface, but below 150 feet the silver content decreased as depth was gained with the exception of one chimney which produced a uniform quality of ore so far as it was worked."

Also, he mentions that, up to 1887, these manganese ores had yielded not less than 750,000 ounces of silver, which has made them worthy of study.

The relative quantity of gold and silver in certain oxide ores and in the hypogene sulphides is of interest if mining is carried on into the sulphide zone. It is believed that the samples collected by the writer are as represent-
ative of the oxidized and sulphide ores as are now available. The assays were made by the assayer and chemist of the Tombstone Development Co.

A dark "chocolate" ore from the lower end of the "Holderness roll" assayed 0.48 ounce gold, 58.92 ounces silver, per ton, and 8.5 percent lead. Assays on this kind of ore from the Toughnut mine are reported as high as 200 ounces of silver per ton. Yellow crystalline jarosite, lower down the flank of the "Holderness roll", assayed 0.20 ounce gold and 4.40 ounces silver per ton, and 2.1 percent lead. Another sample of jarosite from the bottom of stope A, 4th level of the Empire mine, assayed gold none, silver 0.92 ounce per ton, and 4.8 percent lead.

Pyritic ore from the Sulphuret stope in the West Side mine assayed 0.04 ounce gold, and 4.18 ounces silver per ton. Galena-sphalerite ore from the same stope assayed 0.38 ounce gold, and 21.86 ounces silver per ton. In the "Holderness roll" clean galena ore assayed 0.16 ounce gold, and 42.44 ounces silver, per ton. Clean galena ore from the Ship Shaft fissure vein on the 4th level of the Empire mine assayed 2.46 ounces gold and 237.84 ounces silver. Siliceous ore consisting of vitreous white quartz with disseminated tetrahedrite and bournonite was assayed from two stopes on the 4th level of the Empire mine. That from stope No. 417
assayed 1.50 ounces gold, and 87.38 ounces silver, per ton. That from stope No. 488 assayed 0.12 ounce gold, and 18.08 ounces silver per ton.

Tetrahedrite from the "Jeanes roll" deposit on the 4th level of the Toughnut mine is reported to have assayed 85 ounces silver, per ton, which was checked by the assayer for the Arizona Bureau of Mines at 85.3 ounces silver, and 0.12 ounce gold, per ton.

It has been reported that the increase in gold content of the ore from the Lucky Cuss mine was due to the presence of alabandite found on the 4th level. An assay of a specimen of this alabandite gave 0.05 ounce gold, and 7.51 ounces silver, per ton. A polished section of the specimen (Plate III, A and B) shows that the alabandite contains small particles of other sulphides, namely, chalcopyrite, galena, tetrahedrite, and sphalerite.

Three minerals are regarded as the source of the hypogene silver. Hessite (Ag₂Te) has been described from both the West Side and Flora Morrison mines, and it probably was present in other mines. Tetrahedrite and galena are argentiferous. The silver in galena and tetrahedrite is probably contained in the molecule and not in small inclusions of an extraneous silver mineral.
The identity of the hypogene gold mineral or minerals is less certain. It is believed that gold tellurides are present with the silver tellurides, but, so far, they have not been identified.

The supergene silver minerals are the haloids; bromyrite, embolite, and cerargyrite; the sulphides, argentite and stromeyerite, native silver, and possibly argentobarosite.

The vertical distribution and the relative abundance of the silver haloids is uncertain, but the rare silver bromide, bromyrite, is believed to be the most abundant and to have occupied a definite zone in the ore. The occurrence of bromyrite at Tombstone is believed to be the first described from any mining district in the United States. It has not been reported from the famous silver mining camps of Nevada, though it has been looked for. The more usual bromine minerals are embolite and iodobromite. The depth of oxidation at Tombstone is unknown, but probably it is at least 600 feet. Bromyrite was present at least within 100 feet of this depth in the Grand Central and Contention mines, and may have extended deeper. This is not an unusual depth, for Burgess found iodobromite at a depth of


1300 feet at Wonder, Nevada. At Tonopah, as well as at
Wonder, Nevada, the silver haloids occupy fairly well marked horizons in the altered veins, according to Burgess.\footnote{Burgess, J. A., - The halogen salts of silver and associated minerals at Tonopah, Nevada. Econ. Geology, vol. 6, pp. 13-21, 1911.}

The order of deposition was chloride, bromochloride, and iodide, at Tonopah, and bromochloride, iodobromochloride, and iodide, at Wonder, the chloride being absent. This order is contrary to their respective solubilities. Of these relations Emmons says:


"If, in a solution containing the three halogens, chlorides are vastly in excess, silver chloride will be precipitated first even if bromides and iodides are present, for in a mixed solution the least soluble salts are not precipitated first if a more soluble salt is present in sufficiently greater concentration.

"However, if the three halogens were equally abundant in mine waters, the bromide and iodide of silver would probably predominate in the silver deposits."

The analysis of a sample of bromyrite from the Skip Shaft fissure vein exposed on the 4th level of the Empire mine gave 38.0 percent bromine, 2.6 percent iodine, and 0.6 percent chlorine. The silver haloid found at the surface has usually been called cerargyrite, although there are no published analyses to confirm this belief. Bromyrite is the abundant silver haloid mineral around 400 feet depth, and in some places
at least, there is some indication of an increase of iodine with increased depth.

The source of the halogen salts is not definitely known, but they may well have been derived from alkali lakes or playas which are not far distant.

**Manganese Mineralization**

Manganese oxides are common constituents of many silver-bearing veins in the district. Some bodies of manganese oxides have been sufficiently large to mine for manganese alone, but the greater number were mined for their silver content. The chief source of manganese ore has been the Oregon-Prompter mine, but the Lucky Cuss, Luck Sure, and Wedge mines, have also been important producers from a belt lying near the contact of the granodiorite intrusive. A second group of mines that have produced manganese includes the Telephone, Emerald, Rattlesnake, Mammoth, and Comet. These are situated about one mile southeast from the first group.

The origin of the manganese ore has received some discussion. Some writers have considered the Carboniferous limestones as the source of the manganese. Others believed that rhodocrosite and rhodonite were probably the source of the manganese. Since alabandite, occurring in small amount in one area in the Lucky Cuss mine, is the only definitely
established hypogene manganese mineral in the district, it is believed by the writer that the manganese oxides were derived from alabandite.

Alabandite was first described from Tombstone by Moses and Luquer who state that it was first found in April, 1891.


in the footwall of the Lucky Cuss fissure vein in pure white, strongly crystalline, limestone. The mineral was found by following a body of manganese oxide and lime spar which gradually merged into nearly pure alabandite, which in turn gave place to iron, zinc, and copper sulphides, with small amounts of alabandite. Church mentions further that a mass of ore rich in alabandite, mingled with pyrite and galena, occurred under a tongue of minette on the 350-foot level. In this position, it was protected from surface waters and oxidation, thus preserving the original form of the manganese.

Microscopical examination of two specimens in the Mineralogical Museum at the University of Arizona gave little evidence of the position of alabandite in the mineral sequence. The specimens are nearly pure alabandite embedded in a gray
carbonate gangue with microscopic grains of galena, tetrahedrite, and sphalerite. (Plate III, B) Chalcopyrite occurs in alabandite as small tetragonal-sphenoids, (Plate III, A) and as blebs along the crystal borders; a relationship similar to that often seen between sphalerite and chalcopyrite.

Hewett and Rove have shown that alabandite is later than galena in the Trench mine in the Harshaw district, Arizona, and later than tetrahedrite in the Humboldt mine in the Chiricahua mountains. Since the association of minerals at Tombstone is much the same as in the two localities mentioned, it seems likely that alabandite is a late sulphide.

Throughout the mines are numerous veins of coarse crystalline black calcite which vary from a few inches to two feet thick. Black calcite in other districts has been considered by Hewett and Pardee as hypogene, and at least part of it at Tombstone may be hypogene. That deposited in "water courses" is known to be supergene. The study of black calcite has been limited through the lack of exposures through
the zone of oxidation. So far as known, it may change below the zone of oxidation to ordinary white calcite.

Thin sections of black calcite show under the microscope minute fibrous and arborescent growths (Plate XX,A and B) of a brownish to black oxide of manganese replacing the calcite along the cleavage cracks, more in one cleavage direction than in the others.

Black calcite dissolved in a 10 percent solution of hydrochloric acid left a black residue. Calcium and manganese reactions were obtained when the solution was tested. The residue on the filter paper effervesced and was completely dissolved by hydrogen peroxide, suggesting that the brownish black oxide is probably pyrolusite or some other dark brown hydrated oxide of manganese.

What is the origin of the manganese oxide in the black calcite? Is the manganese oxide hypogene or supergene? Thin sections show that it is later than calcite, since it replaces calcite along cleavages. If the oxide is later, why did it choose certain calcite veins, and not the limestone wall rock? The manganese oxide may have been deposited as the mineral now present by either supergene or hypogene solutions. Manganese oxides known to be hypogene are manganosite (MnO) and pyrochroite (Mn(OH)₂) which turn dark on exposure. It may have been deposited by hypogene solution as carbonate, silicate, or sulphide of manganese, and subsequent-
ly altered. No relics or other evidence of an earlier mineral have been recognized, and it seems doubtful if such was deposited.

There seems to be no direct and positive evidence pointing to either hypogene or supergene solutions as the source of much of the manganese in the black calcite. Positive evidence may be obtained from specimens below the zone of oxidation.

The black calcite and associated manganese oxides in the "water courses" seem quite clearly to have been deposited from supergene solutions, as long columnar crystals projecting into the caverns.

Oxidation of alabandite to acid manganic sulphate might permit the transportation of manganese which would hydrolize and precipitate as oxides, on reaction with calcite.

The supergene minerals in the main are believed to have been derived primarily from the oxidation of alabandite. Alabandite is known to have occurred in considerable amounts in the Lucky Cuss mine. Rhodochrosite and rhodonite have never been identified at Tombstone. Alabandite oxidizes much more readily and rapidly than either the carbonate or silicate.

Hewett and Rove have suggested that the oxidized manganese ore bodies at Bisbee came from the oxidation of alabandite.

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If alabandite was the primary mineral source for the oxidized manganese ores in the Lucky Cuss mine, it is reasonable to assume that it was the source in the other manganese mines of the district. In all the mines the large manganese ore shoots occur as chimney or pipe-like bodies at the intersection of fractures in the massive white limestone. The pipes are somewhat irregular in shape and variable in size. There are no indications of ore along the drifts until within a few feet of the ore bodies. The manganese minerals of the pipes are polianite, pyrolusite, psilomelane, earthy black wad, manganite, and the rare zinc hausmannite, hetaerolite. Search has failed to discover the rarer oxides, braunite and hausmannite. The gangue minerals are quartz and calcite. The centers of these bodies usually consisted of a soft porous iron and manganese ore with variable quantities of lead, zinc, and silver, surrounded by a hard compact envelope of black manganese oxides. Goodale reports that caverns were found in the widest parts of the ore bodies lined with snow-white calcite, that the purest manganese ore formed the lining of the pipes, and that the siliceous ores in the center were richest in silver.

If alabandite is the probable mineral from which the oxides were derived, then what are the processes in its
oxidation? In contrast with the extensive investigations of the oxidation of copper and iron sulphides, the oxidation of alabandite has been little studied, owing to its rarity. Manganese sulphide reacts quickly to acid solution, and decomposes more rapidly than the sulphides of any other common metal. Alabandite exposed on the mine dump oxidizes very rapidly on the surface, and hence is not easily distinguished from the manganese oxides. Unless one knows what to look for, the weathered specimens are easily overlooked and mistaken for oxides.

The freshly broken surface of one specimen of oxidizing alabandite showed pyrite grains unaffected, hence, alabandite probably oxidized earlier than pyrite by an air-water process, possibly by the following reaction,

\[ \text{MnS} + 4 \text{O} = \text{MnSO}_4 \]

In the same specimen between the unaltered alabandite and the oxidized surface occurs a reddish-brown carbonate believed to represent supergene rhodochrosite. Hewett and Rove have also mentioned alabandite altering to supergene rhodochrosite.

Manganous sulphate is soluble in acid solution, but the processes involved in going from manganous sulphate to pre-
cipitated manganous carbonate are not as clearly understood as the reactions in going from a bicarbonate solution of manganese to manganese carbonate. Savage has proved by experiments that manganese will remain in solution as bicarbonate until the solution becomes slightly alkaline by reaction with calcium carbonate. Savage explains the reaction as follows:

"Manganese bicarbonate, in the presence of calcium carbonate, releases the carbonic acid molecule which dissolves some of the calcium carbonate, to form calcium bicarbonate, and a precipitation of manganese carbonate takes place according to the following equation:

\[ \text{Mn(HCO}_3\text{)}_2 + \text{CaCO}_3 = \text{Ca(HCO}_3\text{)}_2 + \text{MnCO}_3 \]

Some of the manganese has probably gone into solution as bicarbonate, but more has probably gone into solution as sulphate.

In the hypogene deposits alabandite was associated with pyrite, galena, sphalerite, and tetrahedrite, and during oxidation there was a separation of iron and manganese oxides as suggested by the relations in the pipe-like bodies.

Alabandite may oxidize to manganous sulphate (MnSO\(_4\)) by direct oxidation, or by sulphuric acid and ferrous sulphate formed by the oxidation of pyrite. Further oxidation of the
acid sulphate is said to take place according to the following scheme under strongly acid conditions, such as might be present when free acid is produced by the oxidation of pyrite.

\[ \text{MnSO}_4 \rightarrow \text{Mn}_2(\text{SO}_4)_3 \rightarrow \text{Mn}(\text{SO}_4)_2 \rightarrow \text{Mn}_2(\text{SO}_4)_7 \rightarrow \text{HMnO}_4 \]

The higher oxidized sulphates \( \text{Mn}_2(\text{SO}_4)_3 \) and \( \text{Mn}(\text{SO}_4)_2 \) are known to exist, but \( \text{Mn}(\text{SO}_4)_2 \) cannot be isolated, and exists only in a solution of \( \text{H}_2\text{SO}_4 \). Emmons mentions that manganic sulphate \( \text{Mn}_2(\text{SO}_4)_3 \), though possibly present, has not been identified in mineral waters, and appears to play no part in the weathering of ores, but the present writer believes that it may play an important part in the transportation of manganese.

The sulphates hydrolyze much more readily than ferric sulphate to form acid solutions according to the following reactions:

\[ \text{Mn}_2(\text{SO}_4)_3 + \text{H}_2\text{O} \rightarrow \text{Mn}_2\text{O}_3 + 3\text{H}_2\text{SO}_4 \]
\[ \text{Mn}(\text{SO}_4)_2 + \text{H}_2\text{O} \rightarrow \text{H}_2\text{MnO}_3 + 2\text{H}_2\text{SO}_4 \]

Once these oxides are formed, they are relatively insoluble.
Savage has given equations for the reaction of manganese bicarbonate with water to obtain the same oxides.

Savage, W. S., - op. cit., p. 288.

Regardless of the type of solution, whether sulphate or bicarbonate, the end products are the same. None the less it is believed that the manganese oxide deposits at Tombstone owe their formation to the action of sulphate solutions. Dunnington was probably the first to suggest that many deposits of manganese in calciferous rocks owe their formation to the action of sulphates. He arrived at this conclusion from a series of experiments in which he subjected manganese oxides, chiefly psilomelane, to the action of ferrous sulphate and sulphuric acid in about the proportions that would form from the oxidation of pyrite. The rate of solution was equivalent to 6 inches in one year. If the rate of solution is so great on relatively insoluble oxide, what might it be on the relatively soluble manganese sulphide? As far as known, there have been no laboratory experiments on the oxidation of manganese sulphide by any agents that approach those found in an ore body undergoing oxidation.

If the pipe-like manganese ore bodies in limestone consisted of alabandite with pyrite, galena, sphalerite, and
sulphides of copper, exposure of the ore body to erosion and fluctuation of the water table would cause the pyrite to oxidize to ferrous sulphate and sulphuric acid. These would act on the sulphides of the other metals, but more easily on manganese than the others because of its decided solubility in acid solutions. At the same time ferric sulphate solutions would form under favorable conditions. The ferric sulphate would react immediately upon the calcium carbonate to form soluble calcium sulphate, carbonic acid, and ferric hydroxide. During this process of oxidation, the manganese sulphate may move downward to great depths as manganese is more soluble than iron in sulphate solutions, and hence, will remain in solution after the iron has been precipitated. Therefore, as Emmons, W. H., op. cit., p. 439.

Dunnington has suggested, manganese sulphate in solution without the presence of air is not readily acted upon by the limestone and might be carried considerable distances downward in limestone before precipitation. But in the presence of both air and limestone the manganese is precipitated as oxide.

Thus, during the oxidation of these pipe-like bodies, the iron was precipitated by hydrolysis in the porous siliceous center with silver, lead, zinc, and some manganese forming the manganiferous silver deposits, and manganese migrated
downward and to the walls to form a hard massive envelope of pyrolusite and psilomelane.

Lead Mineralization

The character of the hypogene ore has been determined partly from specimens of oxidized ore with sulphide cores, and partly from unoxidized sulphide ores of lead, copper, and zinc, collected from many mine dumps. These ores indicate that galena, one of the later sulphide minerals, was deposited as coarsely crystalline aggregates replacing principally coarse crystalline calcite, but also to some extent, quartz, pyrite, and sphalerite. Galena in the Tombstone Extension mine has a gneissic texture, probably the result of shearing along the ore fissure.

Bournonite, the only other hypogene lead mineral recognized in the district, occurs in such minor amounts that it is not important in the formation of oxidized lead ores.

Supergene lead minerals have been formed, largely through the oxidation of galena by acid solutions as illustrated in Figure 2. All the steps in the process of alteration of one mineral to another are not clearly understood, as only the end products are present. It is believed that either some of the lead is taken into solution by acid sulphate, or chloride solutions, to be later combined with
rare elements and deposited as rare occurring minerals, or that the rare elements in solution combine with lead and migrate some distance from the original source of the lead.

Oxygenated waters percolating from the surface have altered galena to lead sulphate (anglesite) along cleavage cracks of galena to form concentric bands around cores of unaltered galena. This action is usually expressed by the following formula:

$$\text{Pb}_4\text{S}_4 + 4\text{O} \rightarrow \text{Pb}_4\text{SO}_4$$

With complete alteration, the sulphate may completely fill the space originally occupied by the galena. Some of the lead may be carried away in solution to be deposited in some other form.

The abundance of coarsely crystalline lead carbonate surrounding anglesite and galena indicate that carbonated waters passing over the sulphate have partially or completely changed it to the more stable carbonate. The usual suggested reaction is as follows:

$$\text{Pb}_4\text{SO}_4 + \text{H}_2\text{CO}_3 \rightarrow \text{Pb}_4\text{CO}_3 + \text{H}_2\text{SO}_4$$

Pseudomorphs of cerussite after cubes of galena show open spaces corresponding to the cleavage cracks of the galena in some of which incrustations of pyromorphite occur.
The same agencies that oxidize galena to lead sulphate and carbonate, alter pyrite to sulphuric acid and ferrous sulphate, and the ferrous sulphate to ferric sulphate. Ferric sulphate solutions reacting with the lead minerals yield ferric lead sulphates, which may, in turn, break down to the more stable lead carbonate and limonite.

There is a series of yellow basic lead-ferric-copper sulphates, arsenites, and phosphates, that may form and be stable under certain conditions, but which tend to break down to the more stable limonite and carbonate. Beaverite, \( \text{CuO-PbO-Fe}_2\text{O}_3\cdot 2\text{SO}_3\cdot 4\text{H}_2\text{O} \), a hydrous sulphate of copper, lead, and iron, occurs rather abundantly with cerussite. The mineral is canary-yellow and is commonly mixed with quartz and other secondary lead and copper minerals. The relations of beaverite to cerussite indicate that ferric sulphate solutions with copper reacted with cerussite to form beaverite. Another yellow sulphate appears to form in a like manner with chalcocite. Minute reticulating veinlets in chalcocite consist first of some green copper sulphate, but on reacting with ferric sulphate, the veinlets turn yellow, and on testing microchemically, consisted of copper-iron sulphates.

Plumbojarosite, \( \text{PbO-Fe}_2\text{O}_3\cdot 4\text{SO}_3\cdot 6\text{H}_2\text{O} \), which is found more abundantly than beaverite in the lead ore is probably a more stable sulphate. Plumbojarosite, also, appears to be
a direct replacement of cerussite, as the two are intimately mixed. With continued alteration, the plumbojarosite goes to limonite. Some jarosite is commonly present. Hewett has suggested that plumbojarosite and jarosite form an isomorphous mixture, that is, plumbiferous jarosite. Optical examination of some well-crystallized specimens gave an index higher than that of jarosite, but not as high as that of plumbojarosite. Representative samples were submitted to the Chemistry Department, University of Arizona, for analyses, but the results are not available at present writing (May, 1937).

Some lead has probably been carried in solution, for such minerals as pyromorphite, descloizite, vanadinite, and wulfenite, were deposited many feet distant from the nearest hypogene lead minerals. A few specimens, however, show pyromorphite replacing carbonate, which might indicate that solutions carrying chlorine and phosphorous reacted with lead carbonate to form pyromorphite. Nevertheless, most of the pyromorphite has formed as tiny yellow, gray, and green, hexagonal crystals around the borders of lead ore bodies.

The lead vanadates, descloizite, $\text{Pb}(\text{Zn},\text{Cu})\text{OH} \cdot (\text{VO}_4)_3$ and motttramite, $\text{Pb}(\text{Cu},\text{Zn})\text{OH} \cdot (\text{VO}_4)_3$ probably formed at differ-
ent times, as they represent opposite end members of an
isomorphous series, but there is no physical or chemical
evidence as to which one was first. Vanadinite, \( \text{Pb}_4(\text{WO}_4)_3 \)
PbCl) crystals rest on descloizite and, hence, formed later
in the sequence than descloizite. A notable distinction is
that the mineral with the chlorine radicle formed later than
those with the hydroxyl radicle. This is not fortuitous, for
a brief examination of vanadates from other mining districts
shows the same general sequence.

Wulfenite appears to be the last lead mineral to form,
as well as being one of the latest in the entire oxidation
series. The excellent crystals suggest that it formed slowly
from dilute solutions. The source of vanadium, phosphorous,
and molybdenum, has not been determined, though molybdenum
may be from molybdenite, but molybdenite has not been found in
the ores.
Contact Metamorphism

Introduction

The intrusion of the granodiorite stock caused widespread metamorphism of the limestones. Beds of coarsely crystalline marble alternate with beds composed largely of idocrase (vesuvianite), olivines, pyroxenes, and other silicates. The original limestone beds in which the silicates have formed were impure. They have not been traced in detail into unmetamorphosed rocks, but it is believed that they represent parts of the upper Naco limestone that consists of interbedded layers of sandy, clayey, and dolomitic limestones, that might be rearranged to form the silicates. Field relations favor the idea that the silicates have resulted largely from the recombination of impurities present in the limestones instead of the introduction of silica and alumina from igneous sources.

Superimposed on this metamorphism, in certain areas cut by fissures, are minerals of hydrothermal origin that partly replace the earlier metamorphic minerals. Some of the rare and unusual minerals in this metamorphic zone are thaumasite \( (3\text{CaO} \cdot \text{CO}_2 \cdot \text{SO}_3 \cdot \text{SiO}_2 \cdot 15\text{H}_2\text{O}) \), ettringite \( (6\text{CaO} \cdot \text{Al}_2\text{O}_3 \cdot 3\text{SO}_3 \cdot 33\text{H}_2\text{O}) \), hillebrandite \( (2\text{CaO} \cdot \text{SiO}_2 \cdot \text{H}_2\text{O}) \), an unknown calcium silicate similar to hillebrandite, and blue calcite.
Hydrothermal solutions have also partly altered the earlier metamorphic silicates to serpentine, talc, brittle micas, and other unidentified minerals.

Field occurrence

The detailed study of the metamorphism has been of two areas that show the type of metamorphism expressed by the stock. Similar metamorphism is present to some degree along the entire stock.

Comstock Hill (Plate XXIII, A), one-half mile northeast from the center of Tombstone, shows conspicuous outcrops of alternating beds of garnet, idocrase (vesuvianite), olivines, wollastonite (?), and pyroxenes (Plate XXIII, B). The same alternating beds are present at the Lucky Cuss mine, but they are there partly and in places largely replaced by hydrothermal minerals associated with fissure veins.

Sedimentary beds affected by the metamorphism are relatively pure limestones and interbedded dolomitic and argillaceous members. The metamorphism has recrystallized the pure limestones to marbles, and the impure beds to silicates, making it impossible to tell closely what part of the stratigraphic sequence has been metamorphosed. Analyses of the unmetamorphosed beds were not undertaken, but Goodale

reports three partial analyses. Their location indicates that they were marbles rather than limestones, and that they can be representative only of those beds from which they came.

Analyses of limestones from Tombstone
(F.C. Earle, analyst)

<table>
<thead>
<tr>
<th>No.</th>
<th>CaCO$_3$</th>
<th>MgCO$_3$</th>
<th>SiO$_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. 1</td>
<td>91.33</td>
<td>trace</td>
<td>6.00</td>
</tr>
<tr>
<td>No. 2</td>
<td>90.75</td>
<td>2.85</td>
<td>5.20</td>
</tr>
<tr>
<td>No. 3</td>
<td>96.46</td>
<td>trace</td>
<td>2.41</td>
</tr>
</tbody>
</table>

No. 1  Main working shaft, Lucky Cuss mine, near contact with granite. White and crystalline.
No. 2  West end of "Knoxville" (Oregon mine). Blue and compact.
No. 3  Luck Sure. Represents general character of limestone in the belt. What little Fe, Al, and Mn occurred in the samples was not determined.

Note that analysis No. 1 represents white crystalline limestone in contact with the intrusive, but there is little addition of material from the igneous mass, only a recrystallization of the limestone to marble, with possibly some addition of silica.

The igneous rock appears everywhere to have been intruded into a region where the limestones were folded or faulted. The steepness of the contact near the Lucky Cuss mine suggests that the stock is probably a cupola on the top of a much larger mass. Apophyses of the stock intrude the bedding planes of the sedimentary rocks as sills rather than
as cross-cutting dikes. The apophyses as well as the stock are granodiorite. The igneous rock, both of the stock and the apophyses, shows an absence of chilled borders, fine-grained textures, and lack of dark ferromagnesium minerals, where in contact with the sedimentary rocks. It is believed, therefore, that the intrusion was into rocks already heated.

The metamorphic silicate zone is confined entirely to the limestone side of the contact and is generally of irregular width, probably not over 500 feet. Intense metamorphism extends about 50 feet from the igneous rock. Some argillaceous beds exposed near the Oregon mine have been considered as silicified and recrystallized by the intrusive, but further consideration of these beds is deferred until they have been studied microscopically. The geological interest of the metamorphism focuses on the source of the material for the garnets, idocrase (vesuvianite), and many other silicates that occur in the zone. Some consider the lime-silicate zone as formed by additions from igneous sources. Others consider that the impurities in the limestones furnished the necessary elements for the silicates. The field evidence at Comstock Hill and at other places favors the recrystallization idea for the Tombstone district.

Mineralogy

Detailed study of the mineralogy of the contact silicate zone is not complete. Besides the usual silicate miner-
als found in contact zones, a few rare mineralogical curiosities like hillebrandite, thaumasite, ettringite, and possibly merwinite, occur, which offers possibilities of finding other rare minerals usually occurring with this group.

At Tombstone, the most abundant minerals are the calcium-aluminum silicates, grossularite, and idocrase (vesuvianite). Grossularite ranges in color from white to cinnamon-brown. The cinnamon-brown is the more abundant of the two and occurs as bands or layers associated with idocrase. The white variety usually occurs as crystals which, on weathered surfaces, show octahedral faces modified by small cube faces. Its index of refraction \( n = 1.752 \pm 0.003 \) is close to that of pure calcium garnet.

Idocrase is difficult to distinguish from associated garnet where they both occur in the same compact mass. Individual crystals in coarse calcite gangue, however, are readily distinguished by their deep olive-green color and tetragonal crystallization. Grossularite and idocrase have formed by recrystallization from the impure limestone beds, but the order of crystallization is not apparent. The two minerals are closely alike in percentage of components, and it is most probable that a certain condition of physical-chemical equilibria determines why two minerals form instead of one from the same constituents.

Clinozoisite, a calcium-aluminum silicate of the epidote
group, also occurs in small quantities with grossularite and idocrase.

The pyroxenes, diopside and pigeonite, occur as compact masses and as individual crystals in widely spaced beds exposed in Comstock Hill. These beds alternate with those of grossularite and idocrase, and also with the less abundant beds of olivine. Before metamorphism these beds were probably dolomitic and siliceous. Pigeonite, a calcium-magnesium-iron silicate, intermediate in composition between diopside and clinoenstatite, generally occurs as dark green grains in a light blue calcite matrix. Some individual crystals of diopside are almost one-half inch in length, clear green to dark green, and generally separated from other silicate minerals.

Light green olivine and pale brown to white monticellite, principally magnesium and calcium silicates, form beds of coarsely crystalline masses separate from those consisting of pyroxenes and calcium-aluminum silicates. Generally coarse crystalline calcite is the associated mineral.

The contact zone at Tombstone differs from many contact zones in other localities in that it lacks iron-bearing silicates like epidote, hedenbergite, and andradite. These minerals are absent, probably from the lack of iron in the limestone.

Some minerals in the contact zone were deposited by
hydrothermal solutions and consequently occur in or near fissures that cross the silicate zone. Others are considered as having formed from pre-existing silicates through the action of hydrothermal solutions. The minerals recognized as hydrothermal are pale blue calcite, thaumasite, hillebrandite, an unknown hydrous calcium silicate, and possibly ettringite. Those believed to be derived from pre-existing silicates through the action of hydrothermal solutions are serpentine, talc, and probably a mineral belonging to the brittle micas.

Pale blue calcite in veins up to 2 inches wide occurs on the 5th level of the Lucky Cuss mine where it is associated with fibrous chrysotile, a variety of serpentine, and a pearly white micaceous mineral, probably one of the brittle micas.

Thaumasite \((3\text{CaO}.\text{CO}_2.\text{SO}_3.\text{SiO}_2.15\text{H}_2\text{O})\) is abundant in the Lucky Cuss mine where it replaces the limestone as narrow fissures up to 4 inches wide. The snow-white color and minute interlocking crystals serve to distinguish it from the fine-grained white limestone in which the veins occur, for both effervesce readily in dilute hydrochloric acid.

Ettringite \((6\text{CaO}.\text{Al}_2\text{O}_3.3\text{SO}_3.33\text{H}_2\text{O})\) has not been identified by the writer but was described from the Lucky Cuss mine by Moses. He thought ettringite was formed by the action of hydrothermal solutions.

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sulphuric acids of supergene origin upon limestone and silicate bearing rocks. It is believed by the writer that both thaumasite and ettringite owe their formation to the action of hypogene sulphate solutions on limestones, and in part on contact silicates.

Hillebrandita \((2\text{CaO}.\text{SiO}_2.\text{H}_2\text{O})\) previously described from Velardeña district, Mexico, also occurs in the Lucky Cuss mine, the second locality for it. The small amount of material collected gives little information as to its general occurrence and mineral associations. Spurr and Garrey believe that it formed at Velardeña through the contact action of a basic intrusive upon limestone. It is believed by the writer that hillebrandite was formed by the action of hydrothermal solutions upon contact silicates, since, at both localities, hillebrandite was found in the contact zone only where mines were developed.

A hydrous calcium silicate that belongs in the same series as hillebrandite occurs in the contact zone with calcite, grossularite, and idocrase. Its indices of refraction indicate a new mineral. It is glassy white to colorless, occurs
as short stubby crystals, and looks like wollastonite. In
the following list of hydrous calcium silicates, the indices
of refraction and optical character are given to show the
position of the new mineral in the series.

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Formula</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Okenite</td>
<td>CaO.2SiO₂.2H₂O</td>
<td>1.530</td>
<td>1.555</td>
<td>1.540</td>
</tr>
<tr>
<td>Centrallasite</td>
<td>4CaO.7SiO₂.3H₂O</td>
<td>1.555</td>
<td>1.548</td>
<td>1.549</td>
</tr>
<tr>
<td>Riversideite</td>
<td>2CaO.2SiO₂.3H₂O</td>
<td>1.595</td>
<td>1.600</td>
<td>1.603</td>
</tr>
<tr>
<td>Foshagite</td>
<td>5CaO.3SiO₂.3H₂O</td>
<td>1.597</td>
<td>1.603</td>
<td>1.605</td>
</tr>
<tr>
<td>Crestmorite</td>
<td>4CaO.4SiO₂.7H₂O</td>
<td>1.593</td>
<td>1.605</td>
<td>1.607</td>
</tr>
<tr>
<td>Hillebrandite</td>
<td>2CaO. SiO₂. H₂O</td>
<td>1.605</td>
<td>1.610</td>
<td>1.612</td>
</tr>
<tr>
<td>Unknown</td>
<td>?CaO.?SiO₂.?H₂O</td>
<td>1.616</td>
<td>1.624</td>
<td>1.626</td>
</tr>
<tr>
<td>Wollastonite</td>
<td>CaO. SiO₂</td>
<td>1.620</td>
<td>1.632</td>
<td>1.634</td>
</tr>
<tr>
<td>Zonolithite</td>
<td>5CaO.5SiO₂. H₂O</td>
<td>1.583</td>
<td>1.583</td>
<td>1.595</td>
</tr>
<tr>
<td>Afwillite</td>
<td>3CaO.2SiO₂.3H₂O</td>
<td>1.617</td>
<td>1.621</td>
<td>1.635</td>
</tr>
<tr>
<td>Larnite</td>
<td>2CaO. SiO₂</td>
<td>1.707</td>
<td>1.715</td>
<td>1.730</td>
</tr>
</tbody>
</table>

Based on indices of refraction, there is more reason to
consider this silicate a new mineral separate from wollaston-
ite, than there is for making the three separate mineral
species, riversideite, foshagite, and crestmorite, with their
slightly differing indices. When sufficient quantity of the
mineral can be separated and analysed it is suggested that it
be named tombstonite.

Known and described occurrences of minerals of this
group and other rare associated minerals are few. Two of the
best known localities are Crestmore, California, and Scawt
Hill, County Antrim, Ireland. Two references are chosen as
69,70
representative of the areas.

69 Daly, J. W., - Paragenesis of the mineral assemblages at
Crestmore, Riverside, County, Calif. Am.

70 Tilley, C. E., and Harwood, H.F., - The dolerite-chalk
contact of Scawt Hill Co., Antrim. The
production of basic alkali rocks by assim-
ilation of limestone by basaltic magma.
Mineralogy Mag., vol. 22, pp. 439-468, 1931.
In summary, the following reasons are given for suggesting rearrangement of materials already in the sedimentary beds to form the lime silicates. Pure limestone alters to marble, and impure limestone beds alter to silicates. In all areas examined the lime silicate rocks retain the original bedding structures of the limestones.

Some beds are predominantly pyroxenes, others are predominantly garnets, others idocrase, and still others olivines. If the materials were introduced from igneous sources one would expect a more uniform distribution rather than a segregation of certain minerals in certain alternating beds.

There is a lack of metamorphic silicate minerals in the igneous rock near the contact. If the magma had copious quantities of water, some reaction would be expected that would cause dark silicates and garnets to replace the igneous rock near the contact.

Nearly all the minerals are lime-alumina silicates or magnesium-calcium silicates. The iron minerals epidote, andradite, hedenbergite, and magnetite, so characteristic of many contact zones, are nearly, or completely, lacking. All the elements of the metamorphic silicates, therefore, are normal impurities of limestones, and no elements appear to have been added in large amounts.
III.

The deposits furnish an excellent illustration of the simple heat effect of an intruded body on adjacent rock as contrasted with other deposits where addition of material from the igneous source has been a large factor in the alteration.
Bibliography

The following publications include all those known that relate to the mineralogy of Tombstone mining district and a few that deal with the main features in the study of the mineralogy.


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**Figure 1.** General paragenetic relations of the hypogene vein minerals.
Figure 2.

Pyrrite, in the presence of oxygen and water, is changed to ferrous sulphate and sulphur and ferric sulphate is oxidized to ferric sulphate. The sulphate solutions react with gallium and chalcopryte to form a series of sparingly soluble minerals.
Plate I - A

Galena and anglesite replaced by sulphur, Galena, white, anglesite, dark gray, sulphur, light gray. Plain light. Enlarged 40 diameters.

Plate I - B

Same relations as above in A, but in addition, shows better the quartz walls that separate galena crystals. Upon complete oxidation, only the quartz box-work remains. Plain light. Enlarged 120 diameters.

Symbols

gn - galena
an - anglesite
s - sulphur
q - quartz
Plate II - A

Argentite, chalcocite, stromeyerite relationships in iron oxide gangue. Minute blades of covellite replacing chalcocite and stromeyerite. Two small fragments of gold are seen. Plain light. Enlarged 40 diameters.

Plate II - B

Covelliteization of chalcocite in oxidized gangue. Plain light. Enlarged 120 diameters.

Plate II - C


Symbols

arg - argentite
co - chalcocite
str - stromeyerite
au - gold
Plate III - A

Microscopic tetragonal-sphenoidal crystals of chalcopyrite concentrated near the borders of alabandite crystals. Fissure in alabandite is filled with quartz and calcite. Plain light. Enlarged 120 diameters.

Plate III - B

Remnants of galena and sphalerite surrounded by calcite in alabandite. Indicates the scarcity of other sulphides and the possible source of gold and silver in the assays of alabandite. Plain light. Enlarged 40 diameters.

Symbols

al - alabandite
q - quartz
cl - calcite
sp - sphalerite
gn - galena
op - chalcopyrite
Plate IV - A


Plate IV - B

Fractures in tetrahedrite, gray mineral, healed by quartz. Along the fractures, chalcopyrite, white mineral, alters before tetrahedrite does. The alteration proceeds as chalcopyrite to bornite to chalcocite.

Symbols

td - tetrahedrite
cc - chalcocite
cp - chalcopyrite
bn - bornite
Plate V - A

Chalcocite replacing chalcopyrite along fractures. Plain light. Enlarged 40 diameters.

Plate V - B

Small grains of famatinite surrounded by a ring of quartz. Unidentified oxidation mineral replacing famatinite in reticulating veinlets. Plain light. Enlarged 120 diameters.

Symbols

op - chalcopyrite
co - chalcocite
fa - famatinite
q - quartz
ci - calcite
Plate VI - A

Bourbonite altering along small fissures to an unidentified mineral. The mineral is probably the first alteration of bourbonite and is probably a complex sulphate of lead and antimony. Plain light. Enlarged 40 diameters.

Plate VI - B

Bourbonite from the same specimen as A with higher magnification. Alteration mineral replacing bourbonite inwardly from the boundaries of the crystal. Plain light. Enlarged 120 diameters.
Plate VII - A

Galena, white mineral, replacing brecciated tetrahedrite, gray mineral. Dark veins filled with quartz. The section indicates movement during ore deposition. Plain light. Enlarged 120 diameters.

Plate VII - B

Same specimen as above, but in different section. Shows the intense fracturing of tetrahedrite which continued with decreasing strength during deposition of galena.

Symbols

- td - tetrahedrite
- gn - galena
- sp - sphalerite
- op - chalcopyrite
Plate VIII - A

Specimen believed to contain romanachite(?), white mineral, that is barely separable from pyrolusite. Has a fibrous character. Small square and rectangular limonite pseudomorphs after pyrite are visible. Dark gray mineral is quartz. Black mineral is barite. Plain light. Enlarged 40 diameters.

Plate VIII - B

Magnified vein of crystal believed to be a limonite pseudomorph after pyrite. There is indication of more than one mineral. Manganese oxides, probably psilomelane and quartz surround limonite crystal. Plain light. Enlarged 120 diameters.

Plate VIII - C

White mineral is polianite or pyrolusite being replaced by light gray mineral, tentatively identified as psilomelane, but which contains antimony. The crystal X is a pseudomorph of the unknown mineral after polianite. Plain light. Enlarged 120 diameters.

Symbols

lm - limonite
q - quartz
ba - barite
pr - pyrolusite
ro - romanachite
Plate IX - A

Typical grain pattern of polianite. Plain light. Enlarged 40 diameters.

Plate IX - B

Polianite, light gray, being replaced by mineral x, darker gray, similar to psilomelane along fractures. Few grains of quartz remain. Plain light. Enlarged 40 diameters.
Plate X - A

Heterogeneous mass of manganese oxides from a hand specimen that appeared to be homogeneous. Manganite as a long fibrous mineral replaced by stringers of pyrolusite, white mineral, and hetaerolite, gray mineral. Plain light. Enlarged 40 diameters.

Plate X - B

Higher magnification of a small stringer. Manganite is replaced by hetaerolite and a few stringers of pyrolusite. An unknown manganese oxide appears in some places to be replacing hetaerolite; in other places hetaerolite appears to be replacing it. Manganite has not been found in contact with it. Plain light. Enlarged 75 diameters.

Symbols

pr - pyrolusite
het- hetaerolite
man- manganite
y - unknown
Plate XI - A

Section showing the stringer-like character of hetaerolite and the relationship between hetaerolite, manganite, and mineral y. Plain light. Enlarged 40 diameters.

Plate XI - B

Enlargement of section shown in A. Hetaerolite has high relief in comparison with manganite. Pyrolusite, as small blebs and stringers, in association with hetaerolite and manganite. Plain light. Enlarged 120 diameters.

Symbols

het - hetaerolite
man - manganite
pr - pyrolusite
y - unknown manganese oxide
Plate XII - A

Typical microstructure of psilomelane. The different colors probably represent layers of varying hardness. Plain light. Enlarged 40 diameters.

Plate XII - B

Enlarged view of the "boot" seen in A. The photograph indicates more than one mineral, but since there are several varieties of psilomelane with varying water content, one may assume that the white minerals with a higher degree of polish represent a less hydrous variety. Plain light. Enlarged 120 diameters.
Plate XIII - A

Psilomelan showing contraction cracks filled with later psilomelan. Concentric structure of psilomelan is conspicuously developed. Plain light. Enlarged 40 diameters.

Plate XIII - B

Specimen of manganese ore from the Emerald mine. Small crystals of pyrolusite replacing quartz. Plain light. Enlarged 40 diameters.
Plate XIV - A

View of Tombstone, looking southeast from Comstock Hill, with the mineralized belt outlined roughly in relation to the topography and townsite.

Plate XIV - B

White outcrops of rhyolite porphyry exposed in southeast part of the Tombstone area. The rhyolite porphyry intrudes as sills parallel to the bedding of the Upper Naco limestone.
Plate XV - A

Typical section of pre-Cambrian quartz diorite showing the idiomorphic crystal form of the nearly completely sericitized plagioclase, dark mineral. Later microcline and quartz, white mineral, surround the plagioclase. Crossed nicols. Enlarged 24 diameters.

Plate XV - B

Zoning in hornblende phenocryst in andesite porphyry, six miles east of Tombstone. Plain light. Enlarged 27 diameters.
Plate XVI - A

Thin section of granodiorite from stock showing the cloudiness of the orthoclase, prismatic section of hornblende, the complete alteration of biotite to chlorite which, in turn, is being replaced by epidote, the small grains of allanite (orthite), and the arrangement of plagioclase and quartz. Plain light. Enlarged 96 diameters.

Plate XVI - B

Thin section of same granodiorite showing the tabular arrangement of the plagioclase feldspars with interstitial quartz. Feldspar shows no zoning or alteration. Crossed nicols. Enlarged 24 diameters.

Symbols

q - quartz
plagio - plagioclase
or - orthoclase
ch - chlorite
hbl - hornblende
all - allanite
ep - epidote
Plates XVII - A

Flow banding in the groundmass of the quartz latite porphyry. Quartz and feldspar are fragmental as though broken by movement in the viscous groundmass. Plain light. Enlarged 24 diameters.

Plates XVII - B

Enlarged view of flow banding showing the fragmental character of the feldspar and the corroded edges of quartz phenocryst. Plain light. Enlarged 96 diameters.
Plate XVIII - A

View of the Three Brothers Hills in the distance with Uncle Sam Hill at the base. These hills are all composed of quartz latite porphyry.

Plate XVIII - B

Hill in the foreground composed of quartz latite porphyry. Its contact with the pre-Cambrian quartz diorite not seen in the view. In the background is seen Bolsa quartzite resting on pre-Cambrian intrusive. On the farthest hill the relationships of the formations are complicated by faulting.
Plate XIX - A

Typical topography of the weathered and eroded Tombstone granodiorite stock. The rounded boulders have been produced by granular disintegration along joint planes. Photo taken near Schieffelin's monument looking toward the Dragoon mountains.

Plate XIX - B

Close view of the disintegration of the granodiorite to coarse soil.
Plate XX - A

Groundmass of monzonite porphyry composed of spherulitic quartz and orthoclase. Large crystal at the top is orthoclase. Crossed nicols. Enlarged 24 diameters.

Plate XX - B

Typical porphyritic texture of augite diorite porphyry. The feldspar crystals are andesine, exhibiting slight zonal structures. Actinolite altered from augite is the main dark mineral filling in the interstices. Plain light. Enlarged 24 diameters.

Plate XX - C

Photograph showing the spotted appearance of the platy and conchoidal slabs of basalt.
Plate XXI - A

Typical ophitic texture of basalt dike east of Emerald mine. The lath shaped feldspars are labradorite. Groundmass is magnetite and augite. Plain light. Enlarged 24 diameters.

Plate XXI - B

Fine grained texture of basalt northeast of Tombstone. Olivine grains surrounded by iddingsite. Feldspar is labradorite. Interstices are filled with augite and magnetite. White mineral in right side of photograph possibly nephelite. Plain light. Enlarged 75 diameters.
Plate XXII - A

Photomicrograph of thin section of black calcite showing the microscopic replacement of calcite by brown hydrated manganese oxide along cleavage cracks. Plain light. Enlarged 24 diameters.

Plate XXII - B

Enlarged view of intersection of cleavage planes showing the concentration of feathery and spherulitic masses of brown hydrated manganese oxide. Plain light. Enlarged 320 diameters.
Plate XXIII - A

View of Comstock Hill from the northwest, where many unusual contact metamorphic minerals may be found. The top and flanks of the hill are composed of steeply dipping metamorphosed limestone beds. Near the center of the picture, granodiorite intrudes within 30 feet of the top.

Plate XXIII - B

Typical exposure of steeply dipping metamorphosed limestone beds on Comstock Hill. Hard and soft beds alternate depending upon their mineral composition.
Plate XXIV - A

Metamorphosed "blue limestone" from the 4th level of the Toughnut mine showing bladed crystals of tremolite with residual grains of calcite and quartz and interstitial grains of garnet. Plain light. Enlarged 24 diameters.

Plate XXIV - B

Metamorphosed white limestone from the Silver Thread mine showing radiating fibers of wollastonite with few grains of residual quartz. Galena replacing wollastonite in lower part of microphotograph. Plain light. Enlarged 24 diameters.

Symbols

Te - tremolite
q - quartz
cal - calcite
woll - wollastonite
gn - galena
Plate XXV - A
Thin section of silicate rock from 5th level of Lucky Cuss mine. Dark gray mineral represents residual grains of calcite. White mineral probably represents serpentine pseudomorphs after monticellite. Plain light. Enlarged 81 diameters.

Plate XXV - B