ARIZONA ZINC AND LEAD DEPOSITS

PART I

ARIZONA BUREAU OF MINES, GEOLOGICAL SERIES No. 18,
BULLETIN NO. 156

PUBLISHED BY
University of Arizona
TUCSON, ARIZONA
SERVICES OFFERED BY THE ARIZONA BUREAU OF MINES

Among the many lines of activity in which the Bureau engages, the following have proved especially important and valuable:

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ARIZONA ZINC AND LEAD DEPOSITS — PART I

CHAPTER I.—GENERAL FEATURES

By Eldred D. Wilson

INTRODUCTION

This bulletin constitutes part of a general report on the zinc and lead deposits in Arizona. It includes much new information as well as some material compiled from published sources.

Descriptions of several districts and mines not included by this Part I have been prepared for subsequent publication, and others are in course of preparation.

Appreciative acknowledgment is made to the mining companies, mine operators, U. S. Geological Survey, and others for furnishing information. Their generous co-operation is further indicated by the list of authors who contributed articles for this bulletin.

PRODUCTION SUMMARY

Arizona's output of zinc and lead has increased remarkably since 1933, as shown by Figure 1; approximately 85 per cent of the total zinc and 57 per cent of the total lead were mined during 1934-49.

Arizona ranked fifth in zinc and fourth in lead production within the United States for 1946, and second in zinc for 1949. In 1948 her production of zinc was 8.12 times, and of lead 2.78 times, greater than in 1939, whereas the yield of these metals for the United States as a whole, exclusive of Arizona, was less in 1948 than in 1939.

For Arizona, commercial zinc production did not begin until 1905, but lead was recovered prior to the Civil War.

The early lead output was essentially a by-product from the smelting of silver ores. Although not large according to present standards, it was important to the local economy of that time. Notable among the earliest producers were the Mowry and other mines in southern Arizona, but no reliable estimates of their output are available. In Yuma County, the Castle Dome district probably yielded 6,000,000 pounds, and the Silver district 1,000,000 pounds, of lead before 1883.

As of 1882, Kirchoff stated:2

In Arizona and New Mexico a number of deposits of lead ores have been opened. They are rich in lead, though generally poor in silver, but steps are being taken in different places to smelt these ores, using the lead as a carrier for silver. The smelters buy high-grade refractory silver ores and smelt them together with their lead ores, a rich base bullion being produced in fair quantity in some instances.

Kirchhoff\(^3\) mentioned that the two principal lead smelters operating in Arizona during 1883-85 were the Benson and the Tombstone Mill & Mining Company works; during the eighties, considerable Arizona lead ore went to smelters in Colorado and to refining works. He listed the Arizona lead output during certain years, for which its value has been computed as follows:

<table>
<thead>
<tr>
<th>Years</th>
<th>Pounds of Lead</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1883</td>
<td>3,000,000</td>
<td>$129,000</td>
</tr>
<tr>
<td>1884</td>
<td>5,400,000</td>
<td>199,800</td>
</tr>
<tr>
<td>1885</td>
<td>6,000,000</td>
<td>240,000</td>
</tr>
<tr>
<td>1889-90</td>
<td>6,316,000</td>
<td>265,272</td>
</tr>
</tbody>
</table>

Continuous records of lead production have been maintained for the State as a whole since 1894, and for districts since 1906.

The first reported recovery of Arizona zinc was from concentrates, shipped in 1905 to Pueblo, Colorado, from the Crown King area of Yavapai County.\(^4\)

Of the approximately $4,530,000,000 value of all minerals produced in Arizona prior to 1950, zinc has constituted 2.18 per cent, and lead 1.72 per cent; for 1939-49, however, zinc amounted to 6.08 per cent, and lead 3.54 per cent, of the total. Zinc supplanted gold as Arizona's second most valuable metal product during 1944-49, and lead took third place over silver during 1945-49.

Arizona's total yearly output of lead since 1894 and of zinc since 1905 is shown in Figure 1.

Production by several of the leading districts for 1939-47 is shown by graphs in Figures 2 and 3.

The percentages of the total output by districts are listed in Table 1. According to the U. S. Minerals Yearbook,\(^5\) the number of Arizona districts producing zinc increased from nine in 1939 to thirty-one in 1948, and the number producing lead decreased from sixty-three in 1939 to sixty in 1948.

<p>| TABLE 1.—PERCENTAGES OF ARIZONA TOTAL ZINC AND LEAD—FURNISHED BY TWENTY-FOUR DISTRICTS |
|--------------------------------------|-------------------------------------|-------------------------------------|</p>
<table>
<thead>
<tr>
<th>District</th>
<th>Per cent Arizona total Zn</th>
<th>Per cent Arizona total Pb</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bisbee</td>
<td>28.6</td>
<td>29.2</td>
</tr>
<tr>
<td>Wallapai</td>
<td>19.9</td>
<td>8.5</td>
</tr>
<tr>
<td>Harshaw</td>
<td>6.7</td>
<td>7.8</td>
</tr>
<tr>
<td>Old Hat</td>
<td>5.4</td>
<td>8.2</td>
</tr>
<tr>
<td>Oro Blanco</td>
<td>5.7</td>
<td>6.7</td>
</tr>
<tr>
<td>Big Bug</td>
<td>8.5</td>
<td>3.7</td>
</tr>
<tr>
<td>Pima</td>
<td>6.0</td>
<td>3.5</td>
</tr>
<tr>
<td>Superior</td>
<td>7.3</td>
<td>0.4</td>
</tr>
</tbody>
</table>

\(^3\)Works cited.


\(^5\)Published by the U.S. Bureau of Mines.
TABLE 1.—PERCENTAGES OF ARIZONA TOTAL ZINC AND LEAD—FURNISHED BY TWENTY-FOUR DISTRICTS—Continued

<table>
<thead>
<tr>
<th>District</th>
<th>Per cent Arizona total Zn 1905-47</th>
<th>1939-47</th>
<th>Per cent Arizona total Pb 1894-1947</th>
<th>1939-47</th>
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<tr>
<td>Tombstone</td>
<td>6.1</td>
<td>1.0</td>
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</tr>
<tr>
<td>Patagonia</td>
<td>3.5</td>
<td>4.0</td>
<td>1.6</td>
<td>2.3</td>
</tr>
<tr>
<td>Banner</td>
<td>0.7</td>
<td>0.7</td>
<td>4.2</td>
<td>1.8</td>
</tr>
<tr>
<td>Eureka</td>
<td>2.0</td>
<td>1.0</td>
<td>0.8</td>
<td>1.0</td>
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<tr>
<td>Johnson</td>
<td>2.3</td>
<td>3.1</td>
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<td>Aravaipa</td>
<td>0.4</td>
<td>0.3</td>
<td>1.8</td>
<td>1.4</td>
</tr>
<tr>
<td>Castle Dome</td>
<td>2.2</td>
<td>1.7</td>
<td></td>
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<tr>
<td>Dragoon Mts.</td>
<td>0.8</td>
<td>1.0</td>
<td></td>
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<tr>
<td>Mineral Creek</td>
<td>1.0</td>
<td>0.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Osborn</td>
<td>1.0</td>
<td>0.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Empire</td>
<td>0.8</td>
<td>0.0</td>
<td></td>
<td></td>
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<tr>
<td>Chiricahua</td>
<td>0.8</td>
<td>0.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Swisshelm</td>
<td>0.7</td>
<td>1.6</td>
<td></td>
<td></td>
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<tr>
<td>Silver</td>
<td>0.6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pine Grove</td>
<td>0.5</td>
<td>0.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cedar Valley</td>
<td>0.4</td>
<td>0.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Totals</td>
<td>98.7</td>
<td>99.2</td>
<td>90.3</td>
<td>95.5</td>
</tr>
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</table>

Available figures for the county totals since 1900 are as follows:

TABLE 2.—ZINC AND LEAD PRODUCTION BY ARIZONA COUNTIES, 1900-1948

<table>
<thead>
<tr>
<th>County</th>
<th>Zinc</th>
<th>Lead</th>
<th>Total value zinc and lead</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Years</td>
<td>Pounds</td>
<td>Value</td>
</tr>
<tr>
<td>Cochise</td>
<td>1908-48</td>
<td>274,066,766</td>
<td>$32,293,081</td>
</tr>
<tr>
<td>Santa Cruz</td>
<td>1907-48</td>
<td>113,250,659</td>
<td>9,513,780</td>
</tr>
<tr>
<td>Pinal</td>
<td>1905-48</td>
<td>92,361,599</td>
<td>9,633,536</td>
</tr>
<tr>
<td>Mohave</td>
<td>1907-48</td>
<td>136,212,330</td>
<td>12,139,877</td>
</tr>
<tr>
<td>Yavapai</td>
<td>1905-48</td>
<td>5,302,808</td>
<td>10,161,113</td>
</tr>
<tr>
<td>Pima</td>
<td>1912-48</td>
<td>54,126,970</td>
<td>6,372,997</td>
</tr>
<tr>
<td>Gila</td>
<td>1916-48</td>
<td>4,914,019</td>
<td>482,852</td>
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<td>Graham</td>
<td>1926-48</td>
<td>5,062,297</td>
<td>577,904</td>
</tr>
<tr>
<td>Yuma</td>
<td>1948</td>
<td>3,000</td>
<td>479</td>
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<tr>
<td>Maricopa</td>
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<td></td>
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<tr>
<td>Greenlee</td>
<td>1939-47</td>
<td>218,439</td>
<td>15,168</td>
</tr>
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<td>Coconino</td>
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</table>

CLASSES AND GRADES OF ORE

The zinc and lead produced in Arizona have come chiefly from ores classified as zinc-lead, zinc-copper, lead, zinc, and zinc-lead-copper. Minor amounts have been derived from the gold, silver, copper, and lead-copper ores. Some of the ore is sent directly to smelters, but most of it is concentrated before smelting. As shown by Tables 3 and 4, there is a considerable difference between the gross contents of zinc or lead in an ore and the amounts of those metals which may be recovered; aside from general losses, the lead is recovered only at a lead smelter, and the zinc at a zinc reduction plant.
Figure 2.—Arizona zinc production by districts, 1939-47.
Figure 3.—Arizona lead production by districts, 1939-47
Data for 1948 are as follows:

**TABLE 3-A.—ARIZONA CRUDE ORE SHIPPED TO SMELTERS IN 1948**

<table>
<thead>
<tr>
<th>Class of ore</th>
<th>Ore tons</th>
<th>Gross Metal Content</th>
<th>Gold oz.</th>
<th>Silver oz.</th>
<th>Copper pounds</th>
<th>Lead pounds</th>
<th>Zinc pounds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry and siliceous gold ore</td>
<td>11,304</td>
<td>5,324</td>
<td>18,867</td>
<td>144,292</td>
<td>7,283</td>
<td>4,300</td>
<td></td>
</tr>
<tr>
<td>Dry and siliceous gold-silver ore</td>
<td>15,265</td>
<td>770</td>
<td>21,303</td>
<td>113,311</td>
<td>3,956</td>
<td>2,091</td>
<td></td>
</tr>
<tr>
<td>Dry and siliceous silver ore</td>
<td>27,688</td>
<td>605</td>
<td>251,303</td>
<td>128,922</td>
<td>5,393</td>
<td>2,822</td>
<td></td>
</tr>
<tr>
<td>Copper ore</td>
<td>686,780</td>
<td>22,172</td>
<td>1,138,923</td>
<td>63,891,522</td>
<td>8,000</td>
<td>7,142,584</td>
<td></td>
</tr>
<tr>
<td>Lead ore</td>
<td>14,256</td>
<td>578</td>
<td>18,867</td>
<td>144,292</td>
<td>7,283</td>
<td>4,300</td>
<td></td>
</tr>
<tr>
<td>Lead-copper ore</td>
<td>147</td>
<td>578</td>
<td>18,867</td>
<td>144,292</td>
<td>7,283</td>
<td>4,300</td>
<td></td>
</tr>
<tr>
<td>Zinc-lead ore</td>
<td>4,866</td>
<td>1,525</td>
<td>56,381</td>
<td>291,901</td>
<td>1,288,599</td>
<td>973,491</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>760,097</td>
<td>30,556</td>
<td>1,523,096</td>
<td>61,232,600</td>
<td>5,803,434</td>
<td>184,654</td>
<td></td>
</tr>
</tbody>
</table>

**TABLE 3-B.—METALS RECOVERED FROM ARIZONA CRUDE ORE SHIPPED TO SMELTERS IN 1948**

<table>
<thead>
<tr>
<th>Class of ore</th>
<th>Ore tons</th>
<th>Recovered Metals</th>
<th>Gold oz.</th>
<th>Silver oz.</th>
<th>Copper pounds</th>
<th>Lead pounds</th>
<th>Zinc pounds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry and siliceous gold ore</td>
<td>11,304</td>
<td>5,324</td>
<td>18,867</td>
<td>137,029</td>
<td>6,609</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dry and siliceous gold-silver ore</td>
<td>15,265</td>
<td>770</td>
<td>38,205</td>
<td>51,517</td>
<td>2,091</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dry and siliceous silver ore</td>
<td>27,688</td>
<td>605</td>
<td>251,303</td>
<td>29,889</td>
<td>18,998</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Copper ore</td>
<td>686,780</td>
<td>22,172</td>
<td>1,138,923</td>
<td>60,820,312</td>
<td>5,756,290</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lead ore</td>
<td>14,256</td>
<td>578</td>
<td>18,867</td>
<td>144,292</td>
<td>7,283</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lead-copper ore</td>
<td>147</td>
<td>578</td>
<td>18,867</td>
<td>144,292</td>
<td>7,283</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zinc-lead ore</td>
<td>4,866</td>
<td>1,525</td>
<td>56,381</td>
<td>291,901</td>
<td>1,288,599</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>760,097</td>
<td>30,556</td>
<td>1,523,096</td>
<td>61,232,600</td>
<td>5,803,434</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**TABLE 4-A.—ARIZONA ORE CONCENTRATED IN 1948**

<table>
<thead>
<tr>
<th>Class of ore</th>
<th>Ore tons</th>
<th>Gross metal content of mill feed</th>
<th>Gold oz.</th>
<th>Silver oz.</th>
<th>Copper pounds</th>
<th>Lead pounds</th>
<th>Zinc pounds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry and siliceous gold ore</td>
<td>1,813</td>
<td>230</td>
<td>3,954</td>
<td>3,150</td>
<td>30,350</td>
<td>50,000</td>
<td></td>
</tr>
<tr>
<td>Dry and siliceous silver ore</td>
<td>1,813</td>
<td>230</td>
<td>3,954</td>
<td>3,150</td>
<td>30,350</td>
<td>50,000</td>
<td></td>
</tr>
<tr>
<td>Copper ore</td>
<td>34,632,227</td>
<td>78,949</td>
<td>2,110,963</td>
<td>704,733,920</td>
<td>6,500</td>
<td>7,100,000</td>
<td></td>
</tr>
<tr>
<td>Lead ore</td>
<td>8,975</td>
<td>345</td>
<td>23,524</td>
<td>14,317</td>
<td>1,058,023</td>
<td>139,023</td>
<td></td>
</tr>
<tr>
<td>Lead-copper ore</td>
<td>105</td>
<td>8</td>
<td>1,176</td>
<td>5,317</td>
<td>11,018</td>
<td>2,800</td>
<td></td>
</tr>
<tr>
<td>Zinc ore</td>
<td>3,945</td>
<td>25</td>
<td>2,434</td>
<td>25,951</td>
<td>20,205</td>
<td>597,065</td>
<td></td>
</tr>
<tr>
<td>Zinc-copper ore</td>
<td>101,405</td>
<td>1,054</td>
<td>83,255</td>
<td>139,892</td>
<td>352,225</td>
<td>16,745,137</td>
<td></td>
</tr>
<tr>
<td>Zinc-lead-copper ore</td>
<td>3,945</td>
<td>2</td>
<td>17,982</td>
<td>83,255</td>
<td>126,725,137</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>35,412,392</td>
<td>102,804</td>
<td>1,422,731</td>
<td>714,828,125</td>
<td>62,677,804</td>
<td>151,457,959</td>
<td></td>
</tr>
</tbody>
</table>

**TABLE 4-B.—CONCENTRATES MADE FROM ARIZONA ORES MINED IN 1948**

<table>
<thead>
<tr>
<th>Class of concentrates</th>
<th>Conc. tons</th>
<th>Gross metal content of concentrates</th>
<th>Gold oz.</th>
<th>Silver oz.</th>
<th>Copper pounds</th>
<th>Lead pounds</th>
<th>Zinc pounds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry gold</td>
<td>59</td>
<td>118</td>
<td>1,948</td>
<td>947</td>
<td>5,827</td>
<td>8,385</td>
<td></td>
</tr>
<tr>
<td>Dry silver</td>
<td>4</td>
<td>323</td>
<td>5,827</td>
<td>8,385</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Copper</td>
<td>1,328,187</td>
<td>63,639</td>
<td>1,800,782</td>
<td>611,339,927</td>
<td>4,922</td>
<td>5,756,290</td>
<td></td>
</tr>
<tr>
<td>Lead</td>
<td>55,293</td>
<td>11,111</td>
<td>1,155,506</td>
<td>3,331,796</td>
<td>50,547,050</td>
<td>10,711,603</td>
<td></td>
</tr>
<tr>
<td>Lead-copper</td>
<td>1,057</td>
<td>29</td>
<td>2,4614</td>
<td>216,406</td>
<td>456,565</td>
<td>400,181</td>
<td></td>
</tr>
<tr>
<td>Zinc</td>
<td>107,136</td>
<td>2,615</td>
<td>416,157</td>
<td>2,264,742</td>
<td>5,628,620</td>
<td>115,355,997</td>
<td></td>
</tr>
<tr>
<td>Zinc-lead</td>
<td>172</td>
<td>23</td>
<td>5,420</td>
<td>9,565</td>
<td>106,951</td>
<td>133,918</td>
<td></td>
</tr>
<tr>
<td>Zinc-lead-copper</td>
<td>176</td>
<td>34</td>
<td>4,887</td>
<td>29,379</td>
<td>46,056</td>
<td>63,534</td>
<td></td>
</tr>
<tr>
<td>Iron</td>
<td>9,836</td>
<td>1,462</td>
<td>5,718</td>
<td>19,989</td>
<td>228,880</td>
<td>1,543,007</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>1,562,513</td>
<td>79,556</td>
<td>3,435,562</td>
<td>617,732,751</td>
<td>57,019,687</td>
<td>121,978,570</td>
<td></td>
</tr>
</tbody>
</table>

TABLE 4-C.—METALS RECOVERED FROM ARIZONA CONCENTRATES SHIPPED TO SMELTERS, 1948

<table>
<thead>
<tr>
<th>Class of concentrates</th>
<th>Concs. tons</th>
<th>Gold oz.</th>
<th>Silver oz.</th>
<th>Copper pounds</th>
<th>Lead pounds</th>
<th>Zinc pounds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gold</td>
<td>59</td>
<td>113</td>
<td>1,948</td>
<td>805</td>
<td>5,593</td>
<td>-</td>
</tr>
<tr>
<td>Silver</td>
<td>4</td>
<td>523</td>
<td>-</td>
<td>1,112</td>
<td>108,540</td>
<td>-</td>
</tr>
<tr>
<td>Copper</td>
<td>1,328,187</td>
<td>62,508</td>
<td>1,722,765</td>
<td>2,948,366</td>
<td>602,899,717</td>
<td>53,994,566</td>
</tr>
<tr>
<td>Lead</td>
<td>55,923</td>
<td>11,611</td>
<td>1,455,906</td>
<td>3,748,479</td>
<td>23,200</td>
<td>49,670</td>
</tr>
<tr>
<td>Lead-copper</td>
<td>1,057</td>
<td>29</td>
<td>24,614</td>
<td>191,017</td>
<td>438,479</td>
<td>23,200</td>
</tr>
<tr>
<td>Zinc</td>
<td>107,136</td>
<td>2,267</td>
<td>373,701</td>
<td>6,912,197</td>
<td>105,739,144</td>
<td>321,787</td>
</tr>
<tr>
<td>Zinc-lead</td>
<td>135</td>
<td>18</td>
<td>4,744</td>
<td>8,610</td>
<td>93,261</td>
<td>111,757</td>
</tr>
<tr>
<td>Zinc-lead-copper</td>
<td>176</td>
<td>34</td>
<td>4,887</td>
<td>25,683</td>
<td>43,362</td>
<td>49,670</td>
</tr>
<tr>
<td>Iron</td>
<td>9,836</td>
<td>1,462</td>
<td>25,718</td>
<td>17,009</td>
<td>219,349</td>
<td>321,787</td>
</tr>
</tbody>
</table>

DISTRIBUTION OF DEPOSITS

As shown by Figure 4 and Table 1, the principal zinc and lead districts of Arizona are in the southwestern half of the State. Along with other metal districts, they occur in the Basin and Range Province, within areas of relatively intense deformation and igneous intrusion. Of this region, the southeastern section, from Superior south and southeast to the Mexican boundary, yielded approximately 67.4 per cent of the total zinc and 73.5 per cent of the total lead mined in Arizona up to 1948; the northwestern section, comprising the Cerbat and Hualpai Mountains (Wallapai and Cedar Valley districts) of Mohave County, 20.3 per cent of the total zinc and 8.5 per cent of the total lead; the central section, including the Bradshaw Mountains, Verde, and Eureka (Bagdad) districts, 11 per cent of the total zinc and 4.5 per cent of the total lead; and the southwestern section, including Yuma County and western Maricopa County, 3.8 per cent of the total lead. There is no recorded production of zinc from Maricopa and Coconino counties, and none of zinc or lead from Apache and Navajo counties.

TYPES OF DEPOSITS

Most of the Arizona zinc and lead deposits may be classed as replacements. They range from irregular masses, mantos, pipes, or “chimneys” to tabular or vein forms. Notable space filling obtains in some breccia and vein zones, but simple fissure fillings appear to be of relatively minor quantitative importance.

No zinc or lead deposits analogous to the “porphyry” copper type and no great disseminated deposits of the Bonne Terre type are known in Arizona.

HOST ROCKS

Deposits of zinc, lead, or zinc and lead occur in rocks of various types and of ages ranging from Older pre-Cambrian to Tertiary. Limestone: The most numerous and productive bodies have been found in limestone within the southeastern part of the State, as represented in the Bisbee, Pima (San Xavier), Superior, Tombstone, Patagonia, Banner, Johnson, Aravaipa, Dragoon Mountains, Mineral Creek, Empire, and Swisshelm districts. Together they have yielded almost as much zinc as lead or approximately 45 per cent of the total zinc and 47 per cent of the total lead mined in Arizona during 1900-47.
The limestone host rocks are Paleozoic mainly, except at Tombstone where they are of both Paleozoic and Lower Cretaceous ages. Apparently the physical character of the rock was much more influential than its chemical composition in affecting replacement. In many of the areas, contact metamorphism has been strong, and silicated limestone is a much more favorable host rock than pure marble; presumably the silicated limestone acquired extensive permeability where fractured under stress, whereas minute fractures in the marble tended to heal and remain impermeable. In contrast, where metamorphic effects are relatively feeble, as at Bisbee and a few other places, such pure limestone as the Escabrosa (Mississippian) is particularly favorable for ore bodies.

**Older pre-Cambrian rocks:** Schist, gneiss, and various intrusives of known or supposed pre-Cambrian age constitute host rocks for the principal deposits in central and northwestern Arizona, including Yavapai and Mohave counties, and for some in Yuma County. During 1900-47, deposits in these rocks yielded approximately twenty-one units of zinc for each thirteen units of lead. They form massive replacements in the Verde and Cedar Valley districts, replacements and veins in the Eureka (Bagdad) district, veins in the Cerbat Mountains (Wallapai district), and veins in the Bradshaw Mountains (Big Bug, Pine Grove, and other districts).

**Clastic rocks:** Conglomerate of presumed Mesozoic age was the host rock for the principal lead-zinc veins mined in the Montana area of the Oro Blanco district.

Arkosic sandstone, quartzite, and shale, together with some limestone, of Cretaceous age, is the wall rock of veins in the Harshaw, Tombstone, and Castle Dome districts.

Middle Cambrian Troy quartzite is wall rock for portions of the Magma (Superior) vein and for small veins in the Dripping Spring Mountains.

Veins in the Globe district occur along contacts of Younger pre-Cambrian quartzite with diabase.

**Mesozoic-Tertiary intrusives:** Rhyolite porphyry and quartz monzonite are host rocks for the Mammoth veins in the Old Hat district; rhyolitic porphyry, for veins in the Aravaipa district; diabase, for a large portion of the Magma vein; rhyolite porphyry, for the Belmont-McNeil veins in the Osborn district; and diorite porphyry, for veins in the Castle Dome district.

**Mesozoic-Tertiary volcanic rocks:** Veins in andesitic rocks are exemplified in the Harshaw and Silver districts.

ASSOCIATED IGNEOUS ACTIVITY

The relation of ore deposits in general to igneous rocks has been outlined by B. S. Butler as follows:

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The lode deposits, except those of iron and manganese, are closely associated with igneous activity and especially with intrusive bodies.

The grouping of ore deposits around intrusive bodies, and especially around the tops of stocks, has long been recognized and shown to be a general relation.

The association as now seen is dependent first on the depth below the surface at which the igneous body came to rest, and second, on the amount of erosion that has occurred since the deposits were formed.

It is probable that the different depth relations were present in each major period of igneous activity, and the deposits as we now see them are what is left after various stages of erosion.

The deposits have characteristics indicative of their depth of formation aside from their relation to the intrusive bodies. The deep deposits are in shear zones, and the ore minerals have largely formed as a replacement of the sheared rock. This contrasts with the filling of fissures or the filling and replacement of breccia zones or breccia pipes in deposits formed nearer the surface. The minerals in the deep deposits are coarsely crystalline, whereas those formed near the surface are likely to be finer grained.

There is also a difference in the degree of separation of the metals. The deep deposits may have copper and zinc in the same lode, whereas nearer the surface copper deposits are commonly in or very close to the intrusive body and contain little zinc or lead, and zinc and lead deposits are some distance from the intrusive bodies and are low in copper.

Different areas in the Southwest have been eroded to very different depths relative to the surface when intrusion took place at the different periods. The Older pre-Cambrian rocks have been deeply eroded, and over wide areas any near-surface deposits of that age have been removed. The pipelike deposits of Jerome and the shear deposits in adjacent areas suggest formation in a zone between deep and shallow.

In contrast with the deeply eroded pre-Cambrian, the later deposits are within and closely grouped about stocks, as exemplified at Bisbee and Morenci-Metcalf, Arizona, and at Santa Rita-Hanover, New Mexico. The more deeply eroded stocks seem to have had much of the lodes removed with the upper parts of the stocks. The Schultze granite stock, for example, between Superior and Miami, is nearly barren of mineral deposits within and around its central portion, but at either end where the roof of the stock plunges beneath the sedimentary cover valuable deposits are present.

The later deposits are in or associated with fissures, breccia zones, or breccia pipes, as contrasted with the shear-zone replacements of the deeper deposits, and there is more tendency for separation of the metals in districts where copper, zinc, and lead are present.

The Tertiary deposits are in part in Tertiary lavas, which indicates that their erosion has not been great. The veins fill fissures with only slight replacement, and vein minerals, especially the quartz, have the fine-grained, banded texture that suggests rapid change and rapid deposition. Characteristically, the deposits change rapidly with depth. Intrusive bodies with which the Tertiary deposits may be associated have not been exposed by erosion.

These near-surface types are well exemplified by the Oatman and Mammoth deposits of Arizona and the Mogollon deposits of New Mexico.

**STRUCTURAL FEATURES**

Deformation and breaking of the earth's crust was of primary importance in localizing the deposits as well as the intrusive masses with which the deposits are genetically associated. It

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has been well established\(^9\) that the general structure is closely related to the periods of igneous activity, each of which was associated with a revolution or period of crustal disturbance.

The effects of compressional stresses, as expressed by shear faults, folds, bedding-plane slips, thrust faults, and tension fissures, are particularly important. Not all of these effects may be demonstrated in all of the Arizona zinc and lead districts, although in each district two or more types of them are prominent, and others more obscure may be found by detailed work.

**Shear faults:** The shear faults are characterized by both horizontal and vertical components of movement. They may be of ancient origin, with one or more periods of renewed activity. These faults comprise two systems trending approximately at right angles to each other.

In southern Arizona those of one system strike generally between N. 70° W. and N. 70° E., and those of the other between N. 20° E. and N. 20° W. Their dip is generally steeper than 45 degrees. Displacement is normal on some but reverse on others and ranges from a few feet to several thousand feet. That the shear faults were deep seated is indicated by the fact that porphyry dikes and stocks commonly were intruded along them.

**Folds, bedding-plane slips, and thrust faults:** The principal folds trend northwest to northward and others cross them approximately at right angles, as evidenced by anticlinal domes and synclinal basins. Bedding slips\(^10\) commonly accompany folding. Folds may break into steeply dipping reverse faults or low-angle thrusts, and folded areas may overlie thrust faults. All these structures tended to form concurrently with the shear faults, generally in proportion to the intensity of compressive deformation. In many Arizona districts they have been complicated by faulting or obscured by other subsequent events and may be recognized only after detailed work; the faulted limbs of broad folds easily may be mistaken for simple tilted fault blocks, and thrust faults as well as bedding slips may be disguised.

In the southeastern quarter of Arizona, particularly, the principal limestone-replacement ore bodies occur within folded areas and beneath bedding slips. Some important deposits are associated with thrust faults.

**Tension fissures:** In southeastern Arizona, fissures of little or no displacement strike northeast and northwest, essentially at angles of 45 degrees to the shear faults. They are interpreted as the tensional resultants of compressive forces. The northeast fissures commonly extend in echelon patterns rather than continuously for long distances.

In several of the districts there is strong evidence that the northeast fissures constituted routes of access for the mineraliz-

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\(^9\)B. S. Butler, work cited, page 17.

ing solutions; ore shoots commonly occur where these fissures intersect replaceable rocks within anticlines or "rolls," beneath impervious beds or bedding slips, or where they cross shear faults, dikes, and northwest fissures.

Although typically inconspicuous, the northeast fissures are one of the most important guides to ore within those mineralized districts where they have been mapped. It has become increasingly apparent during recent years that their development is regional rather than local, but the limits of their occurrence outside of the southeastern quarter of Arizona have not been determined.

The northwest fissures are similarly mineralized in some districts, but their relative importance as channelways for ore solutions has not been appraised.

**OXIDATION**

Oxidation is known to extend well below present water levels in most of the Arizona districts. Its lower limit is very irregular and generally conditioned by zones of fissuring or permeability.

So far as zinc and lead deposits are concerned, the depth of largely complete oxidation ranges from a few feet in certain areas to more than 1,000 feet below the surface in other areas. Above this limit some residual sulfides may exist, and below it may be a mixed sulfide-oxide zone of very irregular thickness.

It is well known that oxidized lead minerals are relatively insoluble and may occur in outcrops, particular as cerussite and anglesite. Oxidized zinc minerals, on the other hand, are rather soluble and generally do not crop out, but in a limestone environment they tend to be reprecipitated at variable distances below the surface.

Interpretation of the outcrops or gossans has been discussed by Boswell and Blanchard.\(^{11}\)

\(^{11}\)P. F. Boswell and Roland Blanchard, Oxidation products derived from sphalerite and galena: Econ. Geol., vol. 22, pp. 419-453, 1927.

**CHAPTER II.—BISBEE OR WARREN DISTRICT**

**By Wm. G. Hogue\(^{1}\) and Eldred D. Wilson**

**INTRODUCTION**

Much has been written about the geology and copper deposits of Bisbee,\(^{2}\) the leading copper district in Arizona from the standpoint of total output.

\(^{1}\)Chief Geologist, Copper Queen Branch, Phelps Dodge Corporation.

\(^{2}\)For footnote, see next page.
In 1938, at the time of its most recent published description, the district was not known to have potentially important zinc and lead resources. During 1945-49, however, Bisbee annually yielded more zinc than copper and was by far the largest producer of zinc and lead in Arizona; in 1948 it furnished more than half of the total zinc and almost half of the total lead output of the State.

GENERAL HISTORY

1877-79. Discovery by Army scouts. First mining was of lead carbonate ore in Hendricks Gulch.

1878. George Warren and associates relocated the claims from which, in 1880, the first copper was produced.4

1880-84. Early development of Queen copper ore body and smelting of oxidized copper ore in water-jacket furnaces.

In 1881 Dr. James Douglas formed Atlanta Mining Company, which in 1884 was combined with Copper Queen Mining Company to form Copper Queen Consolidated Mining Company of which Phelps, Dodge, and Company gained control.5

This activity was stimulated by railway construction; the Southern Pacific line reached Benson in 1880, and the Santa Fe built from Benson to Guaymas in 1883-84.

1888-89. Railway connecting Bisbee with the Santa Fe line at Fairbank built by the Copper Queen company.

1893. Dr. James Douglas introduced converters for smelting of mixed oxide and sulfide copper ores by the matte process.

1898-1901. In 1898 Lake Superior and Western Development Company was organized and started work on Irish Mag claim. In 1901 ore was encountered in Irish Mag workings, and Calumet and Arizona Mining Company was formed to take over the stock of Lake Superior and Western Development Company.6

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3Carl Trischka, work cited.
5H. M. Lavender, work cited, p. 2.
6H. M. Lavender, work cited, p. 2.

1904-05. Organization of Shattuck Arizona and Denn Arizona companies.

1917. Stripping operations began on Sacramento Hill.
1918. Shattuck concentrator built.
1923. Concentrator of 4,000 tons daily capacity for Sacramento Hill porphyry ores constructed at Warren.
1925. Shattuck and Denn companies merged into Shattuck-Denn Mining Corporation.
1940. Shattuck-Denn concentrator remodeled.
1945. Phelps Dodge Corporation erected a zinc-lead flotation concentrator with daily capacity of 450 tons which was increased to 900 tons in 1946.
1947. Shattuck-Denn Mining Corporation sold Denn mine to Phelps Dodge Corporation and terminated its lease on Shattuck mine.

HISTORY OF LEAD AND ZINC MINING

Prior to 1880, lead carbonate ore was mined from the Hendricks claim, about a quarter of a mile south of Bisbee, and smelted in a primitive furnace at a spring near the present main street of the town. Some oxidized lead ore from the Hendricks claim was used for flux at Charleston during the early eighties, but there is no available record of the quantity of lead produced by the district prior to 1908.

The Copper Queen company granted leases on lead areas in the Uncle Sam mine during 1908, and in the Gardner and Southwest mines during 1910. Subsequently the company carried on successful development of lead ore in the Gardner and Southwest mines.

During 1911-17 notable bodies of oxidized siliceous lead ore were discovered and worked in upper levels of the Shattuck mine.

The first zinc production of the district was in 1917-18; during those years Calumet and Arizona Mining Company shipped lead-zinc sulfide ore to paint manufacturers in Kansas. Shipment of zinc ore to smelters began in 1922.

7James Douglas, work cited.
F. L. Ransome, work cited.
8Unpublished notes of J. B. Tenney.
In 1925 the Shattuck mill, which had been built in 1918, was converted entirely to flotation.

In 1927 Phelps Dodge Corporation built a flotation plant of 150 tons daily capacity for treatment of low-grade lead ore, and installed at Douglas a lead smelter of 200 tons daily capacity.\(^{10}\) Owing to low metal prices and resultant curtailment by custom ore shippers, the concentrator operated for only five months, and the lead smelter closed in April, 1930.

In 1939 the district produced zinc for the first time since 1927. Subsequently zinc-lead ore bodies were mined in the eastern part of the district. Part of the ore was sent to the Shattuck-Denn custom mill at Bisbee, and some to the Eagle-Picher mill at Sahuarita, until November 1945, when Phelps Dodge Corporation completed its present zinc-lead concentrator.

The district yielded record amounts of zinc each year during 1944-47 and 1949, and of lead during 1945-47 and 1949.

**PRODUCTION**\(^{11}\)

During 1880-1948, production of major metals in the Bisbee district was as follows:

<table>
<thead>
<tr>
<th></th>
<th>Copper</th>
<th>Silver</th>
<th>Gold</th>
<th>Zinc</th>
<th>Lead</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5,409,052,617 pounds, valued at $811,966,127</td>
<td>78,650,304 ounces, valued at $53,851,645</td>
<td>1,848,874 ounces, valued at $48,335,310</td>
<td>245,182,920 pounds, valued at $28,847,429</td>
<td>258,602,762 pounds, valued at $22,653,667</td>
</tr>
</tbody>
</table>

The output of zinc and lead by periods was as follows:

<table>
<thead>
<tr>
<th>Years</th>
<th>Zinc</th>
<th>Lead</th>
</tr>
</thead>
<tbody>
<tr>
<td>1908-16</td>
<td>53,708,143 pounds, valued at $2,729,229</td>
<td>13,451,793 pounds, valued at $1,100,964</td>
</tr>
<tr>
<td>1917-18</td>
<td>709,387</td>
<td>$61,670</td>
</tr>
<tr>
<td>1919-21</td>
<td>1,850,345</td>
<td>1,050,345</td>
</tr>
<tr>
<td>1922-27</td>
<td>14,235,610</td>
<td>1,050,345</td>
</tr>
<tr>
<td>1928-38</td>
<td>14,671,635</td>
<td>1,050,345</td>
</tr>
<tr>
<td>1939-48</td>
<td>230,237,923</td>
<td>27,726,184</td>
</tr>
<tr>
<td>1908-48</td>
<td>245,182,920</td>
<td>28,847,429</td>
</tr>
</tbody>
</table>

**PHYSICAL FEATURES**

Bisbee is in the south-central part of the Mule Mountains, 8 miles north of the international boundary and 26 miles by highway northwest of Douglas.

The Mule Mountain range trends northwestward between San Pedro and Sulphur Spring valleys. It is approximately 20 miles long by 6 to 12 miles wide and attains a maximum altitude of 7,400 feet. Tombstone Canyon and Mule Gulch cut deeply into the range along the general southeast-northwest course followed


by U.S. Highway 80. Bisbee is at an altitude of approximately 5,500 feet, and the neighboring towns of Lowell and Warren are a few hundred feet lower.

The topography of the Mule Mountains is shown on the Bisbee, Bisbee Special, Hereford, Benson, and Pearce quadrangle sheets published by the U. S. Geological Survey.

ROCKS

The general character and sequence of rocks in the vicinity of Bisbee are illustrated in Figure 5. The geological map (Figure 6) shows the general distribution of formations.

SEDIMENTARY SERIES

Pre-Cambrian schist is overlain unconformably by a maximum of 5,240 feet of Paleozoic, and 4,950 feet of Mesozoic sedimentary beds.

The Paleozoic consists largely of limestone above a basal quartzite. In contrast, the Mesozoic is made up of conglomerate, sandstone, shale, and 650 feet of limestone.

INTRUSIVES

Granite and porphyry: The Juniper Flat granite, which crops out northwest of Bisbee (Fig. 7), intrudes pre-Cambrian schist and is overlain by the basal conglomerate of the Cretaceous, but its relation to the Paleozoic is not clear. Porphyry, ranging from granitic to monzonitic composition, intruded the Paleozoic and older rocks. It forms numerous dikes and sills and the important Sacramento Hill stock.

As stated by Ransome,12

Many of the granite-porphyry dikes and the stock of Sacramento Hill are intrusive into the Naco limestone and are therefore clearly post-Carboniferous. Although the granitic stock of Juniper Flat is in contact with no rocks younger than the pre-Cambrian Pinal schist, yet from the close connection of this granite with the granite porphyry it is fair to conclude that all of the forms assumed by the granitic magma belong to one general period of intrusion, and are accordingly post-Carboniferous and pre-Cretaceous. The period of eruptive activity, however, extended over a sufficient length of time to allow the solidification of the granite, and some of the granite-porphyry dikes, before they were cut by later intrusions of the same magma.

Subsequently13 the Juniper Flat granite was tentatively referred to the pre-Cambrian on the basis of its lithologic character. The age of the Sacramento Hill porphyry is regarded as pre-Cretaceous by Trischka14 and Hogue, but as early Tertiary by Tenney.15

12Work cited.
14Carl Trischka, work cited.
Figure 5.—Generalized columnar section of rocks in Bisbee quadrangle (after F. L. Ransome).
Dikes of andesite porphyry cut the Cretaceous and earlier rocks in the Mule Mountains.

**Contact breccia and breccia dikes:** Breccia, ranging from a few feet to more than 500 feet in width, surrounds the Sacramento Hill porphyry stock, as mapped on Figure 6. This breccia includes fragments of all the local pre-Cretaceous rocks.

Material resembling the contact breccia in texture and composition has been found within fissures of the various fracture systems of the district. These breccia-filled fissures were identified by G. M. Schwartz as breccia dikes. In places they are mineralized.

**STRUCTURE**

The rocks of the Bisbee area have been folded and much faulted. Part of the deformation occurred before Lower Cretaceous, presumably in post-Jurassic time, and part of it during the Laramide (late-Cretaceous-early-Tertiary) interval.

As shown on Figure 6, the principal dislocation is the Dividend fault which, with a displacement of 2,000-5,000 feet, brings Paleozoic and Cretaceous beds on the southwest against pre-Cambrian schist on the northeast. Along Mule Gulch in Bisbee it trends N. 70° W. and dips 55°-60° SW., but east of the Sacramento Hill stock, which intrudes it, the fault zone steepens to almost vertical. It has been mapped for a length of 3½ miles, between the Quarry fault and a point 1 mile east of the Mexican Canyon fault.

The continuation of the Dividend fault northwesterly from its junction with the Quarry fault is indicated in upper Mule Gulch. Furthermore, as noted by B. S. Butler, the linear southwestern margin of the Juniper Flat granite along Tombstone Canyon suggests intrusion guided by a northwesterly trending fault, in general alignment with the Dividend fault.

North of the Dividend fault, pre-Cambrian schist is overlain by the Cretaceous Glance, Morita, Mural, and Cintura formations, dipping gently northeastward. Ransome mentioned that the strata north of the Dividend fault have been deformed only by gentle folding and moderate faulting. Here the Glance rests directly upon pre-Cambrian schist, presumably because erosion removed all of the Paleozoic during an interval between Dividend faulting and early Cretaceous sedimentation.

Within the area southwest of Mule Gulch and Tombstone Canyon, folding and relatively intense faulting are evident. This area, as mapped by Ransome, comprises six main structural blocks (Fig. 7).

In Escabrosa Ridge, west of the Copper Queen block, the faults trend generally northwest, subparallel to the Dividend fault. Many of them are of reverse character and in places are occupied by porphyry dikes. The Escabrosa block has been dropped 2,000-2,500 feet with reference to the Bisbee block, and the Naco block has been dropped about the same amount with reference to the Escabrosa block. The Gold Hill and Glance blocks consist of Paleozoic beds overthrusted on Cretaceous.
As stated by Schmitt,\textsuperscript{16} reverse faults and low-angle overthrusts, later than the Cretaceous beds, are more important in the district than has been shown on published maps.

*Structure of the Copper Queen block:* The Copper Queen block, which contains the principal ore bodies that have been found in the district, was described by Ransome\textsuperscript{17} as follows:

On the northeast it is bounded by the Dividend fault, the granite-porphyry stock of Sacramento Hill, and, superficially, by the overlapping Cretaceous beds. On the northwest it is cut off by the Quarry fault. On the southwest it is limited by the Bisbee West fault of the Escabrosa zone and is partly overlapped by Quaternary deposits. On the southeast it disappears beneath the Gold Hill overthrust.

In its broader structural aspect the Copper Queen block is a fragment of a canoe-shaped syncline having a nearly northwest-southeast axis that pitches southeastward. The northeastern limb of this syncline, cut off by the Dividend fault and relatively upheaved, has been removed by pre-Cretaceous erosion. In the down-dropped Copper Queen block is preserved the northwestern end of the southwestern half of the original synclinal canoe.

Superimposed upon this syncline are minor folds or "rolls," the importance of which has not been appraised. They have been mapped in only a few places, and the accessible mine workings afford rather limited exposures of them.

Faults which coincide with bedding planes, or cross the beds at low angles, are abundant in the area.

The Copper Queen block is further deformed by steeply dipping faults which trend in various directions. The principal ones strike somewhat east of north, and those of another system lie approximately at right angles to them or roughly parallel to the Dividend fault. These faults consist of zones which range from a few feet up to 100 feet in width. In places they are occupied by porphyry dikes. Average approximate vertical displacements upon some of the faults are as follows: Saginaw, 500; Campbell, 40; West Branch Mexican Canyon, 300-400; Oliver, 500-1,000; Shattuck, 300; Roy, 300; Quarry, 500 feet.

The horizontal component of movement upon the faults is not known, but apparently it was considerable upon some of them.

Subparallel to the faults are numerous fractures of little or no displacement. The northeast fractures range in strike from N. 10° E. to N. 45° E. and dip about 70° NW. The northwest breaks prevailingy dip steeply or vertically.

ORE DEPOSITS

**Distribution and Types**

Mining of the Bisbee ore deposits has been carried on mainly within an area of approximately 4 square miles, as indicated on the horizontal projection (Fig. 8), and the bulk of the district's


\textsuperscript{17}F. L. Ransome, work cited.
production has come from a tract 2 miles long from northwest to southeast by an average of less than half a mile wide.

The principal mineralization is believed to have followed closely the intrusion and solidification of the porphyry and the fissuring of it and the older rocks.

Two main types of deposits are represented: (1) replacements of limestone and (2) those that formed in fissures and as disseminations within the porphyry of Sacramento Hill.

The limestone replacements are of first-order importance from the standpoint of copper production, and they have furnished the zinc-lead output of the district.

The deposits in the Sacramento Hill porphyry and the contact breccia which surrounds it have yielded copper but no zinc and lead ore. Some zinc-lead mineralization is known to occur at places within the contact breccia.

**Favorable Beds**

Ore occurs in all of the Paleozoic limestones, but the Escabrosa and Martin formations have been the most productive. Considerable ore has been mined from the Naco limestone in the eastern part of the area and from the Abrigo formation in the southern part.

**Associated Structural Features**

The general structure of the Copper Queen block, which includes the productive area, has been outlined on a previous page.

Replacements in the limestone tend to follow beds, particularly beneath bedding-plane faults or bedding slips. The mineralization is associated generally with faults and fractures of the northeast system and less commonly with those of the northwest system, but it may switch from the direction of one system of fractures to that of the other. In places, veins follow the fissures, particularly those of the northeast system and, for example, the Judeah and Pay Day breaks of the northwest system.

Within the large copper ore bodies, replacement has tended to obscure many structural details.

Some of the structural zones of the mineralization have been described by Trischka\(^\text{18}\) as follows:

The first to develop was along the Czar fault, a zone about 100 feet wide which contains ore intermittently along one or several breaks. Granite porphyry, as dikes and sill connected with the Sacramento Hill mass, is present in this zone.

The Shattuck ore zone, composed of four or five parallel fault zones, is as wide as it is long and is closely confined to the trough made by the Shattuck and Wolverine granite-porphyry dikes. This trough plunges northeast, and its bottom becomes a sill. Ore is found in and below the trough and also on the north side of the part designated as the Shattuck dike.

The Junction-Briggs ore trend is composed of numerous fractures and fracture zones and, from the standpoint of mineralization, is next to the

widest and strongest in the district. Its southern end also terminates in veiilike bodies. In the north its ore is associated with granite porphyry. The strongest, most important productive zone formed a semicircle around the granite-porphyry stock of Sacramento Hill and occurred both in the limestone and the contact breccia.

ZINC AND LEAD ORE BODIES

Complete records on the occurrence of zinc-lead deposits are available only for the eastern part of the district. However some of the records of the earlier mines indicate that zinc and lead occurred throughout the district in areas mined for copper.

A generalized map of the relation of zinc-lead ore to copper ore would show that, in the heavily mineralized central portion of the district, copper and zinc-lead deposits were formed together or in the same mineralized zones. Progressively away from this general center, the ratio of zinc and lead to copper increases. Thus, the area east of the Campbell fault had, as of June, 1947, produced 17 units of zinc and 11 units of lead for each unit of copper.

The zinc-lead deposits vary greatly as to size, shape, and mode of occurrence, but in general they may be classified as follows:

Deposits along structural breaks and in combination with bedding.

Deposits peripheral to barren siliceous-pyritic bodies.

Deposits intimately associated with, or peripheral to, rather massive pyrite-copper ore bodies.

Deposits associated with porphyry.

**Deposits along structural breaks:** This type is very common, particularly in the eastern part of the district. The ore “channels” are fissures, many of which appear entirely insignificant when traced out of the ore into barren limestone. Along these breaks, particular beds may be replaced for relatively narrow widths, forming a veinlike deposit; or, replacement may be complete between parallel sets of fissures, forming a blanket-like deposit. The ore may follow a particular fissure or set of fissures for some distance and shift abruptly to an intersecting fissure, as shown on Figure 9. Generally the back of the stope in this type of deposit shows a layer of gouge, indicating that bedding-plane slips played an important role in localizing the ore. It is not uncommon to find that several other beds above or below a stope have also been replaced by ore along the same mineralized fissures.

**Deposits peripheral to siliceous-pyritic bodies:** Deposits of this type are more characteristic of strongly mineralized areas and have been productive of fairly large tonnages of ore. Silicification of the core may be partial or almost complete. The silica characteristically is somewhat shattered and commonly is veined with pyrite. Zinc, lead, and copper minerals occur around the periphery as very irregular replacements in the limestone and as partial fillings in the silica breccia, as illustrated on Figure 10.

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19 Appreciative acknowledgment is made to Mr. Harry E. Metz for detailed mapping and assistance in preparing Figure 9.
deposits of this type may grade into bedding replacements or make out along fissures.

*Deposits associated with pyrite-copper ore bodies:* In this type of deposit, copper and zinc-lead sulfides occur closely associated as massive replacements, with the zinc-lead minerals commonly outside of and partly around the copper bodies. Although mixed ore occurs in some places, the gradation between copper and zinc-lead ore as a rule is sharp, even in the same sulfide mass.

In these massive replacements, some evidence of control by northeast or northwest fissures, or a combination of the two, can be detected.

*Deposits associated with porphyry:* Ore bodies directly related to porphyry dikes and sills are fairly common, especially in the Campbell dike area. The factors which localized replacement tend to be obscure. Some ore bodies have been found within small rolls or embayments of porphyry. As a rule, the porphyry itself shows little effect from the mineralizing solutions. However, in some places, notably the upper levels of the Campbell mine where the porphyry is strongly shattered, veinlets of sphalerite and galena cut the dike, and the porphyry itself has been partially replaced by zinc and lead sulfides to form ore of mineable grade.

**Zinc and Lead Deposits in Eastern Part of District**

The zinc and lead production of Bisbee since 1939 has come largely from the eastern part of the district, particularly the Campbell and Junction areas. Some general relations of the ore bodies that have been stoped in these areas are indicated on Figures 8, 11, and 12.

The Campbell area became very important from the standpoint of copper production after about 1925, and during the past decade it has yielded also much zinc-lead ore. Some of its features were outlined by Lavender\(^{20}\) as follows:

The ore body as developed on the 1600, 1700, and 1800 foot levels averages about 500 feet in length and varies in width from 50 to 250 feet.

The footwall contact is fairly well defined, with the exception of fracture zones which have caused some displacement. The dip shows a marked variation from nearly 90° to as flat as 25°. Above the 1700 level the footwall roughly conforms to the normal dip of the limestone beds of the district.

The hanging wall is subject to a greater degree of variation than the footwall and changes from an economic silica-pyrite contact of low copper content to a sharply defined hanging wall conforming to the local bedding planes.

Schwartz and Park\(^{21}\) give the following statements regarding the Campbell ore body:

Besides the main lense there are several minor ore bodies having a smaller area and vertical extent.


On the upper levels the ore bodies are separated by limestone, but on the lower levels the limestone has been largely replaced by pyrite, and the ore bodies are arranged around the periphery of a mass of pyrite. The (footwall) zone passes outwardly from the sulphide copper ore through bunches of copper ore mixed with lead-zinc sulphides into hematite and recrystallized limestone and finally into unaltered limestone.

At the north end of the ore body an oxidized zone extends from about 50 feet above the 1600 level to the 2000 level. Present development shows the greatest extent of this oxidized zone to be between the 1600 and 1800 levels. In this area cuprite, malachite, and native copper are intimately associated with the sulphides. There is also scattered oxidation along fractures in the main ore body.

Considered as a whole, the ore body of the Campbell area is composed mainly of chalcopyrite with important masses of bornite and chalcocite. Near the borders of the ore, sphalerite and galena become increasingly abundant. As these in turn decrease, specular hematite becomes prominent to the almost complete exclusion of the sulphides.

The general order of paragenesis of the hypogene sulphide minerals is pyrite, chalcopyrite, bornite, chalcocite with tetrahedrite, tennantite, enargite, famatinite, and stromeyerite closely connected with chalcocite in origin. In the border phases, where sphalerite and galena appear abundantly at places, they seem to follow chalcopyrite and bornite with galena later than sphalerite. The specularite of the border phase seems to follow pyrite and chalcopyrite where these minerals are in juxtaposition.

The principal supergene sulphide is chalcocite.

LEAD AND ZINC IN WESTERN PART OF DISTRICT

Lead and zinc have been found at various places in the western portion of the district, but details regarding the occurrences throughout much of this ground are not available.

The presence of sphalerite in rather large bodies with pyrite and chalcopyrite in the area between the Southwest and Czar mines, in the Gardner mine, and in the Briggs area has been noted. Lead ore has been mined from the Hendricks, Southwest, Uncle Sam, Gardner, and Shattuck areas.

Lead carbonate in Hendricks Gulch constituted the first body of ore to be worked in the Bisbee district. According to Ransome, it formed very irregular bunches in the limestone in the vicinity of a fault fissure. Regarding the lead carbonate deposits in this general area, Trischka wrote as follows:

The ore is mostly in the Martin (Devonian) limestone and clusters about a siliceous core which crops out as silica breccia and manganese on the surface. This siliceous core, which is porous due to leaching, contained most of the lead carbonate ores that were mined from the district. The iron and possibly some copper were leached out of this silica core, which later collapsed. The lead, altering in place, remained in the silica. In this silica also the gold was both mechanically and chemically concentrated during leaching. Where shelves of contact material occurred between the silica and the limestone, variable thicknesses of silica resting on this contact were mineable for gold.

24Carl Trischka, work cited, p. 37.
The silica core may have resulted from complete leaching of siliceous pyrite which is commonly associated with ore bodies in all parts of the district. The oxidation slumping above the ore body as well as around its sides suggests this possibility.

**METAMORPHISM AND ALTERATION**

It is beyond the scope of this paper to discuss metamorphism and alteration in the Bisbee district.

As summarized by Ransome,\(^2\)

It was recognized that the ore bodies are related in their occurrence to the porphyry mass of Sacramento Hill, but it was realized also that the intrusion of that mass was not accompanied by general contact-metamorphic phenomena at all comparable in intensity with the size of the copper deposits. Measured by the development of characteristic contact-metamorphic silicates, the effect of the porphyry at Bisbee upon the intruded limestones was notably feeble.

Much silica, specularite, and magnetite were introduced for a considerable distance away from Sacramento Hill.

The most characteristic chemical change around the periphery of a zinc-lead ore body is the introduction of manganese, commonly marked by bleaching of the limestone; in places the bleached limestone has been found to contain as much as 13 percent of manganese.

**OXIDATION**

The depth to the general groundwater level when mining began was probably from 1,000 to 1,100 feet, whereas the known lower limit of oxidation ranges from about 200 feet in the northwestern part of the district to below 2,500 feet in the Junction area. The oxidation below the 1,200 level, however is largely confined to fissure zones.

**OUTCROPS**

The Bisbee district was marked by numerous outcrops of manganese oxides which have yielded the greater part of Arizona's total manganese production. These bodies, however, generally do not extend to depths of more than 20 to 50 feet below the surface.

Outcrops of copper or lead ore bodies were very few in the district, and surface indications of zinc mineralization seem to be lacking. As stated by Ransome,\(^3\) many of the most important ore bodies would have remained undiscovered if such surficial indications alone had been relied upon to suggest exploration.

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\(^2\)F. L. Ransome, work cited, p. 19.
\(^3\)F. L. Ransome, work cited, p. 13.
CHAPTER III.—JOHNSON CAMP AREA, COCHISE COUNTY, ARIZONA

By John R. Cooper

INTRODUCTION

The Cochise mining district, in northwestern Cochise County, contains deposits of copper, zinc, tungsten, gold, silver, and lead. The largest deposits are of copper and zinc and occur in the eastern foothills of the Little Dragoon Mountains near the mining town of Johnson, which is 53 miles east of Tucson and 27 miles north of Tombstone. This report is confined to the area of these copper and zinc deposits, known as the Johnson Camp area.

HISTORY AND PRODUCTION

The copper ores near Johnson were discovered before the Southern Pacific Railroad was completed in 1881. Since 1881 the deposits have been worked intermittently by many different operators, the production reaching peaks during times of high copper prices and stopping altogether during times of low prices. A production peak in the eighties came from relatively high-grade oxidized ores, and more important later peaks, during the first World War and since 1944, came from lower grade sulfide ores. Some zinc occurs with copper in all the ores, but the early operators found it a liability for which a penalty had to be paid to the smelters. In 1942, for the first time, the ore was concentrated, in a small way, by selective flotation, and zinc became a valuable product. Since 1944 zinc has been produced in considerably greater quantities than copper. The total production to the end of 1947 was approximately 33,000,000 pounds of copper, 15,301,000 pounds of zinc, 358,000 ounces of silver, 30,000 pounds of lead, and a negligible amount of gold, in all valued at approximately $8,837,000. Over 99 per cent of the ore mined has come from four mines — the Republic, Mammoth, Peabody, and Copper Chief mines—owned since 1942 by the Coronado Copper and Zinc Company.

Following are the dates of some important events in the area:

1882. Russell Gold and Silver Mining Company of Philadelphia started smelting ores from the district at Russellville, where water was available.
1883. Pipeline laid from Russellville to Peabody mine and smelter moved there. Smelter removed and mine closed some time in the eighties.
1899. Peabody mine reopened by Dragoon Mining Company, a subsidiary of the Federal Copper Company of New York; company failed in 1903, but mine operated at intervals until 1918 by the Bonanza Belt Copper Company and its successor the Peabody Consolidated Copper Company.
1901. Black Prince Copper Company organized by Denver capitalists and started exploration program which continued at intervals for a decade.

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1905. Arizona Consolidated Mining Company (later Arizona United Mining Company), organized by Philadelphia capitalists, reopened Republic and Mammoth mines. Arizona and Michigan Development Company of Benson purchased the Copper Chief Mine.

1906-08. Railroad constructed between Johnson and Southern Pacific line at Dragoon. Railroad much used during first World War. Tracks removed 1925.

1909. Arizona United Mining Company blew in smelter at Republic mine but soon abandoned it.

1912. Main Manto ore body at Republic mine discovered.


1920. All mines closed because of fall in copper price.

1920-41. Almost no mining. Republic, Mammoth, Copper Chief, and Peabody mines consolidated under ownership of Roy Wilson of Prescott and the late Samuel Traylor of Beverly Hills, California. American Metal Company did limited amount of geological work and diamond drilling on this property in 1939-40 under lease-option agreement.

1941. William A. Hooton of Tucson started shipping ore from Republic and Mammoth mines under lease-option agreement with Messrs. Wilson and Traylor.

1942. Coronado Copper and Zinc Company, controlled by Harvey S. Mudd interests of Los Angeles, took over Hooton's lease and option and later purchased the property.

1945. Coronado Copper and Zinc Company completed 150-ton selective flotation concentrator at Republic mine and start shipping copper and zinc concentrates.

GEOLOGIC SETTING

The rocks exposed in the Little Dragoon Mountains are illustrated diagrammatically in Figure 13. The oldest rocks, comprising the Pinal schist of pre-Cambrian age, consist of metamorphosed arkosic sands, silts, and volcanics intruded by various igneous rocks. Resting on the schist with profound angular unconformity is a part of the Apache group also of pre-Cambrian age. A thick section of Paleozoic rocks lies unconformably on these older formations indicate a discordance of over 2 degrees in some parts of Pinal schist. The lowest Paleozoic formation, the Bolsa quartzite, was deposited on a surface of considerable relief, for the Bolsa varies abruptly in thickness from 335 to less than 50 feet and commonly has a thick, coarse basal conglomerate where the formation fills old valleys. Angular discordance between the Bolsa and the Apache group is not apparent in outcrops, but the regional relations indicate a discordance of over 2 degrees in some parts of the mountains. The diabase sills in the Apache group are known to be of pre-Bolsa age because old Bolsa-filled valleys cut into and through the sills, and the basal conglomerate of the Bolsa contains fragments of quartz-orthoclase-ilmenite pegmatite which is identical petrographically with that occurring in the diabase. Diabase boulders were not found in the conglomerate, probably because the diabase decomposes readily and very rarely yields identifiable fragments.

A part of the Bisbee group, of Lower Cretaceous age, occurs on the south side of the Little Dragoon Mountains in fault contact.
Figure 13.—Diagrammatic section of rocks of the Little Dragoon Mountains.
with the older rocks. A few miles to the east, in the Gunnison Hills, the lower part of the group rests unconformably on strata of Permian age, the unconformity representing a time of warping, faulting, volcanic eruption, and deep erosion.

After the deposition of the Lower Cretaceous rocks, presumably during the Laramide revolution, the rocks of the Little Dragoons were deformed into a broad dome which, in its southern and southwestern part, was folded into smaller anticlimes and synclines with axes trending roughly northwest. Many steep faults and a few flat thrust faults complicate the structure.

After the regional folding and faulting a body of quartz monzonite, about 21 square miles of which is exposed, was intruded in the southeastern flank of the dome, cutting rocks as young as the Bisbee group. Dikes of aplite and lamprophyre, both differentiates of the quartz monzonite magma, cut the quartz monzonite and the country rocks. The Johnson Camp ore deposits are attributed to this intrusive cycle though, for reasons given later, the ore deposition is thought to have followed intrusion of the lamprophyre which is the youngest exposed member of the intrusive sequence.

The geology of the Johnson Camp area is shown on Figure 14. The quartz monzonite here intruded the Pinal schist and Apache group. In the early stages of intrusion it exerted lateral pressure as indicated by folds and schistosity near and parallel to the intrusive contact. The lateral pressure had ceased before final consolidation as indicated by apophyses and dikes of the intrusive cutting these older structures. The lateral thrust effects of the intrusion are evident for 500 to 1,000 feet from the contact but are not evident in the Paleozoic rocks which dip 20° to 45° NE. as part of the main dome structure of the Little Dragoon Mountains. The ore bodies are in the Paleozoic rocks ¼ to 1½ miles from the quartz monzonite body as exposed. No quartz monzonite has been found in mine workings or borings in the mine area.

STRUCTURE OF THE MINING AREA

The rocks of the mining area are cut by a well defined set of faults and fractures striking N. 5° to 30° E. and dipping 60° to 80° SE., called the Northeasters; a less well defined but important set striking N. 60° to 90° E. and dipping 30° to 60° S., the Easters; and a rare and relatively unimportant group striking N. 10° to 45° W. and dipping over 65° SW. or NE., the Northwesterners. Subsidiary fractures striking essentially parallel to the Easters but dipping over 60° S. are commonly associated with the Easters and also occur where no close relation to an Easter is evident.

With several minor exceptions, the faults are normal faults and the east or southeast sides are downthrown. The displacements range from almost nothing to a few tens of feet on most of the faults, but locally exceed 100 feet on the Mammoth and Copper Chief faults, 250 feet on the Republic fault and 1,000 feet on the Keystone fault (Fig. 14). Many of the faults appear to have
formed before the mineralization, for fractures belonging to each set have localized ore at one place or another in the district, for example, the 467 fault (Northeaster) at the Mammoth mine, an unnamed Easter in the accessible part of the Peabody mine, and an unnamed Northwester at the O.K. mine. It is probable that the main movement on the large Keystone fault took place during the regional faulting of the area which preceded consolidation of the quartz monzonite, for there is no indication that this fault cuts the quartz monzonite. It is possible that all the faults were formed at this time.

Fault movements were renewed at intervals, and some movement took place after the ore was formed. At least two periods of movement, each followed by introduction of quartz, are indicated for some Northeasters by brecciated early quartz fillings cut by later unbrecciated fillings. A prominent Northeaster carrying about 3 feet of quartz (No. 9 fault) at the west end of the Main Manto stope of the Republic mine was cut and offset a few feet by an Easter, but later movements reopened the Northeaster across the Easter and this fracture was also filled by quartz. The most common relationship is that Easters cut and offset Northeasters, but there are many examples of the reverse relationship. That faulting occurred after the ore was formed is indicated by fragments of ore in the gouge of some Northeasters and Easters. The "offset" of ore bodies along faults is not a reliable criterion of faulting after the formation of the ore because the stratigraphic control of ore deposition was so strong that, after the fault movement ceased, the same beds may have been mineralized on the two sides.

METAMORPHISM IN THE MINING AREA

The rocks of the mining area are altered texturally and mineralogically in a way that is characteristic of igneous contact zones. Their appearance and mineral composition depend to a large extent on the original composition of the rocks from which they are derived. Shale beds, like most of the lower member of the Abrigo formation and several beds in the Martin limestone (Fig. 14), have been altered in most parts of the area to compact fine-grained hornfels having mica, feldspars, diopside, tremolite, epidote, and chlorite as the principal minerals. Impure limestone, calcareous sandstone and calcareous shale, like the middle member of the Abrigo, are more or less altered to granular brown or greenish silicate rocks characterized by any or all of the lime silicates, garnet, epidote, vesuvianite, and wollastonite, together with some diopside. Before becoming granular lime-silicate rocks the most shaly layers passed through a stage in which they were dark hornfels, preserved in some parts of the area because of arrested metamorphism. Sandy dolomite and dolomitic sandstone, like the upper member of the Abrigo and middle part of the Martin, are altered to granular nearly white silicate rock weathering rusty brown and characterized by the lime-magnesia silicates
diopside and tremolite. At a few places impure limestone has been converted to white silicate rock indistinguishable from that derived from dolomite, but no place is known where dolomite has been altered to garnet or any of the other magnesia-free minerals so characteristic of the metamorphosed limestones. Nearly pure dolomite, like the lower part of the Escabrosa limestone and parts of the Martin limestone, is generally recrystallized to dolomitic marble although in places it has been de-dolomitized into calcite-tremolite, calcite-forsterite or calcite-serpentine rocks. In general pure limestone, like most of the Carboniferous limestones, has been recrystallized into calcite marble lacking silicate minerals.

The silicate rocks commonly contain considerable quantities of potash feldspar (which makes over 25 per cent of many specimens and over 70 per cent of some), quartz, and calcite. These minerals are, in part, products of late stage metasomatic replacement as shown by distribution and textural relations. They are also, in part, recrystallized minerals from the original sediment.

The lime and magnesian silicates seem to be products of reactions at high temperature between the original minerals, with migration of material rarely if ever exceeding a few feet. The reactions forming silicates from impure carbonate rocks release carbon dioxide as shown in the following examples:

\[
\begin{align*}
\text{Calcite} & \quad \text{Quartz} & \quad \text{Wollastonite} & \quad \text{Carbon dioxide} \\
\text{CaCO}_3 & \quad \text{SiO}_2 & \quad \text{CaSiO}_3 & \quad \text{CO}_2 \\
\text{Dolomite} & \quad \text{Quartz} & \quad \text{Diopside} & \quad \text{Carbon dioxide} \\
\text{CaMg(CO}_3 \text{)}_2 & \quad 2\text{SiO}_2 & \quad \text{CaMg(SiO}_3 \text{)}_2 & \quad 2\text{CO}_2
\end{align*}
\]

The carbon dioxide moves away through cracks and pores in the rock until it escapes at the surface, is dissolved in underground water, or re-enters a mineral phase. The silicate remaining has substantially less volume than the original minerals because of the loss of carbon dioxide and the greater density of the silicate. The volume loss in the first example is about 33 per cent and in the second nearly 40 per cent. Such large losses would seldom, if ever, occur in nature because the reactions fail to go to completion and the original composition is not such that all parts of every constituent are involved in the reactions.

There is field evidence in the Johnson Camp area of a decrease in volume of impure carbonate beds on metamorphism. Cross-sections through the metamorphic area show that such beds are thinner than they are outside the metamorphic area and that the amount of thinning, up to a maximum of about 25 per cent, is proportional to the amount of silication.

The mineralization appears to have taken place after the intrusion of the quartz monzonite, aplite, and lamprophyre, judging from evidence secured at the Peabody mine. This mine is now abandoned and mostly inaccessible, but an old report states that one of the principal ore bodies was "in a contact vein between lime and diabase."2 Fragments of the "diabase" found on the mine dump

are considerably altered but retain enough remnants of the original minerals and textures to indicate that, before alteration, the rock was similar petrographically to lamprophre dikes cutting the quartz monzonite and aplite. It is presumed to be of the same age. The alteration of the lamprophyre at the Peabody mine included introduction of about 5 per cent by volume of ore minerals, mostly chalcopyrite, which are interstitial to and corrode the silicates. Calcite, which is a constituent of all other specimens of the lamprophyre studied, is completely absent, its place being taken by clinozoisite, fluorite, and tremolite. Seams of chalcopyrite, associated with sphalerite, potash feldspar, oligoclase, diopside, fluorite, and hypogene hemimorphite (?), cut the rock. Most of these seams are bordered by a band of white, intensely altered lamprophyre about a millimeter wide in which the hornblende and feldspar of the lamprophyre have been converted to diopside. The mineralization of the lamprophyre is clearly of the pyrometasomatic type like that in the adjacent limestone.

ORE BODIES

The ore bodies occur at or near the intersection of mineralized fractures with favorable beds. Some ore bodies are tabular deposits parallel to the beds, 3 to 15 feet thick and several hundred feet across. The largest deposits are chimneys which are more or less oval in cross section and have the long axis and intermediate axis in the plane of the beds, and the short axis perpendicular to the beds. The chimney is known as a manto if its long axis lies at a large angle to the dip of the beds. The largest ore body as yet mined in the district, the Main Manto at the Republic mine, was 1,500 feet long, 30 to about 100 feet wide and 15 to 40 feet thick, with several large extensions of the bedded type; the down-dip extensions become chimneylike at greater depths (Figs. 15, 16). Smaller ore bodies of the chimney and bedded types have been mined at the Mammoth, Copper Chief, Peabody, and other mines (Fig. 14). Several very small ore bodies at the Peabody, Black Prince, and O.K. mines were tabular deposits following fractures at a considerable angle to the beds.

The primary ore consists of varying proportions of chalcopyrite, sphalerite, bornite, and pyrite, with a little molybdenite and scheelite in a gangue of lime-silicates, potash feldspar, quartz, and calcite. The most abundant lime-silicates in the ore at the Republic, Mammoth, and Copper Chief mines are garnet, diopside, and epidote. At the Peabody and Black Prince mines, vesuvianite and wollastonite are also abundant.

The mineralization was probably a single but complex process brought about by ascending hot fluids. Two stages are recognized. At first there was a metamorphic stage during which most of the lime silicates, and much of the potash feldspar were formed. Fracturing and brecciation followed. Later there was a metasomatic stage during which ore minerals, potash feldspar, a new generation of lime silicates, quartz, and calcite were intro-
duced. The metasomatic stage started at a high temperature, judging from the second generation of contact silicates. It continued to much lower temperatures, at which quartz and calcite formed in juxtaposition without reacting with one another to form silicates. In general the ore minerals are interstitial to the silicates, but locally the ore minerals fill fractures in the silicates and replace them.

Near-surface oxidized ores were mined in the early history of the deposits but are no longer of importance. Supergene sulfide enrichment is negligible in amount.

*Favorable beds:* The ore has selectively replaced particular layers, here called favorable beds. These include thin, once more or less shaly layers in the Naco limestone, as at the Peabody mine; and one or more zones of interbedded limestone, sandstone, and shale in a stratigraphic interval of several hundred feet making up the middle member of the Abrigo formation, as at the Republic, Mammoth, and Copper Chief mines. Only valueless disseminations and a few small masses of ore have been found at other stratigraphic horizons.

The middle member of the Abrigo formation has been much the most productive part of the whole stratigraphic section. Outside the metamorphic area the middle member consists of about 240 feet of thin-bedded limestone interbedded with shale and calcareous arkosic sandstone—in contrast with the lower member of the formation, about 300 feet thick, which is predominantly shale, and the upper member, about 140 feet thick, which is sandy dolomite and dolomitic sandstone with several thin quartzite beds (Fig. 13). In the metamorphic area the lower member of the Abrigo is predominantly dark-gray somewhat shaly hornstone, the middle member is more or less converted to granular brown (garnet) or more rarely greenish (epidote) tactite, and the upper member is nearly white tactite (diopside, tremolite, potash feldspar). The middle member was less sensitive to metamorphism than the other two subdivisions; essentially unsilicated portions of it are common in the mining area, and its alteration is slight northwest of the Mammoth fault which limits the area of productive deposits (Fig. 14). The ore bodies occur where it is silicated, but unsilicated portions occur close to ore, and large silicated areas are barren.

The upper strata of the middle member of the Abrigo are the most favorable beds in the Mammoth-Copper Chief-Republic area. The upper contact of this member has been indicated on the geologic map, Figure 14, as an aid in visualizing the relationships. At the Mammoth and Copper Chief mines the main ore bodies are just below and all ore bodies are less than 50 feet below this plane. The relationships at the Republic mine, further illustrated on Figures 16 and 17, are somewhat more complicated; the best ore is at the very top of the middle member, but local extensions of the Main Manto ore body occur in beds as much as 90 feet
below the top, and the minor West Manto ore bodies occur in beds about 150 feet below the top.

Mineralizing fractures: Many but not all the Northeasters and Easters are mineralizing fractures. It is impossible to outline reliable criteria for recognizing a mineralizing fracture prior to exploring the intersection of that fracture with a favorable bed. Small, weak concentrations of ore minerals near a fracture even though in unfavorable beds are the best sign. The presence of vein quartz in a fracture is a good indication if the quartz contains appreciable quantities of ore minerals, fluorite, and potash feldspar. The size of a fracture and the amount of fault movement are not necessarily favorable signs, but a large fault should not be condemned hastily as barren. The largest ore bodies occur nearly parallel to but some distance away from relatively large faults—apparently localized by subsidiary structures.

The relationship of the Republic ore bodies to beds and prominent fractures is illustrated in Figures 15 and 16. Figure 15 is based on large-scale geologic maps of the surface and of the thirteen principal levels of the mine and also on twelve cross sections. Two of the cross sections are presented in Figure 16. In Figure 15 the trace of fractures on an inclined surface is shown and, therefore, the trend of the fractures is different from the strike; the Easters appear as bands because of their flat dips, and the Northeasters are shown as lines, which require only slight generalization because of their steep dip and small displacement. The localization of ore by certain fractures is evident—bedded bodies and down-dip chimneys by Northeasters, and mantos by Easters. The mantos are on the footwall side and generally some distance away from the large controlling Easter. Thus the Main Manto is 100 to 200 feet down-dip from the Republic fault. It is cut by many subordinate Easters at the west end as shown in section A-A\textsuperscript{1}. At the east end it follows a slight roll in the beds as shown in section B-B\textsuperscript{1} and by the 4500 contour on Figure 15. The West Manto ore bodies lie along an anticlinal roll in the beds.

At the Mammoth mine, where the geologic relations are somewhat simpler than at the Republic mine, two ore chimneys have been mined from the beds at the very top of the middle member of the Abrigo. One chimney was a manto, found about 50 feet down the dip of the beds from an Easter, the Old Manto fault. The other chimney ran almost down the dip of the beds on the footwall side of a conspicuous Northeaster, the 467 fault (Fig. 14).

Ore grade: The ores produced from the district from 1902 to 1942 inclusive averaged about 4.3 per cent copper, 0.9 ounce of silver, and an unknown amount of zinc per ton. Most of the ores produced since 1942 have carried less copper and silver but up to 10 per cent or more of zinc. The ratio of zinc to copper is variable, the heart of an ore body being high in copper and the fringes high in zinc. The largest body of zinc-rich ore is at the east end of the Republic mine below the 900 level. This was
passed over by the early operators who mined the high-copper ores down to the 1250 level. In the upper levels of the mine, unmined shells of zinc-rich ore are essentially lacking, which suggests that increasing quantities of zinc may be found as the deposits are developed to greater depths. It should be emphasized, however, that the facts suggesting this possibility are so few that they may be fortuitous and that no information is available as to the zinc content of ore shipped from the upper levels.

Metals other than copper, zinc, and silver are present in very small amounts in the ore. The ores of the Republic, Mammoth, and Copper Chief mines contain, on the average, about 0.02 per cent lead, 0.002 ounce of gold per ton, a little tungsten (about 0.1 per cent WO3), and a trace of molybdenum. The ores of the Peabody mine contain somewhat more lead and precious metals, particularly silver.

CHAPTER IV.—PIMA DISTRICT

By Eldred D. Wilson

INTRODUCTION

The Pima district is on the eastern margin of the Sierrita Mountains, from 18 to 30 miles by road south-southwest of Tucson. As generally considered, it comprises the Mineral Hill, San Xavier, Olive Camp, and Twin Buttes areas, although the U.S. Minerals Yearbooks include with it the Papago and other districts of the Sierrita Mountains.

A small number of people reside at the San Xavier and Twin Buttes mines and at scattered ranches within the area.

PHYSICAL FEATURES

From the foot of the Sierrita Mountains a pediment slopes gently eastward towards Santa Cruz Valley. This pediment ranges in altitude from approximately 4,500 feet on the west to 3,300 feet on the east. Rising prominently above it are scattered hills, such as the Twin Buttes, Helmet Peak, and Mineral Hill. Numerous eastward-flowing arroyos carry the runoff of wet seasons eastward towards Santa Cruz River. Topography of the district is shown on the Twin Buttes quadrangle sheet, published by the U.S. Geological Survey.

GEOLOGY

General Statement

Because of faulting, igneous intrusion, and alluvial cover, few if any of the sedimentary rock units are exposed in their original entire thickness. Over much of the area structural relations are obscure, and many features of the igneous bodies are not revealed.
F. L. Ransome briefly examined the Sierrita Mountains in 1920. Further studies have been carried on over a long period of years by geologists for mining companies, by students under direction of the Geology department of the University of Arizona, and by the Arizona Bureau of Mines. Much credit is due Dr. B. S. Butler for active collaboration in the field problems.

Sedimentary Rocks

The following sequence for the sedimentary rocks in the district has been proposed:

Upper Cretaceous
- Arkose with shale and thin limestone
- Recreation red beds
- Undifferentiated volcanics and sedimentary beds

Permian
- Snyder Hill limestone
- Quartzite
- Limestone
- Quartzite
- Limestone
- Shale, limestone, marl, and gypsum

Pennsylvanian
- Naco limestone
- Mississippian
- Escabrosa limestone

Devonian
- Martin limestone

Cambrian
- Abrigo formation
- Bolsa quartzite

Bolsa quartzite: The oldest exposed formation, the Bolsa quartzite, crops out in the Twin Buttes and Mineral Hill areas.

Southwest of Twin Buttes camp, the Bolsa attains a maximum thickness of approximately 600 feet. Its upper half characteristically weathers darker brown than does its lower half.

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5 B. N. Webber, Marcasite in the contact metamorphic ore deposits of the Twin Buttes district, Pima County, Arizona: Econ. Geol., vol. 24, pp. 304-10, 1929.
10 M. N. Mayuga, work cited.
At Mineral Hill the formation appears to be 600 feet thick.

*Abrigo formation*: Silicified limestone, correlated with the Abrigo formation, occurs on Mineral Hill. It ranges from brown to light green and is estimated to be 350 feet thick. 

Southwest of Twin Buttes, Bolsa is overlain by a series consisting of novaculite, mottled bluish limestone, and cherty shale, with a total estimated thickness of 310 feet. This series may represent the Abrigo.

*Martin limestone*: Limestone containing Devonian Martin fossils is present at Mineral Hill, Twin Buttes, and west of the Contention mine. Its exposed thickness ranges from 100 to 350 feet.

*Escabrosa limestone*: Massive, cliff-forming granular limestone containing Lower Mississippian fossils occurs in the Mineral Hill, San Xavier Extension, and Twin Buttes areas. Characteristically, this limestone is relatively pure except for scattered chert nodules. Its apparent thickness is 350 feet at Mineral Hill and 375 feet at Twin Buttes.

*Naco limestone*: The Naco, in contrast to the Escabrosa, consists largely of thin-bedded cherty limestone interstratified with thin shale. Commonly the shale has been metamorphosed to hornfels which stands out in relief on weathered surfaces. The Naco contains Pennsylvanian fossils. It is estimated to be 750 feet thick at Mineral Hill, 900 feet west of the San Xavier, and possibly 1,200 feet at Twin Buttes.

*Permian beds*: A series of shale, limestone, marl, and gypsum lies stratigraphically above the Naco. Its apparent thickness amounts to a few hundred feet.

Above the gysiferous series are beds of quartzite and limestone. They in turn are overlain by the Snyder Hill limestone, which forms Helmet Peak.

*Cretaceous beds*: The Cretaceous in this district includes undifferentiated volcanics, conglomerate, arkosic sandstone, shale, and quartzite; red shale, arkose, and conglomerate similar to the Recreation red beds of the Tucson Mountains; and light-colored arkose with local shale and limestone. The stratigraphic relation and thickness of these members is not clearly revealed.

**Igneous Rocks**

*Granite*: Coarse-textured intrusive rock, ranging in composition from granite to quartz monzonite and granodiorite, floors much of the pediment area of the district.

Strong metamorphism and mineralization of the neighboring sedimentary rocks suggests that the granitic mass invaded them,
although actual intrusive contacts are not convincingly exposed in the Mineral Hill and San Xavier areas. At Twin Buttes, however, irregular masses of the granite intrude Bolsa quartzite. Southwest of the Senator Morgan mine, tongues of the granite invade Cretaceous beds.

Porphyry dikes of acidic to basic composition cut the sedimentary rocks and are believed to be related to the granitic intrusion. Likewise, irregular areas of andesite are younger than some of the Cretaceous beds and have been mineralized. Some small masses of red basalt may be later.

**Structure**

*General statement:* The structure of the Sierrita Mountains has been complicated by folds, overturns, low-angle faults, and steeply dipping faults. Much of it remains obscure and unknown.

Some of the structures localized emplacement of the igneous intrusions and deposition of the ores. Some post-ore faulting has taken place.

*Folds:* In Mineral Hill faulted Paleozoic beds dip steeply southwestward, with older beds above younger. This block may be interpreted as one limb of a southeastward-trending, overturned fold, or it may be a remnant of a thrust-fault slice.

Helmet Peak consists of Snyder Hill limestone, bounded on the northeast by down-faulted red beds and on the southwest by shaly and arkosic beds of uncertain structural relation. According to Galbraith the limestone of the peak shows a closely compressed anticline plunging southeastward.

Flexures are evident in the hill west of the San Xavier Extension mine.

Some unrecognized large folds may be present, as suggested by the wide variation in dips of beds in the Twin Buttes area.

*Low-angle faults:* As interpreted by Mayuga, the sedimentary rocks in the Mineral Hill, San Xavier, and Olive Camp areas rest upon the intrusive granite. Fault planes and breccia exposed above the granite indicate the contact to be a low-angle fault zone of general eastward dip. This fault zone may have localized the granite intrusion, or movement may have occurred along it after the intrusion.

At the San Xavier Extension mine, Naco limestone has been faulted over Escabrosa, and the fault contact dips about $25^\circ$ southward.

In the Cretaceous area south of the San Xavier mine, older beds have been thrust over younger beds.

In the northern part of Mineral Hill, a block of Escabrosa and Martin limestones has been thrust over Permian and Naco beds.

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8M. N. Mayuga, work cited.
9M. N. Mayuga, work cited.
10F. W. Galbraith, oral communication.
11Work cited.
The thrust plane appears to dip northeast about 40°.\textsuperscript{12}

*Steeperly dipping faults:* Steeply dipping fissures are numerous in the district. On the basis of general strike, they may be grouped into northeast, northwest, and east systems. Some of them have effected displacements of several hundred feet.

Faults and fractures of the northeast and east systems appear to be most commonly associated with mineralization.

**ORE DEPOSITS**

**HISTORY OF MINING\textsuperscript{13}**

Silver-lead deposits in the San Xavier and other districts of the Sierrita Mountains were known to the Jesuits and early Spaniards, who probably worked them in a small way. Some development was carried on there prior to 1875.

In 1880, Colonel C. P. Sykes purchased the San Xavier mine and organized San Xavier Mining and Smelting Company. To treat the ore, a small blast furnace was erected on the Santa Cruz River, 9 miles south of Tucson, but it was unsuccessful. From 1882 until the demonetization of silver in 1893, silver-lead ore was shipped intermittently from the Sierrita Mountains to various reduction works. The principal mines worked were the San Xavier, Olive, Matchless, Silver Blende, Fortuna, Arizona Queen, Veta, Democrat, Banner, Santa Cruz, Patterson, Annie, Minor, Chloride, and Celia.

Emperor Copper Mining Company developed the Mineral Hill copper deposits from 1882 until the slump in the copper market of 1884.

During 1897, L. H. Manning shipped ore from the San Xavier mine.

In 1898, Azurite Copper and Gold Company built a water-jacket furnace of 30 tons daily capacity at the Mineral Hill mines and produced copper for about a year. After remaining idle for six years, the property was acquired by Mineral Hill Consolidated Copper Company which developed it until the 1907 panic. In 1916, the old smelter was enlarged, and production was resumed for three years, after which the mine was closed again.

During 1906-7, Calumet and Arizona Mining Company carried on development of the Red Carbonate group, southwest of Twin Buttes. During World War I, low-grade fluxing ore was shipped from this property by Alfred Paul.

During 1908-13, Chesterfield Mining Company shipped lead-silver ore from the Esperanza and Annie mines.

The Twin Buttes copper deposits were worked in a small way during the nineties by Baxter, Ellis, and Irish. In 1903, Twin Buttes Mining and Smelting Company began extensive development in the district, and by 1906 had built a railway from Tucson.

\textsuperscript{12}M. E. Mershon and A. B. Short, work cited.

\textsuperscript{13}For years prior to 1931, largely abstracted from unpublished notes of J. B. Tenney.
through Sahuarita to the mines. Operating the Senator Morgan, Copper Glance, Copper Queen, and Copper King mines, this company shipped ore to smelters at Sasco and elsewhere until 1914.

Early in 1912, Pioneer Smelting Company completed a custom smelter of 150 tons daily capacity at Sahuarita, but it operated for only about a year.

In 1913, Bush-Baxter Company, which had been working the Minnie mine, leased the Senator Morgan and worked it for nine months. American Smelting and Refining Company operated the Minnie for a while prior to 1916. As Glance Mining Company, Bush and associates developed the Glance. As Midland Copper Company, they acquired the Queen and shipped ore up to the end of 1926. In 1929, Buttes Mining Company shipped ore from the Minnie.

Empire Zinc Company purchased the San Xavier mine in 1912 and shipped lead-zinc-silver ore from it until 1918.

In 1943 Eagle-Picher Mining and Smelting Company constructed at Sahuarita a concentrator of some 175 tons daily capacity and reopened the San Xavier mine. The capacity of the concentrator was doubled during the following year and later increased to 400 tons per day to take care of custom ores. Since 1943 the San Xavier mine has been one of the more important producers of zinc and lead in Arizona, and for 1948 its output of these metals ranked third in the State.

Zinc-lead ore was shipped from the San Xavier Extension property during 1943-45 by Chilson Mines Company. The Contention mine produced zinc-copper ore during 1944-47.

**Types and Distribution**

*General Statement:* The ore deposits in the Pima district include contact, replacement, and vein types. These types are somewhat related to one another. Available evidence suggests that the ore solutions ascended through fissures of northeast to eastward strike. The principal mines are less than a mile from the granite outcrop.

As stated by Mayuga,15 the contact zone, nearest the granitic intrusive, is characterized by garnet and other ferric iron minerals; next outward is a zone containing ferrous iron, marked by hedenbergite; and farther outward, sulfides occur associated with little or no contact minerals.

*Contact deposits:* The Twin Buttes, Senator Morgan, Mineral Hill, and Vulcan ores are of the contact type. They contain principally copper and silver. Except in the Contention zinc-copper and the Copper King copper-zinc mines, they have been found to be subordinate in zinc and lead content. Some scheelite occurs in several of the contact areas.

The contact deposits are limestone replacements which are characterized by association with garnet, epidote, wollastonite,

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15M. N. Mayuga, work cited.
<table>
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<th>Years</th>
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<th>Copper Pounds</th>
<th>Copper Value</th>
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<td>1876-1907</td>
<td>?</td>
<td>2,100,000</td>
<td>?</td>
<td>4,000,000</td>
<td>?</td>
<td>613,000</td>
<td>?</td>
<td></td>
<td></td>
<td>850</td>
<td>$17,000</td>
<td>?</td>
</tr>
<tr>
<td>1908-11</td>
<td>36,156</td>
<td>3,763,957</td>
<td>$487,131</td>
<td>690,048</td>
<td>$29,877</td>
<td>103,921</td>
<td>$54,814</td>
<td></td>
<td></td>
<td>149</td>
<td>3,087</td>
<td>$574,909</td>
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<tr>
<td>1912-17</td>
<td>205,579</td>
<td>18,166,174</td>
<td>4,009,908</td>
<td>2,311,040</td>
<td>$148,791</td>
<td>2,658,734</td>
<td>137,990</td>
<td>331,172</td>
<td>212,071</td>
<td>254</td>
<td>5,249</td>
<td>4,514,009</td>
</tr>
<tr>
<td>1918-29</td>
<td>165,229</td>
<td>13,001,173</td>
<td>2,247,499</td>
<td>513,251</td>
<td>34,517</td>
<td>221,086</td>
<td>184,491</td>
<td>171</td>
<td>3,547</td>
<td>148</td>
<td>4,783</td>
<td>2,470,054</td>
</tr>
<tr>
<td>1930-42</td>
<td>1,789</td>
<td>45,027</td>
<td>5,125</td>
<td>212,927</td>
<td>10,177</td>
<td>183,239</td>
<td>12,365</td>
<td>148</td>
<td>2,823</td>
<td>148</td>
<td>4,263</td>
<td>22,451</td>
</tr>
<tr>
<td>1943-48</td>
<td>299,440</td>
<td>2,856,900</td>
<td>484,208</td>
<td>49,378,500</td>
<td>5,967,991</td>
<td>28,417,800</td>
<td>3,537,547</td>
<td>711,538</td>
<td>620,987</td>
<td>107</td>
<td>2,745</td>
<td>10,649,578</td>
</tr>
<tr>
<td>1908-48</td>
<td>648,297</td>
<td>37,833,781</td>
<td>7,233,872</td>
<td>51,689,540</td>
<td>6,116,782</td>
<td>32,492,680</td>
<td>3,786,108</td>
<td>1,447,446</td>
<td>1,083,628</td>
<td>827</td>
<td>20,411</td>
<td>$18,241,001</td>
</tr>
</tbody>
</table>

and other silicates. These minerals occur somewhat erratically distributed in masses along fissures of various trends. In places they appear to be genetically connected with fissures of north­east to eastward strike.

**Replacements:** The principal replacement deposits occur in limestone, other than the pure Escabrosa limestone. They are exemplified by the San Xavier and San Xavier Extension mines, whose ores contain zinc, lead, copper, and silver. These deposits seem to be associated with northeast fissures.

Replacements have been found also in brecciated andesite, as at the Helmet Peak mine.

**Veins:** Fissure deposits containing lead, silver, and zinc occur in arkosic or volcanic rocks of the Olive Camp area, as at the Olivette, Swastika, Paymaster, and Vivienne mines. Some gold-pyrite veins are found in quartzite breccia of the Alpha group area. Quartz-sheelite veins occur in arkosic beds of the Senator Morgan mine area.

In general the veins trend northeasterly to N. 8° W. and dip steeply.

**San Xavier Mine**

**Introduction:** The San Xavier mine is in the northern part of the Pima district, 22 miles by road south of Tucson. Ore from this mine is hauled by truck 9 miles to the Sahuarita concentrator of the Eagle-Picher Mining and Smelting Company.

The San Xavier property, whose general history is outlined on earlier pages, yielded a large portion of the metals produced in the Pima district during 1943-49. In 1949, the gross metal content of ores mined from the San Xavier was as follows:\(^{10}\): Zinc, 17,260,303 pounds; lead, 9,637,071 pounds; copper, 1,009,398 pounds; and silver, 274,516 ounces.

The following description is based largely upon information furnished by Grover J. Duff, Arizona Manager of Eagle-Picher Mining and Smelting Company, together with unpublished observations by B. S. Butler.

**Geology:** At the San Xavier mine, the Permian series of limestone, quartzite, and marl-gypsum beds is overlain on the south by Cretaceous arkose and shale. In places, pre-Cretaceous erosion removed part of the Permian series.

The beds lie in a southward-plunging syncline. Their dip ranges from 20° to 90°, and averages about 55°, southward. Relatively small rolls of southward trend are apparent underground.

A steeply southward-dipping fault zone strikes about N. 70° E. at the mine but swings southeasterly on the east and southwesterly on the west. It is a complex zone with variable dip generally somewhat steeper than the bedding. Its hanging wall apparently moved relatively upward and possibly eastward, but the amount of displacement is unknown. Two principal faults, termed the 17 and 10, are found in this fault zone. The 10 fault, in the eastern

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\(^{10}\)Figures courtesy of Mr. Grover J. Duff.
part of the mine, is within the hanging wall of 17 fault and subparallel to it in strike but of steeper dip. Other breaks strike northeastward and dip steeply. Another strikes eastward and dips at low angles southward.

Ore Deposits: Mineralization occurs as replacements of limestone within the San Xavier fault zone. Thin-bedded dark-gray limestone was an especially favorable host rock.

The principal deposits form "chimneys," more or less closely associated with the 17 and 10 faults. These "chimneys" plunge steeply with the dip of the beds or with intersections of the faults and beds. Less important replacements follow northeast fissures and extend outward along beds.

High-grade ore tends to lie immediately below the arkose or shale and also beneath low-angle slips.

As a rule the individual ore bodies are small and not continuous for long distances. They average about 15 or 18 feet in width, and their level lengths range unpredictably. In plan, the four principal "shoots" occur within an arcuate sector approximately 500 feet long.

The principal metallic minerals are sphalerite, galena, chalcopyrite, and pyrite, together with silver in undetermined form. Gangue minerals include garnet, quartz, hedenbergite, calcite, hematite, magnetite, epidote, and other silicates. This general mineralogy has been found to be essentially constant with depth.

Oxidation extends to irregular depths, generally 100-200 feet and exceptionally to the 420 level. The oxidized ore consisted chiefly of cerussite and smithsonite, together with some limonite and very sparsely distributed wulfenite.

Water stood a few feet above the 200 level when operations were resumed in 1942. The present workings yield about 1,080,000 gallons of water per day.

In March, 1949, ore had been produced from the 660 level, and development had extended to the 900 level.

San Xavier Extension Mine

The San Xavier Extension mine is on the Red Oxide claim, west of the Twin Buttes road and northwest of the San Xavier mine. The San Xavier Extension mine was developed originally by E. G. Bush. Prior to 1919 it yielded some 900 tons of ore that averaged about 4 per cent copper and 2 ounces silver per ton.17 During 1943-45 Chilson Mines Company shipped from the property a few thousand tons of ore containing zinc, lead, copper, and silver.

Here Naco limestone overlaps Escabrosa with a fault contact that dips 25° southeastward. The Escabrosa limestone, particularly, has been metamorphosed to marble.

The mine workings include a vertical shaft 500 feet deep with drifts extending northwestward on the 227 and 313 levels. The 227 level connects with the bottom of a shaft inclined 70° south-

eastward, 250 feet northwest of the vertical shaft. Water normally stands at a depth of 200-250 feet, and during 1943-45 only about 500 gallons of pumping per day was required to keep it below the 313 level.

Many faults, largely of northeastward trend, were cut by the mine workings. A thrust-fault wedge of Escabrosa marble, bounded above, beneath, and on the north by impure Naco beds, was found to apex at the 100 level and thicken with depth southeastward.

Mineralization occurred in the impure limestone on the northwest or lower contact of the marble wedge. It was stoped mainly above the 227 level and to a limited extent above the 313 level. Sphalerite, galena, and chalcopyrite were the principal ore minerals.

Olivette Mine

The Olivette or Olive mine is near Olive Camp, about 1/2 mile south of the San Xavier.

The Olivette and Annette claims were located in 1886. They were actively worked during 1887 and productive until 1893. In 1913 the Tucson Mining Company built a concentrator of 100 tons daily capacity at the Olive mine, but nothing was learned about its operation. Total production from the property is reported to have been about $750,000 in silver.

The prevailing rock in this area is light-colored Cretaceous arkose. Granite crops out as a small mass about 300 feet northwest of the Olivette shaft and probably underlies the present surface at no great depth.

The principal Olivette vein strikes N. 80° E. and dips 45° NW. Near the Olivette shaft it is intersected by the Annette vein which strikes about N. 8° W. and dips 40° NE. These veins for the most part are rather obscure at the surface. They consist of breccia about 3 to 5 feet wide between well-defined walls. The breccia contains streaks of quartz and ore minerals, and the ore shoots ranged from a few inches to 2 or more feet in width. Ore minerals are galena, argentiferous tetrahedrite, sphalerite, and pyrite, together with subordinate chalcopyrite, bornite, and chalcocite. Some of the ore is reported to have contained from 100 to 300 ounces of silver per ton and more than 20 per cent lead.

The Olivette vein is developed by two main inclined shafts about 75 feet apart, reported to be 210 feet deep and connected on the 200 level. The deepest work is reported to be at 300 feet. On the Annette vein are several vertical shafts of unknown depth, now filled with water to about 100 feet below the surface.

Swastika Group

The Swastika property is west of the Olivette. Its Richmond claim is reported to have yielded a notable production during the

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18 Description abstracted from M. N. Mayuga and F. L. Ransome, works cited.
19 Abstracted from M. N. Mayuga, work cited.
early days.
Within this group the fissures strike N. 65°-85° E., and mineralization is similar to that of the Olivette. The ore minerals contain principally lead, zinc, and silver, together with subordinate amounts of copper.

**Helmet Peak Mine**

The Helmet Peak or Prosperity claims are immediately south of the Olivette and Swastika.
Little historical information is available. Considerable oxidized lead and zinc ore is reported to have been mined from near the surface.
This area consists of brecciated andesite in which hydrothermal alteration has formed chlorite, epidote, and some serpentine. Granite crops out 3,000 feet northwest of the mine and probably underlies the workings at some unknown depth.
The ore bodies occur as irregular replacements within a northeastward-trending zone of brecciation several hundred feet long by about 250 feet wide. Ore minerals below the zone of oxidation include galena, sphalerite, argentiferous tetrahedrite, tennantite, pyrite, bornite, chalcopyrite, and quartz. Supergene chalcocite and covellite are also present.
The deposits were explored from several vertical shafts of which the deepest, No. 1 on the Camden claim, reached 600 feet, and No. 2 on the Elsie claim was 400 feet. More than 3,500 feet of drifting is reported to have been done between these two shafts. Water stood in the old shafts at about 80 feet below the surface.

**Paymaster Mine**

The Paymaster mine is about 1 1/4 miles southwest of the Helmet Peak workings. It is reported to have produced 260,000 pounds of lead and 200,000 ounces of silver during 1887-1908, and a little silver-lead ore in 1939-40.
Here the surface rock consists of andesite breccia. It is underlain, at a depth of 300 feet, by granite.
The ore consists mainly of argentiferous galena with subordinate copper and zinc minerals. It occurs in strong fissure zones marked by soft, crushed andesite and gouge. These fissures strike from about N. 8° E. to north-northwest and have a variable dip which averages about 70° W. above the 205 level but reportedly changes to eastward below the 250 level.
Workings include a vertical shaft 340 feet deep and an unknown amount of drifting. Water stands in this shaft at less than 300 feet. The 205 level, which extends 120 feet northeast from the shaft, cuts the Lead vein and the Iron vein. The Lead vein is re-

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20Abstracted from M. N. Mayuga and F. L. Ransome, works cited.
21Abstracted from F. L. Ransome and M. N. Mayuga, works cited.
ported to contain mainly galena and the Iron vein mainly pyrite with a little chalcopyrite and tetrahedrite.

**Copper King Mine**

The Copper King shaft is 500 feet east-southeast of the old Twin Buttes railway depot. This mine was worked for several years prior to 1914. According to Wm. Foy,\(^3\) its production, valued at $150,000, consisted mainly of carbonate ore that averaged about 8 per cent copper and 2 ounces of silver per ton; also, a body of oxidized ore in the footwall yielded 2,183 tons, averaging about 25 per cent zinc, which was shipped to plants in Kansas and Colorado.

From south to north the surface consists of cherty Naco limestone; a belt of relatively pure crystalline marble of Escabrosa aspect, 200 feet wide; a belt of bluish limestone 50 feet wide; siliceous beds, 25 feet; and cherty Naco limestone. These beds strike northwest and dip from 80° NE. to vertically. An irregular body of gray porphyry, 100 feet long by 15-25 feet wide, cuts across the southwest contact of the marble.

The Copper King fissure trends west to northwesterly and dips about 75° S. It is traceable for a length of some 350 feet, becoming tight and indistinct on the ends. On the east, near the bluish limestone, it apparently forks and is marked by a mass of garnet.

Ore occurred as an irregular vein-like replacement, averaging about 5 feet in width, along the Copper King fissure. Several mineralized northeast fissures, dipping from 65° SE. to vertically, are visible in the hanging wall of the ore body.

Commercial mineralization apparently was limited to the marble; where the main fissure passes into Naco limestone, at a vertical depth of 225 feet in the shaft, it becomes tight and essentially barren. The shaft inclines with the fissure and reaches a vertical depth of 335 feet.

**Contention Mine**

The Contention mine is in the Twin Buttes area, about \(\frac{1}{4}\) mile north of the Morgan mine. During 1944-47 it was operated by Wm. Foy and produced several thousand tons of ore of which 5,177 tons\(^4\) were mined in 1944 and 1946-47. The ore is reported\(^5\) to have contained about 15 per cent zinc, 2-3 per cent copper, and 1.5 ounces silver per ton.

Here a strike-fault zone trends N. 40° W. and dips 60°-70° SW. On its hanging-wall side are faulted slivers of quartzite and impure limestone, intruded by granite. A mass of dark garnet approximately 100 feet wide irregularly and partially replaces the impure limestone. On the southwest side of the fault zone is Escabrosa limestone, largely metamorphosed to marble.

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\(^3\) Oral communication.


The ore consists mainly of sphalerite and chalcopyrite associated with the garnet and apparently localized by closely spaced northeast fissures.

Workings include a vertical shaft 220 feet deep with drifts on the 210, 150, and 120 levels. From the upper levels, which later were flooded, ore up to 15 feet wide was stoped for a length of 120 feet and a height of 50 feet.26

26H. A. Whitcomb, work cited.

CHAPTER V.—ARAVAIPA DISTRICT

BY ELDRED D. WILSON

LOCATION AND ACCESSIBILITY

As defined by Ross,¹ the Aravaipa district is in the western part of Graham County, within Tps. 5-7S., Rs. 19-20-E., south of Stanley Butte.

Klondyke and Aravaipa are the main centers of population in the district. Klondyke consists of an old-time store and post office in the ranch community of Aravaipa Valley. One mile north of Klondyke is the Athletic Mining Company concentrator and housing project. Aravaipa, 12 miles north, is inhabited by employees of this company.

By road, Klondyke is 60 miles north of Willcox and 38 miles west of Glenbar, a siding on the Bowie-Miami branch of the Southern Pacific railway. Transportation difficulties have always retarded development of the district.

TOPOGRAPHY

The Aravaipa district is on the southwestern slopes of the Santa Teresa and Turnbull ranges. Southwestward-flowing tributaries of Aravaipa Creek have carved the region into a series of steep-sided gulches and ridges ranging in altitude from 3,200 feet in the western part to over 6,000 feet in the northeastern part. Klondyke is at an altitude of 3,500 feet, and Aravaipa is approximately 1,000 feet higher.

Topography of this region is shown on the Klondyke quadrangle topographic sheet, published by the U.S. Geological Survey on a scale of 1:62,500 and a contour interval of 50 feet.

WATER SUPPLY

Most of the stream channels are dry for the greater part of each year, although they may carry occasional floods of amazing size during wet seasons. Tule Spring, about 2 miles southeast of Aravaipa, and Lawrence Spring, at Landsman’s camp, south of the

¹C. P. Ross, Geology and ore deposits of the Aravaipa and Stanley mining districts, Graham County, Arizona: U.S. Geol. Survey Bull. 763, 1925.
Iron Cap mine, furnish limited domestic supplies, but the only dependable large sources of water known in the area are shallow wells in the valley of Aravaipa Creek.

GEOLOGY

The geology of the Aravaipa district is complex. Not enough work has been done there to determine the age and thickness of all the stratified rocks. Much of the general and detailed structure remains unknown.

The only published description of the geology is by Ross, who spent less than two months within the area of 300 square miles. Additional data have been obtained by the writer and through the courtesy of Athletic Mining Company.

Rocks

Following is a tabulation of the stratified rocks in the Aravaipa district:

<table>
<thead>
<tr>
<th>Age</th>
<th>Formation</th>
<th>Thickness in feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tertiary</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pliocene</td>
<td>Gila conglomerate: Weakly cemented gravel, sand, and silt. Unconformity.</td>
<td>?</td>
</tr>
<tr>
<td>Miocene (?)</td>
<td>Rhyolite, latite, breccia, tuff, and interbedded sedimentary material.</td>
<td>?</td>
</tr>
<tr>
<td>Cretaceous</td>
<td>Sandstone, shale, and conglomerate, with interbedded andesite, breccia, and tuff. Unconformity.</td>
<td>1,000-1,500</td>
</tr>
<tr>
<td>(upper)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carboniferous</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pennsylvanian</td>
<td></td>
<td></td>
</tr>
<tr>
<td>and</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mississippian</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Devonian</td>
<td>Tornado limestone</td>
<td>1,000±</td>
</tr>
<tr>
<td>Cambrian</td>
<td>Martin limestone: Dark to yellowish limestone and paper shale Unconformity</td>
<td>100±</td>
</tr>
<tr>
<td>Pre-Cambrian</td>
<td>Bolsa (?) quartzite Unconformity</td>
<td>200±</td>
</tr>
<tr>
<td></td>
<td>Pinal schist and associated igneous rocks.</td>
<td>?</td>
</tr>
</tbody>
</table>

_Pinal schist:_ Ross mapped as Pinal schist two principal areas of which one lies east of Klondyke in the vicinity of Quartz and Buford hills, and the other extends eastward from the southern end of Iron Cap Ridge past Landsman's camp and Cobre Grande Mountain.

The formation in the Buford Hill area is described as quartzitic schist interbedded with fine-grained quartz-sericite-chlorite schist. The “schist” between the southern end of Iron Cap Ridge and Landsman's camp consists of weakly metamorphosed sedimentary rock, not markedly schistose, which underlies lower Paleozoic beds with low-angle fault contact. It resembles the Cretaceous series, and correlation with the Pinal seems questionable.

*C.P. Ross, work cited.*

*C.P. Ross, work cited.*
**Bolsa (?) quartzite:** Fine-grained, locally pebbly quartzite, weathering brown, forms the fault-block ridge immediately east of Aravaipa. It also crops out in the southern part of Iron Cap Ridge, unconformably below Devonian and faulted above Carboniferous limestone.

**Martin limestone:** Yellowish-gray limestone with thin-bedded shale appears in the southern part of Iron Cap Ridge, in the next ridge west, and in the bluff east of Aravaipa. Paper shale crops out along the western margin of the quartzite northeast of Aravaipa.

**Tornado limestone:** Overlying the Martin is well-bedded bluish-gray to light-gray limestone, Mississippian and Pennsylvanian in age, which Ross correlated with the Tornado limestone of Ray and Globe. It forms prominent ridges in the vicinity of Aravaipa and between the Head Center, Grand Central, Iron Cap, and Cobre Grande mines. In general the Mississippian beds are crystalline and relatively pure, whereas the Pennsylvanian tend to be dense, impure, and cherty.

**Cretaceous beds:** A series of arkosic sandstone, shale, and conglomerate, interbedded with volcanic rocks of predominantly andesitic composition, unconformably overlies Tornado limestone in the northern part of the district. This series contains notable coal deposits in Deer Creek Basin, about 7 miles northwest of Aravaipa. Its age has been established as Upper Cretaceous.

**Intrusive rocks:** The Cretaceous and older rocks have been intruded by granite, rhyolite, porphyry, andesitic porphyry, and basaltic porphyry. These intrusions presumably occurred during the Laramide interval, from late Cretaceous into early Tertiary time.

As mapped by Ross, the granite is a batholithic mass which forms the main high portions of the Turnbull and Santa Teresa mountains. It is described as a sodic granite, locally approaching quartz monzonite in composition.

The rhyolite porphyry crops out as an irregular belt up to 2 miles wide along the western border of the main granite batholith, branching northwestward through the Head Center and Horse Mountain areas. Rhyolitic dikes are prominent in the northern part of the district. According to Ross, the rhyolite porphyry is intruded by the granite, although the two rocks are closely related in age and origin.

Andesitic and basaltic porphyry occurs as dikes, irregular masses, and sills, particularly north of Aravaipa. These rocks are prevailing fine grained and dark-colored, but one variety is marked by diabasic texture. Some of them are older than the rhyolite porphyry, and some are younger.

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*Work cited.

**M.R. Campbell, The Deer Creek coal field, Arizona: U.S. Geol. Survey Bull. 225, 1904; C.P. Ross, work cited.**
Tertiary rocks: Rhyolite and latite flows, breccia, tuff, and interbedded sedimentary material unconformably overlap the Cretaceous and older rocks. According to Ross\(^6\) this series, of Miocene (?) age, forms Stanley Butte and some isolated ridges in Aravaipa Valley.

Gila conglomerate floors most of the Aravaipa Valley, overlapping all the older rocks along the southwestern margin of the district.

**Structure**

*General statement:* Compressive stresses, acting in a southwest-northeast direction, deformed this region after the Cretaceous rocks were laid down and probably before the close of early Tertiary time. The region was bent into broad, open folds of northwest to westward trend and broken by faults of low to steep dip. These structures influenced emplacement of the intrusive bodies and localization of the ore deposits.

*Folds:* The principal fold exposed in this region is the Deer Creek syncline. It crops out at a point 6 miles northwest of Aravaipa and extends, with a maximum width of more than 5 miles, northwestward for at least 16 miles. Remnants of broad, open folds which have been largely obliterated by igneous intrusions, broken by faults, or concealed by later Tertiary rocks, are exposed in the north part of the Aravaipa district. Probably most of the dips of strata are expressions of either large-scale or drag folding rather than of block tilting.

*Low-angle faults:* At the Iron Cap mine, Carboniferous limestone has been thrust over gray arkosic sandstone and shale of probably Cretaceous age. The probable continuation of this fault zone appears at the southern end of Iron Cap Ridge where shale and sandstone of Cretaceous aspect are separated by low-angle fault contact from overlying Paleozoic beds.

In the Stanley district, 6 miles north of Aravaipa, Ross\(^7\) mapped overthrusts of Carboniferous limestone on Cretaceous rocks.

The fault zones that contain the Head Center and Grand Central veins dip 30°-45°. These zones are believed to be genetically related to the Iron Cap thrusts although not known to be continuations of them. The Head Center fissure extends for an unknown distance northwest.

In addition, there are numerous bedding-plane faults. Emplacement of the porphyry sills was doubtless influenced by them.

*Steeply dipping faults:* The steeply dipping faults are of normal and reverse types.

Most of the normal faults strike between north and N. 35° W. On many of them, movement occurred from pre-mineral to post-mineral time. In places they are mineralized. A minor number of normal faults strike east to northeastward and seem to displace the northerly faults.

\(^6\)Work cited.

\(^7\)Work cited.
At Aravaipa there has been relative uplift of northerly trending blocks of sedimentary rocks and relative depression of intervening belts of andesite porphyry. Easterly faults separate these blocks from porphyry on the north. The occurrence of limestone beneath porphyry at a depth of 500 feet in the Arizona shaft indicates that northern area to be considerably downthrown in reference to the southern part of the district.

A long system of presumably normal fault fissures is marked by the Grand Reef and associated veins. As interpreted by Ross⁸ this lode system extends from a point east of Klondyke northward through Imperial Hill and northwesterly past Aravaipa and the Arizona mine, a distance of more than 8 miles.

Steeply dipping reverse faults, of which the hanging wall has moved upward relative to the footwall, have been noted only in the Iron Cap area, although they probably are represented elsewhere in the district. Here most of the numerous displacements trend west or northwesterly and dip 40° to 85° N. They are regarded as results of lateral compressive stresses reacting in a general south or southwesterly direction. Thus the lower angle or overthrust faults are related genetically to the steeper reverse faults, which displace them.

For the examples studied, displacement of the hanging wall seems to be mainly lateral on the faults which dip more than 75°, and mainly upward on those of lesser dip; apparently footwall resistance influenced direction of movement.

The reverse faults are believed to be pre-mineral, although on some of them renewed movement of later age seems to have occurred.

ORE DEPOSITS

HISTORICAL OUTLINE⁹

1870-89. Mineral deposits were discovered in the Aravaipa district before 1880. A small smelter is reported to have been built here in the late seventies by Col. C. W. Birdwell, but little is known about production or operations prior to 1890.

1890-95. Aravaipa Mining Corporation, operating in northern part of the district, sank Arizona shaft to its present depth of 580 feet and shipped two cars of ore.

1890-1900. J. W. Mackay opened Grand Reef mine to a depth of 300 feet. Other properties in the district were worked, and presumably some lead-silver and copper ores were shipped.

1900-14. Small-scale operations, mainly by lessees.

1915-19. Grand Reef mine leased by local people who built a small mill and shipped ore and concentrates.

1916. John Gleeson and T. C. Parker, lessees, reportedly shipped $90,000 worth of lead carbonate ore from No. 1 claim.

1919-20. Aravaipa Leasing Company obtained Grand Reef property and made some production.


⁸Work cited.

⁹Data for years prior to 1923 abstracted from C.P. Ross, work cited.
1925-28. Grand Central Mining Company, headed by Lewis Douglas, acquired the old Aravaipa property, including the Iron Cap and other claims near Aravaipa, in 1925 and built a mill with a flotation capacity of 90 tons per day. In 1927 this plant was operated for five months. Production from crude ore and concentrates shipped during 1926-28 was approximately 3,500,000 pounds of lead, 1,214,797 pounds of zinc, and $20,000 worth of silver.\(^{10}\)

1929-31. Production was mainly oxidized lead ore from the Grand Reef which in 1931 ranked second as a producer of lead in Arizona.\(^{11}\)

1932. Little activity and small production.

1937-41. Base-metal production was resumed in the district. The Grand Reef Mining Corporation in 1939 installed a milling plant of 100 tons daily capacity. During 1941, the Calistoga Mining and Development Company treated Grand Reef tailings.

1942-49. Athletic Mining Company bought the Aravaipa group of claims, developed the Iron Cap and Head Center mines, and became the district's largest shipper of lead and zinc ores. This company built at Klondyke a flotation concentrator of 100 tons daily capacity, which was operated throughout 1948 and part of 1949 chiefly on Iron Cap ores, and subsequently on other ores.

**Types**

The ore deposits of the Aravaipa district consist of veins and replacements. The veins are represented in the Iron Cap, Head Center, Grand Central, and Grand Reef mines. Replacements predominate in the Aravaipa No. 1, No. 2, and Landsman mines, in parts of the Iron Cap mine, and probably in lower levels of the Arizona mine.

The veins occur in low-angle fault zones and related bedding slips, as at the Iron Cap, Head Center, and Grand Central mines, and in steeply dipping fissures, as in the Grand Reef lode system. The rocks most favorable for them are the Pennsylvanian limestone and the intrusive rhyolite.

Irregular replacements are best developed in limestone that has been brecciated or fractured, as in the hanging wall of a low-angle fault, in the footwall of a steep reverse fault, and in some normal faults. In places they occur associated with epidote, garnet, and specularite. Commonly their outcrops are marked by dark oxides of iron and manganese together with silicate minerals.

Some of the ore shoots are localized where northeasterly fissures intersect favorable structures, but this relation has not yet been established as general for the district.

**Iron Cap Mine**

The Iron Cap mine is 2 miles northeast of Aravaipa and near the head of Arizona Gulch, at an altitude of approximately 5,000 feet.

The first workings in this mine consisted of an upper adit. It was run westerly for 115 feet, following a vein within a reverse fault zone that dips 70° N. in Pennsylvanian limestone. This work


## PRODUCTION OF ARAVAIPA DISTRICT

<table>
<thead>
<tr>
<th>Years</th>
<th>Tons Ore</th>
<th>Lead Lb.</th>
<th>Lead Value</th>
<th>Zinc Lb.</th>
<th>Zinc Value</th>
<th>Copper Lb.</th>
<th>Copper Value</th>
<th>Silver Oz.</th>
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<td>15,798</td>
<td>2,433,782</td>
<td>166,847</td>
<td>1,214,797</td>
<td>$90,248</td>
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<td>6,179</td>
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<td>266,794</td>
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<td>1929-31</td>
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<td>112,134</td>
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<tr>
<td>1937-41</td>
<td>5,689</td>
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<td>229,289</td>
<td>$174,807</td>
<td>777</td>
<td>$25,313</td>
<td>$2,465,208</td>
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</table>

12 Figures compiled by John W. Anthony
indicated the vein to be from 2 to 4 feet wide and of good lead-zinc content.

Evidently to prospect the downward continuation of this vein, an adit was run at 150 feet lower elevation, southwesterly for 650 feet. It passed through Cretaceous sandstone for 475 feet to reach the Upper Tunnel fault zone, beyond which only Pennsylvanian limestone was encountered.

The lower adit shows several northwestward-trending reverse faults of steep northeastward dip. One of them termed the Winze fault, at a distance of 410 feet from the portal intersects a fault which strikes westerly, dips 40° N., and brings Pennsylvanian beds over Cretaceous. This low-angle fault zone, now known as the East vein, proved to contain the most important ore shoot found in the mine. It might have escaped discovery if the adit had been a few feet farther southeast.

The East Vein ore shoot was mined to a limited extent by Grand Central Mining Company and more completely by Athletic Mining Company. It ranged from a few feet to more than 15 feet thick and from 35 to 100 feet wide throughout a length of more than 200 feet down the dip between the Upper Tunnel fault and the Winze fault. During recent years step-faulted segments of this ore zone were discovered by diamond drilling north of the Winze fault.

A considerable tonnage has been mined from the Upper Stope and West ore bodies, immediately south of the Upper Tunnel fault. They consist of veins, thin stringers, and irregular spotty replacements, associated with bedding slips and fractures in Pennsylvanian limestone.

Most of the ore shoots occur within broad, low anticlines that plunge down the dip.

The Iron Cap ores consist essentially of sphalerite and galena, together with a little pyrite and chalcopyrite. Small amounts of chalcocite and covellite are present locally, but in general the ores are not oxidized to any important extent.

**Head Center Mine**

The Head Center mine is in Williamson Canyon, about 2½ miles by road northeast of Aravaipa and ½ mile in air line west of the Iron Cap mine.

Prior to 1942, development of the Head Center mine consisted of the present adit, a winze 45 feet deep on the vein, and shallow surface workings. Small tonnages of ore were shipped in 1939 and earlier. Since 1942 development and production of lead ore have been continued by Athletic Mining Company. In 1943 the U.S. Bureau of Mines sampled the mine workings and explored the vein by means of limited diamond drilling.

In the northwestern part of the Head Center claim, rhyolite porphyry has intruded Carboniferous limestone with irregular
to sill-like contacts which have been complicated by faulting.

Here the Head Center vein strikes eastward and dips 32°-45° N. It occurs within a brecciated fault zone 10 or more feet wide which from the Head Center portal is traceable for some 500 feet southeast and for an unknown distance westward. Its irregular trend on the surface is partly due to topography and partly to variations of the fault zone.

The mine workings are almost entirely within the vein zone. As of April, 1949, they included an adit extending east for about 210 feet and an inclined shaft 400 feet deep with workings on five levels below the adit. Drifting has extended for a maximum of 250 feet east, and 125 feet west, of the shaft. Stoping on both sides of the shaft indicated that the ore shoot then worked had an east-west dimension of approximately 350 feet.

As exposed in the mine, the vein zone is all in rhyolite porphyry except for the eastern part of the adit, where faulted limestone and rhyolite porphyry form the wall rocks.

The vein ranges in thickness up to about 10 feet in the rhyolite and 14 feet in the limestone. The segment of the vein containing the ore shoot forms a low northward-plunging arch, within which both the strike and dip show local variations of several degrees. Displacement of the vein by cross faults has not exceeded a few feet in the area explored.

Some residual sulfides occur near the surface, but in general oxidation has been thorough to a depth of about 30 feet below the adit and continues downward throughout all the workings; in general, from 70 to 80 per cent of all the lead and zinc minerals occur in nonsulfide form.14 Sufficient water was encountered below the fourth level to require intermittent pumping.

Galena and sphalerite, together with minor pyrite and a little chalcopyrite, are the sulfide minerals. Some of the sphalerite is pale lemon yellow to colorless. Most of the ore has been sufficiently low in zinc to be shipped for lead smelting.

No. 1 Mine Area

An area of lead-zinc mineralization on No. 1 and No. 2 claims, in Arizona Gulch immediately west of Aravaipa, was developed from several adits and shafts during the early days.

In this part of the district, Paleozoic limestone, shale, and quartzite have been intruded by sills and dikes of andesite porphyry. Faults and fissures of northwesterly and northeasterly trend have broken these rocks.

The principal mineralization is within a belt a few hundred feet wide on both sides of a fault that strikes N. 65 E., along the course of Arizona Gulch. Within the limestone of this belt are abundant surface croppings of silicates and manganese oxide, locally with irregular masses of galena, sphalerite, pyrite, and oxidized lead and zinc minerals.

14Written communication from Raymond F. Orr, President, Athletic Mining Company.
Most of the mine workings are inaccessible. The No. 1 mine, as indicated by maps made by the old Aravaipa Mining Corporation, had an inclined shaft with a few hundred feet of drifts on the 60, 126, and 226 levels. As stated on a previous page, this mine was a notable producer of lead carbonate ore in 1916.

**Arizona Mine**

The Arizona mine is about a mile north of Aravaipa, on the west slope of a low southward-trending ridge.

Here the prevailing rock is andesite porphyry, intruded by a dike of rhyolite porphyry that strikes S. 20° E., and dips 65°-75° W. This dike, which may be traced on the surface for 3,000 feet, attains a width of about 60 feet at the Arizona shaft. It has been sheared parallel to the dip and along its walls. Its central portion contains the Arizona vein.

The Arizona workings include an adit run east for 600 feet, crossing the vein at 200 feet and connecting with a drift that extends 275 feet south and 400 feet north on the vein; the north drift connects with the 83 level of the Arizona vertical shaft. This shaft is reported to be 580 feet deep and flooded below a depth of 516 feet. Maps made by the old Aravaipa Mining Corporation show several short drifts and stopes extending from the shaft below the 83 level. According to these maps, limestone prevailed below a depth of 500 feet, and on the 569 level an irregular drift about 250 feet long was in limestone containing lead-zinc sulfide ore. On the basis of these old map data, Athletic Mining Company during 1942-43 retimbered the Arizona shaft to the 516 level and from there did several hundred feet of diamond drilling. As shown by this work, gray to pinkish limestone with local silicates and oxidized iron minerals extends for at least 100 feet below the 516 level.

As exposed in the adit level workings, the Arizona vein consists largely of banded to granular quartz from a few inches to about 6 feet wide, locally stained with iron and manganese oxides. In places, especially near the Arizona shaft, small bodies of oxidized lead and zinc minerals with some residual galena are exposed.

**Grand Reef Area**

*Situation:* The principal lead mines in the Grand Reef area are on the Grand Reef, Aravaipa, Dog Water, and Silver Cable claims, which are owned by American Zinc, Lead, and Smelting Company, of St. Louis, Mo.

The Grand Reef mine is in Laurel Canyon, about 4 miles by road northeast of Klondyke. The Aravaipa shaft is 1½ miles farther north. The Dog Water and Silver Cable, about ¾ mile south of the Grand Reef mine, were formerly accessible by a branch road from Laurel Canyon. In late 1948 the roads to all these mines were blocked by talus.
Workings: The Grand Reef mine has a total of more than 4,000 feet of workings. Its haulage level is an adit about 1,400 feet long, run northward beneath the main stopes. A winze extending 300 feet below the adit, under the stope area, has three levels of drifts at 100-foot intervals.

The Aravaipa shaft was less than 100 feet deep. From it were about 500 feet of drifts connecting with the Ten Strike mine and an undetermined amount of stoping.

The Dog Water workings included an adit about 140 feet long, with a small stope to the surface and a short winze.

The Silver Cable mine was opened by an adit a few hundred feet long, with stopes above.

Production: According to Ross these mines during 1915-20 produced 1,506 tons of shipping ore and 2,862 tons of concentrates. Of the shipping ore 1,389 tons came from the Grand Reef and 117 tons from the Grand Reef, Aravaipa, and Dog Water. Of the concentrates 2,613 tons were from Grand Reef, 160 tons from Dog Water, and 89 tons from Aravaipa mine ores. Ross gives the following average assays for the 1,389 tons shipped from Grand Reef:

<table>
<thead>
<tr>
<th>Material</th>
<th>Assay</th>
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<tbody>
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<td>Gold</td>
<td>0.01 oz. per ton</td>
</tr>
<tr>
<td>Silver</td>
<td>20.0 oz. per ton</td>
</tr>
<tr>
<td>Lead</td>
<td>40.9 per cent</td>
</tr>
<tr>
<td>Zinc</td>
<td>1.4 per cent</td>
</tr>
<tr>
<td>Copper</td>
<td>2.83 per cent</td>
</tr>
<tr>
<td>Iron</td>
<td>2.4 per cent</td>
</tr>
<tr>
<td>Lime</td>
<td>3.1 per cent</td>
</tr>
<tr>
<td>Sulfur</td>
<td>6.0 per cent</td>
</tr>
<tr>
<td>Insol.</td>
<td>32.3 per cent</td>
</tr>
</tbody>
</table>

The Dog Water ore is reported to have contained cerussite, galena, wulfenite, and a little argentite. Considerable fluor spar was present in the gangue.

The Silver Cable ore was probably somewhat similar to that of the Dog Water.

Except during the year 1916, the Grand Reef mine yielded most of the output of the district during 1915-20, 1929-31, and 1937-41. The Dog Water was mentioned as producing in 1938.

Grand Reef deposit: The Grand Reef lode occurs within iron-stained, silicified breccia cemented with quartz and other vein minerals. In Laurel Canyon the breccia forms a reef more than 100 feet wide and over 200 feet high. It strikes approximately N. 12° W. and dips from 70° W. to almost vertical. Southward it separates into smaller branches such as the Silver Cable and Dog Water lodes.

The reef occurs within rhyolite porphyry which a short distance farther east is intruded by granite of the main batholith. In places diabase appears between the granite and rhyolite. According
to D. R. Stewart, a narrow belt of schist is present along the western boarder of the granite.

In 1922 the water level in the winze was 130-140 feet below the adit.

The principal known ore shoot, as stoped on and above the adit level, was 120 feet long and from 15 to more than 30 feet wide. Ore was found below these stopes, to the bottom of the winze. Smaller ore shoots were opened 10 feet west of the main shoot; 600 feet farther north, both on the ridge and in the adit; and south of the winze on the 200 level.

The ore is mainly breccia cemented with fine-grained quartz containing specks of fluorite and flakes of chlorite. Quartz also occurs as irregular bands of light-gray chert, as drusy veinlets, and as white to pink vitreous masses. The most abundant sulphide is galena. It forms irregular fragments and bands and commonly includes tiny blebs of argentite. A little sphalerite and chalcopyrite are associated with the galena, but pyrite is scarce.

The ore is partly oxidized, and a mass of oxidized ore was reported to occur on the 300 level. Limonite, although not plentiful, stains the outcrop.

Structure and alteration at Grand Reef: Some additional features were noted by the writer during a brief visit to the Grand Reef in October, 1948.

The main Grand Reef stope exhibits numerous fractures striking N. 60° E. and dipping about 80° SE. A main break along its axis strikes slightly east of north and dips steeply east to vertically and steeply west downward to the adit level; associated with it is considerable iron stain as well as white clay alteration. Along the west wall of the stope is a vertical break trending approximately north. The southeast apex of the stope is along a fissure that strikes northeast and dips 75° SE.; it is marked by considerable iron oxide, local copper stain, and white clay alteration.

Where exposed, the rhyolite in the hanging wall shows alteration to white clay minerals, intense for more than 50 feet and notable for 1,000 feet west of the Grand Reef stopes. Strong alteration of similar character appears on the west side of the Dog Water lode.

The outcrop over the Grand Reef stopes is marked by a grayish-brown color, in contrast to the darker brown tint that prevails immediately north of the ore shoot.

Much of the reef south of Laurel Canyon is concealed by Tertiary gravels.

**Other Properties**

The following small lead mines and prospects have been described by Ross: The Silver Coin, 3 miles east of Klondyke; Ten

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19Oral communication.
20Work cited.
Strike and Aravaipa, north of Laurel Canyon; Bullis group and Windsor, on Imperial Hill; Bullis-Landsman group, in the vicinity of Tule Canyon; Tolman-Babcock group, east of the Arizona shaft and north of Aravaipa; Landsman group, east and south of Iron Cap Ridge; and Starlight, 4 miles north of Stanley.

A small production of lead ore from the Silver Coin, Landsman, Starlight, and Stanley Butte properties was reported in 1947.

During 1948, the Sinn Fein mine, southwest of the Head Center, produced several carloads of lead ore, and the Pointer workings, immediately west of the Head Center, yielded similar ore.

CHAPTER VI.—GEOLOGY OF THE ST. ANTHONY (MAMMOTH) AREA, PINAL COUNTY, ARIZONA

By S. C. Creasey

ABSTRACT

The St. Anthony deposit, located in Pinal County, Ariz., has produced intermittently since 1881. Until 1944 gold was the most valuable metal produced, though large amounts of vanadium and molybdenum were recovered. After 1944 galena and sphalerite became the chief ore minerals.

The rocks in the St. Anthony area are chiefly granitic and volcanic; they range in age from pre-Cambrian to Pleistocene. The deposit is of the vein type, controlled by pre-mineral faulting. The wall rocks are chiefly rhyolite and quartz monzonite. Both space filling and replacement have been involved in the emplacement of the deposit. The history of the vein can be divided into several stages during which sulfide and associated silicate minerals were introduced. The deposit was oxidized to a depth of about 900 feet and then faulted into two major segments by the Mammoth fault. Each segment was further broken by smaller faults. Molybdenum- and vanadium-bearing solutions were then introduced into the faults and into the oxidized parts of the veins. Presumably reaction with lead carbonate and possibly with lead sulfate produced wulfenite and vanadinite. The deposit has received further oxidation since the formation of these minerals.

INTRODUCTION

The St. Anthony mine at the town of Tiger is about 50 miles north-northeast of Tucson and 21 miles south of Winkelman. State Highway 77, which passes through Winkelman, runs within

1Published by permission of the Director, U.S. Geological Survey.
1 mile of Tiger and joins U. S. Highway 80-89 at Oracle Junction between Tucson and Florence. The mine is on the east slope of the Black Hills, a small range north of the Santa Catalina Mountains. The relief in the area does not exceed 1,000 feet; the drainage is to the northeast into the San Pedro River several miles away. Physiographically the area lies at about the boundary between the Mountain Region to the northeast and the Desert Region to the southwest, as defined by Ransome.\textsuperscript{3}

The published reports on the deposit include several short articles, pertaining in large part to some specific feature, and one comprehensive report by Peterson.\textsuperscript{4} When Peterson examined the mine, the Collins 700 level was the only working below the zone of oxidation, consequently his report deals with the oxide ores of the Collins and Mammoth veins (Fig. 20). The present report treats mainly the occurrence of the sulfide ores in the Collins vein.

The San Manuel disseminated copper deposit, described by Schwartz\textsuperscript{5} and by Steele and Rubley\textsuperscript{6}, lies in a belt trending N. 60° E. and about 5,000 feet south of the Mammoth shaft. Most of the exposed rock units are common to the San Manuel and St. Anthony areas, but a monzonite porphyry which occurs in the San Manuel area does not extend as far north as the St. Anthony mine and the volcanic rocks which occur in the St. Anthony area are not represented in the San Manuel area.

The writer worked in the St. Anthony area from April to August 1945, devoting all of this time to underground mapping except for a short period spent in a general reconnaissance of the surface geology. For information on rocks not exposed in the mine and for the surface distribution of the rock units the reader is referred to Peterson's report mentioned above, of which a part is reproduced in generalized form as Figure 18.

The writer is indebted to John Richards, General Manager of the St. Anthony mine, for his many courtesies and for granting access to the mine and company records. Mr. Richards also supplied part of the production record given in Table 5. To B. S. Butler and N. P. Peterson, who visited the project and made many helpful suggestions, the writer is grateful. C. A. Anderson and Edwin T. McKnight of the U. S. Geological Survey kindly reviewed the manuscript and offered many helpful comments.


SUMMARY OF HISTORY AND PRODUCTION

The St. Anthony mine, operated by the St. Anthony Mining and Development Co., Ltd., has had a long and varied history of development and production. The camp actually was developed as three different mines—the Mammoth, Collins, and
Mohawk-New Years—which have been consolidated since 1934 by the present operating company.

The first claims were located in 1879 and mining continued intermittently by several companies, mostly on the Mammoth vein, until 1901 when the workings on their vein caved from the 750 level to the surface. This early mining was done entirely for gold; production from the Mammoth and Collins mines through 1901 was over 150,000 ounces of gold valued at more than $3,000,000.

The camp was largely inactive from 1901 until 1915 when the wartime demand for molybdenum and vanadium resulted in reopening the mines for a short period. In 1919 prices fell, and the mines closed again.

Increase in the price of gold in 1933 caused renewed activity, and production of gold-vanadium-molybdenum ores began in 1934 from the oxidized part of the veins. Mining of this ore continued into 1943 when, stimulated by high prices and the need for base metals, the management developed sulfide ore bodies below the 650 level on the Collins vein. All lead and zinc production subsequent to 1944 has been from the sulfide vein where galena and sphalerite are the chief ore minerals.

The production of the Mammoth Mining Camp from 1881 through 1947 is given in Table 5.

ROCKS

The rocks in the St. Anthony area range in age from pre-Cambrian to Quaternary. As the only sedimentary unit whose age is known is the Gila conglomerate of Pliocene and Pleistocene (?) age, the age of the igneous rocks intervening between this conglomerate and the pre-Cambrian rocks is indeterminate and can be suggested only by correlation with adjacent districts.

Oracle Granite

The oldest rock is the pre-Cambrian Oracle granite which underlies wide areas in the region. It forms much of the northern slope of the Santa Catalina Mountains where, locally at least, it is overlain by the pre-Cambrian Apache group with depositional contact. To the north, in Camp Grant Wash 11 miles south of Winkelman, similar granitic rocks are overlain by the Apache group, as described by Darton.7

The Oracle granite at the St. Anthony and San Manuel deposits is a porphyritic quartz monzonite composed of phenocrysts of potash feldspar in a granitic groundmass of plagioclase, quartz, and biotite. In the St. Anthony mine where the quartz monzonite forms the walls of the Collins vein, the feldspar is partially to completely altered to a soft, unctuous, claylike material and to sericite. Associated with, but intruding the quartz monzonite, are dikes of aplite.

### TABLE 5.—PRODUCTION OF THE MAMMOTH MINING CAMP

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<thead>
<tr>
<th>Year</th>
<th>Location</th>
<th>Ore mined tons</th>
<th>Gold ounces</th>
<th>Silver ounces</th>
<th>Copper pounds</th>
<th>Lead pounds</th>
<th>Zinc pounds</th>
<th>MoO₃ pounds</th>
<th>V₂O₅ pounds</th>
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</thead>
<tbody>
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<td>1881 to 1901</td>
<td>Mammoth-Collins</td>
<td>350,000</td>
<td>150,000</td>
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<td>1896 to 1912</td>
<td>Mohawk-New Year</td>
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<td></td>
<td></td>
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<td>1912 to 1916</td>
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</tr>
<tr>
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<td>1934</td>
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<td>49,869</td>
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<td>1936</td>
<td>Mohawk-New Year</td>
<td>34,036</td>
<td>3,522</td>
<td>7,673</td>
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<td>137,889</td>
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<td>1937</td>
<td>Mammoth</td>
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<td>10,477</td>
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<td>1938</td>
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<td>1,275</td>
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<td>397,201</td>
<td>983,918</td>
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<td>74,730,269</td>
<td>48,272,654</td>
<td>6,314,822</td>
<td>2,540,842</td>
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</tbody>
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*Approximate.
(Production from 1881-1936 after N. P. Peterson, Arizona Bureau of Mines Bull. No. 144; production from 1937-1947 supplied by the St. Anthony Mining and Development Company, Ltd.)
Volcanic Rocks

Volcanic rocks crop out a short distance north, northwest, and, in isolated patches, east of the St. Anthony deposit. They are not known in the mine openings, but it is reasonable to assume that they once covered the area of the mine. Peterson recognized flows, flow-breccias, agglomerates, possibly tuffs, and some intercalated conglomerates and arkoses. These volcanics are largely basaltic and andesitic in composition, but some latitic material occurs. They have been faulted and tilted, striking N. 30°-45° W., and dipping from 45° to 65° NE.

Whether related intrusive rocks occur with the volcanic rocks in the vicinity of the St. Anthony mine is not known, but Schwartz described a diabase dike that cuts the monzonite porphyry at the San Manuel deposit. If this dike is genetically related to volcanic rocks, then the volcanics are younger than the monzonite porphyry. The diabase dike in turn is cut by intrusive rhyolite as are the volcanic rocks at the St. Anthony deposit.

The age of the volcanic rocks is not certain, but by analogy from adjacent districts, it is probably late Cretaceous or Tertiary. These rocks are overlain unconformably by the Gila conglomerate of Pliocene and Pleistocene (?) age.

Intrusive Rhyolite

Intrusive rhyolite occurs abundantly in the St. Anthony area where it is found in the underground openings of both the Mammoth and Collins veins as well as in extensive, irregular dikes and masses cropping on the surface. In general, it crops out most abundantly in a zone parallel to the Mammoth fault and east of the main mass of quartz monzonite, but it is not limited to this occurrence. As will be discussed in a later section, the distribution of the rhyolite in part may be controlled by pre-existing fractures.

The rhyolite is a light-colored, locally flow-banded rock and has in places a well-defined breccia structure. A nonporphyritic facies consists of microcrystalline quartz and feldspar. A porphyritic part has a groundmass texture and composition similar to the non-porphyritic but in addition contains phenocrysts of sanidine and quartz. Zones of breccia composed of angular fragments of rhyolite matrix occur locally along the margins of the larger rhyolite masses, indicating that earlier solidified rock was brecciated and engulfed by a later surge of the intruding mass.

In the St. Anthony area the intrusive rhyolite cuts the Oracle granite and the volcanic rocks, and in the San Manuel area the rhyolite (labeled “felsite dike” on Schwartz’s map) intrudes the monzonite porphyry and diabase dike.

*op. cit.*
*op. cit.*
A puzzling breccia occurs in close association with the rhyolite, though small patches are in contact with the Oracle granite and volcanic rocks, Figure 18. The largest mass lies around and north of the Mammoth shaft. Peterson reported the breccia on all the levels in the Mohawk mine, in the Tunnel level of the Collins mine, on the 300 and higher levels in the Mammoth mine, and in one stope on the Mammoth 700 level. The writer observed excellent exposures on the Collins side of the Mammoth fault in the 520 crosscut between the Mammoth and Collins veins.

The origin of the breccia is doubtful. Where observed by the writer, the breccia consists of fragments up to 1 foot in diameter of granite and rhyolite in an arkosic matrix of feldspar and quartz. In the 520 crosscut it has a loose jumbled appearance much like talus material; however this exposure is not far removed from the Mammoth fault. In several localities on the surface it shows a crude banding, reminiscent of bedding in some fanglomerates. Peterson believes this breccia to be intrusive, and describes it as follows, “The breccia differs considerably from place to place. The fragments generally do not exceed 1.2 inches in diameter. In some exposures fragments of rhyolite, basalt, granite, quartz, and several varieties of feldspar are present in an area of a few square inches. In other places the fragments are almost entirely of rhyolite, and in still others granitic material predominates.”

Truly a rock consisting of fragments of granite, basalt, and rhyolite with a matrix containing quartz and feldspar is not suggestive of an intrusive relationship but is more indicative of a sedimentary breccia. However, the erratic distribution and especially the occurrences in the Mammoth 700 level and the 520 crosscut cannot be explained by the structural history as known, if the rock is of sedimentary accumulation. Until additional detailed mapping is done in the district, the origin of the breccia will remain an unsolved problem.

Ore is not known within the breccia in either the Mammoth or Collins veins. Peterson reports that one wall of the vein in the Mohawk mine is formed by the breccia, but the vein is confined to the adjacent rhyolite. The reason for the refractoriness of the breccia as a host for ore is not known, for the major constituents are rhyolite and granite, both of which commonly are the host for for the veins elsewhere.

The breccia is thought to be younger than the intrusive rhyolite because rhyolite fragments of appearance similar to the intrusive rock are one of its major constituents. Should, however, the fragments prove to be from another source, the breccia could be pre-rhyolite.

\textsuperscript{10}op. cit., p. 14.
Peterson has reported dikes and other small intrusive bodies of basalt as common along some of the younger faults in the area east of the Mammoth fault. Basalt is not known to occur in the mine, and it constitutes only a small part of the surface exposures.

Gila Conglomerate

Much of the area east of the Mammoth fault is covered by Gila conglomerate. One of the caved areas over the Mammoth vein exposes about 200 feet of the conglomerate, but in other areas nearby the formation appears to be much thinner.

The Gila conglomerate is an unconsolidated deposit of well-rounded boulders and cobbles of variable size with a claylike matrix. The cobbles in this area consist largely of volcanic rocks. The conglomerate is deformed and cut by many of the younger faults, including the Mammoth fault. Dips in the conglomerate as high as 60° have been recorded by Schwartz in the San Manuel area.

Fossil collections from the Gila conglomerate in the San Pedro Valley, not far removed from the St. Anthony area, led Gidley to believe that the formation is of late Pliocene age. Other geologists have expressed the opinion that the Gila may also include deposits of Pleistocene age.

Structure

The regional structure in the district which includes the St. Anthony and San Manuel deposits is complex, and sufficient work has not been done to integrate the known structural trends. The most pronounced and probably the youngest trend is north-northwest, parallel to the Basin and Range structure in southeastern Arizona. The grosser features, such as the San Pedro Valley, the Galiuro and Santa Catalina Mountains, and the Black Hills in which the St. Anthony deposit occurs, all exhibit a north-northwest trend. Within the St. Anthony area this direction is shown by the Mammoth and Collins veins and by the Mammoth and related faults. In the San Manuel area the important San Manuel fault strikes west northwest and is clearly older than the Mammoth fault but younger than the Gila conglomerate. The San Manuel might be of essentially the same age as the Mammoth and Collins vein which are older than the Mammoth fault.

The N. 60° E. strike of the San Manuel ore deposit represents a structural trend older than either the San Manuel or Mammoth faults, and probably older than the Collins and Mammoth veins. Both Schwartz and Steele and Rubley report that the rhyolite (felsite in their papers) cuts the mineralized diabase and mineralized monzonite porphyry but it is itself unmineralized. This point

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12op. cit.
13op. cit., p. 2.
is of major importance, as the rhyolite commonly is the host for the veins in the St. Anthony deposit, indicating that these veins were formed later than the San Manuel deposit.

**Structural Features in the St. Anthony Deposit**

The structural history that is directly related to the Collins and Mammoth veins and that can be deduced from a study of the underground openings starts with the intrusion of the rhyolite. However, an earlier period of northwest faulting is suggested by the position and shape of the rhyolite masses in the St. Anthony area, (Fig. 18). The general coincidence of an intrusive dikelike body and a fault-vein known to have undergone later active movement over a considerable length of time, such as the Collins vein and associated rhyolite mass, is suggestive, at least, of an earlier period of fissuring that controlled the location of the rhyolite mass.

Intrusion of the rhyolite was followed by two periods of faulting. The first period accounts for such faults as the one on which the Mammoth and Collins veins were developed, and the second displaced the veins. Faults are the only structural features that can be related directly to the spatial position of the present ore shoots and to the control of the original mineralizing solutions. If any other structural controls for the ore existed, the evidence by which they might be recognized has been obliterated by post-sulfide faulting.

The faults of the first period followed the same general trend as the rhyolite mass. In general the fault which became the site for the Mammoth and Collins veins strikes toward the northwest and dips toward the southwest. In Figure 18 the Collins east vein has an east dip, but the dip underground is generally westward. The anomolous dip on the surface may be the result of post-vein faulting, as suggested by old mine maps, or perhaps is the result of a local reversal in dip direction. The fault that became the site for the Mammoth and Collins veins commonly followed the contact of the granite and the rhyolite, but in many places broke away from the contact into either the granite or the rhyolite, (Fig. 20). The deposition of the vein minerals commenced while the faulting was still active and probably con­tinued after the movement stopped until the channels were choked. At least two periods of more pronounced movement, or of renewed movement following a passive stage during the mineralization, are evidenced by repeated brecciation, replacement, and veining of earlier by later minerals. The minerals characteristic of the different periods of mineralization were not everywhere superimposed, revealing that the recurrent movements on the faults did not always follow the preceding zones of fissuring. The new zone, however, was parallel and at no great distance from the old. In this manner a fault zone was formed ranging in width from 3 feet to more than 20 feet in some cases where both walls were granite.
The direction of movement along the Collins vein can be determined, in part, from the attitude of the mineralized tension fractures branching from the vein. These tension fractures consistently strike more northerly than the vein, indicating a horizontal component in which the hanging wall moved north. Unfortunately they do not consistently indicate the direction of the vertical component; however, the majority have the acute angle between vein and tension fracture pointing down on the hanging wall of the vein, suggesting that the hanging wall moved down.

The second period of faulting offset the original vein into segments on two sets of faults of opposite dip (Fig. 19). The dominant set—exemplified by the Mammoth fault—consists of normal faults striking N. 25° W. and dipping 60°-80° NE. This set probably represents the dominant break of a pair of conjugate shears. The second set has a variable strike, ranging from N. 20° W. to N. 50° W., and dips steeply southwestward, an attitude similar in many places to that of the Collins vein.

The Mammoth fault is the largest known fault in the area; it has a normal dip-slip component of about 700 feet as shown by the faulting of the original vein into two segments—the Mammoth and Collins veins (Fig. 20). Both veins have the same general attitude, and any differences between are no more than would be expected from rotation during a displacement of 700 feet and from local modifications on other faults. Except for small offsetting by the faults of small displacement, both veins maintain their continuity until they reach the fault zone. The breccia zone of the Mammoth fault varies in width from about 40 feet to over 100 feet, being widest where it is joined by other faults. The displacement, however, appears to have taken place along a more restricted zone; the adjacent breccia is probably the result of stresses from the friction during movement. Similar but smaller normal faults are exposed in the workings of the Collins vein; of the two largest, one is at the northwest end of the Collins 800 and 900 levels and the other is near the center of the Collins 900 level (Fig. 19). They are similar in attitude and direction of relative movement to the Mammoth fault but have much smaller net displacements and narrower breccias.

Evidence obtained from underground observations — chiefly grooving on fault surfaces — and from the direction of movement necessary to move the Mammoth vein back to its original position over the Collins vein indicates that the movement on the normal faults was of the oblique-slip type. The dip-slip component was several times greater than the strike slip, with the hanging wall slide moving down and to the northwest.

The southwest-dipping faults commonly strike a few degrees more northerly and dip a few degrees less steeply than the veins. Commonly they produce a thinning or a gap in the veins in both plan and sectional views. The slicken-sides on these faults rake from about 45° to 75° northwestward, which in general is

\[\text{For footnotes, see next page.}\]
a little less steeply than those on the Mammoth-type faults, but in the same direction. Because of the near-parallelism of the faults and veins, a relative change of a few degrees in their strike and dip makes an appreciable difference in the plunge of their intersection and in the direction of offset of the vein. Within the range of the angle of rake of slicken-sides observed (given by A-A' and B-B', Fig. 21), two types of movement are possible, either of which would produce the observed offsets in the vein. Movement in the direction A-A' would move the hanging wall down with respect to the footwall, although the apparent displacement would be that of a reverse fault; movement in the direction B-B' would produce a true reverse fault in which the hanging wall moved up with respect to the footwall. Within the limits of observation either type of movement is possible. The A-A' direction, however, is precisely that necessary for these faults to be the set complementary to the Mammoth-type faults; hence, it is far more reasonable to believe that the hanging wall is the down-thrown side and that the faults are contemporaneous with the Mammoth-type and related to the same forces. To postulate movement along B-B' would necessitate an additional period of faulting younger than the veins but older than the Mammoth-type faults.

The width of the breccia zones along the southwest-dipping faults is variable, ranging from 20 feet to a single shear plane no more than an inch wide. In general, the width of the breccia zone is proportionate to the magnitude of the displacement. Where the displacement along the faults was small and the faults closely spaced, the faulting so effectively thinned and diluted the ore with wall rock that in places it could not be mined profitably. The displacement on the faults dies out abruptly both horizontally and vertically, and ore on one level may be sheared out on the next level. As would be expected, the amount of movement along individual faults is extremely variable, ranging from an imperceptible amount to about 100 feet. This "stretching" of the Collins vein explains, in part at least, the discontinuities along the strike and dip and the variation in the attitude of different ore shoots. The strike and dip of the vein in the individual ore shoots is reasonably constant; the difference in attitude between the ore shoots resulted from the movement on the faults separating them (Fig. 19).

The elapsed time between the first and second period of faulting is not known. The Mammoth vein, however, probably was oxidized before displacement on the Mammoth fault. The Collins vein is oxidized down to an irregular surface that locally reaches the Collins 700 level, (Fig. 23). When Peterson examined the St. Anthony deposit in 1937, the water level ranged from 33 to 46

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15The discussion that follows does not apply to the southwest-dipping fault at the north end of the 900 level which has produced an overlapping of the vein. This particular fault is believed to be a fault of the Mammoth type but having a complementary dip.

16Rake, as used in this paper, is measured in the plane of the fault.
Figure 21.—Diagrammatic projection of the Collins vein in the plane of a fault belonging to the set that dips southwest: I, foot-wall segment of the vein; II, hanging-wall segment of the vein; A–A', rake of line of slip less than rake of intersection of vein and fault, hanging-wall downthrown side; B–B', rake of line of slip greater than rake of intersection of vein and fault, hanging-wall upthrown side.

Figure 22.—Cross section of vein and fault shown in Fig. 21.
Figure 23.—Longitudinal projection of Collins vein, St. Anthony mine (modified from map supplied by St. Anthony Mining and Development Co., Ltd.)
feet below the 700 level of the Collins and Mammoth mines. Thus it appears reasonable to assume that the depth of oxidation in the Collins vein represents the uninhibited depth of oxidation during the present erosion cycle. The Mammoth vein, however, is oxidized throughout its entire depth, the last 150-200 feet of which is below the depth of oxidation on the Collins vein, only a short distance away (Fig. 20). Because the Mammoth vein is oxidized below what appears to be the lower limit of oxidation, the oxidation on this vein may have occurred prior to down faulting. The Mammoth and related faults are younger than the Gila conglomerate which is cut by the faults.

ORE DEPOSIT

FORM AND STRUCTURE OF THE DEPOSIT

The veins, formed during the first period of faulting, are mineralized fault zones striking northwest and dipping steeply to the northeast and southwest; those that have been productive dip chiefly to the southwest. Vein minerals are widespread in the fault zone, hence the faults and veins are essentially coextensive. The outcrop of the Mammoth vein is covered largely by the surface installations of the mine; the outcrop of the Collins East vein, which is the surface extension of the Collins vein as known underground, or a branch from it, can be traced on the surface to the point where it passes into the volcanic rocks, where its surface continuity is either lost or interrupted by faulting (Fig. 18).

Post-sulfide faulting has displaced the Collins vein to such an extent that the exact original attitude is not known. The attitude of the vein below the 500 level in the individual ore shoots bounded by faults is relatively consistent in both strike and dip, but varies greatly from one ore shoot to the next. The inference is that the original vein was much more regular than its present configuration. However, the attitude of the original Collins vein may not be represented by any of the present segments, all of which may have been shifted or rotated.

The Collins vein is of the composite type, having been formed during the period of active movement on the fault. The width of the fissure zone is variable and is commonly widest where one or both walls are quartz monzonite (Fig. 19).

VEIN FILLING

The veins resulted from a combination of open-space deposition and replacement; all graduations exist between the two types. More intense replacement produced the high-grade ore shoots in which commonly no vestige of wall rock remains over widths of from 3 to 7 feet. In other places the vein is a breccia composed of angular rock fragments separated by irregular masses of sulfide and gangue minerals.

The character of the breccia-type ore differs, depending on whether the vein was formed in rhyolite or quartz monzonite. In rhyolite the size of the rock fragments is small, ranging from mic-
roscopie to a maximum of about 6 inches. The fragments are invariably angular, and the angularity was maintained during all stages of replacement; even in large masses of replacement sulfide, the small remnants of rhyolite are angular. In quartz monzonite the size of the fragments is much larger, ranging from a quarter of an inch to several feet in diameter, and the fragments vary in shape from subrounded to angular. The volume ratio of sulfides to rock gangue appears to be less for the average quartz monzonite breccia-ore, but this is compensated, to some extent, by greater mining widths.

The deposition of the vein minerals occurred in six stages controlled in part by recurrent movement on the faults which re-opened the solution channels. Each stage was characterized by a distinct mineral assemblage differing in the main from the preceding and following stages, although certain minerals, such as quartz, continued to be deposited through more than one stage. It is possible that different stages do not indicate any change in the character of the mineralizing solutions, but that the recurrent opening of the vein changed the physico-chemical equilibrium, thereby shifting the site of deposition of the various mineral assemblages. Under such conditions deposition of vein minerals was more or less continuous throughout the stages into which the history of the vein can be divided. Table 6 shows the general age relations of the vein minerals, based on underground mapping and study of polished sections, thin sections, and polished hand specimens.

For the first six months of 1945 the sulfide ore from the Collins vein averaged 7.2 per cent Pb and 8.9 per cent Zn. However, the percentage of mill recovery of zinc and to a lesser extent of lead is erratic, owing to the presence of secondary minerals formed in and near the post-sulfide faults that have allowed oxidation to extend locally into the sulfide zone. In general, the recovery of the lead and zinc sulfides is good when the ores are not contaminated by oxide material. In addition to galena and sphalerite, the ore contains appreciable amounts of chalcopyrite and silver; the exact amounts of these are not known, but the copper is estimated to average between 0.5 and 1.0 per cent.

Craven\textsuperscript{16} gives the following as a typical analysis of the ore: Pb, 7.16 per cent; Zn, 8.87 per cent; nonsulfide Zn, 1.27 per cent; Au, 0.011 ounce; Ag, 1.53 ounces; Cu, 0.74 per cent; Fe, 7.5 per cent; SiO\textsubscript{2}, 47.5 per cent; S, 22.10 per cent; Ca, 2.75 per cent; and Mg, 0.60 per cent.

\textbf{First Stage of Mineralization}

The first stage of mineralization is visible only in the breccia fragments in the vein. It consists of small megascopic to microscopic veinlets of quartz containing a few crystals of adularia. The veinlets do not cut the vein material around the fragments, but where they terminate against the later minerals they have been

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cut and replaced. Apparently, the fissuring that accompanied this early stage of mineralization was very weak—more crackling than brecciation or fissuring, as shown by the lack of offsetting where the veinlets intersect. No sulfide minerals were deposited during this stage.

**TABLE 6.—AGE RELATIONS OF THE VEIN MINERALS, MAMMOTH ST. ANTHONY MINE**

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<th>Second stage</th>
<th>Third stage</th>
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**SECOND STAGE OF MINERALIZATION**

Quartz and specularite are the only minerals recognized in the second stage. They may actually be an early phase of the third stage, but appear to be replaced and veined by sulfide minerals. Although they are apparently contemporaneous, some specularite is included in quartz grains, and some is deposited around the quartz, presumably being later than quartz with which it is in contact. The ratio of quartz to specularite is high, although the specularite is evenly dispersed in very small crystals throughout the quartz, giving it a dark color.

The volume of material deposited during this stage may have been large, but these minerals were veined and replaced largely by third-stage minerals which include the sulfides. In those zones in the vein where sulfide minerals are not abundant, the quartz-specularite material is the predominant vein filling. Brecciation accompanying this stage was extensive, for a large amount of material was introduced and widely distributed. Replacement as well as open-space deposition must have been important.

**THIRD STAGE OF MINERALIZATION**

All or nearly all the sulfide minerals were deposited in the third stage of mineralization. Undoubtedly major fracturing accom-
panied or preceded this stage, although it did not in every place coincide in location and intensity with that of the previous stage. The earliest minerals deposited during this stage were quartz and chlorite which were in part replaced and veined by the sulfide minerals. Quartz probably was deposited throughout the period, as it has mutual contact relations with all other minerals of this stage. Amethystine quartz occurs as comb crystals filling the last vestiges of open spaces formed by fracturing during the third stage; it must have formed late in the stage.

The mutual age relations of the sulfides are not everywhere clear, and for the most part there may have been simultaneous deposition. Certain age relations, however, were noted, though there is no assurance that these relations hold for the bulk of the sulfides in question. Some chalcopyrite and pyrite appear to be essentially contemporaneous. The bulk of the sphalerite apparently was later than pyrite; it was accompanied by a second stage of chalcopyrite which appears to have been formed in part by exsolution from the sphalerite. In all places where the relations were clear, galena was later than sphalerite, and a second stage of pyrite was deposited later than galena. Rims of supergene covellite are common on chalcopyrite and occur uncommonly on sphalerite.

Fluorite is common in vein material of this stage, mostly in microscopic crystals. Some of it is younger than the sulfide. Barite was deposited late in the third stage and was limited largely to small fractures not completely filled and to the fringes of the large masses of sulfide. On the Collins 900 level the following sequence of minerals was deposited in an open fracture with deposition proceeding from both walls toward the center of the fracture: pyrite, galena, pyrite, fluorite, and barite.

**Fourth Stage of Mineralization**

Following the end of the third stage the original vein was oxidized during a period of structural stability which was interrupted by faulting of the vein into the two segments that form the Mammoth and Collins veins. After the faulting oxidation continued on the Collins vein and the faults to about the present extent before the fifth stage of mineralization intervened. The minerals formed during the fourth stage were the supergene minerals typical of the oxidation of lead-zinc-copper deposits. The most common and abundant of these minerals are malachite, azurite, chrysocolla, cerussite, anglesite, smithsonite, and probably hemimorphite. Rarer supergene minerals of copper, lead, and zinc were formed in limited amounts; among those known to be present and those reported from reliable sources are willemite, dioptase, brochantite, linarite, and diaboleite.

**Fifth Stage of Mineralization**

Wulfenite, in places accompanied by quartz, was the earliest mineral in the fifth stage. It was followed by the vanadium min-
erals of which mottramite and descloizite were deposited before vanadinite. The distribution of the wulfenite and the vanadium minerals is not coextensive, and the deposition of wulfenite may have ceased before the vanadium minerals were introduced. Wherever wulfenite and vanadinite are in contact, which is not commonly, wulfenite is corroded or partly leached and the vanadinite is deposited on the corroded crystals. Although both wulfenite and vanadinite were abundant in the oxidized parts of the Mammoth and Collins veins, the zones high in content of one mineral were commonly low in content of the other. Wulfenite is abundant in post-sulfide faults on the lower levels of the Collins vein, but vanadinite was not identified below the 700 level. Both minerals occur abundantly for several feet in the hanging wall and footwall of the Mammoth and Collins veins in the oxidized zone; and in the Hanging Wall fault on the Mammoth 900 level well below where the toe of the vein intersects the fault. Commonly wulfenite is in post-sulfide faults several hundred feet from the Mammoth vein where there is no indication of other vein minerals except a small amount of quartz. Thus the distribution of these minerals is partly independent of the Mammoth and Collins veins and of each other.

Both wulfenite and vanadinite occur extensively in crystal form coating open fractures and breccia fragments. Wulfenite crystals were observed in the porous, iron-stained, gossan cavities interpreted as resulting from the oxidation of sulfide minerals, and were perched on smithsonite, willemite, and, in one locality, on cerussite. But wulfenite crystals also were imbedded in a malachitelike material and had quartz and malachite crystals deposited on them. Thus oxidation appears to have preceded and to have followed the deposition of wulfenite.

Sixth Stage of Mineralization

Further oxidation and the deposition of supergene minerals of copper, lead, and zinc, such as were formed during the fourth stage, constitutes the sixth stage. The deposition of malachite on wulfenite is evidence of oxidation subsequent to the fifth stage.

Origin of the Wulfenite and of the Vanadium Minerals

Were the wulfenite and vanadium minerals introduced from some outside source by supergene solutions, or released by oxidation from the primary sulfides, or were they derived from hypogene solutions? A sedimentary source has been suggested for the origin of the vanadium deposits in the Otavi Mountains, Southwest Africa,17 and at Broken Hill, Northern Rhodesia.18 In both places the vanadium reportedly came from surrounding and overlying vanadiferous sediments. In neither case is wulfenite

associated with the vanadium minerals. The wulfenite and the vanadium minerals in the St. Anthony deposit formed after the Mammoth fault, and this fault cuts the Gila conglomerate. The indicated late Tertiary or Recent age of the molybdenum and vanadium mineralization vitiates the possibility of assigning the source to some sedimentary unit subsequently removed by erosion. The units exposed in the vicinity of the deposit must have been all that were present during the deposition of the molybdenum and vanadium minerals, hence the only sedimentary unit present was the Gila conglomerate, not a very likely prospect for the source bed. It also appears unlikely that supergene solutions flowing under gravity could transfer the vast quantity of vanadium and molybdenum from some distant source through a random set of fractures and concentrate it almost entirely in the Mammoth and Collins veins and to a lesser extent in the Mammoth fault system. Over 6,300,000 pounds of MoO$_3$ and 2,500,000 pounds of V$_2$O$_5$ have been recovered (Table 5), and much remains in the ground.

The molybdenum and vanadium might be attributed to the sulfides, where they could occur in an isomorphous mixture with galena or sphalerite as suggested by Butler$^{19}$ for the origin of wulfenite associated with galena in southwestern Utah. However, analysis of the galena and sphalerite for vanadium and molybdenum by Peterson$^{20}$ and Vanderwilt$^{21}$ gave negative results. From different places in the Collins vein the writer collected specimens selected for purity and abundance of the sulfide minerals, chiefly pyrite, chalcopyrite, sphalerite, and galena. The specimens, crushed and hand sorted to further increase the purity of the minerals, were analyzed spectroscopically for molybdenum, vanadium, and tungsten. Six samples each of galena and sphalerite, and four each of pyrite, chalcopyrite, sphalerite, and galena. The specimens, crushed and hand sorted to further increase the purity of the minerals, were analyzed spectroscopically for molybdenum, vanadium, and tungsten. Six samples each of galena and sphalerite, and four each of pyrite, chalcopyrite, sphalerite, and galena. The specimens, crushed and hand sorted to further increase the purity of the minerals, were analyzed spectroscopically for molybdenum, vanadium, and tungsten.

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One sample of galena contained 0.2 per cent vanadium, but the other galena and all of the sphalerite samples were barren of vanadium. All the pyrite and chalcopyrite samples contained from 0.001 to 0.0001 per cent vanadium. Chlorite contained vanadium in amounts ranging from 0.01 to 0.07 per cent, and the quartz-specularite contained from 0.008 to 0.04 per cent. With the exception of the one sample of galena, none of the samples carried sufficient vanadium to account for the amount present in the deposit. The absence of any molybdenum, which is undoubtedly related genetically to the same source as the vanadium, is strongly indicative that the vein minerals are not the source. All the information available from both laboratory.

$^{19}$ B. S. Butler, Geology and ore deposits of the San Francisco and adjacent districts, Utah: U.S. Geol. Survey Prof. Paper 80, p. 110, 1913.
$^{20}$ op. cit., p. 50.
analyses and field observations prohibits attributing to the sulfide minerals the source of the molybdenum and vanadium.

Peterson\textsuperscript{22} believed the source of the molybdenum and vanadium was hypogene solutions and wrote, "There is no other known source of vanadium and molybdenum for these deposits." His thesis merits careful consideration and is favored by the writer with certain reservations as to the details of the deposition. Peterson apparently did not believe supergene lead minerals were necessary for the deposition of wulfenite, whereas the writer holds they were essential. Dittler\textsuperscript{23} by laboratory studies found that wulfenite was fairly stable in alkaline solutions but was attacked by acids except carbonic acid. He was unable to synthesize wulfenite from lead sulfide and concluded that wulfenite was the result of ascending molybdenum-bearing solutions reacting on lead carbonate previously formed under oxidizing conditions. The conditions in the St. Anthony deposit at the time the wulfenite was deposited were like those stipulated by Dittler as favorable for the deposition of this mineral. The deposit had been oxidized and, undoubtedly, much cerussite had formed. The presence of wulfenite today in the oxidized zone is evidence of oxidation prior to its deposition, as wulfenite would not be stable under oxidizing conditions in a deposit containing pyrite, from which acid would form.

Wulfenite and the vanadium minerals as mentioned heretofore, are not coextensive. Wulfenite was observed in the sulfide zone of the Collins vein but vanadium minerals were not identified below the Collins 700 level. On the lower levels of the Mammoth vein, on the other hand, both wulfenite and vanadinite are present and the relative distribution can be observed. The reason for the lack of vanadium minerals on the lower Collins levels is not known. Conceivably it might be due to zoning induced by physical-chemical conditions, or possibly the earlier molybdenum-bearing solutions may have combined with all the available lead carbonate and sulfate, thereby forcing the vanadium-bearing solutions to higher level before encountering cerussite.

In the Collins vein, oxidation has extended to lower levels along faults, and wulfenite is common in these faults near the vein. The oxidized breccia zone of the east dipping fault in the central part of the Collins 900 level contains wulfenite over a width of about 30 feet (Fig. 19). It was sampled at a point between the offset ends of the Collins vein and found to contain 2.90 per cent Pb and 1.16 per cent Mo. As lead combines with molybdenum in about the ratio of 2 to 1, it would appear that most of the lead, which came from the vein by drag along the fault zone, had combined with the molybdenum to form wulfenite. If the molybdenum had not combined with practically all of the

\textsuperscript{22}op. cit., p. 50.

available lead, there should have been lead in excess of the amount necessary to form wulfenite. Where post-sulfide faults cut the vein in zones poor in sulfides, the wulfenite is scarce, owing presumably to the scarcity of supergene lead minerals. The oxidized fault zone at the south end of the 92 stope on the Collins 800 level contains only a few scattered crystals of wulfenite and only 0.20 per cent Pb by assay (Fig. 23). The evidence strongly indicates that lead carbonate or sulfate was necessary to form wulfenite, and the source for the molybdenum may have been ascending solutions.

The St. Anthony deposit is not the only occurrence of molybdenum minerals in the district. Prospects approximately on strike with the Collins vein but as much as several miles north are reported to contain molybdenum minerals, and some of the prospects near Oracle, 8 miles to the southwest, contain small amounts of wulfenite. Several breccia pipes on Copper Creek, located in the Galiuro Mountains about 12 miles east of the St. Anthony deposit, contain appreciable amounts of molybdenite. One of these, the Childes-Aldwinkle mine, produced over 6,000,000 pounds of molybdenite in conjunction with copper.24

In summary, the wulfenite and vanadium minerals were formed late in the history of the St. Anthony deposit. The original vein had already undergone several stages of mineralization ending in the deposition of large amounts of sphalerite and galena and lesser amounts of pyrite and chalcopyrite. Oxidation had reached a depth of not less than 900 feet after which the vein was faulted into two segments and further oxidized. Then molybdenum- and vanadium-bearing solutions were introduced along the vein segments and faults where they reacted with cerussite and possibly with anglesite derived from the oxidation of galena, forming wulfenite and possibly vanadinite. The source of the solutions is problematic, but so far as known, no reasonable sedimentary source existed at the time they were introduced, and the present sulfide vein does not carry sufficient amount of molybdenum and vanadium to account for the concentration. The solutions may have been of hypogene origin. After the deposition of the wulfenite and vanadium minerals, oxidation continued.

**ZONING OF THE SULFIDE MINERALS**

The amount of pyrite and chalcopyrite originally present in the Mammoth vein and above the 650 level of the Collins vein is not known, but malachite, azurite, and chrysocolla indicate the former presence of chalcopyrite, and the limonite-coating of gossan cavities suggests pyrite. In general, chalcopyrite and pyrite appear to be increasing with depth. An increase is noticeable between the Collins 700 and 900 levels.

Because of the fugitive nature of secondary zinc minerals, little is known of the original zinc content of the oxidized part of the

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deposit. The lack of adequate assay data on the oxide and sulfide zone and the abundance of zinc on all the sulfide levels vitiate the possibility of determining any quantitative changes in the zinc content of the deposit with depth.

Because of the relative insolubility of PbSO$_4$ and PbCO$_3$, lead assays in oxidized zones are conceded generally to approximate the original lead content of the deposit. The lead contents of an oxide stope between the Mammoth 760 and 800 levels and of one between the Collins 500 and 600 levels were determined accurately by assays on every floor level. From the first stope 323 assays averaged 1.80 per cent Pb, and from the second stope 142 assays averaged 2.22 per cent Pb. Individual assays from adjacent stopes substantiate the grade given for the two stopes. The lead assays from the mill heads for a six-month period in 1945 for sulfide ore drawn from all parts of the Collins 800 and 900 levels averaged 7.15 per cent Pb. The quantitative data, although not as complete as desirable, show the lead content increasing with depth, with a sharp increase between the Collins 500 and 700 levels.

**Hydrothermal Alteration**

Hydrothermal alteration, though not intense, is readily apparent and consists of replacement by silica and the formation of sericite and clay from quartz monzonite and rhyolite. Quartz, which has the widest range and is the most abundant of the vein minerals, was deposited throughout several stages in the history of the deposit (Table 6), both as open-space filling and as replacement of fragments and wall rocks, especially where they were rhyolitic. All stages from slight silicification of wallrock fragments to complete replacement are common in the vein. Moderate to intense silicification appears to be limited to the vein proper. The wallrocks and many of the breccia fragments in the veins are partly altered to sericite and clay. The sericitic alteration has affected the rhyolite and quartz monzonite about equally and has penetrated the wallrocks to a greater extent than the silicification. The clay alteration is more abundant in the quartz monzonite than in the rhyolite; however, its general distribution is similar to that of the sericite.

**CHAPTER VII.—SUPERIOR AREA**

**Compiled by Eldred D. Wilson**

**INTRODUCTION**

The Superior mining area, in northeastern Pinal County, extends for about 3 miles north and 2 miles south of Superior. It is part of the Pioneer district which in some statistical reports

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1For footnote, see next page.
has been considered as including also the Reymert, Martinez Canyon or Silver Bell, and Mineral Hill or Cottonwood areas.

Superior, the principal settlement, in 1940 had a population of approximately 4,300, depending largely upon operations at the mine, mill, and smelter of the Magma Copper Company.

The Magma Arizona railroad, maintained by the Magma Copper Company, connects Superior with the Christmas branch of the Southern Pacific. Superior is reached by U.S. Highway 70 and the Ray road.

ACKNOWLEDGMENTS

Most of the following description is abstracted from Arizona Bureau of Mines Bulletin No. 151, with a few modifications based upon subsequent work. Additional data have been provided through courtesy of Magma Copper Company.

HISTORICAL OUTLINE

1873. Discovery of Silver King outcrop at foot of Stoneman Grade by a soldier named Sullivan.
1874. Discovery of Silver Queen (Magma) vein by C. G. Mason.
1875-89. Main productive activity of Silver King mine.
1880-93. Silver Queen Mining Co. worked Silver Queen property.
1906. Lake Superior and Arizona mine actively developed.
1910. Magma Copper Company organized to work the Silver Queen property.
1914. Construction of Magma concentrator with about 200 tons per day initial capacity.
1915. Magma Arizona railway completed.
1916. Capacity of the Magma concentrator increased to 300 tons daily. The additional section was of 50 tons daily capacity and designed for zinc-lead ores. After 3 months' successful use, it was converted to treat copper ores.
1922. Capacity of Magma concentrator increased to 600 tons daily, and construction of a copper smelter started.
1923-28. Principal development of Belmont mine.
1933. Lake Superior and Arizona mine became important gold producer.
1937. Refrigeration cooling plant installed in Magma mine. A new unit of 250 tons daily capacity for treatment of complex zinc-copper ore was added to the concentrator.
1940. Koerner vein discovered by diamond drilling.
1943. Magma mine was the largest producer of zinc in Arizona.
1945. Production of zinc ore ceased in July, owing to labor shortage.
1946-48. New Magma concentrator under construction.

PRODUCTION

The Superior area to the end of 1948 has been credited with a metal production valued at $153,398,683 of which $364,043 is undistributed, and the remainder accounted as follows: Copper,

849,869,979 pounds, value $113,561,780; silver, 32,440,230 ounces, value $26,687,288; gold, 281,138 ounces, value $8,269,574; zinc, 48,483,000 pounds, value $4,316,071; and lead, 2,969,320 pounds, value $199,927. All of this zinc came from the Magma mine during 1938-45. Also, in 1916 the Magma produced 429 tons of zinc concentrates containing 38.27 per cent zinc and 7.00 per cent lead, together with 183 tons of lead concentrates containing 15.10 per cent lead and 16.97 per cent zinc; the net value of the zinc and lead product was $24,491.78. Lead was produced also by the Belmont and Silver King mines, but figures for the amounts are not available; possibly some of the total lead credited to the Superior area came from outlying properties.

TOPOGRAPHY

Superior is at an altitude of 2,800 feet on the eastern edge of a small intermontane basin bounded by the Superstition Mountains on the northwest and Picket Post Mountain on the southwest. Overlooking Superior from the east is a rugged slope or escarpment of northerly trend. It rises steeply for more than 2,000 feet, culminating as dacite cliffs known in part as Apache Leap (Fig. 24). East from its crest is an extensive dacite mesa into which the drainage system of Mineral Creek has carved deep gulches.

ROCKS

A generalized geologic columnar section of the Superior area is shown in Figure 25.

The oldest formation is Pinal schist, of early pre-Cambrian age. It crops out in the northwestern part of the area and appears in deep levels of the Magma mine. This rock is largely of sedimentary origin but in places contains greenstone derived from igneous rocks of basic composition.

In the Pinal and Mescal Mountains, 12 to 30 miles east of Superior, extensive granitic intrusions of early pre-Cambrian age invade the schist, but they are not exposed in the Superior area.

Unconformably upon the Pinal schist is the late pre-Cambrian Apache group consisting, from base to top, of Scanlan conglomerate, Pioneer shale, Barnes conglomerate, Dripping Spring quartzite, and Mescal limestone with locally an overlying flow of basalt.

Resting upon the Apache group are the Cambrian Troy quartzite, Devonian Martin limestone, Mississippian Escabrosa limestone, and Pennsylvanian Naco limestone.

The entire succession, from base of the Apache to top of the Naco, is conformable in strike and dip but includes at least four disconformities. Thickness of the principal formations are shown in Figure 25.

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Intrusive into the Troy quartzite and earlier rocks are extensive sills of diabase which in the Superior area have a combined thickness of more than 3,000 feet. In places the diabase breaks across the intruded beds. Its age is considered as post-Cambrian, pre-Devonian.

Mesozoic sedimentary rocks are not found in the area, although Cretaceous beds occur near Christmas, 30 miles southeast of Superior; possibly they once covered this region but were removed by erosion.

Intruded presumably during the Laramide interval, between late Cretaceous and early Tertiary time, are stocks and dikes which appear to be offshoots of the Central Arizona Batholith.\(^5\) These intrusives are exemplified by the Schultze granite which crops out 8 miles northeast of Superior and extends to Miami;

a stock of quartz diorite and complementary dikes in the Silver
King area; the Silver King stock of quartz monzonite porphyry,
in which the Silver King ore body occurred; and dikes of quartz
monzonite porphyry in the Magma mine.

In Tertiary time, after the Laramide interval, this region under­
went vigorous erosion which extended down into the Naco lime­
stone east of Superior, exposed the intrusive rocks at Silver King,
and out into the Pinal schist west of Picket Post Mountain. The
course debris and sandy to silty material resulting from this
erosion were deposited in local basins upon the old erosion sur­
face and comprise the Whitetail conglomerate (Fig. 24). Subse­
quently the region was covered by a series of predominantly
dacitic volcanic rocks.

Younger than the dacite and flooring the valley in the western
part of the area is a thick accumulation of weakly consolidated
boulders, gravel, sand, and silt. This material, which Short 6 terms
"Dacite Conglomerate," is regarded as equivalent to the Gila con­
glomerate, of Pliocene age. Associated with it in places are flows
of basalt.

Younger than the Whitetail and possibly younger than part
of the Gila conglomerate are glassy to perlitic plugs and sills,
tuff beds, and rhyolitic flows. These rocks are exemplified in a
belt extending southward through Picket Post Mountain.

Dikes and plugs of basalt, presumably of late Tertiary or early
Quaternary age, represent the youngest recognized igneous ac­
tivity in the area.

STRUCTURE

FOLDS

East of the Concentrator fault (Figs. 24, 29), Apache and Paleo­
zoic beds form most of the mountain front for 10 miles north and
8 miles south of Superior. Throughout this belt they strike gen­
erally northward and dip 30°-40° eastward, with arcuate vari­
tions in strike reflected by contours of the mountain front.

Under Apache Leap an angular discordance of 15°-25° separates
Paleozoic beds from overlying Whitetail and dacite series (Fig.
27). Eastward the structure of Paleozoic and older rocks is con­
cealed by dacite which lies in a shallow syncline. The major
tilting of the pre-dacite rocks is of importance in connection with
the ore deposits, as discussed on subsequent pages. Although
commonly ascribed to simple block faulting, field evidence sug­
gests that it represents a faulted limb of a syncline.

As shown by Ransome's7 maps and cross-sections, the belt be­
tween the Dripping Spring and Tortilla mountains may be a
southeastward-plunging faulted syncline. Strongly suggestive of

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Survey Prof. Paper 115 (1919); Description of the Ray quadrangle: U.S.
a northwestward continuation of this structure through the Ray, Superior, and Silver King areas is the general alignment of its western limb with the eastward-dipping Apache and Paleozoic beds in Apache Leap Ridge.

Action of strong compressive forces in this region is demonstrated by folding of Cretaceous and earlier beds southeast of Christmas; major thrust faulting at Aravaipa; thrust faulting in the Globe, Ray, Dripping Spring Mountains, and Superior areas; and horizontal displacement on east-west faults in the Superior area.

The pre-dacite compression is regarded as Laramide (late Cretaceous-early Tertiary) in age. Probably it was associated with emplacement of the Central Arizona Batholith; as a rule batholiths and associated intrusives favor regions of strong compression, folding, and thrust faulting.

**Pre-Dacite Faults**

Among the earlier displacements are bedding slips or faults which influenced invasion of the diabase. These features tend to be obscure and are comparatively little known.

Thrust faulting likewise may be obscure, but its occurrence in this area is shown by the low-angle displacement of Naco limestone in upper Elm Canyon, southeast of Superior, as mapped by Harshman. Furthermore, recent field work has shown that, west of Teapot Mountain, between Superior and Ray, the Apache and Paleozoic beds are brought into contact with Pinal schist by a reverse fault. This fault extends northeastward up Walnut Canyon until, on the high main limestone ridge, it flattens into a thrust above which the Paleozoic beds are upside down.

West of the Concentrator fault at a locality 5 miles south of Superior, Paleozoic limestone dips beneath Pinal schist.

Strong bedding faults are indicated by brecciation along the contact between Troy quartzite and Martin limestone in the Queen Creek-Belmont area, and in the “Lake Superior and Arizona zone,” 10-20 feet above the base of the Martin.

The most important pre-dacite faults strike eastward to northeastward and dip steeply. They effected horizontal as well as vertical displacements; characteristically, their north walls moved eastward relative to their south walls, suggestive of lateral compressive shearing. In places their outcrops are marked by silica and manganese oxides. Fault zones of this type contain the largest known ore deposits in the area, as exemplified at the Magma mine.

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*F. L. Ransome, works cited.
*M. N. Short and others, work cited.
Magma fault: The Magma fault, in which occurs the Magma vein, crops out for a length of about 3,300 feet, limited by the Main fault on the west and covered by dacite on the east (Fig. 24). It has been followed underground for almost 7,000 feet, with an average strike between east and N. 80° E. Its average dip is 65° N. from the surface to the 900 level but reverses to 78° S. below that level (Fig. 26). Local changes in its strike and dip are common.

Movement on the Magma fault took place along a zone, ranging from less than a foot to more than 50 feet wide, of closely spaced fractures. Shattering near the vein is slight, and the walls commonly are definite except in Pinal schist where the fault forms a wide shear zone. Near the main ore shoot, the north wall apparently moved 475 feet east relative to the south wall. Apparent vertical displacement was about 500 feet, with the north side relatively upward. The net direction of displacement is believed to incline westward at an angle of about 55° to the dip of the beds. In places the walls of the fault zone show considerable gouge. Some movement within the zone was post-ore.

Koerner fault: As far as known, between the 3,600 and 4,400 levels, the Koerner fault is about 1,100 to 1,300 feet south of the Magma fault and in general subparallel to it in strike and dip. The Koerner fault has been explored as a definite zone for a length of 1,900 feet on the 3,600 and 4,000 levels but neither its outcrop nor direction of movement have been determined.
Silver King fissures: The Silver King deposit occupied a compact plexus of fissures in quartz monzonite porphyry. These fissures probably were formed very soon after intrusion of the porphyry.

L.S. and A. faults: In the Lake Superior and Arizona mine, immediately east of Superior, at least seven east-west faults have been recognized. Associated with them are bodies of gold ore.12

Belmont-Queen Creek faults: South of Queen Creek, faults of the east-west type provided access for ore solutions in the Belmont, Queen Creek, Grand Pacific, and other deposits. Most of these faults are characterized by steep southward dip, displacement horizontal as well as vertical, and little or no surface expression. Displacement on them appears to exceed 500 feet locally, but as a rule the amount is not evident.

Post-Dacite Faults

Some of the north to northwestward-trending faults in the Superior area dislocated the dacite and influenced topography. The largest, the Concentrator fault, has been traced along the entire western foot of the range (Fig. 24), cutting Gila conglomerate and older rocks. It dips about 70° SW. and has a vertical displacement exceeding 2,000 feet, with the southwest side relatively downthrown.

The Main fault (Fig. 24) is a branch of the Concentrator fault. With one principal dislocation and a series of subparallel breaks, it comprises a zone several hundred feet wide which offset the Magma vein. The movement on this fault zone may have been horizontal as well as vertical, but of magnitude not accurately known. In the Magma mine its stratigraphic displacement was about 500 feet, but it dies out northward.

Intense faulting occurred between the Main and Concentrator faults, and minor transverse faults displaced the Magma vein east of the Main fault.

Other post-dacite faults occur in the Magma area, as discussed in Arizona Bureau of Mines Bulletin No. 151. Application of geologic work to the resulting mining and exploration problems has been described by Michell.13

Zinc and Lead Mineralization

General Statement

The only deposits of the Superior area which have been worked for zinc are in the Magma copper mine. Sphalerite occurred also in the Silver King, Belmont, and other properties.

Lead minerals, although present in several of the mines and prospects, have been of commercial importance mainly in the Belmont, Magma, and Silver King.

**MAGMA MINE**

*Ore bodies:* The ore bodies of the Magma mine are replacements within the Magma and Koerner fault zones of the east-west system. Those of the Magma vein constitute by far the greater proportion of the tonnage extracted or developed. The ore consists of distinct shoots or bodies (Fig. 27).

The main or largest ore body has been developed laterally between the Main fault and No. 4 shaft and vertically from the 400 to below the 4,600 level as measured below the collar of No. 1 shaft or 5,800 feet down the pitch. In the vicinity of the 1,200 level at 4,600 co-ordinate (Fig. 27), the ore consists of sphalerite and a little galena, with only traces of copper. Between the 1,300 and 1,400 levels it changes abruptly into a bornite-rich ore with little or no zinc and lead. In levels above the schist the width of the Main ore body ranges from 5 to 40 feet. Where the vein is wide, the ore generally occurs as two or more rich stringers separated by poorer vein material.

The West ore body is a faulted segment, possibly of the Magma vein, west of the Main fault and east of the Concentrator fault (Fig. 27). This vein segment strikes almost east and dips steeply north. The West ore body averaged about 15 feet in width and 7 per cent in copper content together with subordinate zinc and lead.

The East ore bodies or “zinc stopes” lie east of zero crosscut. These bodies are not continuous, and none of the known ore shoots persist for more than several hundred feet (Fig. 27). In general, sphalerite predominates above the 2,550 level, and chalcopyrite below.

The Koerner vein ore body is similar to the Main ore body, but smaller. Mineralogically, its ore is indistinguishable from that of the Main ore body on the same levels.

*Relation of ore to wall rocks:* A dike of quartz monzonite porphyry occurs within the Magma fault zone from the surface to the 1,200 level, and in many places deeper it forms either the north or south wall of the vein. The dike was not sufficiently mineralized to constitute ore.

Diabase was the most favorable host rock for ore deposition in the Main ore shoot (Fig. 27).

Practically all of the zinc ore bodies have quartzite or limestone for one wall. Replacement bodies in limestone are limited chiefly to the zinc-copper area. Here the “Lake Superior and Arizona” zone, in Martin limestone about 20 feet stratigraphically above the Troy quartzite, has been replaced by ore of good grade for a thickness of 30-50 feet and a width ranging up to 30 feet.

In the Pinal schist, the zone of faulting and mineralization in the Magma vein is considerably wider than in the upper levels.
and commonly contains horses of relatively unbroken, unmineralized wall rock. Its walls are less distinct, in many places indefinite, and perhaps more than 100 feet apart. Ore bodies here tend to be lenticular both horizontally and vertically. Where both walls are in schist, the mineable vein forms two branches (Fig. 27).

Oxidation and supergene enrichment: The outcrop of the Magma vein has been so leached that gossan is generally lacking.

The general lower limit of intense oxidation is indicated by a line on Figure 27, but in detail it grades downward without sharp definition into a zone of incomplete oxidation. Above it, in stopes above the East 1,800 and 2,000 levels, sphalerite is rare, and much of the zinc has been leached out. Some zinc remains as hemimorphite and zinciferous tallow clay, associated with abundant limonite and hematite.

Oxidation and enrichment here have no apparent relation to present water level. If oxidation took place after tilting, the water level must have been at least 1,600 feet deeper than at present. However, deep oxidation, entirely unrelated to present water level, is common in the Southwest.

The general parallelism of the sedimentary beds with the lower limit of oxidation might indicate that the beds were tilted after oxidation and supergene enrichment. This view has been favored by M. N. Short and other geologists who have done detailed work in the district. It implies that oxidation may continue indefinitely down the dip eastward, limiting the prospective extent of sulfide ore in that direction.

Another interpretation is that oxidation and supergene enrichment took place after the principal or pre-dacite tilting, during the long erosion interval marked by sedimentation of the Whitetail conglomerate. This interpretation seemingly is in accord with the structural history of the region, as summarized on earlier pages. Furthermore, as demonstrated by Ransome, the principal oxidation and supergene enrichment in the neighboring Miami and Ray districts occurred during the Whitetail cycle.

Minerals: Sulfide minerals in the Magma mine are as follows:

- Pyrite (FeS₂)
- Sphalerite ZnS
- Enargite (Cu₃AsS₄)
- Tennantite (5Cu₅S₂(Cu, Fe)S₂AsS₃)
- Chalcopyrite (CuFeS₂)
- Bornite (Cu₅Fe₃S₈)
- Galena (PbS)
- Stromeyerite (Cu₃S₄AgS)
- Chalcocite (Cu₅S₄)
- Digenite (Cu₃S₄)

Oxidized minerals:

- Azurite (2 Cu CO₃Cu(OH)₂)
- Chrysocolla (CuSiO₃·2H₂O)
- Copper (Cu)
- Cuprite (Cu₂O)

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Zinc and lead minerals: Sphalerite is abundant on the eastern margin of the Main ore body in the upper levels. In the lower levels it is abundant in scattered ore shoots east of shafts No. 2 and 3. Here it is almost invariably accompanied by galena which is regarded as slightly later. Sparse sphalerite occurs in the Main ore bodies as small grains surrounded by copper sulfides. It is later than pyrite, earlier than the copper minerals, excepting possibly enargite, and slightly earlier than galena.

Intergrowths of galena with bornite, and of galena with chalcopyrite, occur in unimportant amounts.

Lead minerals have not been found in commercial abundance in the Magma mine.

A white tallowlike clay occurs in fair abundance near the lower limit of oxidation on the East 2,000 level. It contains from 14 to 30 per cent zinc and consists of fine particles of probable hemimorphite disseminated in a clay mineral believed to be halloysite.

A hard black zinc-bearing mineral, identified as coronadite, occurs sparingly in the tallow clay.

White films of hydrozincite coat some of the sphalerite on the 1,600 level.

Belmont Mine and Vicinity

History and production: The Belmont mine, about 2 miles southeast of Superior, was developed principally by the Calumet and Arizona Mining Company during 1913-14; the North Butte Mining Company, 1923-24; the South Syndicate, 1924; and the Belmont Copper Mining Company, 1925-28. These companies sank a vertical shaft 1,600 feet deep (Fig. 29), ran approximately 30,000 feet of development (Fig. 28), and did about 50,000 feet of diamond drilling. During 1934-42 lessees mined, principally on outlying claims, for silver, gold, and copper.

Production from the property for 1926-38 was approximately 312,000 pounds of copper, 268,000 ounces of silver, and 4,670 ounces of gold, valued in all at $245,000.15

The amount of lead produced is not stated. During 1926-27, 200 tons of ore averaging 50 ounces of silver, 0.35 ounce gold, 2 per cent lead, and 3 per cent zinc were mined on the 1,150 level. A small flotation mill, constructed in 1928, treated about 4,000 tons of galena and gold-silver ore. In 1931, C. H. Smith, lessee, mined from the 140 level 30 tons which assayed 38 per cent lead, 2 per cent copper, 11 ounces of silver, and 0.06 ounce of gold.

Ore deposits: The ore in the outlying, near-surface mines is completely oxidized. Ore minerals are cerargyrite, silver, gold, malachite, azurite, and cerussite, with a little wulfenite and vanadinite. It commonly occurs with limonite and sugary to massive gray or greenish-yellow quartz. These deposits occur as lenticular shoots along intersections of east-west faults with the upper beds of Escabrosa limestone.

As the deeper workings of the Belmont mine are flooded, the following description is abstracted from private reports made by I. A. Ettlinger to the Belmont Copper Mining Company in 1927 and 1929:

Most of the development in the Belmont has been along a strong fissure vein, the Eureka. Its outcrop, highly stained with iron and manganese oxides, is just north of the Belmont shaft. Some near-surface gold-silver ore was mined from it.

The ores were formed chiefly by replacement of the shattered walls of the Eureka fault zone. Open-space filling was not common. On the 1,150 and 1,450 levels the wall rock is shattered diabase, but on the 1,000 and 1,600 levels Mescal limestone blocks occur in diabase. On the 1,000 and 1,150 levels the vein is developed for several hundred feet along its strike. It ranges from 2 to 5 feet in width and is mineralized by pyrite, chalcopyrite, galena, sphalerite, and argentite. It was from this area that the lead-silver ore previously mentioned was mined. On the 1,450 level the vein was developed for 730 feet along its strike. Here the silver content is lower, but the copper content is higher, than on the upper level. From the Belmont 1,450 level the Sandal vein of the Grand Pacific mine was developed for 1,300 feet along its strike. It is a fissure vein from 1 to 5 feet wide, characterized by weak mineralization with base-metal sulfides and strong silicification of the diabase walls. On the 1,600 level the Eureka vein was developed for over 2,000 feet along its strike. Mineralization
on this level is weaker than on those above. The wall rocks are highly silicified, and the vein contains minor amounts of pyrite, chalcopyrite, and sphalerite. Mineralization is strongest where both walls are diabase. Westward the vein feathers out and becomes indefinite; at a point 900 feet west of the shaft it could not be located.

**Silver King Mine**

*Operations and production:* The Silver King mine, about 2 miles north of Superior, was worked almost exclusively for silver, but its ores contained also important quantities of base metals which were not recovered. Under present-day metallurgy, those ores might have yielded substantial amounts of zinc, lead, and copper.

Production of the Silver King mine has been reported as follows:

<table>
<thead>
<tr>
<th>Years</th>
<th>Ounces silver</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1875-89</td>
<td>5,943,157</td>
<td>$6,526,094</td>
</tr>
<tr>
<td>1918-28</td>
<td>232,764</td>
<td>252,674</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>6,175,921</strong></td>
<td><strong>$6,778,768</strong></td>
</tr>
</tbody>
</table>

During 1876-96 the mine was operated by Silver King Mining Company which paid $1,950,000 in dividends to the end of 1887. Most of the ore was milled at Pinal, on Queen Creek at the base of Picket Post Mountain. In 1883 this mill treated about 50 tons per day, with a concentration ratio of nearly 2 to 1. The average grade of the heads was 61.08 in silver, and the reported extraction was 92.31 per cent. In addition to silver, the concentrates assayed 21.5 per cent lead and 18 per cent zinc.

As stated by Ransome,

Some idea of the character of the ore during a rather late stage in the activity of the mine is obtainable from the company's report for 1887, wherein it is stated that Mill No. 1, employing wet crushing and concentration, treated 2,699 tons of ore with an average content of 21.08 ounces of silver to the ton. The product was 577.813 tons of first-class concentrates averaging 83.4135 ounces of silver to the ton and 31 per cent of lead. Of the total silver contents, 53.95 per cent was native silver. In addition the mill turned out 1,261 tons of second-class concentrates carrying 31.77 ounces of silver to the ton, chiefly combined in zinc blende and galena. Mill No. 2, in which chloridizing, roasting, and pan amalgamation were employed, treated 8,840 tons of first-class ore, 1,914 tons of second-class concentrates, and 3,875 tons of old tailings.

In 1916 the property was acquired by Silver King of Arizona Mining Company. The old shaft, 987 feet deep, was unwatered, and a new shaft was sunk to a depth of 615 feet. A small flotation mill treated 12,546 tons of ore and dump material during 1916-20. Its concentrates contained 1,000 to 1,980 ounces of silver per ton, 20 per cent lead, and 7 to 8 per cent copper. Subsequently

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the property was acquired by Bat Gays who has carried on small-scale operations. Several shipments have been made from the dumps. During 1945-46 some of the area was prospected by diamond drilling.

**Geology**: The Silver King porphyry, in which was developed the Silver King ore body, crops out as an irregular mass approximately 2,500 feet long from east to west by 1,200 feet wide. It was intruded into the southeastern part of a much larger stock of quartz diorite.

The pit marking the former outcrop of the ore body shows brecciated quartz and porphyry. Extending N. 60°-70° E. from the breccia mass is a steeply northwestward-dipping fissure which was mineralized for a few hundred feet along its strike. Evidence for other structural control of the breccia mass is not readily apparent; alluvium and mine dumps conceal most of the area north, south, and west of the pit, and the mine workings are not accessible.

**Ore body**: Blake published an original description of the Silver King ore body and a map (Fig. 30) of the workings as of 1883. Ransome gave a summary of Blake's report together with data collected by himself. Quoting from Ransome,

The ore body formerly cropped out at the top of a little hill about 75 feet high, composed of much-altered yellowish-brown to greenish-

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gray porphyry. Stoping was carried to the surface, and a craterlike pit from 100 to 125 feet in diameter marks the site of the former outcrop. Here and there in the porphyry walls of the pit may be found small veinlets of rich, partly oxidized silver ore, but so far as can be seen from the surface, the ore body was not part of a vein, and there is nothing to suggest that it was determined by the intersection of two or more persistent fissures. It apparently was a compact plexus of veinlets inclosed in comparatively un fissured porphyry.

Blake's description and the maps of underground workings show that the ore body was a stockwork about 130 feet in maximum diameter, with a general dip of 70° west. The stockwork was disposed about an irregular core or axis of milk-white quartz, containing some bunches of rich ore but as a whole comparatively barren. The ore consisted of altered porphyry traversed in all directions by innumerable veinlets carrying stromeyerite, tetrahedrite, galena, sphalerite, chalcopyrite, and pyrite in a gangue of quartz with some barite. Blake makes the interesting observation that stromeyerite and highly argentiferous tetrahedrite with more or less argentite were the most important constituents of the ore on the upper levels, whereas argentiferous sphalerite had become the principal ore mineral on the seventh level.

Other minerals listed by Blake were native silver, native copper, cuprite, oxidized lead minerals, bornite, calcite, and siderite.

The paragenesis of the minerals has been described in detail by Galbraith, who noted that sphalerite was the most abundant sulfide mineral, and galena the next most abundant.

Ransome's conclusion was:

Various explanations are given locally for the failure of this interesting deposit below the 800-foot level, some stating that the ore body was faulted, some that the ore changed in character and grade. The latter is probably true. The worked-out part of the deposit appears to have been a striking example of deep downward enrichment. If so, the time may come when the old mine will be reopened and its low-grade ore utilized.

22F. L. Ransome, work cited, p. 158.

CHAPTER VIII.—LEAD AND ZINC DEPOSITS IN THE GLOBE-MIAMI DISTRICT, ARIZONA

By NELS P. PETERSON

INTRODUCTION

The Globe-Miami district is in the northern foothills of the Pinal Mountains about 90 miles by road east of Phoenix, Arizona. It is almost entirely within the Inspiration and Globe quadrangles as mapped by the U. S. Geological Survey in 1945. The topography of the district is fairly rugged, the altitude ranging from 3,400 feet at Miami to 5,060 feet on Needle Mountain near the southern edge of the Inspiration quadrangle.

1Published by permission of the Director, U. S. Geological Survey.
The columnar section of sedimentary and volcanic rocks in the district is illustrated in Figure 31. The oldest rock of the region is the Pinal schist, a complex of metamorphosed sedimentary rocks of early pre-Cambrian age. Also of pre-Cambrian age, but much younger than the Pinal schist and separated from it by a major unconformity, are rocks of the Apache group. All formations of the group are represented in the district, but in most places the Mescal limestone and much of the Dripping Spring quartzite were removed during the period of erosion preceding the deposition of the Troy quartzite of Cambrian age. Another period of intense erosion following the Cambrian period removed the Troy quartzite in most parts of the district and cut still deeper into the rocks of the underlying Apache group.

The Martin limestone of Devonian age rests either on Dripping Spring quartzite or on small remnants of Troy quartzite. The Mississippian Escabrosa limestone and Pennsylvanian Naco limestone overlie the Martin limestone with no apparent disconformity, although beds of upper Mississippian age are absent throughout the district.

There is no record of sedimentation between the Pennsylvanian epoch and the deposition of the Tertiary (?) Whitetail conglomerate, but widespread igneous intrusions occurred during this interval. A thick flow of dacite younger than the Whitetail conglomerate covered the entire region. In later Tertiary and Quaternary time the Gila conglomerate was deposited as great coalescing alluvial fans and stream deposits filling valleys and spreading more thinly over much of the higher parts of the region.

All the rocks of the district are cut by a complex pattern of faults which Ransome aptly described as "regional brecciation." The deformation of the rocks by faulting appears to have been continuous from pre-Cambrian time until after deposition of the Gila conglomerate when many of the largest displacements of the rocks occurred.

Diabase magma in great volumes was intruded into the earlier rocks probably during Mesozoic time. The diabase forced its way between beds of sedimentary rock as sills and occupied many of the faults. Great blocks of strata, particularly those of pre-Cambrian and Cambrian age, were pushed apart and in places completely enveloped in diabase.

Several other intrusions of igneous rocks, ranging from granodiorite to quartz monzonite, took place probably during late Mesozoic and early Tertiary time. The latest of these is the mass of Schultze granite, which underlies the southern part of the district, and numerous smaller bodies of granite porphyry which may be offshoots of the main Schultze granite mass. The mineralization of the district is most nearly contemporaneous with the Schultze granite and the granite porphyry and is probably genetically related to them.

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Figure 31.—Columnar section of rocks in the Globe-Miami district, Arizona.
The Globe-Miami district is known mainly for its large disseminated copper deposits and the copper-bearing veins of the Old Dominion system. The value of past and future production of metals from these deposits will probably exceed $1,000,000,000. The lead and zinc deposits of the district are small and are mainly near the outer limits of the mineralized area related to the Old Dominion vein system (Fig. 32). The value of the past production of lead and zinc is probably not in excess of $250,000.

**DESCRIPTION OF DEPOSITS**

**Defiance Property**

**Location and ownership:** The Defiance mine is 5 miles northwest of Globe and 1 1/4 miles northeast of Radium, a siding on the Miami branch of the Southern Pacific railroad. The property is owned by Mrs. Ida McDonald and is being operated under lease by Edwin Sikes.

**Production:** Attention was first drawn to the property by vanadium minerals present in the outcrop of the vein. In 1930, Edward C. O'Brien & Company shipped 20 tons of vanadium concentrate containing 14 per cent V₂O₅. Since 1936, the mine was operated intermittently by D. S. McDonald and various lessees, and has produced lead ore which was shipped to the American Smelting & Refining Company's smelter at El Paso. A summary of the production of the property compiled from records supplied by the owner is shown below.

<table>
<thead>
<tr>
<th>Year</th>
<th>Ore tons</th>
<th>Lead⁴ lb.</th>
<th>Gold⁴ oz.</th>
<th>Silver⁴ oz.</th>
<th>V₂O₅ lb.</th>
<th>Value⁵</th>
</tr>
</thead>
<tbody>
<tr>
<td>1930</td>
<td>......</td>
<td>22,248</td>
<td>......</td>
<td>5,577</td>
<td>$3,680</td>
<td></td>
</tr>
<tr>
<td>1936</td>
<td>40</td>
<td>43,978</td>
<td>41</td>
<td>12</td>
<td>1,316</td>
<td></td>
</tr>
<tr>
<td>1940</td>
<td>91</td>
<td>85,282</td>
<td>39</td>
<td>316</td>
<td>3,325</td>
<td></td>
</tr>
<tr>
<td>1941</td>
<td>151</td>
<td>89,458</td>
<td>14</td>
<td>535</td>
<td>5,731</td>
<td></td>
</tr>
<tr>
<td>1942</td>
<td>151</td>
<td>39,278</td>
<td>10</td>
<td>1,145</td>
<td>5,731</td>
<td></td>
</tr>
<tr>
<td>1943</td>
<td>143</td>
<td>33,673</td>
<td>19</td>
<td>543</td>
<td>5,232</td>
<td></td>
</tr>
<tr>
<td>1944</td>
<td>140</td>
<td>40,491</td>
<td>10</td>
<td>31</td>
<td>2,403</td>
<td></td>
</tr>
<tr>
<td>1945</td>
<td>90</td>
<td>29,646</td>
<td>28</td>
<td>1,117</td>
<td>2,451</td>
<td></td>
</tr>
<tr>
<td>1946</td>
<td>134</td>
<td>53,665</td>
<td>41</td>
<td>334</td>
<td>8,788</td>
<td></td>
</tr>
<tr>
<td>1947</td>
<td>276</td>
<td>11,918</td>
<td>13</td>
<td>243</td>
<td>3,452</td>
<td></td>
</tr>
<tr>
<td>1948</td>
<td>99</td>
<td>3,680</td>
<td>3,755</td>
<td>5,577</td>
<td>$39,978</td>
<td></td>
</tr>
</tbody>
</table>

**Development:** The mine workings consist of two shafts and approximately 1,400 feet of drifts, crosscuts, and raises. A large number of the workings have been used for disposal of waste rock and are at present inaccessible.

Shaft No. 1 is 150 feet deep with levels at 50 and 150 feet below the collar. The collar of shaft No. 2 is 160 feet southwest of shaft No. 1, and 40 feet lower in altitude. Shaft No. 2 is 110 feet deep with levels at 30, 65, and 110 feet; as it has been filled with waste below the 65-foot level, the bottom level is now inaccessible. The bottom level is said to connect with the 150-foot level of shaft No.

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⁴Metal paid for by the smelter.
⁵Net value of metals paid for, before deduction for treatment.
Figure 32.—Index map showing location of lead and zinc deposits in the Globe-Miami district and their relation to the Old Dominion copper vein.
1, which is at the same elevation. The present water level in the mine is 14 inches above the sill of the bottom level at shaft No. 1.

Drifts from the two shafts explore the vein for 550 feet along its strike; except for small pillars left to protect the shafts, the vein has been stopeed continuously for a length of at least 450 feet. Much of the stopeed vein has been back-filled with waste rock sorted from the ore.

**Geology:** The rocks exposed in the vicinity of the Defiance mine are diabase and Pioneer quartzite. The Pioneer quartzite crops out in a number of small blocks on the south slope of a chain of low hills trending west-northwest. The general dip of the beds is $30^\circ$ to $40^\circ$ S., a little steeper than the slope of the hills. The structural relationships of the diabase and quartzite apparently resulted from intrusion of the diabase between the blocks of quartzite along old faults and also between the beds as sills. Most of the north contacts of the blocks are steep, whereas those at the south conform with the bedding of the quartzite. In some places along the south contacts, diabase overlaps quartzite beds; in others, quartzite blocks are underlain by diabase. Details of the structure cannot be worked out by a study of the outcrops because of the mantle of quartzite talus that obscures the contacts in many places. It appears, however, that several small, discontinuous diabase sills are necessary to produce the observed relationships.

The Defiance vein strikes N. $35^\circ$ E. and dips about $80^\circ$ SE. The outcrop of the vein fault can be traced for 1,500 feet southwest of the mine by slight mineralized and altered appearance of the diabase. Northeast of the mine, the vein appears to end at the north contact of the quartzite with the diabase. West of the mine are several small faults in the quartzite that are parallel to the main vein and are slightly mineralized.

The collar of shaft No. 1 is in the outcrop of the vein 220 feet south of the outcrop of Pioneer quartzite. The quartzite has a steep contact on the north side; the south contact is parallel with the bedding and dips under the diabase, which is probably the lower part of a sill. The shaft was begun in diabase but passes into the underlying quartzite about 35 feet below the collar. Below the 50-foot level, the shaft crosses the vein fault zone and on the 150-foot level is 20 feet northwest of the fault. Near the shaft on the 50-foot level, the fault zone is filled with diabase gouge, and no quartzite is visible in the south wall. Both walls are probably diabase a short distance southwest of the shaft. In the workings accessible from shaft No. 2, no quartzite appears in either wall of the vein fault. The striations on the walls of the fault zone indicate that at least the latest displacement was nearly horizontal. However, the displacement must have been small as no offset of the quartzite can be recognized where the fault crosses the outcrop.

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*In the Globe area the unit identified with the Pioneer shale as originally defined is a fine-grained, arkosic quartzite. In the ensuing descriptions it will be referred to as Pioneer quartzite.*
The vein fault zone is bounded by very regular walls which generally dip 80° to 85° S.E. The stopes range in width from 3 feet to 12 feet, averaging 5 feet. The top of the stopes is near the contact of the quartzite with the overlying diabase. The bottom limit of the ore is said to be a bedding-plane fault which crosses the 50-foot level 150 feet northeast of shaft No. 1. The influence of the fault is not clear from what can be seen in the accessible workings. At the northeast end of the mine in the footwall block of the fault, a short segment of vein has been stoped for short distances both above and below the 50-foot level. The underhand stope is filled and could not be examined. The vein segment is parallel to and 20 feet southeast of the projected strike of the main vein. If the two veins were once continuous, the present relationship could be accounted for by a reverse displacement of about 30 feet on the bedding-plane fault. The continuity of the fault through the mine workings could not be established.

On the 150-foot level, the drifts driven northeast and southwest from shaft No. 1 follow a strong fault zone which is very weakly mineralized; crosscuts driven into the footwall and hanging wall did not reveal any other fault zones. It is very possible that the bedding-plane fault served as a barrier which obstructed, to a large extent, the passage of mineralizing solutions into the rocks below the fault, rather than as a means of offsetting the mineralized vein.

Southwest of shaft No. 2, the vein has been explored by drifts for 380 feet, but stopes extend for only about half this distance. The stopes and drifts are not accessible, and the reason for discontinuing work in that direction cannot be determined underground. However, the outcrop area of the fault beyond the stopes is very weakly mineralized. Probably, like many of the veins in the Globe area, mineralized rock of ore grade does not continue for more than a short distance beyond the point where both walls of the fault are diabase.

Character of the ore: The mineralized fault zone is bounded by very regular slickensided walls, and contains mainly fragments of quartzite and diabase gouge which has been altered to a porous white mass of kaolinite, sericite, and finely disseminated calcite. The ore minerals appear to have been confined largely to a narrow band in the middle part of the zone. The ore that was shipped to the smelter was very carefully hand sorted and probably represents no more than 20 per cent of the rock broken in the stopes. It averaged approximately 0.17 ounce gold and 3.7 ounces of silver to the ton, and 19 per cent lead, 3.7 per cent zinc, and 0.55 per cent copper.

The lead was present mainly as masses of cerussite which commonly surrounded small remnants of galena inclosed in shells of anglesite as much as an inch thick. A little copper carbonate is generally associated with cerussite. Willemite occurs as granular aggregates of small hexagonal prisms, rarely over 0.04 inch long, interspersed with fine-grained vanadinite and descloizite.
Limonite is present but not abundant. There is no general silification in the mineralized zone, and the only introduced quartz recognized is found as fine-grained druses.

Vanadinite, descloizite, and mottramite are present throughout the mineralized zone but are more abundant in the fractured quartzite wall rock, especially in the footwall of the vein. How far the vanadium minerals penetrated into the wall rocks is not known, but in the vanadium stope on the north side of the vein, crusts of large, orange-red vanadinite crystals coat the walls of fractures 20 feet from the vein. In and near the vein, the vanadinite is finer-grained and is generally associated with descloizite, mottramite, and calcite. The calcite was deposited on vanadinite crystals and in the open spaces between them. In some places the two minerals appear to be intergrown, although most of the calcite is clearly the younger. Along the margins of the vein, corroded crystals of vanadinite are commonly engulfed by thin crusts of descloizite and mottramite.

**ALBERT LEA GROUP**

The Albert Lea property, comprising one patented and two unpatented mining claims, is near the south boundary of sec. 22, T. 1 N., R. 15½ E., 1½ miles northeast of Globe. The claims are held by Lenor C. Liano. The lead deposits were developed by Ceferino Liano who made shipments of lead ore to the American Smelting and Refining Company's smelter at El Paso from 1944 to 1946. A summary of the production of the property, compiled from records furnished by the owner, is shown below.

<table>
<thead>
<tr>
<th>Year</th>
<th>Ore dry tons</th>
<th>Lead lb.</th>
<th>Silver oz.</th>
<th>Value $</th>
</tr>
</thead>
<tbody>
<tr>
<td>1944</td>
<td>254</td>
<td>40,577</td>
<td>1,441</td>
<td>1,571</td>
</tr>
<tr>
<td>1945</td>
<td>769</td>
<td>164,662</td>
<td>5,087</td>
<td>7,775</td>
</tr>
<tr>
<td>1946</td>
<td>180</td>
<td>27,009</td>
<td>972</td>
<td>1,584</td>
</tr>
<tr>
<td>Total</td>
<td>1,203</td>
<td>232,248</td>
<td>7,500</td>
<td>10,930</td>
</tr>
</tbody>
</table>

*Development:* The mine workings comprise two adits from which drifts and crosscuts have been driven to explore several weakly mineralized fault zones. The two adits are 35 feet apart vertically and are connected by a vertical shaft sunk from the surface on a prominent fault zone that strikes N. 35° W. A small amount of ore is said to have been stope in this fault zone near the shaft. The objectives of several of the tributary workings are not apparent.

The main productive vein was encountered by workings of the upper adit apparently by accident, as the outcrop is hidden by a mantle of quartzite talus. A drift follows the vein fault for 140 feet; from this drift, a winze was sunk on the fault to a depth of 120 feet below the level. Three sublevel drifts have been driven from the winze at 38, 65, and 95 feet respectively below the adit.

---

Metal paid for by the smelter.

Net value of metals paid for, before deductions for treatment.
level. Most of the production of the property was obtained from stopes between the sublevels and above the drift on the upper adit level.

Geology: The rocks that crop out in the vicinity of the Albert Lea property are Troy quartzite and narrow dikes and small bodies of diabase. The quartzite generally dips about 10° S. to SW. and is cut by numerous faults near which the quartzite is broken to a coarse breccia. Thin diabase dikes have been intruded along some of the faults. Later displacements occurred along the walls of the dikes and on small cross faults which, in some places, offset the dikes.

The surface over the mine is largely covered by quartzite talus, but some of the faults are marked by cemented breccia that stands above the mantle of talus. A few small patches of diabase can be seen, but the exposures are too poor to assist materially in working out structural details. The outcrop of the principal vein is almost completely hidden by talus. As seen in the mine workings, the vein fault strikes about due east; the dip ranges from about 75° N. at the upper adit level to about 60° N., 65 feet below the level. At the west the vein ends at a diabase dike intruded along a fault striking approximately north and dipping 55° E. The collar of the winze sunk on the vein is 95 feet east of the dike on the upper adit level, and at 120 feet below the collar the winze bottoms in the dike.

The diabase dike was formed prior to the mineralization; it was probably an important factor in controlling the course of the mineralizing solutions. The presence of a mineralized segment of the vein fault west of the dike has not been entirely disproved, although the workings on the lower adit level preclude the possibility of an extension of more than 100 feet west from the dike.

The eastward extent of the mineralized zone has not been determined. The maximum development on the fault is on the first sublevel where the drift extends east 175 feet from the dike.

Character of the ore: The ore occurred in small bunches or discontinuous shoots along a fault zone in quartzite. Judging by the location of the stopes, the bunches of ore showed no definite pattern of arrangement. Between the stopes, the quartzite breccia is practically barren of ore minerals. In the accessible workings of the mine, only a few small patches of ore remain from which the character of the mineralization can be roughly determined.

The ore shipped to the smelter averaged approximately 0.012 ounce gold, 6.7 ounces silver, 12 per cent lead, 4 per cent zinc, and less than 0.1 per cent copper. The vein matter was completely oxidized except for scattered remnants of galena. The lead is present mainly as cerussite generally accompanied by a sprinkling of bright-yellow massicot. The zinc apparently occurs mainly as the carbonate associated with cerussite, although none could be recognized in the samples studied. Hemimorphite is present but too sparse to account for the total amount of zinc reported in the ore. Mixtures of brown limonite and manganese oxides, mainly
hard psilomelane-like minerals, are abundant especially along the hanging-wall side of the fault zone. Drusy quartz occurs throughout the mineralized quartzite breccia, but there is little or no replacement by silica. Most specimens of the ore contain small amounts of kaolinite. Fragments of vein material containing veinlets of specularite were seen on the mine dumps.

In the quartzite breccia along faults and in the walls of the vein, the fragments are commonly coated by thin crusts of pale-yellow or orange vanadinite crystals or brown desclozite. Rosettes of thin, platelike rhombohedrons of calcite and tufts of fine, almost hairlike, crystals of hemimorphite are attached to the desclozite crusts. A little vanadinite occurs in the vein matter on the first sublevel, and undoubtedly some vanadinite is present throughout the developed extent of the vein, although none was recognized in samples collected on the lower levels.

IRENE OR LIBERTY DEPOSIT

Location and ownership: The Irene or Liberty deposit is on the south side of Irene Gulch about 2½ miles due north of Globe. The property includes nine patented and fourteen unpatented mining claims in secs. 11, 12, 13, and 14, T. 1 N., R. 15 E., held by the Comstock Extension Mining Company. Development work and exploration by diamond drilling has been carried on by this company since its incorporation in 1945.

Production: Prior to 1931 several operators made small shipments of oxidized lead ore from the upper levels of the Irene mine. The only production since that date was in 1947 when four cars of oxidized ore were shipped to a lead smelter. The production prior to 1931, as compiled by Elsing and Heineman, amounted to 250,000 pounds of lead and 5,000 ounces of silver, having a total value of $15,000.

Development: The underground development of the property consists of two adits which give access to drifts, crosscuts, raises, and a winze driven in the mineralized fault zone. The principal ore shoot is developed by No. 1 adit which was driven southward to intersect the vein 150 feet below its outcrop. The vein is explored on the adit level for 300 feet along the strike by drifts and a few crosscuts. A winze, inclined northward 85°, has its collar at the hanging wall and remains entirely within the fault zone to a depth of 270 feet below the adit level. At 75 feet, 150 feet, and 270 feet below the collar of the winze short development drifts and crosscuts have been driven. From a point near the collar of the winze, a raise connects with the surface.

Above the adit level and west of the winze is a large open stope from which the early output of the mine was obtained. Between the 75-foot level and the adit level is a small stope from which some ore was shipped in 1947.

Adit No. 2 intersects the vein fault about 700 feet farther east than No. 1 adit, and at 33 feet higher elevation. A drift with a few minor tributary workings follows the fault east for 280 feet from the intersection.

**Geology:** The vein occurs along a zone of mineralized fault breccia that crops out for 4,200 feet on the south side of Irene Gulch. In some places, particularly over the main ore shoot, the cemented breccia has nearly vertical walls and protrudes as much as 25 feet above the surface of the hillside. The strike of the fault ranges from N. 50° E. at its east end to N. 80° E. at its west end and is roughly parallel to the gulch. The dip, as determined from underground development, ranges from vertical to 75° N.

Dripping Spring quartzite forms the outcrop on the south side of the fault except in one small gulch cutting across the vein where the underlying Barnes conglomerate and Pioneer quartzite are exposed. Farther south the Dripping Spring quartzite is overlain by small remnants of Troy quartzite, Martin limestone, and a few caps of Escabrosa limestone on the highest points. Diabase crops out along the north side of the fault except for a short distance at the west end where the hanging wall is Pioneer quartzite. This diabase was probably intruded along an old fault. Renewed movement on the fault after the intrusion of the diabase produced the breccia zone along the diabase-quartzite contact which later became the channel of mineralizing solutions. There was also slight displacement along the fault after mineralization took place. Exploration by diamond drilling shows that the diabase forming the north wall of the fault continues to a depth of more than 1,300 feet below the outcrop of the vein.

South of the vein fault, diabase was intruded as a sill at or near the base of the Pioneer quartzite, as shown in Figure 33. Above the winze in No. 1 adit, the top of the Pioneer quartzite on the south, or footwall side of the vein, is approximately 110 feet above the adit level. Pioneer quartzite is exposed in the footwall of the vein by a crosscut 150 feet below the adit level. The contact of the Pioneer with the underlying diabase sill is not exposed in the mine workings, but if a thickness of 270 feet is assumed for the Pioneer, the maximum depth of the contact below the adit level would be about 190 feet. Below the bottom of the Pioneer, both walls of the vein fault are diabase. The thickness of the diabase sill under the quartzite is not known, but exploratory drilling shows that it is at least 600 feet.

At the west end of the vein outcrop, Pioneer quartzite forms the north wall for about 900 feet along the strike, indicating that the north or hanging wall is displaced upward with respect to the footwall. Blocks of Barnes conglomerate in the vein breccia cropping out near the east end of the vein fault also indicate a relative upward displacement of the hanging wall. The amount of displacement that occurred after the diabase intrusion is probably relatively small; the vertical throw need not exceed 100 feet in order to account for the relationships described above.
About 1,000 feet eastward from No. 1 adit, the vein passes into diabase and cannot be traced for more than a few tens of feet beyond the end of the quartzite; however, the vein here is poorly mineralized and the exposure poor. About 1,000 feet farther eastward and approximately on the projected strike of the Irene vein, a fault, which may be the continuation of the Irene vein fault, crops out and can be followed northeastward for a distance of about 1 mile. This fault is weakly mineralized throughout its extent; the minerals along the eastern portion of the fault are mainly quartz, calcite, and manganese oxides.

At the west end, the Irene vein is cut off by a crossfault which drops a block of Martin limestone into contact with the Pioneer and Dripping Spring quartzites that form the walls of the vein.

**Character of the ore:** The Irene vein occupies a zone of fault breccia ranging from 5 to 20 feet wide. Both walls are generally regular and are separated from the vein by thin seams of gouge. In many places gouge-filled fractures, generally parallel to the walls, occur within the vein. The breccia consists of angular fragments of quartzite and diabase. Greenish, stony quartz fills interstices of the breccia and largely replaces the diabase fragments and gouge. Small cavities lined with quartz crystals are common throughout the vein.

Although small amounts of metallic minerals occur in most parts of the vein breccia, only one shoot is known in which the minerals are sufficiently concentrated to constitute ore. This shoot is developed by the workings reached through No. 1 adit. The ore is largely oxidized to the depth reached by the mine workings, but small remnants of galena are present in many places. Sampling by the Comstock Extension Mining Company indicates that between the adit and 270-foot levels the oxidized ore contains about twice as much zinc as lead and approximately 0.7 ounce of silver per unit of lead.

Oxidation of the ore minerals probably extends to the permanent water level, the elevation of which is not known. The water level is not likely to be much higher than the level of Pinal Creek, southwest of the deposit; that is, approximately 250 feet below the 270-foot level of the mine.

The oxidized vein matter is a soft, porous mass consisting largely of quartz, chlorite, quartzite fragments, and altered and partly replaced diabase. Limonite and powdery masses of manganese oxides are also abundant constituents. Glistening flakes of specularite are generally present and in some places comprise 10 to 20 per cent of the vein matter. The principal ore minerals are cerussite and hemimorphite. Crystals and crusts of hemimorphite are widely disseminated throughout the ore. No smithsonite was recognized but a little is probably present. The wide dissemination of hemimorphite is undoubtedly due to leaching of sphalerite and transportation by supergene solutions from which zinc was later precipitated as the silicate. Cerussite is less widely distributed and not as conspicuous as hemimorphite but is easily recog-
nized by its characteristic adamantine lustre. It generally occurs as small masses, less than an inch in diameter, which commonly surround small remnants of galena. A little vanadinite and desclouzite are present in a few places near the margins of the vein. Stains of copper carbonates are rarely seen.

The unoxidized primary ore is probably well represented by a diamond-drill core recovered from a hole that cut the ore shoot about 800 feet below the adit level (Fig. 33). Examination of an incomplete split of the core shows that the vein is largely quartz and light-colored sphalerite accompanied by small masses of specularite and more or less unreplaced diabase. No galena was recognized in the samples studied but a little is probably present, although the proportion may be less than that in the upper part of the vein. The core, representing an intersection of the mineral-
ARIZONA ZINC AND LEAD DEPOSITS

ized zone 15 feet long, is reported to average 16.7 per cent zinc. No assays for lead and silver are available.

Slumbering Beauty Group

The Slumbering Beauty group, formerly known as the Money Metal property, is at the east end of Myberg Basin, 7½ miles west northwest of Globe. At present writing (1948) it is accessible by way of State Highway 88 and Gerald Wash to Granite Basin, thence southward 2 miles along the east side of the basin. When not in constant use this road soon becomes impassable, but the property can be reached by foot-trail from Fly Ranch near the head of Lost Gulch. The group, comprising nine patented and twelve unpatented mining claims, is held by Kenneth Hoopes and Louis Winn. Winn operated the property under lease in 1928 and 1929 and again in 1938. During these periods he shipped five small lots of gold-silver-lead ore totaling about 75 tons.

The early workings on the property are all caved and inaccessible. They are said to include an inclined shaft sunk on the vein to a depth of 190 feet, with levels at 65, 100, and 190 feet. On the 65-foot level, drifts extend 40 feet northward and 40 feet southward; on the 100-foot level, drifts extend 53 feet northward and 100 feet southward; and on the bottom level, drifts extend 45 feet northward. Two vertical shafts and an inclined shaft are reported to be 40, 50, and 100 feet deep, respectively. There are also several short adits all of which are now caved.

Geology: The Slumbering Beauty vein occurs along a fault zone in a diabase sill intruded between beds of Pioneer quartzite. East and west of the vein, the higher hills are capped by remnants of Pioneer quartzite which are projections of the hanging wall of the sill. To the north, the diabase is in contact with the pre-Cambrian Ruin granite of the Granite Basin mass. The diabase-granite contact probably represents an old fault along which the Apache group had been down-dropped into contact with the granite before intrusion of the diabase. South and west of the property, the diabase is overlain by dacite lavas which conceal all the older formations in an area several square miles in extent.

The mineralized fault zone strikes N. 30° E., the average dip is approximately 75° NW. At the north, the vein appears to end near the diabase-granite contact, whence the outcrop can be followed for about 1,000 feet southwestward to the north edge of the talus deposits from the dacite cliffs that form the south rim of Myberg Basin.

The fault zone exposed in the underground workings is said to be about 20 feet wide and to be bounded by clay gouge and slickensides. The ore minerals occur in lenses in which the gouge and breccia are largely replaced by quartz, pyrite, and a little chalcopyrite. Small bunches of galena, accompanied by minor amounts of pyrite, sphalerite, and chalcopyrite are present locally in the replaced breccia, but their relationships with the more gen-
eral quartz-pyrite mineralization could not be observed. Some specimens of the vein matter show a network of thin veinlets of galena. The five small lots of selected ore shipped from the property averaged approximately 0.4 ounce of gold and 10 ounces of silver to the ton. Three of the lots were shipped to a lead smelter and ranged from 7.5 per cent to 14.5 per cent lead.

Supergene oxidation of the sulfide minerals is shallow and probably does not penetrate to a depth of more than 20 feet below the outcrop.

CHAPTER IX.—IRON KING MINE, YAVAPAI COUNTY, ARIZONA

By S. C. Creasey

INTRODUCTION

The Iron King mine is in sec. 21, T. 13 N., R. 1 E., in the Big Bug mining district about 12 miles east of Prescott, Yavapai County, Ariz. It is at the base of the Bradshaw Mountains, at the edge of the gravels that comprise the fill for Lonesome Valley which extends to the north and northeast from the area. The relief in the vicinity of the mine is slight; the surface slopes gently eastward but rises more sharply toward the west.

State Highway 69 (Black Canyon Highway) is about ½ mile east of the mine, and the town of Humboldt, through which the highway passes, is about 1 mile to the northeast.

From September 15, 1947, to April 1, 1948, the writer mapped in the Iron King mine and in adjoining areas. This work was done as a part of a study being made by the U. S. Geological Survey of the Jerome mining district, the Iron King mine, and adjacent areas. The writer is indebted to H. F. Mills, General Manager of the Iron King mine, and to John Kellogg, Geologist, for their assistance in the mapping at the mine and for access to company maps and reports. Charles A. Anderson and Edwin T. McKnight of the U. S. Geological Survey reviewed the manuscript and made many helpful comments.

HISTORY AND PRODUCTION

In 1901 Jaggar and Palache mapped the Bradshaw Mountains quadrangle and showed the Iron King mine by a symbol on the geologic map, although they did not mention the mine in the text of the folio. In 1922 Lindgren studied the ore deposits of the
Jerome and Bradshaw Mountains quadrangles and published some information on the history, production, and ore occurrences of the Iron King mine.

The first production from the mine was in 1906 and 1907 from oxide ores; in 1907 it consisted of 1,253 ounces of gold, 35,491 ounces of silver, and 3,933 pounds of copper. Mining activity soon ceased, but was renewed during World War I by George Colvocoresses who mined heavy sulfide for his Humboldt smelter. By 1922 several thousand tons of ore, averaging $8 per ton in gold and silver had been shipped to the smelter.

The mine remained inactive from this period until 1936 when it was purchased at a tax sale by Fred Gibbs, of Prescott, Ariz. In 1937 the Iron King Mining Co. purchased the mine and began development work on the lead-zinc veins. In 1938 a bulk flotation mill of 140-ton daily capacity was put into operation. In the following year the mill was converted to differential flotation and its capacity was increased still further until by 1948 it had reached about 500 tons. The Shattuck Denn Mining Corp. purchased the physical assets of the Iron King Mining Co. in 1942 and has operated the mine since that time.

Bacon, assisted by Gladstone, examined and reported on the Iron King mine as part of a study of the Big Bug mining district.

Since the development of the lead-zinc ore bodies, H. F. Mills, General Manager of the Iron King mine, has described the history, ore occurrence, and mining; H. R. Hendricks has reported on the milling. The mining and milling practices at the mine have been further described in two articles in Mining World.

The production of the Iron King mine from 1906 to 1947 is given in Table 7. The average grade of all ore mined on the 400 and lower levels has been $7 per ton in gold and silver, 2.17 per cent Pb, and 6.80 per cent Zn. In general, the dollar value of the gold has been about twice that of the silver. Figure 34 is a generalized longitudinal projection of the stopes along the mineralized zone, including workings on all the veins. As development is still proceeding to the north, the stope length will increase.

\[\text{(Waldemar Lindgren, op. cit., p. 128.)}\]
\[\text{(Mining at the Iron King: Mining World, vol. 6, no. 3, pp. 13-16, 1944. Iron King milling practice: Mining World, vol. 6, no. 4, pp. 21-24, 1944.)}\]
Figure 34.—Longitudinal projection of the Iron King mine, Yavapai County, Arizona (from a map supplied by Iron King Branch, Shattuck Denn Mining Corp.).
ARIZONA ZINC AND LEAD DEPOSITS

TABLE 7.—PRODUCTION OF THE IRON KING MINE, YAVAPAI COUNTY, ARIZONA, IN TERMS OF METAL CONTENT. (BASED ON FIGURES SUPPLIED BY THE IRON KING BRANCH, SHATTUCK DENN MINING CORP.)

<table>
<thead>
<tr>
<th>Year</th>
<th>Tons mined</th>
<th>Oz. of Au</th>
<th>Oz. of Ag</th>
<th>Tons of Pb</th>
<th>Tons of Zn</th>
<th>Tons of Cu</th>
</tr>
</thead>
<tbody>
<tr>
<td>1906-1938*</td>
<td>91,929</td>
<td>18,007</td>
<td>350,746</td>
<td>1,171</td>
<td>3,677</td>
<td>269</td>
</tr>
<tr>
<td>1939</td>
<td>70,227</td>
<td>9,911</td>
<td>272,604</td>
<td>936</td>
<td>2,927</td>
<td>175†</td>
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<tr>
<td>1940</td>
<td>65,812</td>
<td>9,239</td>
<td>266,497</td>
<td>945</td>
<td>3,610</td>
<td>164†</td>
</tr>
<tr>
<td>1941</td>
<td>69,156</td>
<td>9,720</td>
<td>331,746</td>
<td>1,160</td>
<td>3,808</td>
<td>173†</td>
</tr>
<tr>
<td>1942</td>
<td>91,213</td>
<td>12,180</td>
<td>443,952</td>
<td>1,910</td>
<td>4,635</td>
<td>228†</td>
</tr>
<tr>
<td>1943</td>
<td>75,309</td>
<td>8,672</td>
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<td>1,762</td>
<td>5,570</td>
<td>263</td>
</tr>
<tr>
<td>1944</td>
<td>103,231</td>
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<td>330,841</td>
<td>1,979</td>
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<td>294</td>
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<tr>
<td>1945</td>
<td>120,211</td>
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<td>430,369</td>
<td>2,705</td>
<td>8,742</td>
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<tr>
<td>1946</td>
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<td>8,715</td>
<td>251</td>
</tr>
<tr>
<td>1947</td>
<td>122,368</td>
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<td>533,642</td>
<td>3,097</td>
<td>8,463</td>
<td>206</td>
</tr>
<tr>
<td>TOTAL</td>
<td>926,802</td>
<td>119,465</td>
<td>3,765,850</td>
<td>18,589</td>
<td>57,727</td>
<td>2,230</td>
</tr>
</tbody>
</table>

*Some early production estimated.
†Approximate, but probably very close to actual production.

GENERAL GEOLOGY

General Statement

Pre-Cambrian rocks are widespread in the district; they are represented most abundantly by the Yavapai schist, a series of metamorphosed sedimentary rocks, partly tuffaceous, and related flows. Current work by the U. S. Geological Survey will result in the subdivision of the Yavapai schist into several units. Intrusive rocks, also of pre-Cambrian age, are common in the schist and range in composition from granite to gabbro.

In the Black Hills, 12 miles northeast of the Iron King mine, relatively flat-lying Paleozoic rocks represent the southern extension of the Plateau Region. Locally, Tertiary basalts cap the Paleozoic and pre-Cambrian rocks, and Quaternary gravels fill the valleys and local basins.

In the Iron King and adjacent areas, faults and a pronounced foliation are the dominant structures. Folds were not recognized in the Iron King area, but several miles to the east several isoclinal folds, whose magnitudes are measureable in hundreds of feet, were determined during regional mapping.

Rocks in the Iron King Area

The Iron King area is underlain by the Yavapai schist which has been subdivided into meta-andesite flows, meta-andesite tuffs, metarhyolite tuff and conglomerate, and hydrothermally altered rocks formed prior to and at the time of ore deposition (Fig. 35). The top of this sequence is not known, although several exposures of bedded tuffs suggest that the top is toward the west. Quaternary gravels overlie the Yavapai schist.

The meta-andesite flows consist of a green rock of uniform granularity containing relic plagioclase phenocrysts in a chloritic groundmass. Granules of epidote are common, and in some localities the rock is amygdaloidal. Foliation is well developed, but not so prominently as in some of the meta-tuffs.
The meta-andesite tuffs are fine- to medium-grained rocks which locally show bedding. The dominant megascopic constituents are chlorite, saussuritized feldspar, and quartz in variable amounts. The finer-grained facies is composed largely of chlorite, being essentially a chlorite phyllite in which the foliation is very well developed; the meta-andesite tuffs are the host rock for the alteration and mineralization in the Iron King mine.

The metarhyolite tuff is a well foliated rock composed essentially of quartz, feldspar, and sericite. In the finer-grained beds only sericite can be recognized. This tuff occurs in a thick section of andesitic rocks and apparently represents a sudden flood
of rhyolitic detritus. Interbedded with it is a zone 60 feet thick containing conglomerate beds in which the pebbles and cobbles are chiefly jasper, chalcedony, and other fine-grained siliceous material that could be either chert or a derivative of rhyolite. Prominent bedding can be recognized in the conglomerate in spite of a well-developed foliation.

Quaternary gravels, extending from the mine north and northeastward into Lonesome Valley, cover the northeastern part of the Iron King area (Fig. 35) and the northeastern extension of the Iron King vein zone. The cobbles and boulders constituting the gravels were derived chiefly from the Yavapai schist and associated pre-Cambrian intrusive rocks.

STRUCTURE IN THE IRON KING AREA

The dominant structural features in the Iron King area are regional foliation striking N. 15° to 30° E. and dipping 70° to 85° NW., and the fault zones occupied by the Iron King veins with accompanying alteration zone. The foliation is well developed in the metamorphic rocks throughout the area but is more prominent in zones of fine-grained material, which circumstance may be the result of more intense deformation in this material. The attitude of the foliation varies locally and is both parallel to and at a slight angle to the bedding. The foliation is cut in places by south-dipping slip planes striking northeast and northwest.

The altered shear zone occupied by the Iron King deposit strikes about N. 25° E., generally parallel to the foliation. It represents two periods of shearing. The earlier period localized the early minerals characterizing the hydrothermal alteration zone (Fig. 35). The second period brecciated the early minerals and permitted the introduction of the ore-forming minerals in the Iron King vein system. Other zones of hydrothermal alteration similar in attitude occur in the region, but most of them are much smaller and none is known to contain massive sulfides such as the Iron King deposit.

Younger reverse faults recognized in the mine have offset the vein, but the displacement on them is not great, the maximum vertical displacement being from 80 to 100 feet. The attitude of these faults commonly is close to that of the foliation, and, as a result, they were not recognized in the surface mapping for they apparently do not offset the rock units sufficiently to be noticeable. Underground mapping indicates that the displacement on these faults diminishes rapidly along the strike. Where the reverse faults are less steep than the vein, they have produced a gap or separation of the vein as mapped on a mine level; and where they are steeper, an overlap has resulted.

ORE DEPOSITS

GENERAL STATEMENT

The Iron King mine is worked through a two-compartment shaft (No. 6) which extends below the 1,200 level. Eleven levels, extending to about 1,140 feet below the collar of the shaft, have
provided the openings for development and mining. In 1948 mining was in progress on the 700, 800, and 900 levels, and preparations were nearly complete for mining on the 1,000 and 1,100 levels. Development drifting supplemented by diamond drilling was active on all levels below the 700.

The mine is relatively dry, making only about 30 gallons of water per minute. Water for the mill is obtained from a company-owned well near Humboldt and pumped to the mine.

Oxidation extends to approximately 200 feet below the surface in the area southwest of No. 6 shaft, its lower limit roughly coinciding with the 200 level in the mine. North of the shaft, oxidation extends nearly 250 feet below the surface. Except for the top few feet of leached vein material, the ores from the oxide zone were mined for their gold content; some copper was recovered also.

**Character of the Veins**

The Iron King deposit is a massive sulfide replacement of schist along well defined veins which have sharp contacts with the wall rocks. The host rock within the veins is nearly completely replaced. The deposit consists of eleven veins and one composite vein to the west of the others. The composite vein is made up of several veins that have schist partings from 6 inches to 1 foot wide separating the individual components. Individual veins strike N. 21° to 22° E. and dip about 71° NW. Vein widths range from 3 feet to as much as 14 feet, and the stope length of minable ore ranges from 60 feet for individual veins to about 1,000 for the composite vein.

The veins are en echelon; most commonly each vein extends farther north than its adjacent neighbor on the east and southeast (Fig. 35). In section, the veins maintain the same en echelon arrangement; each succeeding vein to the west commonly extends to higher altitudes, as seen in a section at right angles to the veins (Fig. 37). The north end of each vein commonly plunges northward at a constant angle, but the plunge varies between 55° and 60° from vein to vein. The schist partings between the veins, where not affected by post-sulfide faulting, range in width from a foot or two to as much as 10 or 15 feet but the width remains quite constant for individual partings. The veins all lie on the footwall side of the zone of hydrothermal alteration; commonly the south end of a vein is entirely within the alteration zone, but the north end is at the footwall contact or within the footwall meta-andesite tuff. The faults on which the veins were formed are not parallel to either the foliation in the footwall meta-andesite tuff or to the well-foliated rocks in the hanging-wall alteration zone, although the angular discordance is small (Fig. 35).

The individual veins and the individual components of the composite vein all have the same general physical characteristics and mineral constituents. The vein material is massive sulfide,
and the principal mineral constituents are pyrite, arsenopyrite, chalcopyrite, sphalerite, tennantite, galena, gold, and quartz. Pyrite composes about half the vein material and contains a large part of the gold. Apparently silver is more closely related to copper minerals than to galena, possibly being associated with the tennantite, as suggested in a private report by E. H. Crabtree.

All the veins are zoned and all in a similar manner. The north end of each one consists of massive quartz having sparse pyritic disseminations and ramifying veinlets. The quartz is commonly fine grained, compact, gray to greenish in color, and almost chalcedonic in appearance. Locally, white bull quartz is associated as irregular patches or as veinlike masses cutting the finer-grained type. The quartz has a sharp contact with the massive sulfide. This contact trends obliquely across the vein in a northerly direction and is more nearly vertical than the vein in cross section (Figs. 36, 37). In places the quartz contains sufficient gold and silver to be ore, and it may have a slight concentration of more granular galena near the contact with massive sulfides.

South of the quartz the veins are massive sulfide in which sphalerite and galena are the dominant ore minerals. The highest content of sphalerite plus galena commonly occurs some distance south of the quartz zone. Closely spaced assays show that in each of several veins the zone of higher lead and zinc content begins as a narrow stringer on the footwall of the vein and gradually migrates northward to the hanging wall, duplicating the pattern of the transition to the quartz masses at the north ends of the veins. In general, however, from the quartz southward the content of galena and sphalerite increases gradually to a maximum and then decreases gradually farther toward the south. The south limit of ore in any vein is an economic limit; drilling shows that corresponding to the gradual decrease in lead and zinc there is a complementary increase in pyrite. The pyrite at the south end of the veins is more granular and commonly has a characteristic cubic form. Farther south, the massive sulfide character of the veins grades into zones of quartz-pyrite stringers separated by thin schist partings containing granular, disseminated pyrite.

**Change of the Veins in Depth**

There have been no major changes of the veins in depth. The zoning is similar in each vein on all levels, and the mineralogical and structural character of the veins is about the same on the upper and lower levels. However, the lead-zinc content of several of the more easterly veins diminishes on the 700 and 800 levels. Recent development work suggests it may increase with greater depth. Two closely related veins in the central part of the veined zone showed such a decrease on the intermediate levels, but their lead-zinc content increased substantially with greater depth. Below the 700 level the lead-zinc content of the more easterly veins diminished but this decrease was more than compensated by increases in the central and western veins.
Hydrothermal Wall Rock Alteration

As mentioned earlier the fracturing and shearing related to the alteration and vein deposition is divisible into an earlier period resulting in the wide altered and mineralized zone of the hanging wall, and a later period of brecciation and shear that controlled
the location of the ore minerals. The earlier period affected a zone varying in width from 100 to 300 feet, and shearing appears to have been general throughout the zone, although some local zones were more sheared than others. The related mineralizing processes were sericitization, silicification, pyritization, and the introduc-
tion of carbonate. Sericite is sporadically distributed in the alteration zone as disseminated flakes and as microscopic anastromosing "ribbons." Silica locally permeated the rock as a general silicification and as quartz and quartz-pyrite veinlets and lenses both parallel and at an angle to foliation. The pyrite is in small veinlets and disseminated crystals. Carbonate in veinlets and in disseminated specks occurs in the alteration zone below the zone of oxidation but is absent above it, owing, presumably, to solution action of sulfuric acid generated by the oxidation of pyrite.

A second generation of sericite accompanied the introduction of the ore minerals. It commonly is abundant around the north ends of the veins, but decreases in amount in the vein walls southward. The second period of sericitization is distinguishable from the first by the relative absence of silica and pyrite.

The hydrothermally altered rocks are better exposed on the surface than underground, and to some extent their appearance is different on the surface from that in the mine because of weathering. Megascopically the zone on the surface consists of sericite, quartz, and gossan derived from the oxidation of sulfide minerals. Underground the zone contains chlorite and carbonate, but these minerals are not apparent in the surface outcrops. The quartz veinlets and lenses are conspicuous, but the occurrence of disseminated silica is indicated only by the brittle character of some of the fine-grained sericite phyllites. The hydrothermally altered rocks are uniformly fine-grained, exhibiting none of the granular character of the adjacent meta-andesite tuffs.

CHAPTER X.—LEAD-ZINC DEPOSITS, BAGDAD AREA, YAVAPAI COUNTY, ARIZONA

BY CHARLES A. ANDERSON

INTRODUCTION

Bagdad, Arizona, is recognized primarily as a copper district, owing to the recent expansion of the mining activities by the Bagdad Copper Corp., but notable amounts of lead and zinc have been mined in the area. In 1887 lead, associated with gold-silver ore was mined, and, by the end of 1945, 6,625,835 pounds of recoverable lead having a value in excess of $350,000 had been reported. Zinc mining started in 1917, and, by the end of 1945, 12,376,697 pounds of recoverable zinc having a value of $938,465 had been reported. Most of the lead-zinc production came from two mines, the Hillside, where gold and silver constituted the valuable metals in the ore, and the Copper King, where zinc has been the valuable metal. At the present time zinc ore is mined

1Published by permission of the Director, U.S. Geological Survey.
at the Old Dick mine (Fig. 38). Several small mines on narrow fissure veins have produced a small amount of lead and zinc.

Bagdad is in west-central Arizona, 42 miles west of Prescott, the county seat of Yavapai County. The Bagdad area, as defined in this report, includes approximately 38 square miles mapped geologically in 1943-45 by the writer, E. A. Scholz, and J. D. Strobell, Jr., as part of the copper investigations of the U. S. Geological Survey. Approximately 22 square miles of this map are generalized on Figure 38. The Bagdad area is a part of the much larger Eureka mining district.

GENERAL GEOLOGY

About two thirds of the rocks exposed in the Bagdad area are of pre-Cambrian age. The oldest, the Yavapai schist, consists of amphibolite and mica schist derived from original lava flows, tuff, tuffaceous sediment, sandstone, and shale. Sufficient relic textures and structures are preserved to detect the original characters. These rocks were folded, faulted, and intruded by a series of pre-Cambrian igneous rocks culminating in widespread granite. The oldest of the intrusive rocks is a metarhyolite to which the Old Dick and Copper King mines are spatially related (Fig. 38). Gabbro, alaskite porphyry, and granite have been grouped on Figure 38.

West of the area shown on Figure 38, rhyolite tuff rests on an eroded surface of alaskite porphyry and by analogy to similar rocks elsewhere in Arizona, this tuff is probably late Cretaceous or early Tertiary in age. The tuff is cut by rhyolite dikes that are intruded by quartz monzonite which is also of probable late Cretaceous or Tertiary age. The quartz monzonite crops out in a series of stocks and plugs; the largest stock contains the copper ore mined at the Bagdad mine. Diorite porphyry and quartz monzonite porphyry dikes cut the quartz monzonite but probably belong to the same period of igneous intrusion.

During the Pliocene or Pleistocene, a surface of considerable relief was partly buried by Gila (?) conglomerate and intercalated basalt flows.

The Mountain Spring fault cuts the pre-Cambrian rocks but is older than the quartz monzonite. The dip-slip displacement on this west-dipping normal fault is probably between 1,000 and 3,000 feet. The Hillside fault, also a west-dipping normal fault, but of unknown total displacement, cuts the Yavapai schist and younger rocks. This fault forms the fissure vein at the Hillside mine. Post-ore movement has displaced the Gila (?) conglomerate and lava flows 250 to 300 feet. The Mountain Spring and Hillside faults may have been connected prior to quartz monzonite intrusion.

The Bozarth and Hawkeye faults are of post-Gila (?) age and show displacements of 100 to 300 feet. These two faults are probably connected under an appreciable blanket of talus and soil.
Figure 38.—Generalized geologic map of part of the Bagdad area, Yavapai County, Arizona. Geology by C. A. Anderson, E. A. Scholz, and J. D. Strobell, Jr., 1943-45.
MINERALIZATION

The copper sulfide in the Bagdad mine occurs in minor fractures and disseminated in the quartz monzonite forming a typical "porphyry copper" deposit. Lead-zinc-copper are in the Old Dick and Copper King mines as massive sulfide ores replacing Yavapai schist. Supergene enrichment has formed some of the shipping ore. Gold-silver-lead-zinc-copper fissure veins occur in the area and the Hillside vein has been the most productive.

The mineralization appears to be related to the late Cretaceous or early Tertiary intrusions of quartz monzonite and related dike rocks. Copper occurs in the stock at Bagdad and quartz veins containing galena, sphalerite, and chalcopyrite cut quartz monzonite porphyry dikes. Diorite porphyry in the Copper King mine is cut by veinlets of pyrite, chalcopyrite, and sooty chalcocite, the last-named mineral probably replacing sphalerite. The evidence that the mineralization occurred after the intrusion of the quartz monzonite is conclusive, and in the absence of later igneous bodies as probable sources of the hydrothermal solutions and metals, the time of mineralization is essentially limited to the period of quartz monzonite activity.

The Hillside and Mountain Spring faults probably exerted a broad control over the distribution of the gold-silver-lead-zinc-copper deposits in the area. Deposits of these metals are limited essentially to a north-trending zone 2 miles wide; the faults are in the middle of this belt. The Hillside fault is mineralized at the Hillside and Comstock-Dexter mines. The Mountain Spring fault is mineralized at the Mountain Spring mine (Fig. 38). The Old Dick and Copper King mines are less than a mile west of the Mountain Spring fault.

HILLSIDE MINE

The Hillside mine (Fig. 38) is on a typical fissure vein which has a remarkable continuity of both vein and grade, considering its narrow width. The mine, including six patented claims, is owned by the Hillside Mining and Milling Co. At the time of the examination by the Geological Survey the mine was inactive and filled with water to the 400 level. In 1947, a 150-ton mill was constructed and unwatering of the mine started. A graded dirt road connects to the excellent Bagdad-Hillside gravel road. Hillside, on the Phoenix line of the Atchison, Topeka, & Santa Fe Railroad, is the nearest rail shipping point.

The Hillside mine started production in 1887 and the first shipment of oxidized ore contained 3.15 ounces of gold per ton, 193.35 ounces of silver per ton, and 11.7 per cent of lead, yielding a net return of $203.94 per ton. Production was fairly regular until 1912. From 1912 to 1934 the mine was inactive. A mill was installed in 1934 for concentrating the sulfides, and in 1937 additions to the mill provided for the separation of zinc. Operations

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3 Homer R. Wood, Prescott, Arizona, personal communication.
continued until 1942 when the mine was shut down because of financial difficulties. The ownership reverted to the State of Arizona and all surface buildings were sold and removed. In 1944 it was purchased by the East Vulture Mining Co. at a tax sale and later, ownership was transferred to the Hillside Mining and Milling Co.

Production in terms of recoverable metals is as follows: 1887-1900, 7,824 ounces of gold; 192,949 ounces of silver; 106,906 pounds of lead, having a total value of $267,919. From 1901-1945, 47,828 ounces of gold; 1,057,511 ounces of silver; 345,001 pounds of copper; 5,783,918 pounds of lead; 2,609,342 pounds of zinc, having a total value of $2,914,779. Total value, 1887-1945, $3,182,698.

More than 16,000 feet of underground workings have been driven along the vein at various levels and a longitudinal projection is shown on Figure 39. The shaft connects with the 200 level at the surface, and is 765 feet deep to the 1,000 level. The vein was worked for 2,400 feet along the strike and stoped almost completely above the 700 level for an average length of 2,000 feet.

The main Hillside vein is in muscovite schist, an important unit of the Yavapai schist. The strike of the vein is N. 10° W. at the south end of the mine and changes to N. 25° E. at the north end. The dip is variable but averages 75°-80° W. The main vein and several branches occupy a zone of pre-mineral faults because unbrecciated vein material occurs in irregular veinlets in gouge and fault breccia 3 feet wide. Branching veins appear on both sides of the main vein; those to the east in general dip west less steeply than the main vein, whereas those to the west are nearly vertical. In places branch veins are of sufficient width and grade to be minable. The vein averages 2½ feet in width in the upper levels and 4 feet on the 800 and 900 levels. Work on the 1,000 level was limited to about 365 feet of drifting which disclosed a vein width of 2½ feet.

Four periods of quartz-sulfide deposition have been recognized from the banding and local comb structure. Some intraminalization faulting is indicated by microbrecciation of the sulfides and cementation by later quartz. The common sulfide minerals, pyrite, arsenopyrite, galena, and sphalerite, occur usually in blebs or bunches in quartz. Chalcopyrite occurs sparingly. Argentiferous tetrahedrite occurs as coatings on other sulfides in vuggy quartz. At both ends of the workings the vein tends to spray out, but high-grade stringers of silver ore have been found in these narrow veins. In the oxidized zone the lead mineral is cerussite, but there are some coatings of anglesite on galena. Zinc in the oxidized zone is present as smithsonite and hemimorphite, but is low grade.

Strike faults locally cut out the vein and elsewhere repeat it. In other places the vein has been broken so completely as to form

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*Data furnished by Homer R. Wood.
*Compiled by Salt Lake office Metal Economics Division, U.S. Bureau of Mines.
Figure 39.—Longitudinal projection of the Hillside mine. Modified from projection prepared by Hillside Mines, Inc.
only an unrecognizable part of the gouge. After the strike faulting that followed mineralization there were offsets along north-dipping ($25^\circ-45^\circ$) cross faults. In general these late cross faults have formed clean-cut breaks, and the vein on the hanging-wall side of the cross faults has been displaced 1 to 25 feet eastward.

The grade of the ore has been fairly consistent throughout the mine although the lower levels contain slightly more gold, sphalerite, and pyrite. In 1941 the mill head assays had an average grade per ton of 0.18 ounce gold, 4.1 ounces silver, 2.0 per cent lead, 3.7 per cent zinc, and 0.30 per cent copper. Reserves are probably of this general grade, but estimation of the tonnage is difficult because of the inaccessibility of the lower levels. Exploration to date indicates the vein may not extend far north of the workings. Additional ore shoots will probably be found south of the stoped portion of the vein and in depth because the bottom of the vein has not been reached.

**COMSTOCK-DEXTER MINE**

The Comstock-Dexter mine is also on the Hillside fault, 1 mile south of the Hillside mine (Fig. 38). Two patented claims, having an area of 26 acres, are owned by the Comstock-Dexter Mines, Inc. The claims were first located in 1892 and 1896, and some time prior to 1901, high-grade ore was shipped. Some of the oxidized ore was crushed in a stamp mill and $18,000 in gold and silver recovered. The Comstock-Dexter Mines, Inc., acquired ownership in 1934, built a 100-ton mill and during 1938 produced 410 ounces of gold, 6,500 ounces of silver, 1,363 pounds of copper, and 8,080 pounds of lead, having a total value of $19,058. Because of financial difficulties the company stopped operations in 1938, and all of the surface buildings have been removed.

The mine is inaccessible because of caving, and no maps are available of the underground workings. According to T. F. M. Fitzgerald, the mine consists of 4,000 feet of underground workings and includes a shaft sunk on the vein and four connecting levels, chiefly drifts along the vein. North of the shaft the main vein splits into two veins having the same general strike and dip as the Hillside fault. The vein can be followed south of the shaft for 2,000 feet.

No figures are available for the tonnage mined in 1938.

**COPPER KING MINE**

The Copper King mine is approximately 1½ miles southwest of Bagdad and it is reached by a dirt road that joins the Bagdad-Hillside road 2 miles southeast of Bagdad. The property consists of one patented claim owned by M. L. Lynch and J. W. Lawler, and has been under lease since 1942 to Valerio Rossi who has been

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6Hoagland, Jackson, Comstock-Dexter’s plan for production, Min. Jour., vol. 21, no. 8, pp. 3-4, 1937.
8President, Comstock-Dexter Mines, Inc., oral communication.
mining pillars of massive sulfide ore and selectively mining oxidized ore near the surface. Some of the low-grade ore dump was shipped for concentration.

The Copper King claim was located in 1880 and patented in 1893, but no ore was shipped until 1917 when the Arizona Hillside Development Co. held an option on the property. The mine operated continuously from 1917 to 1921 and much of the development, exploration, and production was during this period. In 1925 the World Exploration Co. obtained control and shipped ore until the decline in zinc prices prohibited further mining. The ore consisted chiefly of sphalerite and after hand sorting, was hauled first by wagons and later by trucks to Hillside for shipment by rail. The ore averaged 46.89 per cent zinc, 5.7 ounces silver per ton, 3.58 per cent lead, and 1.68 per cent copper. Total production to the end of 1945 has been 70 ounces of gold, 57,612 ounces of silver, 331,822 pounds of copper, 665,954 pounds of lead, and 9,767,355 pounds of zinc. Total value of recoverable metals has been $900,389.

The mine is filled with water to the 200 level and very little reliable information has been obtained regarding the workings or nature of the ore below that level. More than 4,000 feet of workings are reported for the entire mine, which probably includes inclined and vertical openings as well as drifts and crosscuts. An inclined shaft 624 feet long provides access to nine irregularly spaced levels (Fig. 41).

The ore is in discontinuous lenses, 2 to 10 feet wide, and 10 to 120 feet long, and as much as 100 feet deep, located in a zone of minor faulting. In detail the ore is localized along small interlacing faults and rolls in the overturned beds of meta-tuffaceous sediments (chlorite and biotite schists) that strike northwest and dip 45°-55°SW. (Fig. 40). Hydrothermal alteration is indicated by a bleached sericitized-silicified schist zone from several inches to 3 feet wide, adjacent to the ore-bearing channels. A diorite porphyry dike, 60 to 70 feet wide, crops out south and east of the collar of the shaft; information is not available regarding the effect of this dike on the ore. A small diorite porphyry dike in the north end of the 100 level (Fig. 42) is partly mineralized, indicating that the mineralization occurred after the intrusion of the dike, but no minable lenses of ore have been found in the diorite porphyry. Possibly the physical and chemical character of this rock is not favorable for extensive replacement by sulfide minerals.

The ore consists of granular resinous sphalerite and smaller quantities of chalcopyrite, pyrite, and galena. Some quartz, rarely appearing as minute crystals in vugs, was introduced during metallization and is associated with the sulfides. Magnetite-hematite occurs locally along the margins and ends of the lenses of massive sulfides and a large mass crops out at the surface on the footwall side of the ore zone (Fig. 40).
EXPLANATION

- **Gossan**
- **Magnetite-hematite**
- **Diorite porphyry**
- **Meta-rhyolite**
- **Meta-lavas**
- **Meta-tuffaceous sediments**

**Strike and dip of overturned beds; foliation parallel to bedding**

**Strike and dip of foliation**

**Shaft** — Inclined shaft

**Pit** — Cut — Adit

**Road**

Figure 40.—Geologic map of vicinity of Copper King mine. Geology by E. A. Scholz.
Oxidized ore appears in the higher levels and on the hanging walls of the sulfide lenses. Supergene minerals in the oxidized zone include chrysocolla, malachite, azurite, and native copper. Immediately below, supergene chalcocite and covellite, partly replacing sphalerite and chalcopyrite, locally form masses containing as much as 40 per cent copper. Earthy smithsonite and crystals of hemimorphite are the common zinc-bearing minerals in the oxidized zone. The zinc is associated with some anglesite and cerussite developed from the galena. Appreciable quantities of cellular to fluffy iron oxide occur in the oxidized zone, either adjacent to or above the massive sulfides.

Because the primary structural control in ore deposition is the fault zone parallel to the bedding of the meta-tuffaceous sediments, future exploration should be guided by this control. There is a suggestion that some of the lenses (Fig. 42) of ore dip more steeply into the footwall than the main fault zone, therefore some future exploration should be directed toward the footwall to see if extensions or additional lenses are present.

No accurate estimate of reserves can be made because of the lenticularity of the ore bodies and limited accessibility of the workings.

OLD DICK MINE

The Old Dick mine is 2¾ miles southwest of Bagdad and 1½ miles south of the Copper King mine. A short truck road connects with the Copper King-Hillside road. The mine is on the Old Dick patented claim, owned by M. L. Lynch, J. W. Lawler, Elmer Wells,
Figure 42.—Section and level maps of Copper King mine. Location of section A-A' given on Figure 40. Prepared by E. A. Scholz; brunton and tape surveys.

and Minnie A. Wells. The 1st South Extension Old Dick and Young Dick patented claims are adjacent to or near the Old Dick claims and are owned by M. L. Lynch and J. W. Lawler. These claims are under lease and option to the Hillside Mining and Milling Co. which has been mining ore since September, 1947.

The Old Dick claim was located in 1882 and patented in 1892. No production came from this claim until 1943 when George
Green and associates shipped 500 tons of oxidized copper ore, obtained from the surface and near-surface workings. These shipments averaged 10.8 per cent copper, 3.8 per cent zinc, and 0.55 ounce of silver per ton. A total of 7 ounces of gold, 244 ounces of silver, and 92,794 pounds of copper were recovered. The total value, based on the ceiling price for copper, was $11,554.10

During the early exploration of the Old Dick claim, the northern shaft was sunk 50 feet and the southern shaft 67 feet. The 3910 adit (Fig. 43) was driven 240 feet and from the adit a vertical winze (now filled with water) was sunk 68 feet. The present lessees have extended the adit an additional 65 feet. The 3960 adit was started in 1944 but abandoned when massive sphalerite was encountered 100 feet from the portal. In 1947 the adit was extended 34 feet in ore and a connecting raise driven between the two adits (Fig. 44).

The ore occurs in the Yavapai schist (Fig. 43) which consists of chlorite schist and amphibolite derived from lava flows and tuffs. The meta-volcanics have been silicified and sericitized in zones adjacent to the metarhyolite and metadiabase. However, alteration is post-metadiabase for it is locally sericitized and silicified. The textures and structures of the foliated meta-volcanics are preserved in the altered zone.

The massive sulfide ore consists of resinous and black sphalerite. Pyrite is concentrated in irregularly spaced narrow bands. Where banding is dominant crystals of pyrite, apparently corroded, are disseminated throughout the massive sphalerite. Chalcopyrite occurs in minute stringers that cut the massive sphalerite or follow the edges of pyrite bands. Microscopic grains of chalcopyrite are uniformly distributed throughout the sphalerite. Conspicuous steel gray arsenopyrite crystals up to one quarter of an inch in length are disseminated through the massive sulfides. These crystals contain 1.21 per cent of cobalt proving a cobaltian variety of arsenopyrite.

Supergene enrichment has formed chalcocite and covellite coatings primarily on the sphalerite, but also on the pyrite and chalcopyrite. The distribution is not uniform, but where these two copper sulfides are abundant the copper content is two to three times that of the primary sulfides. The oxidation of the copper minerals at or near the surface has produced ore of shipping grade to a depth of 30 feet. Malachite and azurite are the chief copper minerals, but cuprite is locally important.

The massive sulfides form tabular masses in the sericitized and silicified Yavapai schist. The lenses are vertical or dip steeply west essentially parallel to the foliation of the schist. Their size and number are incompletely known. The massive sulfide body encountered in the two adits (Fig. 44) forms a continuous body 10 to 20 feet wide, more than 150 feet long, and at least 120 feet deep. Present exploration indicates that the north end plunges

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*Compiled by the Salt Lake office, Metal Economics Div., U.S. Bur. of Mines.*
Figure 43.—Geologic map of vicinity of Old Dick mine. Geology by J. D. Strobell, Jr.
Figure 44.—Section and level maps of Old Dick mine. Relative position of adits and location of section A-A' given in Figure 43. Prepared by J. D. Strobell, Jr., with additions by C. A. Anderson; bruntion and tape surveys.
south about 45°. Surface gossan appears only at the north end. The primary sulfides are not confined entirely to tabular massive aggregates but also occur disseminated in thoroughly silicified rock, but this material may be too low grade to mine. Sulfides are also found in small veinlets along the foliation planes of the country rock beyond the zone of intense alteration, but these are of doubtful economic importance.

No massive gossan occurs at the surface of the wide belt of intensely altered meta-volcanics west of the metadiabase and the leached cavities in the outcrops suggest only original disseminated pyrite. Because of the apparent lack of uniform distribution of copper-zinc metallization throughout the altered metavolcanics, the structural influence of the intrusive metadiabase and metarhyolite may have been important in providing channels for the ore-bearing solutions.

The winze in the 3910 adit is reported to have bottomed in massive sulfides, and future exploration might test for ore continuity at depth as well as along the strike. Massive sulfide on the dump of this adit was sampled and assayed 12.92 per cent zinc, 2.10 per cent copper, 0.31 per cent lead, and 0.07 per cent cobalt. Ore mined in January, 1948, from the 3910 adit contained from 20 to 25 per cent zinc and 2 per cent copper.\textsuperscript{11} Gold and silver content was very low. The ore was concentrated to 50 per cent zinc at the Hillside mine until April, 1948, when the zinc grade increased sufficiently to ship direct to the smelter.

Future exploration should test at depth the altered zone between the metarhyolite and the metadiabase and if minable bodies of sulfide ore are found, it would be worthwhile to explore the zone of silicified and sericitized rocks west of the metadiabase.

**MOUNTAIN SPRING MINE**

The patented Mountain Spring claim is along the south end of the Mountain Spring fault, less than 1 mile east northeast of the Old Dick mine (Fig. 38). The claim is owned by M. L. Lynch and J. W. Lawler. Development along the quartz vein consists of two shafts, each approximately 45 feet deep, and several cuts and pits. The production to 1945 has been of hand-sorted sulfide ore, one shipment averaging 25 per cent lead, 1 per cent copper, and 19 ounces of silver per ton. The total production has amounted to 14,405 pounds of lead, 510 pounds of copper, and 560 ounces of silver, having a total value of \$1,396\textsuperscript{12} based on ceiling prices.

Several parallel and branching quartz veins contain galena, sphalerite, chalcopyrite, and pyrite. These veins average about 1 foot or less in width; the observed maximum width is 3 feet. The veins are all steeply dipping, and one can be traced for approximately 1,500 feet.

\textsuperscript{11}E. R. Dickie, personal communication.

\textsuperscript{12}Compiled by Salt Lake office, Metal Economics Div., U.S. Bur. of Mines.
STUKEY MINE

The Stukey mine is 2 miles south of Bagdad and about a mile east of the Mountain Spring fault (Fig. 38). The initial prospecting was done in the early part of the century and in 1916, C. C. Stukey and Charles Crosby shipped fluxing ore to the Humboldt smelter. The last shipment of ore was made in 1938. The claims are unpatented and no recent assessment work or filing of relocation are recorded.

Production has been 38,743 pounds of lead, 7 ounces of gold, 355 ounces of silver, and 114 pounds of copper, having a total value of $3,588.13

A narrow vertical quartz vein, usually less than a foot wide, strikes north. Pyrite, galena, sphalerite, and minor chalcopyrite are the principal primary sulfides. The vein has been explored by numerous small pits, one adit, a shaft at the south end of the vein, and a main working shaft north of the road. No information is available as to the extent of the underground workings.

COWBOY MINE

The Cowboy mine is 2½ miles southeast of Bagdad, less than a mile south of the Bagdad-Hillside road (not shown on Fig. 38). G. G. Gray holds six unpatented claims by annual assessment work. It is reported that the chief value of the ore has been in gold and silver, but some lead is present. The vein is a small, irregular quartz vein that strikes N. 10°-30° W. and dips 50°-80° W. It has a maximum width of 3 feet but averages about 1 foot. A shaft about 200 feet deep connects with approximately 400 feet of drifts, north and south of the shaft. The workings are now under water.

GOODENOUGH MINE

The Goodenough patented claim is about a mile southwest of the Hillside mine on the west bank of Boulder Creek (Fig. 38). A copper-lead-zinc quartz vein, carrying some gold and silver, occurs in a rhyolite plug. A shaft has been sunk on the vein, and a small shipment of ore was packed out on burros. The arsenic content is reported too high for shipping ore.

CUPRUM CLAIM

The Cuprum patented claim is 2 miles northwest of Bagdad along Boulder Creek (Fig. 38). It is owned by M. L. Lynch and J. W. Lawler. A 30-foot adit has prospected a quartz vein 1 foot wide that strikes N. 45° W. and dips 80° SW. The vein is oxidized and crushed by post-mineral faulting. Vein quartz containing stringers of galena, sphalerite coated by covellite, and pyrite was found on the dump, and presumably this came from a winze at the face of the adit.

VIDANO CLAIMS

Two and one-half miles north of Bagdad and west of the Hillside mine road (Fig. 38), several quartz veins, 3 inches to 1 foot wide, occur in the granite. They have a general north strike and steep dip east and west. Eight unpatented claims, Vidano 1 to 8, are held by annual assessment work by Bert Vidano. Several trenches, shafts, and short adits have been excavated along the veins. Most of the vein outcrops are barren except for a little limonite and malachite stain. Locally sulfides occur in the quartz and a shipment in 1936 of hand-sorted galena is reported to have contained gold, silver, and copper, in addition to the lead.

CHAPTER XI.—WALLAPAI MINING DISTRICT, MOHAVE COUNTY, ARIZONA

BY McCLELLAND G. DINGS

INTRODUCTION

The Wallapi mining district, northwestern Arizona, is in Mohave County about 15 miles north of Kingman. The district is about 10 miles long and 4 miles wide, trending northwest obliquely across the Cerbat Mountains. It includes the principal mining camps of Chloride, Mineral Park, Cerbat, and Stockton, all of which are nearly deserted, except Chloride.

The topography is moderately rugged with maximum relief of about 3,500 feet; the highest point is Cherums Peak, altitude 6,973 feet. The Cerbat Mountains rise sharply from the detritus-filled valleys bordering the mountains on the east and west.

HISTORY AND PRODUCTION

Between 1863 and 1900 many of the deposits were discovered by prospectors in quest of silver and gold which occur in the oxidized parts of the fissure veins; the silver is commonly in very rich concentrations. Cergryrite, argentite, native gold, and galena were the principal ore minerals recovered in the early days. Improvement in transportation facilities and in milling methods led to subsequent production of base-metal ores. At first galena with a low silver content was mined, but later sphalerite also became an important ore mineral of the district. Zinc-lead production reached its peak during the years 1915 to 1917 when metal prices were high and there was large-scale production from the Tennes-see and Golconda mines. In October, 1917, a fire destroyed the Golconda mill and other surface equipment, and since then the

1Published by permission of the Director, U.S. Geological Survey. Manuscript received March 31, 1949. A detailed report is in preparation pertaining to the field work done in the district from February to June, 1943.

mine has produced only on an intermittent and small scale. The Tennessee mine, however, has produced for many years except for occasional short periods during which operations were not in progress.

There are about 225 mines, plus an estimated 1,000 shallow pits, shafts, and prospects in the district. Most of the mines are old and largely or entirely inaccessible. Only a few reached depths below the oxidized zone which commonly ranges from 50 to 200 feet.

The total value of gold, silver, copper, lead, and zinc produced in the district from 1901 to 1946 was $23,984,960. Several million dollars may be added to this total for the value of ore produced prior to 1901 when no accurate records were kept. The largest past producers have been the Tennessee and Golconda mines, whose combined output has accounted for about 87 per cent of the total value of the lead and zinc produced.

GEOLOGY

The rocks of the district consist of pre-Cambrian crystalline rocks, chiefly of granitic composition, cut by large masses of Mesozoic (?) granite (Fig. 45). Dikes are scattered throughout the area. Some are parallel to the prominent northwest-trending system of veins, but others trend in various directions. Remnants of volcanic rocks of probable Tertiary and Quaternary age are around the margins of the Cerbat Mountains but are not present in the area shown on Figure 45.

The pre-Cambrian rocks consist of a complex of amphibolite, hornblende schist, biotite schist, chlorite schist, diorite gneiss, granite and associated pegmatitic bodies, granite gneiss, schistose granite, granitic schist, and garnetiferous schist. Granite and amphibolite are the most widespread types, and the granite is predominant.

The amphibolite, which is one of the oldest rocks in the area, is a dark green to black, fine to medium-grained rock commonly epidotized and cut by granite pegmatite intrusions. It is widely distributed throughout the area but is particularly conspicuous near Chloride and in the low hills between Cerbat Canyon and Mineral Park Wash.

The pre-Cambrian granites are represented by many types. Some of the bodies are distinct and separate intrusions but others are probably differentiation facies. Typically the rock is light-gray, medium-grained, gneissoid granite containing a small amount of mafic minerals, chiefly biotite. Weathered surfaces are usually light buff, less commonly reddish brown.

Near Mineral Park in the central part of the district a large granite stock has intruded the pre-Cambrian granites, gneisses, and schists. Its age is tentatively assigned to late Jurassic or early

*Production data furnished by C. E. Needham, U.S. Bur. of Mines, Salt Lake City, Utah.*
Cretaceous, the same as the batholiths of California and western Nevada. The granite is essentially medium-grained, slightly porphyritic, and intensely altered, although there are many facies of fine or coarse grained granite, granite porphyry, porphyritic granite, and granite pegmatite. Numerous small stocks and irregular bodies of greenish-black gabbro and associated diabase dikes occur most commonly in the southern part of the district. These are probably differentiation facies of the granite stock. Mineralizing solutions that formed the veins in the district are believed to be genetically related to the late Mesozoic (?) granitic intrusion.

Dikes of many different compositions are widespread. In thickness they range from a few inches to 300 feet. Some extend along strike for only a hundred feet or less whereas others, notably the rhyolites, extend for long distances (Fig. 45). The most abundant dike rocks are granite pegmatites of both pre-Cambrian and late Mesozoic (?) age, and dikes formed from them are usually narrow and of short lateral extent. Aplites are not common. Other dike rocks, some of which are abundant locally, include lamprophyre, andesite, diabase, porphyritic granite, granite porphyry, and rhyolite, and are probably differentiation products of the late Mesozoic (?) intrusion.

The structure of the rocks is complex. Gneissic and schistose structures are common; the prevailing schistosity strikes northeast with steep dips either northwest or southeast. Large and small folds, generally with northeast trends, are common. The most prominent fold is near Chloride where the outcrop pattern of the amphibolite indicates a northeast-plunging anticline. Prominent joint systems, sheeting, and small shear zones, commonly with northwest strikes, are abundant. Faulting is widespread and is usually well expressed by a prominent system of northwest-trending fault fissures in which many of the later veins are located. The dips of the fissures are generally steep, and northeast dips predominate. In places the fault fissures are in conjugate systems. The fissures show much branching and in a few places considerable horsetailing. Gouge and breccia, as well as numerous tear faults in the walls, are present along some fault fissures. The direction of the striations along the walls of the faults is nearly horizontal in places, but a greater number of striations show dips ranging from horizontal to parallel with the dip of the steep fault surface.

From the southern end of the district northwest to the folded area near Chloride the fissures maintain a general parallelism in strike, which is approximately at right angles to the regional schistosity. In the folded area near Chloride, however, the fissures conform to the general direction of schistosity. Here they change first to a more nearly north strike, then follow the curvature in the strike of the rocks to the north and west around the axis of the fold so that in the extreme northwest part of the mapped area the fissures strike nearly due west.
The age of the faulting that produced the prominent northwest fault fissures is not known. The fact that the faults cut the old gneissic and schistose structures and in turn are filled, or partly filled, in many places by late Mesozoic (?) dikes and vein material indicates that the initial, and probably most intense, movement occurred after the gneissic and schistose foliation was developed in the pre-Cambrian complex and prior to the late Mesozoic (?) intrusion. Brecciation of the vein material in a few places indicates that some movement occurred at intervals throughout and following ore deposition. This movement is believed to have been largely a minor adjustment along the relatively weak northwest fault fractures. Additional faulting, believed to be younger than the minor adjustments along the northwest fault fissures, occurred in a few places; this faulting was of minor importance and is most commonly expressed by crosscutting faults of small displacements offsetting the dikes and veins.

ORE DEPOSITS

The ore deposits occur in quartz veins filling the fault fissures. The width of the veins ranges from a few inches to about 35 feet and averages 3 to 4 feet. In a few places the deposits are in lodes which rarely exceed a width of 50 feet. In length the veins range from less than 100 feet to almost 2 miles (Victory vein), and the aggregate length of the veins in the district is about 85 miles. Dips are commonly steep, and some veins show reversal in dips along the strike or down dip.

The type of wall rock has had little effect upon the character of the veins except that some veins tend to branch more readily in amphibolite than in granite. Soft gouge bands, a fraction of an inch to several feet in width, may be present on the hanging or footwall, on both walls, or they may traverse the veins irregularly. Many veins, however, are frozen to the walls. Wall rock alteration is moderate to slight. Sericitization is the most common type of alteration, but locally silicification has developed along sheeted and shear zones. Rhyolite and granite are generally more intensely silicified than the basic dikes and amphibolite bodies. Pyrite commonly impregnates the wall rock for distances ranging from a fraction of an inch to several feet.

The vein minerals fall into three general groups: oxidation products, products of downward sulfide enrichment, and primary (hypogene) minerals. Minerals of interest in the oxidized zone are cerargyrite, and, to a less extent, native silver, native gold, and cerussite. Argentite is the most important ore mineral in the secondary sulfide enrichment zone. In the early years of mining most attention was paid to the oxidized and secondary sulfide enrichment zones because of their precious metal content, but in recent years the base metals of the primary zone have been the most important. The most important ore minerals of the primary zone are sphalerite and galena, and, to a lesser extent, chalcopyrite. Gangue and less common ore minerals include quartz, cal-
cite, manganiferous siderite, rhodochrosite, pyrite, molybdenite, argentite, tennantite, pearceite, polybasite, and stibnite.

The ore shoots in the unoxidized zone are complex assemblages of galena, sphalerite, and pyrite in quartz gangue. Chalcopyrite is not nearly as abundant as sphalerite, galena, or pyrite; but at a few of the mines, such as the Pinkham, Midnight, and Keystone, a moderate amount of copper was recovered along with the other ores. Much of the vein matter is very low grade. Narrow stringers and small irregular masses of the valuable minerals may persist throughout almost the entire length of the vein, but they are too narrow to be commercially valuable unless their gold and silver content is high. A few quartz veins that are barren occur but such veins are short. Most of the veins have not been explored to sufficient depths to warrant condemnation based on the low base-metal content.

Ore shoots commonly range in widths from 1 to 4 feet, and lengths and breadths of 10 to 50 feet. However, one ore shoot in the Tennessee mine extends 400 feet horizontally and 700 feet vertically. Reports on the inaccessible workings of the Golconda mine are that one ore shoot exceeded in size any in the Tennessee mine. Commercial ore has been reported at a depth of about 1,600 feet from both these mines, which are the two deepest in the district.

Localization of ore bodies may occur at intersections or forkings of veins or where the strike of the vein changes, but these criteria are extremely general and none too trustworthy. Chalcopyrite and sphalerite show a tendency to increase with depth although exceptions occur. Chalcopyrite has been found in larger amounts nearer the Mesozoic (?) granite intrusion than in the outlying areas, but indications of pronounced lateral zoning in the district are generally lacking. Also high silver content is present in veins in the extreme southeast and northwest parts of the district, suggesting that the greatest silver concentration formed at a considerable distance from the main intrusive body.

FUTURE ECONOMIC IMPORTANCE

The future economic importance of the district lies chiefly in the base-metal content of the veins. The majority of veins have not been explored sufficiently at depth to test the base-metal content, particularly the zinc content. From a geologic study of the veins in the district there is no positive reason for assuming that any of several other veins will not be as productive of lead and zinc as the Tennessee or Golconda veins. Future development work, particularly at greater depths, on the many miles of veins in the district may disclose several veins that will prove to be their equal or better.
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SERVICES OFFERED BY THE ARIZONA BUREAU OF MINES

(Continued from inside front cover)

3. Geologic investigations of mining districts and counties and the making of topographic and geologic maps and reports. In co-operation with the United States Geological Survey a large-scale base map, a reconnaissance geologic map, and a topographic map (100-meter contours) of the entire state have been published. Geologic reports on various mineral resources of the state are prepared.

4. The Bureau provides an ore-testing service for ores originating within the state of Arizona. Full details will be furnished on request.

5. Semitechnical meetings with miners and prospectors are held throughout the state.

6. The collection and dissemination of statistics relating to the mineral industries of the state.

7. The collecting and filing of all items relating to Arizona mines and minerals that appear in Arizona newspapers and in many technical periodicals.

MAPS OF ARIZONA

The Arizona Bureau of Mines now has available for distribution the following maps of the state:

A. Base Map of Arizona on a scale of about 17 miles to the inch. This map is strictly geographic, indicating the positions of towns, railroads, rivers, surveyed lands, national forests, national parks and monuments, etc., revised to 1939. It is printed in black on one sheet 22x26 inches and sells for 30c unmounted.

B. Topographic Map of Arizona in one sheet 42x54 inches, on a scale of about eight miles to the inch. It conveys all of the information given by the Base Map and, in addition, shows topography and highways. The topography is indicated by contour lines of 100-meter interval. A table for converting meters to feet is printed on the map. This map was issued in 1933 and revised as to highways in 1946. It is sold, unmounted, for $1.25.

C. Geologic Map of Arizona in one sheet of many colors. It was issued in 1924 on the same scale as the Topographic Map, but it is now out of print, and its lithographic plates are worn beyond repair. The Arizona Bureau of Mines has only a few remaining office copies of the Geologic Map available. They may be borrowed upon deposit of $15.00 per mounted copy. If the map is returned in good condition at the end of a specified period, usually 30 days, the full amount of the deposit will be refunded. The Arizona Bureau of Mines hopes that persons who obtain the map on loan will not retain the map and forfeit the deposit but will return it within the specified time, in order that the few remaining copies may be conserved for future use.

D. Metallic Mineral Map of Arizona, 25x27 inches. This map consists of a red overprint made on Map A, and shows the principal known localities of metallic minerals by means of representative symbols. It also gives the value of metal production for the major districts and for the State. Roads are indicated. This map was revised in May, 1946, and sells for 35c.

E. Nonmetallic Mineral Map of Arizona, 25x27 inches, similar to Map D but devoted to nonmetallic minerals. This map was revised in May, 1946, and sells for 35c.

F. Map of Arizona Mining Districts, 25x27 inches. This map consists of a red overprint made on Map A and shows the principal known mining districts or mining localities by means of numerals. Roads are also indicated. An index to the districts or localities is printed on the margin. This map was revised in May, 1946, and is sold for 35c.

All communications should be addressed and remittances made payable to the Arizona Bureau of Mines, University Station, Tucson, Arizona.
The Arizona Bureau of Mines still has the following bulletins available for free distribution to residents of Arizona. Bulletins not listed here are out of stock and cannot be procured from the Bureau.

Because of the very heavy demands for bulletins from nonresidents of Arizona, which quickly exhausts stocks, it has become necessary to discontinue to send free bulletins out of the state. Nonresidents may purchase bulletins at the prices quoted, which include mailing charges.

127. Manganese Ore Deposits in Arizona, by Eldred D. Wilson and G. M. Butler, 1930.......................................................... $ .25

134. Geology and Mineral Deposits of Southern Yuma County, by Eldred D. Wilson, 1933.......................................................... .50


139. Some Facts About Ore Deposits, by G. M. Butler, 1935............ .15

140. Arizona Metal Production, by Morris J. Elsing and Robert E. S. Heineman, 1936................................................................. .25

141. Geology and Ore Deposits of the Ajo Quadrangle, by James Gilluly, 1937................................................................. .25

143. Geology and Ore Deposits of the Tombstone District, Arizona, by E. S. Butler, E. D. Wilson, and C. A. Rasor, 1938............. .50

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148. Tungsten Deposits of Arizona, by Eldred D. Wilson, 1941........ .25

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