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Tiger: A Brief Look at Current Utilization and Potential

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Senior Geologist

1984 Magma Co?

Introduction

The mines of Tiger, or Schultz, as it once was known, are famous. Not, perhaps, for the value of their production (other mines have exceeded them) nor for the variety of metals produced (significant production of Au, Ag, Pb, Zn, Cu, V, and Mo), but largely for the diversity and beauty of the mineral specimens found here. Many of the seventy or so minerals have been found in few other deposits. Specimens from Tiger are found in most of the major mineral collections of the world.

Tiger has a colorful history going back to 1878, when Frank Schultz staked his first claim on the Collins vein. We are not going to dwell on the history or the details of the deposit. For these, please refer to the publications listed in the bibliography.

Today's paper will dwell primarily with Magma's current utilization of the deposit, examine some of the evidence regarding its origin and geologic history, then consider its potential and future if time allows.

By the time Magma had acquired the San Manuel deposit and commenced development in the early fifties, the Mammoth-St. Anthony Company was reaching the end of economic production. The final years of operation were in the sulfide zone deep in the Collins vein. Gold and silver content was low and lead and zinc prices were not high enough to justify continued mining. Magma acquired the property in exchange for stock in the new operation.

Early utilization was restricted to using the Mohawk Shaft as a supply of potable water for the new mine. By 1959 the water table was lowered below the old workings and the pumps in the Mohawk Shaft were shut off. Efforts were made to close all access to the mine to prevent injury to the curious and persistent rock collectors.

Current Utilization

Decontrol of gold changed the economic perspective. In the mid seventies an examination suggested that there was auriferous silicification in the mineralization peripheral to the primary veins that could provide siliceous flux for the smelter with sufficient metal credits to pay the cost of mining. A shallow diamond drilling program and surface sampling was conducted.

An open pit was started over the Mammoth Mine. Through 1978, over 100,000 tons were produced and used as converter flux by the smelter. Drilling had suggested a usable zone 80 ft. wide, centered on the Mammoth vein. The procedure was to mine this zone and combine it with silicified rhyolite to yield the desired volume of material with acceptable assays. Gold assays should have approximated 0.03 opt.

The results were disappointing. It was impossible to maintain sufficiently uniform silica content and the gold values were too low--0.011 opt. This application was discontinued in early 1979.

Tests conducted on stockpiled vein material suggested that, by crushing and screening to +3/8-in. minus two-in. size, the gold and silica content could be upgraded. In addition, the stockpiling operation would perform a blending function to stabilize grade fluctuations. While the siliceous flux (quartzite) in use then was high silica, it must be hauled 30 miles and incurs a royalty payment to the State. The cost is on the order of $10/ton, with no metal credits. Some of this material is still used to raise the silica content for fluxing.

In April 1983 a contractor, quarrying quartzite at our Camp Grant quarry, was invited to mine and process 20,000 tons of Tiger rock. Economics precluded extensive additional drilling, but the information available and visual examination extended the mining width for the test to 120 ft. Results were startling. The grade achieved for the minus two-in. rock was 73.7% silica and 0.044 opt. Au. Mining cost was approximately $5 per ton and the fines are usable as reverberatory flux.

Accordingly, a contract was let to produce 100,000 tons of minus two-in. Tiger flux at $5.45/ton. Silica content was 74.7% (75% of which is available silica) and metal credits were 0.048 opt. Au and 0.25 opt. Ag. Mining width was 250 ft. The metal content was bolstered by values contained in old dumps, stope filling, and pillars. The major advantage of this utilization is that there is no direct milling cost in recovering the gold values. They report to the slimes in the refinery.

Mining practice to date has been to drill and blast the approximate tonnage desired and make up any shortfall by ripping and dozing.

Origin and Geologic History

Probably no geologist has worked in the San Manuel area without speculating on the relationship between Tiger and the porphyry deposit. Is the spatial relationship causal in nature or coincidental? There have been many questions unanswered regarding time relationships of the various events recorded in the lithology of the area.

This year, with the known details of Tiger foremost in our thoughts because of the flux mining campaign, serendipity became an active force. Several pieces of information came to our attention in fortuitous sequence. One of the AGS sessions dealt with the mode of transport of epithermal gold. At this meeting I chanced to be seated by Jim Loghry, who logged core for Dave Lowell on the Kalamazoo project. He had some comments on gold distribution perceived in that project that were thought provoking. We happened to gain access to Weibel's thesis on the Cloudburst formation west of the mine with some pertinent age dating.

Before we proceed, let us consider a thumbnail sketch of the lithology of the two mines.

The San Manuel/Kalamazoo deposits are the faulted halves of mineralization emplaced following the intrusion of Laramide porphyry some 70 million years ago. The formerly economic mineralization created a near vertical elliptical cylinder with minor and major diameters of 2,500 and 5,000 ft. It probably had some primary tilt to the NE and was at least 8,000 ft. on the long axis. Mineralization occurs in both the porphyry and the pre-Cambrian host, Oracle granite, but is not necessarily symmetrical with regard to the intrusion. Subsequently, some sequence of faulting and tilting displaced the SW half down 8,000 ft. and laid the system over to the NE. The San Manuel fault which split the ore body also displaced the Cloudburst conglomerate and the younger Gila conglomerate. The only significant post mineral intrusion is rhyolite, which predates the fault and intrudes the Cloudburst, but not the Gila. Both the Gila and the Cloudburst units normally strike north to northwest and dip 30 to 45° to the east. Basin range faulting has offset the San Manuel fault in several places, usually down to the east, with displacements generally less than 200 ft.

The Tiger system occupies a NNW trending structural zone dipping steeply to the SW. This zone is occupied by or involves rhyolite. Much of the mineralization is along rhyolite contacts or in rhyolite breccia in the Mammoth vein portion. The vein was deeply oxidized and then faulted. The Mammoth fault strikes slightly more north than the vein, but dips steeply east, generally 75°. The originally deeper part of the faulted vein is called the Collins. It has Oracle granite in both walls, but the structure still involves rhyolite and rhyolite breccia.

The Mammoth vein was oxidized full depth to where it was intercepted by the fault between 700 and 800 ft. down. The Collins portion was almost entirely oxidized to the 600-ft. level and from the 700-ft. level down was largely sulfide, predominantly galena and sphalerite. By the time the lowest level, the 1025, was reached, pyrite and chalcopyrite seemed to be increasing.

The general concensus of workers in this area for a number of years regarding the age of the Cloudburst formation was that it was near contemporaneous with the porphyry intrusion a la Sillitoe. We now know that this is not true.

Weibel's thesis on the Cloudburst west of the mine lends several pieces of pertinent data. A rhyolitic welded tuff in the E half of section 33 near Schultz Spring was dated at 22 million years. This fits nicely as a known period of rhyolite activity.

An andesite unit striking NS through the middle of section 32, a mile west of Schultz Spring, dates at 28 million years, indicating normal sequence and position.

Imbrication studies indicate flow in the direction of dip, so there has been no reversal of dip. There are, however, any number of inferred or observed structures crossing Magma's property between Schultz Spring and Tiger. Much study is needed here.

Several working hypotheses have been developed or reinforced this year relating to local problems. Some of these are here briefly stated.

There has often been a problem in distinguishing the conglomerates of the area. It appears likely that the disconformity between the Gila and the Cloudburst was brief, but was marked by the emplacement of the closely related rhyolites and rhyodacites of the area. Conglomerate intruded by rhyolite or rhyodacite is Cloudburst, but if it contains clasts of these materials it is Gila.

Rhyodacite is marked by biotite plates, while the rhyolite is distinguished by quartz or feldspar phenocrysts. The tuff of Schultz Spring probably represents the Cloudburst surface at the time of rhyolite emplacement.

Now that Weibel's work places the Cloudburst formation in the Oligocene, it appears that there was ample time for erosion to reduce the cover over the porphyry system and allow oxidation to make the necessary ions available for redistribution of elements. The rhyolite event provided the trigger and added lead and zinc.

The rhyolites entered the area from a position that is now below the hoisting shafts. In many places in the shaft pillar we find evidence of lead-zinc mineralization spatially related to the rhyolites. The mineralogical sequence is quartz, specular hematite, galena, sphalerite, minor pyrite and chalcopyrite, and pink barite. The sulfides are discontinuous and are enclosed in gray quartz making their precise paragenesis vague. The alteration envelope is characterized by chlorite and is usually narrow, a foot or so. Gold and silver levels are low. The volume of material available for study has never been large and these occurrences are not economic.

References other than Weibel include Creasey's comments on multiple oxidation periods, the older one being related to an old erosion surface now tilted to the north. Also, Chaffee's trace element study indicated lower than background levels of lead-zinc in the porphyry system.

Tiger's Potential and Future

It is certain that we will continue to use some 50,000 tons per year of Tiger rock for flux. This usage will be proportional to smelter throughput. There are some options available to us that can alter the economics of this application.

The most recent mining contract was for 100,000 tons. Costs can be reduced by mining and stockpiling larger tonnages through the use of larger and more efficient equipment.

If gold prices move up and hold, it is possible to heap leach the stockpile and move some of the gold values forward in the cash flow.

Even though preliminary reports suggest low recovery from a heap leach, this is no drawback when the residual values will be recovered in the smelter.

The low leaching recovery has caused another series of tests to be requested. The recovery is low because a large percentage of the gold is micron-sized and locked in or between quartz grains.

If gold prices move up as some economists predict, Tiger potentially will once again become a mine in its own right. To this end it is prudent to establish some parameters for metallurgical treatment. One procedure suggested by the gold occurrence is a quartz float. The cationic collectors used in this process should also recover the molybdates and vanadinates.

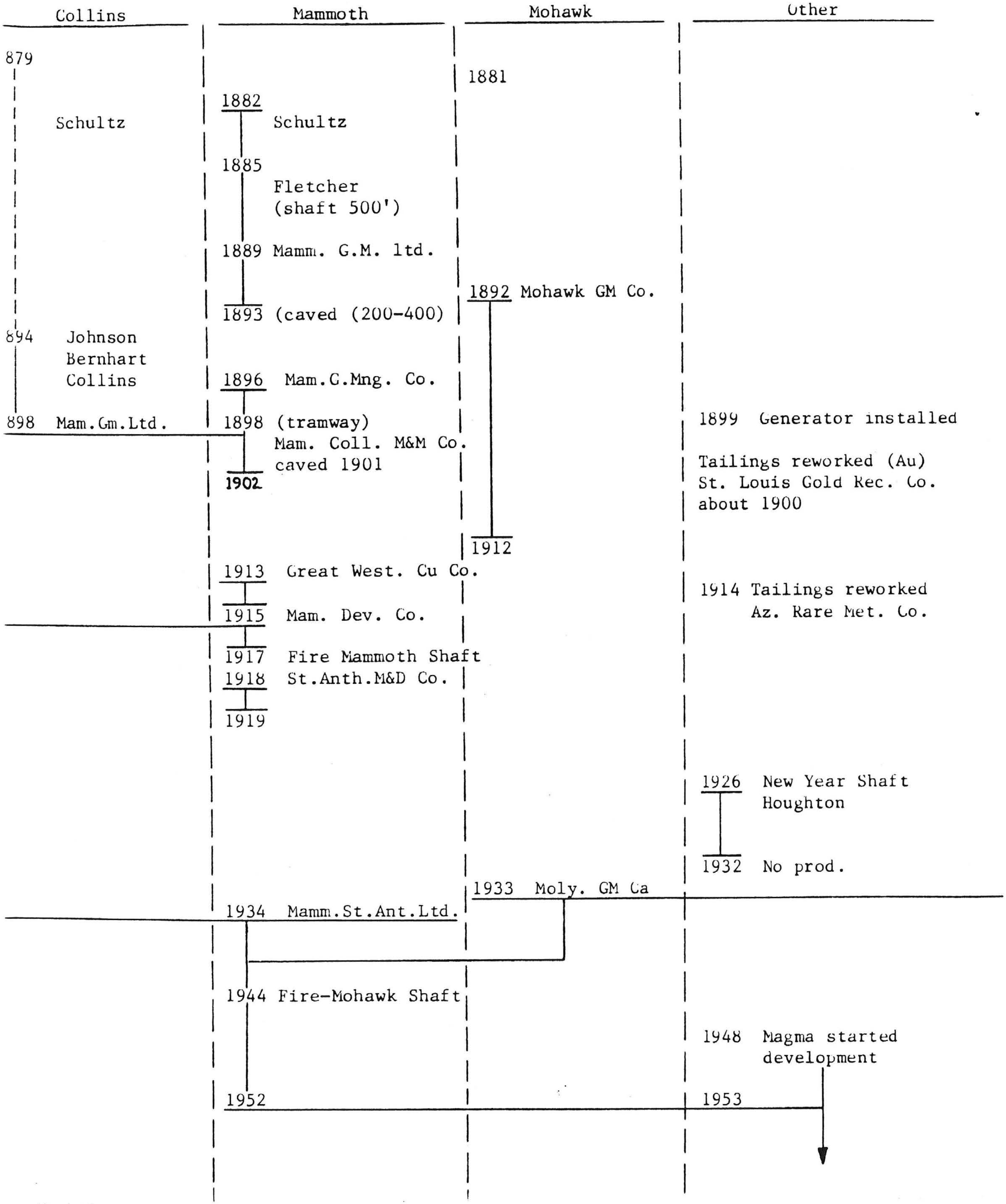
Gold production at Tiger was listed by Creasey as 397,201 ounces through 1947. How much gold remains? A gross calculation involving the Mammoth vein alone gives a clue. Known length is 2,000 ft. Minimum depth is 700 ft. Using a 100-ft. width for the zone, we have a volume of 140 million cu.ft. Using a bulk density of 14 cu.ft. per ton to allow for mine openings and filled stopes would indicate 10 million tons. At 0.04 ounces per ton, there is a suggested potential of 400,000 ounces, or something equivalent to past production.

The current pit was designed to provide siliceous flux with no stripping. Planned depth is to 3,100 ft. elevation, or just below the old 100-ft. level. This will allow recovery of the pillars and sills. Gold cutoff grade is mining cost, or 0.015 ounces per ton. Internal waste is processed. It usually is higher than average in silica. What would have been waste in the high NE wall was also processed because of a high silica content. Planned gold content was 0.04 ounces per ton, but this has been persistently bettered. There are 700,000 tons remaining, but this is open ended to the SE.

Additional open pit mining would involve considerable stripping. There is one other feasibility study that needs to be conducted that was suggested by an event in 1901. The early stopes were supported by square sets and were not filled. On the night of April 15, 1901, the stopes north of the Mammoth Shaft caved from the 750 level to the surface. No one was injured nor was the surface plant or shaft damaged. The cave followed the vein to the surface where there was 25 ft. or more of subsidence.

Should economics suggest that maximum production were desirable, the action of that cave suggests that a slot caving procedure could be successful. It may be some time before we let go of the Tiger's tail.

Tiger Mines' Chronology



Collins

879
Schultz
894 Johnson
Bernhart
Collins
898 Mam.Gm.Ltd.

Mammoth

1882 Schultz
1885 Fletcher
(shaft 500')
1889 Mamm. G.M. ltd.
1893 (caved (200-400)
1896 Mam.G.Mng. Co.
1898 (tramway)
Mam. Coll. M&M Co.
caved 1901
1902
1913 Great West. Cu Co.
1915 Mam. Dev. Co.
1917 Fire Mammoth Shaft
1918 St.Anth.M&D Co.
1919
1934 Mamm.St.Ant.Ltd.
1944 Fire-Mohawk Shaft
1952

Mohawk

1881
1892 Mohawk GM Co.
1912
1933 Moly. GM Ca

Other

1899 Generator installed

Tailings reworked (Au)
St. Louis Gold Rec. Co.
about 1900

1914 Tailings reworked
Az. Rare Met. Co.

1926 New Year Shaft
Houghton
1932 No prod.

1948 Magma started
development
1953

9/91

Mammoth (F) PINAL 4 K

TIGER PROJECT SUMMARY

INCLUDES TIGER AND MOHAWK DEPOSITS

The Tiger Project is located in Pinal County, Arizona on property owned by Magma Copper Company adjacent to the San Manuel Mining Division's underground block caving and open pit copper oxide dump leach facilities. The Tiger deposit is a narrow vein precious metals ore body previously mined by underground methods. Extensive exploration drilling has delineated a potentially open pit minable reserve. Preliminary designs are completed and detailed cost data is required to complete the feasibility study.

The ore deposit is to be mined by open pit methods in benches 20 feet high. The pit wall will be "triple benched." In other words, three benches (60 feet) will be mined before stepping in to leave a catchment. Overall pit walls will be left at about 53 degrees, depending on ramp locations, with inter-ramp slopes of 60 degrees. The face angle is expected to be 75 degrees. This will leave an 18.5 foot catchment every 60 vertical feet. (See the attached sketch.)

Blasting practices must be very well controlled as both a competent pit wall must be maintained and the very close SX-EW facilities must be protected. Magma will be responsible for the design, loading and firing of blast patterns in the Tiger pits with the aid of our current blasting contractor. A typical pattern will consist of 5 inch blast holes, 25 feet deep, spaced 12 feet apart on a square grid. Magma staff will sample drill hole cuttings and deliver them to our assayer. To minimize ore dilution, blast patterns may be designed to extract waste away from unbroken ore.

To insure delivery of material to its proper location, Magma's engineering staff will survey and stake out ore/waste zones and monitor the delivery of mined material. Pit progress will be surveyed monthly to determine volumes of material mined and placed in waste dumps. Quarterly aerial surveys will be flown to verify monthly surveys. These surveys will be used to determine monthly pay quantities. Magma's engineering staff will design, and pass to the surveyor for staking, pit plans and designs. These plans will include temporary and permanent ramp locations, bench toes and crests, and other required control points. Magma will provide minimal bench and dump grade control.

The design parameters used for the permanent haul road in the preliminary pit contained in this data, are based on the general characteristics of a 50 ton mechanical drive haulage truck. Roads are 40 wide, including berm, at 12% grade. Temporary haul roads for stripping the upper benches will vary considerably and will be designed to take best advantage of each situation. Other roads, to and from the crusher site for instance, will built and maintained by the mining contractor whose input into the design will be critical.

Ore is to be crushed by the contractor to 100% passing a 6" grizzly and delivered to a stockpile or storage bin at Magma's crushing/agglomeration facility. Magma will take possession of the ore at that point for final sizing, agglomeration and stacking on the leach pad.

The total volume of material to be mined is 7,000,000 yards or 14,700,000 tons. Ore volume is approximately 1,337,000 yards (2,888,000 tons). Total waste volume is 5,634,000 yards (11,834,000 tons) of which 1,295,000 yards (2,332,000 tons) is Gila conglomerate.

The preliminary mining schedule calls for a 6-month pre-production stripping phase (ore stockpiled as the pad is constructed), followed by 39 months of sustained ore production. The Stripping requirements decrease as the production continues. The early high stripping requirements is a reflection of the deposit geometry; a narrow, near vertical ore zone with essentially barren wall rock. The ore delivery rate is a function of the long leach cycle of the ore and the limited pad area. Although a fixed total mining rate would be advantageous from a mining point of view, an increasing ore delivery rate it is not considered a viable schedule for the heap.

COST ASSUMPTIONS

DAILY WORK SCHEDULE: No restrictions. Prefer 3 shifts/day-7 days/week.

ELECTRIC POWER: Available line power at crusher site suitable for crushing/screening equipment. Include estimate of power consumption only (kw-hrs) with cost estimate. (Magma pays electric bill.)

WATER: Process water for dust control available at crusher site. Potable water available at nearby facilities.

FUEL: Diesel fuel available on site for off-road equipment only.

OFFICE SPACE: No on site offices available; contractor to provide their own.

CHANGE ROOM FACILITIES: No on site facilities available; contractor to provide their own.

EQUIPMENT MAINTENANCE FACILITIES: No on site facilities available; contractor to provide their own.

PROJECT ACCESS: Paved access from town of Mammoth to east side of Magma property (gate #5). Well maintained dirt road to mine site (about 1.5 miles) around north side of existing copper oxide leach dump.

COST ESTIMATE FORMAT

Three separate costs need to be estimated. Drilling, loading and hauling, and crushing. In each of these estimates, please outline the fuel and electric power requirements separately, we will apply our costs to those items. A listing of the primary equipment items and manpower requirements by job classification is also requested. Please include an estimate of water requirements and a proposed daily work schedule (ie. shifts/day etc.).

For example:

X DRILLING: COST PER FOOT =
FUEL GAL/FOOT =

MINING: COST PER CUBIC YARD =
FUEL GAL/CUBIC YARD =

CRUSHING: COST PER TON =
KW-HRS PER TON =

EQUIPMENT FLEET:
- LOADERS: number, size, make/model
- TRUCKS: number, size, make/model, performance data
- DRILLS: number, make/model
- DOZERS:
- ROAD MAINTENANCE EQUIPMENT: graders, RT dozers, water trucks, etc.
- CRUSHING PLANT: crusher make/model, size, power requirements, permitted?
  screens, conveyors

MANPOWER:
- EQUIPMENT OPERATORS:
- TRUCK DRIVERS:
- CRUSHER OPERATORS:
- MAINTENANCE:
- SUPERVISION:

WORK SCHEDULE:

WATER REQUIRED: gpm or gallons per day

MOHAWK PIT RESERVES

YARDS

AJF 09-Sep-91

FCONE 001 MODEL #6

BENCH	ORE YDS.	WASTE YDS.	TOTAL	CUM. TOTAL
3140	0	3,142	3,142	3,142
3120	0	13,613	13,613	16,755
3100	156	50,823	50,979	67,734
3080	5,687	139,288	144,975	212,709
3060	18,785	137,941	156,726	369,435
3040	20,741	124,029	144,770	514,205
3020	17,184	96,283	113,467	627,672
3000	24,555	77,756	102,311	729,983
2980	25,805	65,081	90,886	820,869
2960	21,385	42,814	64,199	885,068
2940	23,890	30,501	54,391	939,459
2920	22,066	22,524	44,590	984,049
2900	14,465	10,551	25,016	1,009,065
2880	11,484	4,137	15,621	1,024,686
TOTAL	206,203	818,483	1,024,686	

MAMMOTH PIT RESERVES

YARDS

AJF 09-Sep-91
FCONE 001 MODEL #6

BENCH	ORE YDS.	WASTE YDS.	TOTAL	CUM. TOTAL
3440	0	1,445	1,445	1,445
3420	0	9,183	9,183	10,628
3400	0	18,836	18,836	29,464
3380	0	25,647	25,647	55,111
3360	0	43,126	43,126	98,237
3340	6,975	56,093	63,068	161,305
3320	12,179	50,862	63,041	224,346
3300	9,719	65,163	74,882	299,228
3280	7,669	80,215	87,884	387,112
3260	12	87,952	87,964	475,076
3240	0	118,184	118,184	593,260
3220	74	204,827	204,901	798,161
3200	8,115	277,431	285,546	1,083,707
3180	10,106	335,903	346,009	1,429,716
3160	17,409	404,122	421,531	1,851,247
3140	43,526	400,680	444,206	2,295,453
3120	73,940	393,844	467,784	2,763,237
3100	79,680	367,332	447,012	3,210,249
3080	79,621	303,662	383,283	3,593,532
3060	76,944	287,368	364,312	3,957,844
3040	108,694	370,092	478,786	4,436,630
3020	89,934	187,580	277,514	4,714,144
3000	90,520	170,828	261,348	4,975,492
2980	85,700	159,598	245,298	5,220,790
2960	76,039	117,748	193,787	5,414,577
2940	68,356	100,897	169,253	5,583,830
2920	71,709	83,254	154,963	5,738,793
2900	49,179	62,981	112,160	5,850,953
2880	21,643	39,584	61,227	5,912,180
2860	16,507	27,772	44,279	5,956,459
2840	11,270	13,572	24,842	5,981,301
2820	9,696	7,015	16,711	5,998,012
2800	5,626	3,331	8,957	6,006,969
TOTAL	1,130,842	4,876,127	6,006,969	

MAMMOTH PIT RESERVES

YARDS

AJF 09/09/91

	ORE				WASTE				
BENCH	QUARTZ MONZONITE	TERTIARY ROCKS	GILA CON-GLOMERATE	TOTAL YDS. ORE	QUARTZ MONZONITE	TERTIARY ROCKS	GILA CON-GLOMERATE	TOTAL YDS. WASTE	TOTAL ALL YARDS
3440	0	0	0	0	34	1,411	0	1,445	1,445
3420	0	0	0	0	2,818	6,365	0	9,183	9,183
3400	0	0	0	0	1,970	16,866	0	18,836	18,836
3380	0	0	0	0	711	24,936	0	25,647	25,647
3360	0	0	0	0	4,423	38,703	0	43,126	43,126
3340	0	6,975	0	6,975	2,281	53,812	0	56,093	63,068
3320	3,263	8,916	0	12,179	3,519	47,343	0	50,862	63,041
3300	1,377	8,342	0	9,719	1,962	52,641	10,560	65,163	74,882
3280	319	7,350	0	7,669	324	56,715	23,176	80,215	87,884
3260	0	12	0	12	0	56,877	31,075	87,952	87,964
3240	0	0	0	0	4,907	60,143	53,134	118,184	118,184
3220	0	74	0	74	7,636	98,227	98,964	204,827	204,901
3200	4,625	3,490	0	8,115	52,262	97,929	127,240	277,431	285,546
3180	0	10,106	0	10,106	0	169,541	166,362	335,903	346,009
3160	7,118	10,291	0	17,409	33,549	186,043	184,530	404,122	421,531
3140	11,830	31,696	0	43,526	50,206	199,860	150,614	400,680	444,206
3120	19,633	54,307	0	73,940	143,149	175,990	74,705	393,844	467,784
3100	23,976	55,704	0	79,680	45,654	269,636	52,042	367,332	447,012
3080	34,199	45,422	0	79,621	79,469	201,971	22,222	303,662	383,283
3060	15,579	61,365	0	76,944	117,011	141,773	28,584	287,368	364,312
3040	42,026	66,668	0	108,694	93,121	221,063	55,908	370,092	478,786
3020	69,771	20,163	0	89,934	101,429	86,151	0	187,580	277,514
3000	70,016	20,504	0	90,520	91,119	79,709	0	170,828	261,348
2980	67,331	18,369	0	85,700	92,109	67,489	0	159,598	245,298
2960	67,988	8,051	0	76,039	80,436	37,312	0	117,748	193,787
2940	57,109	11,247	0	68,356	70,005	30,892	0	100,897	169,253
2920	62,334	9,375	0	71,709	59,571	23,683	0	83,254	154,963
2900	42,634	6,545	0	49,179	61,218	1,763	0	62,981	112,160
2880	21,643	0	0	21,643	39,089	495	0	39,584	61,227
2860	16,084	423	0	16,507	27,712	60	0	27,772	44,279
2840	11,232	38	0	11,270	13,444	128	0	13,572	24,842
2820	9,696	0	0	9,696	6,956	59	0	7,015	16,711
2800	5,626	0	0	5,626	3,331	0	0	3,331	8,957
TOTAL	665,409	465,433	0	1,130,842	1,291,425	2,505,586	1,079,116	4,876,127	6,006,969

MOHAWK PIT RESERVES

YARDS

AJF 09/09/91

	ORE				WASTE				
BENCH	QUARTZ MONZONITE	TERTIARY ROCKS	GILA CON-GLOMERATE	TOTAL YDS. ORE	QUARTZ MONZONITE	TERTIARY ROCKS	GILA CON-GLOMERATE	TOTAL YDS. WASTE	TOTAL ALL YARDS
3140	0	0	0	0	0	41	3,101	3,142	3,142
3120	0	0	0	0	0	5,522	8,091	13,613	13,613
3100	0	156	0	156	0	15,105	35,718	50,823	50,979
3080	0	5,687	0	5,687	0	57,327	81,961	139,288	144,975
3060	0	18,785	0	18,785	0	116,344	21,597	137,941	156,726
3040	0	20,741	0	20,741	0	85,253	38,776	124,029	144,770
3020	0	17,184	0	17,184	0	69,124	27,159	96,283	113,467
3000	0	24,555	0	24,555	0	77,756	0	77,756	102,311
2980	0	25,805	0	25,805	0	65,081	0	65,081	90,886
2960	0	21,385	0	21,385	0	42,814	0	42,814	64,199
2940	0	23,890	0	23,890	0	30,501	0	30,501	54,391
2920	0	22,066	0	22,066	0	22,524	0	22,524	44,590
2900	0	14,465	0	14,465	0	10,551	0	10,551	25,016
2880	0	11,484	0	11,484	0	4,137	0	4,137	15,621
TOTAL	0	206,203	0	206,203	0	602,080	216,403	818,483	1,024,686

TIGER MINE PRODUCTION SCHEDULE

AJF 09/09/91

QUARTER	BENCHES	MAMMOTH ORE YDS.	WASTE YDS.		SUBTOTAL	BENCH	ORE YDS.	MOHAWK WASTE YDS.		SUBTOTAL	GRAND TOTAL
			ROCK	GILA				ROCK	GILA		
1ST	3440 TO 3260	36,553	564,816	207,602	808,971	3140 TO 3080	156	20,668	46,910	67,734	876,705
2ND	3260 TO 3200	5,106	455,149	373,791	834,047	3080	5,425	54,687	78,188	138,301	972,348
3RD	3200 TO 3120	87,499	371,771	277,780	737,050	3080 TO 3060	16,667	104,241	22,634	143,541	880,591
4TH	3120 TO 3100	87,499	367,987	78,784	534,270	3060 TO 3040	16,667	73,463	29,445	119,575	653,846
5 TH	3100 TO 3080	87,499	331,559	44,150	463,208	3040 TO 3020	16,667	67,608	28,206	112,481	575,689
6 TH	3080 TO 3060	87,499	301,978	28,361	417,838	3020 TO 3000	16,667	58,744	11,020	86,430	504,269
7 TH	3060 TO 3040	87,499	269,138	40,106	396,743	3000 TO 2980	16,667	51,612	0	68,279	465,022
8 TH	3040 TO 3020	87,499	227,170	28,549	343,218	2980 TO 2980	16,667	42,034	0	58,701	401,919
9 TH	3020 TO 3000	87,499	176,633	0	264,132	2980 TO 2960	16,667	37,180	0	53,846	317,979
10 TH	3000 TO 2980	87,499	164,467	0	251,966	2960 TO 2940	16,667	30,019	0	46,685	298,652
11 TH	2980 TO 2960	87,499	154,056	0	241,555	2940 TO 2940	16,667	21,279	0	37,946	279,501
12 TH	2960 TO 2940	87,499	132,611	0	220,111	2940 TO 2920	16,667	17,680	0	34,347	254,457
13 TH	2940 TO 2920	87,499	110,582	0	198,081	2920 TO 2900	16,667	14,489	0	31,156	229,237
14 TH	2920 TO 2860	87,499	123,971	0	211,471	2900 TO 2880	16,667	8,146	0	24,812	236,283
15 TH	2860 TO 2800	39,180	45,095	0	84,275	2880	622	224	0	846	85,121
TOTAL		1,130,833	3,796,982	1,079,122	6,006,937		206,201	602,075	216,404	1,024,681	7,031,618

ORE	1,337,034
WASTE ROCK	4,399,057
GILA	1,295,526
GRAND TOTAL	7,031,618

MOHAWK PIT RESERVES

TONS

AJF 09-Sep-91

FCONE 001 MODEL #6

BENCH	ORE TONS	WASTE TONS	TOTAL	CUM. TOTAL
3140	0	5,671	5,671	5,671
3120	0	26,491	26,491	32,162
3100	337	96,920	97,257	129,419
3080	12,285	271,356	283,641	413,060
3060	40,576	290,177	330,753	743,813
3040	44,801	253,943	298,744	1,042,557
3020	37,118	198,193	235,311	1,277,868
3000	53,039	167,953	220,992	1,498,860
2980	55,738	140,576	196,314	1,695,174
2960	46,192	92,477	138,669	1,833,843
2940	51,602	65,883	117,485	1,951,328
2920	47,662	48,652	96,314	2,047,642
2900	31,244	22,791	54,035	2,101,677
2880	24,806	8,935	33,741	2,135,418
TOTAL	445,400	1,690,018	2,135,418	

MAMMOTH PIT RESERVES

TONS

AJF 09-Sep-91

FCONE 001 MODEL #6

BENCH	ORE TONS	WASTE TONS	TOTAL	CUM. TOTAL
3440	0	3,121	3,121	3,121
3420	0	19,834	19,834	22,955
3400	0	40,687	40,687	63,642
3380	0	55,397	55,397	119,039
3360	0	93,152	93,152	212,191
3340	15,066	121,162	136,228	348,419
3320	26,306	109,863	136,169	484,588
3300	20,994	136,950	157,944	642,532
3280	16,564	164,924	181,488	824,020
3260	26	178,790	178,816	1,002,836
3240	0	236,148	236,148	1,238,984
3220	160	406,797	406,957	1,645,941
3200	17,529	553,444	570,973	2,216,914
3180	21,829	665,659	687,488	2,904,402
3160	37,603	806,470	844,073	3,748,475
3140	94,017	811,243	905,260	4,653,735
3120	159,710	823,810	983,520	5,637,255
3100	172,109	774,699	946,808	6,584,063
3080	171,980	647,911	819,891	7,403,954
3060	166,200	610,423	776,623	8,180,577
3040	234,778	779,271	1,014,049	9,194,626
3020	194,257	405,173	599,430	9,794,056
3000	195,522	368,990	564,512	10,358,568
2980	185,112	344,731	529,843	10,888,411
2960	164,243	254,336	418,579	11,306,990
2940	147,649	217,938	365,587	11,672,577
2920	154,891	179,829	334,720	12,007,297
2900	106,226	136,040	242,266	12,249,563
2880	46,748	85,502	132,250	12,381,813
2860	35,654	59,987	95,641	12,477,454
2840	24,345	29,312	53,657	12,531,111
2820	20,943	15,153	36,096	12,567,207
2800	12,152	7,195	19,347	12,586,554
TOTAL	2,442,613	10,143,941	12,586,554	

MOHAWK PIT RESERVES

TONS

AJF 09/09/91

BENCH	ORE				WASTE				
	QUARTZ MONZONITE	TERTIARY ROCKS	GILA CON-GLOMERATE	TOTAL TONS ORE	QUARTZ MONZONITE	TERTIARY ROCKS	GILA CON-GLOMERATE	TOTAL TONS WASTE	TOTAL ALL TONS
3140	0	0	0	0	0	90	5,581	5,671	5,671
3120	0	0	0	0	0	11,927	14,564	26,491	26,491
3100	0	337	0	337	0	32,627	64,293	96,920	97,257
3080	0	12,285	0	12,285	0	123,826	147,530	271,356	283,641
3060	0	40,576	0	40,576	0	251,302	38,875	290,177	330,753
3040	0	44,801	0	44,801	0	184,146	69,797	253,943	298,744
3020	0	37,118	0	37,118	0	149,308	48,885	198,193	235,311
3000	0	53,039	0	53,039	0	167,953	0	167,953	220,992
2980	0	55,738	0	55,738	0	140,576	0	140,576	196,314
2960	0	46,192	0	46,192	0	92,477	0	92,477	138,669
2940	0	51,602	0	51,602	0	65,883	0	65,883	117,485
2920	0	47,662	0	47,662	0	48,652	0	48,652	96,314
2900	0	31,244	0	31,244	0	22,791	0	22,791	54,035
2880	0	24,806	0	24,806	0	8,935	0	8,935	33,741
TOTAL	0	445,400	0	445,400	0	1,300,493	389,525	1,690,018	2,135,418

MAMMOTH PIT RESERVES

TONS

AJF 09/09/91

BENCH	ORE				WASTE				
	QUARTZ MONZONITE	TERTIARY ROCKS	GILA CON-GLOMERATE	TOTAL TONS ORE	QUARTZ MONZONITE	TERTIARY ROCKS	GILA CON-GLOMERATE	TOTAL TONS WASTE	TOTAL ALL TONS
3440	0	0	0	0	73	3,048	0	3,121	3,121
3420	0	0	0	0	6,087	13,747	0	19,834	19,834
3400	0	0	0	0	4,255	36,432	0	40,687	40,687
3380	0	0	0	0	1,536	53,861	0	55,397	55,397
3360	0	0	0	0	9,554	83,598	0	93,152	93,152
3340	0	15,066	0	15,066	4,928	116,234	0	121,162	136,228
3320	7,048	19,258	0	26,306	7,602	102,261	0	109,863	136,169
3300	2,975	18,019	0	20,994	4,238	113,704	19,008	136,950	157,944
3280	689	15,875	0	16,564	701	122,506	41,717	164,924	181,488
3260	0	26	0	26	0	122,855	55,935	178,790	178,816
3240	0	0	0	0	10,598	129,909	95,641	236,148	236,148
3220	0	160	0	160	16,493	212,169	178,135	406,797	406,957
3200	9,990	7,539	0	17,529	112,885	211,527	229,032	553,444	570,973
3180	0	21,829	0	21,829	0	366,209	299,450	665,559	687,488
3160	15,375	22,228	0	37,603	72,465	401,853	332,152	806,470	844,073
3140	25,553	68,464	0	94,017	108,444	431,696	271,103	811,243	905,260
3120	42,406	117,304	0	159,710	309,204	380,136	134,470	823.810	983,520
3100	51,789	120,320	0	172,109	98,611	582,413	93,675	774,699	946,808
3080	73,869	98,111	0	171,980	171,654	436,257	40,000	647,911	819,891
3060	33,651	132,549	0	166,200	252,743	306,229	51,451	610,423	776,623
3040	90,776	144,002	0	234,778	201,141	477,495	100,635	779,271	1,014,049
3020	150,705	43,552	0	194,257	219,087	186,086	0	405,173	599,430
3000	151,234	44,288	0	195,522	196,817	172,173	0	368,990	564,512
2980	145,435	39,677	0	185,112	198,955	145,776	0	344,731	529,843
2960	146,853	17,390	0	164,243	173,742	80,594	0	254,336	418,579
2940	123,356	24,293	0	147,649	151,210	66,728	0	217,938	365,587
2920	134,642	20,249	0	154,891	128,673	51,156	0	179,829	334,720
2900	92,089	14,137	0	106,226	132,231	3,809	0	136,040	242,266
2880	46,748	0	0	46,748	84,433	1,069	0	85,502	132,250
2860	34,741	913	0	35,654	59,857	130	0	59,987	95,641
2840	24,262	83	0	24,345	29,037	275	0	29,312	53,657
2820	20,943	0	0	20,943	15,025	128	0	15,153	36,096
2800	12,152	0	0	12,152	7,195	0	0	7,195	19,347
TOTAL	1,437,281	1,005,332	0	2,442,613	2,789,474	5,412,063	1,942,404	10,143,941	12,586,554

TIGER MINE PRODUCTION SCHEDULE

TONS

AJF 09/09/91

QUARTER	MAMMOTH PIT					MOHAWK PIT					
	BENCHES	ORE TONS	WASTE TONS		SUBTOTAL	BENCH	ORE TONS	WASTE TONS		SUBTOTAL	GRAND TOTAL
			ROCK	GILA				ROCK	GILA		
1ST	3440 TO 3260	78,956	1,220,010	373,680	1,672,646	3140 TO 3080	336	44,644	84,438	129,418	1,802,064
2ND	3260 TO 3200	11,030	983,128	672,819	1,666,977	3080	11,719	118,125	140,738	270,582	1,937,559
3RD	3200 TO 3120	189,000	803,030	500,000	1,492,030	3080 TO 3060	36,000	225,161	40,741	301,902	1,793,932
4TH	3120 TO 3100	189,000	794,857	141,810	1,125,667	3060 TO 3040	36,000	158,682	53,001	247,683	1,373,350
5 TH	3100 TO 3080	189,000	716,171	79,469	984,640	3040 TO 3020	36,000	146,035	50,771	232,806	1,217,446
6 TH	3080 TO 3060	189,000	652,277	51,049	892,326	3020 TO 3000	36,000	126,888	19,835	182,723	1,075,049
7 TH	3060 TO 3040	189,000	581,342	72,190	842,532	3000 TO 2980	36,000	111,483	0	147,483	990,015
8 TH	3040 TO 3020	189,000	490,690	51,387	731,077	2980 TO 2980	36,000	90,795	0	126,795	857,872
9 TH	3020 TO 3000	189,000	381,529	0	570,529	2980 TO 2960	36,000	80,309	0	116,309	686,838
10 TH	3000 TO 2980	189,000	355,251	0	544,251	2960 TO 2940	36,000	64,841	0	100,841	645,092
11 TH	2980 TO 2960	189,000	332,763	0	521,763	2940 TO 2940	36,000	45,963	0	81,963	603,726
12 TH	2960 TO 2940	189,000	286,442	0	475,442	2340 TO 2920	36,000	33,189	0	74,189	549,631
13 TH	2940 TO 2920	189,000	238,858	0	427,858	2920 TO 2900	36,000	31,297	0	67,297	495,155
14 TH	2920 TO 2860	189,000	267,780	0	456,780	2900 TO 2880	36.000	17,595	0	53,595	510,375
15 TH	2860 TO 2800	84,629	97,406	0	182,035	2880	1,343	484	0	1,827	183,862
TOTAL		2,442,615	8,201,534	1,942,404	12,586,553		445.398	1,300,491	389,524	2,135,413	14,721,966

ORE	2,888,013
WASTE ROCK	9,502,025
GILA	2,331,928
GRAND TOTAL	14,721,966

Mammoth-St. Anthony
Pinal Co.

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THE HISTORY OF TIGER, ARIZONA

by

Kim K. Howell

Introduction

In February of 1988, the Magma Copper Company announced that it had entered into a joint-venture agreement with the Cyprus Minerals Company for the exploration of the old townsite of Tiger, Arizona, which Magma owns. Cyprus will be drilling along the Mammoth-Mohawk vein, looking for mineable reserves of gold ore. This activity represents the most recent incarnation of a unique patch of earth.

There is an old saying that "gold is where you find it." It also applies to any other mineral commodity. Minerals are concentrated in certain spots of the earth's crust due to a complex and fortuitous series of circumstances. Such circumstances worked overtime at Tiger. For over 100 years, men have been striving to recover the mineral wealth bestowed on the rocks at Tiger.

The face of a mining district is determined by human circumstances as well as geologic ones. Such things as metal prices, interest rates, tax laws, technical innovations, and even personality conflicts decide between a boom town and a ghost town. Tiger has been both, more than once.

Fifty years ago, Tiger was a bustling community with houses, dormitories, and tents housing almost 2,000 people. Twenty years ago, Tiger was a silent, empty patch of desert with old tailings piles, a few mine buildings, and scars on the rock attesting to its history. Now the headframe above the Mohawk shaft stands watch over a scene of ever increasing activity, which may lead to another rebirth of the mines at Tiger, if not the town which was once supported by them.

The San Manuel solvent extraction-electrowinning plant, and the ever-rising leach pads which feed it, loom over the western edge of Tiger's little basin. A swath of bedrock hundreds of feet wide has been quarried from the surface of the Mammoth vein, shipped as smelter flux for its gold and silica content. Most of the old dumps and tailings have gone the same route. And now, drilling machines will be churning away, seeking ore to suit the latest innovation in gold mining technology.

The Geologic History of Tiger

The geological history of Tiger began almost 1 1/2 billion years ago, when the Oracle Granite crystallized deep beneath the surface of the earth. This granite, which makes up most of the bedrock in the Tiger area, is classified by geologists as a "porphyritic quartz monzonite."

Much later, geologically speaking, between 69 and 67 million years ago, the Oracle Granite was intruded by a similar kind of rock, called "monzonite" or "granodiorite." All of these rocks were exposed at the earth's surface sometime between 30 and 28 million years ago. They provided grains and pebbles and boulders which were incorporated into a conglomerate rock, referred to by geologists as the Cloudburst Formation.

Sometime after the Cloudburst Formation was cemented into hard, brittle rock, it and the granite beneath were broken repeatedly by movements of the earth's crust. The breaks in the rocks were all more or less parallel to each other; they trended northwestward and were steeply inclined toward the southwest.

Molten, liquid rock squeezed upward along these fissures; it cooled and crystallized about 22 million years ago to form a hard, fine-grained kind of rock called "rhyolite." Some of the liquid rhyolite may have exploded out onto the surface of the earth to form part of the abundant volcanic rocks in the area.

The forces which sheared and fractured these rocks continued after the rhyolite had crystallized into solid rock, and the rhyolite and surrounding Oracle Granite were shattered and crushed repeatedly. During the several million years that this cracking and grinding was taking place, hot mineral water was circulating through the cracks and open spaces in the rocks. This hot water carried dissolved silica and sulfur and many different metals.

Gradually, in response to changing chemical and physical conditions, minerals crystallized from the hot solution, replacing fragments of rock and filling open spaces around them. These minerals included quartz, some in the form of purple amethyst, gold, and the sulfides of such metals as iron, copper, lead, silver, and zinc. The Tiger veins had been born.

As the temperature of the circulating hot water began to cool, and it mixed more and more with cooler ground water, it began to dissolve oxygen and carbon dioxide from the atmosphere. The chemical composition of this water was such that it reacted with the sulfide minerals and produced new, oxygen- and sulfate- and carbonate-bearing minerals of iron and copper and lead and zinc. Gold and silver were left behind. This process, called oxidation, took place within the recently formed vein down to a depth of at least 900 feet.

At the surface of the earth during this time, and for millions of years afterward, the exposed rocks were being worn down by weather and running water to form another conglomerate, which geologists call the Gila Formation. The Gila conglomerate, which is several million years old, is not cemented together as tightly as older rocks, but it is rigid enough to break. And it did break, along with all of the other rocks in the Tiger area, when the earth's crust began to move again about a million years ago.

The primary result of this movement was a huge zone of cracks known as the Mammoth Fault. The Mammoth Fault trends north-northwest and is steeply inclined to the northeast, opposite to the dip of the vein. Because of this geometry, and the 700 to 1,200 feet of displacement across the fault, the original vein was broken into two segments.

The lower part moved relatively upward and westward, forming what has come to be known as the Collins vein; the upper part, which moved relatively downward and eastward, was sliced up by smaller faults into numerous slivers. It has come to be called the Mammoth vein. Most of the other veins named by miners in the Tiger area, such as the Mohawk and the New Year, are really parts of the Mammoth vein. One branch of the Mammoth fault itself had enough ore minerals along it that it was called the Dream vein by early miners.

After the vein was broken and separated by the Mammoth fault, mineral water again circulated through the cracks, this time introducing molybdenum and vanadium to the minerals already present in the veins, and causing more oxidation. The Mammoth vein is oxidized for its entire depth. The Collins vein is oxidized down to about 700 feet below the present surface of the ground; it is partly oxidized from that point down to about 900 feet. Below the 900-foot level, only unoxidized sulfide minerals remain.

As a result of their extremely complex chemical and physical history, the veins at Tiger have yielded some of the rarest and most beautiful mineral specimens in the world. Almost 100 different mineral species have been identified there. Tiger has long been famous among mineral collectors around the world. The first scholarly descriptions of mineral specimens from Tiger, then called Schultz, were in 1886 in a German journal, and in 1887 in an American journal. Dealer advertisements for the sale of Tiger minerals go back as far as 1897.

The Early History of Tiger: Gold!

The early history of the San Pedro Valley area, including the Black Hills where Tiger is located, was controlled by the danger of Apache raids. Settlements were not permanent, and all were apparently abandoned by 1854. In the years before the Civil War, settlement of the area by Americans began, and in 1857 the San Diego and San Antonio stage line built a road down the San Pedro valley and established posts at what are now Benson and

Winkleman. There are records of a mine in operation near the confluence of the San Pedro River and Aravaipa Creek in 1860.

According to the records of the Bureau of Land Management, the earliest mining claim recorded at Tiger was the Hackney claim, located by Charles Dyke and T.C. Weed on July 14, 1879. The claim was on a quartz vein that has come to be called the Collins vein.

On February 8, 1882, an Austrian prospector named Frank Schultz located the Mars claim and the Mammoth claim on what he referred to as a "mammoth lode gold vein." The vein has ever since been called the Mammoth vein, and the first mine developed on it was the Mammoth mine. Mr. Schultz is credited with giving the mining district its name, the Old Hat District.

Frank Schultz took on a partner, named Mr. Goldtree, and the two erected a small, unsuccessful "cannonball" mill on the San Pedro river. When the mill proved a failure, Mr. Schultz had a Nevada company come in to develop the mine. The company, under Merril P. Freeman, sunk a shaft on the vein but then lost the "pay streak." Meanwhile, the Hackney claim was being developed by an open cut on the vein. The first recorded production of gold from the district was in 1881.

In 1884, the Mammoth property was purchased from Mr. Schultz by a Michigan lumberman named George W. Fletcher. The Mammoth was by no means the only Arizona mine to be developed by Michigan capital. Mr. Fletcher put the management of the Mammoth mine under the direction of a Captain Johnson.

Captain Johnson's crew sunk a shaft down to a depth of 300 feet and found the Mammoth vein; construction was begun on a mill on the San Pedro River three miles away, where water was available. Most methods of ore processing require large amounts of water, and at that time it was more practical to haul the ore to a source of water than to haul water to the mines.

Over the next several years, Mr. Fletcher's employees built a 30-stamp mill along the river to crush the ore from the mine and liberate the gold. The free gold was then taken up in mercury by a process called amalgamation.

The little town which grew up around Mr. Fletcher's mill came to be known as Mammoth. In 1887 a U.S. Post Office was established there. A school was opened early in the history of the community, while the mill was still under construction. A number of stores and saloons sprung up, including the store of J.N. Dodson, former postmaster of Mesaville. Johnny Dubois operated a saloon in Mammoth for many years.

Ore was hauled the three miles down the hill from the mine in 20-mule-team wagons, on a contract with William Neal of Oracle. Many of the miners lived in Mammoth and traveled to and from work on the wagon road. Mr. Neal also had a contract to furnish wood and water to the mines.

On July 20, 1885, Charles Dyke and a Mr. Collins located the Aaven claim adjacent to Mr. Dyke's Hackney claim on the Collins vein.

On July 8, 1887, Mr. Fletcher located two more claims in the vicinity of the Mammoth mine, the Remnant and the Raven claim, which was a millsite claim. Perhaps he considered moving his mill closer to the mine. During that year he began negotiations with a British syndicate for the sale of the entire property. In 1888 the Mammoth shaft was deepened from 300 to 500 feet in anticipation of the sale.

In 1889 the sale of the Mammoth mine and mill was completed; the new company was called Mammoth Gold Mines Limited. Although all newspaper accounts and engineers' reports at this time referred to the transfer of the Mammoth mine and mill as a sale, later reports, dated around 1900, refer to it as a lease.

By this time a little settlement of miners' shacks had grown up around the mines. The community was called Schultz after Frank Schultz. During the year 1889, Mr. Schultz opened a store to serve the residents there.

In 1890 Mammoth Gold Mines, Ltd., enlarged the mill on the San Pedro River from 30 to 50 stamps. The average value of ore produced that year was $14 a ton; it cost the company $4 a ton to mine and process it. By 1890 the town of Mammoth had a population of 600 to 700. The school had 70 pupils and one teacher, and the town had six saloons.

The ore which occurred near the surface on the Mammoth vein was "free milling," which means that simply crushing it with the heavy stamps was sufficient to separate the gold from the enclosing quartz and other minerals. Amalgamation could then complete the recovery. The deeper the miners went on the vein, however, the less ore was free milling. More and more of the gold was being lost in the "tailings," the waste material left after processing.

On January 1, 1891, Andrew Dannon and J.G. Fraser located the Mohawk claim on the Mammoth vein southeast of the Mammoth mine. In 1892 they sold the claim to a group of capitalists from Hartford, Connecticut, who organized the Mohawk Gold Mining Company. Over the next three years, this company sunk a shaft and developed the vein down to a depth of 300 feet. They also built a small, 10-stamp mill on the property.

Mammoth Gold Mines, Ltd., continued to mine the Mammoth vein. Timber to support the expanding mine openings had to be brought to the mines from the forested slopes of the Santa Catalina Mountains, which was quite a long haul. For this reason, the miners tended to cut corners and did not provide adequate support for many of the open stopes along the Mammoth vein. So much ore was taken from the vein without properly supporting the open ground that in 1893 a massive cave-in occurred between the 200- and 400-foot levels. This cave-in caused Mammoth Gold Mines, Ltd., to cease operations for several years.

During 1894, three men named Johnston, Barnhart, and Collins organized a company to lease the workings on the Hackney and Aaven claims, which became the Collins mine, and the idle Mammoth mill. They sunk a 300-foot shaft on the Collins vein and shipped 40,000 to 60,000 tons to the mill at $16 a ton, for a value of $240,000 to $260,000. The upper levels of the recently caved Mammoth mine were worked independently at this time by a Mr. Rabix, an employee of the English company.

On May 1, 1896, production began at the ten-stamp mill which the Mohawk Gold Mining Company had built at Schultz. The mill processed ore from the Mohawk mine at a rate of 70 tons a day. On July 27, 1896, a U.S. Post Office was established for Schultz, Arizona.

Also during 1896, Mammoth Gold Mines, Ltd., began the process of reorganization in order to develop new capital and to settle a dispute among shareholders. Under the name of the Mammoth Gold Mining Company, it began negotiations toward acquiring the Collins mine.

The company also studied the feasibility of moving the mill from Mammoth to the mine site and pumping river water to Schultz. The deepest mine workings were still above the water table, so the closest source of water was the San Pedro river. Ultimately, however, the company decided to continue hauling its ore to Mammoth for milling.

A contemporary description of the activities at Schultz was given by George Hilzinger in "Treasure Land," an 1897 publication of the Arizona Advancement Company of Tucson:

> East of Tucson, in the foothills of the Santa Catalina Mountains, there have been some wonderful discoveries of precious mineral. Several of these have been extensively worked, notably in the vicinity of Mammoth, a mining camp near the San Pedro river. The Mammoth Gold Mining and Milling Company has a large mill here, which is now idle, owing to a disagreement

> between the English and American stockholders. It has been a large gold producer in the past, and the signs are now favorable for extensive operations in the future. The Mohawk mines are on a continuation of the famous Mammoth mine and are owned by The Mohawk Mining and Milling Company, whose headquarters are at Hartford, Conn. This company has pursued a conservative policy in developing its property before going to the expense of erecting works, having, by means of a horse whim, sunk a double compartment shaft 330 feet on the lead, and driven over 1,000 feet of crosscuts and drifts at different levels. The results proving highly satisfactory, machinery for hoisting works and a twenty-stamp mill were put up, and a three-inch pipe line laid to the pumping plant, five miles distant and 700 feet lower. The pump, a Riedler, with six-inch suction and five-inch discharge, has a capacity of 500,000 gallons per twenty-four hours.

By the end of 1897, the reorganization of the Mammoth Gold Mining Company was complete, and it had acquired the Collins mine. The new company was called Mammoth Collins Gold Mines, Ltd., and was capitalized at 100,000 pounds in shares of 1 shilling each.

The company built a 2.3/4-mile aerial tramway, also referred to as a "Bleichert wire rope transportation system," to carry ore from the mine to the mill at Mammoth. The tramway was enlarged a year or so later; the tram buckets were used to carry river water to the mines on their return trip.

The proportion of "free-milling" gold in the district ore continued to decrease, and the amalgamation recovery along with it. Amalgamation only recovered 45% to 60% of the gold in the ore. So the new company entered into a contract agreement with the St. Louis Gold Saving Company, under the management of the Anderson brothers, to apply a new technology called cyanidation. The company built a separate plant for this purpose near the mill at Mammoth, with a capacity of 200 tons a day.

The tailings from the amalgamation process were picked up with a mule-drawn scraper and placed in tanks where the gold was dissolved in a cyanide solution. The gold was then removed from solution by precipitation on zinc shavings. By this means, 50% to 60% of the gold which had been lost by the amalgamation process was recovered.

The tailings from the Mammoth mill contained many other minerals along with the gold and quartz. Among these were the lead minerals anglesite and cerussite and the lead and molybdenum mineral wulfenite, which forms beautiful, shiny, bright yellow-orange book-shaped crystals. Minerals which contain lead are heavy, and they can be concentrated using this property of high specific gravity.

In 1898, the Mammoth mill shipped 12 tons of a 90% wulfenite concentrate to a buyer, for both its lead and molybdenum content. This concentrate apparently exhausted the market for the wulfenite, and no more of it was concentrated until 1914.

The Mohawk mill at Schultz was enlarged in 1898 with the addition of 20 stamps. The Mohawk mine was closed that year. In 1899 a new company was organized to work both the Mammoth and the Mohawk mines. The company built one of the first electrical generating stations in Arizona Territory to provide electrical power for the mines and mill.

By the end of 1900, the ore in the Mammoth mine above the 700-foot level was mined out. A contemporary engineering report, prepared by Mr. T.J. Davey for the English company, estimated that about 10,000 tons of ore remained between the 700- and 760-foot levels at a value of $8.63 per ton. The average costs of operation per ton of ore in 1900 were: mining--$1.15; milling--$0.64; transportation by aerial tramway--$0.13; management, etc.--$0.28; total costs $2.20.

Down in Tucson Wash, across from the hill where the Collins vein was discovered, a Mr. Ford developed a small high-grade lead-silver vein which came to be known as the Ford Mine. He shipped a small quantity of ore in 1900.

By 1900 the main working shaft of the Mammoth mine was down to a vertical depth of 800 feet, and was below the water table. According to Mr. Davey's report, the water influx at that depth was so great that "cross-cutting," or mining laterally from the shaft, could not be accomplished. The lowest level on which the miners could work was the 760-foot level. Just below this level, the water flow into the shaft was 157 gallons a minute. In addition to their problem with water, or perhaps because of it, the miners also encountered very soft rock at this level which required heavy square-set timbering for support.

An attempt was made during 1900 to connect the Collins and the Mammoth mines underground. A "drift," or tunnel, was begun on the 700-foot level of the Mammoth mine, but it was still several hundred feet short of the Collins workings when it was stopped. The drift was apparently not completed and the two mines connected until 1913.

Cave-in and Ghost Town

According to Mr. Davey's report, the English company, whose most recent incarnation was Mammoth Collins Gold Mines, Ltd., did not in fact own the mines or mill, but had a lease and bond on the property for $300,000. The company apparently failed to pay either principal or interest and was sued by the property's owners, who eventually regained possession.

Ownership reverted to George W. Fletcher and/or Frank W. Fletcher of Michigan. Frank W. Fletcher is assumed to be the son and heir of George Fletcher; he is referred to as the owner of the Mammoth mine and mill as late as 1918, and is named as owner or locator of a number of other mining claims in the district.

In mining the Mammoth and Collins veins underground, the miners used square-set timbers to hold open their access drifts and some of the large "stopes," the openings on the veins where ore was removed. As more and more rock was taken from the veins, the stopes became enormous caverns up to 60 feet wide, hundreds of feet long, and close to a hundred feet high.

Openings of such a size in solid rock are unnatural, and sooner or later gravity tends to close them up. Timbers can hold them open for a time, but wood cannot support the weight of hundreds of tons of rock. The only sure way to support it would be to fill the mined-out stopes with waste rock or tailings, which was not done at the Mammoth-Collins mine.

In April of 1901, the rock overlying a large mined-out portion of the Collins vein failed suddenly, resulting in a large cave-in from the 760-foot level to the surface. About an acre of ground over the north end of the mine dropped as much as 25 feet. As a contemporary report described it:

> One night in April, 1901, an extensive caving occurred in the main [stopes], but without loss of life or injury to the shaft. It started suddenly without warning at the north end of the mine and extended from the surface to the bottom of the workings, 750 feet deep...The cave-in brought the company to realize that if they continued to work they would have to do extensive and expensive timbering.

The cave-in of 1901 seemed to be the final blow to the Mammoth and Collins mines. Most of the accessible ore was mined out, the bottom level of the Mammoth mine was flooding, and the owners and operators were tied up in court. The mines were closed down and most of the jobs they had provided were eliminated.

The settlement of Schultz was on its way to becoming a ghost town. In 1902 the U.S. Post Office at Schultz was closed. By 1903, the population of nearby Mammoth had dwindled to about 300. From the first production of ore in 1881 until the cave-in of 1901, the Mammoth and Collins veins together yielded 350,000 tons of ore from which 150,000 ounces of gold were recovered.

During the next few years, the only activity in the Schultz area was claim staking. There was still gold in the rocks, and deserted mining camps have a way of coming back to life over and over again. In January of 1902, T.H. Collins and T.E. Baier located the Golden Slipper claim along the trend of the Hackney and Aaven claims.

In October and December of 1905, Andrew J. Collins located three more claims along this same trend, all southeast of the Collins mine. They were called the Arizona, the Wyoming, and the Washington claims. A.J. Collins was listed on the location notices as the president of the Arizona Gold Mining Company.

In 1906 the Mohawk Gold Mining Company was reorganized under the same name, for the purpose of refinancing, and placed under the management of Williams Roberts. The company built a new mill at the mine site which consisted of an amalgamation and concentrating plant; arrangements were made to use water from the bottom of the Mammoth shaft for the mill, which had a capacity of 30 tons a day.

The Mohawk company sunk a new vertical shaft down to a depth of 500 feet, and began to develop new orebodies on the Mammoth vein. The Mammoth and Collins mines were not in operation at this time.

On Red Hill, a mile or so west of Schultz, in 1906, some of the primary claims were located on what would eventually become the San Manuel mine. There are records of claims having been located on Red Hill as early as 1870, before the first claims were located at Schultz.

Actual production from the new Mohawk mine began in 1907 and continued until 1912. The grade of ore produced from the Mohawk was considerably lower than what had come from the neighboring Mammoth mine. During the years 1907 to 1909, the Mohawk mine produced $88,945 worth of gold and silver.

On January 1, 1909, Frank W. Fletcher located the Manana claim to the northeast of the Mammoth and Collins veins. On June 14, 1910, J. B. Bourne located the Remnant Extension claim in the same area, on behalf of Mr. Fletcher.

Production at the Mohawk mine and mill ceased at the end of 1912, leaving all of the mines in the district idle. A contemporary newspaper report described the Mammoth mine as "now idle because it happens to be owned by a rich lumberman of the north who will neither work it nor sell it, having refused $600,000."

According to the same report, local owners of the "Extension" property, immediately south of and adjoining the Mohawk claim, were doing development work. They had a shaft down 200 feet with 26 feet of crosscuts. The two-foot "pay streak" produced assays of from $1.86 to $47.48 per ton in free-milling gold. Also during 1912, the Ford property was producing 45% copper ore from the 300-foot level, with a silver-lead vein nearby.

Stirrings of Renewed Activity

In July of 1913, the Young brothers of Iowa obtained a working bond and option on the Mammoth and Collins mines and the Mammoth mill. The amount of the bond was $400,000. The property at Schultz consisted of six patented and seven unpatented claims, making up a total of 273 acres. The Mammoth amalgamation mill had been completely destroyed by fire during the time it was idle.

The Youngs were the owners of the Great Western Copper Company, which had been formed in 1900 for the purchase of a group of claims in the Courtland district of Arizona. The Young brothers were said to be millionaires who had made their fortune in the lumber business in Iowa. One brother was William J. Young, and another was Mayor G.U. Young of Phoenix. G.U. Young was also president of Madiselle Mines, located west of Prescott.

The Youngs were active in the Schultz area for several years doing repair, construction, and development work. They never produced any ore, but paved the way for later production. They began studying the possibility of building a power line from Ray's power plant at Hayden. During 1913 they employed from 10 to 45 men doing clean-up work and preparing to deepen the main Mammoth shaft. The chief engineer for the Youngs was named Wilbert G. McBride.

An October, 1913, newspaper report described speculation and rumors that if the Mammoth-Collins mines were put into operation, a railroad would be built down the San Pedro Valley to Winkleman, and a bridge built at Winkleman. The railroad and bridge would have been a boon to the local population, and also to the Sibley mines at Copper Creek, which were hauling ore by wagon at that time.

During October and November of 1913, Frank W. Fletcher located the Erfletch claim, and filed amended location notices on the Manana, Ford, Ford Fraction, and Quien Sabe claims. In December, the Youngs installed a 150 horsepower engine to pump water from the mine shafts. They completed the tunnel connecting the Mammoth and Collins mines on the 700-foot level of the Mammoth.

They also began repairing the Oracle and Mammoth road to facilitate hauling supplies. They had an agreement with Pinal County for the County to pay half the cost of the road if the Youngs would do the work.

During 1914 the Young brothers deepened the Mammoth shaft to 840 feet, which necessitated handling 300 gallons a minute of water. They developed ore on the 760-foot level, and drove a drift on the 700-foot level around the old caved area northwest of the shaft.

In January of that year there were 75 men employed at the mine. By the middle of July, they had erected a new headframe and installed a new hoist, replaced timbers, cleared drifts, and had a crew diamond drilling on the 600-foot level of the Collins mine.

Also by July of 1914, a local resident named Pascual Figueroa had sunk a shaft near the old Mohawk mine over 200 feet deep. Apparently this is the property referred to as the "Extension" in other reports. Another small prospect was being worked at this time by a Mr. Ed Brady of Mammoth.

The Molybdenum-Vanadium Boom

Another event during 1914 which affected the mines at Schultz was the outbreak of World War I. The war caused both the price and demand for the steel-alloy metal molybdenum to soar. A minor amount of this metal had been concentrated from the tailings in Mammoth back in 1898, and it was well known that wulfenite, a molybdenum-bearing mineral, made up a large percentage of those tailings.

During 1914, Frank M. Herford and W.J. Bryan, Jr., of Tucson and Robert C. Boykin of Mammoth gained control of all but 25,000 tons of the old tailings. The estimated tonnage of tailings which could be reworked at a profit was 250,000 tons.

The partners installed two concentrating tables in the building of the old cyanide plant, and began using gravity concentration to separate wulfenite from the tailings. A contemporary report described the tailings as "spread over a considerable area of ground and [they] lay so long undisturbed that they had been in part farmed as if they were soil."

Herford, Bryan, and Boykin formed the Arizona Rare Metals Company. For three years during World War I, they produced all of the molybdenum marketed in the United States. Their operation was so successful that in early 1915, they completely remodeled the small plant and installed five more concentrating tables.

The tailings were dug from the piles with a four-horse scraper and dragged up an inclined ramp to a loading platform. Beneath the platform, in a short underground tunnel, were one-ton ore cars on rails. The cars were loaded through a grizzly. The loaded cars were then pushed by hand, or "trammed," along rails several hundred feet to the base of another inclined ramp, where they were hooked to a cable to be pulled up the ramp. The cars were pulled up to a bin about 30 feet above the ground, dumped, and then allowed to slide down the ramp freely. The work of scraping and loading the tailings into the bin was done by contractors at a cost of about 14 cents a ton.

The mill operated 24 hours a day, on three eight-hour shifts, and employed 10 to 20 men. It produced two tons of concentrate a day from about 200 tons of tailings. The plant was powered by two Fairbanks-Morse "oil engines" of 12 and 20 horsepower; the smaller operated a sand pump which discharged waste from the plant, and the larger operated the concentrating tables, water pump, and a dynamo to generate electricity for lighting the mill and the scraping and tramming operations at night.

The product of the operation consisted of the minerals wulfenite, cerussite, vanadinite, and anglesite, all of which are lead minerals and have about the same specific gravity. These minerals made up 91.12% of the concentrate. According to a report of the U.S. Bureau of Mines, the concentrate contained 22.62% MoO_3, 61.83% PbO, and 1.28% V_2O_5.

The concentrate was worth $300 a ton. It was bagged into 150-pound sacks, hauled by freight team to Tucson, and shipped by rail to a refinery in Pittsburgh, Pennsylvania. The teams hired to haul the sacks of concentrate to Tucson belonged to J.L. Clark of Mammoth. A contemporary newspaper report described the appearance of the yellow-orange wulfenite concentrate as giving "the mill and surroundings the appearance of being a large grain-buying institution."

The Young brothers introduced several technical innovations to the operations at Schultz. Beginning in August of 1913, they employed two "motor-trucks" for the purpose of hauling fuel, machinery, timbers, rail, pipe, and other supplies from Tucson to the mines. On July 9, 1916, Chief Engineer Wilbert McBride published an engineering analysis of the applications of these vehicles to mining in the Mining and Scientific Press.

The trucks were driven to Tucson empty. Drivers were paid $4.50 to $5.00 a shift, and a one-way trip was considered a shift. The drivers were provided with a room in Tucson for their overnight stay. The price of gasoline ranged from 17 to 21 cents a gallon.

The article describes the conditions of the road: "There were no excessive grades or bad sand, but wagon-ruts, too narrow for the truck-wheels and of a different gage, caused heavy tire loss; while chuck-holes, sharp curves, and stones, both imbedded and loose, were objectionable features. During wet weather the trucks could not get sufficient traction to climb some of the hills and were likely to stick in the mud, so that no attempt was made to run them unless they were on the road when the rain started."

The cost of hauling a load from Tucson to the mines with a truck was $12 a ton, compared with a cost of no less than $15 a ton for a freight team. Furthermore, a team made only one round trip a week, while a truck made a round trip in two days, and occasionally in one day. The only disadvantage of the trucks was that they lost twice as much time as the teams in wet weather.

As of 1916, the workings of the Mammoth mine consisted of a main shaft 833 feet deep and about one mile of drifts on eight different levels. The workings to the north of the shaft were caved to within 125 feet of the shaft. The water level was 760 feet below the shaft collar. The Collins mine consisted of an access tunnel 550 feet long and a shaft 700 feet deep, and about 2,000 feet of tunnel and drifts.

The Mammoth mine was equipped with a shaft house, engine and compressor house, boiler house, machine and blacksmith shops, and oil storage tanks. A 100 horsepower Fairbanks-Morse engine operated a Sullivan compressor with a capacity of 528 cubic feet per minute at 100 pounds of pressure. A 150 horsepower Fairbanks-Morse was set up to run a 440-volt generator which supplied power for the mine pump, electric lights, and various small motors in the shops. The hoisting equipment consisted of a 12-inch by 14-inch, double-drum hoist, which could be operated either by steam or compressed air. The mine pump was on the 750-foot level, and had a lifting capacity of 400 gallons a minute.

The U.S. Bureau of Mines studied the Mammoth and Collins mines in 1916 for the possibility of mining them for wulfenite. Although the Arizona Rare Metals Company was producing a wulfenite concentrate from the old mill tailings at Mammoth, the mineral was not being mined at that time from any of the mines at Schultz. The study, published as U.S.B.M. Bulletin 111, notes that:

> Wulfenite is of common occurrence throughout the veins and much of it is beautifully crystallized. The Mammoth mine alone has probably furnished more fine cabinet spicimens [sic] of the crystallized mineral than any other locality. Most of the crystals are light orange, but they range through various shades of orange, brown, and green, to almost black...In many

> places there are 1-inch and 2-inch streaks of nearly pure wulfenite near the center of the orebodies, and many cracks and fractures throughout the vein material are filled with the mineral. On the 750-foot level of the Mammoth mine the writer noted a shoot of wulfenite and cerussite ore, exposed for 100 feet or more, that averaged 10 to 12 inches wide, and probably contained 20 to 30 percent of wulfenite...veinlets and minute stringers of wulfenite are visible throughout the stopes and in the roofs and floors of most of the drifts...The mines have, however, never been worked for wulfenite, but have been developed chiefly for gold, of which their ores are said to carry $6 to $7 per ton.

The Bulletin concluded that there would be problems with trying to extract wulfenite from the Mammoth mine ores. The presence of so many other lead minerals with the same specific gravity made it impossible to separate the wulfenite from them by gravity methods. A successful separation would require a complex, high-technology process.

As early as February, 1916, there were rumors that the Young brothers were having financial difficulties with the mines at Schultz. By January, 1917, the Youngs had decided to give up their efforts. They had spent an estimated $200,000, and they had concluded that the ore was of too low a grade to justify milling. They pulled out the second week in February.

According to Frank W. Fletcher, the owner of the mines, the Youngs had gotten several extensions on their first $100,000 payment required under the bond, but he would not give any more extensions. The Youngs had estimated that it would cost $250,000 to build a new mill to replace the old one which had burned. They felt that the ore was too complex to concentrate profitably.

When the Young brothers relinquished control of the Mammoth and Collins property, it was leased immediately by a group of partners who formed the Mammoth Development Company. The prime mover of this group was Col. Epes Randolph, described by contemporary reports as "one of Tucson's chief citizens."

Col. Randolph was head of the Arizona operations of the Arizona Eastern railroad lines and was involved in other mining ventures. He was also Chancellor of the University of Arizona. His partners in the company were Frank Herford and R.O. Boykin, who were involved in producing wulfenite from the old mill tailings at Mammoth.

The continuing high price of molybdenum made the other mines at Schultz attractive, also. A report prepared on June 15, 1917, by a Tucson engineer named Colin Timmons described the Mohawk mine. It was owned by the Mohawk Gold Mining Company, and included the Mohawk and Wedge claims on 21.6 acres and a 5-acre millsite claim, all patented.

The main Mohawk shaft was 532 feet deep, with two hoisting compartments about 4 1/2 by 5 1/2 feet, and a manway compartment. The shaft was vertical and sunk in rhyolite. The third and fourth levels were square-set timbered; the stoping was done without timbers.

The report suggested deepening a 115-foot winze below the fifth level an additional 50 feet to the water table, to supply water to the mill. At that time water had to be pumped three miles from the San Pedro River. Equipment and buildings on the property consisted of a blacksmith shop, assay office, manager's residence, bunk houses, and office buildings of adobe and lumber; a 30-stamp mill, with six batteries of 850-pound stamps, for amalgamation; a double-drum hoist, 250 horsepower mill engine, 50 horsepower electric motor, a 5,000-gallon galvanized oil tank and a 25,000 gallon water tank.

Mr. Timmons advised that in order to put the mill into operation, a concentrating plant would have to be built and the mine and mill would have to be remodeled. Given the price of molybdenum at the time, he considered that investment to be worthwhile.

During 1917, at least two exploratory holes were drilled on Red Hill, at what would become the San Manuel mine. The copper content was too low to justify continued drilling.

Early in 1918 the shaft timbers in the Mammoth working shaft caught fire and were destroyed. The fire started from gasoline dripping near the compressor exhaust pipe. The fire went down the main shaft, and also destroyed the hoist and compressor houses. There was an escapeway through another shaft, so no one in the mine was injured.

By April 15, 1918, the mines and plant at Mammoth had a combined payroll of 100 men. Production at that time was 150 to 175 tons a day, and it was projected at 400 tons a day when full capacity was reached. As the timbers in the burned-out shaft were replaced, it was enlarged to a three compartment shaft. Retimbering had been completed to the seventh level by April, and ore was being produced from the sixth level. The Mammoth Development company began to pay dividends early in 1918.

During mid-1918 the Arizona Rare Metals Company suspended its operations at Mammoth due to an unsettled molybdenum market. At that time another company, the Hondo Oil Company, was taking the tailings from the Arizona Rare Metals plant and processing them yet again. The Hondo company had erected a small plant near the Arizona Rare Metals plant. Because of the very fine size of the wulfenite in the tailings, gravity concentration was not terribly efficient. Hondo used a flotation process to try to recover wulfenite which had been missed by Arizona Rare Metals.

On May 4, 1918, Colin Timmons and Associates announced that they were preparing to work the Mohawk mine on a large scale and using "improved methods." They also planned to renovate the mill and rework the old tailings at the Mohawk millsite.

By October of 1918, the Arizona Rare Metals Company had resumed operations under the name of the Mammoth Development Company, which was owned by the same investors. At that time, the mine superintendent was Jack Acres, the mill superintendent at Mammoth was D.W. Hales, and the general manager was Horace Pomeroy of Schultz. The ore produced by the Mammoth-Collins mine was being transported to the mill at Mammoth by truck.

As of April 9, 1919, the officers of the Mammoth Development Company were: R.C. Gillis of Los Angeles, President; Mr. Fleming of Pasadena, California, Vice President; Epes Randolph of Tucson, Treasurer; and Charles Bundy of Los Angeles, Secretary. Besides the Mammoth and Collins mines at Schultz and the mill at Mammoth, the company owned a refining plant at Vernon, California. Some time during 1919, the company was renamed the St. Anthony Mining and Development Company.

Ghost Town Again

The end of World War I caused a dramatic drop in the demand for and price of molybdenum. None of the mining or processing operations at Schultz and Mammoth could survive such a blow, and all were shut down.

The Ford mine in Tucson Wash was closed in 1920 due to high pumping costs and the cost of hauling ore to Tucson. The mine was allowed to flood and remained filled with water for many years. By 1921 most of the mines in the state were shut down by the post-war depression.

In September of 1924, Frank K. Herford of Tallulah Falls, Georgia, corresponded with W.P. Gohring of Phoenix and Horace Pomeroy of Mammoth concerning the future of the Mammoth and Collins mines at Schultz. Mr. Pomeroy recommended that the properties were worth developing. He emphasized that there was a good showing of lead on the 700-foot level of the Mammoth mine, on the Collins vein. The ore assayed about 10% lead and 6% to 7% zinc over a width of more than six feet.

In October of 1924, there were rumors of the purchase of the Mohawk and probably the Mammoth mines by a Denver man, Mr. C.S. McClevins, on behalf of a New York company, the Metal Exploration Company. The owner of the Mohawk mine at that time was listed as

Lee S. Woods of Mammoth, and the owner of the Mammoth mine was the estate of Col. Epes Randolph.

During September of 1925, Mr. J.F. Harrington corresponded with several members of the mining and geology faculty at the University of Arizona concerning the mines at Schultz. He was told that the Mammoth mine property was owned by the St. Anthony Mining and Development Company, with C.L. Bundy of Los Angeles, president. The company was capitalized at $2,000,000, with shares having a face value of $1,700,000 in the treasury as of 1924.

A March 27, 1925, news release stated that J.A Poindexter was doing preliminary work on the Mohawk mine at Schultz. In November of 1925, a certificate of incorporation was issued to the Mohawk Gold Mining Company. Also during 1925, five of the principal claims on what would eventually become the San Manuel copper orebody were located on Red Hill by Anselma Laguna of Superior.

During 1926 a young mining engineer named Sam Houghton, who had recently graduated from Princeton, obtained an option on the New Year group of claims from the heirs of Frank Schultz. These claims were adjacent to the Mohawk mine on the east. Mr. Houghton sunk a 140-foot deep shaft and encountered gold, vanadium, and lead mineralization in lateral workings.

As of December, 1926, the Mohawk mine was being developed by a company from Denver, Colorado. George W. Logan was secretary/treasurer of the company, and J.A. Poindexter, "a well-known local mining man," was in charge of renovating and modernizing the Mohawk mill.

According to further correspondence among Frank Herford, W.P. Gohring, and Horace Pomeroy, the Mammoth mine was sampled and examined during the summer of 1926 by the United Verde Copper Company. That company found an estimated 30,000 tons of ore ready to mine which assayed 0.5% copper, 9.3% lead, 7.2% zinc, 1.7 ounces per ton silver, and 0.015 ounces per ton gold. The company's report stated that the mine made a great deal of water, which would result in a high pumping cost. It estimated a cost of $134,000 to properly equip the mine and do the necessary development work to put it into production.

During 1927 Mr. Poindexter, manager of the Mohawk mine, was supervising the renovation of the mill, converting it from stamps to a concentrating and chemical plant to recover gold, silver, lead, and molybdenum. It was announced in June of 1928 that the Mohawk mine would be reopened. However, no production was recorded during that time.

In 1929 the Great Depression began. Once again, the mines at Schultz sat idle. However, Sam Houghton did not give up on the district. By the end of 1931, he had assembled a group of investors to develop his mine. They included: Jack Mulcahy, head of Mulcahy Lumber Company of Tucson; Clyde Martin Reed, former Governor of Kansas and publisher of the Daily Sun in Parsons, Kansas; F.B. Houghton of Chicago, vice-president of the Santa Fe Railroad; and himself. No stock was offered to the public, and no ore was produced.

In 1933 the United States Government raised the price of gold from $20 to $25.26 an ounce. The price increase stimulated interest in gold mines in general, and in the mines at Schultz in particular. The Molybdenum Corporation of America gained control of the New Year, or Houghton, property and the Mohawk mine. The combined mines included two vertical shafts and five underground levels, all in ore.

On June 18, 1933, the Mammoth Arizona Gold Mining Company filed an amended location notice on the New Year claim. On June 22, 1933, the articles of incorporation were published for the Molybdenum Gold Mining Company of Tucson. The incorporators were Cleon T. Knapp and B.G. Thompson. The company, a subsidiary of the Molybdenum Corporation of America, had a capital stock of $100,000.

On September 26, 1933, the Coyote and June Bug claims were located by Fred Marston. The claims were situated to the northeast of the Mohawk and New Year mines.

In 1934, the price of gold was again raised by the U.S. government, to $34.95 an ounce. This tremendous price increase spurred a boom in small gold properties. The St. Anthony Mining and Development Company became affiliated with the Mammoth-St. Anthony Company, Ltd., "due to the need for new capital." The two companies shared in the operation of the Mammoth-Collins property until 1945, when Mammoth-St. Anthony was dissolved. At that time, Foster S. Naething was vice president and managing director of St. Anthony Mining and Development.

A description of the district as of January 5, 1934, was submitted to the Arizona Bureau of Mines by P.C. Benedict. The Mammoth and Collins workings were connected on the 700-foot level of the Mammoth by a crosscut tunnel. The mines were located on two roughly parallel veins. The Mohawk mine was located to the southeast of the Mammoth mine, on the Mammoth vein and the Mammoth Fault, also called the Dream Vein. The New Year mine, southeast of the Mohawk, was on the same vein. The Brady workings were located on the Dream Vein, southeast of the Mohawk and New Year shafts. The Smith workings lay to the southeast of the Collins mine, along the projection of the Collins vein.

However, those workings did not encounter the vein, which was offset by faulting.

By January 12, 1934, the Molybdenum Gold Mining Company had 32 men on its payroll. Fred N. Marston was manager, and the Mohawk mine was producing 1,200 tons a month. By the middle of July, the company had a crew of 60 men. Several carloads of ore had been sent to the parent company's refinery in Washington, Pennsylvania, for processing.

Toward the end of 1934, Mammoth-St. Anthony, Ltd. began studying the relative cost of running a power line to the mines or installing a Diesel generator. The decision was made to run a power line, and by March 23, 1935, poles were up and wire was being strung on an extension of the line from Coolidge dam to Hayden. The company financed the line at a cost of $60,000. By April 5, 1935, the power line was complete, with continuous electrical power beginning on April 1. The line, built from Hayden to Mammoth, was 24.3 miles long and was erected in 45 days.

In exchange for building the power line, Mammoth-St. Anthony received light and power at a reduced cost from the federal government. Power was also supplied to the town of Mammoth, and by 1939 the line had been extended to Oracle and was providing electricity to a number of guest ranches in the area. The Federal Power Project insured against a power failure caused by low water at the dam by having the U.S. Indian Service construct a 2,600 horsepower Diesel electrical generating plant a mile and a half north of Coolidge. This stand-by unit cost $164,000.

By June 15, 1935, St. Anthony Mining and Development had 75 men on its payroll; 25 at the mine, 25 at the mill, 10 in the shops, and 15 in miscellaneous jobs. Carl Geib was mine superintendent.

The Molybdenum Gold Mining Company completed construction of its mill in May of 1935, and by the end of July it was operating at capacity. The mill could process ore by both gravity concentration and cyanidation. It processed 200 tons a day, half of which was being supplied from the Mammoth mine on contract, and the other half from the company's own Mohawk-New Year mine. Fred Marston, St. Anthony's general manager, was also serving as general manager for the Molybdenum Gold Mining Company.

Tiger Becomes a Lead and Zinc Producer

The year 1936 began a period of general economic recovery from the Great Depression. By May, 39 men were employed in the Mohawk-New Year mine. In June, the mill was enlarged from 200 to 300 tons a day. Twenty-thousand dollars worth of new equipment was installed, including crushing and flotation units. A flotation concentrate containing gold, lead, zinc, molybdenum and vanadium was shipped to the Molybdenum Corporation of America plant at Washington, Pennsylvania.

The mill employed a very complex process. There was a gravity concentrating plant with six concentrating tables, from which the tailings went to a cyanide leaching plant. The gravity concentrate went to two sets of eight-cell, mechanically driven flotation machines.

Ore was transported from the Mammoth-Collins mine to the mill at the Mohawk mine site by means of a motor-driven aerial tramway. The tramway passed high over the townsite to bins at the mill, eliminating the need for truck haulage, which had been used previously.

In July, 1936, St. Anthony Mining and Development began sinking a new shaft near the old Collins glory hole for supply, ventilation, and production. It was a three-compartment vertical shaft with two-ton, self-dumping skips and a 100-horsepower, double-drum hoist. One million gallons of water were pumped from the shaft per month. The water was sold to the Molybdenum Gold Mining Company for its mill.

As of July 30, 1936, Foster S. Naething was listed as managing director of Mammoth-St. Anthony Mining and also as manager of the Molybdenum Gold Mining Company mill. Production from the Mammoth-Collins mine was 3,000 tons a month.

Beginning in 1936 and continuing through 1942, James M. Douglas, with partners Henry Nichols, Burns Giffin, and Victor Erickson, acquired the San Manuel claims and other claims in the vicinity of Red Hill.

On March 15, 1937, Mammoth-St. Anthony Mining purchased the Molybdenum Gold Mining Company mill, which had been under the same management as Mammoth-St. Anthony for most of its existence. The mill was treating ore from the mines of both companies, and at that time it claimed a 90% recovery. In April of 1937, Molybdenum Gold Mining Company opened a small smelter to further process the concentrates from the mill.

In October of 1937, St. Anthony Mining and Development was producing 5,000 tons a month and employed 60 men in the Mammoth and Collins mines. By July of 1938 the company was producing 9,000 tons a month and employed 122 men. At that time Molybdenum Gold Mining Company was producing 3,000 tons a month from the Mohawk and New Year mines.

By October of 1938, St. Anthony Mining and Development employed 250 men working seven days a week, twenty-four hours a day. They produced 500 tons of ore a day. The company was shipping gold, silver, lead, and copper bullion to a refinery. It also shipped a low-grade molybdenum-vanadium concentrate by truck to San Diego, California, to be further processed. About 150 tons a month of this product was purchased by Italy, and any excess was sold to American markets.

On February 15, 1939, Mammoth-St. Anthony, Ltd., acquired the Mohawk and New Year mines from the Molybdenum Gold Mining Company. This action consolidated all the mines in the district under one company. F.S. Naething was general manager of the entire operation; the company employed 260 men and was producing 550 tons a day.

By the end of February, 1939, the little settlement around the mines consisted of 20 "modern" houses and dormitories, a company store, which boasted a refrigerated meat counter, a barber shop, and a beauty salon. Employees not given houses built a tent city which was the largest ever to exist in the state. The company would loan employees the money to purchase tents. The total payroll of the mines rose to 400, and on March 15, 1939, a U.S. Post Office was again established in the community, which was rechristened Tiger, Arizona.

There are several different stories of how the new post office came to be called Tiger. According to one version, the camp became known as Tiger during the late twenties and early thirties when Sam Houghton was active in the area. Mr. Houghton was a recent alumnus of Princeton, whose football mascot was the "fighting Tigers." It was said that Mr. Houghton began to call the district Tiger in honor of his alma mater.

Another version has it that the name was chosen by popular vote. According to Harvey Willeford, an employee of St. Anthony Mining and Development at that time, residents of the community were offered the choice of two names. One was St. Anthony, named for the company which employed them all; the other was Tiger, after a rather famous tobacco pouch, made from the scrotum of a Tiger.

According to Mr. Willeford, the tobacco pouch belonged to the mines' owner, a big-game hunter from New York named Mr. Brown. A similar version attributes ownership of the pouch to the mine manager, Wilton Lloyd Smith. In any case, Mr. Willeford was given the task of canvassing the town's residents door-to-door. The vote was unanimous in favor of Tiger.

In February or March of 1939, a new 24-ton reverberatory furnace was added to the smelter. Lead, gold and silver bullion was being shipped to El Paso for refining. The smelter slag was crushed in a chemical solution, filtered, and evaporated in large pans heated by waste heat from the reverberatory furnaces. The sodium molybdate and vanadate salts, which remained after evaporation, were shipped to molybdenum refineries.

During 1939, R.A. Chapman was resident manager of the Mammoth-Collins and Mohawk-New Year properties; Warren L. Howes was mill superintendent; K.V. Gieb was superintendent of the Mohawk-New Year mine; Sam Field was superintendent of the Mammoth-Collins mine; and Foster S. Naething was managing director. Mr. Naething died sometime around the first of January, 1940, and Mr. Henry C. Carlisle, a San Francisco consulting mining engineer, was named as a temporary replacement.

Mammoth-St. Anthony superintendent Sam Field was described by Harvey Willeford, an employee at the time, as always walking around "with a newspaper in his hand, and his hands behind his back, smoking a pipe...If he saw someone he thought was not working, he would just walk up to them and fire them. There were always men waiting for a job."

On September 21, 1941, revised articles of incorporation for Mammoth-St. Anthony, Limited, a Delaware corporation, were published. The articles were a revision, and detailed the merger of Mammoth-St. Anthony with Tiger Management, which had been incorporated on July 21, 1939. The President of Mammoth-St. Anthony at that time was James A. Fowler, Jr.

During 1940 Roy L. Baird and a Mr. Dietrich, of Los Angeles, organized a company to mine the old Ford Mine. They acquired five claims on the Tucson Wash road. In August of 1941, the Mammoth-Tiger Extension Mining Company was incorporated in Arizona, with authorized common stock of 150,000 shares, 100,000 of it issued and 50,000 of it in the treasury. Roy N. Baird of Los Angeles was president. The company applied for a $20,000 Reconstruction Finance Corporation loan on February 19, 1942. It was granted $8,500.

With the beginning of World War II, vanadium production statistics from Tiger were withheld by the U.S. Bureau of Mines. After the United States entered the war in 1941, able bodied miners were hard to find. During the fall of 1942, the U.S. Army sent 65 men to the mines at Tiger. The men were discharged early from the Army to help produce strategic metals.

During 1942, the Mammoth-Tiger Extension Mining Company cleaned out the underground workings of the Ford mine. The company erected a new headframe; installed new ladders, platforms, and air and water lines in the shaft; built a hoist house, blacksmith shed and supply house; and installed tanks, a compressor, and hoist. The shaft, which was allowed to flood in 1920, was completely dry in 1942. Pumping in the nearby mines at Tiger had lowered the water table below the bottom of the Ford shaft. The ore which was blocked out at this time was reported to assay 3.02% lead, 1.75 ounces of silver a ton, 7.8 ounces of gold a ton, and 3.7% copper.

In 1943 the U.S. Bureau of Mines began exploratory churn drilling on the San Manuel copper deposit, which was adjacent to Tiger. The drilling was begun on the recommendation of B.S. Butler of the University of Arizona and N.P. Peterson of the U.S. Geological Survey.

By June of 1943, the labor shortage at Tiger was critical. The company was exploring the possibility of importing Mexican nationals, and again requested U.S. troops to help mine the strategic metals at the mines. Production was down 50%; peacetime employment had been 415 to 500 men, and there were now only 340 on the payroll. The company needed another 100 men to achieve full production.

At that time Tiger had one of only two processing plants in the United States which could separate molybdenum and vanadium from other metals. As of June, 1943, J.L. Fozard was General Manager of both St. Anthony Mining and Development Company and Mammoth-St. Anthony, Ltd., which were still operating the Tiger mines jointly.

In October of 1943, the War Production Board granted a 40-cents-per-shift pay increase to Mammoth-St. Anthony employees, retroactive to June. This increase was the result of a dispute between the company and the Mine, Mill, and Smelter Workers Union. It brought the base pay of miners to $6.40 a day, with annual vacations of seven days at six days' pay.

By November, 1943, William Miller, a rancher from Higley, Arizona, and partners had control of the Mammoth-Tiger Extension Mining Company. They engaged the services of a prominent Phoenix mining engineer to investigate whether or not Mammoth-St. Anthony had crossed underground onto their claims at the Ford mine. The engineer, Mr. Colvocoresses, visited both mining properties and determined that the nearest workings on the Collins vein were no closer than 1,000 feet to the Mammoth-Tiger Extension sideline.

By this time, Mammoth-Tiger Extension had been denied further loans from the R.F.C., which had placed a lien on the ore and a mortgage on the equipment at the Ford mine. The company approached Mammoth-St. Anthony about the possible purchase of the Ford property, paying off the R.F.C. loan as part of the sale. Mammoth-St. Anthony had found no extensions of the Ford vein on any of its property, and had found no ore on the Dream Vein or the Collins East vein, on the Ford side of its holdings. The company therefore considered the Ford property to be of little value and declined to purchase it.

In December of 1943, Mammoth-St. Anthony was not in the best financial condition, anyway. The company was on the verge of shutting down at any time, due to extremely high pumping costs. The only thing keeping it in operation were government bonus payments for the strategically important molybdenum and vanadium, lead and zinc that the mines were producing.

During 1944 the Magma Copper Company, under general manager W.P. Goss, purchased the 21 claims which made up the San Manuel property. Magma continued the exploratory drilling there.

On September 3, 1944, the Mohawk shaft caught fire. All of the timbering in the shaft was destroyed, along with the headframe, hoist house, warehouse, coarse ore bins, coarse crushing plant, fine crushing plant, and all wiring and pipe lines. Shortly after the fire broke out, the pumps in the shaft failed, leaving the entire community of 1,400 people without water. And there was no water with which to fight the fire. The fire was not brought under control until help arrived from Davis-Monthan Air Base in Tucson.

The company arranged to haul water for the town until the pumps could be put back into operation. Mrs. Jamie Dicus, who was a young child living in Tiger at the time, recalled vividly the huge cloud of smoke billowing up from the headframe. It went on hour after hour, and the entire town was in a state of turmoil.

At that time, John A. Richards was general manager, Henry Carlisle was consulting engineer, R. Eddy, Sr., was mine superintendent, and C.E. Craven was mill and smelter superintendent. All employees of the company were kept on the payroll after the fire, doing clean-up and repair work.

The mine pumps were back in operation by the September 6. By September 12, most of the clean-up work was completed. And by November 15, 1944, the shaft had been repaired by a rather ingenious method. The Mohawk shaft was accessible underground through the Mammoth shaft. The burned-out shaft was filled to within 15 feet of the collar with mill tailings, which were loaded by hand into trucks and dumped into the shaft. New timbers were set at the collar and were concreted.

Then the tailings were drawn out of the shaft from below in stages, far enough to allow the workmen a floor to stand on while they installed new timber. This method eliminated the hazard of working in an open shaft, over a 900-foot deep hole. As work progressed downward, the air was sampled frequently, and care was taken to remove any carbon monoxide left from the fire.

A steel headframe was purchased from the Verde Central mine in Arizona, a hoist from the Atolia mine in California.

compressors and steel ore bins were scavenged. The truck hauling the hoist overturned on its way to the mines, destroying the hoist; another one had to be purchased and hauled in from Tonopah, Nevada. The change of hoists forced the workmen to tear out and remodel the newly installed foundation for the headframe.

While the fire damage was being cleaned up and repaired, the mill, which was not damaged by the fire, was overhauled. New steel ore bins and crushers were installed there.

Before the fire, all of the ore was hoisted from the Mammoth shaft and carried by tramway to the crushing plant and mill near the Mohawk shaft. After the wooden tram towers near the Mohawk shaft burned, it was decided to equip the Mohawk shaft for hoisting ore. After the shaft was repaired, it was deepened and sulfide ore was mined from the lower part of the Collins vein, between the 700- and 900-foot levels. The minerals which were of primary significance now were the lead and zinc minerals, galena and sphalerite.

After the end of World War II, St. Anthony continued to produce lead and zinc ore from the lower levels on the Collins vein. On December 31, 1945, Mammoth-St. Anthony, Ltd., was formally dissolved. St. Anthony Mining and Development Company continued to operate the properties at Tiger, now as a single entity. The primary function of Mammoth-St. Anthony, which had been to handle shipments, was taken over by St. Anthony Mining and Development. Production of lead and zinc from the mines continued, with 1946 production exceeding that of 1945.

In 1948, underground exploration began at nearby San Manuel. The San Manuel Copper Corporation had been formed by Magma in 1945. Exploratory drilling on that property was completed in 1948 and the company began sinking No. 1 shaft.

The year 1949 marked a peak in demand for and production of lead and zinc. A tapering off in production began in 1950. By 1951, a flood of lead and zinc imports of had caused many lead and zinc mines in the United States to shut down. The situation became progressively worse, with more and more mines shutting down during the next few years.

During the entire period of lead and zinc production at Tiger, mill recovery had been erratic. The best recovery was from pure sulfide ore, from the deepest levels of the vein. The more oxides present in the ore, the worse recovery was. But as the mine workings progressed deeper and deeper, the influx of water increased.

By 1952, mining on the Collins vein was down to the 1,125-foot level. The amount of lead and zinc in the ore was decreasing with depth and the amount of water which had to be pumped out of the workings was increasing. At the same time, the prices for lead and zinc continued to decrease. Production during 1952 was about 8,000 tons a month, and there were 190 men on the payroll.

The town of Tiger by this time had evolved into a mature community. The miners had modest homes in the lower part of the basin with neat, well-kept yards. As late as 1954, outdoor privies were not a rarity. The larger staff houses were up on the hillsides, and the general manager's house had a swimming pool. There were no bars or saloons in Tiger, but there were many churches. A cafe-boardinghouse was run by Rosalee Hendrickson and provided meals for the single men. The town boasted a movie house, two school buildings, a laundromat, a gas station, and a mercantile store operated by Kenny and Janet Creed.

The End for Tiger

On December 1, 1952, St. Anthony Mining and Development suspended operations at Tiger. On February 11, 1953, the Magma Copper Company announced the purchase of nearly all the property of St. Anthony Mining and Development at Tiger. The property was acquired in exchange for 10,000 shares of Magma capital stock, which at the current market rate on the New York Exchange was worth $275,000.

Through 1953, the mines at Tiger produced over five million dollars' worth of metals, including about 400,000 ounces of gold, 1 million ounces of silver, 3.5 million pounds of copper, 75 million pounds of lead, 50 million pounds of zinc, 6 million pounds of molybdenum oxide, and 2.5 million pounds of vanadium oxide.

One of Magma's primary reasons for purchasing Tiger was to acquire St. Anthony's company housing, dispensary and equipment, school house, store, offices, warehouse, and other buildings, and its supply of potable water. As underground development on the San Manuel mine continued, and construction on the plant began, more and more employees were in need of housing. Construction of the San Manuel townsite was begun by the Del E. Webb Company in the spring of 1953.

The town of Tiger housed San Manuel employees, some of whom had been St. Anthony employees, until company housing at the San Manuel townsite was completed in 1954. San Manuel's mine development and construction stimulated a population boom in the Mammoth-Tiger area.

Tiger was evacuated of residents by the end of June, 1954, although some of the buildings were still in use. San Manuel wanted to take no chances that subsidence over its growing underground mine would reach the residents of Tiger. The Tiger post office was closed on November 26, 1954.

After the houses in Tiger were vacated, many were sold to individuals who moved them to Mammoth. The sale of the houses was handled by Jim Gardner, the purchasing agent for San Manuel. Mr. Gardner had been employed by St. Anthony Mining and Development for many years before going to work for Magma. His family was the last to leave Tiger.

In January of 1956, the San Manuel smelter began operation and the first undercut in the mine was completed. San Manuel was pumping large amounts of water from its workings, which were much deeper than those at Tiger. By 1959 the water table had been lowered below the bottom of the Mohawk shaft, and the pumps there were removed. The shaft had been a source of potable water for San Manuel.

According to company geologist Robert L. Hockett, San Manuel tried to "close all access to the mine to prevent injury to the curious and persistent rock collectors." In 1962 the San Manuel Copper Corporation again became Magma Copper Company.

Back to Gold Again

In late 1961 or early 1962, the McFarland and Hollinger Company of Tooele, Utah, purchased the old mill tailings at Mammoth. During January and February of 1962 they began hauling up to 200 tons a day of the tailings to Hayden. The tailings were sold to ASARCO for smelter flux. According to the Arizona Department of Mineral Resources, the material shipped contained about 0.06 ounces of gold per ton with 85% silica.

In 1963 McFarland and Hollinger leased the tailings at Tiger and were shipping them to ASARCO instead of the Mammoth tailings. They shipped about 100 tons a day, with a contract for 20,000 tons a year. One man was employed loading and driving the truck. At that time the volume of the dump was estimated at 1,000,000 tons.

By the late 1970's, the price of gold was rising fast after the U.S. government eliminated price and ownership control. Suddenly the rock at Tiger became attractive again. Magma Copper Company geologists began to study the wall rock along the borders of the Tiger veins. The rock was high enough in silica to make satisfactory smelter flux, and it contained traces of gold. Through 1978 Magma produced over 100,000 tons of this rock from an open pit over the Mammoth mine, shipping it to the company's smelter in San Manuel.

Mining on the open pit was stopped in 1979 because of difficulties in maintaining a uniform silica content, and because of lower-than-expected gold assays. Magma conducted extensive tests, and eventually devised a method of processing the material to achieve the required characteristics. In 1983 open-pit mining was resumed by a contractor. The pit was 250 feet wide along the vein, down to just below the 100-foot level of the old underground workings. Old stope fill and dumps were shipped to the San Manuel smelter along with freshly mined rock.

The flux mining continued through the end of 1987. In January of 1988, the Cyprus Minerals Company began exploration drilling along the Mammoth-Mohawk vein. Depending on the results of that exploration, Cyprus may develop a small open-pit gold mine there.

So it appears that the mines of Tiger have come full circle. They began as gold mines, then became molybdenum-vanadium mines, then lead-zinc mines. Now the veins and surrounding wall rocks may be mined for gold again.

References

This history was compiled mostly from written sources, which include: Arizona Bureau of Mines Bulletins 5, 137, and 156; newspaper clippings, letters, and reports in the files of the Arizona Department of Geology and Mineral Technology and the Arizona Department of Mineral Resources; patent survey records of the U.S. Bureau of Land Management; material in the University of Arizona Special Collections, including the 1927-1929 manuscript of History of Mining in Arizona by J.B. Tenney; U.S. Bureau of Mines Bulletin 111; U.S. Geological Survey Professional Paper 471; articles in The Mineralogist, The Mineralogical Record, Mining and Scientific Press, Paydirt, Magma Copper Company Update, The San Manuel Miner, The Oracle Historian, Mining and Engineering World, and A.I.M.E. Transactions; and unpublished field trip presentations by William Panczner and Robert L. Hockett.

famous mineral localities ARIZONA - I

TIGER

ARIZONA

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From the initial discovery in 1879, over 100 years ago, until the time of their closing in 1953, the Mammoth and Collins mines were producers of spectacular mineral specimens for the collector. Many of the mineral specimens recovered from this deeply oxidized, base and precious metal vein deposit were exceptional examples compared to those found in the numerous similar deposits in Arizona, New Mexico and Sonora. Additionally, the superimposed wulfenite and vanadinite mineralization was outstanding both in quality and volume. Special conditions which obtained in these veins led to a suite of highly unusual copper-lead minerals unmatched in richness and beauty from any other deposit. The nearly 100 species recognized to date seem to occur in endless combinations; while outstanding cabinet specimens of some of the minerals were produced, the full impact and range of the mineralogy can only be appreciated in micromount-size crystals.

LOCATION

The mines are located about 80 km north-northeast of Tucson, near the present town of Mammoth, Pinal County, Arizona, and are today owned by the Magma Copper Company. Access to the grounds is prohibited except by prior arrangement.

MINING HISTORY

Frank Schultz located claims on the Collins vein in 1879, the Mohawk vein in 1881, and the Mammoth vein in 1882. Original workings were an open cut atop a hill on the Collins vein. Mineral specimens from this cut bearing labels with the locality "Schultz gold mine" are still to be seen.

The town of Mammoth, about 5 km northeast of the mine, was established to mill the gold ore. By 1889, the property was in operation by the Mammoth Gold Mines, Ltd., an English company, in turn succeeded in 1896 by the Mammoth Gold Mining Company. At first ore was hauled by 20-mule teams; later connection was made to the town of Mammoth by an aerial tramway, traces of which can still be seen.

In 1901 the workings caved from the 750-foot level to the surface. For this reason and litigation, the mine was not reopened until 1913, by the Great Western Copper Company. Before 1914, the mine was worked for gold alone, but demand for molybdenum during World War I created interest in the mines' wulfenite reserves. The extensive tailings dump was worked for discarded wulfenite, the first of several reworkings by the Arizona Rare Metals Company.

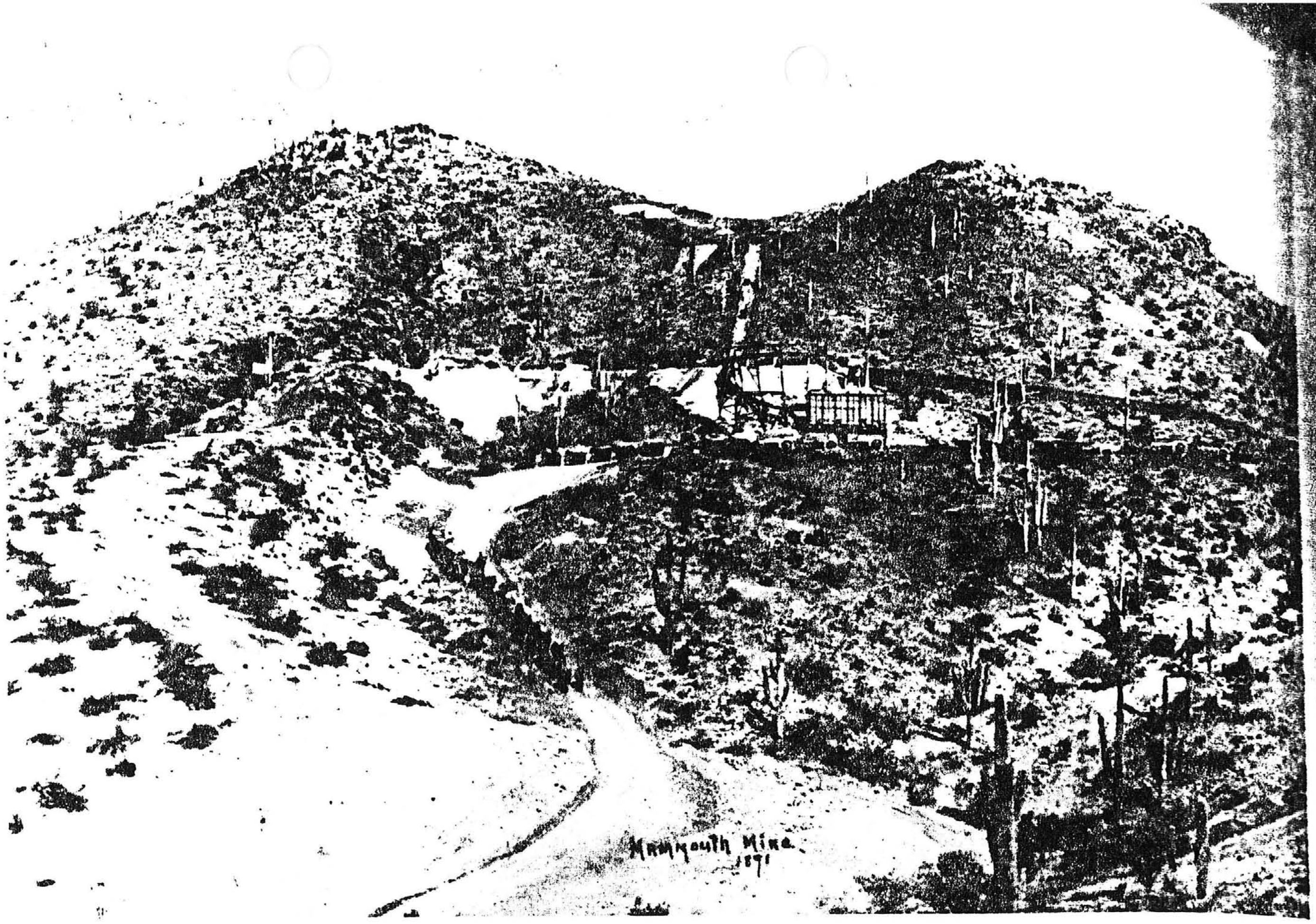

Figure 1. **Mammoth mine in 1891 (photo courtesy of the Arizona Historical Society).**

The Mammoth Development Company acquired the property in 1915, extending the underground workings, then giving way in 1918 to the St. Anthony Mining and Development Company. The collapse in the price of molybdenum necessitated closing the mines in 1919.

By 1943, with increasing demand for base metals due to World War II, the deeper sulfide ores were worked for lead and zinc. Increased mining costs and depleted reserves caused the sale of the property and the town, Tiger, to the Magma Copper Company in 1953; at that time the mine ceased production.

About 400,000 ounces of gold, 1 million ounces of silver, 3.5 million pounds of copper, 75 million pounds of lead, and 50 million pounds of zinc were produced. Six million pounds of MoO_3 and 2.5 million pounds of V_2O_5 were also recovered; these figures correspond to 15 million pounds, or 7500 tons of pure wulfenite concentrates, and 12.5 million pounds, or over 6000 tons of vanadinite-mimetite-descloizite concentrates. The total value at today's prices of all of the seven metals produced would be over $300 million (17, 27, 40).*

GEOLOGY

The area is underlain by Precambrian Oracle granodiorite which has contributed material for younger conglomerate and arkoses. Interbedded with basalt and tuff, these later overlying rocks are collectively known as the Cloudburst formation of Tertiary age. In the area of the mineral deposits, a younger fine-grained to prophyritic intrusive rhyolite is prominent, appearing in places as a breccia of enigmatic origin, which includes fragments of granite and basalt as well as rhyolite.

The Mammoth mine deposit is less than 1 km from the large San Manuel low-grade porphyry copper and molybdenum deposit. The former vein systems are certainly younger than the San Manuel deposit, but their exact age relations are not yet established. Lead-zinc-barite mineralization in the core of the San Manuel deposit may correspond in age to that of the Mammoth mine (L. Thomas, personal communication) (17, 27, 35).

The veins are fault-controlled: the same faults which rhyolite intruded were later mineralized along the granite-rhyolite contacts with vein widths up to 6 m. After emplacement, the sulfide ores were oxidized to great depth. A second period of normal faulting then offset the main vein, forming the separate Collins (lower) and Mammoth (upper) orebodies. The uplifted sulfides in the Collins continued to oxidize to the present water table, while the pre-existing oxidation of the Mammoth orebody extended below it (17, 27, 35).

EARLIER MINERALOGICAL WORK

After vom Rath (1) and Genth (2) originally described vanadinite and descloizite from the Mammoth mine, there was little professional interest in the minerals from the deposit for many years. Blake (8) and Guild (9), in their pioneer Arizona mineralogies, touched on the deposit, but very few species were mentioned. Peterson's PhD thesis (16) and its publication (17) remain the longest description of the geology and mineral occurrences at the Mammoth mine. Galbraith's initial *Minerals of Arizona* (21) summarized Peterson's mineralogical findings.

Following discovery of the rarer minerals about 1940, Palache at Harvard University and Gordon at the Philadelphia Academy

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*Ed. note: Due to the large number of references, this article departs from our usual reference format. Numbers given in parentheses indicate numbered references listed at the end of the article.

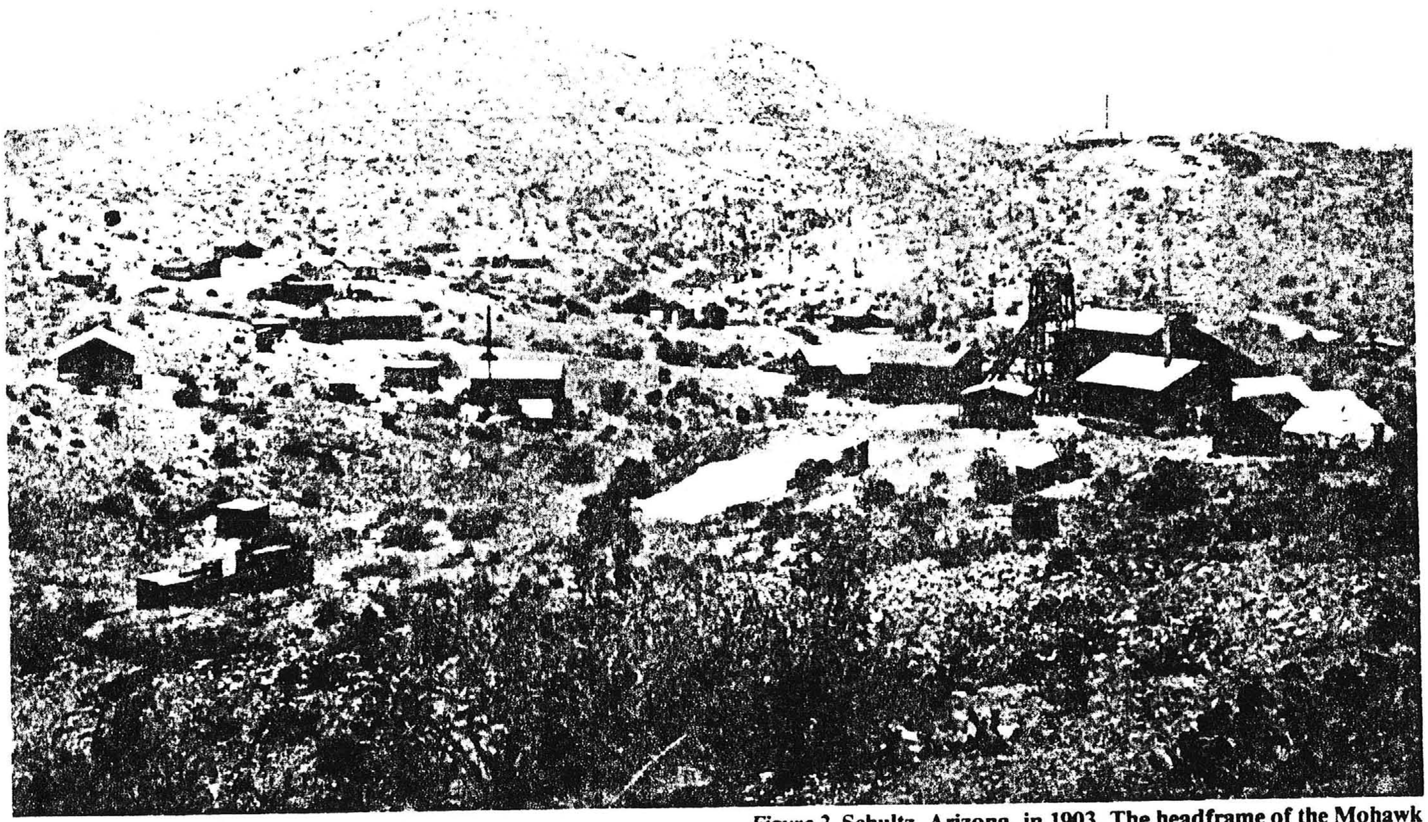
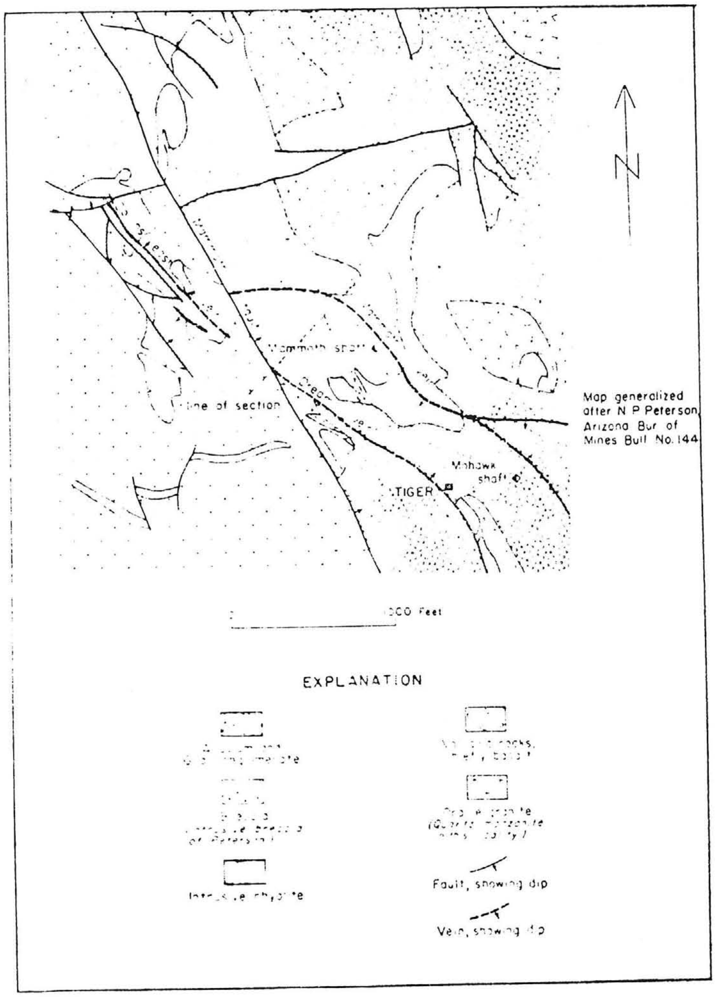
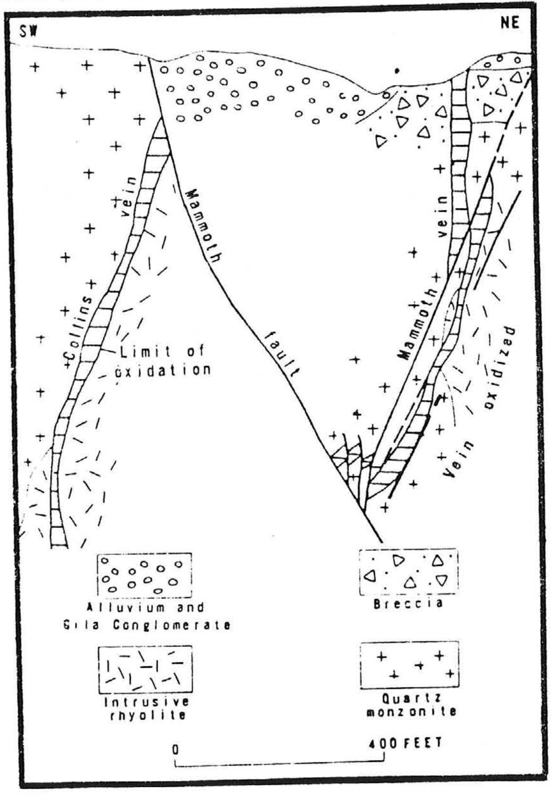


Figure 2. **Schultz, Arizona, in 1903. The headframe of the Mohawk mine is in the foreground, and the Mammoth mine workings are in the saddle of the hills and to the right on the horizon (photo courtesy of the Arizona Historical Society).**

Figure 3. (left) **Generalized geology of the Tiger area (from Creasey (27)).**

Figure 4. (below) **Vertical section through the Collins and Mammoth veins (from Anderson (35)).**





became interested in the mine. Pal [illegible] cted at the deposit in 1941, and Gordon several times in the early 1940's. While both recognized the need for a comprehensive paper on the suite of minerals, neither completed the project. Gordon's work did result in numerous unpublished crystal drawings of some of the most complex crystals he observed in the deposit; these are reproduced here for the first time.

PRESENT WORK

This study had several objectives, among which were a detailed examination and confirmation of the minerals known to occur in the deposit, their inter-relationships and sequence of formation. It was hoped also to find minerals new to the deposit and perhaps new to science.

Several thousand specimens were examined, with detailed notes taken on about 600 of the more interesting and significant of these. X-ray powder diffraction was the principal method employed for confirmation of the various species with several hundred such patterns being prepared. The study was primarily confined to the metal bearing species. No thin sections or other special efforts were made to determine additional species in the host rocks. Other than a few visits to the locality to collect on the surface, the study was conducted entirely on specimens already in collections.

There was considerable success in confirming the already known species, as presented in this paper. About two dozen minerals were found not previously known to occur in the deposit and, of these, three entirely new minerals, bideauxite (37), yedlinite (38) and creaseyite (39), have been fully described.

Progress on unraveling the paragenetic sequences of the Mammoth mine suite, especially of the secondary minerals, has been much less marked. The more closely this problem is examined, the more complex it seems to become. More than one generation, on the same specimen, of nearly every secondary species has been seen. There are obvious implications for misjudging the relative ages of these minerals on other specimens.

There is abundant evidence of earlier formed crystals being physically displaced from their positions by other later minerals, giving the appearance of a reversal in their true order of formation.

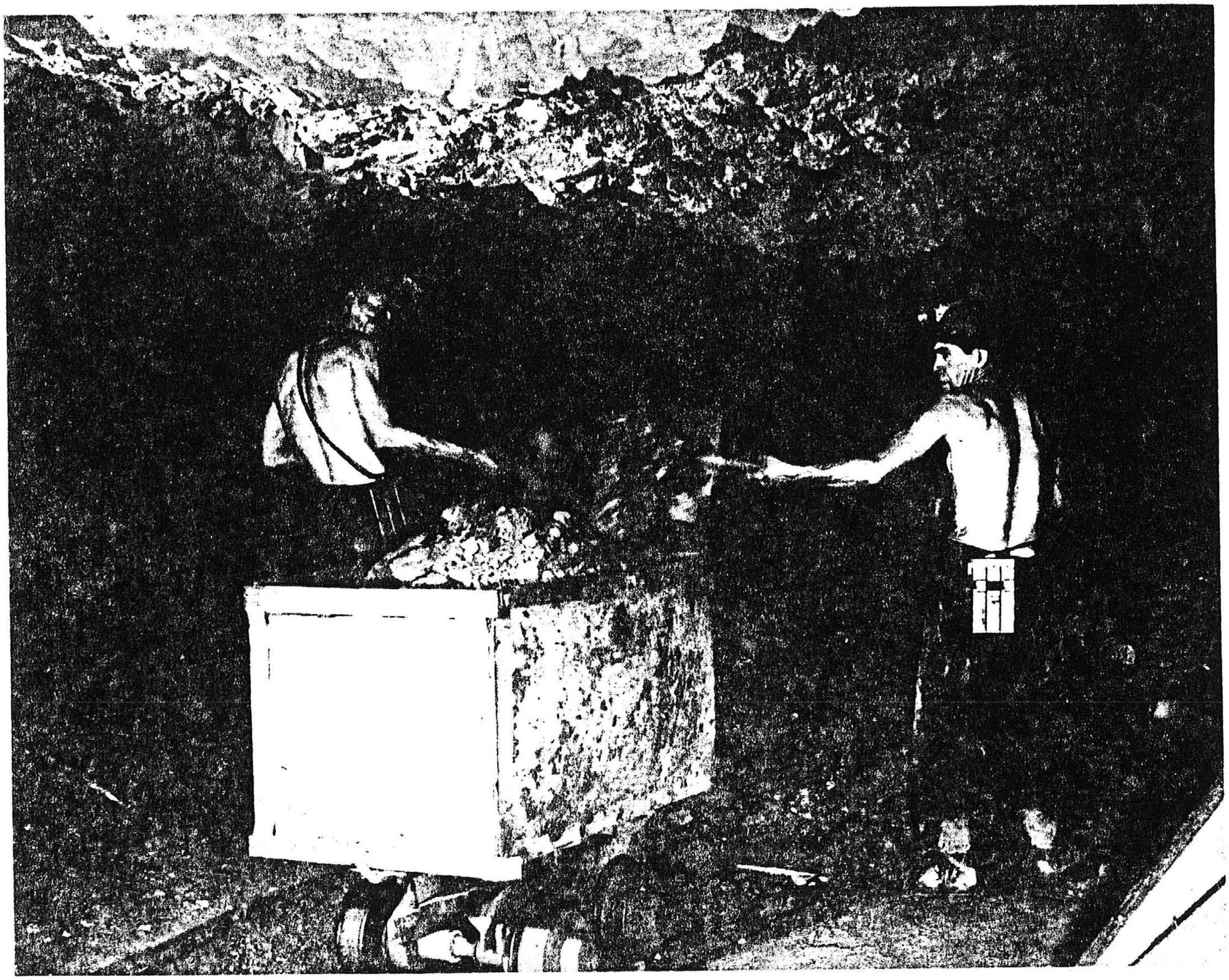


Figure 5. **Miners working in the lower levels of the Mammoth-St. Anthony mine, early 1940's (photo courtesy of the Arizona-Sonora Desert Museum, Fred Houghton collection).**

Pseudomorphic replacements, many seemingly contradictory, were found to be much more widespread than previously reported. Some of these replacements appeared to proceed only by breaching the surfaces of some of the crystals possibly subject to alteration. Effects also were seen which are perhaps best explained by contemporaneous, or nearly so, deposition of several species.

While the order of deposition on most individual specimens was easily understood, some showed a drastic difference in the order, or even the groups of species present, in a distance of only a few mm. These problems, coupled with the lack of data regarding location of occurrence within the deposit for most of the specimens examined, make anything other than a gross estim)f the p enesis difficult, if not impossible. The samples examined, while several thousand in number, obviously have not exhausted the combinations or even the minerals to be observed, and are clearly not samples representative of the entire deposit. Examples of the primary minerals are very rare in collections; those minerals collected have been chosen in large part for their beauty and commercial acceptability, rather than to assist in understanding of the minerals' formation.

Consequently, the minerals known to occur in the deposit have been grouped first by a gross order of formation, as shown in the tables following. These include minerals of the host rocks and gangue, followed by the primary and secondary sulfides. As the result of oxidation of the upper portions of the veins, one group of secondary minerals is defined as a normal alteration sequence, while another group appears to be anomalous. Placement of individual species in either of these groups is based partially on the oxidation sequences reported in deposits with some similar characteristics, and the observed associations in this deposit, especially for some of the quantitatively rarer species. Minerals from one group seem usually not to be found with those from the other, but a considerable number of exceptions could be cited.

The minerals in Table I are also defined by the major rock-forming elements, for the minerals in the wall-rocks and gangue. The qualitative presence of silver, lead, copper, iron or zinc is noted for the secondary minerals listed in the following tables, as these are the principal elements supplied by oxidation of the primary sulfides.

Following the tables, the individual minerals are discussed in alphabetical order. Reference numbers are the last item for each mineral. These are intended to encompass every mention of the species found in the literature listed under references.

Table 1. **Host rock and gangue minerals.**

		K	Na	Ca	Mg	Fe	Al	Silicate	Water	Others
WALL ROCKS	Quartz							X		
	Microcline	X	.	.	.	.	X	X		
	Orthoclase	X	.	.	.	.	X	X		
	Plagioclase	.	X	X	.	.	X	X		
	Biotite	X	.	.	X	X	X	X	X	F
	Magnetite	.	.	.	.	X				O
	Apatite	.	.	X					X	PO_4, Cl F
HYDRO-THERMAL ALTER-TION	Allophane	.	.	.	.	.	X	X	X	
	Muscovite	X	.	.	.	.	X	X	X	
	Antigorite	.	.	.	X	X	.	X	X	
	Serpentine	.	.	.	X	X	.	X	X	
	Palygorskite	.	.	.	X	.	X	X	X	
	Chlorite	.	.	.	X	X	X	X	X	
	Amesite	.	.	.	X	.	X	X	X	
	Epidote	.	.	X	.	X	X	X	X	
	Tourmaline	.	X	X	X	X	X	X	X	F, BO_3
	Stilbite	.	X	X	.	.	X	X	X	
	Heulandite	.	X	X	.	.	X	X	X	
INTRO-DUCED	Barite									Ba, SO_4
	Fluorite	.	.	X						F
	Calcite	.	.	X						CO_3

HOST ROCK AND GANGUE MINERALS

The minerals reported as composing the wall rocks are unexceptional, as was the course of their alteration during later hydrothermal mineralization of the veins. Destruction of the feldspars, with loss of soluble potassium and sodium and the introduction of water, resulted in h ted alu o-silicate minerals. Biotite and the other dark-colored magnesium, aluminum, iron-bearing (mafic) minerals (undoubtedly present but not reported) provided magnesium and iron for the clay species and abundant chlorite. Ba^{2+}, SO_4^{2-} and some F^- were perhaps introduced during hydrothermal mineralization to form barite and fluorite. The elements requires to form these minerals are present in the wall rocks, yet their apparent abundance would argue a wider volume of alteration than seems to occur. For example, the width of the barite zone surrounding the Mammoth vein is considerably greater than the vein itself, or the width of bleaching of the wall rocks. CO_3^{2-} in calcite is probably from intermingled groundwater.

Allophane an amorphous hydrous aluminum silicate.

Undoubtedly many different species are lumped with the general term "clay" as applied to the Mammoth mine suite; they will be discussed here under the heading allophane unless otherwise differentiated. This designation is chosen because of the amorphous nature and high aluminum content of most samples containing thick enough layers for X-ray analyses. Clays in one form or another can be found in association with nearly all of the minerals studied, and at least a little can be found on nearly every specimen; their distinction could form a substantial project in itself.

Allophane formed in abundance in the veins as an alteration product of feldspars from the wallrock, and in turn became copper-stained, finally producing chrysocolla. The various clay minerals in general range in color from white through greens and blues, and are present as powders, films, crusts, sometimes banded, occasionally pisolitic, and range from porous to waxy.

An attractive association is a continuous, smooth but layered coating of allophane over wulfenite crystals and their matrix, the whole then giving a shining porcelaneous appearance. This combination forms a pleasing background for scattered crystals of cerussite, dioptase, later wulfenite, mimetite, fluorite, and quartz.

Clay was noted as entirely replacing a loose cerussite twin, while yet another mass of clay formed a hollow mold of cerussite. Linarite and caledonite have been entirely coated by clay, then dissolved, leaving hollow crystal casts. Atacamite was found to have clay selectively encrusting only certain crystal faces (17, 27, 33, 40, 41).

Amesite $(Mg_2,Al)(Al,Si)O_5(OH)_4$

On one specimen, determined to be the white powdery matrix on which wulfenite occurs (41).

Antigorite $(Mg,Fe)_3Si_2O_5(OH)_4$

On a single specimen, from the 100 level, as white crusts with minute contemporaneous quartz crystals. The quartz includes balls of antigorite just under the surface; later wulfenite and descloizite are also on the specimen (41).

Apatite $Ca_5(PO_4)_3(F,OH,Cl)$

Reported as a very minor accessory in the host rocks, Oracle granodiorite, aplite, and andesite porphyry (17).

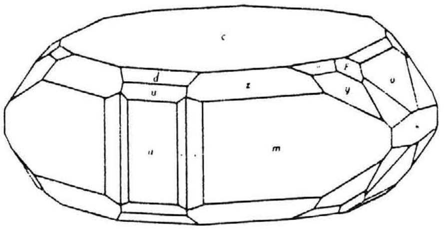


Figure 6. **Barite (Gordon).**

Barite $BaSO_4$

A common gangue mineral, forming the matrix for or intermingled with primary sulfides and their alteration products. Usually as cleavable masses, the mineral occasionally forms in patchily transparent crystal groups with rhombic individuals to several cm.

When not encrusted with metallic [illegible]ier [illegible]n amethystine druse of fluorite crystals is often noted. Tiny water-clear crystals of a later generation may be confused with anglesite (15, 24, 27, 31, 33, 40, 41).

Biotite $K(Mg,Fe)_3(Al,Fe)Si_3O_{10}(OH,F)_2$

A constituent of the host rocks, mostly in the Oracle granodiorite, but accessory in aplite and rhyolite. It is largely replaced by chlorite adjacent to the veins (17, 33, 40, 41).

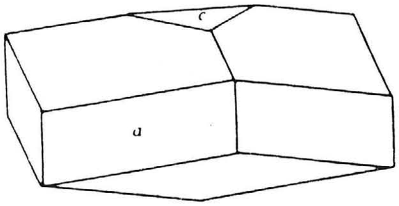


Figure 7. **Calcite (Gordon).**

Calcite $CaCO_3$

A gangue mineral, as cleavable masses up to several inches across veining the wall rock, colorless to black from manganese oxides included along cleavage planes.

Crystals also occur as a very late-stage mineral, alone or with the wulfenite-vanadinite-mimetite-descloizite assemblage. These are usually flat tabular, simple rhombohedral crystals, but occasionally form hexagonal prismatic crystals, investing wulfenite, but often in turn coated by vanadinite-mimetite or descloizite (2, 9, 13, 15, 17, 33, 40, 41).

Chlorite $(Mg,Fe)_{5-6}(Al,Si)_4O_{10}(OH)_8$

A gangue mineral, with barite, quartz, and feldspar, forming part of the matrix for the later primary sulfides. A result of hydrothermal alteration of mafic minerals in the host rocks about the veins.

Powdery to fibrous green masses, usually intimately associated with specular hematite, are to be found on many preserved specimens. Occasionally chlorite is found as inclusions in quartz crystals. Much of the gold for which the deposit was economically mined occurs as micron-sized flakes on chlorite (A. Cockle, pers. comm.). The chlorite sub-species involved have not been determined, but are rich in magnesium and iron. Viridite in part on older lists (15, 17, 27, 31, 33, 40, 41).

Epidote $Ca_2(Al,Fe)_3Si_3O_{12}(OH)$

An alteration product of mafic minerals in the host rocks (S. Williams, pers. comm.). Tiny green needles occur in and on sericitized feldspars, and with chlorite (17, 33, 40, 41).

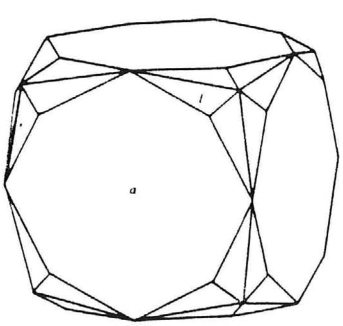


Figure 8. **Fluorite (Gordon).**

Fluorite CaF_2

A gangue mineral with the primary sulfides, and especially with barite. Some large translucent colorless cubic crystals, up to 12 mm, occur rarely in this association. Most crystals are a fraction of 1 mm in size. Colorl[illegible]o[illegible]thystine druses of microscopic crystals often coat barite. Water-clear cubic crystals occur along with clay minerals, and frequently on willemite, quartz, and dioptase crystals associated with wulfenite, mimetite and descloizite. They usually can be found including creaseyite fibers on the few specimens bearing that mineral.

Although usually transparent and colorless, and inconspicuous for this reason, delicate shades of purple sometimes are seen, perhaps zoned along faces, edges or corners. The crystals may be etched to opacity; and rarely may have later, smaller clear fluorite grown on them (15, 17, 21, 24, 26, 27, 29, 30, 31, 33, 38, 39, 40, 41).

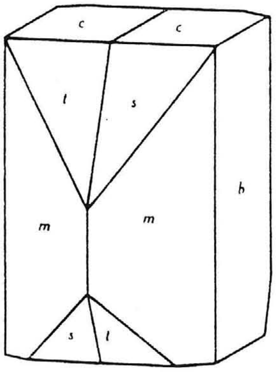


Figure 9. **Heulandite (Gordon).**

Heulandite $(Na,Ca)_{4-6}Al_6(Al,Si)_4Si_{26}O_{72}\cdot 24H_2O$

Two specimens showing microcrystals of translucent white heulandite were seen. On one, it occurs on equally tiny stilbite crystals on large wulfenite plates. On the other, lustrous crystals are strung on loops of gelatinous chrysocolla. The heulandite crystals observed are always twinned. Gordon observed heulandite in the early 1940's; a drawing is extant (41).

Magnetite $FeFe_2O_4$

A minor accessory mineral in the wall rocks, replaced by pyrite near the veins (17, 33, 40, 41).

Microcline $KAlSi_3O_8$

Pink feldspar phenocrysts in Oracle granodiorite and aplite were optically determined to be partially microcline by Peterson (17, 33).

Muscovite $KAl_2(Al,Si_3)O_{10}(OH)_2$

Feldspars in the wall rock near the veins are entirely converted to sericite, a very fine grained hydrous form of muscovite (17, 27, 33).

Orthoclase $KAlSi_3O_8$

Orthoclase phenocrysts and secondary *adularia,* a variety, occur in the wall rocks (4, 17, 31, 33, 40, 41).

Palygorskite $(Mg,Al)_2Si_4O_{10}(OH)\cdot 4H_2O$

A few specimens of the dull gray, matted, *mountain leather* variety have been preserved from their occurrence in fault gouge. Probably the material listed as actinolite *(mountain leather)* (40).

Plagioclase $NaAlSi_3O_8$ to $CaAl_2Si_2O_8$

An essential component of the wall rocks, varying in composition from albite to andesine and oligioclase (4, 17, 33, 40, 41).

Quartz SiO_2

Some quartz was being deposited throughout all phases of mineralization in the veins, as well as being an important component of the host rocks. It can be found in association with every other species. Primary sulfides were deposited along with early coxcomb quartz encrusting brecciated fragments, and very late drusy quartz can be found encrusting wulfenite with clay, among the last minerals formed. The crystals in general are small, only a few mm in length, and often inconspicuous. Several generations of quartz are commonly found on a single specimen, sometimes in parallel overgrowths.

Early in the history of mineralization, galena was replaced along cleavages by multitudes of distinctive doubly-terminated quartz crystals, usually only a mm or two long. These crystals characteristically enclose microscopic blebs of brilliant galena, giving them a gray cast in mass. Loosely attached to one another, with the continuing removal of galena during oxidation they ultimately formed fragile and very light masses which retain the cubic pattern of the galena, with some parts of the boxwork perhaps entirely filled in to give the appearance almost of a pseudocubic crystal.

These quartz casts of galena crystals form a part of the matrix for many of the rarer minerals. Leadhillite, caledonite, and diaboleite especially can hardly be found without their crystallization having been interfered with by some of these quartz crystals, dislodged from their place in the relict boxworks.

Some crystals show phantoms and inclusions of other minerals. Shining plates of microscopic hematite are very common, giving the quartz crystals a blood-red color. Malachite, dioptase, mimetite and wulfenite crystals and spherules of clay may be entirely suspended in quartz crystals. Gold in quartz was of economic importance but apparently was only rarely visible.

Much of the quartz forms fine-grained masses which have encrusted and enclosed earlier minerals, now gone. Many of these molds are suggestive of scalenohedral calcite crystals. A few free-standing epimorphs of drusy quartz, now completely hollow, were found which had covered cerussite sixlings or hemimorphite crystals.

Much of the quartz is amethystine, or colored pale yellow to green. Thin crusts of chalcedony sometimes cover wulfenite crystals (1, 2, 8, 10, 13, 15, 17, 20, 25, 26, 27, 29, 33, 37, 38, 40, 41).

Serpentine a group of minerals $(Mg,Fe)_3Si_2O_5(OH)_4$

Noted as an alteration product of olivine (17, 33, 40).

Stilbite $NaCa_2(Al_5Si_{13})O_{36} \cdot 14H_2O$

Minute white bow-ties of stilbite, rarely associated with another zeolite, heulandite, can be found on some wulfenite specimens (41).

Tourmaline a group of minerals $(Na,Ca)(Mg,Fe)_3Al_6(BO_3)_3(Si_6O_{18})(OH,F)_4$

Minute brownish crystals with the typical rounded triangular cross-section were X-rayed and proved to be a member of this group. Observed on only one specimen, they were coated with brochantite needles (41).

Table 2. **Sulfides**

		Ag	Pb	Cu	Fe	Zn	Others
PRIMARY	Galena	(X)	X				
	Chalcopyrite			X	X		
	Tetrahedrite			X	X		Sb
	Pyrite				X		
	Sphalerite					X	
SECONDARY	Acanthite	X					
	Djurleite			X			
	Chalcocite			X			
	Covellite			X			
	Bornite			X	X		

SULFIDE MINERALS

The primary sulfides were deposited along with gangue minerals in the veins. Galena and sphalerite are about equally abundant, with lesser amounts of pyrite. Chalcopyrite is a minor mineral, and tetrahedrite is present only in traces.

Oxidation of these primary minerals provided the metals for formation of the wide variety of secondary species obtained during mining of the upper portions of the veins. Attack by ferric sulfate, produced from decomposition of the pyrite by weakly acidic groundwater, initiated the dissolution of the other sulfides. Lead was released by galena, along with much smaller amounts of included silver. Chalcopyrite provided copper, and sphalerite the zinc. Some Fe was set free from pyrite and chalcopyrite, but continuing oxidation of rock-forming mafic minerals and hydrothermal chlorite provided substantial amounts of this element as well.

As an intermediate step, secondary copper and iron sulfides were formed in small amounts, as replacements principally of galena.

PRIMARY SULFIDES

Chalcopyrite $CuFeS_2$

Chalcopyrite, the primary source of copper in the Mammoth mine ores, occurs in minor amounts with galena, as inclusions exsolved from sphalerite, and intergrown with pyrite. Tiny sphenoidal crystals seem uncommon in the few primary ore specimens preserved in collections (17, 27, 33, 35, 40, 41).

Galena PbS

Galena is the important primary lead mineral in the Mammoth mine ores, the alteration of which provided the colorful suite of secondary minerals. Little unoxidized material has been preserved in collections, but descriptions of the ores dating from when the mine was in operation indicate that galena was approximately equal in abundance to sphalerite, with pyrite and minor chalcopyrite deposited later. Some galena-rich ore carried as much as 25 ounces of silver and 0.375 ounces of gold per ton. Gangue minerals were barite, fluorite, chlorite, specular hematite, adularia and quartz. Distinct galena crystals were quite rare at the time of mining.

Galena is also preserved in oxidized nodules, when the alteration process starts with replacement of galena by quartz (which includes galena) and djurleite or chalcocite along cleavage planes. All of these minerals may preserve a relic boxwork structure after the galena has been entirely replaced. These nodules are commonly rimmed first by anglesite, then cerussite, both massive in the shells, but crystals of either may form later on the exterior. Oxidized copper minerals, such as linarite and brochantite, may occur in thin shells between galena and anglesite, or in the anglesite; malachite, azurite, and chrysocolla often encrust the cerussite shell. The course of these reactions can be quite complex; relict galena boxworks have been seen in which every cell had varying combinations of minerals (4, 8, 15, 17, 21, 24, 25, 26, 27, 31, 33, 35, 39, 40, 41).

Pyrite FeS_2

A constituent of the primary sulfide ores, pyrite occurs in lesser amounts than galena and sphalerite. Crystals are rare, and of simple cubic habit (4, 17, 27, 33, 35, 40, 41).

Sphalerite ZnS

Massive to radially crystalline, light yellow to brown and black, with crystals very rare. Minute tetrahedra of sphalerite, often as spinel-law twins, could be found in the primary ore. Sphalerite was the most abundant sulfide mineral, and its alteration provided zinc for later smithsonite, hemimorphite, and willemite. It was earlier than the usually intimately occurring galena, and contained exsolved chalcopyrite, which altered to films of covellite. Pyrite, barite, quartz, fluorite, hematite and chlorite were associated in the sphalerite-bearing gangue (15, 17, 21, 24, 27, 31, 33, 35, 40, 41).

Tetrahedrite $(Cu,Fe)_{12}Sb_4S_{13}$

Sharp tetrahedral crystals, modified with small faces of the negative tetrahedron, and less than 1 mm in size, occur on one specimen collected from the dump. Their matrix is pyrite in about the same crystal size.

SECONDARY SULFIDES

Acanthite Ag_2S

Druses of minute black acanthite crystals partially encrust silver wires and crystals imbedded in leadhillite cleavages. On several similar specimens the acanthite also occurs on and in the leadhillite, to which it imparts a characteristic blackish color. The leadhillite is usually replaced by minor caledonite and brochantite.

Although the acanthite crystals are too small for measurement,

Figure 10. Caledonite crystals to 4 mm, Arizona-Sonora Desert Museum collection.

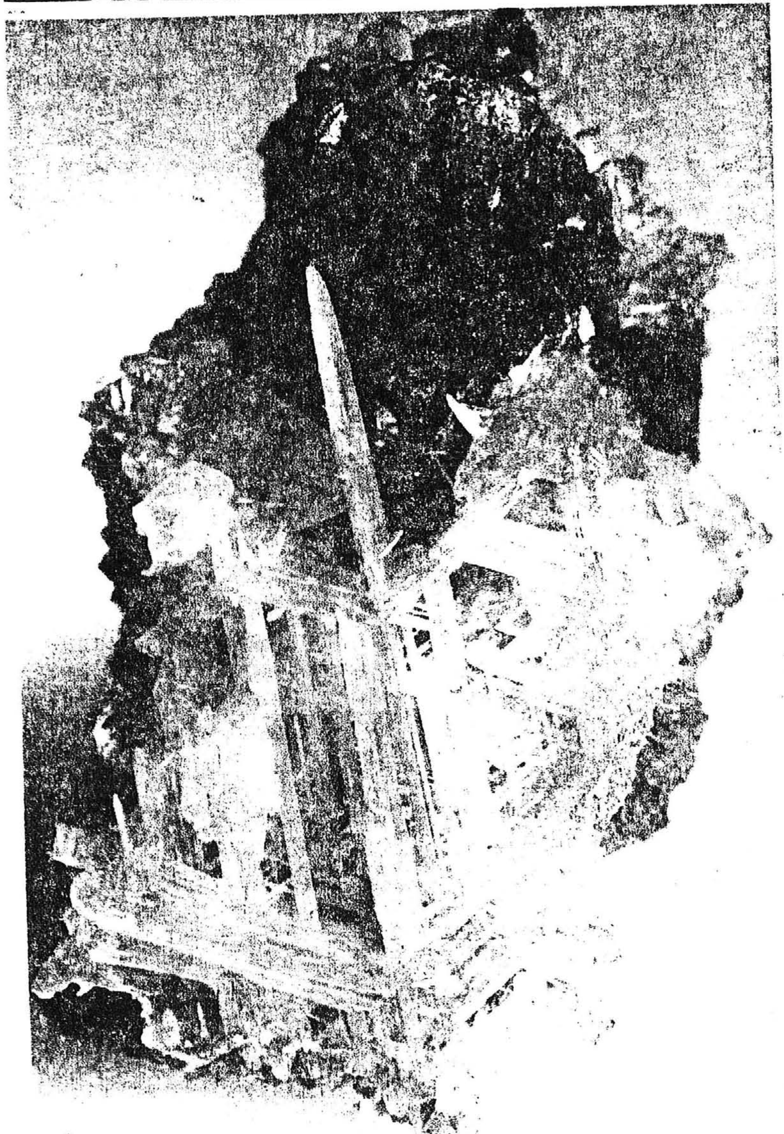
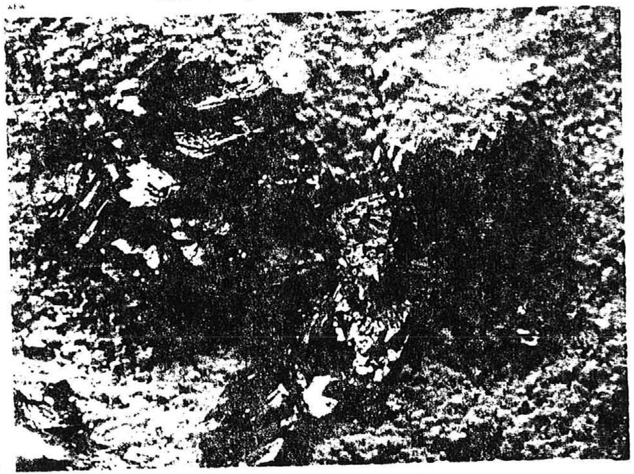


Figure 11. Malachite pseudomorphs after an azurite crystal (2.4 cm tall) on reticulated cerussite. Jelks collection, Arizona-Sonora Desert Museum.

Figure 12. Fornacite group 10 mm across, University of Arizona collection.



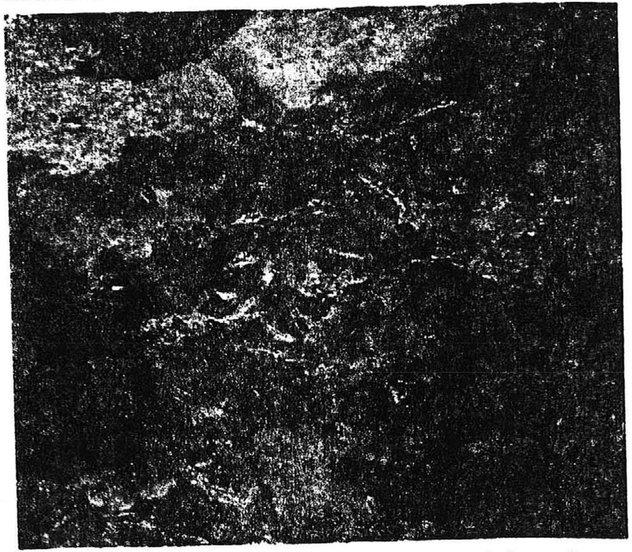


Figure 13. Gold, 1.5 cm across, Arizona-Sonora Desert Museum collection.

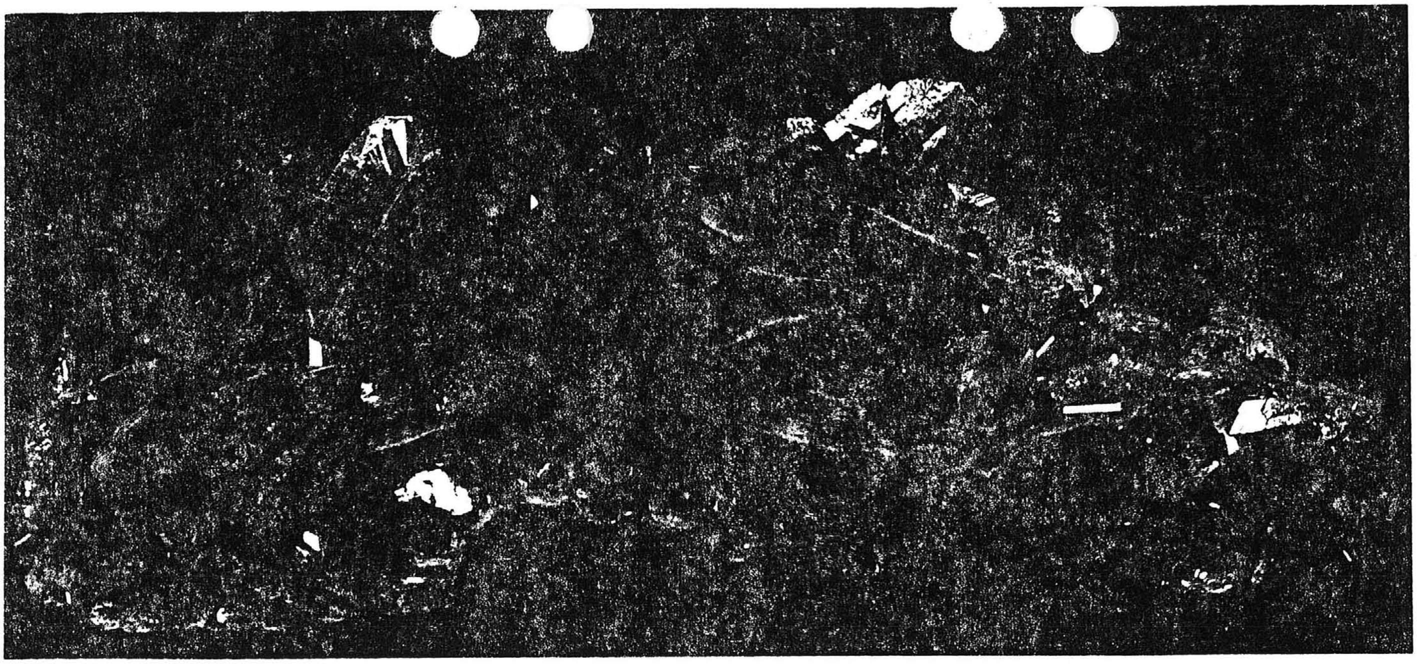


Figure 14. Wulfenite, 15 cm across, Arizona-Sonora Desert Museum collection. Photo by William Panczner.

Figure 15. Spherical aggregate of dioptase crystals 6 mm across, Jelks collection, Arizona-Sonora Desert Museum.

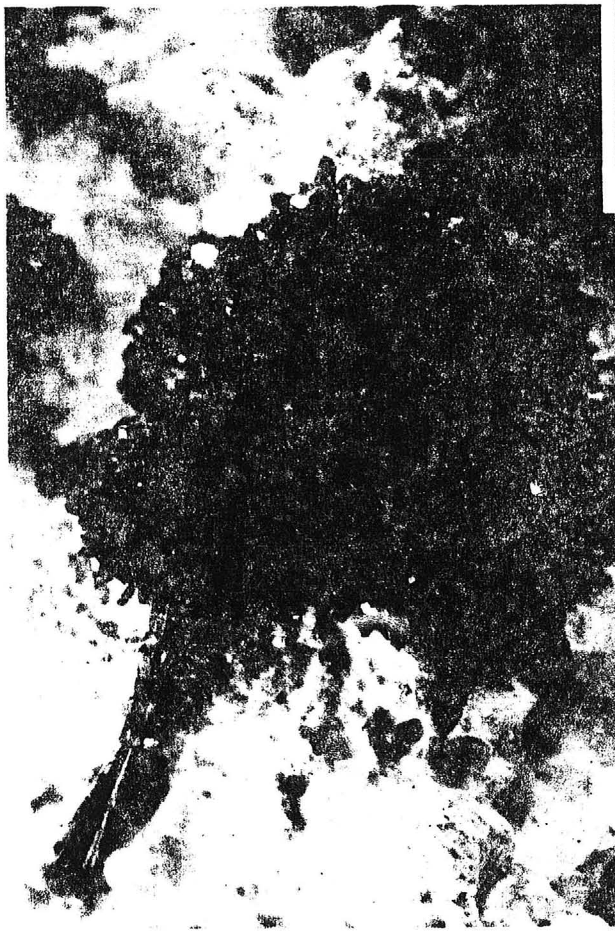
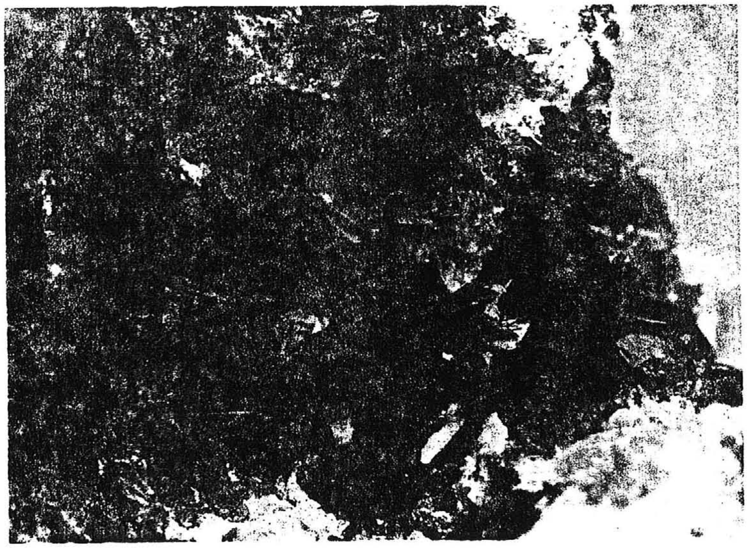


Figure 16. Pale bideauxite crystals to 4 mm with blue boleite, Arizona-Sonora Desert Museum collection.

Figure 17. Diaboleite crystal pocket 3 cm across, University of Arizona collection.



they have bristling and sharply-angled ter[illegible]ations. T[illegible]ndicates crystallization as primary monoclinic acanthite at a temperature below 176° C, rather than inversion from isometric agentite deposited at a higher temperature (41).

Bornite Cu_5FeS_4

Intermixed in small amount with other copper-bearing sulfides replacing galena (17, 33, 40, 41).

Chalcocite Cu_2S

Chalcocite occurs as an alteration product, in thin films, of galena and chalcopyrite. While most suspected chalcocite specimens examined in this study proved to be djurleite, nevertheless its occurrence was confirmed on several pieces (17, 25, 26, 33, 40, 41).

Covellite CuS

At one stage in the oxidation of primary sulfides, galena is partially replaced by sooty djurleite, which is in turn altered to covellite as irridescent films and tiny but distinct metallic purple to red hexagonal crystals. The covellite crystals may be included in anglesite and matlockite crystals, giving them a red color in transmitted light. Pure masses intermixed with pyrite, and veining wall rock, were rarely preserved (17, 21, 24, 27, 31, 33, 37, 40, 41).

Djurleite $Cu_{1.96}S$

Djurleite formed as replacements of galena, sometimes as steel-gray metallic massive nodules rimmed by secondary lead minerals, but more often as fragile shells and crusts of powdery and sooty texture. The crusts usually show relict structure of the replaced galena, and are associated with quartz crystals also replacing galena. The djurleite occurs intermixed in places with bornite and covellite. These alterations are an important step in providing the copper from primary chalcopyrite and lead from primary galena to the formation of the later, more highly oxidized minerals. Most minerals examined during this study which were suspected of being chalcocite proved to be djurleite which is stable only below 93°C (41).

OXIDIZED MINERALS

NORMAL SEQUENCE

The normal alteration sequence for galena, as seen in many deposits other than the Mammoth mine, is first to the lead sulfate, anglesite, then to cerussite, the lead carbonate. In the processes, lead is made available for the formation of the relatively more insoluble molybdates, arsenates, etc., if these anions are present. The copper-bearing sulfates, linarite and brochantite, seem to persist most often along with diaboleite, leadhillite and the other minerals here categorized as anomalous, so they are placed with that group, but the extent of these sulfates in the mine was much wider, up to about 100 meters above the diaboleite occurrences. Copper forms carbonates which have persisted, but much of this element ended up in chrysocolla and some dioptase. Zinc has a geochemical behavior similar to copper; sulfates do not exist in the mine, and either its carbonate, smithsonite, or the silicates, hemimorphite and willemite are the stable forms. Iron was quickly fixed as oxides under a wide range of conditions.

Looking at the other elements in Table 3, only small amounts of manganese are present; but the existence of huge quantities of especially wulfenite, vanadinite and mimetite required introduction of molybdenum, vanadium, and arsenic. Molybdenum at least was probably introduced as a chemical species in solution in groundwater until it encountered lead in solution. It was then fixed as wulfenite, principally in the upper portions of the veins. Wulfenite was found in the deepest level to which the mine was worked, but even these tongues had connection with the surface. The nearby San Manuel copper porphyry deposit is a major producer of molybdenum from molybdenite, MoS_2. The upper oxidized portions of that deposit are relatively depleted in molybdenum (L. Thomas, pers. comm.). Vanadium, arsenic, chromium, etc., may have been leached from the surrounding rocks of dioritic composition. All of the above reactions took place in an aqueous environment; many of the minerals listed contain water in their structure. The somewhat elevated temperatures indicated could have been generated by oxidation within the veins themselves, without necessarily invoking an external source of heat.

Table 3. **O[illegible]ed mine[illegible] normal sequence.**

		Ag	Pb	Cu	Fe	Zn	Others
ELEMENTS	Gold						Au
	Silver	X					
	Sulfur						S
OXIDES	Minium		X				
	Murdochite		X	X			
	Cuprite			X			
	Tenorite			X			
	Goethite				X		
	Hematite				X		
	Ramsdellite						Mn
	Hollandite						Mn, Ba
SULFATES	Anglesite		X				
	Devilline			X			Ca
CARBONATES	Cerussite		X				
	Azurite			X			
	Malachite			X			
	Aurichalcite			X		X	
	Rosasite			X		X	
	Smithsonite					X	
MOLYBDATE	Wulfenite		X				MoO_4
ARSENATE, PHOSPHATE, VANADATE	Mimetite		X				AsO_4, Cl
	Pyromorphite		X				PO_4, Cl
	Vanadinite		X				VO_4, Cl
	Fornacite		X	X			AsO_4, CrO_4
	Tsumebite		X	X			PO_4, SO_4
	Mixite			X			AsO_4, Bi
	Descloizite		X	X		X	VO_4
	Mottramite		X	X		X	VO_4
SILICATES	Chrysocolla			X			Al
	Dioptase			X			
	Plancheite			X			
	Hisingerite				X		
	Creaseyite		X	X	X		Al
	Hemimorphite					X	
	Willemite					X	
	Macquartite		X	X			CrO_4

Anglesite $PbSO_4$

Anglesite occurs frequently but is somewhat rarer than cerussite, with which it is often associated. Other common associates are the sulfate-containing minerals leadhillite, linarite, brochantite, and caledonite; more rarely matlockite, phosgenite, boleite, diaboleite and atacamite.

Anglesite is usually the first alteration product of galena, and is in turn altered to cerussite in the classical sequence. It can either rim the galena or form boxworks within it, sometimes as complete replacements of porcelaneous texture and white to gray color.

Anglesite is notable for a wide diversity of crystal habits, but, in contrast to cerussite, never forms twinned crystals. A commonly occurring, very late type is as powdery to sugary crystalline masses investing crystals of other species. These shining masses are of sparkling white color, or occasionally delicately tinged pink from included iron oxide. Rhombic crystals with the outline of anglesite but with a sugary texture, formed by recrystallization or corrosion, can be seen. These crystals may assume a pseudo-hexagonal

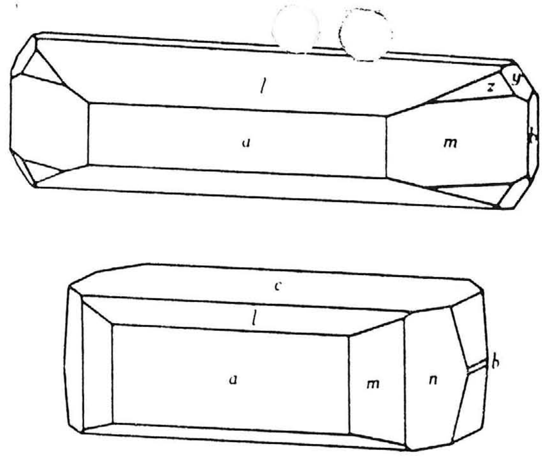


Figure 18. Anglesite (Gordon).

outline, and then are sometimes distinguished from leadhillite only with difficulty.

The better-formed crystals are usually of small size, 1 to 2 mm, and can be recognized by their diamond-shaped outlines, or chisel-shaped to Roman-sword-shaped terminations. These crystals are usually glassy-clear and striated parallel to the axis of elongation, and can be as long as 6 mm.

Crystals of covellite are found as inclusions, and linarite and brochantite may replace the anglesite without destruction of the crystal form. Anglesite commonly alters from crystalline matlockite masses, which it rims, and it is a component in pseudomorphs after linarite and caledonite crystals (4, 8, 15, 17, 21, 22, 24, 25, 26, 27, 31, 33, 37, 40, 41).

Aurichalcite $(Zn,Cu)_5(CO_3)_2(OH)_6$

Only two specimens were noted showing this mineral. On one piece, the aurichalcite occurs as sprays of tiny, pale blue crystals on a matrix of corroded calcite cleavages. On the other, aurichalcite is in fibrous radiating balls perched on glassy tabular willemite crystals, with later wulfenite and descloizite (41).

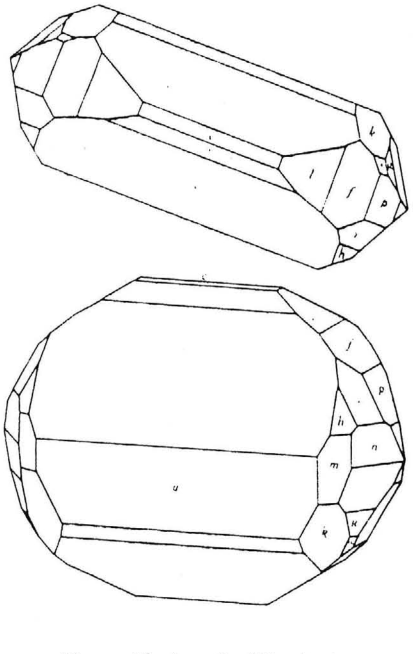


Figure 19. Azurite (Gordon).

Azurite $Cu_3(CO_3)_2(OH)_2$

Azurite forms some of the larger crystals of any of the Mammoth mine species, up to 4 cm, with malachite pseudomorphs afte azurite to over 8 cm. Mammoth mine azurite at its best is comparable to azurite from any locality. Prisms of a deep blue-black color associated with cerussite twins are characteristic, as are stouter crystals altered in part or in whole to fibrous malachite. Both types usually also enclose the doubly terminated quartz crystals so common on Mammoth mine specimens. Very rarely azurite crystals are associated on the same specimen with linarite or diaboleite, then also usually with anglesite.

While the cerussite twins are most often on azurite crystals, a few specimens were noted where the azurite was later than cerussite, perched in interstices or on the tips of cerussite in reticulated masses of crystals. The pseudomorphs of malachite after azurite may have a thin veneer of later azurite grown in parallel position to the earlier azurite crystal (4, 14, 15, 26, 27, 33, 34).

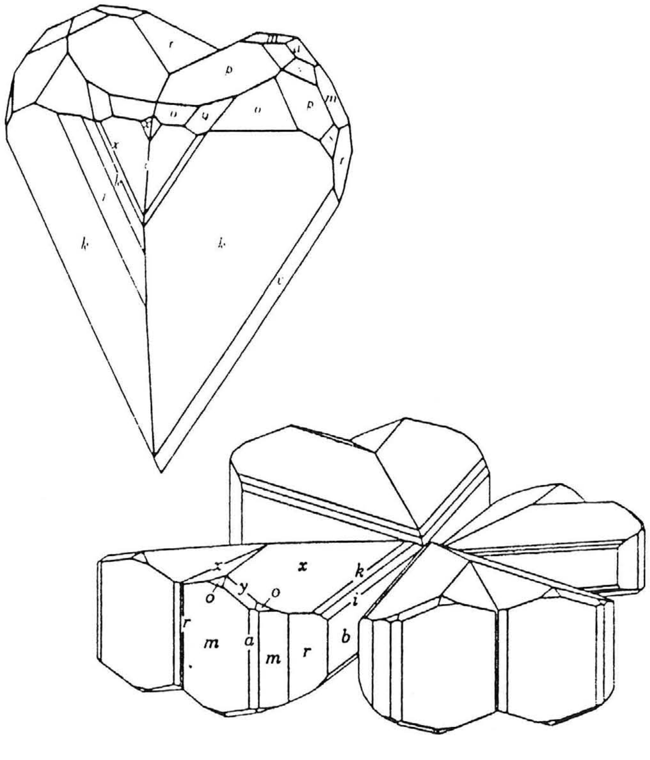


Figure 20. (top) Cerussite (Gordon); *bottom* Cerussite (28).

Cerussite $PbCO_3$

An alteration product of galena, with massive material rimming anglesite in banded nodules. Later cerussite occurs as fine crystal groups, almost always twinned as pairs of individuals, trillings, sixlings, or finely reticulated masses. Only rarely do single prismatic crystals occur.

These later twinned crystals are among the finest U.S. examples of the mineral, and as they can be found on almost every specimen preserved from the Mammoth mine they can assist in determining the correct locality for many specimens. Some twins have been found weighing more than a kilogram with larger reticulated masses of several times this weight.

While some of the crystals are gem-clear, usually they are milky and can even be chatoyant. These effects are caused by fluid inclusions in long hollow tubes and negative crystals which can make up to 5% of the volume of some crystals. The bubble-filling temperature was determined to be about 50 degrees C (B. Austria, pers. comm.).

The crystals are usually colorless to white, but some crystals are tinted a pale yellowish-green to chartreuse, with the color often arranged in thin parallel bands. These colors are thought to be due to small amounts of chromium; rarely fornacite will be found on crystals of this type.

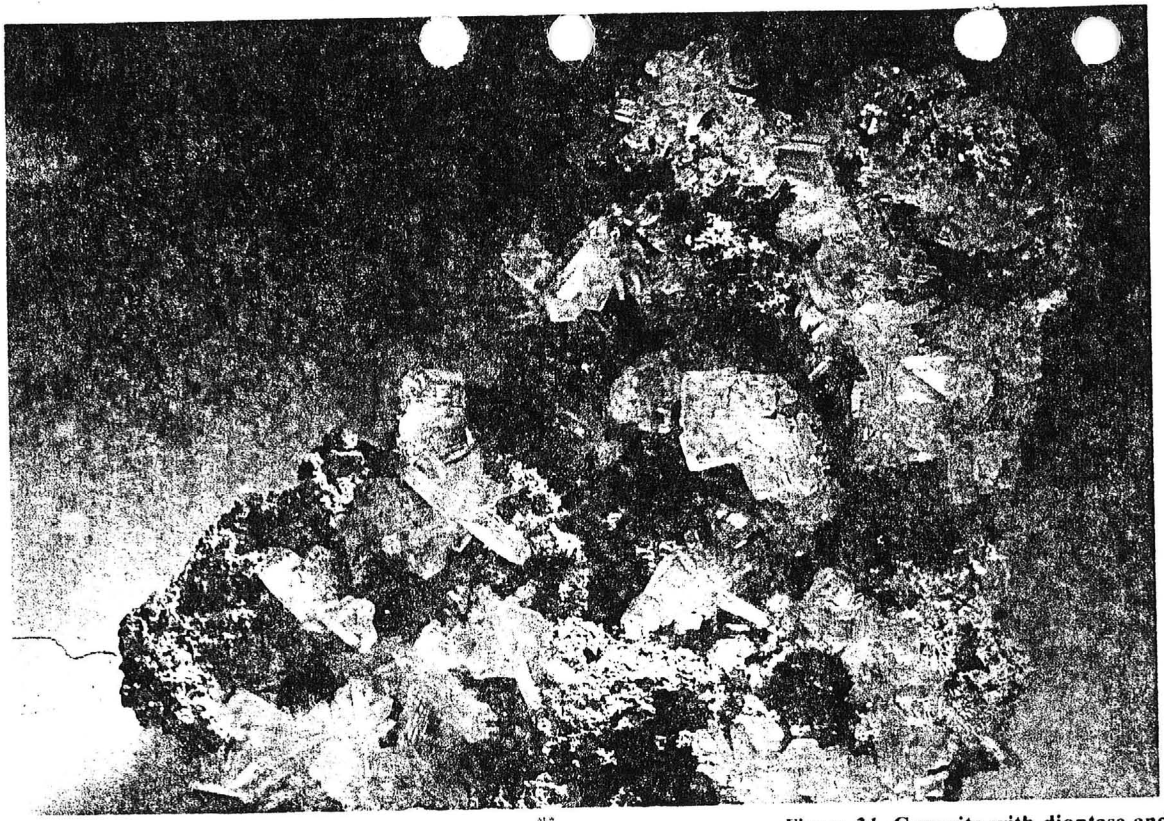


Figure 21. Cerussite with dioptase and wulfenite on matrix 4.5 cm across, Jelks collection, Arizona-Sonora Desert Museum.

Figure 22. (left) Azurite crystal, 5.4 cm across, Curt Van Scriver collection.

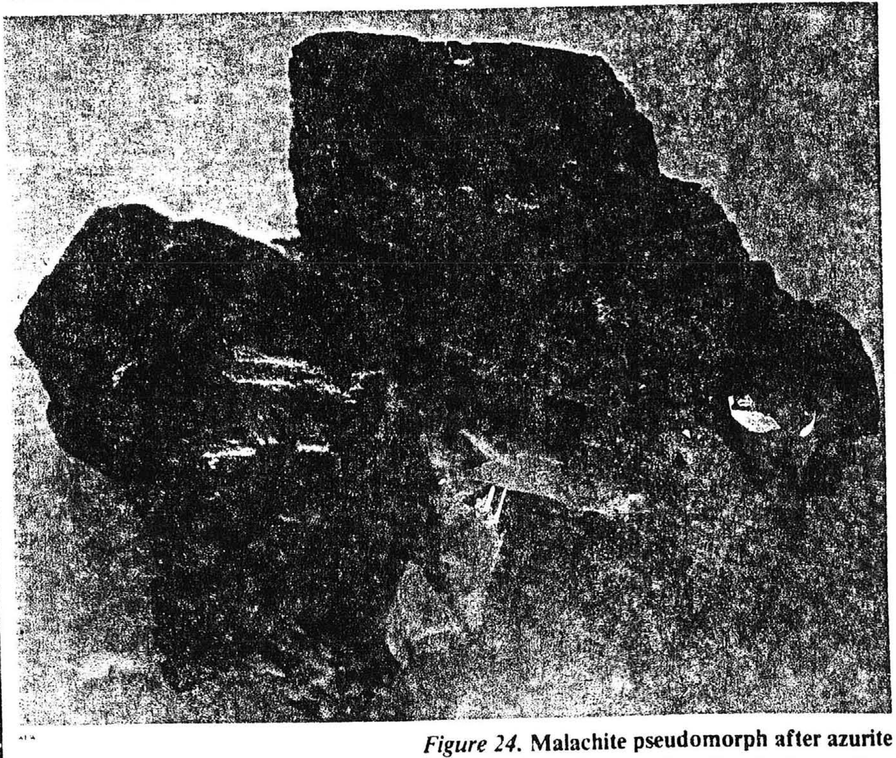


Figure 24. Malachite pseudomorph after azurite crystals, 5.8 cm across, Curt Van Scriver collection.

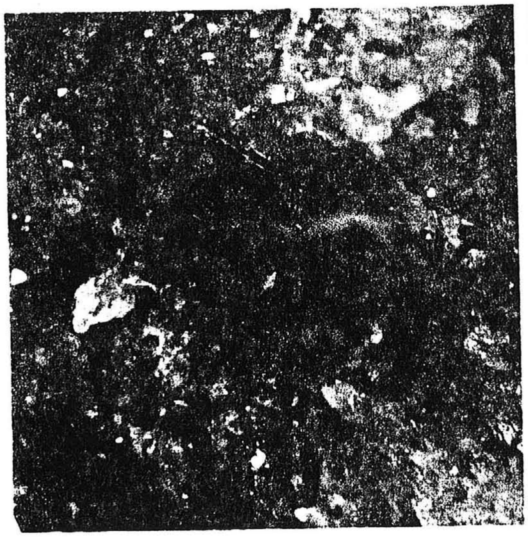


Figure 23. Linarite crystal 2.3 cm across, on amethyst, Arizona-Sonora Desert Museum collection. Photo by Bob Jones.

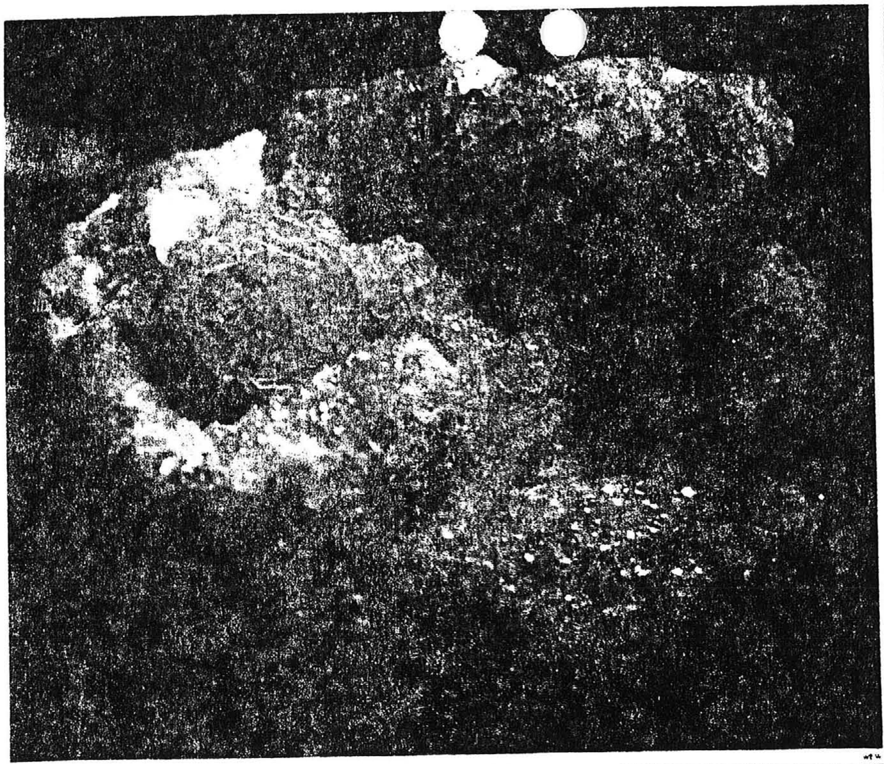


Figure 26. (above) **Wulfenite showing crystal form change from first to second order, 1.6 cm across, Smithsonian Institution collection.**

Figure 25. (above) **Leadhillite, 2.3 cm across, Jelks collection, Arizona-Sonora Desert Museum.**

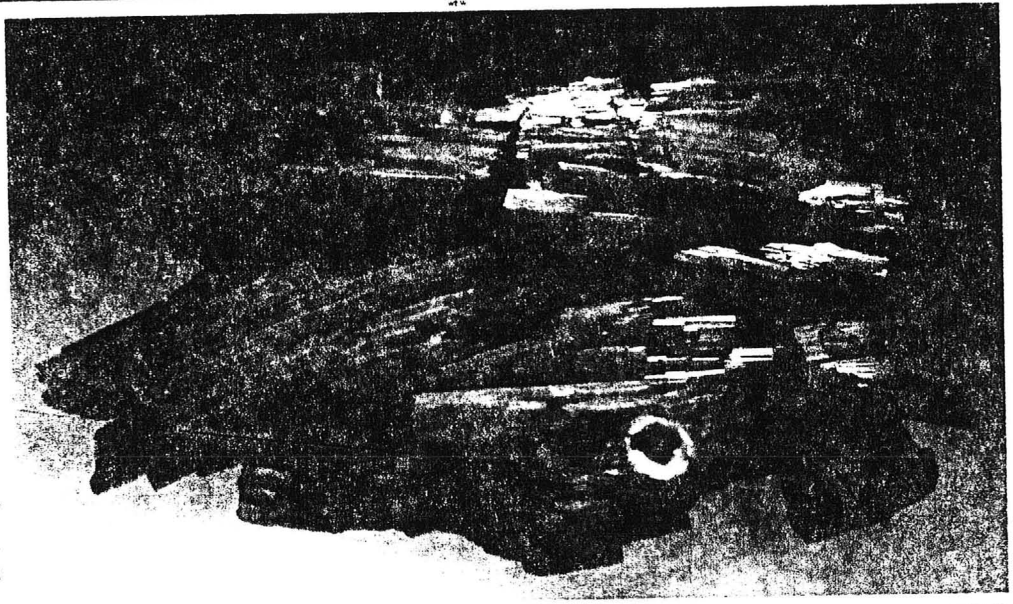
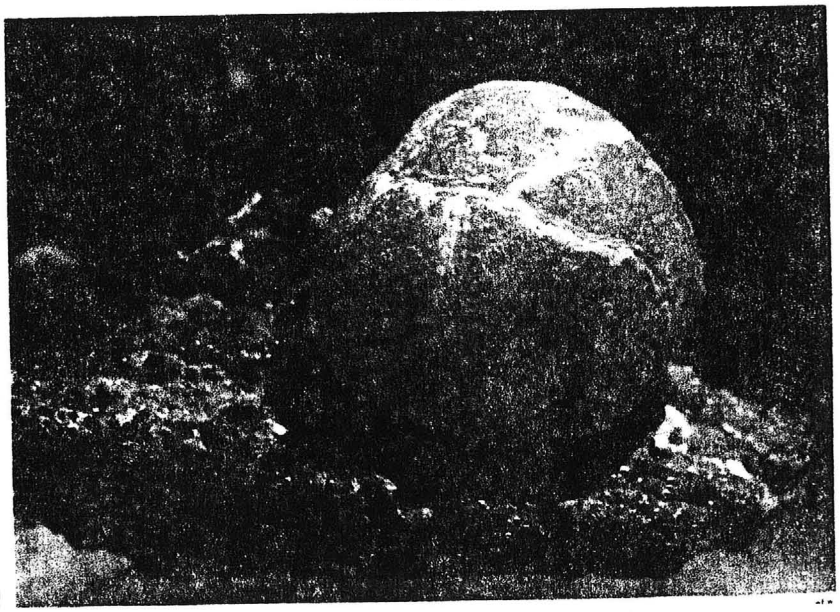


Figure 27. (right) **Vanadinite crystals in sub-parallel group 3.2 cm across, Jelks collection, Arizona-Sonora Desert Museum.**

Figure 28. (lower right) **Smithsonite ball 1.9 cm across on matrix; Jelks collection, Arizona-Sonora Desert Museum collection.**

Figure 29. (below) **Matlockite, one of the largest crystals known, 3.5 cm across; Arizona-Sonora Desert Museum collection.**



Cerussite is especially associated [illegible] azurite and some remarkable reticulated specimens are coated with [illegible]er silvery-lustered malachite. It forms at the expense of diaboleite crystals, but is in turn itself corroded on these pieces. Leadhillite prisms will alter to somewhat oriented, reticulated aggregates of cerussite which sometimes preserve the leadhillite form quite well. Cerussite twins can be entirely replaced by linarite, in turn partially altered to brochantite. Anglesite crystals are usually associated with these latter two occurrences. In one case the anglesite was as hollow epimorphic overgrowths formerly on cerussite. Two generations of cerussite crystals may be found on the same specimen, sometimes in parallel growth.

Wulfenite specimens will often have later cerussite crystals as overgrowths but on some pieces the wulfenite is on cerussite. Late clay minerals form a matrix for cerussite. One specimen was observed in which clay had entirely replaced a loose cyclic cerussite twin, with only the form of the cerussite preserving the transformation. Another clay specimen has an entirely hollow cast in the shape of a similar cyclic cerussite twin (3, 4, 7, 8, 9, 10, 12, 14, 15, 17, 20, 21, 22, 24, 25, 26, 27, 28, 31, 33, 34, 37, 38, 39, 40, 41).

Chrysocolla $(Cu,Al)_2H_2Si_2O_5(OH)_4 \cdot nH_2O$

Noted in the alteration rinds about galena, usually but not always outside the anglesite and cerussite shells. Often there is a black layer with the chrysocolla, commonly misidentified as tenorite. This is more likely to be manganiferous chrysocolla. Relic boxworks after galena are sometimes composed entirely of chrysocolla which then exhibits a pseudo-cubic cleavage.

Highly variable in color, from a translucent, almost gemmy sky-blue, to powdery and nearly white, when it grades insensibly into other clay minerals. It is usually massive in texture, but may form ball-like aggregates. Malachite and rarely plancheite may be intermixed.

Chrysocolla often forms the matrix for later lead and copper minerals. Wulfenite crystals may be imbedded in chrysocolla or formed on the surface, along with cerussite and dioptase. Rarely wulfenite is found entirely replaced by chrysocolla. The chrysocolla may form a hollow shell, formerly around a nodule of galena and its alteration products, now incrusted on the interior and exterior with these later minerals. One interesting specimen shows drusy quartz as epimorphs after cerussite twins, their interiors now partially filled with chrysocolla (17, 19, 21, 22, 24, 25, 27, 31, 33, 40, 41).

Creaseyite $Cu_2Pb_2(Fe,Al)_2Si_5O_{17} \cdot 6H_2O$

Occurs as pale yellowish green fibers, almost always associated with wulfenite, either randomly intergrown or aggregated into spherules less than 1 mm diameter. It is younger than associated wulfenite, cerussite and dioptase. Fluorite, willemite, descloizite and murdochite have been seen on creaseyite fibers. Only a few specimens have been preserved although the mineral was probably relatively common in the upper workings at one time. The Mammoth mine is the type locality. About 1 gram of the mineral is on known specimens in collections. This mineral was noted as beudantite on some other lists (39, 40, 41).

Cuprite Cu_2O

The mineral may have been of substantial occurrence in the Mammoth mine ores to judge from the several nearly pure masses preserved. Otherwise it is of very rare occurrence as crystals, sometimes of the chalcotrichite variety, in chrysocolla, or on specimens with other of the oxidized lead and copper minerals (40, 41).

Descloizite $Pb(Zn,Cu)(VO_4)(OH)$

Usually associated with wulfenite, descloizite is often the last mineral to form on many specimens. Sometimes vanadinite and mimetite will be found on crusts of descloizite, but pseudomorphs of descloizite replacing those minerals have been noted. Fluorite, dioptase, willemite and quartz are also frequently on specimens bearing descloizite, w[illegible] has a maximum crystal size of only 1 or 2 mm.

Crystals of this species are usually rhombic, nearly square in outline, but it can assume a steeper and more pointed habit. Descloizite forms a complete series with mottramite, $Pb(Cu,Zn)(VO_4)(OH)$, and therefore shows a considerable range of color. Variously described as orangish brown, reddish brown, yellow and dark brown, the relatively zinc-rich descloizite crystals can also show color zoning in these shades. Rare intermediate members (the variety cuprodescloizite in part) can assume a green coloration. Mottramite is coal-black. These species might be confused with wulfenite or possibly fornacite without careful observation. This is the dechenite of Rickard (1, 2, 3, 4, 5, 8, 9, 10, 14, 15, 16, 17, 19, 21, 24, 26, 27, 28, 31, 33, 39, 40, 41).

Devilline $CaCu_4(SO_4)_2(OH)_6 \cdot 3H_2O$

Sparse, scaly blue crusts of this mineral occur on partially decomposed primary sulfides, galena, sphalerite and pyrite, with their gangue minerals barite and chlorite. A little fluorite, covellite and brochantite also occur on one of the two known specimens. The other specimen is in association with caledonite. (X-ray identification by S. Williams, pers. comm.) (41).

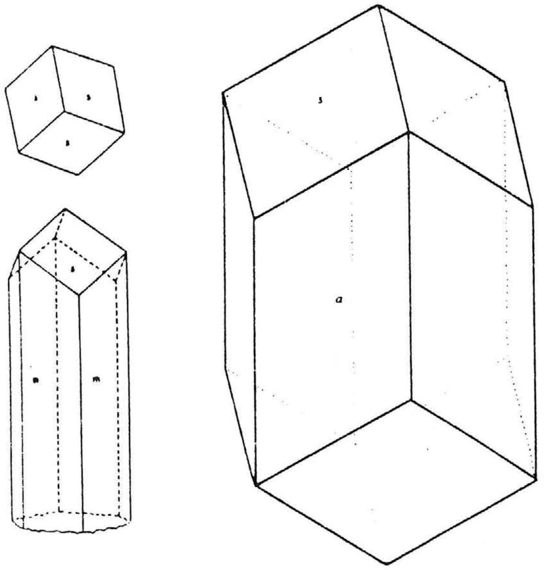


Figure 30. **Dioptase (left, (19); right, Gordon).**

Dioptase $CuSiO_2(OH)_2$

The beautiful specimens with minute needles of brilliant emerald-green dioptase crystals carpeting chrysocolla, clays, cerussite and wulfenite are among the most conspicuous and sought-after of the Mammoth mine specimens. Probably more examples of wulfenite encrusted with willemite and dioptase were preserved than any of the other minerals. Dioptase alone on a clay matrix, perhaps as balls of radiating crystals to about 15 mm, investing clay which has coated earlier wulfenites or, in turn, providing the matrix for large cerussite twins, affords the best examples of this mineral from the U.S.

Scattered among the dioptase needles usually are wulfenite, mimetite and quartz crystals; any of these may be earlier or later than the dioptase. Willemite crystals are often found to be earlier, and fluorite, descloizite, and rarely fornacite crystals are usually later. Dioptase infrequently occurs on and with diaboleite.

One specimen was seen on which the dioptase needles had preferentially incorporated some black mineral, themselves becoming entirely black (4, 19, 20, 21, 22, 24, 26, 27, 28, 31, 33, 34, 38, 39, 40, 41).

Fornacite $(Pb,Cu)_3[(Cr,As)O_4]_2(OH)$

A relatively rare mineral in the Mammoth mine suite, small crystals of this species nevertheless can be found in a variety of associations. The mineral was first properly identified in the mid-1950's, in a lot of material from a single pocket, where crystals several mm long, the largest known from any locality, were scattered on matrix. These occur along with larger wulfenite crystals and etched opaque white fluorite, also up to several mm, large compared to the average size of occurrence of this species at the Mammoth mine. On other specimens, small amounts may be occasionally found with dioptase, hemimorphite, and willemite and on cerussite.

Pseudomorphs, probably after malachite, on chrysocolla, and hollow encrustation pseudomorphs after a mineral with habit and angles similar to crocoite, have also been found. Crystals can be found in old collections, but the mineral was misidentified or overlooked. It can be confused with cuprian descloizite, and has in the past also been identified as olivenite. Its distinctive color, olive to pistachio-green in small crystals, grading to a dark greenish black in the larger ones, as well as more rounded edges and composite faces, should help in visual identifications (32, 33, 38, 40, 41).

Goethite FeO(OH)

This mineral is undoubtedly a large component in the limonite frequently found with oxidized specimens, but its presence was confirmed only in a few cases (33, 39, 41).

Gold, Au

In the early days of operation, this was the principal economic metal recovered. The gold occurring in a particular greenish yellow quartz, the richest ore, tended to be fine-grained, with particles only rarely visible. This ore averaged 0.09 ounces per ton in the New Year mine, and 0.15 in the Mammoth mine. Galena ores were assayed up to 0.375 ounces per ton. Rusty films of iron oxide on cracks in host rock occasionally show visible gold flakes. Modern geochemical sampling across the upper portion of the Mammoth vein found more gold in chlorite-rich portions than elsewhere. The scanning electron microscope showed gold particles in this mineral (A. Cockle, pers. comm.).

Wires and nuggets, less than 1 mm, in massive cerussite are rarely seen. One much larger mass of gold with wulfenite plates on matrix was found in the dump several years ago (1, 2, 3, 4, 8, 10, 13, 14, 15, 17, 21, 24, 31, 33, 40, 41).

Hematite, Fe_2O_3

Earthy, brick-red hematite is abundant on oxidized specimens, with tiny black balls somewhat less so. Shining black masses of specular hematite flakes are intermixed and included in quartz and chlorite. Small specular crystals are to be found along with the boxworks remnant after galena alteration. These tiny crystals, sometimes remarkably red, persist through further changes depositing later minerals, hence are found imbedded in crystals of anglesite, cerussite, diaboleite, boleite and wulfenite (15, 17, 33, 39, 40, 41).

Hemimorphite $Zn_4Si_2O_7(OH)_2 \cdot H_2O$

Glistening white balls of clear, radiating crystals of hemimorphite can reach 8 mm in diameter, but more usually are only 1 to 2 mm. Elongated, flattened crystals with a sword-like termination, several mm long, could be confused with cerussite or anglesite, but the untwinned habit, vertical striations, and lower luster should aid visual identification.

Common associations are willemite, quartz, smithsonite, mimetite, and wulfenite, with the hemimorphite usually later than these minerals. Very rarely the mineral is found on diaboleite (15, 17, 20, 21, 24, 26, 27, 28, 29, 31, 33, 38, 40, 41).

Hisingerite $Fe_2Si_2O_5(OH) \cdot 2H_2O$

Tiny kernels of earthy hisingerite, hematite, and goethite sometimes are found in the center of creaseyite spherules (39, 41).

Hollandite $Ba(Mn^{+4},Mn^{+2})_8O_{16}$

Various black films, crusts and nodules usually ascribed to psilomelane were x-rayed. All examined proved to be hollandite (41).

Macquartite $Pb_3Cu(CrO_4)SiO_3(OH)_4 \cdot 2H_2O$

Slender orange prisms only as large as 1 mm. This extremely rare, newly described mineral has been recognized only from the Mammoth mine in a few old specimens. It would be easily confused with mimetite, but is monoclinic with a good prismatic cleavage.

The macquartite crystals occur associated with dioptase and wulfenite, imbedded in the quartz matrix along with barite, willemite and hematite (42).

Malachite $Cu_2(CO_3)(OH)_2$

Pale to dark green fibers and crystals are usually found with cerussite and azurite. Remarkable masses of reticulated cerussite were found, coated with a dense mat of shining silky malachite molded to their surface and hanging in veils. Massive cerussite nodules replacing galena often include malachite, and have a rim of that mineral as well.

Radial aggregates of malachite have entirely replaced azurite crystals, which are usually overgrown by azurite again, sometimes parallel to the original azurite. A little later cerussite in crystals is usually associated. Hollow, sugary anglesite epimorphs after cerussite twins may have tufts of malachite in their interior. Wulfenite crystals rarely are imbedded in or coated by malachite, usually with associated cerussite (4, 14, 15, 17, 26, 27, 33, 34, 40, 41).

Mimetite $Pb_5(AsO_4)_3Cl$

Brilliant yellow to orange hexagonal crystals, almost always in association with wulfenite, are usually the mimetite end-member of the series with vanadinite. Microcrystals of descloizite, fluorite, willemite, and conspicuous dioptase are usually also present. A fibrous variety, but still with discernable hexagonal outlines, can completely invest large wulfenite plates and masses—a spectacular combination. Mimetite seems to preferentially occur with wulfenite, in contrast to vanadinite, and further, their colors seem to sympathetically vary, indicating substitution by the same chromophore. The best crystals are less than 1 mm in size, and consist of flat tabular hexagonal pyramids, or, less commonly, equant prismatic crystals with dipyramid and base. Two generations of different habit may be on the same specimen, although it is usually the last mineral to form (9, 17, 21, 24, 28, 31, 32, 33, 38, 39, 40, 41).

Minium Pb_3O_4

Thin films and powders of a distinctive brick-red color were found to be this species. Coatings on cerussite, and one interesting specimen where the mineral was confined to a central square portion of a wulfenite plate, overgrown by later wulfenite, were confirmed (33, 41).

Mixite $Cu_{12}Bi_2(AsO_4)_6(OH)_{12} \cdot 6H_2O$

Pale green radiating sprays of minute size were found on a single specimen from the Mammoth mine dump, associated with wulfenite and mimetite on a fine-grained barite matrix. (S. Williams, pers. comm.)

Mottramite $Pb(Cu,Zn)(VO_4)(OH)$

Occurs as jet-black thin films and crusts of tiny pointed crystals, usually on quartz. Wulfenite is usually earlier, and may be entirely replaced by mottramite; vanadinite and rarely pyromorphite crystals may occur on the mottramite crusts. Not as common as descloizite, the other end-member of the series (17, 24, 27, 33, 40, 41).

Murdochite Cu_6PbO_8

Minute, brilliant black octahedra on wulfenite and fluorite provided the type specimen for this species, in association with hemimorphite, willemite and quartz. It has since been noted with descloizite and on dioptase and creaseyite. One fine specimen consists of quartz crystals alone incrusted by murdochite (29, 31, 33, 39, 40, 41).

Plancheite $Cu_8Si_8O_{22}(OH)_4 \cdot H_2O$

Indigo-blue sprays, free-standing with fluorite, descloizite and creaseyite, or imbedded in chrysocolla, and of very small size, constitute the occurrence of this mineral in the Mammoth mine (41).

Pyromorphite $Pb_5(PO_4)_3Cl$

Very rarely occurs as olive-green to bright, apple-green, simple hexagonal crystals, sometimes with hollow terminations, reaching a length of 4 or 5 mm. Crystals are usually the last to form on specimens with wulfenite, mottramite, and mimetite-vanadinite. The mineral occurs as overgrowths, both as smaller crystals on itself, then giving turreted forms, and as oriented caps on mimetite-vanadinite (4, 15, 17, 21, 24, 31, 40, 41).

Ramsdellite MnO_2

A several-meter-thick vein of manganese oxide was once crossed by mining operations (J. Strutzel, pers. comm.). A specimen from this vein was found to be ramsdellite, in part microcrystallized and pseudomorphous after groutite MnO(OH) (41).

Rosasite $(Cu,Zn)_2(CO_3)(OH)_2$

A few mm-sized, hard, dark green balls of rosasite were found in association with hemimorphite (41).

Silver Ag

A valuable component of the galena ores which were reported to contain as much as 25 ounces per ton, but averaged only 1.5 ounces per ton. A few specimens with short wires and dodecahedral crystals of silver, encrusted with acanthite, and intergrown with leadhillite, were seen (4, 15, 17, 33, 40, 41).

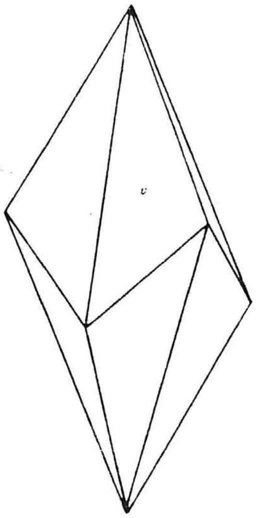


Figure 31. **Smithsonite (Gordon).**

Smithsonite $ZnCO_3$

An alteration product of primary sphalerite, generally inconspicuous although the millheads ran 2-3% zinc when the mine was operating in oxidized material. Specimens are usually waxy balls, up to 15 mm, of white, pale gray, green or rarely blue color. Some sharp crystals about 1 mm in size are occasionally seen. Associated minerals are especially hemimorphite and willemite, as well as wulfenite, mimetite, and fluorite. Calamine, in part, in earlier descriptions (15, 17, 21, 24, 27, 31, 33, 40, 41).

Sulfur S

Some specimens with thin crusts of crystallized sulfur on clay were seen, collected from dump material (24, 31, 33, 40, 41).

Tenorite CuO

Peterson noted "black, coal-like lumps of copper oxide, less than an inch or two in diameter . . . surrounded by thin shells of chrysocolla . . ." These are attributed to tenorite in later lists. Steely nodules of chalcocite or djurleite replacing galena are commonly surrounded by a thin [illegible] of mat [illegible] meeting Peterson's description, in turn layered with chrysocolla. The splendent black mineral is nearly X-ray amorphous, and is probably manganiferous chrysocolla in large part (17, 21, 24, 31, 33, 40, 41).

Tsumebite $Pb_2Cu(PO_4)(SO_4)(OH)$

Apple-green, crystalline spherules less than 1 mm in diameter, coat crystals of a brilliant yellow member of the mimetite-vanadinite series. The X-ray pattern is that of the PO_4 end-member; only traces of AsO_4 and VO_4 were found on analysis (M. Nichols, pers. comm.) (41).

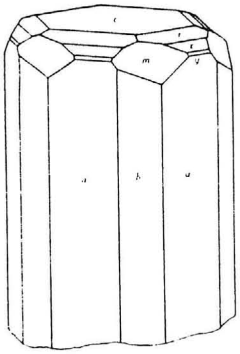


Figure 32. **Vanadinite (Gordon).**

Vanadinite $Pb_5(VO_4)_3Cl$

In short, prismatic hexagonal crystals, often with hollow terminations, this mineral is consistently associated with wulfenite, usually as a encrustation; with fluorite and willemite, and with descloizite or mottramite. It may occur as crystals on crusts of mottramite-descloizite, but even then dusted with tiny crystals of those minerals, or entirely replaced by them.

Vanadinite forms a complete series with mimetite, with the brilliant red crystals usually found to be vanadinite.

The color can range through brown to orange and quite yellow to almost white, with VO_4 still predominanting over AsO_4. Crystals on a specimen can change color from red to orange in the distance of a mm or so. Some crystals are themselves zoned, with red cores and waxy yellow exteriors. Maximum crystal size for individuals is rarely about 22 mm. Endlichite in part (1, 2, 3, 4, 5, 6, 8, 9, 10, 13, 14, 15, 17, 21, 24, 26, 27, 28, 31, 32, 33, 40, 41).

Willemite Zn_2SiO_4

This mineral may be difficult to recognize due to its wide variety of habits, however the diagnostic hexagonal cross-section will usually be visible. It is most usually in isolated, equant barrel-shaped crystals of mm size, colorless to pale green or blue. These often have frosted and opaque white exteriors, sometimes with clear terminations. These crystals might be confused with the frequently associated fluorite cubes. Radial sprays of colorless, long prismatic crystals, white when entirely compact, and up to 8 mm in diameter, simulate the appearance of some hemimorphite. Water-clear, tabular crystals bounded only by a very flat pyramid, are less common, and were seen occasionally strung like beads on mimetite needles.

Rythmically banded crusts of radially fibrous willemite, sometimes alternating with fibrous quartz, or masses of tiny, pale green spherules are often found with wulfenite and dioptase crystals. Specimens consisting of only these three minerals in some combination must have been collected in great quantity, as they are probably the most frequently seen Mammoth mine specimens in collections and on the market.

One specimen shows crusts of willemite which appears to have coated some globular mineral, about 6 mm in diameter. These crusts are now just thin hollow shells, with another generation of willemite formed on the interior of these shells, growing radially outward from the matrix, but r[illegible]llin[illegible] void space.

Several specimens were seen where masses of pale green spherules of willemite had replaced crystallized cerussite. A reticulated mass, entirely replaced, was several cm across. An aggregate of wulfenite crystals at one time had enveloped complete cerussite sixlings up to 2 cm across. These are now voids in the wulfenite, preserving the sixling shape, and almost entirely infilled with the same distinctive willemite spherules which are not elsewhere on the specimens.

Another specimen has these same willemite spherules as an epimorph, now hollow, formerly encrusting cerussite sixlings. The same type of willemite may be found with later cerussite crystals on it as a matrix. Epimorphs of willemite replacing wulfenite plates were also noted. Wulfenite is the most common associate of willemite, and may be earlier or later. Smithsonite rhombs or hemimorphite sprays were also found on willemite. Calamine in part on earlier lists (21, 24, 26, 27, 29, 31, 33, 38, 39, 40, 41).

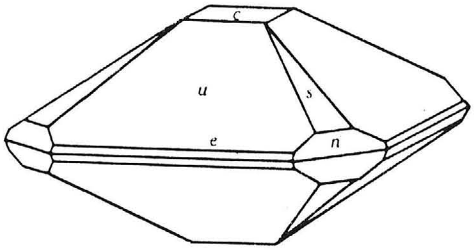


Figure 33. **Wulfenite (Gordon).**

Wulfenite $PbMoO_4$

Formed rather late in the mineralization sequence, and in open places at a distance from the veins as well as in them, immense quantities of wulfenite were recovered at various times during the mining operations. Through World War II, until major molybdenite deposits were brought into production, the Mammoth mine was the principal source of molybdenum in the U.S., all produced from wulfenite. In the top 300 feet of both the Collins and Mammoth veins, fractures up to several feet in width, packed solidly with platy wulfenite, were encountered.

Specimens at their finest from this famous American occurrence are rich masses of large tabular, characteristically orange crystals, with individuals up to as much as 7 or 8 cm across, but more usually in the 1-cm range. These may be thickly encrusted with mimetite of the same color, and less conspicuous later crystals of descloizite, willemite, and fluorite can be found in association.

Other beautiful specimens may have an early generation of wulfenite thickly coated with a slick clay, on which later crystals of brilliant red wulfenite, dioptase and cerussite have been deposited. The wulfenite crystals are usually attached by edges, but occasionally only by their centers, to projections under the clay. In areas of the mine where the wulfenite was exposed to moving surface water, the crstyals appear to be partially dissolved, even with holes, giving them a moth-eaten look. Colors of the crystals are less commonly yellow or brown to nearly black, apparently from included manganese oxide. Analysis of wulfenite concentrates showed up to 2% of contained WO_3, but whether as a substituent tending towards stolzite, $PbWoO_4$, or a separate phase could not be determined.

Parallel overgrowths of wulfenite on earlier wulfenite crystals are not uncommon. Some complete replacements of wulfenite plates by mottramite were seen. Vanadinite deposition on wulfenite appears to etch the crystals, although these two species rarely occur together. Chillagite in part on some earlier lists (3, 4, 5, 8, 9, 10, 13, 14, 15, 17, 19, 20, 21, 24, 26, 27, 28, 29, 31, 33, 34, 35, 38, 39, 40, 41).

Table 4. **Oxidized minerals, anomalous sequence.**

		Ag	Pb	Cu	Fe	Zn	Others
CHLORIDES	Diaboleite		X	X			
	Boleite	X	X	X			
	Pseudoboleite		X	X			
	Matlockite		X				F
	Bideauxite	X	X				F
	Paralaurionite		X				
	Atacamite			X			
	Paratacamite			X			
	Embolite	X					Br
	Iodargyrite	X					I
	Yedlinite		X				Cr
SULFATES	Linarite		X	X			
	Beaverite		X	X	X		Al
	Brochantite			X			
	Connellite			X			Cl
SULFATE-CARBONATES	Susannite		X				
	Leadhillite		X				
	Plumbonacrite		X				
	Caledonite		X	X			
	Wherryite		X	X			Cl
CARBONATES	Phosgenite		X				Cl
	Hydrocerussite		X				
SILICATES	Alamosite		X				
	Melanotekite		X		X		

OXIDIZED MINERALS

ANOMALOUS SEQUENCE

Comparison of Table 4 with Table 3, showing the composition of "normal" sequence minerals, highlights several striking differences. Many of the minerals in Table 4 contain more than one metallic element, with the combination of lead and copper quite noticeable (in fact the Mammoth mine suite has 13 minerals with both lead and copper essential, almost half the total of copper-lead minerals known). A source of both elements is readily seen in the oxidizing galena, coated or entirely replaced by secondary copper sulfides, usually found associated with these anomalous species.

Likewise, there are several minerals containing both sulfate and carbonate. Chlorine was presumably available as a component of dilute hydrothermal solution (the source for fluorine also?), or from groundwater. Other than minor amounts of chlorine in vanadinite and mimetite, the element does not seem to have persisted in any minerals formed except those of the "anomalous" group. The retention of minor amounts of silver in this environment is also evident in the table. It appears as a component in the boleite, altered from diaboleite, and is still present in the rare silver halides, sometimes among the last minerals to form.

Taken together, the minerals in the anomalous sequence argue for formation in a closed system—one from which elements could not escape, and were constrained to react together (S. Williams, pers. comm.). Their persistence to the present time is due to continued protection of this environment, probably by sheathing by quartz and clays of the localized areas in which they were formed.

Turning to some accounts contemporary with the discovery of these minerals, Fahey, Daggett and Gordon's (25) description of the type occurrence of wherryite is pertinent and the only one published (parenthetical comments are mine):

"In May of 1943 one of the authors, E. B. Daggett, then mining engineer at the Mammoth mine, discovered a small vug of leadhillite crystals associated with cerussite, anglesite, phosgenite, paralaurionite, hydrocerussite, diaboleite, boleite, matlockite and quartz. Within the cavity was some friable chalcocite with a relict structure of galena which it has replaced.

"The massive wall of the vug consisted of a light green fine granular mineral (wherryite) enclosing some bluish chrysocolla, and at the cavity some blue diaboleite and greenish paralaurionite. This green matrix was up to 5 cm in thickness and extended to the silicified wall of the vein—an altered quartz monzonite."

A letter from Daggett to Gordon dated March 11, 1949, says, "It (the vug) was a lens about a foot thick and three feet across. The outside shell of the vug was composed of massive minerals with chrysocolla on the outside grading to the apple-green mineral (wherryite) toward the inside, and with the chrystalline (sic) minerals making up the inside core."

Dubins, Mayers and Wenden's paper remarks, under diaboleite, "Two localities are particularly noteworthy. The first, stope #509, produced the finest specimens. Here diaboleite occurs in occasional nodules, associated with leadhillite, caledonite, etc., in magnificent crystals. The stope was, in addition, rich in dioptase, willemite and wulfenite. Diaboleite coming from this stope may be recognized by the abundance and size of the diaboleite crystals, the relative softness of the matrix, and the quantity of associated rare minerals. This stope is now entirely filled and unaccessible.

"The second locality, on the east wall of the main haulage tunnel of the Collins vein, 500 level, is characterized by the occurrence of small crystals of diaboleite in occasional vugs in an exceptionally tough siliceous matrix. The diaboleite crystals are either alone or accompanied by small crystals of caledonite; these latter tend to be more green than are those from other localities. These specimens are readily distinguished by their hard matrix and small, scattered diaboleite crystals. This locality has apparently no connection with the 509 stope adjoining it, as blasting in the direction of the 509 stope revealed entirely barren rock without any trace of diaboleite."

And under willemite, "Both dioptase and willemite are most abundant in and surrounding the diaboleite zone, which centers in the 509 stope. Considerable quantities of both minerals are present directly above the 509 stope on the 400 level, indicating an upward extension of the silicate envelope surrounding the diaboleite zone."

Occurrence of the lead silicates with diaboleite may also be an indication of the unusual degree of silicification protecting this paragenesis or anomalous sequence. The omission of zinc from the table is only an approximation, although hemimorphite and willemite are in fact only rarely present, and then in small quantity.

Alamosite $PbSiO_4$

White, sheaf-like crystal aggregates and spherules to 5 mm in diameter on corroded diaboleite, recrystallized in vugs. On a matrix of the characteristic quartz crystals which have replaced galena, the diaboleite is also associated with corroded phosgenite, cerussite and wulfenite. A few willemite prisms are on the alamosite.

Only a single specimen has been found. The alamosite has been confirmed both by X-ray powder diffraction and qualitative electron probe chemical analysis. It can perhaps be distinguished from the numerous other white minerals by its habit and chalcedony-like luster (41).

Atacamite $Cu_2Cl(OH)_3$

These brilliant green crystals are most often found with leadhillite, anglesite, diaboleite, and its constant associate wherryite. Less often it is with linarite, caledonite, boleite, cerussite and malachite.

Its finest crystallization is as sharp individuals to 3 mm, alone on quartz, or intermixed with anglesite crystals. It is often seen altering from diaboleite, linarite or caledonite, where it forms cross-hatched intergrowths or sugary green crusts.

One specimen exhibited twins, pseudo-octahedral trillings (20, 21, 22, 24, 26, 28, 31, 33, 40, 41).

Beaverite $Pb(Cu,Fe,Al)_3(SO_4)_2(OH)_6$

A single specimen was found with anglesite crystals, brown to red from included iron oxides, in association with linarite crystals. Shining, golden yellow powdery beaverite additionally occurs as an alteration product of linarite (41).

Bideauxite $Pb_2AgCl_3(F,OH)_2$

Transparent and colorless when fresh, isometric crystals of this species may be filmed with cerussite and become lavender on exposure to strong light. The specimens known are all in intimate association with both boleite and matlockite, themselves rare species from the Mammoth mine, but additionally indicating a narrow range of stability, so likely little bideauxite was formed in this only known occurrence. Nevertheless, crystals are up to 7 mm in maximum dimension, and are of cuboctahedral aspect with a variety of other forms present on smaller crystals.

The type specimen has a matrix of covellite and quartz replacing galena, with boleite, matlockite, two generations of leadhillite, sugary anglesite and superficial cerussite associated. The specimens were labeled cerargyrite or anglesite prior to confirmation as a new species (37, 40, 41).

Boleite $Pb_9Ag_3Cu_8Cl_{21}(OH)_{16} \cdot H_2O$

When well-formed as cubes, octahedrons and dodecahedrons, the beautiful prussian-blue to sea-green crystals of this mineral are unmistakable. The crystal size is generally only 1 or 2 mm but can approach 7 or 8 mm in crude crystals. The occasionally rich masses form the best U.S. occurrence of this mineral.

The most frequent associate is diaboleite, which it replaces. The cubic outline and slightly different color of imbedded boleite crystals can be found on most diaboleite specimens, but it is not confined to such close association with that mineral. It can also often be found as crystals perched on quartz, anglesite, atacamite, paratacamite, cerussite and leadhillite, and more rarely on caledonite, paralaurionite, and phosgenite. In association with minor matlockite, it forms the matrix for bideauxite.

Crystals can be entirely enclosed in cerussite and anglesite. Occasionally brochantite and boleite will entirely replace anglesite crystals. Boleite is overgrown by other obviously related minerals, here discussed under "pseudoboleite" (20, 21, 22, 24, 25, 26, 27, 28, 31, 33, 34, 37, 40, 41).

Brochantite $Cu_4(SO_4)(OH)_6$

The most common green acicular mineral associated with the other sulfates anglesite, caledonite, leadhillite, and linarite, altering from the latter. In addition to free-standing tufts of crystals, or sugary masses encrusting these species, it also participates in various pseudomorphs. Examples are: as complete replacements of cerussite twins, intermixed with anglesite replacing linarite crystals, and with boleite replacing anglesite crystals. It is usually the last-formed mineral on any specimen, although some striking inclusions in clear quartz crystals were noted (15, 26, 27, 28, 33, 34, 40, 41).

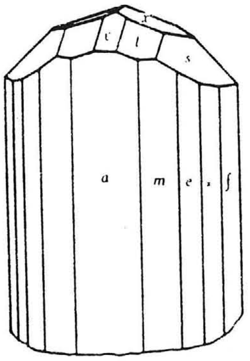


Figure 34. **Caledonite (Gordon)**

Caledonite $Pb_5Cu_2(CO_3)(SO_4)(OH)_6$

Occurs as isolated prismatic crystals to 15 mm long, and intergrown as masses of the pure mineral. Usually the color is a distinctive blue, but this may become sea-green on some specimens, perhaps indicating some degree of chemical substitution. A few crystals show zoning of both colors.

Usual associates are diaboleite and leadhillite with later anglesite and brochantite. Caledonite often appears to replace diaboleite and to be nearly contemporaneous with leadhillite; it is partially replaced by atacamite. Several specimens were seen in which distinct anglesite crystals or linarite crystals had replaced caledonite. In the latter case the replacing linarite has its long axis parallel to the elongation of the caledonite, giving the pseudomorph a foliated appearance.

This is one of the finest occurrences of this mineral in the world. A letter written by Gordon in 1948 contains the sentence, "Specimens in the (Philadelphia) Academy's collection labeled 'linarite and caledonite, Arizona, Genth' were undoubtedly from this locality, and Genth's death in 1893 postponed knowledge of the occurrence of the latter mineral there for many years" (20, 21, 22, 24, 26, 28, 31, 33, 40, 41).

Connellite $Cu_{19}Cl_4(SO_4)(OH)_{32} \cdot 3H_2O$

Slender, microscopic, pale blue needles of connellite can very rarely be found on cerussite and caledonite crystals, forming at the expense of the latter (41).

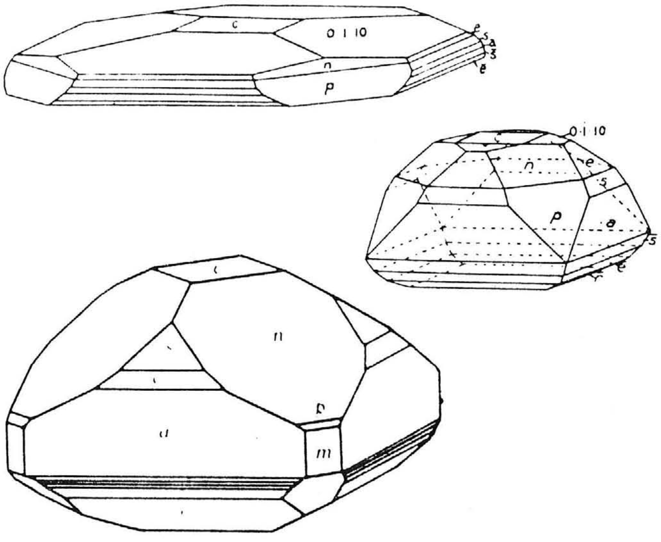


Figure 35. **Diaboleite (top and center (2); bottom, Gordon).**

Diaboleite $Pb_2CuCl_2(OH)_4$

One of the most notable minerals from the Mammoth mine, this is the best world occurrence, with crystals as large as 2 cm. The species was more fully defined by Palache on Mammoth mine material.

The color is a very intense blue, small crystals being nearly transparent. Crystals which are surficially corroded will grade from a powder-blue to nearly white, but this is an effect caused only by the state of aggregation, coming closer to the very light blue streak.

The mineral is usually in flat, tabular, tetragonal crystals or platy crystalline masses, often in parallel growth. A good cleavage in the plane of flattening, and striations caused by a common second-order pyramid, hence meeting at right angles but turned 45 degrees from the crystal outlines, help to visually distinguish diaboleite from linarite, with which it seldom occurs but can be easily confused. Pyramidal hemimorphic crystals are entirely diagnostic but are rarely seen.

Boleite and wherryite are nearly constant associates of diaboleite, of which they are alteration products. The diaboleite plates are usually seen on a quartz matrix, or intergrown with that mineral, of the type that has replaced galena, preserving a boxwork structure. Its alteration provides some of the elements for a number of the other interesting minerals in the Mammoth mine suite.

This is partially due to continued replacement of these later species by yet others, with intermediate crystallization of diaboleite. Some large diaboleite plates were noted on which later tiny diaboleite crystals had formed directly on the earlier.

The sulfate-bearing suite of leadhillite, caledonite and anglesite commonly forms on or at the expense of diaboleite, and these species often include minute diaboleite plates, or these are in turn grown upon them. Cerussite twins may be on diaboleite plates, but diaboleite crystals are as often found on the cerussite. Caledonite and brochantite are frequent associates, as is wulfenite; fluorite, willemite, hemimorphite, yedlinite, and alamosite are much more rare. Diaboleite plates are to be found imbedded in cleavable masses of matlockite and veneering hydrocerussite crystals. Sugary atacamite and paratacamite replace diaboleite. Phosgenite crystals on and in diaboleite plates are usually corroded into a cluster of spires, often tipped by minute diaboleite crystals (20, 21, 22, 24, 25, 26, 27, 28, 31, 33, 38, 40, 41).

Embolite Ag(Cl,Br)

Usually associated with caledonite on the few specimens known, embolite occurs as brilliant yellow cuboctahedral crystals, sometimes flattened, and less than 1 mm in size. The crystals may be implanted directly on caledonite, rarely on cerussite twins, or on quartz crystals. Diaboleite and leadhillite may also be associated (20, 21, 24, 26, 41).

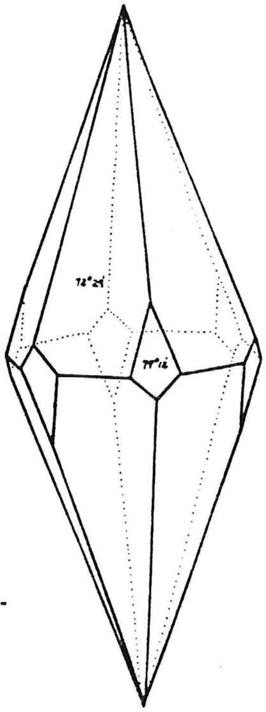


Figure 36. **Hydrocerussite (Gordon).**

Hydrocerussite $Pb_3(CO_3)_2(OH)_2$

The acute hexagonal pyramidal form, giving steep triangular faces, and the perfect basal cleavage, taken together, serve to distinguish this mineral from the numerous other white minerals in the Mammoth mine suite. It is always in close association with diaboleite, which occurs as matrix, a veneer, or as distinct crystals imbedded in the hydrocerussite. Caledonite, paralaurionite, and cerussite are less common associates. These remarkable crystals can attain a length of at least 15 mm. Larger aggregates of these then form some of the best known examples of this rare mineral (22, 24, 25, 26, 28, 31, 33, 34, 40, 41).

Iodargyrite AgI

Minute, pale green globular masses proved to be iodargyrite. They are implanted on caledonite crystals, associated with boleite and cerussite (41).

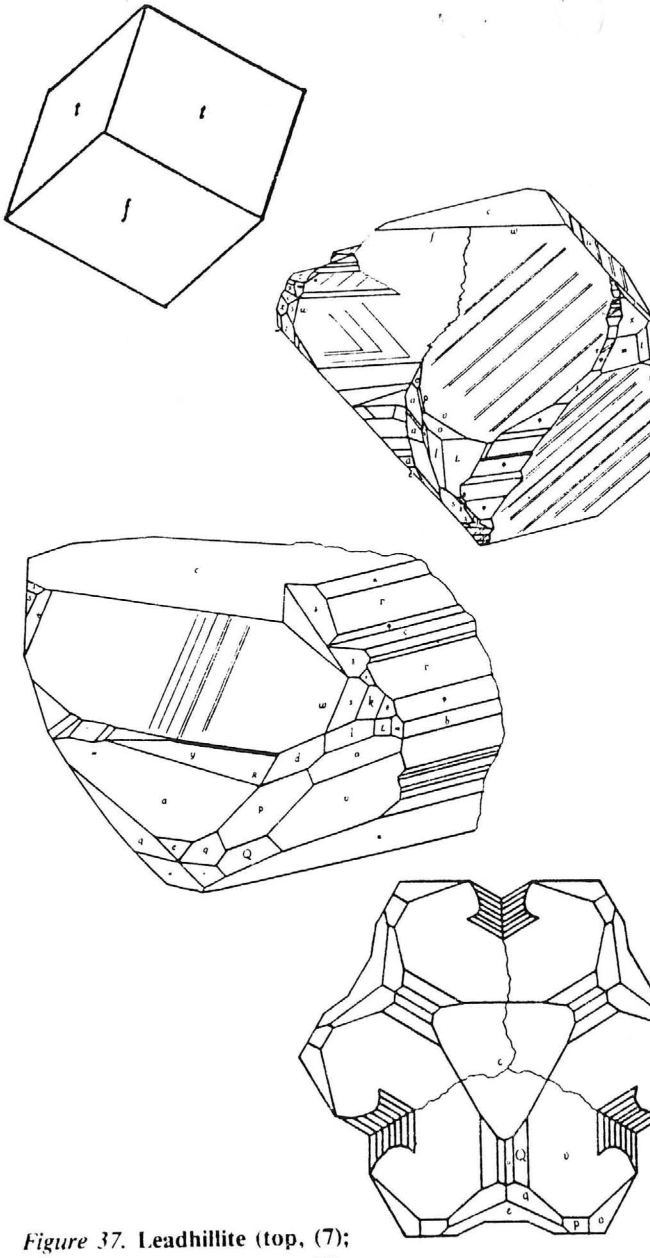


Figure 37. **Leadhillite (top, (7); upper and lower center, (23); bottom, twin on Artini law (23)).**

Leadhillite $Pb_4(SO_4)(CO_3)_2(OH)_2$

A decidedly pearly luster on either the basal termination or highly perfect basal cleavage, and trigonal or hexagonal prismatic crystals, taken together, assist in determination of this mineral. There are two principal crystal habits exhibited.

The first is as simple rhombohedrons, nearly cubic, or short prismatic crystals with large rhombohedral terminations. Transparent and colorless when very small, the mineral as larger individuals is usually opaque and snow-white, ranging to gray from included galena or clay, and sometimes reddish from iron oxides. Very rarely these crystals may be a pale greenish or lemon-yellow, perhaps from chromium. Crystals of white or grayish cast may reach 2.5 cm along an edge. On basal cleavage faces, the rhombohedral crystals often show interior zoning, sometimes with several changes in outline between trigonal and hexagonal, or a 60-degree change between 1st and 2nd order prisms.

While these crystals are now leadhillite, they are probably paramorphic after susannite. Both of these species have the same composition; leadhillite is monoclinic, pseudohexagonal while susannite is rhombohedral and is the stable form above 200°C. Space-group determination by single-crystal X-ray diffraction can reliably distinguish them.

The second predominant habit is as crystals with a hexagonal outline, from flat tabular with a large basal termination, to prismatic with commonly a steep rhombohedral termination. Many are twins, trillings according to the Artini Law, shown by complex three-rayed sutures on the terminations. This material probably crystallized directly as leadhillite rather than susannite.

These leadhillite crystals are usually colorless and transparent, sometimes a delicate sky-blue, but usually with clear tips. Crystals of this type often overgrow those of the rhombohedral habit, always with parallel *c*-axes. Generally much smaller in size, only a few mm long, they then make a forest of projecting crystal spires. When densely overgrown, this effect accounts for the frequent, rounded, barrel-shaped apperance of the best blue crystals, as aggregates to as much as 15 mm long.

Caledonite and associated linarite with brochantite are constant companions, with the leadhillite usually later. Both caledonite and linarite can be found as minute crystals included in leadhillite, accounting in some degree for that mineral's blue color. Leadhillite is often found with diaboleite, and its associated wherryite and boleite. Sometimes it appears to be altering from diaboleite, but also frequently includes small crystals of that species. Leadhillite occurs on paralaurionite when both are present on diaboleite specimens.

Cerussite often replaces leadhillite, as a frosting of the faces to complete replacement. Aggregates of small cerussite crystals are usually at least partially oriented parallel to the hexagonal leadhillite faces. In the more perfect examples of this topotactic replacement, the leadhillite crystal outline is well preserved and the cerussite appears reticulated.

The largest crystals are among the finest known for the species, with an abundance of blue crystals characterizing this locality (3, 7, 9, 20, 21, 22, 23, 24, 25, 26, 28, 31, 33, 34, 37, 38, 40, 41).

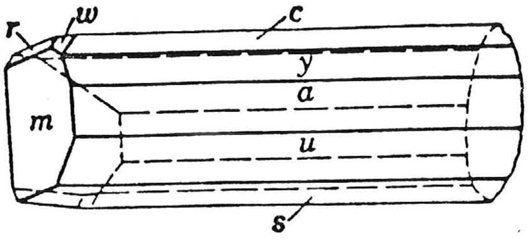


Figure 38. **Linarite (28).**

Linarite $PbCu(SO_4)(OH)_2$

Brilliant blue, thin, prismatic crystals of linarite, transparent when only a few mm long, grew in the Mammoth deposit to the largest size known. These giant crystals were probably from a single pocket or isolated occurrence. Several loose crystals were seen from 6 to over 8 cm long, 3 to 5 cm wide, and 5 to 10 mm thick. These crystal blades are rarely terminated, and must have been entirely imbedded in a sugary mass of brochantite, with traces still in pockets and adhering to the surface of the linarite.

Smaller crystals are not uncommonly found by themselves or with anglesite, caledonite and leadhillite. Usually some crystallized brochantite provides a pleasant color contrast. The relationship between linarite, brochantite, and anglesite is a complex and delicate one. Linarite prisms may occur with tufts of later brochantite and spear-shaped anglesite crystals. Interlocking groups of linarite are found where the linarite crystals are sometimes alternatively individually replaced by white anglesite, or anglesite colored green by included brochantite. Linarite, with brochantite, may grow on anglesite crystals, or the anglesite crystals may be partially or entirely replaced by linarite sprays, [illegible] sometimes replaced by brochantite. Linarite also replaces caledonite crystals, with the linarite blades roughly parallel to the long axis of the caledonite prisms. These may be encrusted with anglesite spears, while other caledonite crystals on the same piece are replaced by the anglesite crystals alone.

Linarite very rarely occurs with the other blue minerals, diaboleite and azurite, which it then usually replaces. One crystalline bladed mass of linarite included small malachite pseudomorphs after azurite. Linarite crystals sometimes occur on cerussite twins. On one specimen, with a matrix of anglesite crystals, linarite entirely replaced some perched cerussite sixlings, and was then itself replaced by brochantite in several cases.

It can be difficult to visually distinguish linarite from diaboleite and azurite. When linarite is well crystallized, the prismatic habit and one perfect cleavage parallel to the long axis serve to distinguish it from diaboleite, yet the combination of linarite and brochantite is deceptively like diaboleite and wherryite in more massive specimens. Azurite at the same crystal size is a much deeper and more opaque Prussian-blue, without prominent cleavage, and tends to form thicker, more equant crystals (4, 8, 9, 10, 15, 20, 21, 22, 24, 26, 27, 28, 31, 33, 34, 40, 41).

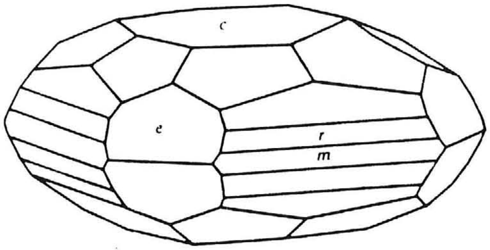


Figure 39. **Matlockite (Gordon).**

Matlockite PbFCl

Large, cleavable, clear to gray masses occurred, altered to anglesite and brochantite on the rims. Very tiny (less than 1 mm), thin, tabular, square or octagonal, transparent crystals occur with diaboleite, boleite, caledonite, and leadhillite. A few crystals were found on altering djurleite, and with anglesite crystals, the matlockite including numerous transparent red covellite crystals. One remarkably large crystal is preserved which is 35 mm in diameter. It is circular in outline, double-convex in cross-section, and deeply striated at right angles on the surface. This crystal is situated on reticulated cerussite (20, 21, 22, 24, 25, 26, 28, 30, 31, 33, 37, 38, 40, 41).

Melanotekite $Pb_2Fe_2Si_2O_9$

During the course of this study, some minute, radially fibrous brown balls imbedded in diaboleite were examined and found to be melanotekite. The mineral has been reported on earlier lists (31, 33, 40, 41).

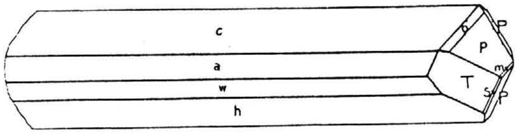


Figure 40. **Paralaurionite (26).**

Paralaurionite PbCl(OH)

Specimens from the Mammoth mine provide, without doubt, the finest examples of this species extant. Elongated crystals as much as 2.5 cm in length, and flattened tabular crystals 15 mm square, occur with diaboleite plates and associated wherryite. The wherryite seems exceptionally rich on the paralaurionite-bearing specimens. Rather than occurring as a minor crystalline alteration of diaboleite, the wh[illegible] usually massive and intermixed with crystalline diaboleite. Paralaurionite crystals commonly enclose diaboleite crystals, and a late generation of leadhillite prisms usually occurs on paralaurionite when both are present on diaboleite specimens.

This rare species varies from colorless to a more usual pale yellow, and shows the unusual property of flexibility without elasticity. The crystals are often found to be bent, but exfoliate if an attempt is made to restore them. They also have a peculiar rounded and almost melted appearance (22, 24, 25, 26, 28, 31, 33, 40, 41).

Paratacamite $Cu_2(OH)_3Cl$

Often associated with its trimorph, atacamite. Both are a brilliant green and occur as sugary masses altered always from diaboleite. This mineral's frequent companion boleite is often found as cubic crystals on the paratacamite. No guidelines can be offered to assist in the visual distinction between atacamite and paratacamite, other than the fact that atacamite sometimes occurs as distinctive elongated prismatic crystals (41).

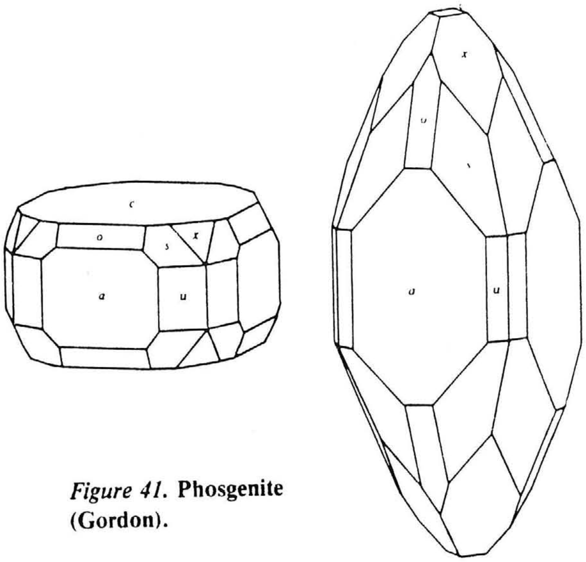


Figure 41. **Phosgenite (Gordon).**

Phosgenite $Pb_2(CO_3)Cl_2$

Sparsely occurring in the diaboleite paragenesis, phosgenite can usually be distinguished by its pale brown color, slender prisms with a square to octagonal outline, acute pyramidal termination, and perfect basal cleavage. It appears to alter from diaboleite, yet is itself corroded into spire-like masses. Crystals frequently enclose minute diaboleite crystals, or have a later generation of these on the tips of its spires. Crystals as long as 35 mm and 25 mm across were seen (20, 21, 22, 24, 25, 26, 28, 31, 33, 38, 40, 41).

Plumbonacrite $Pb_{10}(CO_3)_6(OH)_6O$(?)

Small pearly-white scales, associated with anglesite and linarite on galena, were examined by X-ray diffraction and tentatively assigned to this poorly-defined species, which is easily confused with hydrocerussite (S. Williams, pers. comm.) (41).

Pseudoboleite $Pb_5Cu_4Cl_{10}(OH)_8 \cdot 2H_2O$

Sea-green plates grown parallel to the surfaces of boleite cubes have long been suspected of being pseudoboleite, but their extremely small size has hampered confirmation. On one specimen, the boleite is no longer present, leaving the pseudoboleite (?) plates standing on matrix like a house of cards; this at least indicates a subtle chemical difference. Other, even smaller examples, show six-rayed pyramidal overgrowths reminiscent of cumengite on boleite from Boleo, Mexico (20, 40, 41).

Susannite $Pb_4(SO_4)(CO_3)_2(OH)_2$

Probably occurred in rhombohedral crystals, some with complex modifications, now paramorphed to leadhillite, and discussed un[illegible] that mineral (7, 23, 28).

Wherryite $Pb_4Cu(CO_3)(SO_4)_2(OH,Cl)_2O$

Still known only from the Mammoth mine, wherryite was originally described as a light-green, fine granular mineral. It has since been found that most of the short, tufted, green, polycrystalline mineral almost always associated with older specimens of diaboleite as an alteration product is also wherryite. Individual crystals suitable for single-crystal X-ray and optical goniometric work have been located in recent years.

In the originally recognized occurrence, wherryite and chrysocolla were components of the shell surrounding a cavity in quartz monzonite resulting from the alteration of galena. In the cavity, one of the few scientifically collected, were crystals of leadhillite, cerussite, anglesite, phosgenite, paralaurionite, hydrocerussite, diaboleite, boleite, matlockite, and quartz.

The crystalline varieties are usually formed directly on diaboleite plates, but sprays may occur on other associated minerals. Usually a pale apple-green, the mineral has been confirmed as having also a yellow-green to brilliant lemon-yellow color (25, 26, 28, 31, 33, 36, 38, 40, 41).

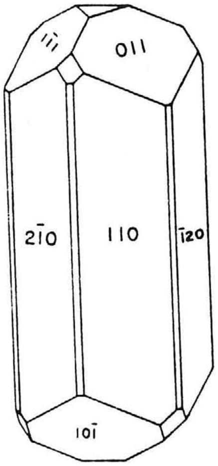


Figure 42. **Yedlinite (38).**

Yedlinite $Pb_6CrCl_6(O,OH)_8$

Red-violet crystals of yedlinite, hexagonal in cross-section with rhombohedral terminations, to a maximum size of 1 mm, are rarely to be found with diaboleite or grown on phosgenite prisms. Crystals of other species such as wulfenite, dioptase, cerussite, mimetite, willemite, hemimorphite, fluorite or quartz may be associated. Yedlinite has been found to date only at the Mammoth mine, with but a few mg known to exist (38, 40, 41).

UNKNOWN MINERALS

Several unknowns have been mentioned or partially described in the literature on the Mammoth mine suite. These are reviewed here, along with three minerals discovered in the present study. There is insufficient material to complete the characterization of the latter three, although enough chemical, optical and single-crystal data has been gathered to verify their status as new species. Their complete description must await better analytical instrumentation or more material.

Unknown mineral of Galbraith and Kuhn (19)

Colorless to very pale blue slender crystals about 0.1 mm in length, isolated or in fan-shaped aggregates, imbedded in chrysocolla. The original material could not be located. Plancheite has been identified from the Mammoth mine, imbedded in chrysocolla, and is an excellent possibility for the identification of this mineral.

Unknown mineral of Palache (20, 28)

"A mineral related to hydrocerussite, in crystals, not certainly of this species, showing a rhombohedral development." These are undoubtedly the leadhillite crystals of rhombohedral habit, so abundantly represented in .e Harva ollection, but not sufficiently studied at that time.

Unknown mineral of Palache (20)

"Diaboleite is altered to an aggregate of lighter blue material." Numerous examples of this effect were seen in the Harvard suite of specimens. It is caused by corrosion of the diaboleite, lowering the intensity of the body color due to smaller grain size, but in fact no alteration has taken place, as verified by X-ray diffraction.

Unknown mineral Lead Tungstate Chloride

Transparent golden yellow needles and flattened crystals to 1 mm long, with sword-shaped terminations. Orthorhombic, generally twinned at approximately 90 degrees. Flexible and elastic. Contains approximately 60% lead, 16% tungsten, 7% chlorine (by microprobe; R. Thomssen, pers. comm.). On quartz, usually alone in cavities. Most closely associated with leadhillite of rhombohedral habit, and sometimes enclosed in crystals of that mineral.

Unknown mineral Lead Copper Antimony Sulfate Chloride

Cerulean blue monoclinic crystals, less than 1 mm in size, occurring on crystallized sugary anglesite. Contains approximately 53% lead, 10% copper, 7% antimony, 5% sulfur and 5% chlorine. Behavior under the microprobe indicates that the mineral is probably hydrated (R. Thomssen, pers. comm.). Antimony in tetrahedrite is a minor constituent of the primary ore.

Unknown mineral Lead Silicate

Tapered, colorless transparent needles, probably hexagonal, a fraction of 1 mm long, form into loose cylindrical aggregates. These are radially fibrous in cross-section, perpendicular to the axis of elongation. Found with crystallized quartz, the aggregates wander across cavities and look astonishingly like woolly caterpillars; several may branch out from a common origin.

MINERALS OF QUESTIONABLE OR DISCREDITED OCCURRENCE

Previous published lists have included species, the occurrence of which could not be verified during this study. Most have probably been based on sight identification, perhaps unusually dangerous due to the demonstrated complexity of the Mammoth mine suite. Some are group names, with specific members of the group found to occur during this work. While it is virtually impossible to absolutely disprove the occurrence reported at one time of a mineral, in my judgment further substantiation is required before accepting the following species.

Actinolite $Ca_2(Mg,Fe)_5Si_8O_{22}(OH)_2$

Variety mountain leather; see sepiolite (40).

Beudantite $PbFe_3(AsO_4)(SO_4)(OH)_6$

Described originally from the Mammoth mine by Peterson as "yellowish-green tufts of fibers associated with wulfenite and limonite . . .," and in his thesis additionally as "also giving a microchemical test for copper."

All such material labeled as beudantite has been found to be creaseyite, including material collected by Peterson, now the type material for creaseyite (16, 17, 21, 24, 31, 33, 40).

Bromargyrite AgBr

Listed as bromyrite in (33).

Chlorargyrite AgCl

Probably the minerals confirmed as embolite and iodargyrite in this study. Listed as cerargyrite (17, 30, 31, 33, 40).

Crocoite $PbCrO_4$

No specimen of this mineral has been authenticated during this study; the few pieces presented have clearly been from the Tasmanian occurrence. The original entry of the species into the literature on the Mammoth mine was based on a single specimen in the University of Arizona collection which could not be located.

Brilliant red vanadinite has occasionally been misidentified as crocoite from other Arizona localities. Very small amounts of chromium do occur in the Mammoth mine ores, coloring wulfenite, cerussite, leadhillite and wherryite, as ıtial constituents of yedlinite and fornacite. Some fornacite casts showing the form of an unknown mineral with habit and angles near crocoite were found (10, 21, 24, 28, 31, 33, 38, 40).

Ecdemite $Pb_6As_2O_7Cl_4$

First described from Långban, Sweden, in 1887, it was reported in the Mammoth mine suite prior to 1900, perhaps based on qualitative chemical tests only. The name is usually applied to needle-like encrustations of an orange mineral on wulfenite. Numerous specimens of varying degrees of authentication have been reexamined and all have proven to be members of the mimetite-vanadinite series. X-ray powder films purportedly of this material in the standards files at both Harvard University and the University of Arizona are also mimetite-vanadinite patterns (4, 9, 10, 17, 21, 24, 28, 31, 32, 40).

Gypsum $CaSO_4$

Although several specimens were seen, bearing selenite crystals or cleavages, and labeled as coming from the Mammoth mine, they were not associated with any other minerals unquestionably authenticating them as from this locality. I consider the mineral of doubtful occurrence here (33, 41).

Huebnerite $MnWO_4$

Listed (40).

Kaolinite $Al_2Si_2O_5(OH)_4$

Often reported as one of the clay minerals present; in fact the occurrence of this mineral could not be confirmed on the numerous specimens sampled. It may nevertheless be present (17, 27, 33, 40).

Lanarkite $Pb_2(SO_4)O$

Listed (40).

Lepidocrocite $FeO(OH)$

Trimorphous with goethite, common at the locality, this species is listed as having been identified on a single specimen. A number of specimens having the shining reddish scales visually suggesting this mineral were X-rayed; all proved to be hematite (24, 31, 33).

Molybdenite MoS_2

At one time thought to occur as a primary mineral, its alteration providing molybdenum for the abundant wulfenite. Diligent search in the ores and underground by later investigators was not successful (15, 17, 40).

Olivenite $Cu_2(AsO_4)(OH)$

A specimen from the Mammoth mine labeled olivenite was on display for many years at the University of Arizona. It was later found to be fornacite (31, 33).

Penfieldite $Pb_2Cl_3(OH)$

Listed (33).

Psilomelane Manganese Oxides

A general term for massive, not specifically identified, hard manganese oxides. Botryoidal masses of manganese oxide ranging from the size of peas to some weighing several kg were seen in the broken ore and lying on the surface by Peterson. All manganese oxide minerals identified in this study were found to be hollandite or ramsdellite; but no examples of compact or massive material were available in the collections examined (17, 21, 28, 33, 40).

Pyrolusite MnO_2

Soft manganese oxides, otherwise unidentified, have been collected under this term. In this study, all manganese oxides examined proved to be hollandite or ramsdellite (15, 17, 19, 33, 40).

Sauconite $Na_{0.33}Zn_3(Si,Al)_4O_{10}(OH)_2 \cdot 4H_2O$

Listed (40).

Vesuvianite $Ca_{10}Mg_2Al_4(SiO_4)_5(Si_2O_7)_2(OH)_4$

The variety *californite* has been reported as a matrix for dioptase. Undoubtedly this is one of the clay minerals (34).

Wad Manganese Oxides

Used to describe undifferentiated soft manganese oxides; see under pyrolusite above (17, 24, 31, 33, 40).

Wolframite (1n)$_4$

Listed (40).

Wurtzite ZnS

This hexagonal polymorph of sphalerite was reported to occur below the 900-foot level. If so, specimens do not seem to be preserved in collections. Sphalerite occurs abundantly to the deepest mine levels (24, 31, 33, 40).

Zoisite $Ca_2Al_3(Si_3O_{12})(OH)$

Peterson suggests this identification for tiny prisms of light green mineral, forming a mat over rhyolite. He also suggests epidote, which is probably more likely (17).

COMPARABLE DEPOSITS

It is interesting to compare the mineralogy of the Mammoth mine with other deposits in Arizona and throughout the world. In Arizona, there are several smaller deposits which have mineralogies also resulting from deep oxidation of veins containing simple primary sulfides like the Mammoth vein. This oxidation has produced a set of secondary minerals comparable to those described under the "normal" sequence for the Mammoth mine, but differing greatly in the ratio of the various minerals. In addition, minor amounts of some of the "anomalous" minerals have been found on close inspection.

These deposits include the Apache mine, near Globe (almost entirely a vanadinite deposit with traces of wulfenite, matlockite, boleite, etc.); the Rowley mine, near Gila Bend (notable for wulfenite and vanadinite; localized caledonite-linarite-brochantite-anglesite, minor diaboleite and matlockite); the Grand Reef mine, Gila County (linarite, caledonite, cerussite, anglesite and leadhillite, some fine specimens in small amounts) and the 79 mine, also in Gila County (fine aurichalcite, wulfenite, cerussite, smithsonite and hemimorphite).

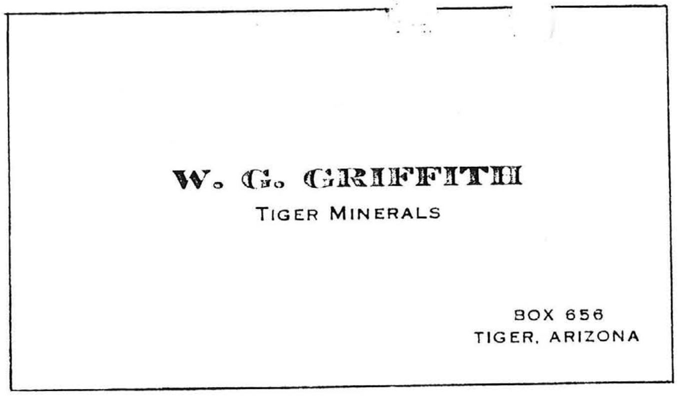
In Mexico, the Ojuela mine in Durango has comparable "normal" sequence mineralogy, but obviously differs due to the great amounts of arsenic in the primary ores, giving the secondary arsenate suite. The same is true of the deposit at Tsumeb, Southwest Africa, which has many minerals in common with the Mammoth mine.

Suites of minerals from the "anomalous" sequence at the Mammoth mine are known elsewhere in the world especially from Leadhills, Scotland; Sierra Gorda, Chile; Matlock and Mendip Hills, England; Laurium, Greece, from the slags; and Boleo, Mexico. The ancient mine workings about Anarak, Iran, provide the closest match to the overall mineralogy of the Mammoth mine.

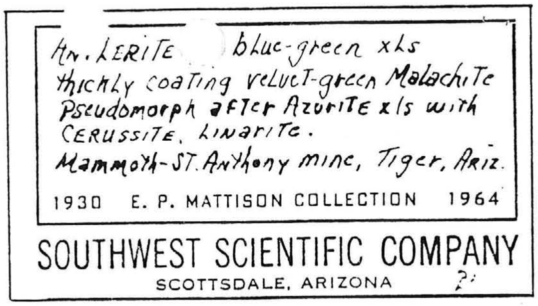
From the reported mineralogy of the above deposits, some important clues to the difference in conditions in the Mammoth veins may be those minerals not occurring (or not yet recognized). These include the apparent absence of plattnerite, a constant associate of murdochite at the other known localities; lead hydroxy- and oxychlorides other than paralaurionite, such as laurionite, penfieldite, fiedlerite and mendipite; and the rare chloroxiphite, known in association with diaboleite from Mendip. Lanarkite might be expected as well.

DEALERS

The best of the Mammoth mine minerals have long been highly prized by dealers and collectors alike. The *Mineral Collector,* a periodical published around the turn of the century, carried a few advertisements for these specimens. In that journal for April, 1897, Maynard Bixby advertised "Wulfenite, groups of choice crystals, also semi-crystallized masses with descloizite and ecdemite." In May of that same year, George L. English announced "A great strike at Mammoth, Arizona—descloizite and vanadinite; wulfenite and descloizite; a few specimens of leadhillite; massive anglesite with linarite and chrysocolla." The December, 1897 issue carried an advertisement by a Mr. Walker, which offered a variety

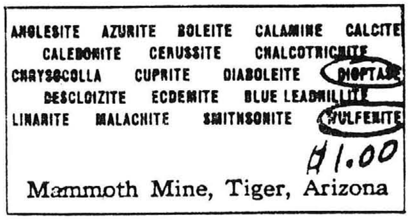

W. G. GRIFFITH
TIGER MINERALS

BOX 656
TIGER, ARIZONA


An.LERITE blue-green xls
thickly coating velvet-green Malachite
Pseudomorph after Azurite xls with
CERUSSITE, Linarite.
Mammoth-ST. Anthony mine, Tiger, Ariz.

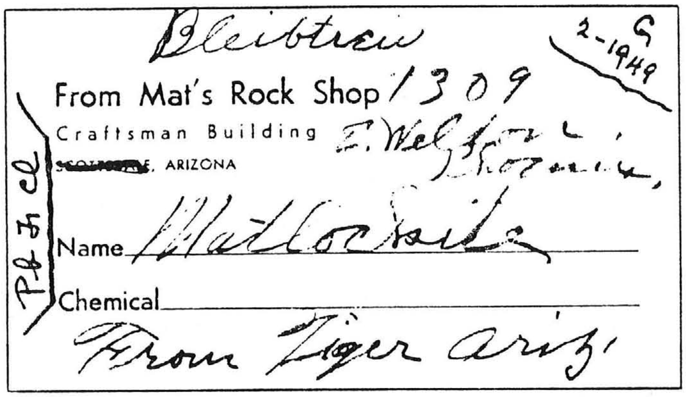
1930 E. P. MATTISON COLLECTION 1964

SOUTHWEST SCIENTIFIC COMPANY
SCOTTSDALE, ARIZONA


ANGLESITE AZURITE BOLEITE CALAMINE CALCITE
CALEDONITE CERUSSITE CHALCOTRICHITE
CHRYSOCOLLA CUPRITE DIABOLEITE DIOPTASE
DESCLOIZITE ECDEMITE BLUE LEADHILLITE
LINARITE MALACHITE SMITHSONITE WULFENITE

$1.00

Mammoth Mine, Tiger, Arizona


Bleibtreu
2-1949
G
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Craftsman Building E. Wel[illegible]
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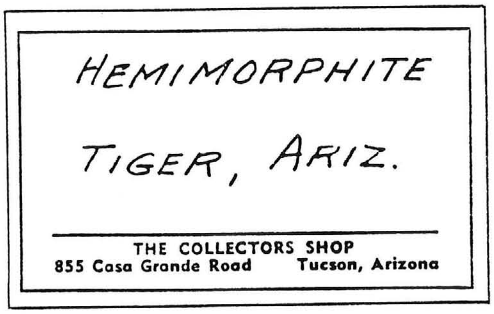
Chemical
From Tiger Ariz.


HEMIMORPHITE

TIGER, ARIZ.

THE COLLECTORS SHOP
855 Casa Grande Road Tucson, Arizona

Figure 43. Mineral labels of prominent dealers in Tiger specimens: W. G. Griffith (top left), Scott Williams (upper right), Bob Roots (center right), Morris J. Elsing (bottom right), and E. P. Mattison (bottom left).

of minerals from the Southwest without giving their localities. Those possibly from the Mammoth mine included "minium, ecdemite, carbonate of lead after sulfate, caledonite, white carbonate of lead, lead carbonate, black cerussite, descloizite, linarite."

The fine collections of Mammoth mine minerals at Harvard University and the U.S. National Museum are due in large part to Edwin Over, another Colorado dealer. His material during the late 1930's and early 1940's was offered through his partnership with Arthur Montgomery and their arrangement with Schortmann's in Easthampton, Massachusetts. Gordon credits him with the discovery of diaboleite and its rare associates on a trip to the mine in 1939.

N. Weiner operated a small mineral store in downtown Tucson, in the early 1940's, and advertised Mammoth mine minerals in *Rocks and Minerals* magazine.

Bob Roots in Denver handled enough of the Mammoth mine material that he had a special label printed, reproduced along with this article, a record of predominant species being produced during the 1940's. He was still offering considerable Mammoth mine material at the first several Tucson Gem and Mineral Society shows in the early 1950's.

Morris J. Elsing, a retired mining engineer, originally had a mineral store on Meyer Street in downtown Tucson, called the "Collectors Shop," where I purchased my first mineral specimens in 1948. He specialized in Mammoth mine and Bisbee minerals. This store was moved to W. Miracle Mile, then known as Casa Grande road, and later to his home in El Encanto Estates.

David Record also ran a mineral store, the "Mission Curio Mart" on S. Mission Road in Tucson, during this same period. After the Mammoth mine shut down, and before his premature death, he purchased several collections from miners; the best of this material was only recently given to the Arizona-Sonora Desert Museum by his parents, Claude and Bernice Motel.

Probably the best dealer contemporary with mining operations was E. P. Mattison, in Scottsdale, Arizona, at "Matt's Rock Shop" (sometimes spelled "Mat's"). He was a regular visitor to the mine, and supplied many prominent collectors and museum curators with their specimens. The bulk of his private collection was offered at a special sale in 1964 by Southwest Scientific Company, in Scottsdale (Scott Williams and David New, owners). A label printed for the sale is reproduced here. It is of minor interest because antlerite is not known to occur at the Mammoth mine. The best pieces from Mattison's collection were acquired by J. Rukin Jelks, and may now be seen at the Arizona-Sonora Desert Museum; several of these are among the best preserved specimens.

In later years, the mine management assigned one miner entirely to the collection of specimens, which were sold or given away at the main company office. I still have a mental picture of the several drugstore showcases full of wulfenite specimens which I saw on my first visit with my father to the mine in 1952, at the invitation of Jack Richards, mine manager. The lucky miner was W. George Griffith, whose card is shown. After the mine shut down, Griffith moved to Tucson where he dealt in Mammoth mine and Mexican minerals for many years. Most of his private collection of Mammoth mine minerals was later sold by Scott Williams, and a number of the best specimens were purchased by Harry Hill. Many of these are now in the collection at the Arizona State Fairgrounds in Phoenix.

PRESENT STATUS

The Mammoth vein was recently again worked by the present owners, Magma Copper Company, San Manuel Division. They began to open-pit the hill on which the Mammoth shaft was sited, in this case for silica flux for the San Manuel copper smelter. The nearby San Manuel mine is the world's largest underground block caving operation on a deep copper prophyry deposit. Their goal was to produce the silica flux required for copper smelting from as close by as possible, and if it also carried recoverable gold values, so much the better.

A contractor benched the hill at [illegible] meter intervals, and a few truck-loads were transported weekly to the San Manuel shafts, railhead for the smelter. Continued operation was halted as the mining operator's ability to control the SiO_2 content for the fluxing material within desired limits was marginal. In general, no collecting was permitted except by a few designated company personnel, however I was allowed to check the exposed mineralogy on one occasion.

Although production was small, the vein was well exposed and there were limited occurrences of minerals for which the mine is already well-known. In the vein itself, amethystine quartz with micromount-sized crystals of wulfenite, descloizite, fluorite, hemimorphite, and cerussite were found. Several specimens of caledonite and linarite were recovered, apparently in dump material. Hexagonal white leadhillite on barite, almost entirely altered to cerussite crystals, was uncovered in the first old stope filling encountered.

Elsewhere on the property (collecting forbidden in recent years except on occasional company-permitted field trips sponsored by the Tucson Gem and Mineral Society, the Mineralogical Society of Arizona (Phoenix), and Friends of Mineralogy), the original Schultz gold mine open cut is capable of producing from the surface representative specimens of wulfenite, vanadinite, descloizite, and minor amounts of creaseyite and fornacite (which therefore could have been described any time during the past hundred years!).

The underground workings have not been entered by company personnel since shortly after the mine was closed. These were completely mapped geologically, and the property offered to contract mining firms. They concluded that insufficient ore was available to justify their efforts, taking into account the dangerous condition of the mine. With the more rigorous governmental safety rules in effect today, it is highly unlikely that the mine could ever be reopened.

Many of the workings filled with water shortly after the mine closed. This has now been drained in large part by the deeper San Manual mine nearby. Eventually the subsidence area above that property will encroach on the Mammoth mine workings, likely causing even more damage underground than now exists, if not complete collapse.

ACKNOWLEDGMENTS

Special efforts have been expended to preserve minerals from the Mammoth mine suite by Harvard University, and I thank Clifford Frondel and Cornelius Hurlbut for access to the collections and to X-ray diffraction equipment. I am also grateful to the U.S. National Museum, where Paul Desautels kindly allowed me to examine their holdings.

I thank John W. Anthony of the University of Arizona for helpful discussions and the use of X-ray diffraction equipment.

The J. Rukin Jelks collection housed at the Arizona-Sonora Desert Museum, was examined by permission of William Panczner, curator, with the assistance of Arthur Roe. Examination of the portion of the E. P. Mattison collection at the Los Angeles County Museum, Bob Gaal, former curator; and the Harry Hill and Joseph J. Strutzel, Jr. collections at the Arizona State Museum, Lee Hammonds, former curator, are gratefully acknowledged.

Many private collectors have assisted in my research by allowing me to examine and in some cases sample their specimens. These include J. Streeter, K. Robertson, J. Klotz, J. Nelson, R. Flagg, J. Hamel, J. Jago, M. Canty, J. Puckett, P. Sonnenberg, D. Boydsten, F. Valenzuela, and J. Ruiz. W. Epler of the *Brewery Gulch Gazette* in Bisbee kindly located early day photographs of the locality.

Personnel of the Mammoth-St. Anthony Mining Company, including E. B. Daggett, J. Richards and J. Strutzel, were helpful in allowing collec[illegible] of [illegible]nerals from the property at various times over the years when the mine was in operation. K. Staley, H. Sweeney, L. Thomas and A. Cockle of the Magma Copper Company have provided helpful discussion and access to the property under San Manuel's ownership.

J. Anthony, S. Williams and R. Thomssen read the manuscript prior to publication, but errors and omissions are my own. C. Olsen and M. Scott kindly typed the various drafts of the manuscript.

REFERENCES (ANNOTATED)

Following are all references touching in any significant degree on the geology, history or mineralogy of the Mammoth mine deposits. Many contain only lists of species observed to that time with little further discussion. The PhD thesis of Nels Paul Peterson, and its subsequent publication, stand above all others as a description and reference to the deposit up to 1938. Unfortunately this work just predates the discovery of the rarer minerals for which the mine is so famous.

The most significant later papers are the formal descriptions of individual species, especially those of Palache and Gordon. While both hoped to publish a description of the mineralogy as a whole, this was never done. Nevertheless, Gordon left some notes and the crystal drawings which are here reproduced for the first time.

A term project was undertaken to study the collection of Mammoth mine minerals at Harvard University by Ira Dubins, Dan E. Mayers, and Henry E. Wenden. I came across a copy of their lengthy but undated paper in the files of Harvard University. Internal evidence indicates it must have been written about 1947 or 1948. Wenden and Mayers were earlier students at the University of Arizona. Mayers had been designated to collect underground at the Mammoth mine on behalf of the University of Arizona. Certain of their observations have been incorporated into this paper.

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   Sketches of vein cross-sections and a listing of 19 species noted, including linarite and dioptase.
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   ". . . the mineral cabinets of the country have been enriched by beautiful crystallizations of wulfenite, vanadinite and descloizite . . ."
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   Indices of vanadinite determined, on a prism.

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8 minerals mentioned.

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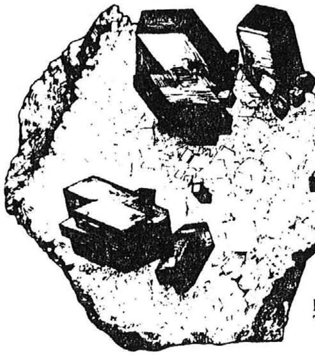

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SUBSIDENCE OF THE TIGER:
THE 1901 MINE COLLAPSE AT MAMMOTH

H. Mason Coggin

Early Arizona miners faced many challenges, one of which was ground control, or the task of securing a mine against collapse and other disturbances. One of the more spectacular mine accidents of the territorial period occurred during the night of 15 April 1901, when the Tiger mine near Mammoth suffered an extensive cave-in. The collapse was large enough that it effectively shut the mine down for a decade-and-a-half until the demand for exotic metals in World War I brought it back into production. In its lifetime, the Tiger District was an important district; it produced approximately 400,000 ounces of gold, 1 million ounces of silver, 3.5 million pounds of copper, 75 million pounds of lead, 50 million pounds of zinc, 6 million pounds of molybdenum oxide, and 2.5 million pounds of vanadium. These minerals had an estimated value of $5 million at the time they were mined, or about $300 million at today's prices.[1]

The area was first prospected prior to the Civil War, but a mine was not located there until 1881, when developers began exploiting a large deposit of gold ore and built a mill on the San Pedro River three miles to the north. From that time until 1893, the property was operated by Mammoth Gold Mines, Ltd. Producing ore that was valued at $14 per ton at a cost of $4 per ton, the company for a time did quite well. By the turn of the century, Mammoth had produced over 150,000 ounces of gold that was valued at over $3 million. The main shaft had been worked down to the 750-foot level and the company was about to mine farther when a large area north of the shaft suddenly collapsed. Nathan Oakes Murphy, who was governor of Arizona Territory at the time, later described the mine and its collapse in his annual report to the Secretary of the Interior, which is excerpted below.[2] Fs

* * *

Fs

The Mammoth mine, in the southern portion of Pinal County, about 60 miles north of Tucson, is one of the prominent gold mines of Arizona, noted for its large bodies of low grade ore. It has long been worked, but during the past four years the management has greatly improved upon former conditions of working, especially in the introduction of the Bleichert system of wire rope transportation, by which the ores are taken at a trifling cost from the mines to the 80-stamp mill on the San Pedro River, 6 miles distant and many feet lower.[3] The whole plant is a very interesting and instructive example of mining, hoisting, transporting, milling, and the final treatment of the tailings by cyaniding. The conditions may be said to have been adverse on all sides. There is no water or timber at the mine, and fuel for motive power at the mill costs $8 to $15 per cord. But with the descending buckets of ore on one side the ascending buckets carry water on the other, effecting a great saving over the cost of hauling, and securing a bountiful supply. It has been proposed to secure water power on the Aravaipa Creek, some 25 miles distant to the mill and to the mine. But as the water supply of the Aravaipa is variable and uncertain this plan may now be superseded by the erection of a power plant on the railway at Tucson and the conveyance of the energy to the mine and mill nearly 50 miles away. In this event it is probable that oil-fuel will be used.

The country rock of the Mammoth and of the Mammoth-Collins group adjoining is a coarse-grained porphyritic granite, like that at Oracle and the gold fields near Mesa and Florence. This granite is highly colored, over considerable areas, with red oxide of iron, and is traversed by several dykes of fine-grained, light-colored porphyry, in association with which the gold-bearing quartz veins occur.[4] The ore is believed to have averaged in value from $7 to $9 per ton, and it has been free-milling, though the tailings have always been rich, and yielded a harvest to the two companies which have been working them by the cyanide process.[5] Considerable bunches of high-grade lead ore have been encountered in mining, and the mineral cabinets of the country have been enriched by beautiful crystallizations of wulfenite, vanadinite and descloizite.

Extraction of ore has been carried on regularly to a depth of 760 feet, where permanent water has been found, which will necessitate pumping.

The principal stoping ground in the Mammoth has been on a large ore chute or chimney north of the main shaft. From the 200 level down to the 500 level a large amount of ore was extracted from stopes in some places about 60 feet wide.[6] There was no thorough timbering. It was chiefly by stulls and some square sets at intervals.[7] Portion of the walls fell in and left a large cavity between the bottom of the 200 and the 500 foot level. This broken and dangerous ground was a constant menace to the lower levels below the 500, which it was intended to make secure by thorough timbering square sets. The

600, 700, and 760 were so timbered, using 10-inch square posts, with sills and caps 8 inches by 10 inches. The 600-foot level was specially braced and lagged, with the expectation of resisting any heavy fall of earth from above.

The Mammoth has thus been a great consumer of timber. For the last 3 years an average of 50,000 feet of squared timber per month has been required. The quantity put into the mine has ranged from 40,000 to 80,000 feet, at an average cost of about $47.50 per thousand feet. This timber is all hauled to the mine by teams from the railroad at Tucson, and has been a heavy item in the cost of working the mine.

On the night of the 15th of April, 1901, an extensive caving occurred in the main stopes, but without loss of life or injury to the shaft. It started suddenly, without warning, at the north end of the mine and extended from the surface to the bottom of the workings, 750 feet deep. About an acre of the surface sank down 25 feet or more, and is still slowly settling down, especially at and near the center of the depression.

The plant of the mine was not damaged, being on firm ground south of the main stopes. The southern part of the mine was not affected and the mine work has since proceeded as usual. The damage is regarded as nominal. Most of the ore of the north end of the mine down to the water level at the 760-foot level has been removed, but some broken-down ore remains under the wreck.

This extensive caving and crushing is another example, out of many, of the futility of attempting to hold up a mountain with timbers. Even on the Comstock lode at Virginia City, within sight almost of the superb pine forests of the Sierra Nevada, the transfer of large portions of those forests to the interior of the mines in the shape of square sets, framed and set with geometrical precision, served only the temporary purpose of checking incipient caving of the walls and securing the safety of the miners for a time. But when heavy splitting off from the walls began, with crowding at one side or the other, the beautiful symmetry of the square-set structure was impaired and the posts were thrown out of the perpendicular, the structure had more the nature of a trap than a secure shield. So it was at the Emma, in Utah; at the Silver King and the United Verde in Arizona, and will ever be in mines where there are large, stoped spaces with walls liable to split off and fall in. It is only a question of a few months or years, in most cases, when a collapse must come and generally with fatal suddenness and great loss of property and life.

It is understood that the Mammoth ground has been worked for several years under a lease which has recently expired by limitation. Another, and adjoining group of important mines, known as the Mammoth-Collins, crops out high up on the hill west of the Mammoth shaft, and it can be reached at a great depth and can be worked to great advantage through a cross-cut drift from the 700-foot level of the Mammoth.[8] A new air compressor has been installed at the Mammoth shaft and the work of extending a cross-cut drift over to the Collins and other lodes has commenced. Machine drills are used and the work proceeds rapidly. Simultaneously a winze has been started from the bottom of the Collins workings so as to connect with the drift so as to secure air and better access.[9] It is estimated that the end of the drift will be 1,000 feet or more below the Collins croppings. Judging from croppings of a vein noted between the Mammoth and the Collins some rich lodes will be intersected by the drift before the Collins ground.

Pending this adjustment of the property rights in the Mammoth and other property and the reorganization of the company, work at the mill has stopped and the whole property has been placed in the hands of the former manager as receiver. Work upon the tailings by the cyanide companies is still in progress.

* * *

Despite Murphy's optimistic predictions that the Tiger mine would soon be back in production, the collapse caused a loss of the operating companies' leases and ushered in a twelve-year period of reduced activity in the district. When World War I broke out in Europe, it drastically changed world metal markets. New technologies in steel making for armaments created a demand for molybdenum and vanadium as alloys. This resulted in a large-scale reactivation of the district as the search for molybdenum and vanadium pulled the mine back into production. Were it not for the new demand for these metals, the Tiger would have remained a mine with some potential but an overwhelming problem that would have made development impractical.

In 1926, Sam Houghton optioned the New Year group east of the Mohawk and did some underground development. He built a small mill in 1932 and then, in 1933, sold the mine to the Molybdenum Corporation of America. By the end of that year, thirty-two men were employed in the district as the increase in gold prices led to renewed mining activity.

By the time President Franklin D. Roosevelt issued his order closing the nation's gold mines at the beginning of World War II, the Tiger district had become established as a gold, vanadium, and molybdenum producer. These important by-products to gold mining kept the mine from suffering the same fate as did many other gold producers, and the Tiger soon became known as the nation's chief source of these little-known metals.

As the mines deepened and the oxide ores above the groundwater were exhausted, mine management discovered that the lower portions of these veins contained large amounts of lead, zinc, and silver. These deposits were mined after World War II by the St. Anthony Mining and Development Co. and sustained the district until the assets of the company were sold to the Magma Copper Company in 1952. After 1952, the adjacent San Manuel copper deposit become one of Arizona's largest copper producers. Magma continues to produce copper today at San Manuel, which has ore reserves that will carry the mine well into the next century.

Notes

1. For more information on mining in the Tiger District, see Kim K. Howell, "A History of the Mines at Tiger," in *History of Mining in Arizona*, ed. Michael N. Greeley and Michael Canty (Tucson: Mining Club of the Southwest, 1991), 2:165-203; Charles H. Dunning and Edward H. Peplow Jr., *Rock to Riches* (Phoenix: Southwest Publishing, 1959), 227-39; and Eldred D. Wilson, J. B. Cunningham, and G. M. Butler, *Arizona Lode Gold Mines and Gold Mining*, Arizona Bureau of Mines Bulletin 137 (Tucson: Arizona Bureau of Mines, 1967), 171-74.

2. *Report of the Governor of Arizona ... 1902* (Washington, D.C.: Government Printing Office, 1902), 102-104.

3. The Bleichert system was an aerial tram with buckets used to haul ore.

4. Porphyry refers to the size and type of mineral crystals found in rock.

5. The cyanide process is a method of refining gold that chemically separates the gold from the ore. Before treatment with the cyanide solution, the ore is crushed into fine particles.

6. A stope is a chamber in a mine where the ore is removed and loaded for transport to the surface.

7. A stull is a prop or supporting timber; a square set is a set of timbers arranged in a prescribed manner.

8. Drifts and cross-cuts are horizontal mine shafts; they may connect the surface with parts of the mine below, or they may be entirely below ground. In this instance, Murphy probably was referring to a cross-cut.

9. A winze is a shaft that is entirely underground and connects drifts, cross-cuts, and stopes inside the mine.

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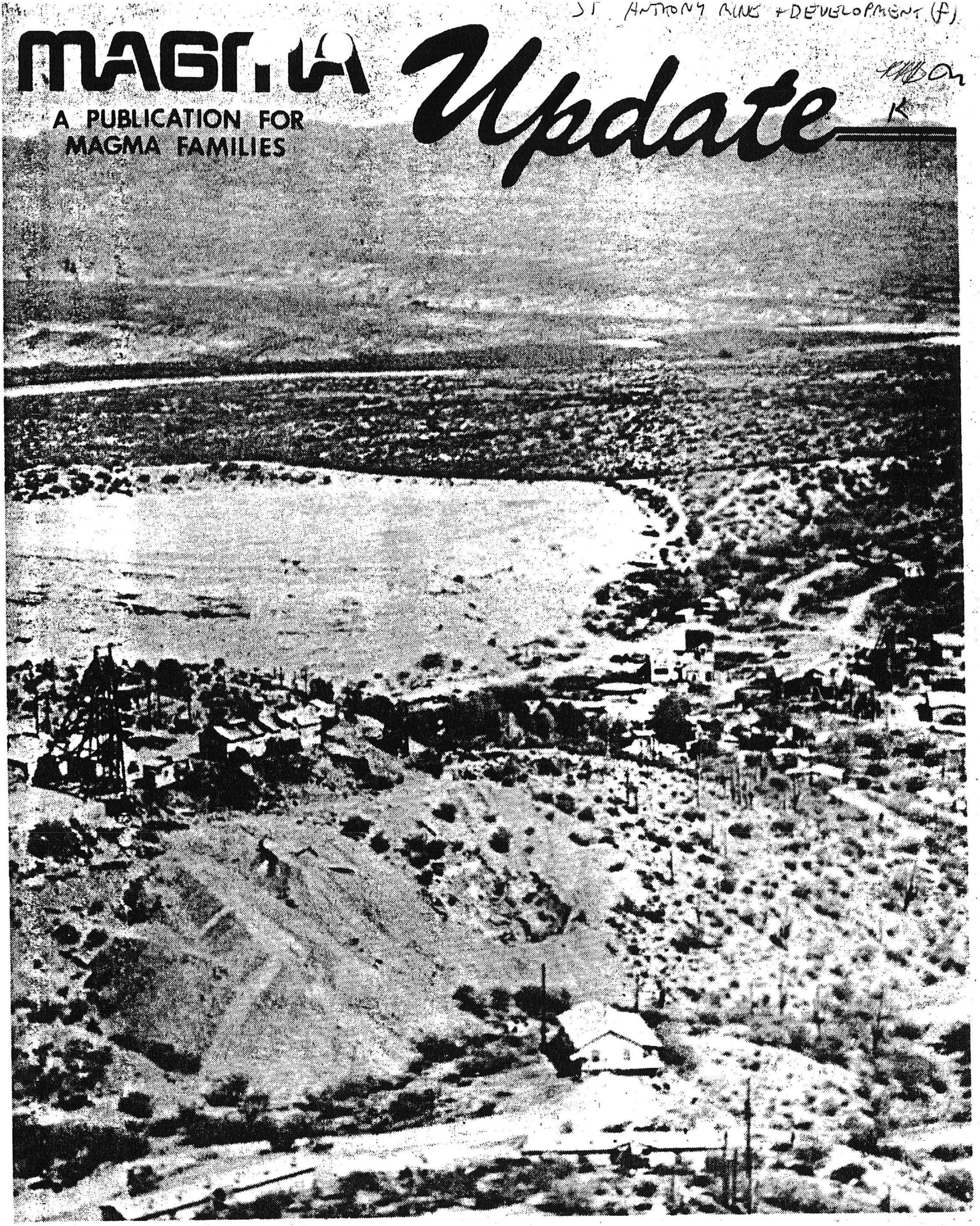

MAMMOTH-ST. ANTHONY MINE headframe, at left, dominated the skyline of Tiger, Arizona until it closed in the early 1950's. Read the history of Tiger, predecessor of San Manuel, on page 3.

Black Dioptase from Tiger, Arizona

by **John Sampson White** and **Joseph A. Nelen**
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The U.S. National Museum of Natural History, Smithsonian Institution, was recently given, for identification, a wulfenite and fluorite specimen from Tiger, Arizona. The specimen contained several small cavities lined with black prismatic crystals less than 0.5 mm in length. The specimen was submitted by Brad Van Scriver of Garden Grove, California.

The result of X-raying the black mineral proved more puzzling than informative; the resulting pattern is that of the usually green mineral dioptase [$CuSiO_2(OH)_2$], but why is this sample black? A polished thin section was prepared for microprobe analysis, revealing pitch-black and uniformly opaque crystals. A preliminary qualitative analysis utilizing an electron microprobe, equipped with a non-dispersive detector, indicated major copper and silicon and traces of aluminum. To eliminate the possibility that the black color was caused by some form of finely dispersed carbon, one of the crystals was analyzed with a Leco 589-600 low-carbon analyzer. The results were negative at a detection limit of less than 0.2 percent.

Returning to the microprobe, the unknown was analyzed, along with two dioptase crystals from the Smithsonian collection (NMNH #R18586 from Guchab, Namibia, and NMNH #R3549 from the People's Rupublic of Congo). The standards used were fayalite for SiO_2 (Rockport, Massachusetts, NMNH #85276), cuprite for CuO (Bisbee, Arizona NMNH #48780) and hornblende for Al_2O_3 (Kakanui, New Zealand, NMNH #143965). Analyses were obtained with the electron beam (1) focused down to about 1 micron and (2) defocused to a larger radius of about 50 microns. Table 1 shows the results of these analyses. Table 2 contains analytical data for the three samples but, for the purpose of this table, the purer of the two green dioptase crystals (R3549) was used as the standard in refining the results for the other two samples, (R18586) and the unknown. All of the probe data have been corrected for background and further refined using a modified version of a MAGIC IV correction program. For comparison, the ideal composition of dioptase is also included in each table.

When the data in parts (1) and (2) of Table 1 are examined, it can be seen that the narrow-beam results (1) for the two known dioptase crystals are very similar to those obtained in the analysis of the unknown. The wide-beam results, (2), while basically the same for the two green dioptase crystals, are quite different from those produced by the unknown. These data invite several significant observations. First, fayalite and cuprite are poor standards to use in analyses of dioptase. Second, in spite of the inadequacy of the figures representing the total amounts of SiO_2 and CuO in Table 1, due to the use of fayalite and cuprite as standards, the Si/Cu ratios (atomic percent) of both green dioptases and the unknown are essentially the same. Finally, Table 1 shows that the narrow beam must have boiled off H_2O from the dioptase samples, while the analysis of the unknown was unaffected by the beam size. This conclusion is further supported by the production of little black dots on the surface of the green dioptase analyzed with the narrow beam, and the absence of such dots on the specimens analyzed with the wide beam.

Table 2, in which all figures are corrected against the dioptase standard, shows that both the SiO_2 and the CuO values for the unknown are increased, just as one would expect if the H_2O had been driven off from these crystals through heating.

As a final test of the effect of heating dioptase until water is lost, a sample of green dioptase (R18586) was heated in a test tube until it turned black. Condensed water was observed in the test tube. When X-rayed the heat-treated black dioptase produced a pattern identical to that of the unknown and nearly identical to that of unheated green dioptase. Some very minor and subtle variations in both the intensities and positions of a few minor lines in the patterns were observed. Weak lines in the positions of the two strongest lines of tenorite (CuO) are most certainly present.

Table 1. **Analyses of Unknown and Dioptase using fayalite, cuprite and hornblende as standards.**

(1.) 1-micron beam

	SiO_2	CuO	Al_2O_3	Si/Cu(At.%)
Ideal	38.1	50.5		
Unknown	44.0	48.2	0.5	1.21
R18586	42.3	47.1	0.1	1.19
R3549	43.3	49.3	0.1	1.16

(2.) 50-micron beam

	SiO_2	CuO	Al_2O_3	Si/Cu(At.%)
Ideal	38.1	50.5		
Unknown	43.9	47.9	0.4	1.21
R18586	38.8	41.9	0.1	1.22
R3549	38.6	42.6	0.1	1.20

Table 2. **Analyses of Unknown and Dioptase using Dioptase #R3549 as the standard. 50 micron beam**

	SiO_2	CuO	Al_2O_3	Si/Cu(At.%)
Ideal	38.1	50.5		
Unknown	42.5	55.5	0.5	1.02
R18586	37.7	49.0	0.1	1.02
R3549	37.8	50.6	0.1	0.99

The authors believe, therefore, that the black crystals of the unknown became black through heating (low red heat, about 700°C) of normal dioptase. Whether accidental (mine fire?) or intentional, we do not know. In the process water was driven off from the sample. Diffuse X-ray diffraction lines in the positions of the two strongest lines for tenorite (CuO) are present, suggesting that some tenorite was formed during heating and accounts for the black color. Associated minerals (wulfenite, mimetite, fluorite) are similar to those present on Tiger specimens in the Smithsonian collection; however, the wulfenite is paler in color, the mimetite is opaque instead of transparent, and the fluorite is chalky and opaque rather than transparent. These differences are additional evidence that the black dioptase specimen has undergone heating.

High grading at Tiger

Tiger was site of rich and productive veins

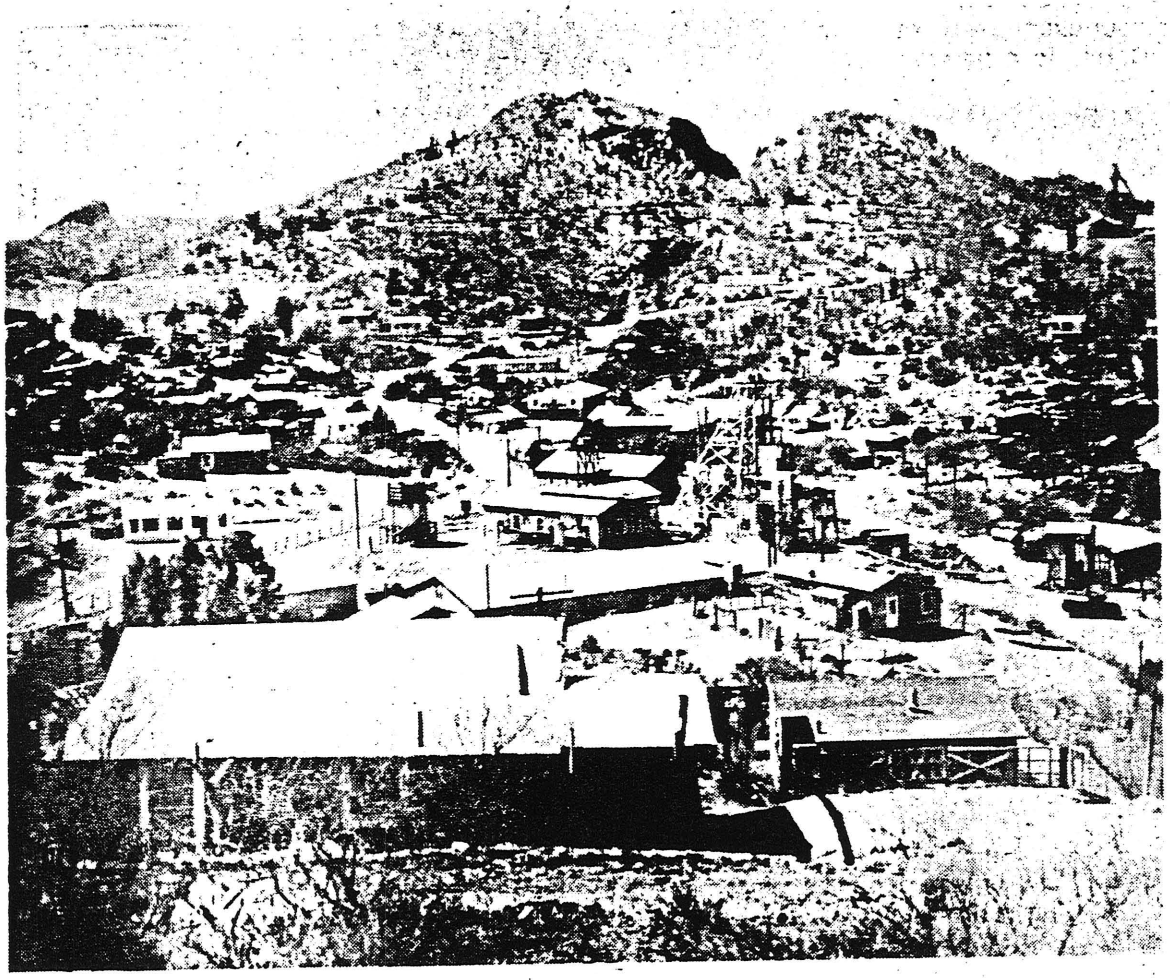
Predecessor to the San Manuel Mine was the long lived and productive group of claims and mines in the area of Mammoth, Red Hill, and Tiger.

Frank Schultz opened a mine there as early as 1881 and designated the area The Old Hat District. As miners began to establish shacks around the mine, he opened a store in 1889. On July 27, 1896 a post office was established for Schultz, Arizona.

The St. Anthony mine, operated by the St. Anthony Mining and Development Company Ltd., 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 were consolidated in 1934 by St. Anthony.

The first claims were located on the Collins vein by Frank Schultz in 1879, and additional claims were located in 1881 and 1882 on the Mammoth vein.

After a few years Schultz sold the Mammoth mine to George Fletcher, who blocked out gold ore and built a 30-stamp amalgamation mill on the San Pedro River a few miles to the east of the mine and, thereby, established the town of Mammoth.



TIGER, ARIZONA, in the early 1950's before it was demolished to make room for the San Manuel Mine. Mohawk headframe in the center and adjacent warehouse are all that remains at the site today. Headframe in the upper right corner was the Mammoth-St. Anthony. The Collins Mine was located at the notch in the center hill, marking the cave-in of the workings. Identifiable in the photo are the movie house in center with nearby grocery store and at left center, the school with children lined-up at back door.

In 1889 the Mammoth property was acquired by the Mammoth Gold Mines, Ltd., an English company.

The mill was enlarged, and gold was profitably extracted from ore mined from the upper levels of the Mammoth vein.

In 1893 the mine caved between the 200 and 400 levels.

In 1896 the Mammoth Gold Mining Co. acquired the property and constructed a cyanide plant to increase the gold recovery and to rework the tailings, which still contain a good part of the original gold.

Mining continued until 1901, when the Mammoth vein again caved, this time from the 750 level to the surface. Shortly thereafter the mine was closed, and it was not reopened for 12 years.

In 1913 the Great Western Copper Co. leased the property but did not operate the mine.

In 1915 the Mammoth Development Co. took over both the Mammoth and Collins mines.

During the early part of World War I, the tailings were successfully treated by the Arizona Rare Metals Mining Co. to extract wulfenite by gravity methods.

In 1918 the St. Anthony Mining and Development Co. acquired the property and successfully mined high-grade wulfenite ore in response to the demand for molybdenum induced by World War I.


MAMMOTH-ST. ANTHONY Mine was the big producer at Tiger between 1881 and 1952.

Following armistice, the price of molybdenum fell, and mining of the wulfenite ore ceased.

In 1892 Frank Schultz sold the Mohawk Claim, which joins the Mammoth on the south, to the Mohawk Gold Mining Co., which mined and treated gold ore in a 10-ton stamp mill until 1897.

In 1906 the company was refinanced, and the stamp mill was enlarged to 30 tons. New ore bodies were found, and production continued until 1916.

Stimulated by the increase in the price of gold in 1933, the Molybdenum Gold Mining Co., a subsidiary of the Molybdenum Corp. of America, acquired the Mohawk mine and the New Year property, which lay just east of the Mohawk claim.

The company successfully developed ore bodies containing gold, lead, vanadium, and molybdenum.

The post office was re-established as Tiger on March 15, 1939 and operated until November 26, 1954, during which period an estimated 1,800 persons lived in the community.

In 1934 the Mammoth and Collins properties were obtained by Mammoth St. Anthony, Ltd., later known as St. Anthony Mining and Development Co., Ltd.

Production of gold-vanadium-molybdenum ore from the oxidized parts of the veins started in 1934.

Production continued until 1943, when the decrease in reserves o these ores and the demand created by World War II fo base metals stimulated the development of lead-zinc sulfide ore bodies in the unoxidized parts of the Collins vein below the 650 level; galena and sphalerite were the chief ore minerals.

With increasing depth the lead-zinc content of the ores decreased, and in 1952 the mine was closed because the company was hard pressed by the depleted reserves and a large influx of water on the lower levels of the Collins vein.

In 1953 Magma Copper Co., owner of the San Manuel Copper Corp., acquired the St. Anthony deposit in exchange for Magma stock.

With the purchase of the claims by Magma and subsequent development of the area for block caving, the town was evacuated by the end of June, 1954 and demolished to make way for the San Manuel mine.

Production from the St. Anthony Deposit's veins totaled 1,889,375 tons of ore between 1881 and 1947 and the following metals were recovered: Gold - 386,701 ounces; silver - 983,918 ounces; copper - 3,456,121 pounds; lead - 74,730,289 pounds; zinc - 48,272,654 pounds; molybdenum - 6,314,812 pounds; and vanadium - 2,540,842 pounds.

Little remains today at Tiger. Only the headframe of the Mohawk and its shaft is kept in repair by Magma. Other buildings and houses have vanished.

The big tailings pile has been mined as a source of flux for our smelter and occasionally, groups of professional rock hounds are permitted to search the dumps for crystal specimens.

Otherwise, the desert is quietly reclaiming Tiger.

How Tiger got its name

Harvey Willeford, San Manuel, retired mine draw boss, SMARRCO conductor, and chief guard remembers how the mining camp of Tiger got that name.

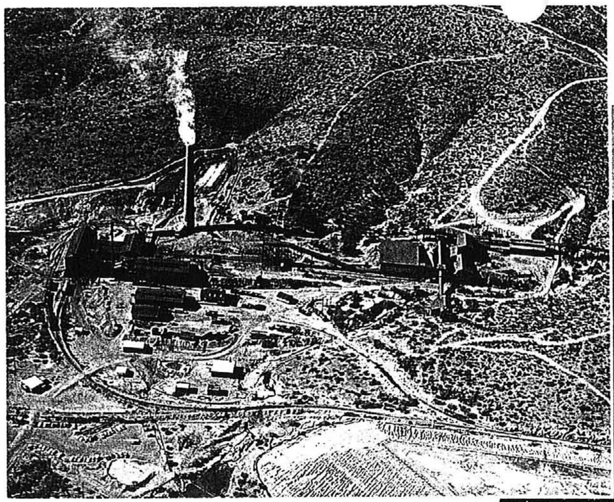
Harvey recalls that in 1938, when he was working at the Mammoth - St. Anthony Mine, the company was making application to reopen the post office and needed a name.

The mine manager, Sam Fields, gave Harvey two names and asked him to survey the workers and find their preference. The names were "St. Anthony" and "Tiger."

The "St. Anthony", of course, came from the mine's name. The "Tiger" referred to an ostentatious tobacco pouch made of tiger skin, carried by a Mr. Brown, the owner from New York, who was a big game hunter.

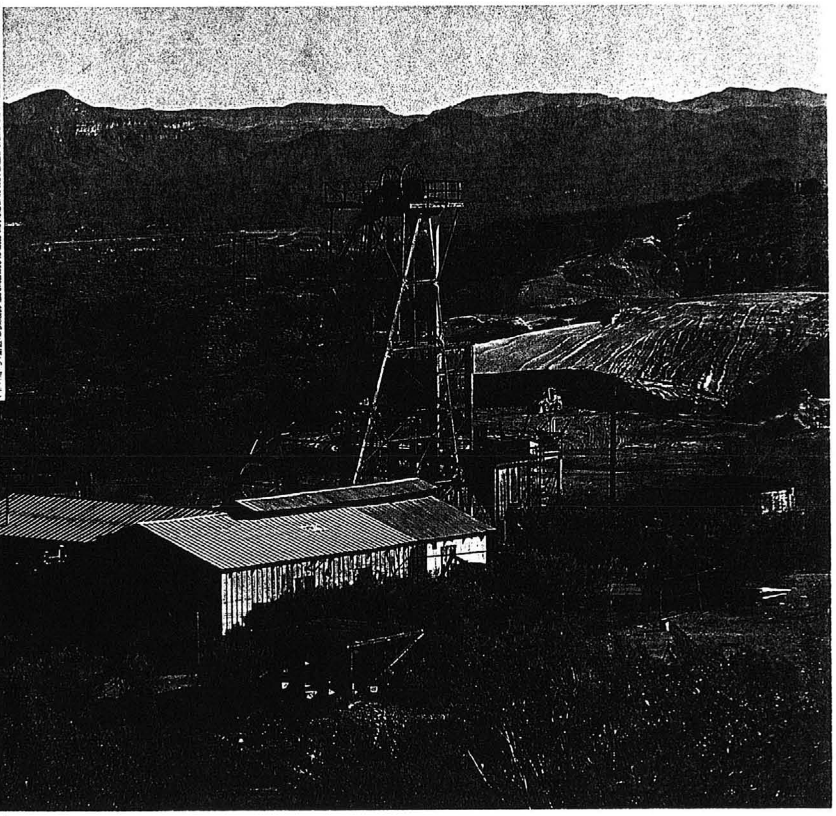
Harvey admits he preferred Tiger and, sure enough, the vote was unanimous for Tiger.

Mammoth (?)



Superior Smelter in the 1950's

Last Remaining Headframe at Tiger, Arizona



OUTLINE HISTORY OF MAGMA COPPER COMPANY

1877	Silver Queen Mine in production at Hastings (Superior) Pioneer Mining district, Arizona Territory.
1879	Mines started in Old Hat District around Mammoth (gold and silver mines).
1896	Post Office opens for Schultz, Arizona, later renamed Tiger (located adjacent to San Manuel's SX-EW plant).
1910	Magma Copper Company organized, Superior, Arizona Territory, holding the old Silver Queen mining property.
1915-19	Molybdenum and vanadium campaigns at Tiger.
1921	Newmont Mining Corporation founded
1924	Smelter erected at Superior, Arizona.
1934	St. Anthony Mining Company buys Tiger mines.
1935-43	Renewal of activity; lead and zinc campaigns at Tiger
1942	War Production Board investigates Mammoth area for copper.
1943-45	Exploration Drilling by U.S. Bureau of Mines at Red Hill (San Manuel).
1944	Magma consolidates and purchases San Manuel claims, and begins additional exploration and drilling.
1948	Underground exploration and development begins.
1952	Federal loan of $94,000,000 made to Magma to build the San Manuel mine, plant, railroads and community.
1953	Construction begins on surface plant.
1956	First stopes undercut and first smelting begins.
1965	Expansion from 30,000 tons of ore per day to 40,000 TPD.
1968	Purchase of nearby Kalamazoo orebody doubles size of reserves.
1969	Merger with Newmont Mining Corporation.
1971	Superior smelter shut down.
1972	Expansion from 40,000 to 60,000 TPD ore processing. Operation of electrolytic refinery and continuous rod casting begins. Smelter expansion underway.
1973	New Superior mine-plant in operation; expanded to 3,300 TPD.
1974	Start-up of air quality control systems and sulfuric acid plant at San Manuel
1982	Superior Division is shut down.
1984	MCR Products rod plant in Chicago is purchased from AT&T.
1985	Production begins at MCR. Development of open pit at San Manuel begins.
1986	Oxide open pit, leaching and SX-EW plant begin production. Newmont recapitalizes Magma and contributes Pinto Valley as an operating division.
1987	Magma is reorganized and spun-off to stockholders of Newmont. In-situ leaching production starts. Sale of Magma owned San Manuel townsite begins. Development of Kalamazoo orebody begins. Modernization programs begin.
1988	Flash furnace at smelter started, old reverbs shut down. Mill and refinery expansion and modernization programs are completed.

MAGMA

Magma Copper Company
P.O. Box M
San Manuel, AZ 85631
Telephone 602-385-3100

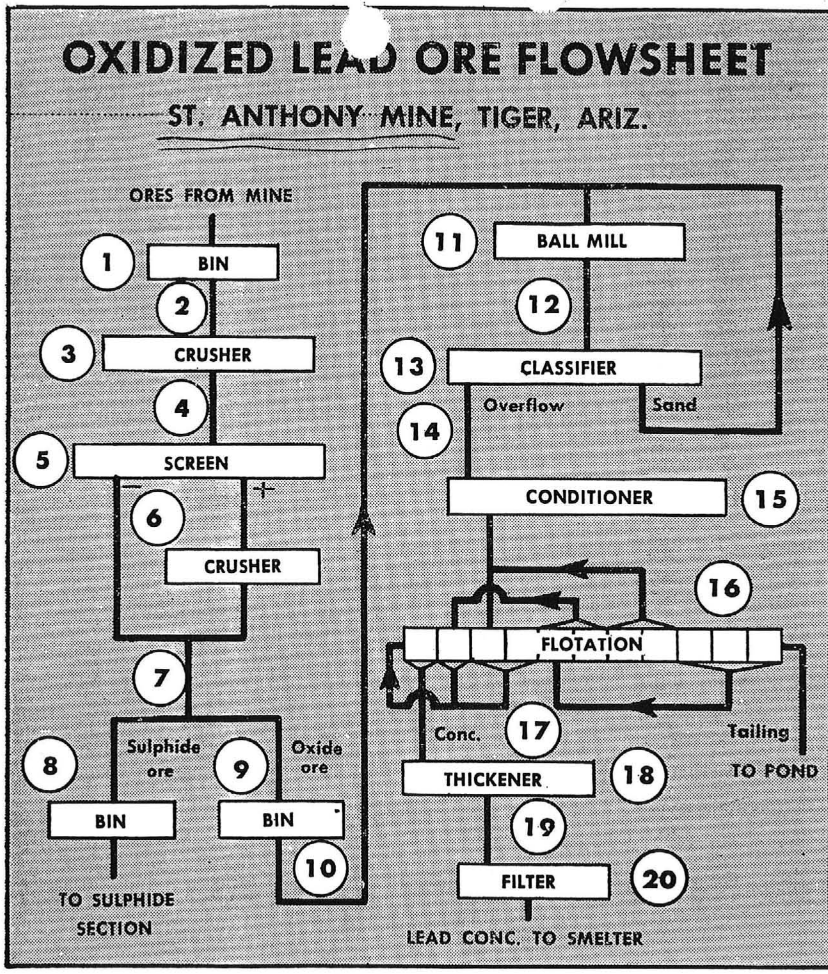
MAMMOTH (F) PINAL

No. 49
by
Raymond Grant

Pinalite is the latest addition to the list of Arizona minerals. It is described in volume 74 of the American Mineralogist, pages 934 - 935. It was found at Tiger in the Mammouth mine and named for the county in which it occurs. The mineral had been known for several years, but the fact that only a very small quantity has been found delayed its being described. Pinalite is acicular bladed crystals up to 0.2 mm long. (You will need a microscope to find these.) It is bright yellow in color, varying to light yellow in mats of fibrous crystals. The hardness and specific gravity could not be determined because of the small size of the material. Chemically, it is a lead tungsten chloride - the first tungsten-bearing mineral found in the Mammoth mine. The occurrence of pinalite is in small cavities in a fine-grained crystalline quartz matrix. The cavities are pseudomorphic casts after some previous mineral, perhaps calcite. Other minerals found in these cavities include: leadhillite, cerussite, matlockite, diaboleite, caledonite, connellite, murdochite, fluorite, and the very rare iranite.

Pinalite is the second new mineral this year to be named after a county in Arizona. It turns out there are seven minerals which have the name of an Arizona county. These are: apachite, coconinoite, gilaite, maricopaite, navajoite, pinalite, and yavapaiite - half the counties in Arizona. Most of these were named because of where they were first found , but apachite and navajoite were named after indian tribes; the counties in Arizona were named after the same tribes. At the rate at which new minerals are being found in Arizona, perhaps the other seven counties will someday have minerals named after them.

The most ironic fact is that the mineral arizonite, named after the state, is now called pseudorutile. Arizonite was first recognized in 1909 as an alteration of ilmenite, but because of the problems of characterizing this fine-grained alteration product, it was not accepted as a mineral. Later work proved that indeed it was a distinct mineral, but at that time it was called psuedorutile. It would seem that the name arizonite should have precedence, but the ways in which minerals are named is not always logical. There are a few minerals which have been named after cities in Arizona such as ajoite, flagstaffite, jeromite, and wickenburgite. One of the most famous of Arizona's mining towns, Bisbee, has a doubtful mineral named after it. Bisbeeite is not at present an accepted mineral, but Dick Bideaux believes that it is a valid mineral and perhaps it will be confirmed as a mineral someday.



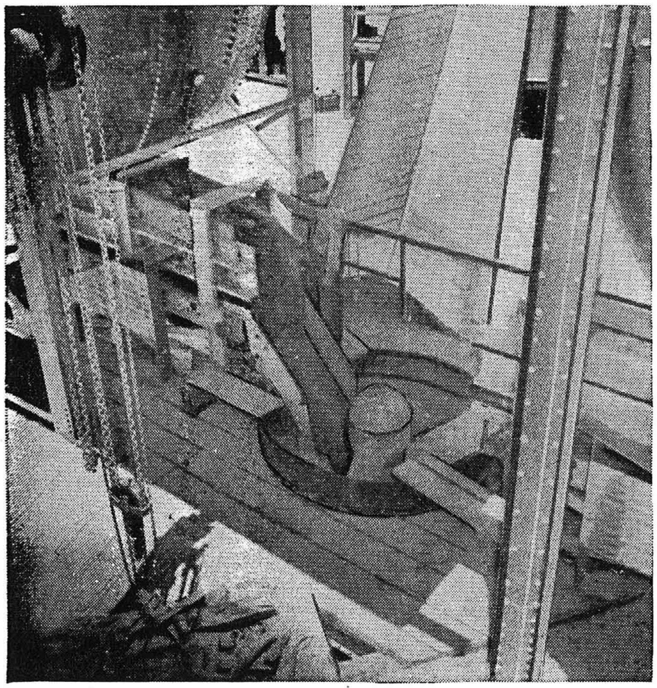
OXIDIZED LEAD ORE FLOWSHEET

ST. ANTHONY MINE, TIGER, ARIZ.

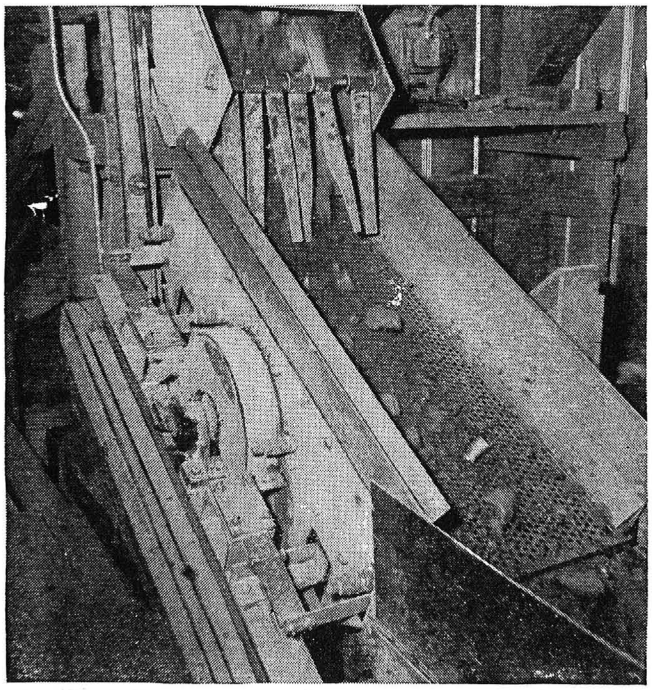
1. Two steel coarse ore bins, 200 tons each.
2. Two 24-in. pan feeders; crushing plant capacity is 50 tons per hour.
3. McCully gyratory, No. 4, minus 3½-in. discharge.
4. Belt conveyor, 16-in., magnetic head pulley.
5. Robins Gyrex vibrating screen, 2x5-ft., ⅝-in. openings.
6. Symons short-head cone, 3-ft.
7. Conveyor belts, 16-in.; Merrick Weightometer.
8. Sulphide ore, wood bin, 600-ton.
9. Oxidized ore, wood bin, 125 tons.
10. Conveyor belt feeder.
11. Marcy grate mill, No. 64½. Ball charge is mixed 3-in. and 2-in. steel balls. Consumption averages 1.98 lb. steel per ton milled.
12. Elevator.
13. Dorr classifier, 4½x18-ft.
14. Wilfey sand pump, 3-in.
15. Conditioner, 6x6-ft.
16. Denver 11-cell flotation machine; two cleaners and six roughers are special No. 18 cells; last three roughers are regular No. 18.
17. Wilfey sand pump, 2-in.
18. Thickener, 10x16-ft.
19. Dorr diaphragm pump, 3-in.
20. Eimco drum filter, 6x6-ft.

April 1948

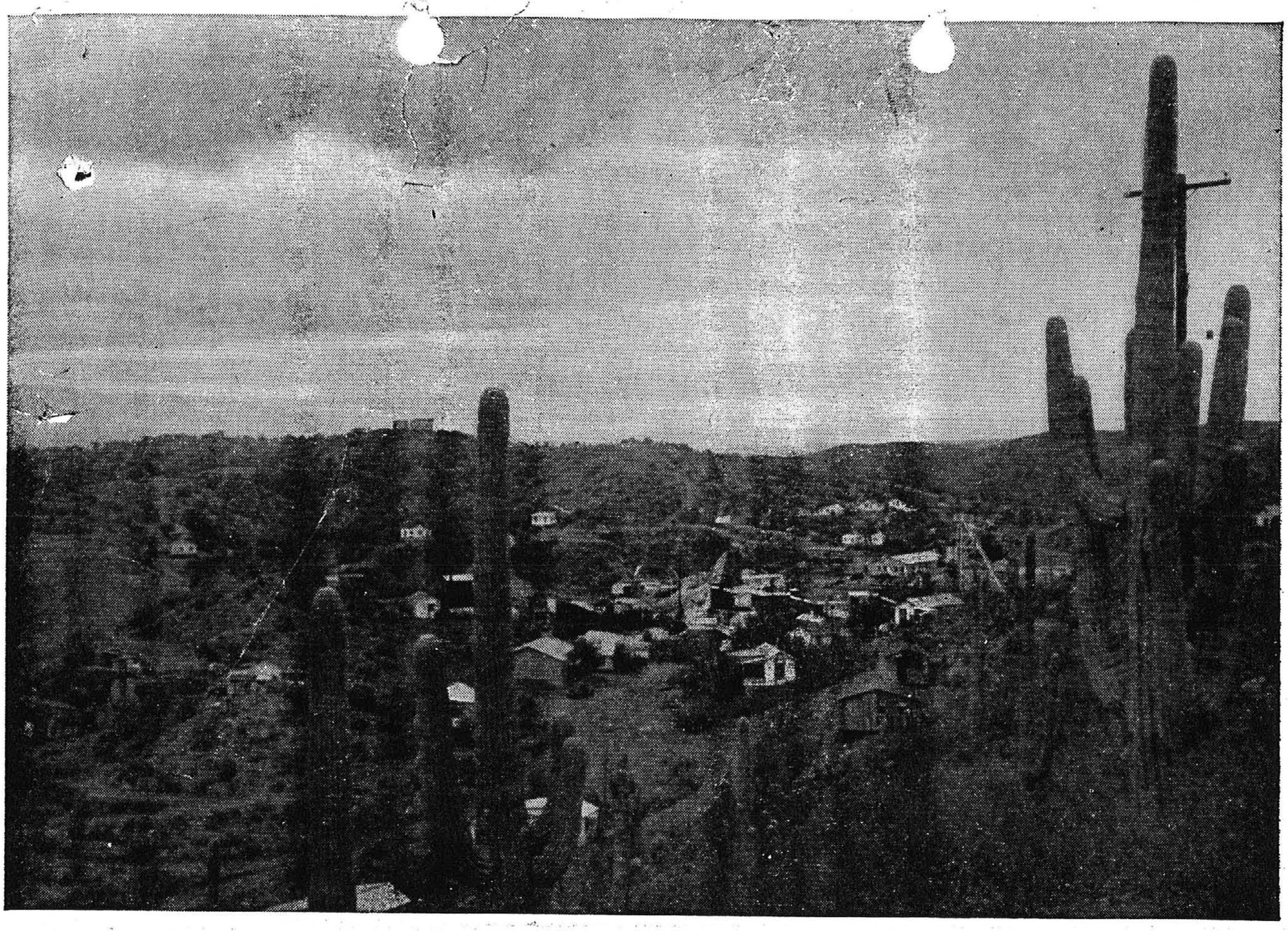
How Oxidized Lead Ore



CRUSHING PLANT takes both sulphide lead-zinc ore from older workings and oxidized ore from newly-developed upper levels of mine.



UNDERSIZE from this screen goes either to sulphide or to oxide bins. Oxidized ore is then ground and floated separately at 100-ton rate.



SPECIAL REAGENT, plus sulphidization, successfully floats oxidized lead minerals for St. Anthony Mining & Development Co.

Is Floated at St. Anthony

E. V. GIVEN
Metallurgical Superintendent
St. Anthony Mining
& Development Co., Ltd.,
Tiger, Ariz.

WHEN THE ST. ANTHONY Mining & Development Co., Ltd., of Tiger, Ariz., recently outlined a body of oxidized lead ore above its producing orebodies, the problem at once arose of concentrating the oxidized ore profitably.

Carrying about 3% to 5% lead in cerussite, galena, anglesite, vanadinite, and wulfenite, the ore did present a problem. After lengthy laboratory and mill tests, we have been able to obtain satisfactory results using the technique outlined in this article. The new oxide section of the St. Anthony mill now treats about 100 tons daily.

Oxide Kept Apart

The St. Anthony mine, located about 50 miles north of Tucson, gets the bulk of its ore (250-300 tons daily) from a lead-zinc sulphide orebody. The oxide ore now being milled comes from exploration and development work in the upper levels of the mine, and it is still very low grade. Both tonnage and grade are expected to improve as soon as stoping begins.

Oxide and sulphide ores are hoisted in the same shaft and crushed by the same equipment, but there they part company. As the flowsheet indicates, sulphide and oxide ores are ground and floated separately. For a description of the St. Anthony sulphide operation, see *E. & M. J.*, November, 1945. All lead and zinc concentrates are shipped by rail from Winkelman, Ariz., a 23-mile truck haul from the mine.

Objectives of Tests

Our laboratory work on the oxidized ore began in April, 1947, with these objectives in mind:

1. To obtain the highest possible economic returns from the ore.
2. To keep the new oxide flowsheet simple, so that no extra operators would be needed to handle both sulphide and oxide circuits.
3. To use all possible equipment already installed in the mill.

(continued on next page)

Table I. Reagent combination for St. Anthony's oxide lead flotation.

Figures are in lb./ton of ore milled.

Place of addition	Soda ash	Cyanamid No. 425	Cyanamid No. 301	Aerofloat No. 31	Cresylic acid	Sodium sulphide
Ball mill	4.00					
Conditioner ..		0.65	0.40	0.13	0.13	
Cell No. 1....						0.40
Cell No. 3....			0.20			0.60
Cell No. 5....						0.50

Soda ash added dry; Aerofloat 31 and cresylic acid are a 50-50 mixture; all other reagents added in 10% solutions;

Table II. Average results for October and November 1947 at St. Anthony's oxide lead flotation plant.

	Assay, percent					Distribution, percent				
	Au, oz.	Ag, oz.	Cu	Pb	Zn	Au	Ag	Cu	Pb	Zn
Heads	0.030	0.51	0.38	3.18	4.01	100.00	100.00	100.00	100.00	100.00
Lead Conc...	0.500	8.17	1.96	53.19	5.80	87.59	84.21	27.07	87.42	7.56
Tailing	0.004	0.08	0.29	0.42	3.91	12.41	15.79	72.93	12.58	92.44

Table III. Average recent assays of St. Anthony lead concentrates.

	Assay, percent.				
	Au, oz.	Ag, oz.	Cu	Pb	Zn
Lead sulphide, gravity conc.	0.037	5.58	0.57	67.68	4.38
Lead sulphide, flot. conc.	0.125	10.54	4.08	67.42	6.08
Lead oxide flotation conc.	0.500	8.17	1.96	53.19	5.80

4. To stick to straight flotation if we could.

Our first samples carried only a small amount of galena along with the cerussite, but when we got as far as mill-scale tests, we found that the run-of-mine ore would be different. Cerussite ($PbCO_3$), is the principal lead mineral, but galena (PbS), wulfenite ($PbMoO_4$), vanadinite, ($Pb_4[PbCl][VO_4]_3$), and anglesite ($PbSO_4$) are present in important amounts. Also there is enough gold, silver, and copper present to warrant going after them.

The procedures that had worked with the samples in the laboratory could not handle the actual ore, and we had to begin over. Eventually we were able to get excellent recoveries of all the lead minerals and good recovery of gold and silver. Copper, occurring as the silicate, chrysocolla, does not float well; and what zinc there is in the ore is non-sulphide and generally not recoverable.

Crushing and Grinding

The St. Anthony crushing and grinding plant follows more or less orthodox practice. It is described in the flowsheet. As indicated there, the oxide ore is ground in a separate circuit to about 60% minus 200 mesh. In a series of tests, the fineness of grind has been varied between 50% to 80% minus 200 mesh, but the 60% grind seems to give best results. Over the last two months, the ground ore has given the following average screen analysis:

Mesh	Weight, percent.
—65	2.95
—65 + 100	8.82
—100 + 200	27.14
—200	61.09
	100.00

Pulp density to flotation has also been a factor, and it requires careful control. Averages for percent solids for the last two months are: in ball mill discharge, 72.0%; in classifier sands, 68.0%; in flotation feed, 19.0%. A rather low pulp density to flotation gives the best metallurgy.

Flotation

In the first tests, when we thought we had only cerussite and galena to deal with, we had good results with the following reagents:

Cyanamid No. 425...2.00 lb./ton
Cyanamid No. 301...0.60 lb./ton
Cresylic acid........0.05 lb./ton

We did not find it necessary to regulate pH, nor to sulphidize the ore. The pH held at 7.4. This was a simple reagent combination, although it was rather expensive. Reagent cost was over $0.90 per ton milled, most of it owing to the price of the No. 425.

When anglesite, wulfenite, and vanadinite turned up in the ore our recoveries dropped. We tried many reagent changes, including sulphidization, and we eventually settled upon the combination shown in Table I. We also found it necessary to give close attention to grinding, pulp density, and pH control. Metallurgical results for the last two months have averaged as shown in Table II.

We get best results by holding the pH at 8.8 to 9.0 at the head of the rougher flotation circuit. By adding the sodium sulphide sparingly and stage-feeding it to every other rougher cell, we have been able to avoid depressing either galena or gold and silver. We add no reagents to the cleaner cells.

The averages for grade of concentrate and recovery shown in Table II are lower than those we have been able to make over short periods when quality of ore was high. At times our concentrates have run over 60% lead, with recoveries well over 90%. Most mill operation has thus far been on ore from development work, and when the oxide section of the mine begins producing in earnest, we hope to improve results in the mill.

Disposal of Concentrate

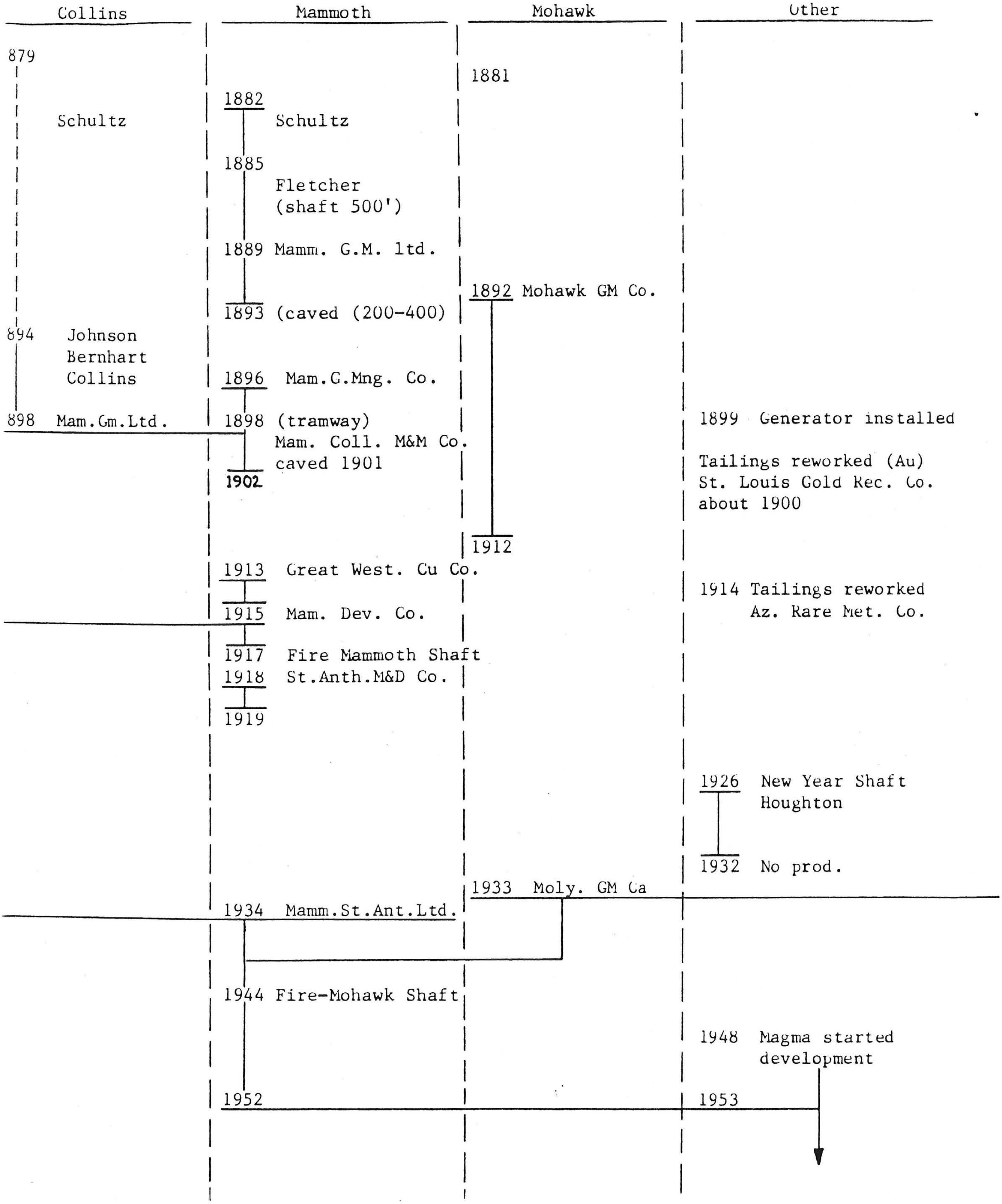
Under present smelter contracts, it has not been necessary to install separate thickening and filtering equipment for the different lead concentrates. The oxide lead concentrate joins the sulphide at the thickener, and they are thickened, filtered, and shipped together. The combined concentrates filter down to a moisture content of about 9.5%. When filtering a sulphide lead flotation concentrate alone, the moisture content is lower by 1.5%.

The mill also produces a lead sulphide gravity concentrate, which is sun-dried and shipped separately.

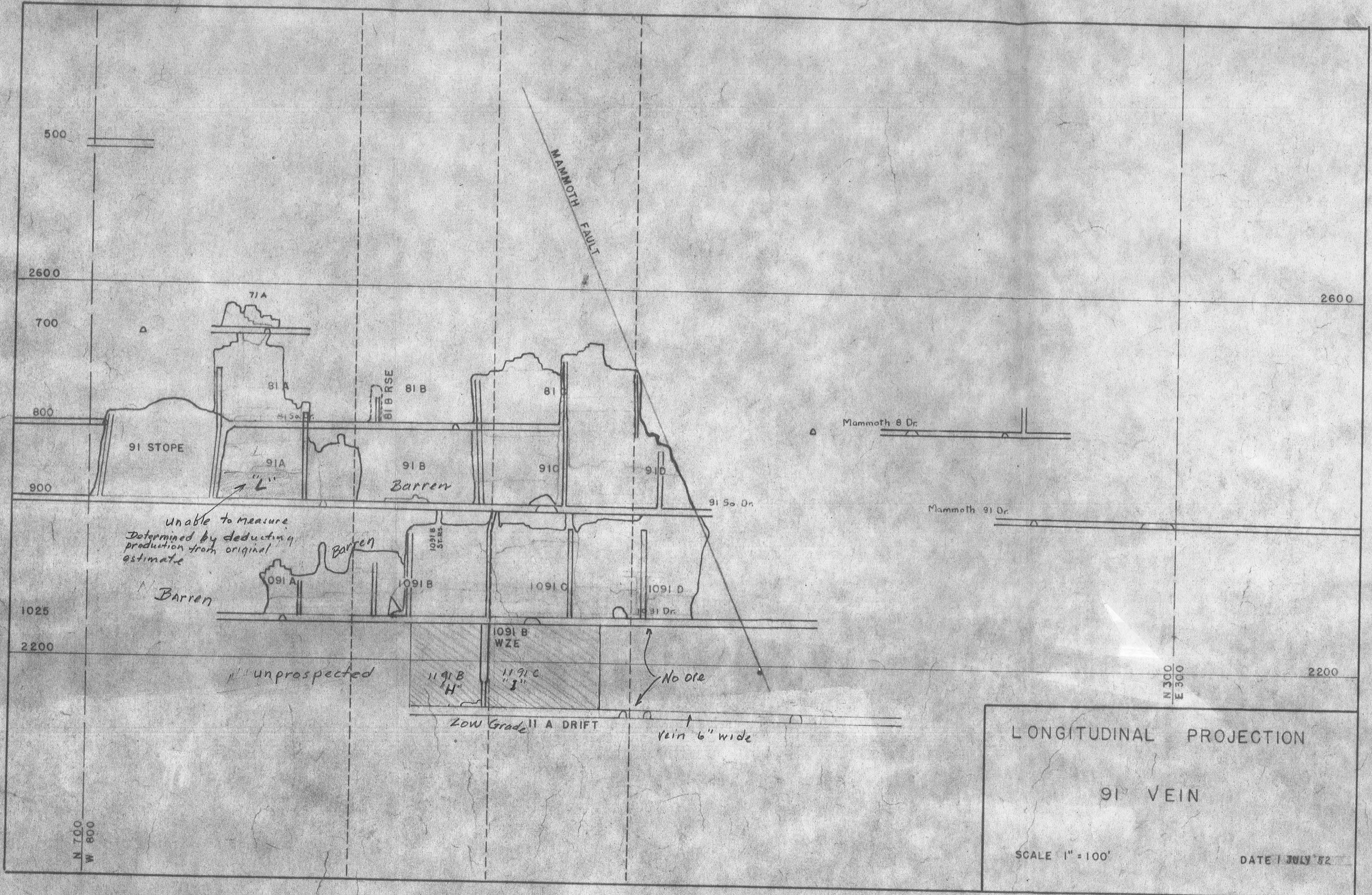
Tonnage of lead concentrate from the mill's sulphide flotation section is much greater than that from the oxide section. A considerable difference is apparent in the metal content of the two products.

Average analyses of the three lead concentrates produced at St. Anthony appear in Table III.

Tiger Mines' Chronology



Collins	Mammoth	Mohawk	Other
879			
		1881	
Schultz	1882 Schultz		
	1885 Fletcher (shaft 500')		
	1889 Mamm. G.M. ltd.		
		1892 Mohawk GM Co.	
	1893 (caved (200-400)		
894 Johnson Bernhart Collins			
	1896 Mam.G.Mng. Co.		
898 Mam.Gm.Ltd.	1898 (tramway) Mam. Coll. M&M Co. caved 1901		1899 Generator installed
	1902		Tailings reworked (Au) St. Louis Gold Rec. Co. about 1900
		1912	
	1913 Great West. Cu Co.		
			1914 Tailings reworked Az. Rare Met. Co.
	1915 Mam. Dev. Co.		
	1917 Fire Mammoth Shaft		
	1918 St.Anth.M&D Co.		
	1919		
			1926 New Year Shaft Houghton
			1932 No prod.
		1933 Moly. GM Ca	
	1934 Mamm.St.Ant.Ltd.		
	1944 Fire-Mohawk Shaft		
			1948 Magma started development
	1952		1953



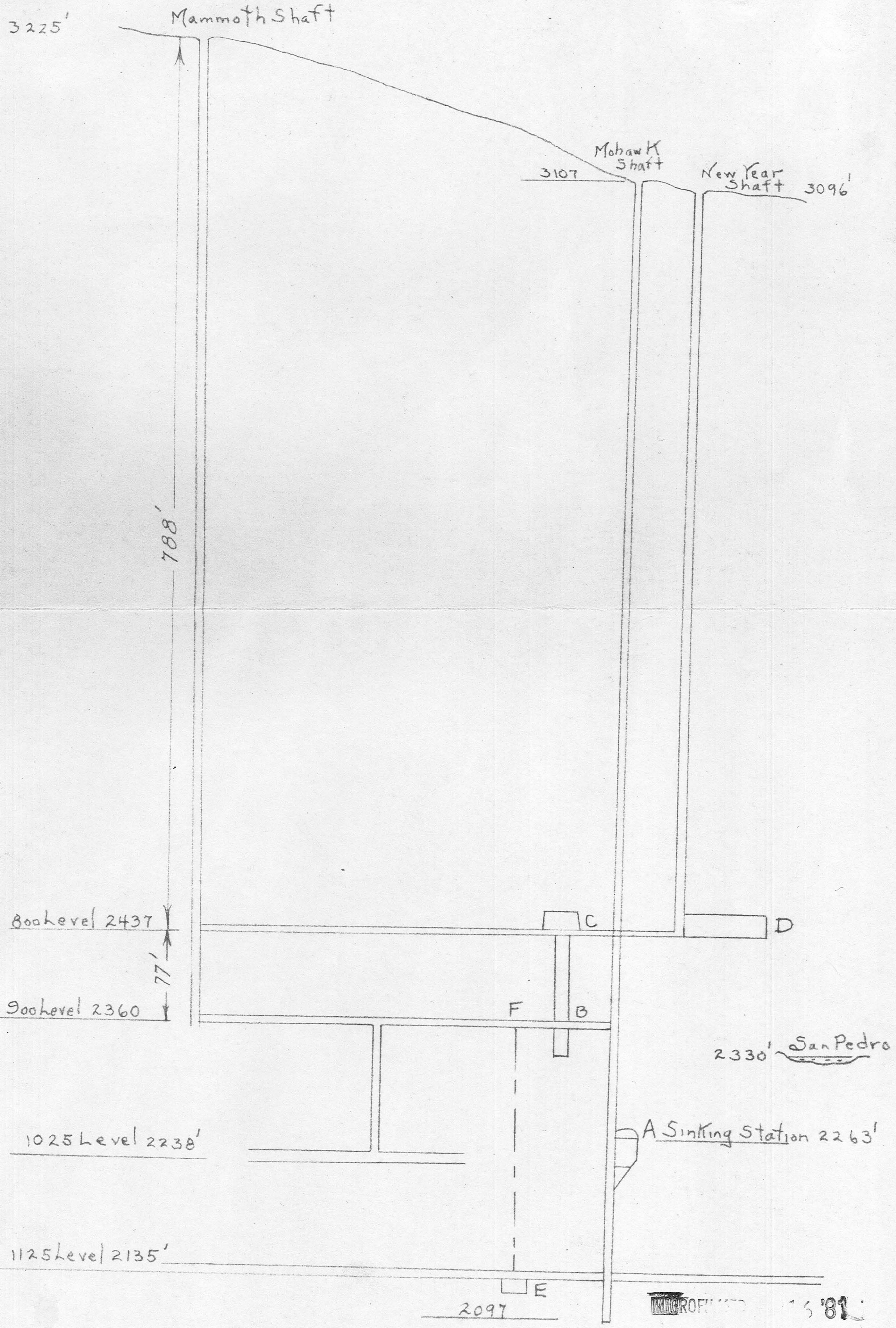
LONGITUDINAL PROJECTION

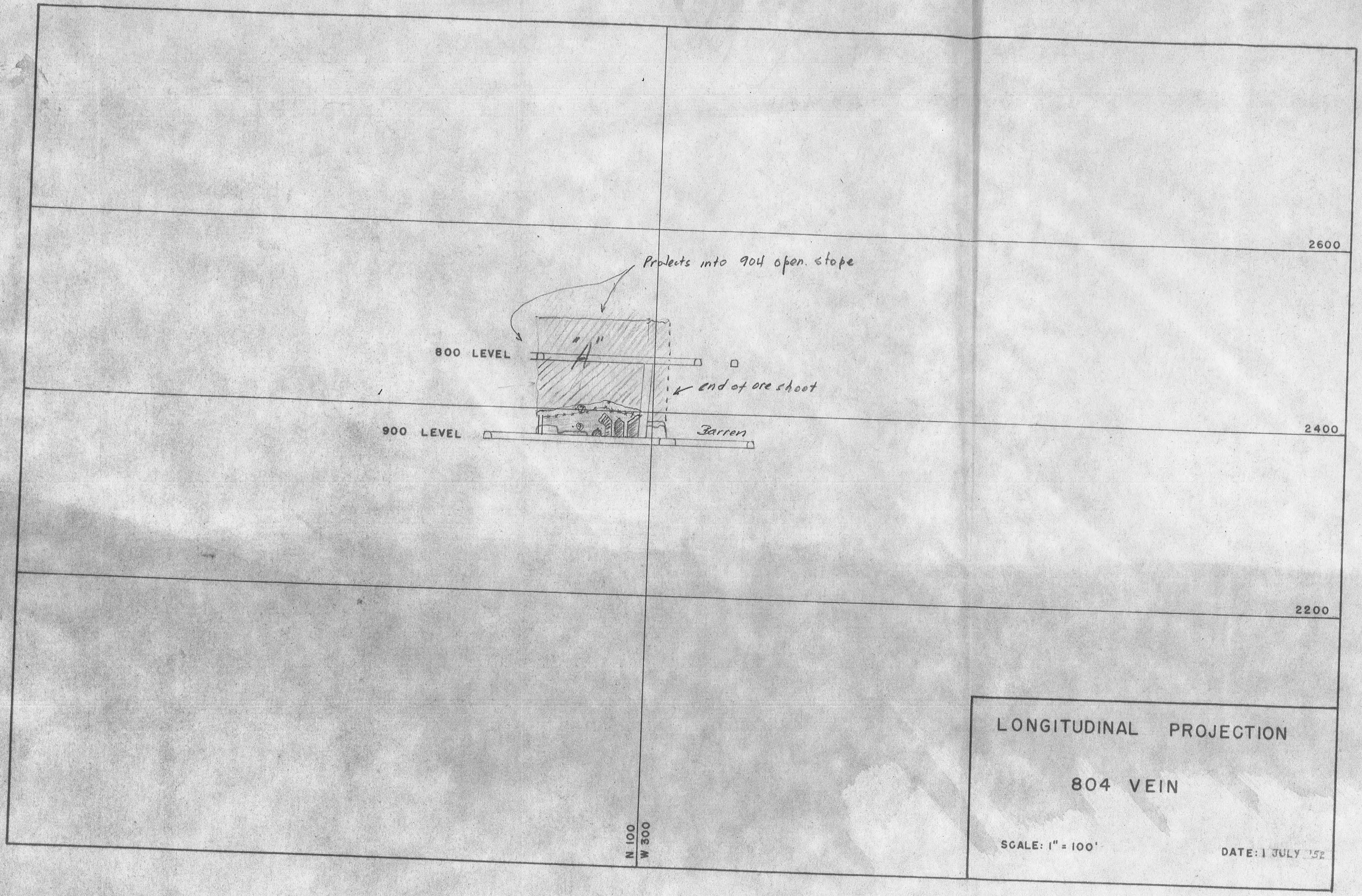
91 VEIN

SCALE 1" = 100'

DATE 1 JULY '52

Diagram of Shafts & Sumps
Tiger Mine



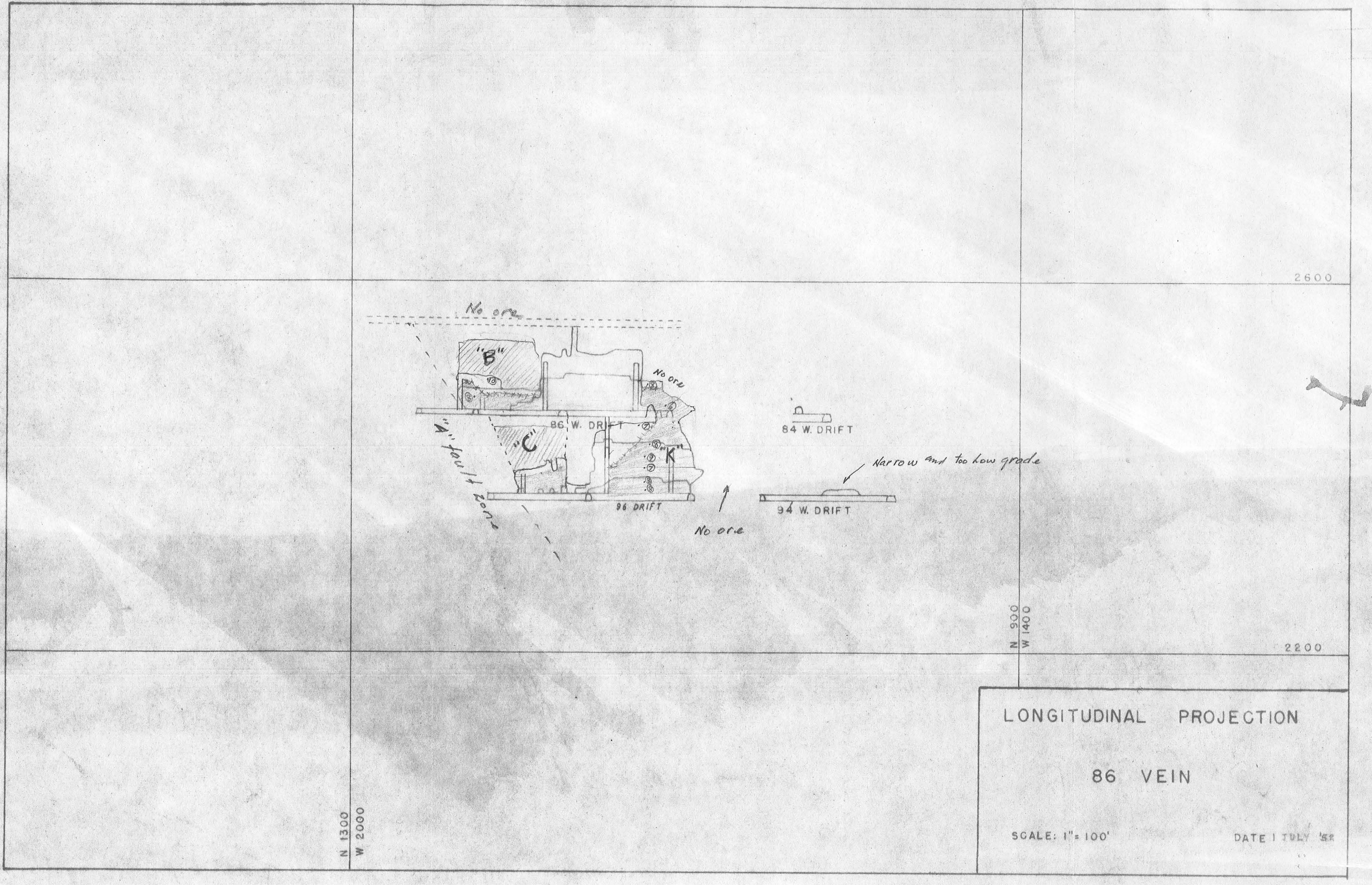


LONGITUDINAL PROJECTION

804 VEIN

SCALE: 1" = 100'

DATE: 1 JULY '52

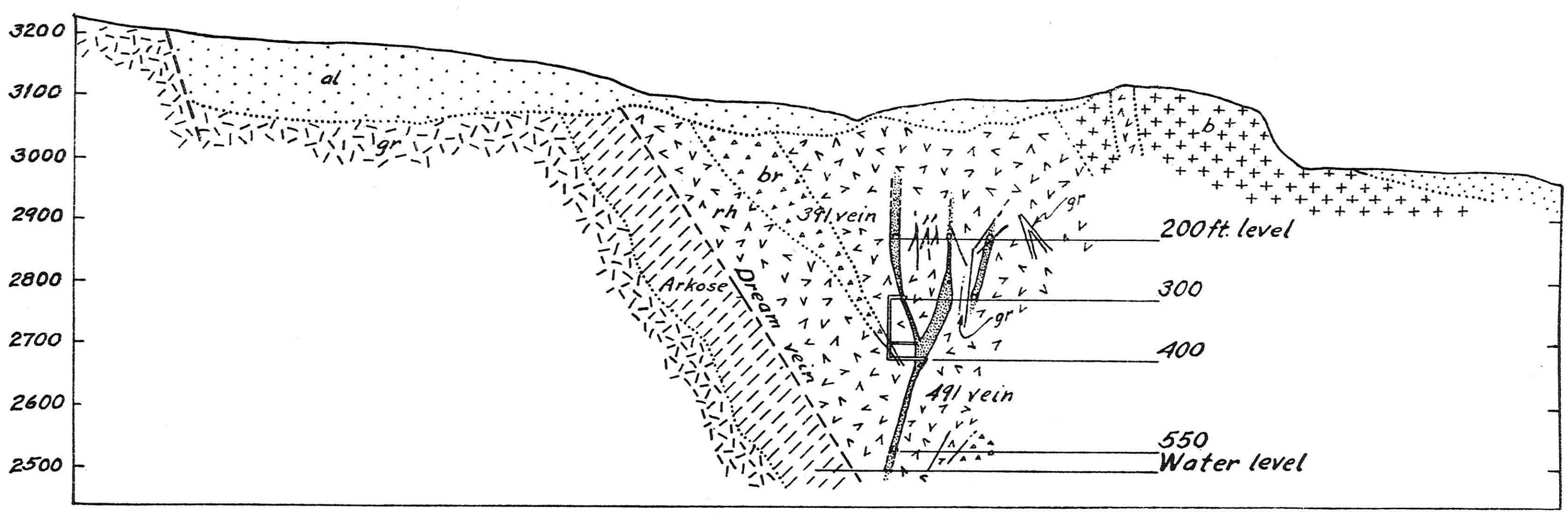


LONGITUDINAL PROJECTION

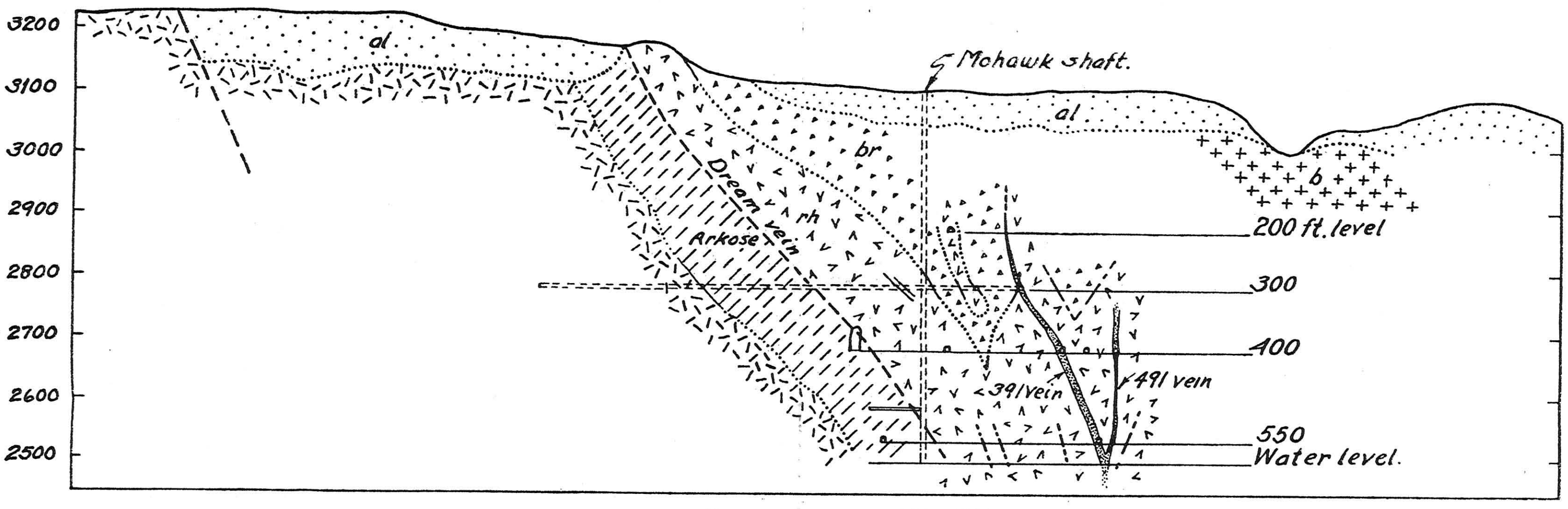
86 VEIN

SCALE: 1" = 100'

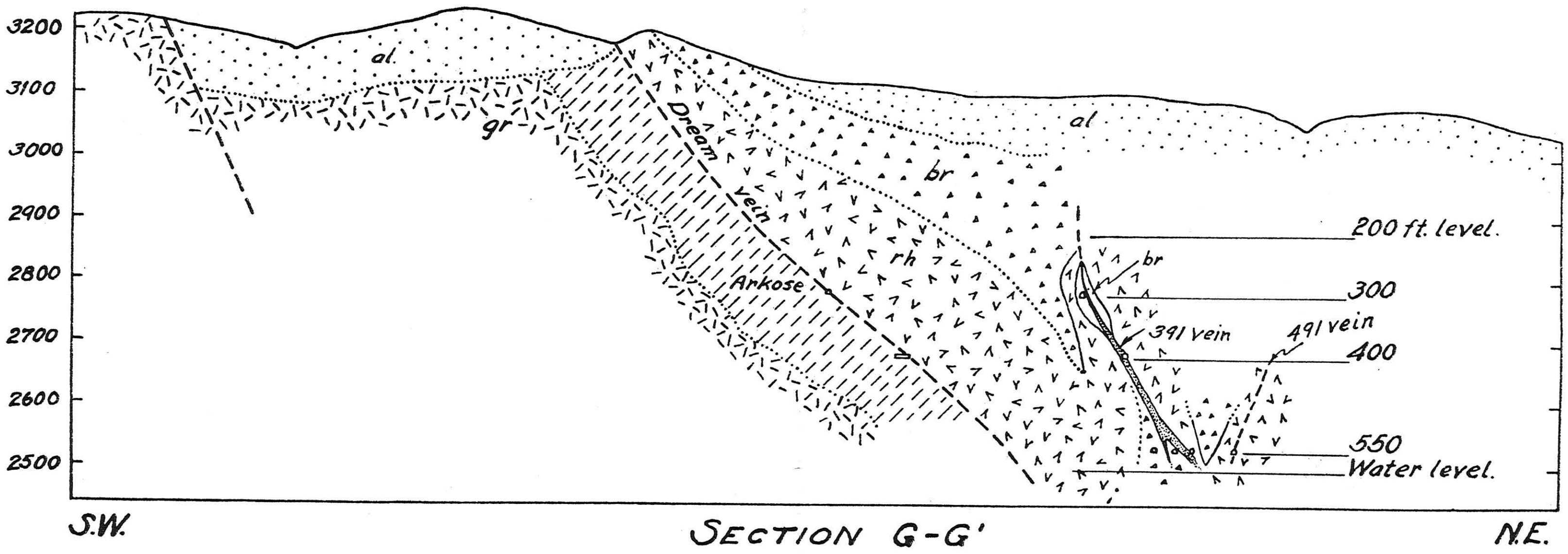
DATE 1 JULY '58



SECTION E-E'

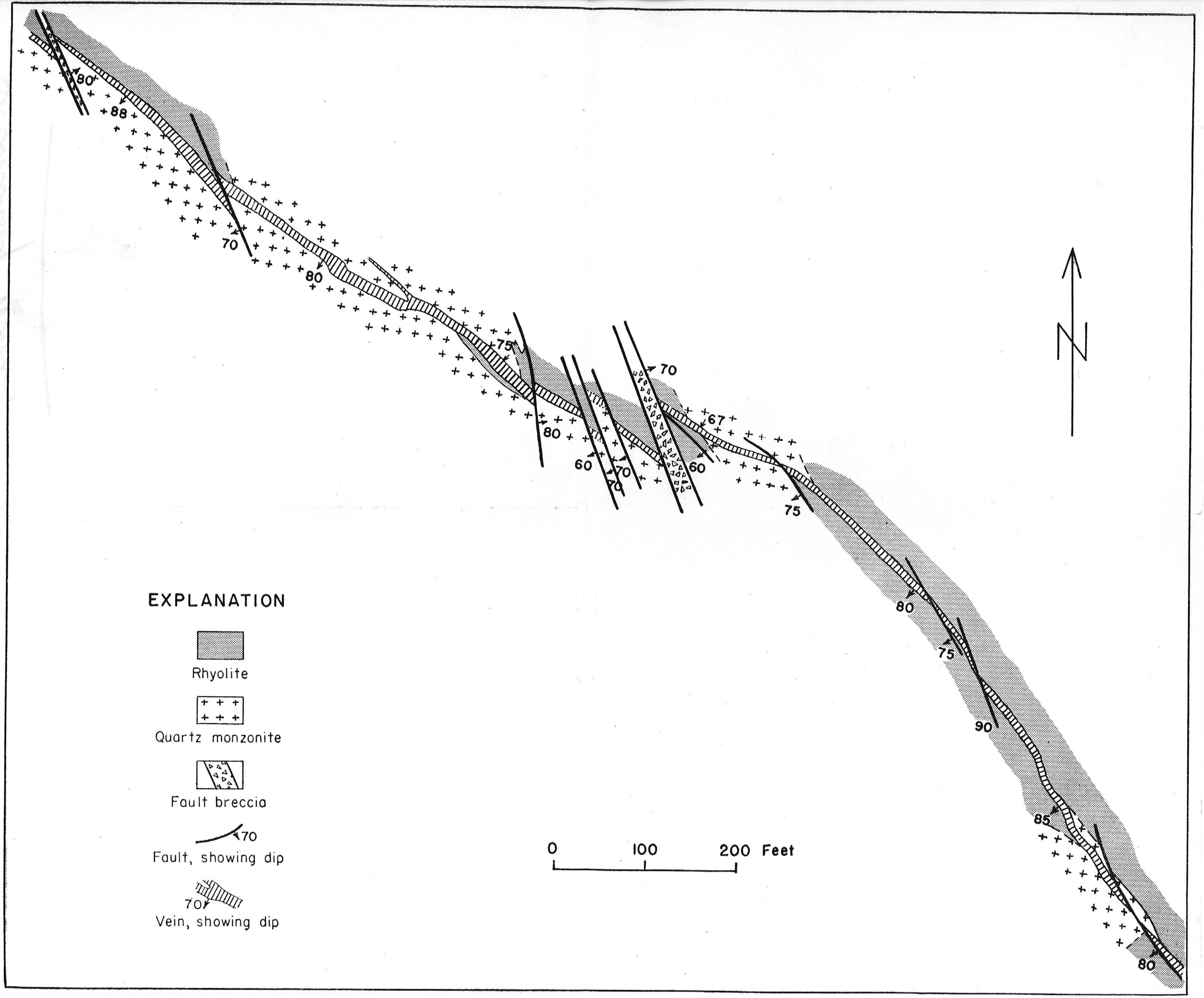


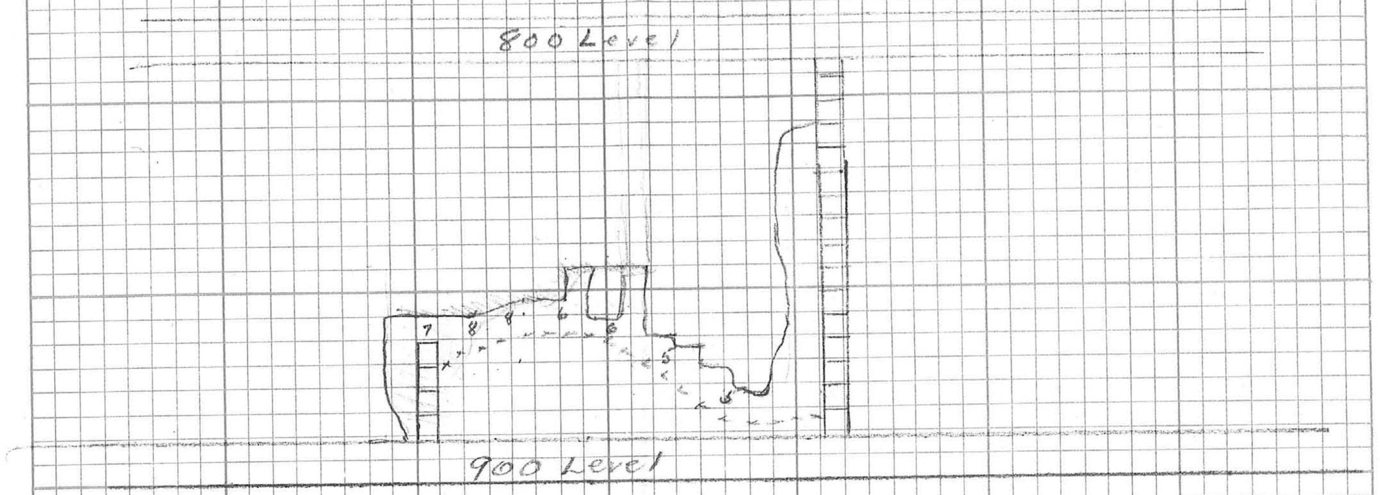
SECTION F-F'



SECTION G-G'

Plate XXXVIII.—Structural sections along lines E-E', F-F', and G-G' of Plate XXXVI, Mammoth Mine area.


EXPLANATION
Rhyolite
Quartz monzonite
Fault breccia
70
Fault, showing dip
70
Vein, showing dip
0
100
200 Feet
N
80
88
70
80
75
80
60
70
70
70
67
60
75
80
75
90
85
80



96 A Stope.

Longitudinal Section
Looking Northeast.

1" = 40'

6-21-52
MG

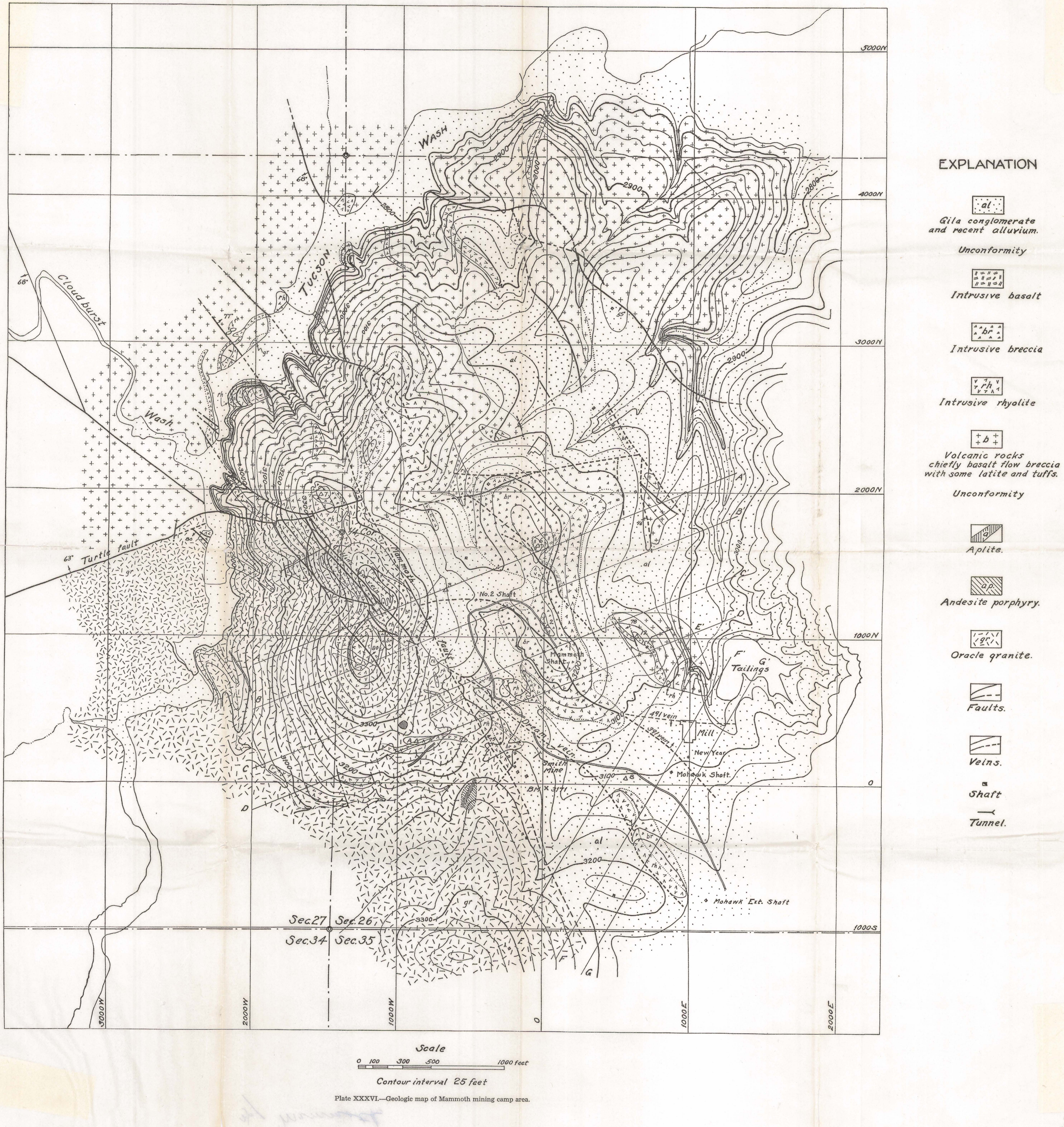
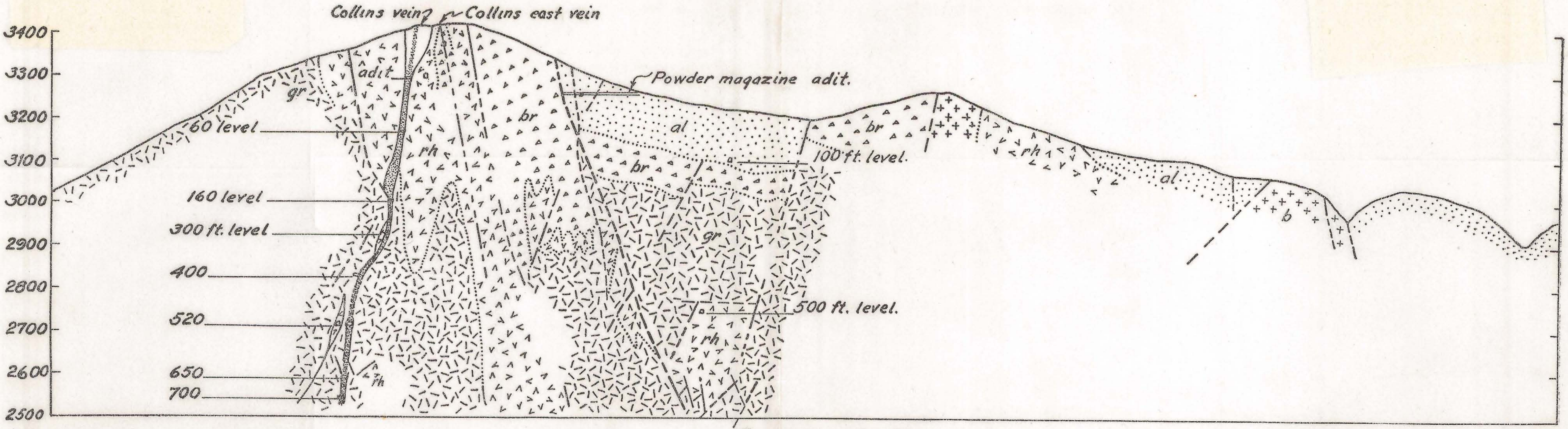
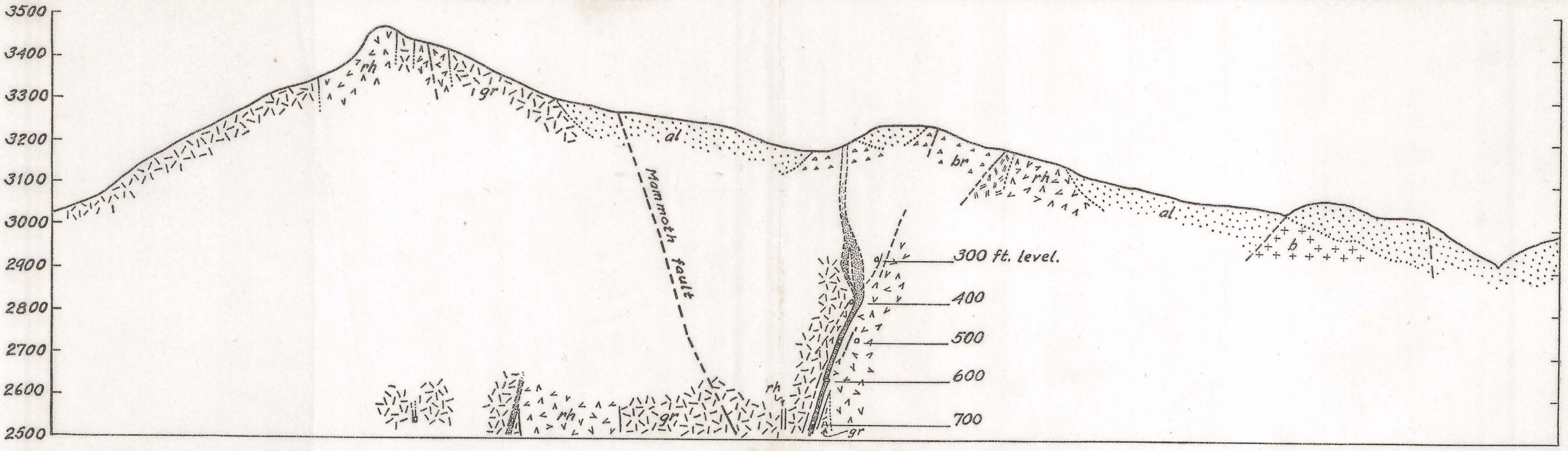


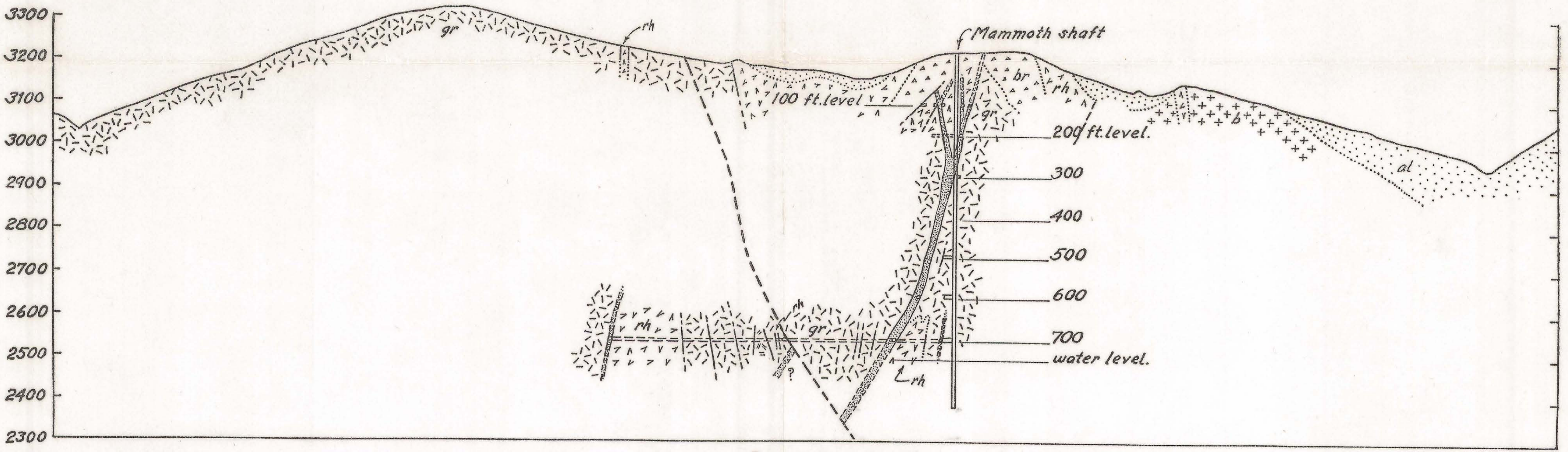
Plate XXXVI.—Geologic map of Mammoth mining camp area.



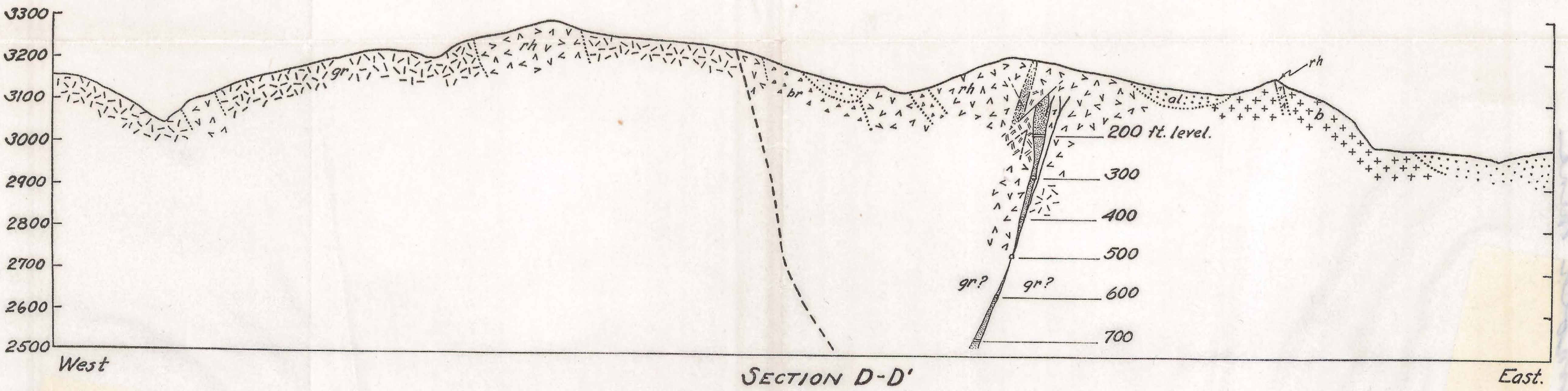
SECTION A-A'



SECTION B-B'



SECTION C-C'



SECTION D-D'

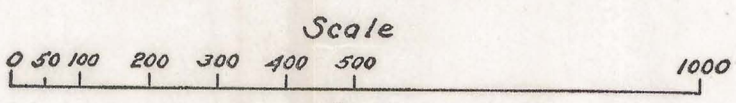


Plate XXXVII.—Structural sections along lines A-A′, B-B′, C-C′, and D-D′ of Plate XXXVI, Mammoth Mine area.


400S
300S
200S
100S
00
100N
200N
300N
400N
500N
700N
800N
900N
1000N
1100N
1200N
1300N
1400N
1500W
1400W
1300W
1200W
1100W
1000W
900W
800W
700W
600W
500W
400W
300W
200W
100W
00
COLLINS SHAFT
COLLINS VEIN
COLLINS VEIN
MAMMOTH FAULT
MAMMOTH VEIN
U.V. CHURN DRILL HOLE 285'
CAVED
CAVED
CAVED
SHULTZ VEIN
MAMMOTH SHAFT

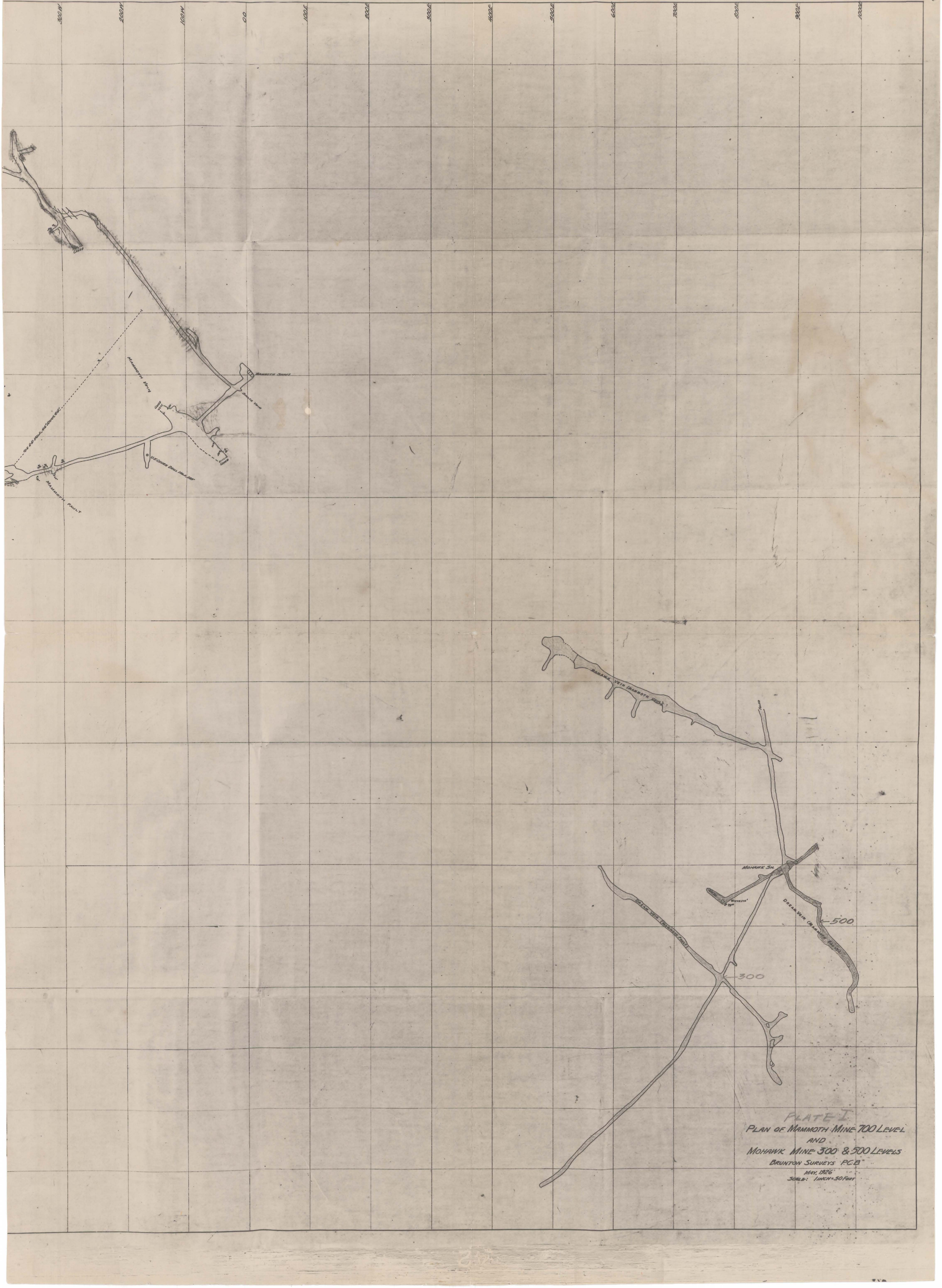


PLATE I

PLAN OF MAMMOTH MINE 700 LEVEL
AND
MOHAWK MINE 300 & 500 LEVELS
BRUNTON SURVEYS P.C.B.
MAY, 1926
SCALE: 1 INCH = 50 FEET

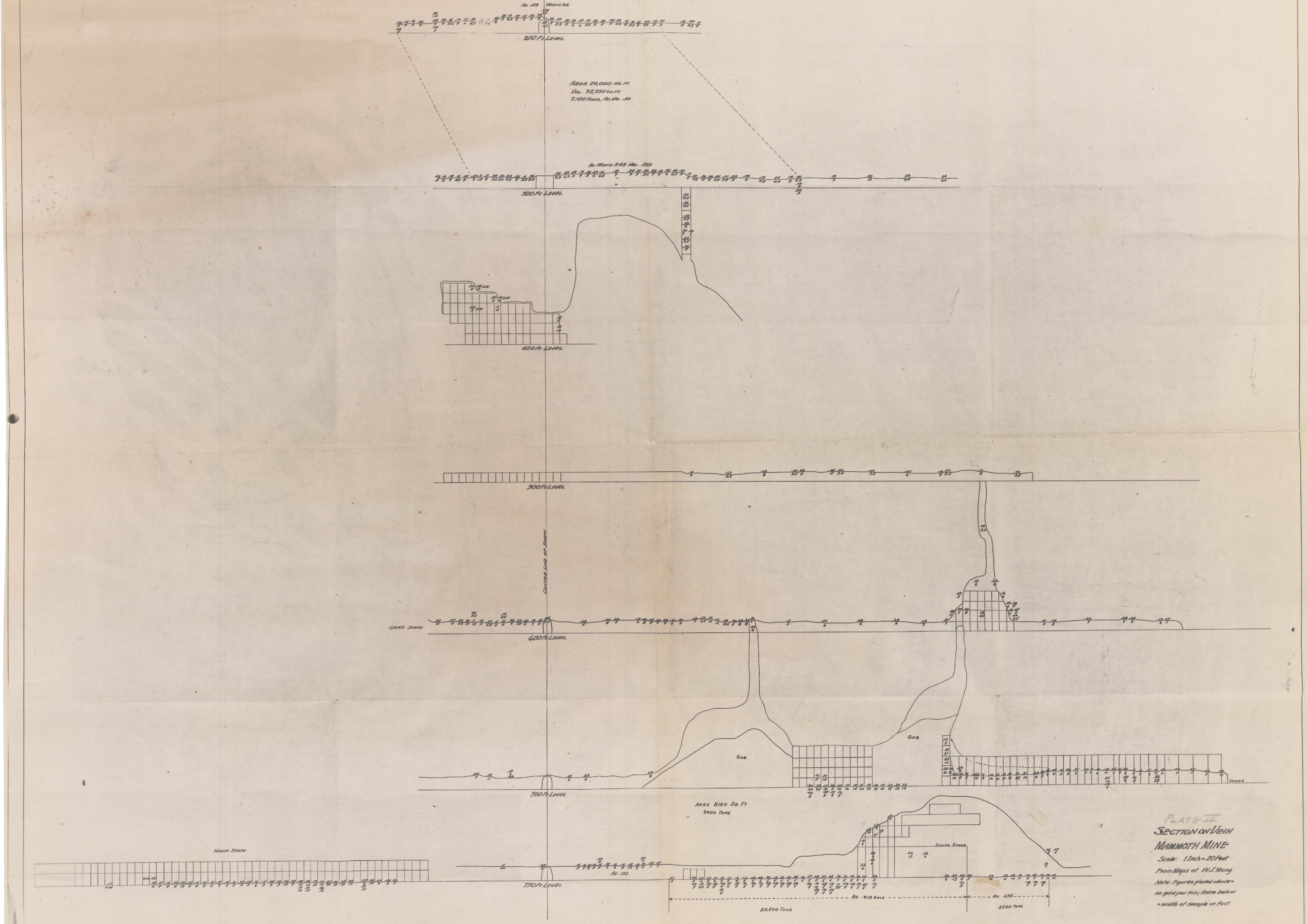


PLATE II

SECTION ON VEIN
MAMMOTH MINE

Scale: 1 Inch = 20 Feet

From Maps of W.J. Young

Note: Figures placed above = oz. gold per ton; those below = width of sample in feet.

sulphide ore in Drill hole
"G"
12
No ore located
by drilling
MOHAWK III DR.
barren area
this side of fault.
adjoining blocks
"H" an "I"
Both ends terminated
by faults
2200
1800
N 200
00
LONGITUDINAL PROJECTION
MOHAWK VEIN
SCALE: 1" = 100'
DATE:

LONGITUDINAL PROJECTION

COLLINS VEIN

LOOKING NORTHEAST

ST. ANTHONY MINING & DEVELOPMENT CO. LTD.

SCALE 1" = 100'

DATE 1 JULY [illegible]

▭ OXIDE

▭ SULFIDE

VGo-11

Abandoned
No ore

No ore found in
Raising or crosscutting from Rse.

Barren

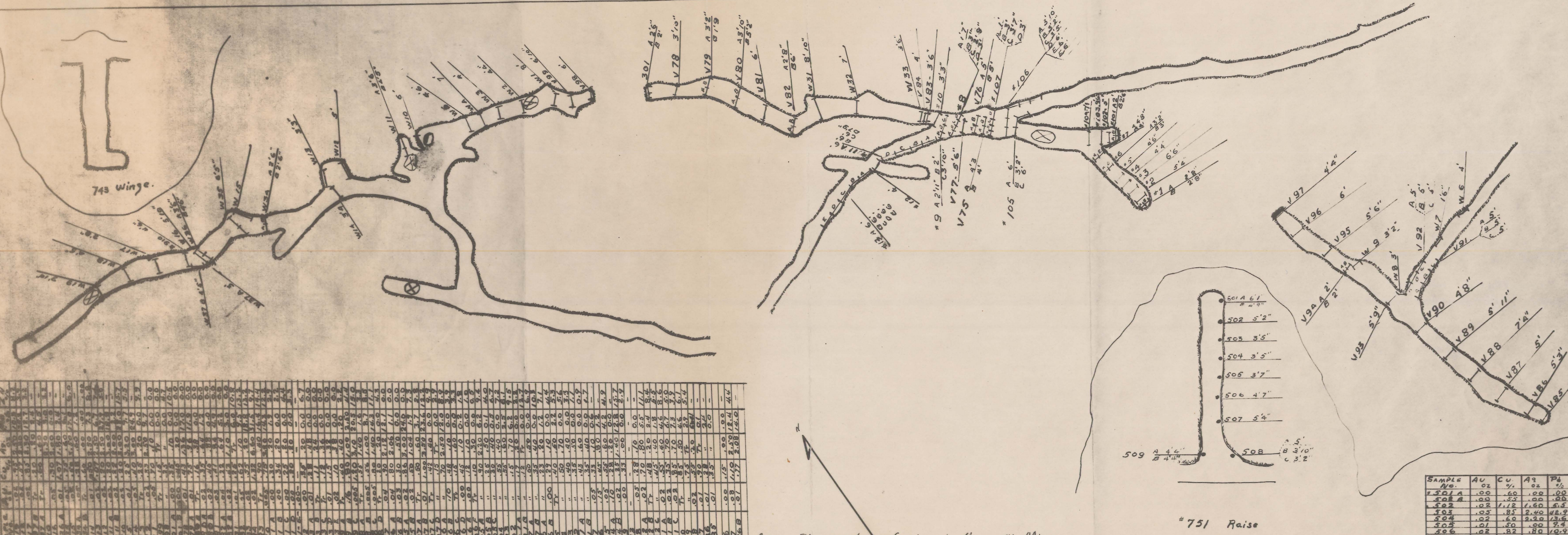
LONGITUDINAL PROJECTION
TORNADO VEIN
LOOKING NORTHEAST
ST. ANTHONY MINING & DEVELOPMENT CO. LTD.

SCALE 1" = 100'
DATE 1 JULY 1952

▭ OXIDE
▭ ORE IN PLACE

V6a-11A

PLATE III



Sample No.	Au. oz	Cu %	Ag. oz	Pb %	Zn %
W 19	.02	.95	2.50	12.8	9.2
W 18	.02	.27	2.80	[illegible]	3.3
W 17	.02	.85	2.30	12.7	3.2
W 37 B	Tr	.20	.10	2.4	–
W 37 A	Tr	.60	.60	4.5	–
#310			2.50	5.0	1.1
W 16	.05	.30	2.00	0.0	–
W 36 A	.01	1.07	1.80	2.4	–
W 35	.05	.75	.60	6.1	–
W 15	.02	.68	5.30	17.2	6.0
W 34 A	.05	.28	.60	1.2	–
W 34 B	Tr	.60	.00	.00	.00
W 14	.01	.50	2.50	7.3	8.8
W 13	.02	1.07	2.50	6.7	7.4
W 12	.02	.20	2.50	27.3	3.0
W 11 A	.02	.10	3.00	18.3	–
W 11 B	.02	.12	2.00	[illegible]	–
W 10	.02	.20	2.00	2[illegible].0	15.7
W 5	.01	.25	3.20	9.7	5.5
W 4	.05	.40	3.00	24.9	–
W 3	Tr	.25	.20	0.0	9.9
W 2	.02	.33	2.50	9.7	–
W 1	.05	.70	.10	0.0	0.0
V 99	Tr	.15	Tr	0.0	0.0
V 98	"	.25	"	0.0	4.7
#301 A	.00	.35	.10	0.0	10.5
#301 B	.00	.46	.20	0.0	0.0
V 78	.01	.43	1.36	17.0	0.0
V 79 A	.01	.75	.96	11.9	0.0
V 79 B	Tr	.16	.38	0.0	0.0
V 80 A	.02	.35	.64	1.2	0.0
V 80 B	.02	.45	.88	0.0	0.0
V 81	.03	.41	.84	4.9	0.0
V 82 A	.04	.22	.64	5.2	0.0
V 82 B	.02	.43	1.10	3.0	0.0
W 31	.01	.26	Tr	6.0	10.8
W 32	.25	.62	.10	9.5	13.2
W 33	.02	.55	.20	18.8	13.2
V 84	.02	1.32	6.60	31.5	9.7
V 83	Tr	.90	.40	16.4	14.4
# 10	.005	.75	3.80	14.3	12.3
11 A	.00	.30	.20	1.9	2.9
11 B	.00	.34	.20	0.0	2.2
11 C	.00	.25	.20	0.0	4.4
11 D	.00	.20	.20	0.0	3.3
~~11 E~~	~~.00~~	–	–	–	–
12	.00	.35	.20	0.0	6.7
13 A	.01	.28	.48	0.0	0.0
13 B	Tr	.11	.24	0.0	0.0
13 C	Tr	.12	.36	0.0	0.0
13 D	.01	.15	.32	0.0	0.0
13 E	.02	.10	.38	0.0	0.0
9 A	Tr	.40	.40	.20	2.2
9 B	.16	.80	1.00	2.50	4.4
9 C	.005	1.20	3.10	20.5	15.0
8 A	Tr	.55	1.40	1.6	3.3
8 B	.005	.56	1.00	8.7	8.5
8 C	.005	.80	1.40	14.3	11.1
8 D	Tr	.20	.20	0.0	4.3
V 77	.04	.90	2.12	12.1	0.0
V 76 A	.04	.80	2.06	1.1	0.0
V 76 B	.03	.30	.50	0.0	0.0
V 75 A	.02	.86	3.00	24.0	0.0
V 75 B	.02	.50	1.04	1.9	7.3
107 A	Tr	.50	.60	3.7	2.8
107 B	.01	1.00	3.50	23.6	12.3
107 C	Tr	.42	.40	0.0	9.9
107 D	"	.15	Tr	0.0	2.9
106 A	"	.70	2.50	12.0	8.9
106 B	.10	.48	.10	0.0	3.9
106 C	Tr	.15	.60	0.0	3.3
106 D	.00	.45	.10	0.2	1.8
106 E	.00	.12	.10	0.0	1.0
106 F	Tr	.10	.30	0.0	0.5
105 A	"	.90	2.20	6.2	9.4
105 B	"	.25	.50	0.1	4.0
105 C	"	.30	.40	0.5	6.7
104	"	.55	.40	0.0	7.2
103	"	.55	.60	2.5	6.1
102	"	.15	.70	6.2	9.5
101 A	"	.17	.20	0.0	2.2
101 B	"	.12	Tr	0.0	12.7
# 7 A	"	.60	.50	0.0	6.9
7 B	"	.35	.40	0.0	10.3
6 A	"	.23	.20	1.2	7.1
6 B	.00	.29	.10	0.0	4.4
5	Tr	.40	.60	2.2	5.3
4	"	.50	.70	0.0	5.6
3	"	.40	.40	0.0	3.3
2	"	.35	.50	0.0	1.1
1 A	"	.43	.60	0.0	0.9
1 B	"	.35	.40	0.0	4.7
V 97	.05	.33	.10	0.6	–
V 96	.15	.45	.80	1.2	–
V 95	.05	.55	.60	4.2	4.9
V 94 A	.10	.28	.20	0.0	–
V 94 B	.02	.25	1.40	12.8	15.7
W 9	.00	.33	.00	0.0	2.9
V 93	–	–	–	–	–
W 8	.05	.28	.10	0.0	–
V 92 A	.02	.70	.80	5.5	11.1
V 92 B	Tr	.48	.20	2.4	8.4
V 92 C	"	.45	.40	1.8	6.5
V 91 A	.02	.55	.40	4.6	8.6
V 91 B	.02	.35	.70	6.7	5.0
V 91 C	.02	.85	.70	7.3	3.9
V 90	Tr	.85	.50	4.6	6.1
V 89	"	.75	Tr	2.9	5.4
V 88	.02	.55	.20	[illegible]	–
V 87	.01	.90	Tr	0.1	–
V 86	.01	.28	"	2.4	–
V 85	.01	.35	"	0.0	–
W 6	.00	.15	.00	.00	–
W 7	.08	1.10	2.50	12.4	4.4
W 36 B	.01	.77	2.08	14.0	–

Assay Plan 700 Level Collins vein Mammoth Mine

Scale 1" = 27½'

#751 Raise

Sample No.	Au oz	Cu %	Ag oz	Pb %	Zn %
#501 A	.00	.60	.00	.00	.00
501 B	.00	.55	.00	.00	.00
502	.02	1.12	1.60	5.5	–
503	.05	.85	2.40	42.9	8.6
504	.02	.60	2.20	13.6	10.8
505	.01	.50	.00	9.4	15.9
506	.02	.82	.80	10.9	12.1
507	.03	.52	.40	8.3	19.8
508 A	.00	.28	.00	2.2	8.1
508 B	.00	.43	.30	7.9	4.9
508 C	Tr	.70	.30	8.4	21.3
509 A	.00	.89	.00	0.6	–
509 B	.05	.52	.40	11.5	–

IV