FIELDNOTES

From The State Of Arizona
Bureau Of Geology And Mineral Technology

Volume 10, No. 3 | Earth Sciences and Mineral Resources in Arizona | September 1980

MOLYBDENUM IN ARIZONA

by Jan C. Wilt and Stanley B. Keith

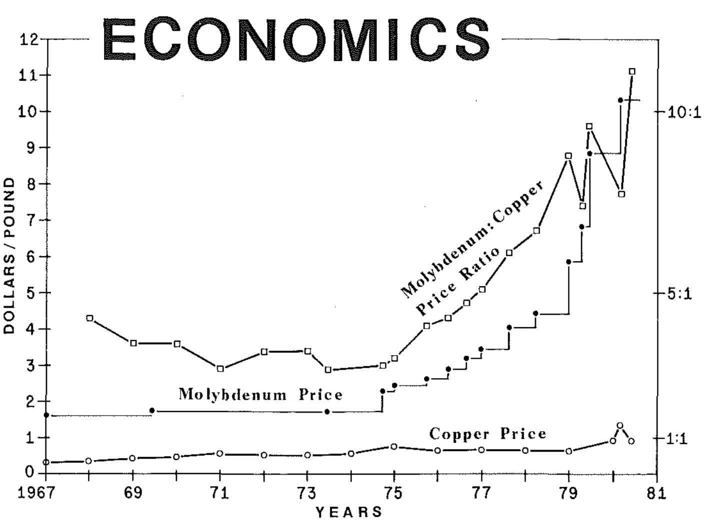
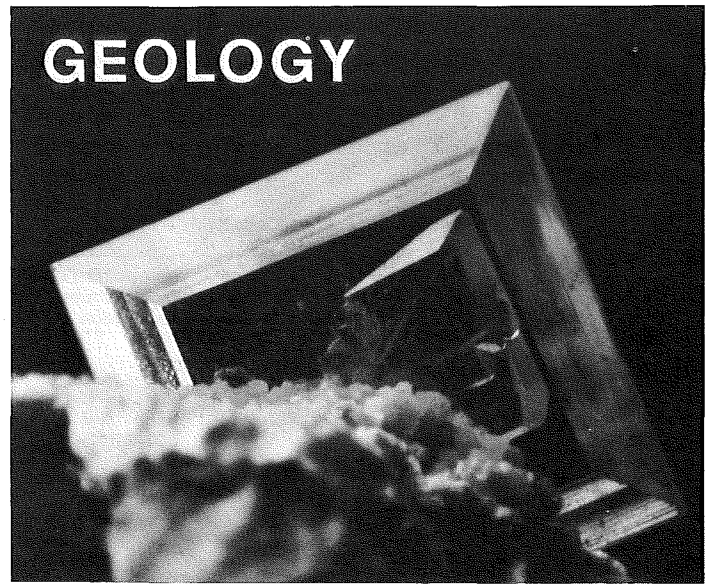


Figure 1, *Moly:* Comparison of 1967 to July 1980 copper and molybdenum prices (absolute dollars). The dramatic price increase of molybdenum in recent years has helped considerably to bail out Arizona's besieged copper industry in 1979 (see text). Molybdenum price is based on Climax price for molybdenum concentrate. Source: Engineering and Mining Journal.



Wulfenite from the 79 mine, Gila County, Arizona. A favorite with mineral collectors, wulfenite occurrence patterns may also help explorationists in their search for porphyry copper deposits (see text). Photo: Stanley Keith.

Arizona's preeminent position during most of the past century in world copper production has been much publicized. However, it has not been as well known that, for the last half century, Arizona has also been the world's third largest producer of molybdenum, behind Colorado (the largest producer) and British Columbia, Canada. Arizona leads such countries as Chile and Russia in molybdenum production. With resources of some 850,000 metric tons of molybdenum, Arizona's porphyry copper deposits account for about 20% of the overall U.S. molybdenum resources. Demand for molybdenum is expected to double by the 1990s and triple or quadruple by the end of the century (Sutulov, 1978).

BUREAU STUDY

As a result of increased interest in this little-publicized metal, a comprehensive literature survey was made by the Arizona Bureau of Geology and Mineral Technology under a grant from the U.S. Geological Survey. For this study, published information about molybdenum occurrences in Arizona was compiled on CRIB (Computerized Resource Information Bank) forms. Recorded information includes the location (by Township, Range, section, latitute-longitude and UTM coordinates) of minerals present in the deposit, metallic elements present, type and age of host rocks, age of mineralization, ore control, structure, alteration, property status (e.g., prospect or mine, active or inactive), mine workings, past production, and reserve data. The computerized data will be released to the public by the U.S. Geological Survey. In addition, the Bureau is preparing a map of molybdenum occurrences, together with a tabulated summary of each occurrence.

The last census of Arizona molybdenum by King (1969) listed 39 occurrences. Examination of molybdenum minerals reported in Anthony and others (1977) revealed an additional 40 occurrences. The file forms prepared by Stanton B. Keith for the Arizona Bureau of Mines metal occurrence maps doubled the number again, and a detailed review of the literature on the districts known to contain molybdenum raised the number of reported molybdenum occurrences to over 400. Recently, molybdenum has acquired new economic significance as a result of the upward explosion in molybdenum prices in 1979 (Figure 1). This article examines the new molybdenum economics and its impacts on the Arizona copper industry and summarizes some of the salient points of Arizona's molybdenum geology.

MOLYBDENUM ECONOMICS

Uses

Molybdenum (or *moly*), like cobalt, platinum and chromium, is one of the more important strategic metals in the world. It is used

In this issue: *Seismic Events, p. 4;* *Casa Grande Bulge, p. 10;* *Symposium, p. 12.*

with chromium as an alloy in missile and aircraft industries, electric and electronic industries, and the nuclear energy industry. Molybdenum's special properties include a high melting point, high strength at elevated temperatures, high resistance to corrosion, a low coefficient of expansion, high thermal conductivity and good alloying properties.

In trace quantities, molybdenum is considered important to various enzyme-related processes in the human body. Although too much molybdenum may produce gout-like symptoms (according to some researchers), molybdenum is presumably essential in maintaining nutritional balance, together with copper and zinc.

More than 75% of molybdenum consumption in the western world is used in constructional alloy (49%), stainless (20%) and tool (9%) steels. While tool steels contain more molybdenum than constructional alloy steels (5% versus 0.25% contained *moly*), most of the molybdenum consumption has been in constructional alloy steels. However, this situation is changing rapidly because of the expanding demand of high-*moly* tool steels in the energy industries, such as, pipe for casing in deep 'sour' oil and gas wells, pipelines and drill steels.

Molybdenum Production in Arizona

Table 1 summarizes historical Arizona molybdenum production. The greatest majority of Arizona molybdenum production comes from molybdenite concentrates obtained as a by-product from copper mining.

Over one-half of the total Arizona production of 190,500 tons of molybdenite concentrates (381 million pounds of contained molybdenum) came from the Pima mining district. Prior to 1956 when the San Manuel mine went into production, much of Arizona's molybdenum was produced from wulfenite concentrates that were mined principally at the Mammoth-St. Anthony mine. Some wulfenite production came from the Total Wreck mine and, possibly, from the Old Yuma mine during World War I.

Molybdenum and the Arizona Copper Industry

Ironically, the two copper mines with the highest historical molybdenum production—Sierrita mine with 133 million pounds and San Manuel with 66 million pounds—would not have been brought into production at the time without government loans. The

TABLE 1. *MOLY:* REPORTED MOLYBDENUM PRODUCTION IN ARIZONA (1915–1979)

County, District and Mine	Cumulative Production in Million Pounds of Recovered Molybdenum		Years of Reported Molybdenum Production
From Molybdenite in Laramide porphyry copper deposits			
Gila County	16.95	(1.65)[1]	1938–1979
Miami-Inspiration District	16.95	(1.65)	1938–1979
Copper Cities Mine	1.45	(.72)	1967–1975
Inspiration Mine	3.83	(.21)	1958–1973 1978–1979
Miami Mine	9.89		1938–1959
Pinto Valley Mine	1.78	(.72)	1975–1979
Greenlee County	11.44	(.53)	1951–1968
Copper-Mountain District	11.44	(.53)	1951–1968, 1979
Morenci Mine	11.44	(.53)	1951–1968, 1979
Mohave County	45.75	+ (3.80)	WW I, WW II? 1964–1979
Wallapai District	45.75	(3.80)	1964–1979
Mineral Park Mine	45.75	(3.80)	1964–1979
Maynard District			
Telluride Chief	Some		WW I
Diamond Joe area			
Leviathan	Some??		WW I and WW II?
Pima County	222.852	(25.56)	1951, 1956–1979
Pima District	216.852	(25.13)	1951, 1959–1979
Esperanza Mine	38.0	(2.08)	1959–1971 1973–1977, 1979
Mission Mine	10.66	(1.72)	1964–1979
New Year's Eve Mine	.032		1951
Pima Mine	16.96	(0.42)	1967–1977, 1979
Sierrita Mine	133.03	(16.24)	1970–1979
Twin Buttes Mine	18.17	(4.67)	1966, 1970–1979
Silver Bell District	6.00	(0.43)	1956–1979
Silver Bell Mines	6.00	(0.43)	1956–1979
Pinal County	69.89	(4.13)	1933–1938 1956–1979
Bunker Hill (Copper Creek) District	4.18		1933–1938 1961, 1965
Childs-Aldwinkle Mine	4.18		1933–1938 1961, 1965
Old Hat District	65.71	(3.31)	1956–1979
San Manuel	65.71	(3.31)	1956–1979
Mineral Creek District	76.37	(.82)	1967–1979
Ray Mine	6.48	(.82)	1967–1979
Yavapai County	13.726	(3.26)	1944–1946 1951–1979
Eureka District	13.72	(3.26)	1944–1945 1951–1979
Bagdad Mine	13.72	(3.26)	1944–1945 1951–1079
Squaw Peak District	.006		1944–1946
Squaw Peak Mine	.006		1944–1946
ARIZONA Sub-Total	380.608	(38.93)	WW I, 1933–1979

County, District and Mine	Cumulative Production in Million Pounds of Recovered Molybdenum	Years of Reported Molybdenum Production
From Wulfenite in lead-zinc-silver and lead-zinc-silver-gold deposits		
MID-TERTIARY DEPOSITS		
Cochise County		
Middle Pass District		
Garnet Group (Escapule Mine)	.0013[2]	1938
Pinal County		
Old Hat District		
Mammoth-St. Anthony Mine	4.21[3]	1916–1919 1934–1944
EARLY TERTIARY? DEPOSITS		
Gila County		
Banner District?		
Kullman-McCool (Reagan Camp?)	.0002[2]	1936
LATE CRETACEOUS DEPOSITS		
Pima County		
Amole District		
Old Yuma Mine	Some?	WW I
Empire District		
Total Wreck Mine	8 tons of wulfenite concentrate	1918
Tyndall District		
Glove Mine	lead from wulfenite	?
ARIZONA Sub-Total	4.2115 +	1916–1919 1934–1944
From Molybdenite in Jurassic veins		
Pima County		
Baboquivari District		
Arizona Molybdenum Mine	Several hundred tons	?
Gold Bullion Mine	Minor molybdenite concentrates	WW I
ARIZONA GRAND TOTAL	384.82+	1915–1919 1933–1979

NOTES: 1) Numbers in parentheses are 1979 production.
Source: Az Dept. of Mineral Resources
2) Reported as recovered molybdenum. Geology of occurrence suggests molybdenum mineral was wulfenite.
3) Number given is contained molybdenum in MoO_3 oxide (6,314,822 pounds reported by Creasey, 1950).

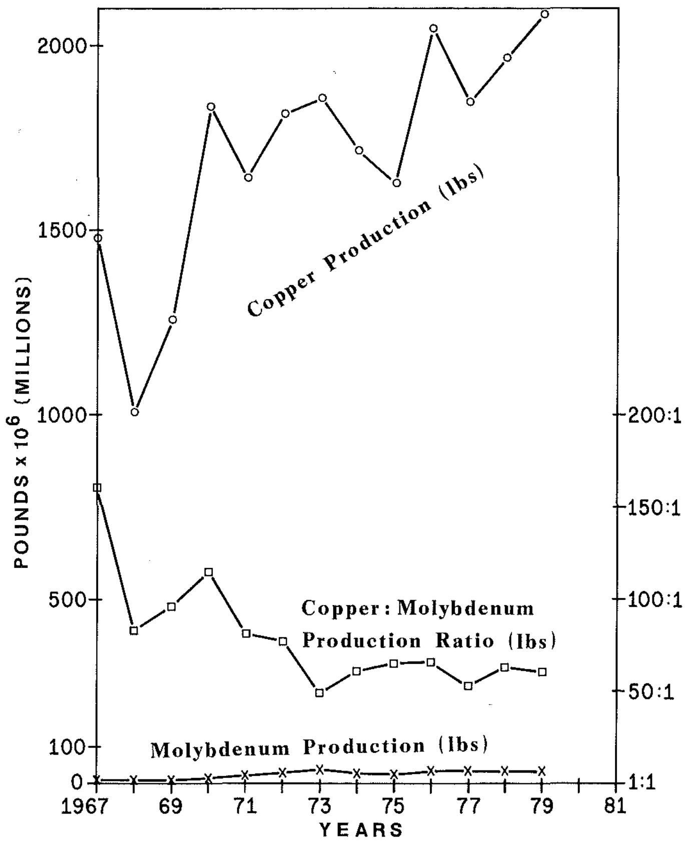


Figure 2, *Moly:* 1967–1979 copper production, molybdenum production and copper-molybdenum production ratio. Source: BGMT file data.

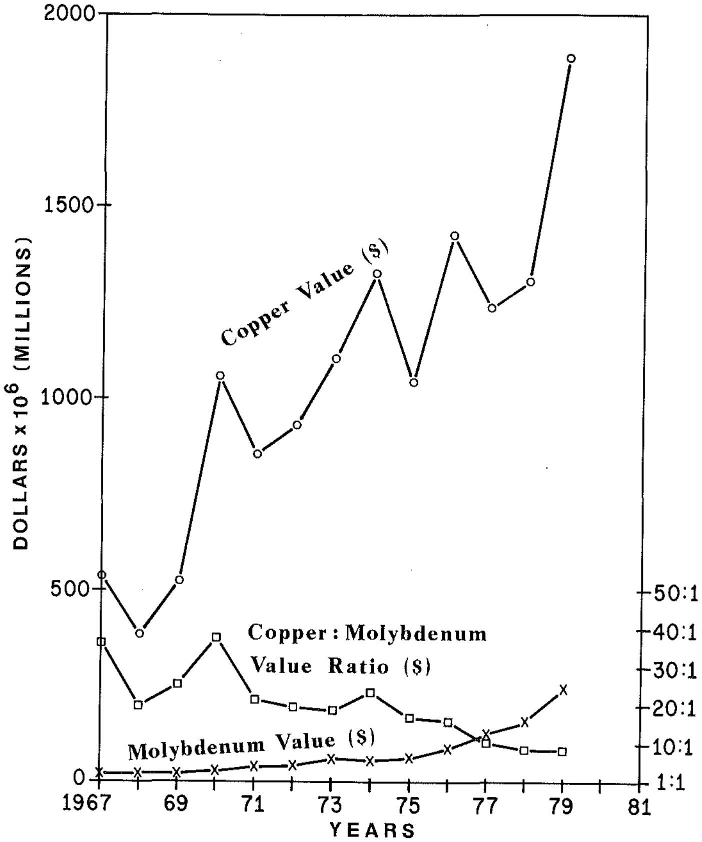


Figure 3, *Moly:* 1967–1979 copper value (absolute dollars), molybdenum value (absolute dollars) and copper-molybdenum value ratio. Source: BGMT file data.

San Manuel mine was developed with the aid of an 80 million-dollar government advance against future copper deliveries, and was originally discovered during a U.S. Bureau of Mines exploration drilling prompted by World War II copper needs. The Sierrita mine in the Pima mining district was developed with the aid of a 68-million dollar loan from G.S.A. (U.S. General Services Administration) in the late 1960s. Without government loans, 60% of Arizona's historical molybdenum production would have been lost.

In the last several years, however, the molybdenum market has turned decidedly bullish and is having considerably more economic impact on Arizona's copper industry than in years past. Figures 1–3 chart molybdenum's increasing economic clout. Since 1970, yearly copper and molybdenum metal production have about doubled (Figure 2). However, during the same period, yearly value of molybdenum production has increased eight times as compared to a twofold increase for copper (Figure 3). From 1967 to 1973, the ratio of copper to molybdenum production in pounds steadily declined as more molybdenum recovery plants came into operation and has leveled off at about 60:1 since 1973.

TABLE 2. *MOLY:* WESTERN WORLD MOLYBDENUM SUPPLY/DEMAND (million lb MO)

	1973	1974	1975	1976	1977	1978	1979**
Demand*	181	207	168	177	182	198	200
Mine Production							
Primary	81	88	89	92	100	106	105
Byproduct	77	73	74	79	83	88	90
Total	158	161	163	171	183	194	195
Excess (Deficit)	(23)	(46)	(5)	(6)	1	(4)	(5)
GSA Releases	7	36	3	1	Stockpile Depleted		
Industry Stock Changes	−16	−10	−2	−5	1	−4	−5

*Indicate net East-West trade
**Estimated

SOURCE OF DATA: MOSAIC: THE JOURNAL OF MOLYBDENUM TECHNOLOGY: V. 4, N. 2.

In contrast, since 1974, the molybdenum-copper dollar ratio for Arizona has steadily declined from 33:1 to 8:1 in 1979. If the trend on Figure 3 continued into the future, Arizona, dollar-wise, would become a molybdenum state after 1981. However, Arizona will maintain its reputation as the 'copper state' well into the foreseeable future for reasons outlined in the next section.

Figure 1 clearly shows that molybdenum's new economic muscle in Arizona is related to a dramatic price rise since 1974. Compared to copper, the price rise is precipitous, with the *moly*/copper price ratio increasing from about 3:1 in 1974 to over 11:1 by May 1980. Two reasons explain the massive *moly* price hike. The first is related to the U.S. government stockpile of 80 million pounds of molybdenum which was largely depleted by the end of 1974 (Table 2). Throughout the early 1970s, demand consistently outstripped production. Much of the extra demand, however, was absorbed by periodic releases from the U.S. government stockpile. These releases clearly had a price-damping effect, as indicated by the nearly constant molybdenum price through 1974. When the stockpile was depleted, the price damper was removed. This depletion, combined with an increasing demand for molybdenum metal, shot the price of *moly* into the economic stratosphere. Demand for molybdenum was so heavy in 1979 that spot prices for *moly* consistently surpassed the 20 dollar mark and in June 1979 soared to 34 dollars per pound. Thus, molybdenum has more clout than ever at Arizona's copper mines.

In contrast, the release of the U.S. government copper stockpile by 1973, together with foreign competition and increased mining costs, severely depressed the domestic copper market. By mid 1978, U.S. copper producers and, interestingly enough, their labor unions were calling for import restrictions on widely-available, cheap foreign copper (see *Fieldnotes*, v. 8, n. 1 & 2). Depletion of

continued on page 7

Earthquakes Causing Damage in Arizona

by Susan M. DuBois & Ann W. Smith

Nearly two years ago (9/78), the Bureau began researching historical seismicity in Arizona. The purpose of current efforts is to produce a revised epicenter map and earthquake catalog for the period of historical record.

In Arizona, written records date back to Spanish exploration. The earliest event documented so far is one experienced by members of the Coronado expedition in 1540. The first seismograph was installed in 1909 in Tucson. However, earthquake chronology has been grossly incomplete until very recently, perhaps in the last 20 years. Arizona still lacks adequate seismic instrumentation to recognize and accurately locate minor earthquakes throughout the state.

FIGURE 1: SUMMARY OF 20 DAMAGING HISTORICAL SEISMIC EVENTS

Date	Time (GMT)	Epicenter Location N-Lat. W-Long.	Place Name Near Epicenter	Max. Int.	Mag.	Felt Area (km²)	Comments	Refs.
[1]*Nov. 30, 1852	08:20	32.45°, 115.25°	Ft. Yuma, CA	IX–XI	•	•	—In the epicentral area, Major Heintzelman and his party, in a trip made after Dec. 15, found over 100 mud volcanoes. The volcanoes were still emitting steam and gasses, the major one erupting every 10–15 min. and throwing mud 60–70 ft. in the air. The shock was violent at Ft. Yuma. Much fissuring occurred in the Yuma area, and rockfalls were observed at Chimney Peak and at other mountains. In some places, Colorado River sank 2 ft. and banks caved in at many locations.	4, 11
[2]May 3, 1872	00:45	32.8°, 115.2°	Yuma, AZ	VI	5.9	•	—In Yuma, people rushed out into the streets. Two buildings were cracked.	21, 27
[3]May 3, 1887	23:12	31.0°, 109.1°	Pitaicachi, MX	XII	7.2	1,600,000	—This major quake caused 51 deaths in northern Sonora, and major destruction to property in Mexico and SW Arizona. A fault scarp 50 km long and 3 m high formed just south of the Arizona-Mexico border. It was felt in nearly fifty towns in Arizona, including Bisbee, Clifton, Globe, Phoenix, Tucson, and Yuma.	9
[4]Jul. 30, 1891	13:05	32.11°, 114.96°	Lerdo, MX	IX–X	•	•	—Large fissures opened up along the Colorado River in Mexico. Homes in Lerdo were badly cracked, and several were destroyed. In Yuma, people rushed into the streets, some walls were cracked, and small objects were moved about.	18, 27
[5]Oct. 7, 1899	06:30	31.71°, 110.070°	Tombstone, AZ	V	•	•	—Windows rattled, hanging objects swung, clocks stopped, and a few people rushed for the street.	13
[6]Jan. 25, 1906	08:32:30	35.2°, 111.7°	San Francisco Mtns, AZ	VII–VIII?	•	223,100	—At Flagstaff, several chimneys were thrown down, walls cracked, and glassware was broken. The shock was felt in Angell, Bellemont, Phoenix, Seligman, Williams, Winslow, and towns in New Mexico and Utah.	7, 10, 17
[7]May 26, 1907	10:00	29.48°, 110.23°	Morales, MX	VIII–IX	•	•	—In the epicentral region, severe damage was done to adobe and stone buildings. The shock was of sufficient force to awaken people in Benson, Bisbee, San Bernardino Ranch, Tombstone, and Tucson.	1, 8
[8]Sept. 24, 1910	04:05	36°, 111.1°	Coconino Forest, AZ	VII	•	116,550	—In the Coconino Forest, a series of shocks caused boulders to roll into the camp of a construction crew. The shocks were felt throughout northern AZ, southern UT, and NW NM. Fifty-two were felt in Flagstaff from Sept. 10 through Sept. 24.	7, 12. 20
[9]Aug. 18, 1912	21:10:40	36.5°, 111.5°	N. of San Francisco Mtns., AZ	VII–VIII(?)	•	142,420	—People fled to streets in Winslow, Flagstaff, Tuba and Williams. Windows and crockery were broken in Williams. Damage to houses was also reported in Williams. Navajo Indians reported earthcrack 30 mi long N of San Francisco Peaks, where rockslides were also reported.	2, 7, 17
[10]Nov. 21, 1915	00:13:27	32.4166°, 115.2500°	Calexico, CA	VII–VIII	7.1	310,800	—In Yuma, buildings trembled, dishes and books fell off shelves, and water in pitchers splashed out. People rushed into the streets.	7, 17, 22
[11]Dec. 31, 1934	18:45	32°, 114.75°	Baja California, MX	VII–X	7.1	207,200	—Crevices opened and roads buckled in the epicentral region. A swaying motion was felt in Phoenix and Yuma. The quake was also noticed in Casa Grande, Coolidge, Eloy, Florence, Nogales, Prescott, and Tucson.	6, 7, 15, 22, 24
[12]Jan. 10, 1935	08:10	36.1°, 112.2°	Grand Canyon, AZ	VI–VII	•	•	—Minor rock slides occurred. Windows broke and plaster cracked in the town of Grand Canyon. A subterranean rumble awakened sleepers.	7, 12, 24
[13]Apr. 8, 1937	12:00	35.7°, 109.5°	Ganado, AZ	VI–VII	•	•	—The shock caused slight damage at Sage Memorial Hospital.	12, 23

Date	Time (GMT)	Epicenter Location N-Lat. W-Long.	Place Name Near Epicenter	Max. Int.	Mag.	Felt Area (km²)	Comments	Refs.
[14]Sept. 17, 1938	17:20:18	33.25°, 108.75°	Duncan, AZ	V–VII	5.5	20,720	—In Duncan, bottles fell from shelves and plaster was cracked. Some cracks occurred in walls. In Clifton, a deep rumble was heard and trees and bushes shook. The shock was also felt in Morenci, Safford, San Simon, and Thatcher.	12, 24
[15]May 19, 1940	15:36:40	32.7°, 115.5°	Imperial Valley, CA	X	6.7–7.1	155,400 (in the U.S.)	—Nine people were killed and 5-$6 million damage was done in the epicentral region. In the Yuma district, damage was estimated at $50,000. Four water service lines were broken and the irrigation system was badly damaged. Large crevices were formed. In Somerton, roads were buckled and bridges were dislodged. Also felt in Phoenix and Tucson.	3, 7, 13, 19, 24, 28
[16]Jan. 17, 1950	00:53	35.5°, 109.5°	Ganado, AZ	VI–VII	•	•	—Ground cracks ½ in. wide to 12 ft. long were found south of Ganado Trading Post.	7, 12
[17]Dec. 25, 1969	12:49:10.1	33.4°, 110.6°	Gila Co., AZ	VI–VII	4.4–5.1	•	—Dishes and windows were broken at Globe. Some buildings were cracked at San Carlos Reservation. It was felt at Coolidge Dam, Miami, Roosevelt Lake, Tucson, and Winkelman.	12, 14, 22, 23 24
[18]Feb. 4, 1976	00:04:58.1	34.66°, 112.50°	Chino Valley, AZ	VI	5.1	80,290	—The shock caused slight damage in the Prescott area. Mirrors, bottles and glasses broke. It was felt in many towns in Arizona, including Flagstaff, Phoenix, Tucson, and Yuma.	12, 16, 24
[19]Oct. 15, 1979	23:16:52.4	32.633°, 115.333°	Imperial Valley, CA	IX	6.5–6.8	•	—The quake caused minor damage in Yuma. It was felt in Phoenix and Tucson. Damage near the epicenter towns of Brawley, Calexico, Imperial and El Centro was estimated to be $30 million; 91 people were injured. Strike slip offset 57 cm measured on Imperial Fault, CA.	5, 14, 25
[20]Jun. 9, 1980	04:28	32.269°, 114.947°	S. of Mexicali, MX	IX	6.2–6.3	•	—Two people were killed and about 100 injured in MX. The quake knocked groceries off of the shelves of stores in Yuma. It was felt in Phoenix and in Tucson.	14, 26

*These numbers correspond to those on the map of Figure 2.

REFERENCES FOR FIGURE 1

1.* Bisbee Daily Review
2. Bulletin of the Seismological Society of America, Seismic Notes section, v. II, p. 209–210
3. Bulletin of the Seismological Society of America, Seismic Notes section, v. XXX, p. 304–306
4. Bureau of Reclamation, U.S. Dept. of Interior, Record of Earthquakes in the Yuma Area, 1776–1976, July 1976
5. Bureau of Reclamation, U.S. Dept. of the Interior, Record of Earthquakes in the Yuma Area, 1776 to present, updated version of 1976 report in progress
6. Casa Grande Dispatch
7. Coffman, J. L., and Von Hake, C. A., editors, 1973, Earthquake History of the U.S., U.S. Dept. of Commerce, and National Oceanic and Atmospheric Administration
8. Douglas Daily Dispatch
9. DuBois, S. M., and Smith, A. W., in press, The 1887 earthquake in San Bernardino Valley, Sonora: historical accounts and intensity patterns in Arizona: Special Paper No. 3, Arizona Bureau of Geology and Mineral Technology
10. Flagstaff Coconino Sun
11. Ft. Yuma Meteorological Report, 1852, Copy from the National Archives, record group no. 27, Center for the Polar Archives
12. National Oceanic and Atmospheric Administration, Computer listing of Arizona earthquakes
13. Phoenix Arizona Republic(an)
14. Phoenix Arizona Republic
15. Phoenix Gazette
16. Prescott Courier
17. Reid, H. F., unpublished, Microfilmed records of worldwide earthquakes, personal clippings and index file
18. San Francisco Examiner
19. Somerton Star
20. Sturgal, J. R. and Irwin, T. D., 1971, Earthquake History of Arizona, 1850–1966: Arizona Geological Society Digest, v. IX
21. Toppozada, 1980, Excerpts from Semi-Annual Report to USGS, re: California Earthquakes, 1800–1899, California Division of Mines and Geology, January
22. Tucson Citizen
23. Tucson Daily Star
24. U.S. Coast and Geodetic Survey, annual volume series, U.S. Earthquakes
25. U.S. Geological Survey, 1980, Earthquake information bulletin, v. 12, n. 2, p. 76
26. U.S.G.S., 1980, Preliminary determination of epicenters, n. 23–80
27. Yuma Arizona Sentinel
28. Yuma Daily Sun

*The numbers preceding the above sources match the numbers in the last column of Figure 1

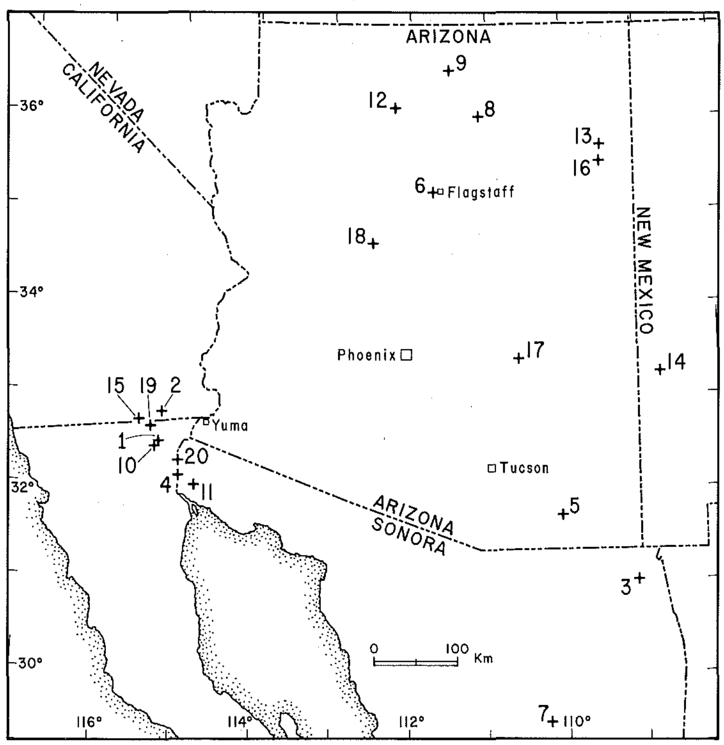


Figure 2: Epicenter locations corresponding to earthquakes in Figure 1.

Information on earthquakes felt or recorded in Arizona was sought from many institutions, references and personal contacts. Library research has been conducted at the University of Arizona, State Capitol Archives (Phoenix), local historical societies and museums, as well as in several departments of the U.S. National Archives and the Library of Congress (Washington, D.C.). Microfilm, bound newspaper volumes and special collections of early correspondence, diaries and documents have been searched. A

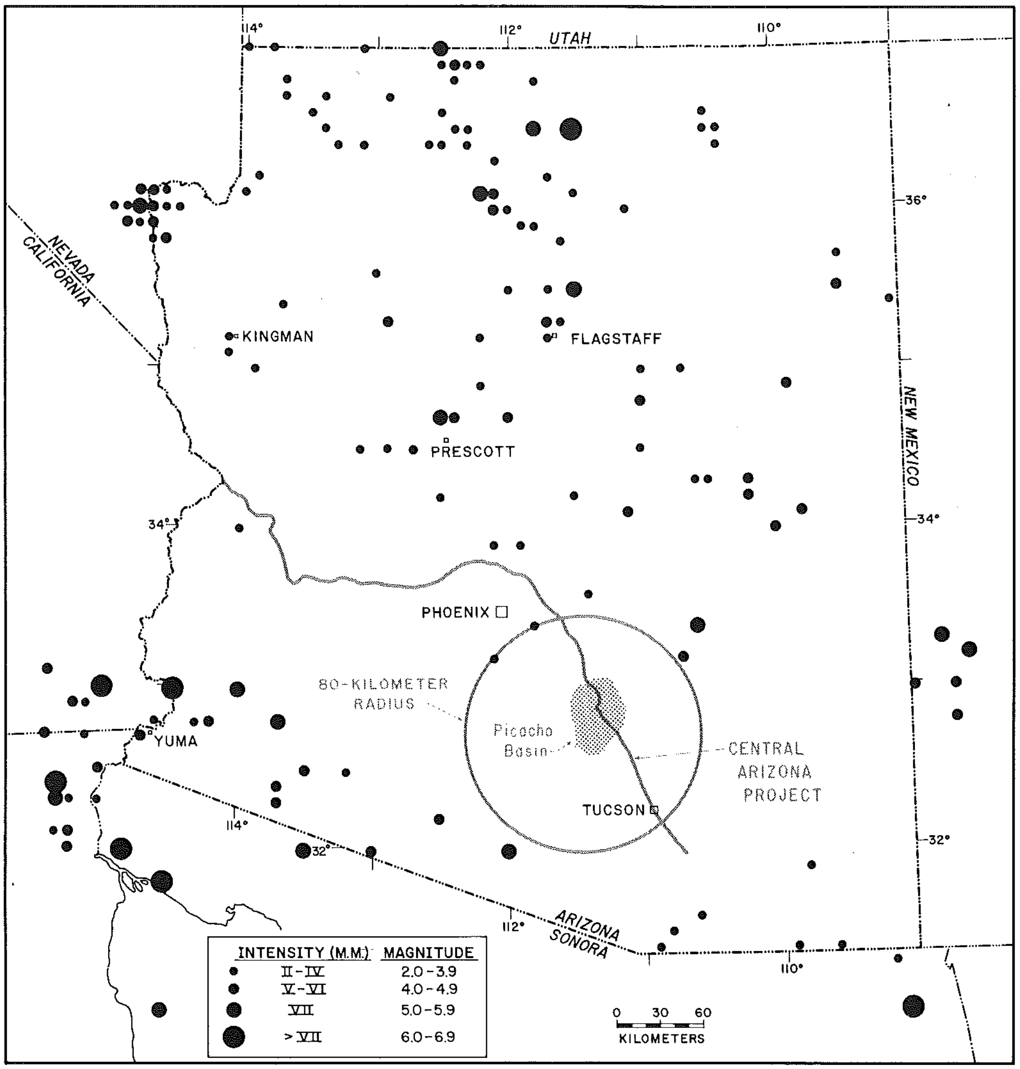
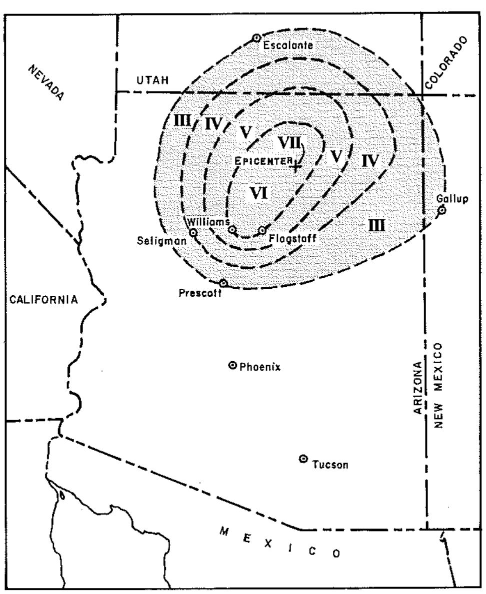


Figure 3: DuBois: Preliminary map of historical earthquake epicenters.

Raymond: Picacho Basin site, gray shaded area on map

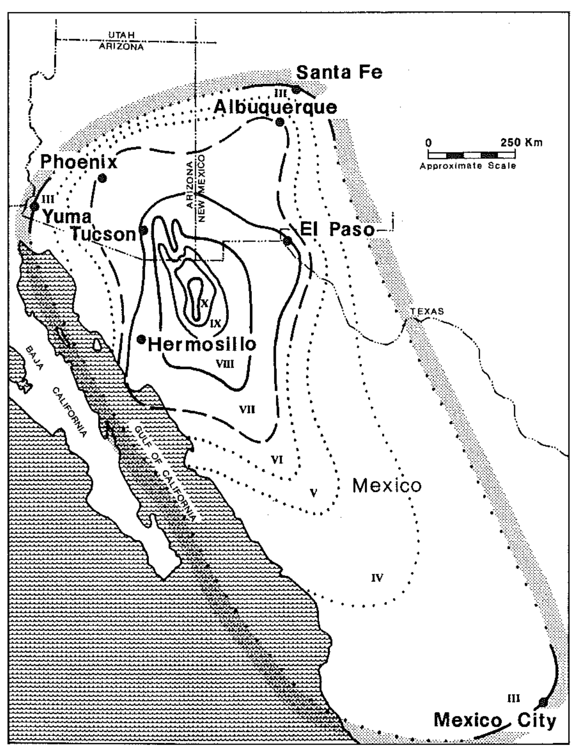


a.

Figure 4: Isoseismal maps

a. August 18, 1912

b. May 3, 1887



b.

few weather reports from early military posts and weather stations were obtained in the Polar and Scientific Archives (Washington, D.C.). However, most of the information on file consists of contemporary newspaper accounts of local and distant earthquakes.

Figure 1 summarizes many of the largest earthquakes in or near Arizona (epicenter locations in Figure 2).

continued on page 12

Moly continued

the copper stockpile exposed U.S. producers to foreign competition that was dedicated to producing cheap copper for badly needed cash to help build their industrial bases. Because U.S. producers were unable to raise prices to cover the increased cost of mining and maintain a profit margin, U.S. copper fell into a severe slump in 1977 and 1978. At the time, restrictions on foreign copper imports seemed the best solution, until the amazing upward explosion in metal prices led by gold during 1979 came to the financial rescue.

Largely because the U.S. *moly* producers had no important foreign competition, the history of the molybdenum industry was quite different. Unlike copper, molybdenum production and known reserves are limited primarily to North America and most of these reserves are Climax-type porphyry molybdenum deposits in Colorado. When the *moly* stockpile was depleted, U.S. producers had no major worry about price wars with foreign competition and could raise prices in order to cover mining costs and maintain a healthy profit margin. Because approximately one in every eight dollars produced from porphyry copper deposits in Arizona was a *moly* dollar in 1979 (as compared to only one in 37 in 1970), molybdenum dollars were a major factor in the recovery of Arizona's copper industry in 1979. While copper prices also increased and briefly flirted with $1.50 per pound, the current $1.00 per pound is barely keeping pace with inflation from $.58 per pound for copper in 1970. The nearly 600% increase in *moly* price from 1974 to March 1980 obviously outstripped inflation and helped considerably to rescue Arizona's besieged copper industry in 1979.

Arizona's Molybdenum Future

Economic indicators within the last several months indicate the *moly* price momentum is slowing. While molybdenite concentrate at Climax, Colorado, remains at $10.31 per pound, spot prices for molybdic oxide fell to as low as $6.50 per pound in early July, 1980.

These prices reflect a consistent price drop for *moly* on the spot market throughout much of the first half of 1980. Market analysts speculate that the 1980 molybdenum market should not see any price hikes comparable to the late 1970s. The principal reason for this is that several major new molybdenum mines are scheduled to come into production in North America during the 1980s. These mines are expected to absorb the rising *moly* demand during the 1980s, and some analysts are hypothesizing a possible molybdenum glut which will stabilize or lower molybdenum prices. Since 1974, the copper/*moly* production ratio in Arizona has been about 60:1, and there is no reason to expect the ratio to change drastically in the next decade. The copper/molybdenum dollar ratio in 1979 was close to what it was in 1978, and, without any major new price changes, should approximate 8:1 in the foreseeable future. Thus, Arizona's future as a copper state is secure, but molybdenum will be a much stronger economic partner than in years past.

GEOLOGY OF ARIZONA MOLYBDENUM OCCURRENCES

Mineralogy

About half of the 400 known molybdenum occurrences in Arizona occur as the mineral molybdenite (182 reported occurrences). Most of the other half of the Arizona molybdenum occurrences (150 occurrences documented) are as the mineral wulfenite. The remaining molybdenum-bearing minerals reported include 27 occurrences of powellite, 21 of ferrimolybdite, 5 of lindgrenite, and 12 occurrences in uranium deposits as the minerals, umohoite, ilsemannite and jordisite.

Molybdenite

Molybdenite is easily recognized by its shiny, lead-grey color, greasy feel and softness (it can be scratched with a fingernail). This molybdenum sulfide, MoS_2, is by far the most abundant molybdenum mineral and usually occurs as disseminated grains, foliated or radiating masses, or thin scales. Molybdenite crystals are usually thin-to-moderately-thick tabular plates with a roughly hexagonal shape due to the poorly developed side crystal faces.

A rosette of molybdenite crystals perched on adularia feldspar and quartz, from Childs Aldwinkle breccia pipe, Copper Creek, Arizona. Molybdenite is the most abundant molybdenum mineral and is far and away the main source of Arizona's molybdenum. Photo: Stanley Keith.

Molybdenite occurs in the central parts of disseminated copper deposits, in association with chalcopyrite and other copper sulfides. These deposits are commonly found near 75–50 m.y. old late Cretaceous early Tertiary silicic igneous intrusions (the later part of the Laramide orogeny). The disseminated molybdenite grains are usually associated with quartz-K-spar (potassic feldspar)-biotite veins in the more potassium-rich assemblages of the porphyry deposits. Examples of this occurrence style are the Sierrita, Esperanza, Twin Buttes and Mission-Pima deposits in the Pima mining district of Pima County; the Copper Creek, San Manuel and Ray deposits of Pinal County; Morenci in Greenlee County and the Mineral Park deposit of Mohave County.

Approximately 10% of the molybdenite occurrences in Arizona are in breccia pipes (cigar-shaped columns of highly-fractured rock) related to porphyry copper occurrences. About half of these are in the Copper Creek area of Pinal County, where the Childs-Aldwinkel mine is a prime example. In this mine, molybdenite was the latest sulfide mineral to be deposited and it was concentrated in the outer part of the breccia pipe, peripheral to chalcopyrite and pyrite. The other half of the breccia pipe deposits are in the Copper Basin area of Yavapai County. Chalcopyrite, pyrite and molybdenite occur on fracture surfaces in a square-mile area in the quartz monzonite porphyry of the Copper Basin intrusion, but the molybdenite is concentrated in fractured pipe structures surrounded by altered areas.

Thirty-two (under 20%) of Arizona's molybdenite occurrences are in 1700 to 1300 m.y. old Precambrian or 190 to 150 m.y. old Jurassic ore deposits in veins, usually tungsten or gold-quartz veins. Fifteen percent of the state's molybdenite localities are associated with Precambrian ore deposit systems. About half of these occurrences are in Yavapai County in gold-quartz veins in Precambrian granodiorites, quartz diorites or Yavapai Schist. A quarter of the Precambrian molybdenite occurrences are in Gila County in tungsten veins associated with pegmatite dikes or quartz veins, or are in brecciated uranium deposits that are associated with a Precambrian-aged Dripping Spring Quartzite of the Sierra Ancha Mountains.

Jurassic veins make up less than 5% of the molybdenite occurrences in Arizona and these are located in southern Arizona: in Pima County at the Baboquivari Mountains; in Santa Cruz County at the Harshaw district; in Cochise County at the Bisbee area; and in northern Yuma County where a molybdenum anomaly at Sugarloaf Peak may represent disseminated molybdenite.

Wulfenite

The fragility of its thin, square plates and the translucent warmth of its orange-to-yellow-to-red color have made wulfenite a great favorite of mineral collectors. Wulfenite is lead molybdate, $PbMoO_4$, that crystallizes in the tetragonal crystal system and most commonly occurs as square, tabular crystals, although it can occur as thin, octahedral crystals or acicular prismatic crystals. Good specimens of cherry red, lustrous wulfenite plates from the Red Cloud mine in Yuma County are acknowledged by many mineral collectors to be among the finest examples known in the world.

Although a few minor wulfenite occurrences have been reported from Precambrian or Jurassic mineralized systems, most wulfenite in Arizona is associated with late Cretaceous (80 to 70 m.y.) and middle Tertiary (35–15 m.y.) age lead-zinc-silver deposits. Wulfenite occurs in the oxidation zone of these deposits and is often associated with other late-stage secondary minerals, such as, limonite, vanadinite, pyromorphite, descloizite, mottramite, mimetite, and fornacite. In lead-zinc-silver deposits, wulfenite typically forms later than cerussite, a lead carbonate ($PbCO_3$) formed by the oxidation of PbS, galena.

About 15% of Arizona's reported wulfenite occurrences are oxidation products of lead-zinc-silver mineral deposits that originally formed during the late Cretaceous (early part of the Laramide orogeny). The Glove mine, located south of Tucson in the western foothills of the Santa Rita Mountains, is world famous for its large vugs lined with wulfenite crystals that are as much as four inches on a side. Other well known wulfenite localities from known or probable late Cretaceous lead-zinc-silver districts are in the famous silver mining districts of Tombstone, the Courtland-Gleeson area 15 miles northeast of Tombstone, the Empire Mountains 25 miles southeast of Tucson and the Old Yuma mine in the Amole district 15 miles northwest of Tucson.

About 25% of Arizona wulfenite occurrences are associated with lead-zinc mines in the outer zones of porphyry copper districts of early Tertiary age (later part of the Laramide orogeny). These wulfenite occurrences are very minor, such as the trace quantities found in the Twin Buttes mine in the Pima district south of Tucson.

The 79 mine is an example of an early Tertiary lead-zinc-silver mine with minor copper periferal to the Christmas and Chilito porphyry copper districts. The 79 mine contains brilliant orange, transparent, commonly unflawed crystals—some of which are as large as two inches across. Much of the wulfenite has a distinctive red dot in the center of the thin, square plates, and is often highlighted on a matrix of black descloizite.

Almost a third (30%) of Arizona wulfenite occurrences are in lead-zinc-silver districts which were formed in middle Tertiary time; these wulfenites are associated with rhyolite volcanics and intrusives that are about 35 to 15 million years old. The most famous among these is the Red Cloud mine north of Yuma in the Silver district of western Arizona. Here, brilliant, dark red crystals occur as thick, square, flat-topped plates modified by slanted sides of the pyramidal crystal form. Other notable mid-Tertiary lead-zinc-silver deposits that have produced quality specimens of wulfenite are the Hilltop mine in the Chiricahua Mountains of southeastern Arizona, the Aravaipa district in Graham County, the Rowley mine 20 miles west of Gila Bend in Maricopa County, and the mineralogically-diverse Mammoth-St. Anthony lead-zinc-silver-gold deposit at Tiger, 45 miles north of Tucson.

Other Molybdenum Minerals

Twenty-seven powellite occurrences have been reported from Arizona. Pure powellite has a formula of $CaMoO_4$. However, varying amounts of tungsten substitute for molybdenum, up to a formula of $CaWO_4$, which is scheelite, the other end member of the group. Scheelite is commonly associated with powellite; they both form in the tetragonal crystal system and commonly occur as crystals with pyramid shapes on upper and lower halves. They are both light-colored straw yellow to greenish-yellow to brown or white.

Sixteen of the reported powellite occurrences are associated with porphyry copper mineralization of early Tertiary age (the later part of the Laramide orogeny). These chalcopyrite, chalcocite and molybdenite deposits generally occur in Paleozoic limestones or quartzites which have been strongly fractured. Only one powellite occurrence was reported from a Late Cretaceous mineral deposit, at the Hilton Tungsten claim in the Empire Mountains southeast of Tucson.

A few minor occurrences of powellite are reported from Jurassic mineralized systems, such as at Bisbee and in the Baboquivari Mountains southwest of Tucson. Six occurrences of powellite were tentatively assigned a Precambrian age. Most of these were in the White Picacho district northwest of Phoenix, in veins parallel to schistosity in the host rocks, which are garnet-epidote schist bands within a black hornblende-biotite schist.

Mineralized systems that carry molybdenite commonly contain yellowish coatings or fibrous bundles of ferrimolybdite ($Fe_2Mo_3O_{12}.8H_2O$ with some $FeMoO_4.3H_2O$) in their oxidized zones. Twenty-one localities were compiled, most of which were from the late Cretaceous-early Tertiary porphyry copper deposits.

Another rare oxidation product of molybdenite-bearing mineralized rocks, lindgrenite, occurs as thin, green, transparent-to-translucent, tabular-to-platy crystals. Four localities are known in Arizona, the most notable of which is at the Inspiration porphyry copper mine in the Globe-Miami district. Here, lindgrenite occurs as platy aggregates in hydrothermally-altered schist and in seams with molybdenite and powellite.

Three other rare molybdenum minerals—ilsemannite, umohoite and jordisite—occur with stratabound copper-uranium deposits in sandstones on the Colorado Plateau. Ilsemannite is a black-to-bluish-black molybdenum oxide, $Mo_3O_8.H_2$ (?), that becomes blue on exposure to air. It occurs as earthy crusts or stains and is readily soluble in water, making a deep blue-colored solution; it sometimes forms after the mine tunnels and shafts are made. Umohoite is another black-to-bluish-black molybdenum oxide, $UO_2MoO_4.4H_2O$, that contains uranium. It occurs as bright, almost metallic-looking, fine-grained, crystalline, platy or foliated aggregates, or small platelike crystals that formed during the early stages of oxidation of uranium minerals. Jordisite is an amorphous, opaque, black, powdery molybdenum sulfide that occurs in association with ilsemannite in uranium deposits on the Colorado

TABLE 3. *MOLY:* SELECTED GEOLOGIC AND METALLOGENIC CHARACTERISTICS OF LATE CRETACEOUS THROUGH MID-TERTIARY WULFENITE AND MOLYBDENITE OCCURRENCES[1]

Principal Molybdenum Mineral	Mineral Deposit Type	Occurrence Description	Reported Metal Production (Kg × 10⁶)			Cu: Pb + Zn	Zn:Pb	Chemistry Of Associated Igneous Rock	Age
			Cu	Pb	Zn				
Wulfenite	Lead-zinc-silver districts (12)[3]	With cerussite in oxidized zones; Galena, sphalerite, and minor chalcopyrite in sulfide zone.	7.6	86.	61.	1:20	1:1.4	alkalic[2]	mid Tertiary (35–15 m.y.)
Molybdenite	Porphyry copper districts (26)[3]	With chalcopyrite and bornite in the sulfide zones of the copper-molybdenum centers of porphyry copper districts.	22,253	274	1,292	14:1	5:1	calcic[2]	late Laramide (70–50 m.y.)
Wulfenite	Lead-zinc-silver districts (11)[3]	With cerussite in oxidized zones; Galena, sphalerite, and minor chalcopyrite in sulfide zone.	7.7	49	17	1.9	1:3	alkalic[2]	early Laramide (80–70 m.y.)

1) Metal abundance figures are based on a compilation of production data for 49 districts within the Southeast Arizona and Southwest New Mexico porphyry copper cluster where a sulfide system could be recognized. In most cases each district constitutes a single sulfide system. That is, sulfide system data includes all mines within a district which have produced from epigenetic vein systems which can be linked spatially and temporally to a single igneous event. Thus, production data was composited from all mines considered to be in the district zoning picture, not simply the mines thought to be at the center of the district. Emphasis is thus on total metal emplaced over an entire sulfide system which is district wide in its dimensions and is a composite of several or many smaller deposits. Data in Table 1 is based on 1900–1975 production data. The 1900–1975 U.S. Bureau of Mines yearbooks are the primary data source. This source was augmented by BGMT file data and annual company reports.

2) Alkalic as used here includes igneous rocks suites whose potassium (K_2O) content at 57.5% silica is equal to or greater than 2.5%. Calcic rocks have K_2O contents less than 2.5% at 57.5% SiO_2.

3) Number in parentheses is number of districts within the porphyry copper cluster area.

Plateau. Jordisite may also be present in the oxidized zones of porphyry copper deposits where it could be intermixed with black copper oxides, like tenorite or 'black' chrysocolla, or could possibly be mixed with manganese oxide minerals at many of the wulfenite locations.

Geologic Implications

While filling out the CRIB sheets for Mohave County, which primarily contained molybdenite occurrences, and those for Yuma County, which predominantly contained wulfenite occurrences, mineralogical patterns emerged which have been consistently maintained in the remaining counties. No molybdenite was reported in the sulfide zone of any mineral occurrence that contained wulfenite; and no wulfenite was reported in the oxide zone of any occurrence that contained molybdenite in the primary sulfide (or unoxidized) zone. Although wulfenite is found in molybdenite-bearing porphyry copper districts, it consistently occurs in the lead-zinc portions of the district and not in the copper-molybdenum part of the district. Thus, molybdenite and wulfenite appear to be mutually exclusive at the local orebody scale. This pattern has been previously recognized for several mines where Olsen (1961) and Creasey (1950) specifically searched for but failed to find primary molybdenite at either the Glove or Mammoth-St. Anthony mines, two famous wulfenite localities. This pattern holds true for the 150 Arizona wulfenite occurrences compiled in the present study. Also, wulfenite was the only oxygen-bearing molybdenum mineral at each reported locality; that is, no specimens of lindgrenite, ferrimolybdite, jordisite, or ilsemannite were reported from any wulfenite locality, although ferrimolybdite is common in the oxide zone of molybdenite occurrences.

Another pattern that emerged was that in late Cretaceous-early Tertiary porphyry copper districts, the great bulk of molybdenite is concentrated in fractures that cut silicic igneous host rocks in the copper-molybdenum cores or centers of the districts. Where a substantial amount of altered, calcium-rich, carbonate sedimentary rocks or skarns occur in the copper-molybdenum cores, powellite is more common and molybdenite less common. With the exception of the Orphan mine in the Grand Canyon, no molybdenite or wulfenite has been reported from the Colorado Plateau.

The mineralogical patterns appear to indicate that different geologic environments influenced the deposition of different molybdenum minerals. Table 3 summarizes the geologic contrasts between wulfenite and molybdenite occurrences. Wulfenite consistently occurs in cerussite-bearing oxide zones of lead-zinc-silver deposits which contain no primary molybdenite. These findings are consistent with the conclusions of several authors (Creasey, 1950; Olsen, 1961; Anthony and Titley, 1961) that molybdenum is exotic to the original deposit and was introduced late in the oxidation sequence of the deposit, typically after cerussite had already formed. Reported wulfenite occurrences in porphyry copper districts are associated with zinc-rich, lead-zinc-silver deposits, while wulfenite occurrences in the non-porphyry copper districts are associated with more lead-rich, lead-zinc-silver districts. Wulfenite is only a minor mineral in the lead-zinc-silver zones of known porphyry coppers, while it is commonly abundant in the lead-zinc-silver districts. Significantly, production of wulfenite concentrates (Table 1) is limited to lead-zinc-silver districts. With the exception of the 79 mine, all localities with enough wulfenite to produce collectable specimens of wulfenite are in lead-zinc-silver districts.

The foregoing observations suggest that molybdenum was introduced to lead-zinc-silver deposits during their oxidation, and that the lead content of these deposits was important to the amount of wulfenite that could form. Hence, wulfenite is more abundant in lead-rich, lead-zinc-silver deposits. Thus, *large* amounts of wulfenite at a given locality provide a *negative* clue to the possible occurrence of a contemporaneous porphyry copper or copper-molybdenum deposit in the district. This may reflect the fact that associated igneous rocks of the same age as the lead-zinc-silver districts are consistently more alkalic (higher in potassium and sodium and comparatively low in calcium) and lead-rich than igneous rocks associated with porphyry coppers. Another important negative finding of the study was that, with the possible exception of the Steeple Rock district on the Arizona-New Mexico boundary east of Morenci, no evidence of a Climax-type porphyry molybdenum occurrence in Arizona was found in the geologic literature that was examined.

continued on page 12

IS THERE A CASA GRANDE BULGE AND WILL IT CAUSE EARTHQUAKES IN ARIZONA?

By Richard H. Raymond, Gail E. Cordy and Gregory M. Tuttle

U.S. Water and Power Resources Service, P.O. Box 6972, Phoenix, Arizona 85005

INTRODUCTION

Heavy groundwater pumping in south-central Arizona has caused groundwater overdraft and extensive water-level declines, particularly in the Picacho Basin (U.S. Bureau of Reclamation, 1976; Laney and others, 1978). Earth fissuring and widespread land subsidence have accompanied the removal of groundwater (Laney and others, 1978). Holzer (1979) stated that the land surface *rose* 6 cm in part of the Picacho Basin in response to groundwater pumping.

Holzer (1979) theorized that unloading of the earth's crust by removal of large amounts of groundwater in south-central Arizona causes the land surface to rise in the same way that loading by large reservoirs causes the land surface to depress. He also speculated that in tectonically active areas, unloading may cause earthquakes. This concept suggests the possibility of earthquakes in the Picacho Basin site of part of the Central Arizona Project aqueduct (Figure 3, p. 6), an area of greatest groundwater level decline in Arizona. Because of the potential for seismic activity in the vicinity of the aqueduct, Holzer's theory required further analysis by the U.S. Water and Power Resources Service. However, after reviewing his work, the authors question Holzer's interpretation of surveying and seismic data, as discussed below.

ELASTIC EXPANSION AND LOADING

Based on leveling surveys in 1905, 1948–49, 1967, and 1977, Holzer (1979) estimated that the land surface rose (elastic expansion) 6 cm from 1948 to 1967 in the areas northwest and northeast of the town of Casa Grande. He suggested that this rise was the result of removal of more than 43.5×10^{12} kg of groundwater and subsequent diminishment of surface stresses.

Holzer (1979) stated that the rise or elastic expansion (mass loss) in areas of groundwater depletion, such as south-central Arizona, is comparable to the depression or elastic compression (mass increase) of the earth's surface caused by loading in reservoir impoundments such as Lake Mead, Arizona. Applying the theory of elasticity, he compared deflection of the earth's surface (W_{max}) in terms of depression or expansion in areas of loading and unloading (see Table 1). Because of the MASS/(AREA)$^{1/2}$ ratio for south-central Arizona (8.93×10^{11} kg/km) is approximately one-half the value of the ratio for Lake Mead (15.3×10^{11} kg/km), Holzer (1979, p. 4690) stated that man-induced uplift in south-central Arizona from 1915 to 1973 should equal approximately one-half the depression of 17.8 cm measured at Lake Mead. In fact, the predicted uplift (W_{max}) for south-central Arizona is 13.2 cm (see Table 1), significantly greater than one-half the depression at Lake Mead.

SURVEY DATA

There are several reasons to question the interpretation of leveling data by Holzer. In determining crustal expansion, Holzer (1979) used unadjusted data from two long level lines. The data were collected over a period of 72 years by various agencies (U.S. Geological Survey—1905 and 1977; National Geodetic Survey—1948, 1949 and 1967). Although all of the surveys (except 1977) were performed to First-Order standards, the data may be less accurate in the early surveys due to limited precision of leveling instruments. Thus, comparison of unadjusted leveling data may not be sufficient to determine the minimal rise in the land surface reported by Holzer.

Data points in the early surveys were widely spaced and many of the early bench marks were disturbed or destroyed before later surveys. The NGS survey of 1948 reported that bench mark 1338 (set in 1905 in alluvium) was leaning. At this time it was labeled T277. Apparently this monument had been disturbed, perhaps by subsidence, yet Holzer used the 1948 leveling at 1338 to determine a 6.2 cm rise in the land surface from 1948 to 1967. In fact, published adjusted values for bench marks 1338 (T277) and nearby W277 show continual subsidence (no uplift) in this area (Table 2).

Holzer (1979, p. 4692) computed all elevational changes in relation to bench mark 1283 which was set in alluvium. The absolute elevation of 1283 was unknown; however, it was considered stable by Holzer on the basis of only one other point, bench mark Enid, which was set in bedrock 1 km away. The authors suggest that bench mark 1283 should not be considered absolutely stable as Holzer suggested, unless the stability of 1283 and Enid are evaluated by reference level data to several other stable points outside the area or by large scale evaluation as part of the national level net data adjustments in Arizona.

In evaluating data errors, Holzer (1979) used the "nominal accuracy between points" formulae published by the Federal Geodetic Control Committee (1974) for the National Geodetic Network. These standards specify limits of allowable misclosure (error) for each class of level line. However, nominal accuracy criteria are applicable to only the most precise data. Assuming First-Order, Class II leveling, the allowable misclosure (nominal accuracy) between bench marks 1283 and 1338 is $\pm$ 2 mm $\sqrt{K}$ = 1.2 cm, where K is the distance between bench marks in kilometers (Holzer, 1979, p. 4695). In practice, the surveyed data can be more realistically evaluated by the "permissible error of closure" technique (Federal Geodetic Control Committee, 1974). An appropriate accuracy of within $\pm$ 4 mm $\sqrt{K}$ (twice the nominal accuracy) is

TABLE 1. Comparison of Potential for Expansion or Depression of the Crust Beneath Selected Areas With Mass Changes*

Location	Mass Loss 10^{12} kg	Area km^2	Time Period	Calc†† W_{max}, cm	Mass/(Area)$^{1/2}$ 10^{11} kg/km	References
South-central Arizona	43.5	8,070	1948–67	7.3	4.84	AWC (1975)
South-central Arizona	80.2	8,070	1915–73	13.2	8.93	AWC (1975)
Lake Mead, Arizona-Nev.	37.6**	601	1935–40	22.7	15.3	Longwell (1960), Raphael (1954)
Lake Powell, Arizona	26.1**	579	July 1975	—	10.8	USGS (1978)

*Modified from Holzer (1979)

**Reservoir impoundment (mass increase)

††Calculated $W_{max} = \frac{2(1-v^2)g}{\pi^{1/2}E} \frac{m}{(\pi R)^{1/2}}$

where: W_{max} = deflection at center of circle; E = Young's modulus; v = Poisson's ratio; m = mass of load; g = acceleration of gravity; R = radius of circular area indicated by this method. Thus, for the 36.6 km distance between bench marks 1283 and 1338 (where Holzer interpreted 6.2 cm of crustal expansion), a misclosure of as much as ± 2.4 cm would be acceptable for any single unadjusted run between these two points, and the maximum acceptable misclosure between unadjusted data run along this line in different years (i.e. 1948 and 1967) could be as much as ± 4.8 cm. Similarly, for bench mark 1283 to D367 (87 km away), using unadjusted data from runs in two different years, a maximum misclosure of as much as ± 7.46 cm is permissible for First-Order, Class II standards. This value for error is greater than the "significant elastic expansion" of 6.2 cm cited by Holzer (1979, p. 4693) in the Picacho Basin, northwest of Casa Grande. A similar situation occurs at bench mark Poston, where Holzer (1979, p. 4695) reported 7.52 cm of uplift (1948–1967) with respect to 1283. Using the permissible error formula cited above for 1948 and 1967 level data, the uplift value is within the range of acceptable misclosure.

TABLE 2. Adjusted Level Values for Bench Marks 1338 and W277*
(Altitude above mean sea level in feet)

Bench Mark	1905	1948–49	1967	1977
1338 (1905) = T277 (1948)	1338.705	1338.462	1338.442	1338.400
W277	—	1340.562	1340.555	1340.545

*Marshall, (1915); NGS (1948–49, 1967); U.S.G.S. (1977).

SEISMICITY

Holzer (1979, p. 4698) theorized that earthquakes may be caused by unloading because of groundwater withdrawal in the Picacho Basin. If earthquakes may result from unloading, and the alleged unloading is similar to reservoir loading at Lake Mead and comparable areas, as Holzer stated, then earthquakes should have followed loading at Lake Mead and comparable areas. In fact, the evidence is to the contrary. The areas of greatest loading and subsidence at Lake Mead were notably aseismic. Anderson and Laney (1975), and Mickey (1973), concluded that seismicity was not a direct result of loading by the mass of the lake. Rather, it was a result of rapid changes in water level.

Similarly, a comparison of MASS/(AREA)$^{1/2}$ values from the Lake Powell reservoir, Arizona, and south-central Arizona further confirms that loading (and comparable unloading) does not cause earthquakes. Lake Powell at Glen Canyon Dam, 523 km from the Picacho Basin, has a ratio value of 10.8×10^{11} kg/km (Table 1); similar to the value for south-central Arizona of 8.93×10^{11} kg/km. However, Mickey (1973) showed a definite decrease in local seismic activity following loading at Lake Powell.

It is particularly significant to note the absence of measurable seismic events within an 80-km (50 mile) radius of the Picacho Basin (Figure 3, p. 6). Holzer (1979) suggested the possibility of seismic activity due to unloading in this area. If Holzer is right then the substantial unloading which has occurred since World War II should have caused earthquakes in the Picacho Basin. Several ground tremors were reported by the BIA supervisor at Picacho Reservoir in early 1975 (Yerkes and Castle, 1976), one of which was coincident with a rapid drop of 150 mm in the reservoir water level; however, Peirce (1975) suggested that many of the low intensity "seismic events" in this area were the result of atmospheric phenomena related to supersonic jet booms. In addition, Holzer and others (1979) cited a microearthquake investigation conducted in 1977, north of Eloy, which confirmed that the Picacho Basin was not subject to seismically-active tectonic processes.

CONCLUSIONS

Elastic expansion or rise in the land surface as reported by Holzer (1979) is questioned on the basis that 1) unadjusted data with varying degrees of accuracy are compared, 2) data points are widely spaced and may have been disturbed or destroyed in some cases, 3) elevational changes are computed in relation to a single bench mark, and most importantly, 4) leveling errors were evaluated by nominal accuracy methods which yield minimal values of one-half of the permissable error.

Unloading due to groundwater withdrawal is unlikely to induce earthquakes in south-central Arizona. Comparable crustal loading at Lake Mead and Lake Powell has not triggered seismic activity, and, more important, no significant earthquake epicenters have been recorded within an 80-km (50 mi) radius of the Picacho Basin (Figure 3, p. 6). In fact, the area is notably aseismic in contrast to the seismically-active areas to the southwest and north-northeast. The evidence indicates that south-central Arizona is not subject to seismic activity as a result of groundwater unloading. In addition, more precise leveling data will be required in order to accurately determine if crustal expansion is indeed occurring as a result of groundwater withdrawal.

ACKNOWLEDGMENTS

The authors express appreciation to R. L. Laney and H. H. Schumann of the U.S.G.S. Water Resources Division, Phoenix; E. S. Davidson, U.S.G.S. Water Resources Division, Tucson; and C. C. Winikka, Arizona Department of Transportation, Phoenix, for their constructive comments and review of this paper.

SELECTED REFERENCES

Federal Geodetic Control Committee, 1974, Classification, standards of accuracy and general specifications of geodetic control surveys: U.S. Department of Commerce Report, NOAA, 12 p.

Holzer, T. L., 1979, Elastic expansion of the lithospere caused by groundwater depletion: Jour. of Geophys. Research, v. 84, no. B9, p. 4689–4698.

Holzer, T. L., Davis, S. N., and Lofgren, B. E., 1979, Faulting caused by groundwater extraction in southcentral Arizona: Jour. of Geophys. Research, v. 84, no. B2, p. 603–612.

Anderson, R. E., and Laney, R. L., 1975, The influence of Late Cenozoic stratigraphy on distribution of impoundment-related seismicity at Lake Mead, Nevada-Arizona: Jour. of Research of the U.S. Geol. Survey, v. 3, no. 3, p. 337–343.

Laney, R. L., Raymond R. H., and Winikka, C. C., 1978, Maps showing water-level declines, land subsidence, and earth fissures in south-central Arizona: U.S. Geological Survey Water-Resources Invest., Open-File Report 78–83, 2 sheets, scale 1:125,000.

Marshall, R. B., 1915, Results of spirit leveling in Arizona, 1899–1915: U.S. Geological Survey Bulletin 573, p. 10.

Mickey, W. V., 1973, Reservoir seismic effects: American Geophys. Union, Geophysical Monograph Series Vol. 17, 472–479.

National Geodetic Survey, 1948–49, 1967, Vertical control data, quadrangle no. 32-1114.

National Oceanic and Atmospheric Administration, 1973, Earthquake history of the United States: U.S. Department of Commerce Publication 41-1, revised edition (through 1970), p. 1.

National Oceanic and Atmospheric Administration, 1980, Earthquake data file to 1977: National Geophys. and Solar Terrestrial Data Center, Boulder, Colo.

Peirce, H. Wesley, 1975, Rumbles and rattles: toward an explanation: Fieldnotes, v. 5, no. 2, p. 5 and 8.

U.S. Bureau of Reclamation, 1976, Geology and ground-water resources report: Maricopa and Pinal Counties, Arizona-Central Arizona Project: Arizona Projects Office, Phoenix, Arizona, v. 1, 104 p.

U.S. Geological Survey, 1977, Eloy Project, Arizona, PV 1006.

Yerkes, R. F., and Castle, R. O., 1976, Seismicity and faulting attributable to fluid extraction *in* Milne, W. G., ed., Induced seismicity: Eng. Geol., v. 10, no. 2–4, p. 151–167.

THE AUTHORS

Richard H. Raymond, engineering geologist, Head, Aqueducts Section, Geology and Materials Branch, Arizona Projects Office, 19 years with the Water and Power Resources Service, last 15 in Arizona.

Gail E. Cordy, geologist, Geology and Materials Branch, B. S. degree from California State University, Sacramento, and M. S. degree from Arizona State University, She has been working in Arizona for five years, concentrating on the environmental geology of Phoenix and the surrounding area.

Gregory M. Tuttle is a professionally-registered Land Surveyor in Arizona. He is a 10-year employee of the Water and Power Resources Service as a civil engineering technician specializing in geodetic, engineering, and land survey activities.

Moly continued

CONCLUSION

Arizona's increasingly prominent molybdenum economic posture is the result of geologic events during Laramide orogeny, 70 to 50 million years ago. It was then that Arizona's great prophyry copper deposits were emplaced and, along with copper, a significant amount of molybdenum was deposited. Thus, not only has Laramide orogeny left Arizonans with an important copper legacy, but also with a valuable molybdenum one as well.

REFERENCES

Anthony, J. W., and Titley, S. R., 1961, Some preliminary observations on theoretical geochemistry of molybdenum under supergene conditions: Ariz. Geol. Soc. Digest IV, p. 103–116

Anthony, J. W., Williams, S. A., and Bideaux, R. A., 1977, Mineralogy of Arizona: Univ. of Ariz. Press, p. 102, 156, 205

Creasey, S. C., 1950, Arizona Zinc and lead deposits: Geology of the St. Anthony (Mammoth) area, Pinal County, Arizona: Ariz. Bur. Mines Bull. 156, p. 63–84

King, R. B., 1969, Molybdenum and rhenium, *in* Mineral and water resources of Arizona: Ariz. Bur. Mines Bull. 180, p. 230–238

Olson, H. J., 1961, The geology of the Glove mine, Santa Cruz County, Arizona: Univ. Ariz., MS Thesis

Sutulov, A., 1978, International Molybdenum Encyclopaedia: 1778–1978, v. 1, Resources & Production: Intermet, Santiago, Chile, 402 p.

ANNOUNCEMENT

The Arizona Geological Society will host a Tectonics and Ore Deposits Symposium at The University of Arizona, Tucson, March 19 and 20, 1981. Field trips are scheduled preceding and following the symposium. If you wish to be placed on the mailing list, contact: John Reinbold, Conferences and Short Courses, The University of Arizona, 1717 E. Speedway Boulevard, Tucson, Arizona 85721.

DuBois continued

Damage in Arizona from earthquakes has been considerable over the past century and a half (see *Fieldnotes*, v. 9 n. 1). Since 1850, nearly every portion of the state has experienced either earthquake vibrations or other induced effects of seismicity (i.e., rockfalls, fires, liquefaction, flooding, water table changes). A *preliminary* version of an epicenter map (Figure 3) indicates at least 115 earthquakes within the state which were felt or recorded since 1850. An additional 100 events must still be assigned locations, based on collected observations. Isoseismal maps, indicating felt area, maximum intensity and patterns of intensity attenuation, are being generated for several of the largest historic earthquakes. Contour lines, enclosing regions of equal Modified Mercalli Intensities, are drawn after intensity data are plotted for each location reporting effects of the earthquake. Two examples are shown in Figure 4. At the conclusion of the historical seismicity study, geologists, seismologists, and engineers will have several historical models for use in prediction of possible damage from large earthquakes, in estimation of earthquake recurrence intervals and maximum sizes, and in analysis of relative seismic activity of various regions of Arizona.

Funds for this project have come from the U.S. Geological Survey, the U.S. Nuclear Regulatory Commission and the State of Arizona.

Fieldnotes

Volume 10, No. 3 September 1980

State of Arizona .... Governor Bruce Babbitt
University of Arizona .... President John P. Schaefer
Bureau of Geology & Mineral Technology
Director .... William H. Dresher
State Geologist .... Larry D. Fellows
Editor .... Anne M. Candea

The Bureau of Geology and Mineral Technology is a Division of the University of Arizona, an Equal Opportunity/ Affirmative Action Employer.

State of Arizona
Bureau of Geology and Mineral Technology
845 N. Park Ave.
Tucson, AZ 85719
(602) 626-2733

NON PROFIT ORG
U.S. POSTAGE
PAID
PERMIT NO 190
TUCSON, ARIZONA