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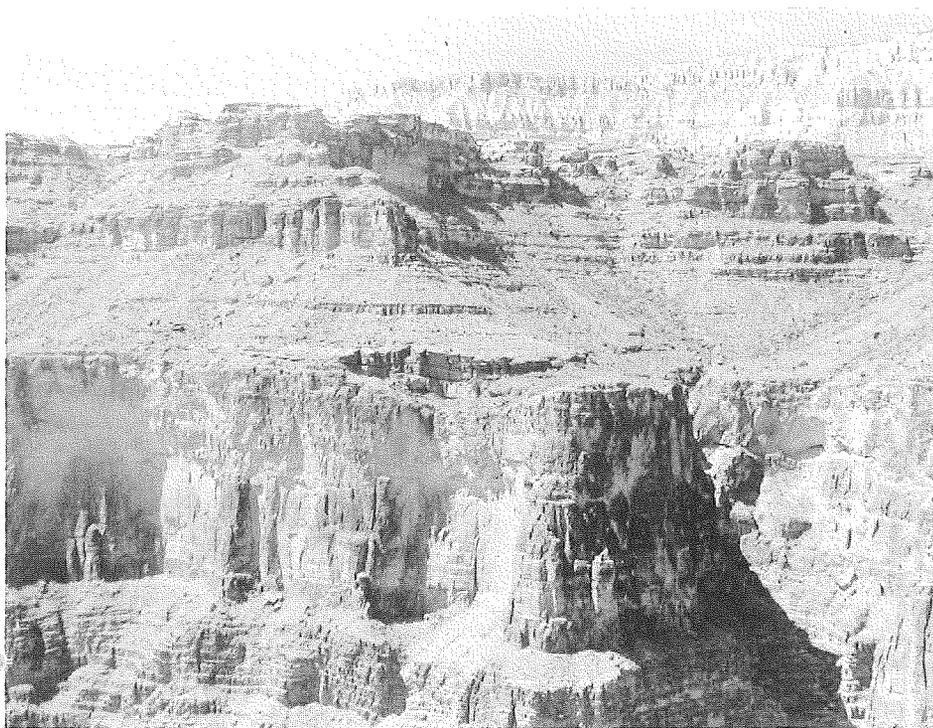


Figure 1. Lens-shaped outcrop of Surprise Canyon Formation (center of photo) near Fern Glen (FG in Figure 2) in central Grand Canyon. View looks northwest.

A Geologic Surprise in the Grand Canyon

by Stanley S. Beus

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Since the epic voyage of John Wesley Powell down the Colorado River in 1869, the Grand Canyon has attracted the interest of geologists, geographers, and many other scientists. Because of the uniqueness of the canyon as a topographic, scenic, and geologic wonder, and because of the unusually prominent and continuous outcrops, the major exposed rock units have been known and studied extensively for nearly a century. The recent discovery of a heretofore unrecognized sedimentary rock layer with numerous outcrops in western and central Grand Canyon comes as a stimulating surprise. This "new" unit has been named the Surprise Canyon Formation.

Discovery

The Surprise Canyon Formation was first recognized by George Billingsley of the U.S.

Geological Survey in the mid-1970's during reconnaissance mapping in western Grand Canyon. Billingsley recognized unusual dark red-brown outcrop patterns during a flight over the canyon and identified numerous such patches on the aerial photographs he used to map the canyon (Figure 1). The remoteness of the outcrops deterred on-site observations for more than a year. In subsequent years Billingsley and others, including this author, examined more than 100 outcrops of this formation, mostly in relatively inaccessible areas of western and central Grand Canyon (Figure 2). Billingsley and McKee (1982) described some of these outcrops in westernmost Grand Canyon in a monograph on the Supai Group. Billingsley and Beus (1985) applied the formal name, Surprise Canyon Formation, and designated a type section near the Bat Tower (BT in Figure 2).

The location and discontinuous nature of the Surprise Canyon outcrops suggest why this unit had never been recognized before (Fig-

ures 2-5). All of the outcrops studied so far are discontinuous lenses up to several hundred feet thick, as in Quartermaster Canyon (Figure 3), and from a few hundred yards to nearly a mile wide. Nowhere does the formation appear as a continuous sheet, as do all of the other sedimentary rock units of Paleozoic age in the Grand Canyon. The Surprise Canyon outcrops are commonly at the top of a major cliff formed by the resistant Redwall Limestone. In many places, the exposures are situated along a narrow shelf some 1,500 feet above the Colorado River and nearly 3,000 feet below the rim (Figures 3-5). The outcrops yielded some unusual fossils and rocks of a different character than any others known in the Grand Canyon.

Geologic Age

The Surprise Canyon Formation provides evidence for a new chapter in the geologic history of Arizona. The formation appears to be about 320 million years (m.y.) old, or of latest Mississippian age. This dating is based upon the abundant fossils in the formation including leaves, trunks, and pollen of various plants such as ferns and *Lepidodendron*; microscopic conodonts and foraminifera; and larger invertebrates including brachiopods, blastoids, corals, and bryozoans. The plant fossils commonly occur in the lower part of the formation in sandstone and conglomerate and record terrestrial (nonmarine) conditions. The micro- and macroinvertebrate shells indicate a warm, shallow marine environment for the limestones in the middle and upper part of the formation.

The geologic evidence indicates that after deposition of the Redwall Limestone, in Early and early Late Mississippian time, there occurred a period of erosion and nondeposition, which left a gap in the rock record of Arizona for a 10-m.y. period. Some deposition did occur in southeastern Arizona (the Paradise Formation) during part of this time interval, but over most of the State the record is blank. The Surprise Canyon Formation records a singular depositional event that occurred in northern Arizona during the latter part of this time gap, i.e., during very latest Mississippian time (Figure 6). The fossils collected thus far indicate latest Mississippian and possibly even earliest Pennsylvanian age and are similar to those found in limestones of

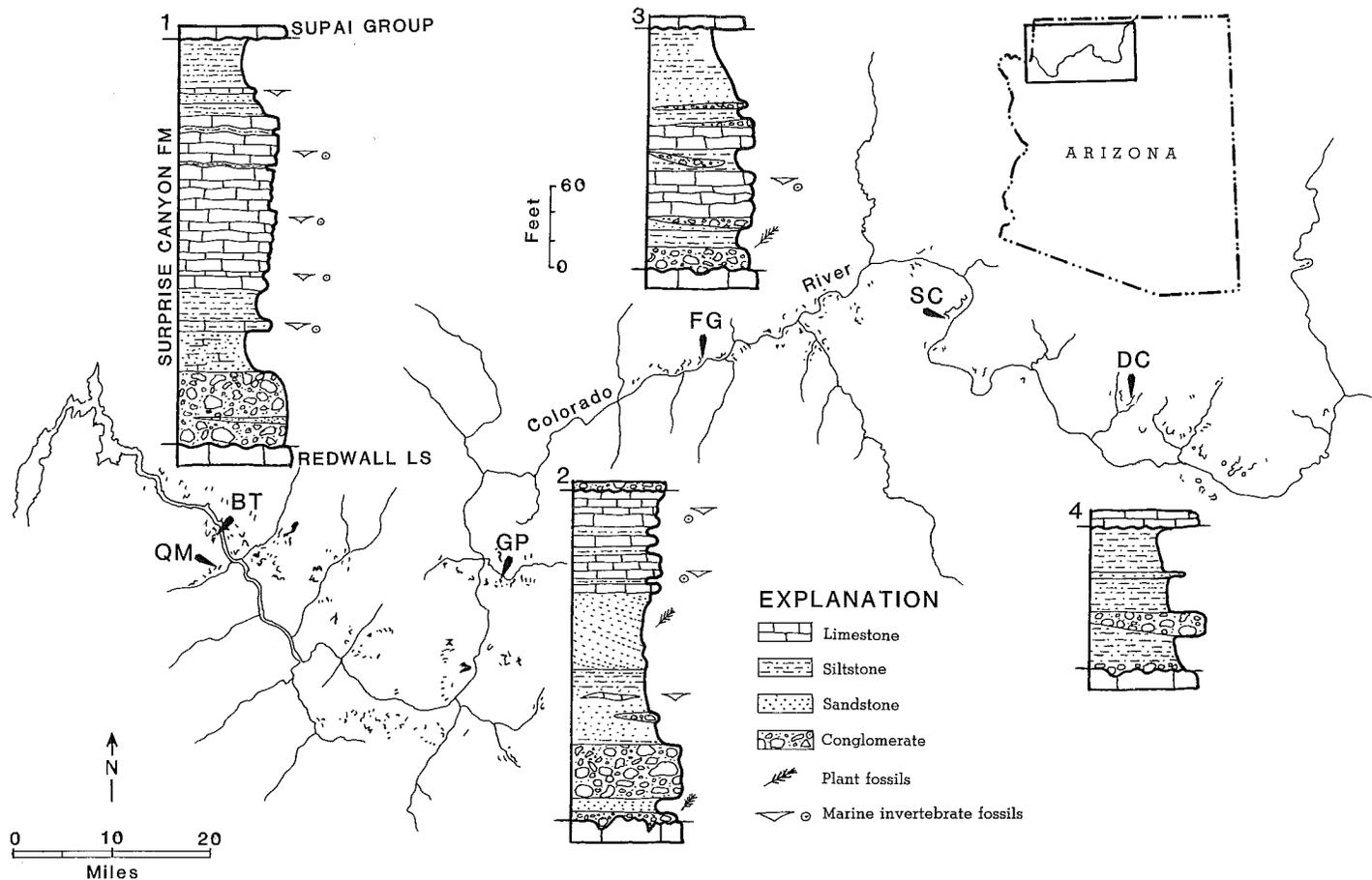


Figure 2. Index map of major outcrops of Surprise Canyon Formation and selected stratigraphic sections in Grand Canyon. Section 1 is the type section near Bat Tower (BT); section 2 is at Granite Park (GP); section 3 is at Fern Glen (FG); and section 4 is at Dragon Creek (DC). Outcrops at Quartermaster Canyon (QM) and Specter Chasm (SC) are illustrated in Figures 3 and 5, respectively.

approximately the same age in southern Nevada (the Indian Springs Formation) some 70 miles to the northwest of the mouth of the

Grand Canyon. The formation is mapped as unnamed Mississippian channel deposits on geologic maps in western Grand Canyon

(Huntoon and others, 1981, 1982; Billingsley and Huntoon, 1983) and as the Surprise Canyon Formation on the new version of the geologic map of eastern Grand Canyon (Huntoon and others, 1986).

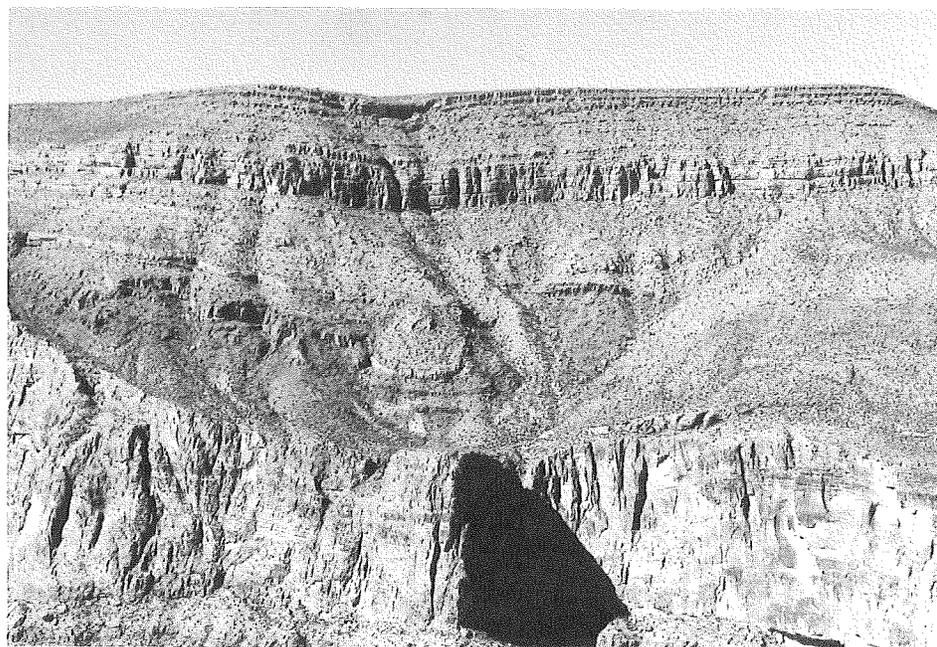


Figure 3. Thickest known section of Surprise Canyon Formation on west wall of Quartermaster Canyon (QM in Figure 2). Note the sharp curved surface of the old valley floor cut into the Redwall Limestone at the base of the Surprise Canyon outcrop.

Preliminary Interpretation

The distribution and shape of the outcrops, all of which are thin to moderately thick lenses, and some of which appear to be straight-line segments [see Granite Park (GP) and Fern Glen (FG) in Figure 2], suggest that the Surprise Canyon Formation was deposited within the valleys of an ancient stream system that had eroded into the top of the Redwall Limestone. It appears that deposition of this formation was entirely confined to this old stream system and occurred nowhere else in Arizona. The valleys were probably carved by streams that flowed across a low, resistant, limestone platform just above sea level and that emptied into the sea along a shoreline in northwestern Arizona or southern Nevada. As marked by the thickness of the Surprise Canyon Formation, the stream valleys are very shallow in eastern Grand Canyon and generally deepen towards the west. The deepest valley, marked by the thickest outcrop, was about 400 feet deep (Figure 3).

Initial sedimentation in the old stream valleys involved the deposition of coarse gravel, sand,

and silt that locally included abundant logs and other plant material. Subsequent deposition involved the accumulation of limestone composed mainly of the skeletons of microscopic and megascopic marine shells. Preliminary interpretation of these fossils and the nature of the enclosing rocks suggests the following series of events in northern Arizona during latest Mississippian time: (1) development of a hard limestone platform exposed at or near sea level, as marked by the top of the Redwall Limestone; (2) mild uplifts that initiated stream erosion across northwestern Arizona to a maximum depth of at least 400 feet in the west; (3) gentle subsidence of this limestone platform or a gradual rise in sea level and infilling of the old stream channel with boulders, cobbles, and pebbles of rubble from the underlying Redwall Limestone, as well as sand and silt from a more distant source; (4) extensive flooding of the valleys by the sea; and (5) accumulation of sand and lime deposits rich in marine shells. At the climax of this deposition period, the old stream valleys must have formed a great estuary system of drowned river valleys that extended at least 70 miles across northwestern Arizona. After the stream valleys were filled, a short period of erosion occurred before deposition of lime mud and red silt and sand, marked by the lowermost layers of the Supai Group, which overlie the Surprise Canyon Formation.

Discussion

One of the most unusual features of the Surprise Canyon Formation is the presence of marine fossils (remains of typical saltwater-loving sea creatures) as far as 70 miles upstream from the presumed mouth of the estuary. If these ancient organisms lived where their fossil remains were found, as at Fem Glen and elsewhere to the east, and were in an estuary system, then they record the presence of normal-salinity sea water 70 miles upriver. This rather unique situation is almost unmatched in today's world. The closest modern analog known to the author is that of the Ord River in western Australia, where macrotidal currents bring water of normal marine salinity 40 miles (65 km) upstream from the mouth during the dry season of the year (Wright and others, 1975, p. 314). During latest Mississippian time, the coastal configuration in Nevada-Arizona may have favored unusually strong high tides, which, coupled with a minimum of fresh-water runoff, might produce such an extensive influx of sea water into a drowned river valley.

It is also possible that the original Surprise Canyon deposits were a more widespread sheet formed in a shallow sea across much of northwestern Arizona and later were uniformly eroded so that only the lower valley-fill portion remained. This would readily explain the great lateral extent of marine fossils in the formation; however, with no convincing evidence for deposition outside the narrow valleys that

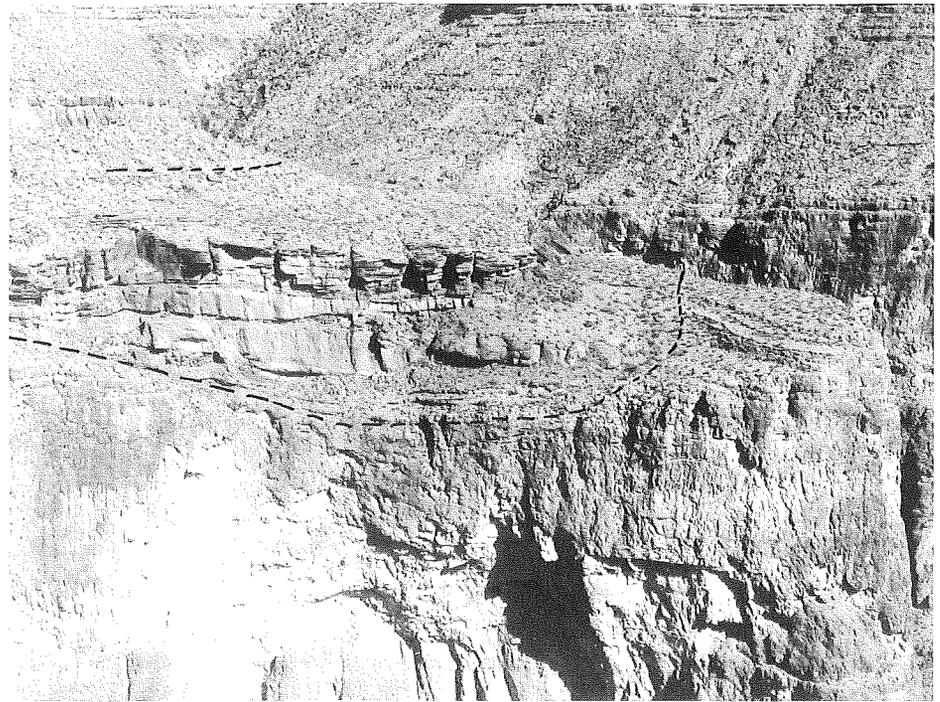


Figure 4. Surprise Canyon outcrop just west of Fem Glen (FG in Figure 2). The approximate base and top of the formation are marked by the dashed line.

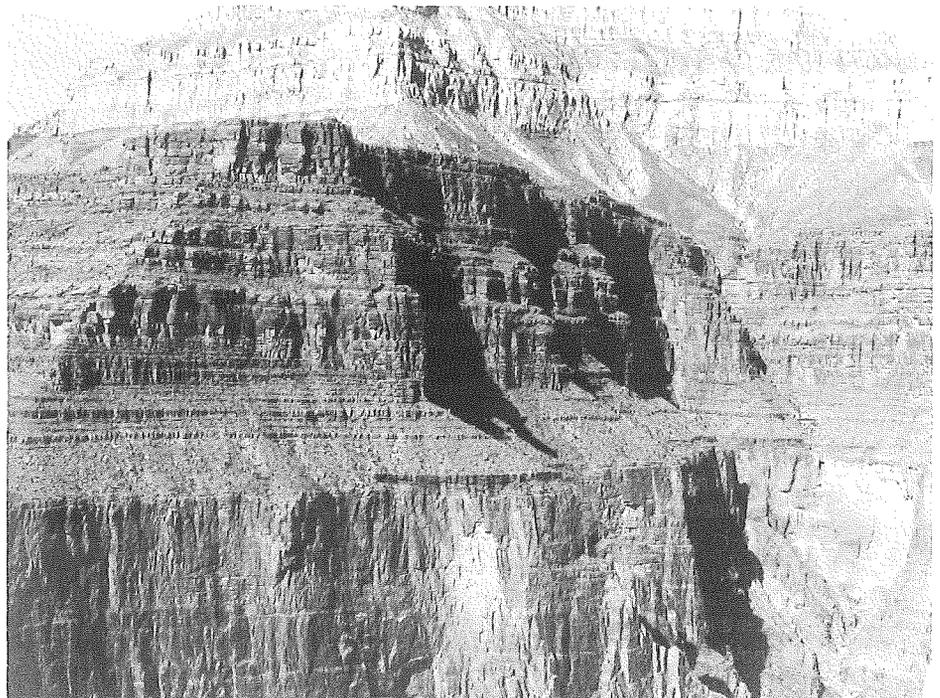


Figure 5. Thin, dark-colored lens of Surprise Canyon Formation overlying Redwall Limestone cliff (center of photo) at Specter Chasm (SC in Figure 2).

contain the formation, deposition confined to an estuary system seems the most reasonable interpretation.

If the interpretations are correct, the Surprise Canyon Formation is a unique record of one of the largest, well-defined, ancient estuary systems in North America. Although more extensive studies must be done to understand and interpret this unit completely, it has already provided a new chapter in the geologic history of Arizona. It is stimulating and even reassuring

to know that the Grand Canyon may still hold some secrets.

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	1	2	3	4
	Arrow Canyon Nevada	Iceberg Ridge Arizona	Bat Tower Arizona	Pedregosa Mountains Arizona
AGE				
EARLY PENNSYLVANIAN	BIRD			
	SPRING	SUPAI	SUPAI	NACO
	FM	GROUP	GROUP	GROUP
LATE MISSISSIPPIAN	?		?	
	INDIAN		SURPRISE CANYON FM	
	SPRINGS FM			PARADISE FM
	BATTLESHIP	REDWALL LIMESTONE	REDWALL LIMESTONE	ESCABROSA
	WASH FM			GROUP



Figure 6. Approximate stratigraphic position of Surprise Canyon Formation and time-equivalent units in Nevada and southern Arizona.

GEOLOGIC PLACE NAMES: TOMBSTONE

Tombstone, Cochise County, Arizona. Population 1,755.

There is a difference between the prospector and mining man. The prospector is marked by his love of the search for precious metals, whereas the miner is he who takes over what the prospector locates. Ed Schieffelin (d. May 12, 1897) was primarily prospector. He was at Signal [Mohave County, Arizona] when he had a chance to go through southeastern Arizona with some military men. Not himself a soldier, Schieffelin packed his few belongings and set off. In the fall of 1877, he was at Camp Huachuca, at that time in the heart of Apache land, and a bloody land it was. The bare, richly colored hills to the northeast looked good to Schieffelin, and his prospector's dreams made him disregard the warning that if he went alone to find mineral wealth, he would find his tombstone. Schieffelin was careful. Cautious and alone, he camped at night without fires. He made no move without searching the landscape for Apaches. At night Schieffelin crawled silently to the seep for water, then crept back again among the boulders to sleep.

In the winter of 1877, Ed Schieffelin hit his first strike and named it Tombstone. Needing help, he hurried north to Signal to have the ore assayed by Richard Gird and to enlist the aid of his brother Al Schieffelin. Gird reported that the find was a rich one and he, Al, and Ed left to settle in southern Arizona, at a place called Gird Camp. Soon the boom was on. Miners streamed in from Signal where word spread that Schieffelin had struck it rich. A community began to grow near Tank Hill, about three miles from the present Tombstone.

Lack of water was a major problem. There was a running stream at Tank Hill,

where concrete foundations for tent houses were built. On the hill was a big tank for storing water. Near the base of the hill was a community known as Watervale; from it water was pumped to the tank. At its best, Watervale was a temporary community. It lacked room for building permanent structures, and hordes of newcomers sought a level place for a town. Tombstone was the result.

The indefatigable John B. Allen, who seems to have established stores in mining communities throughout southern Arizona, was referred to in 1879 as the "founder of Tombstone City," where he was once again in the vanguard of those creating a community. By the end of 1879, Tombstone had about 100 permanent residents, plus at least 1,000 others camped on nearby hills. A year and a half later, Tombstone was emerging as one of the largest cities in the West. The badmen whooped it up at Tombstone, but their noise was nothing compared to the ruckus they created at nearby Charleston or far across the valley at Galeyville. Although it is true that badmen flocked to Tombstone's saloons and gambling houses and that the Earp-Clanton feud is a famous one, it is often overlooked that Tombstone was probably the most cultivated city in the West and Southwest. Tombstone was at that time larger than San Francisco, and whatever cultural opportunities there were in the West could be found at Tombstone. With a population of 15,000, the community erected an opera house, where the best of the world's musicians and actors could be heard.

Ironically, it was water that drowned Tombstone's hopes and plans. As the mining shafts plunged ever deeper into the rich earth, moisture began to appear. When

the shafts reached 500 feet, it became necessary to begin pumping. This was of little avail. To add to difficulties, the surface pumps at the Grand Central and Contention mines burned in 1886 and 1887, and the mining shafts rapidly filled with water. As the mines flooded, the town began to shrivel. By 1890 Tombstone was nearly dead. In 1901 another effort was made to pump out the mines. This had barely achieved partial success when in 1909, water penetrated the boilers, extinguished the fires, and again flooded the mine shaft. The prohibitive cost precluded abstracting the rich ores known to be hundreds of feet deep in Tombstone's earth. Tombstone, however, did not die. For years it led an anemic existence, barely tottering along. As the past receded, the town became of increasing interest to the present, and today Tombstone is a flourishing tourist attraction known as the "Town Too Tough to Die."

As for Ed Schieffelin, his life came full circle when his body was buried where years before he had crept at night to obtain water. He once said that the two most glorious nights he had ever known were those during which he had slept on the hill where he is now buried, and he left a written request in his records that he be buried at that spot. Ever the prospector, he had long since wandered to other fields; in one in the Northwest he died, and his body was brought back for burial at the place he loved.

In 1881 Tombstone became the county seat for Cochise County. It continued to be so until 1929, when the county seat was moved to Bisbee.

—Excerpted from Granger, B. H., 1960, Will C. Barnes' Arizona place names: Tucson, University of Arizona Press, p. 54-55.

The Renaissance of Copper Solution Mining

by J. Brent Hiskey

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The domestic copper industry has suffered for some time from declining ore grades; rising costs associated with conventional mining, milling, smelting, and refining; tightening environmental restrictions; and shrinking markets resulting from materials substitution and foreign competition. Ore-grade depletion, a major problem, is illustrated by the decline in average copper yield shown in Figure 1. From 1940 to 1979, copper grade dropped 60 percent from yields of 1.2 percent to 0.49 percent (Sousa, 1981). In recent years, the ability of the U.S. copper industry to compete internationally has been handicapped by additional factors such as the strong dollar, foreign subsidization, and aggressive use of new technology by foreign producers. Faced with these problems, the U.S. copper industry is undertaking drastic measures to enhance its competitiveness and to guarantee an advantageous worldwide position in the future. These steps include application of solution-mining techniques to the treatment of copper ores and low-grade waste material.

The recovery of copper by leaching techniques has been practiced for centuries. As early as the mid-16th century, some copper mines in Hungary were recycling copper-bearing leach solutions through waste heaps (Nash, 1912). In the United States, the recovery of copper from dilute mine waters has been carried out for more than 100 years. In recent years, however, certain technical innovations have elevated the importance of solution mining as a process for copper recovery. These include the following:

- (1) Advances in solvent extraction-electrowinning (SX-EW)
- (2) Developments in acid and acid-ferrous processes for oxide and mixed oxide-sulfide ores
- (3) Improvements in heap and dump construction
- (4) Advances in in-situ leaching technology.

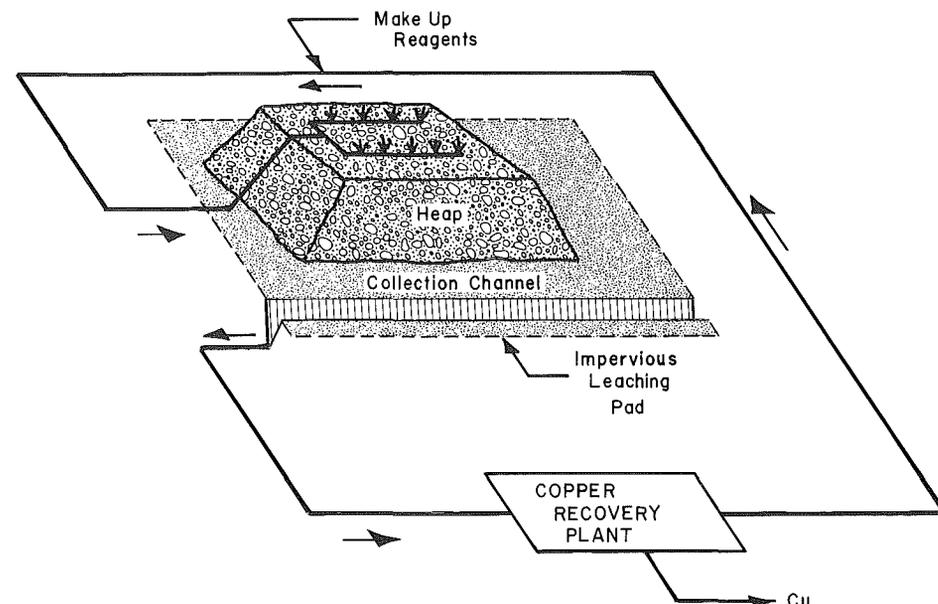


Figure 2. General layout of a copper heap-leaching system.

- (3) Improvements in heap and dump construction
- (4) Advances in in-situ leaching technology.

In a generic sense, solution mining enjoys certain intrinsic advantages over conventional mining and milling: the combined capital and operating costs of leaching facilities are normally lower, start-up times are faster, and the leaching operation usually has less impact on the environment. Furthermore, solution mining represents an expedient way of extracting metals from small, shallow deposits and is particularly suited to treatment of low-grade sources. Waste-dump leaching uses a tremendous in-place resource, the mining cost of which is already "off the books."

This article outlines current trends in copper solution mining in the United States, reviews leaching systems, and analyzes recent production statistics for leach copper.

SOLUTION MINING SYSTEMS

For the purpose of this article, copper solution mining will be divided into three main categories: heap leaching, dump leaching, and in-situ leaching. Wide variation in copper deposits in the United States makes solution mining a more site-specific activity than conventional mining and milling (Schlitt, 1980). Heap leaching is usually selected for moderate- to high-grade ores that contain copper minerals amenable to acid leaching (oxides, silicates, and certain sulfides). Higher grade ores are usually crushed or pretreated through acid curing to optimize copper extraction. Dump leaching, on the other hand, usually involves low-grade waste rock placed on large dumps, the locations of which are dictated by topography and haulage costs. Mine waste is therefore treated in an uncrushed, run-of-mine condition. In-situ

leaching is appropriate for very deep ore bodies or low-grade rock left from earlier mining activities in abandoned pit walls, stopes, and subsidence zones. True in-situ solution mining should be defined as the leaching of ore in its original geologic setting.

Heap Leaching

Heap leaching, as indicated above, has a long history as a hydrometallurgical process for copper recovery. The methodology of heap leaching established at Rio Tinto in Spain more than 300 years ago is basically the same as that used today. Processing concepts such as solution management (sprinklers and leach/rest cycles) and copper recovery (cementation on iron) were introduced at Rio Tinto to maximize copper production (Taylor and Whelan, 1942). Today this technology has been refined and adapted to the recovery of other metals (e.g., gold, silver, and uranium), as well as copper. The treatment of low-grade gold and silver ores by this technique has been especially successful and has been the subject of several technical articles (Chamberlain and Pojar, 1981; Chamberlin, 1981; Potter, 1981; Hiskey, 1984, 1985).

Figure 2 shows a general layout for a heap-leaching system. Run-of-mine or crushed ore is delivered to a specifically prepared, impervious pad and stacked to a height of 3 to 15 meters. [One heap-leaching variation—"thin layer" TL leaching—stacks the ore in relatively shallow 1-meter beds (Johnson, 1977).] Leaching solutions are applied to the surface of the heap, usually by spraying or sprinkling, and are allowed to percolate through the ore by gravity. The pregnant leach solution containing dissolved copper collects on the impervious pad and drains to a channel, which delivers the solution to a metal-recovery circuit.

Average Copper Yield U.S. Copper Ores

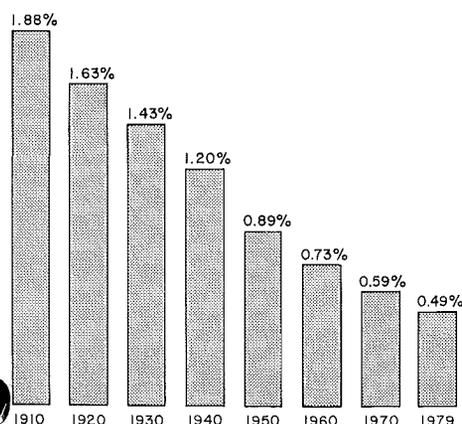


Figure 1. Average yield of copper ores mined in the United States.

Table 1. Leaching reactions for copper minerals in zones of mineralization.

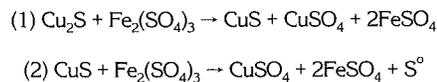
Mineralized Zone	Mineral	Leaching Reaction
Oxidized Zone (Secondary)	Native Copper	---
	Malachite	$\text{CuCO}_3 \cdot \text{Cu}(\text{OH})_2 + 4\text{H}^+ \rightarrow 2\text{Cu}^{2+} + \text{CO}_2 + 3\text{H}_2\text{O}$
	Brochantite	$\text{CuSO}_4 \cdot 3\text{Cu}(\text{OH})_2 + 6\text{H}^+ \rightarrow 4\text{Cu}^{2+} + \text{SO}_4^{2-} + 6\text{H}_2\text{O}$
	Antlerite	$\text{CuSO}_4 \cdot 2\text{Cu}(\text{OH})_2 + 4\text{H}^+ \rightarrow 3\text{Cu}^{2+} + \text{SO}_4^{2-} + 4\text{H}_2\text{O}$
	Atacamite	$3\text{CuO} \cdot \text{CuCl}_2 \cdot 3\text{H}_2\text{O} + 6\text{H}^+ \rightarrow 4\text{Cu}^{2+} + 2\text{Cl}^- + 6\text{H}_2\text{O}$
	Azurite	$2\text{CuCO}_3 \cdot \text{Cu}(\text{OH})_2 + 6\text{H}^+ \rightarrow 3\text{Cu}^{2+} + 2\text{CO}_2 + 4\text{H}_2\text{O}$
	Chrysocolla	$\text{CuO} \cdot \text{SiO}_2 \cdot 2\text{H}_2\text{O} + 2\text{H}^+ \rightarrow \text{Cu}^{2+} + \text{SiO}_2 + 3\text{H}_2\text{O}$
	Cuprite	$\text{Cu}_2\text{O} + 2\text{H}^+ \rightarrow \text{Cu}^{2+} + \text{Cu}^0 + \text{H}_2\text{O}$
	Tenonite	$\text{CuO} + 2\text{H}^+ \rightarrow \text{Cu}^{2+} + \text{H}_2\text{O}$
Supergene Enrichment Zone (Secondary)	Chalcocite	$\text{Cu}_2\text{S} + 2\text{H}^+ + \frac{1}{2}\text{O}_2 \rightarrow \text{Cu}^{2+} + \text{CuS} + \text{H}_2\text{O}$ ← second stage
	Covellite	$\text{CuS} + 2\text{H}^+ + 2\text{O}_2 \rightarrow \text{Cu}^{2+} + \text{H}_2\text{SO}_4$ ← stage
	Native Copper	$\text{Cu}^0 + 2\text{H}^+ + \frac{1}{2}\text{O}_2 \rightarrow \text{Cu}^{2+} + \text{H}_2\text{O}$
Hypogene Zone (Primary)	Chalcopyrite	$\text{CuFeS}_2 + 16\text{Fe}^{3+} + 8\text{H}_2\text{O} \rightarrow \text{Cu}^{2+} + 17\text{Fe}^{2+} + 2\text{SO}_4^{2-} + 16\text{H}^+$
	Bornite	$\text{Cu}_5\text{FeS}_4 + 36\text{Fe}^{3+} + 16\text{H}_2\text{O} \rightarrow 5\text{Cu}^{2+} + 37\text{Fe}^{2+} + 4\text{SO}_4^{2-} + 32\text{H}^+$
	Enargite	$\text{Cu}_3\text{AsS}_4 + 35\text{Fe}^{3+} + 20\text{H}_2\text{O} \rightarrow 3\text{Cu}^{2+} + 35\text{Fe}^{2+} + \text{H}_3\text{AsO}_4 + 4\text{SO}_4^{2-} + 37\text{H}^+$
	Tetrahedrite	$\text{Cu}_{12}\text{Sb}_4\text{S}_{13}$
	Tennantite	$\text{Cu}_{12}\text{As}_4\text{S}_{13}$
	Covellite	$\text{CuS} + 8\text{Fe}^{2+} + 4\text{H}_2\text{O} \rightarrow \text{Cu}^{2+} + 8\text{Fe}^{2+} + \text{SO}_4^{2-} + 8\text{H}^+$

Copper leaching is sensitive to the copper mineralogy of the treated ore. Mineralogy is especially important in heap-leaching schemes that employ relatively short leach cycles. Careful consideration of pH and oxidation potential is required to establish the conditions for solubilizing copper. The work of Garrels and Christ (1965) and Peters (1972) is noteworthy in this regard. Bateman (1951) summarized the relative importance of copper minerals in a typical deposit. This information, along with the respective leaching reactions, is listed in Table 1. Except for native copper, oxidized-zone minerals dissolve under acidic conditions; the rate of dissolution, however, varies. All oxidized-zone minerals, except chrysocolla and cuprite, dissolve completely and at relatively fast rates with a sulfuric-acid lixiviant or leaching solution. Chrysocolla leaching is limited by the diffusion of reactant (H^+) and product (Cu^{2+}) through a porous product layer of $\text{SiO}_2 \cdot n\text{H}_2\text{O}$. Cuprite, on the other hand, dissolves according to a disproportionation reaction under nonoxidizing conditions to yield 50 percent cupric ion and 50 percent metallic copper. With cuprite, therefore, the reaction would be only 50 percent complete under simple acid-leaching conditions.

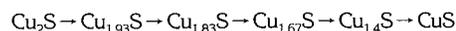
Oxidized copper ores are especially suited for heap leaching because of the fast kinetics associated with the dissolution of these minerals. As a result, processing strategies that involve leaching cycles ranging from days to months are typically used in heap leaching.

Secondary sulfides such as chalcocite and covellite require the presence of an oxidant for dissolution. The reactions shown in Table 1 are written with O_2 as the oxidant. Ferric ion can exist, however, at activities much greater than that of dissolved oxygen and is kinetically more

important in the oxidation of copper-sulfide minerals. The reactions involved in the acid ferric-sulfate leaching of chalcocite (Cu_2S) are as follows:



As indicated, the dissolution of Cu_2S proceeds according to two general reaction steps. A detailed analysis shows that the oxidation of Cu_2S to CuS involves the sequential formation of a series of Cu_xS compounds (Koch and McIntyre, 1976):



The second stage (reaction 2) involves the oxidation of covellite (CuS) to cupric ion and elemental sulfur. The elemental sulfur that is produced is thermodynamically unstable; however, oxidation of sulfur to sulfate is limited by slow kinetics under ambient conditions.

The heap leaching of mixed oxide/sulfide ores is accomplished by acid cure and acid-ferric cure processes (Pazour, 1981; Fountain and others, 1983; Domic, 1984). These processes can increase the rate of copper recovery and reduce acid consumption by controlling the method of acid addition.

Dump Leaching

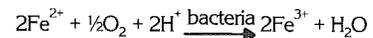
The general methodology of dump leaching is very similar to that of heap leaching. There are important differences, however, between these types of solution-mining operations:

- (1) Material: Dump leaching usually treats waste rock (typically below 0.2 percent Cu), whereas heap leaching involves the

processing of moderately high-grade Cu ores.

- (2) Size: Run-of-mine sizes are leached in dumps. In heap leaching, the ore may be crushed to optimize copper recovery.
- (3) Base: Most leach dumps are deposited on a surface of unmodified rock and soil that represents the preexisting ground surface with its original topographic irregularities. Heaps are customarily built on impervious drainage pads.
- (4) Mineralogy: Copper dumps predominantly contain sulfide mineralization. Studies have shown that the pyrite:copper-sulfide ratio is important because pyrite generates sulfuric acid, provides heat, and supports bacterial activity. Heap leaching, on the other hand, deals mostly with oxides or silicates and at times with mixed oxide/sulfide ores.
- (5) Lixiviant: Acid ferric-sulfate solutions provided by effective air circulation and good bacterial activity are required for the leaching of copper sulfides in dump material. Simple sulfuric-acid solution can effectively treat oxide minerals in heaps. An oxidant is necessary for the leaching of ores containing copper sulfides.
- (6) Leach Cycle: Dump leaching is usually measured in years, whereas heap leaching involves shorter periods ranging from days to months.

Figure 3 shows the general scheme of a typical dump leach/recovery circuit. Leach solution is applied to the surface of dumps by various methods such as ponding/flooding/trickle systems, multiple low-pressure sprinklers, and single high-pressure sprinklers. Air generally flows upward counter-current to the flow of leach solution. Oxygen in the air serves to oxidize ferrous iron to ferric iron under the accelerating effect of bacteria.



Ferric iron then participates directly in the oxidation of copper-sulfide minerals. Pregnant solutions emerging from the "toe" of the dump are collected in an impoundment and pumped to a copper-recovery plant.

Wadsworth (1981) has provided an excellent discussion of dump-leaching practice. Murr (1980) presented a comprehensive review of the theory and practice of copper-sulfide leaching in dump and in-situ leaching.

In-Situ Leaching

In-situ leaching is, by definition, performed on a mineral deposit that is in its natural or original position. Deposits that are candidates for in-situ leaching occur in a number of settings: pit walls, underground stopes, subsidence zones, small near-surface deposits, and deep-seated ore bodies. The first three settings would normally involve deposits above the natural water table and would be treated by principles similar to dump and heap leaching. Near-surface deposits could be either above or below the water table. Deep-seated deposits would probably exist below the natural water

table. For these reasons, hydrologic factors are very important in in-situ leaching. Hydrology is difficult to control in the leaching of deposits above the water table (unsaturated flow conditions). In an unsaturated flow regime, solution flow and mineral contact are greatly influenced by factors such as channeling, fines transport and compaction, salt precipitation (surface blockage), and stagnant zones.

The hydrologic setting of deep ore bodies requires leaching under saturated flow conditions. In in-situ leaching of copper deposits, low rock-matrix permeabilities often cause problems. Deposits like these require hydrologic modification to increase the ore-body permeability and porosity: rubilization, hydrofracturing, or chemical dissolution.

Two types of in-situ leaching systems are illustrated in Figures 4a and 4b (Wadsworth, 1977). Figure 4a represents the system used in underground stopes and remnant subsidence zones. Leach solution can be applied to the ore through injection holes or directly at the surface. Pregnant leach solution is collected in sumps or dams built in the underground workings. This in-situ leaching method is similar to that used at Noranda Lakeshore Mines, Inc., near Casa Grande, Arizona (Kline and Tatro, 1983; Kline and others, 1985).

The in-situ leaching of a deeply buried deposit is shown in Figure 4b. A porous ore body could be created by some hydrologic modification that would create permeable paths for solution flow. The depth of this ore body would position it in the hypogene zone of primary mineralization. An oxidant would clearly be required to dissolve the copper minerals present in this type of environment. Air or oxygen could be introduced in the injection well; at high hydrostatic pressures, oxygen would be competitive with ferric ion as a lixiviant for primary copper minerals.

Ahlness and Pojar (1983) reported case histories of in-situ copper-leaching projects in the United States. From this survey, they provided a list of requirements for a successful in-situ leaching system:

- (1) Non-acid-consuming host rock
- (2) Host rock that will not decrepitate
- (3) Rock sufficiently fractured to permit access of solutions to copper minerals
- (4) Copper minerals primarily concentrated along fracture surfaces
- (5) Solid impervious surface under or surrounding deposit
- (6) Copper minerals that dissolve within required time limits
- (7) Ability to recirculate solutions through ore many times without excessive loss or contamination
- (8) Availability of adequate water.

Table 2 lists commercial in-situ mining projects that have operated since 1970. Big Mike mine, Old Reliable mine, and Zonia mine were all blasted prior to in-situ leaching. None of these are currently active. All other listed operations involved the leaching of old block-caved areas or, in the case of the Copper Queen Branch, an open pit with underground workings. Currently active operations include

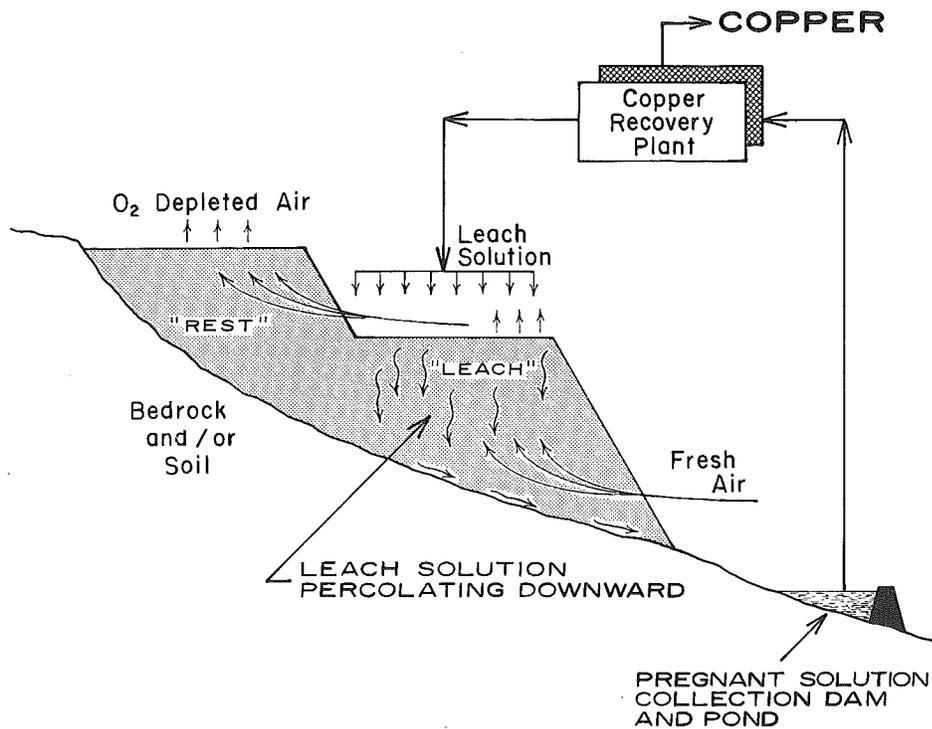


Figure 3. Cross section of a copper waste dump showing one lift under active leaching and another in a rest period.

Lakeshore mine, Miami mine, and Copper Queen Branch. Plans for an in-situ operation at Newmont's San Manuel mine have been announced (Newmont, 1986).

Experimental programs aimed at demonstrating the feasibility of in-situ leaching date back to 1906 at Medler mine near Clifton, Arizona. In recent years, important test programs have been undertaken by Occidental Minerals Corp. at the Van Dyke (Miami, Arizona) deposit, by Kennecott at the Safford

(Arizona) deposit, and by Cleaveland-Cliff and DuPont at the Mountain City (Nevada) mine. The U.S. Bureau of Mines has conducted several fragmentation experiments in conjunction with their in-situ mining studies (Steckley and others, 1975; D'Andrea and others, 1978). During the next few months, the U.S. Bureau of Mines will be negotiating a contract to sponsor a study that will involve the analysis and design of an in-situ copper-leaching project (U.S. Bureau of Mines, 1986).

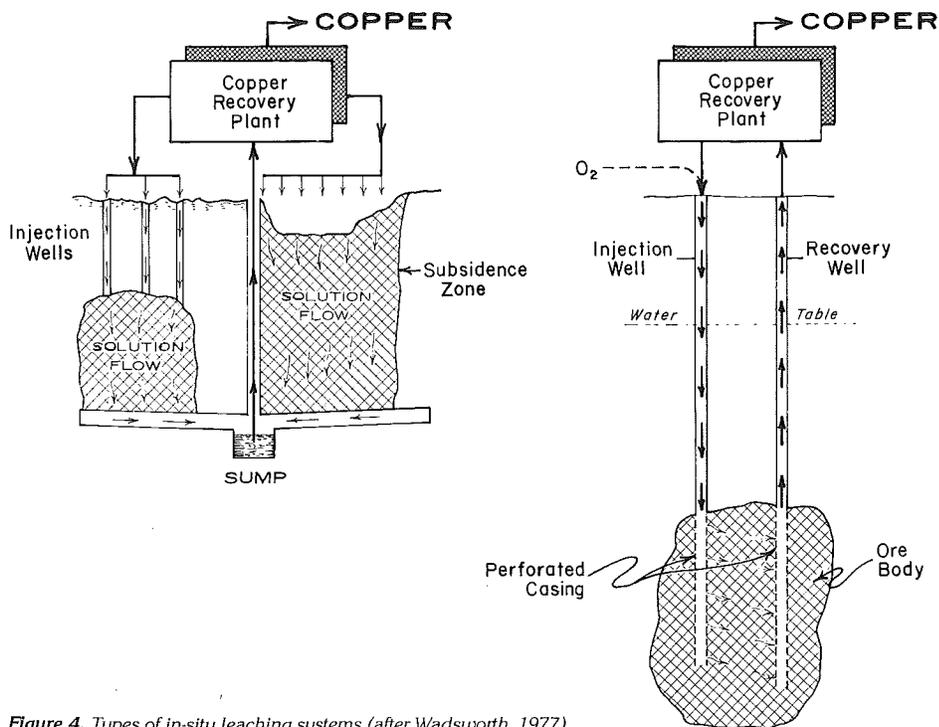


Figure 4. Types of in-situ leaching systems (after Wadsworth, 1977).

Table 2. Commercial in-situ mining activities in the United States since 1970.

Project	Dates	Principal Copper Minerals	Average Grade Percentage Copper	Preparation
Big Mike (NV) Ranchers	1973-74 1978-79	Cuprite, tenorite, and chalcopyrite	1.18	Blasted pit walls and bottom (terraced surface)
Old Reliable (AZ) Ranchers	1972-74 1979-81	Chalcocite, chalcopyrite, malachite, and chrysocolla	0.84	Blasted old under- ground workings (terraced surface)
Zonia (AZ) McAlester Fuel	1973-75	Chrysocolla	0.20	Blasted pit walls and bottom
Copper Queen Branch (AZ) Phelps Dodge	1975-	Chalcocite	0.29	None; Open pit and underground workings
Inspiration (AZ) Inspiration Consolidated	1967-74	Azurite, malachite, and chrysocolla	0.50	None; Block-caved stopes
Miami (AZ) Newmont	1942-	Chalcocite	NA	Surface prepared above block-caved areas
Lakeshore (AZ) Noranda	1983-	Chrysocolla, brochantite, and cuprite	0.45	None; Block-caved areas

CURRENT STATUS OF U.S. COPPER LEACHING

Western U.S. copper operations have historically derived a significant portion of their primary copper production from leaching activities. Leach copper has been mainly produced from low-grade sulfide waste dumps, oxide ores in heaps and vats, and abandoned mine workings (i.e., pit walls and underground stopes). In 1978 leaching accounted for approximately 18 percent of all primary copper production (Schlitt, 1980). Leach production in 1978 ranged from 8.3 percent at Duval operations to about 37 percent at Inspiration Consolidated mines. Kennecott was the largest domestic producer of leach copper (88,200 standard tons), which represented about 25 percent of the company's total production. The following discussion provides an update of leach-copper production for the past few years.

Arizona produces more copper than any other State: approximately two-thirds of the primary mine production in the United States. Arizona also leads the Nation in leach-copper production and is therefore believed to be representative of the trends in leaching practice. Table 3 reports recent copper production from leaching for the major operations in Arizona (Hicks, 1986). In 1984 Inspiration Consolidated Copper Co. produced more leach copper [36,083 metric tons (mt)] than any other operation in Arizona. About 53 percent of the company's total production resulted from leaching activities. Phelps Dodge Corp., the largest copper producer in Arizona, derived 13 percent of its total production from leaching.

Figure 5 shows the trends in Arizona leach-copper production during the past 18 years. Between 1968 and 1974, the percentage of

copper from Arizona leaching operations remained constant at about 11 percent of total mine production. Since 1974 there has been an increasing trend in leach output, which reached about 20 percent of total production in 1982. In 1985 leach production totaled 121,103 mt and accounted for 15 percent of the State's total copper output. Some leaching operations were not immune to the problems of the domestic copper industry and were forced to suspend operations, as reflected in the decline in leach output since 1981.

During the next few years, leach-copper production is likely to provide more than 25 percent of the primary copper produced in Arizona. This figure was determined by considering three new leaching projects. The first, a \$90-million SX-EW complex to be built by Phelps Dodge in Morenci, Arizona, will produce 41,000 mt of copper annually (Phelps Dodge, 1986). The second project, a \$70-million dump-leaching project by Magma Copper Company, is scheduled for start-up in July 1986 (Newmont, 1986). This operation will involve the leaching of oxide ore mined by open-pit methods. A modern SX-EW plant will annually produce about 22,700 mt of copper from this operation at San Manuel, Arizona. Magma plans to produce a similar amount of copper from the in-situ leaching of an oxide ore body that caved in as a result of underground mining activities in San Manuel. Leach production at Magma is estimated to reach 45,500 mt of copper in a few years. The final project, planned by the Ray Mines Division of Kennecott, involves the silicate-ore leaching facility, which was shut down in 1982 and has recently been modified to produce about 18,200 mt of copper per year (Standard Oil, 1986).

These three producers represent a combined total of about 105,000 mt of new leach-

copper production, a significant contribution to Arizona's overall copper output. Based on this figure, it is estimated that Arizona's total leach-copper production will equal 226,000 mt (25 percent of primary copper production) in the near term. With the likelihood of additional leaching projects and expansion of existing plants, the percentage of copper produced by leaching may approach 30 percent by 1990.

At the time of this writing, leaching remains a supplemental form of production for the majority of Arizona copper operations. Despite this subservient role and the declining trend shown in Figure 5, the percentage of copper produced by hydrometallurgical techniques will increase in the future. Porphyry deposits lack a sharp distinction between ore and waste. As a result, the amount of copper contained in waste is large and could equal or exceed the amount of copper in designated ore (Schlitt, 1980). Pitt and Wadsworth (1980) emphasize that as energy costs for milling increase, conventional milling will require higher ore grades, leaving more low- to medium-grade material for leaching. Low- to medium-grade "halo" mineralization zones, deep-lying deposits, and low-grade waste dumps are all future targets for solution mining. Waste dumps from open-pit copper operations in the western United States alone represent a tremendous resource of recoverable copper. Kennecott's Bingham Canyon mine has an estimated 5 billion mt of waste rock in dumps adjacent to the mine. Though not as enormous as Bingham Canyon, significant amounts of low-grade reserves exist in dumps in Montana, Nevada, New Mexico, and Arizona. Based on average stripping ratios and tons of mined copper ore, it is estimated that 2.8 billion mt of leachable waste were collected in low-grade dumps in Arizona during the 10-year period from 1975 through 1984.

SUMMARY

Despite recent problems in the U.S. copper industry, the recovery of copper by leaching is likely to expand. The greatest potential lies in the treatment of waste dumps and the application of in-situ leaching technology to deposits that would otherwise be left unmined by

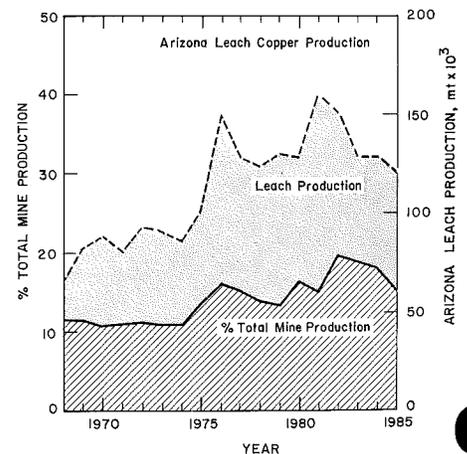


Figure 5. Trends in Arizona leach-copper production, 1968-85.

conventional techniques. Large tonnages of low-grade material can be mined through dump leaching and the copper recovered by state-of-the-art SX-EW plants. Fully integrated plants are now capable of treating very dilute solutions and producing high-quality cathode copper.

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Table 3. Leach production by major Arizona copper producers.

Company/Operation	Copper Production From Leaching (Metric Tons)					
	1979	1980	1981	1982	1983	1984
Anamax Mining Company Twin Buttes	31,907	28,902	30,809	27,577	22,974	22,788
Asarco Inc. Silver Bell	3,166	2,006	3,606	3,940	4,706	4,151
Cyprus Mines Corp. Bagdad	6,503	5,746	6,007	5,975	6,025	6,000
Johnson	4,550	4,673	4,850	4,401	—	3,993
Duval Corp. Esperanza	2,722	4,532	5,246	4,243	2,888	3,856
Mineral Park	1,519	1,674	1,902	1,447	1,407	1,233
Inspiration Consolidated Inspiration	7,547	13,135	22,921	22,680	35,828	36,083
Ox Hide	534	460	345	713	—	—
Kennecott Ray*	12,021	11,737	11,697	10,170	9,087	9,279
Noranda Lakeshore	—	—	11,826	20,689	1,571	6,986
Phelps Dodge Corp. Copper Queen Branch	3,318	2,745	2,087	2,062	2,359	1,584
Morenci Branch	42,630	39,390	43,586	34,353	31,370	27,357
New Cornelia Branch	—	—	2,503	7,555	6,959	—
Pinto Valley Copper Corp. Copper Cities	1,974	1,807	1,643	928	—	—
Miami	5,732	5,073	4,634	4,672	4,213	11,613**
Pinto Valley	—	—	2,503	7,555	6,959	—
Ranchers Bluebird	4,967	5,904	6,045	—	—	—
Old Reliable	456	512	68	—	—	—
TOTAL	129,546	128,296	159,775	151,705	129,287	129,346

* Electrowinning production not included.
** Combined Miami and Pinto Valley production.

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Decade of North American Geology

The Decade of North American Geology (DNAG), the centennial project of the Geological Society of America, spans 10 years of planning, development, and printing, which formally began in 1979. The goal of the project is to publish a modern synthesis of the geology and geophysics of North America and the adjacent oceanic regions. Publications will include 40 volumes, 23 continent-ocean transects, and 7 wall-size geologic and geophysical maps of North America. The 40 volumes

will include a 19-volume set of the geology of North America (United States and Mexico), a 9-volume set of the geology of Canada, 6 field guides for the United States and Canada, and 4 special-topic volumes. More than 1,000 editors, authors, and contributors have collaborated on the DNAG project. For further information, contact the Marketing Dept., Geological Society of America, P.O. Box 9140, Boulder, CO 80301; (303) 447-2020.

Recent Publications on the Geology of Arizona

The following publications were recently added to the Bureau library, where they may be examined during regular working hours. Copies may also be obtained from the respective publishers.

U.S. Bureau of Mines

Mineral Land Assessment Reports

- MLA 51-85**—Schreiner, R. A., 1985, Mineral resources of the lower Burro Creek Wilderness Study Area (AZ-020-060), Mohave and Yavapai Counties, Arizona, 71 p., scale 1:24,000.
- MLA 2-86**—Zelten, J. E., 1986, Mineral resources of a part of the Dos Cabezas Mountains Wilderness Study Area (AZ-040-065), Cochise County, Arizona, 31 p., scale 1:24,000.
- MLA 9-86**—McDonnell, J. R., Jr., 1986, Mineral investigation of the Baboquivari Peak Wilderness Study Area (AZ-020-203B), Pima County, Arizona, 10 p.
- MLA 43-86**—Kreidler, T. J., 1986, Mineral investigation of a part of the Canean Mountain Wilderness Study Area, Kane and Washington Counties, Utah (UT-040-143) and Mohave County, Arizona (AZ-010-041), 13 p., scale 1:48,000.
- MLA 45-86**—Lane, M. E., 1986, Mineral investigation of a part of the Eagletail Mountains Wilderness Study Area (AZ-020-128), La Paz, Maricopa, and Yuma Counties, Arizona, 16 p., scale 1:50,000.
- MLA 46-86**—McDonnell, J. R., Jr., 1986, Mineral investigation of a part of the Woolsey Peak Wilderness Study Area (AZ-020-142/144), Maricopa County, Arizona, 14 p., scale 1:62,500.

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- 1548**—Blacet, P. M., 1985, Proterozoic geology of the Brady Butte area, Yavapai County, Arizona, 55 p., scale 1:24,000 and 1:62,500.
- 1599**—Haxel, G. B., Tosdal, R. M., and Dillon, J. T., 1985, Tectonic setting and lithology of the Winterhaven Formation; a new Mesozoic stratigraphic unit in southeasternmost California and southwestern Arizona, 19 p.

Maps

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- I-1644**—Billingsley, G. H., Barnes, C. W., and Ulrich, G. E., 1985, Geologic map of the Coconino Point and Grandview Point quadrangles, Coconino County, Arizona, scale 1:62,500.
- MF-1558-C**—Martin, R. A., 1986, Aeromagnetic map of the Wet Beaver Roadless Area, Yavapai and Coconino Counties, Arizona, scale 1:24,000.
- MF-1567-C**—Martin, R. A., 1986, Aeromagnetic map of the Rattlesnake Roadless Area, Coconino and Yavapai Counties, Arizona, scale 1:24,000.
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- 86-33**—Page, N. J., Theodore, T. G., and Bradley, L. A., 1986, Discussion of ultramafic and mafic rocks and platinum-group element analyses from the Lost Basin mining district, northwestern Arizona, 13 p.
- 86-36**—Bowles, C. G., and Reimer, G. M., 1986, A soil-gas helium survey of the

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- Wilkins, Joe, Jr., ed., 1984, Gold and silver deposits of the Basin and Range Province, western U.S.A.: Arizona Geological Society Digest, v. 15, 233 p.

New Publications Discuss Geologic Issues

The American Institute of Professional Geologists (AIPG) has released the following publications on current issues for which geology plays a significant role in formulating public policy: **Ground Water**, 24 p.; **Hazardous Waste**, 24 p.; and **Radioactive Waste**, 27 p. The booklets, which are written in nontechnical language, are useful to the general public, as well as professional geologists. In each booklet, terminology is defined in the text and in a separate glossary. Numerous graphs, maps, and charts illustrate key points, and a bibliography lists sources of additional information. To obtain copies and price information, contact AIPG, 7828 Vance Dr., Suite 103, Arvada, CO 80003; (303) 431-0831.

The American Petroleum Institute (API) recently published three booklets on topics related to the petroleum industry: **Environmental Conservation and the Petroleum Industry**, 47 p.; **Geophysics in Petroleum Exploration**, 24 p.; and **Petroleum Exploration, Continuing Need**, 24 p. The first publication contains an extensive reference list for additional reading; the latter two publications are liberally illustrated with photographs and figures. To obtain these free booklets, contact API, 1220 L St., N.W., Washington, DC 20005; (202) 682-8170.

New Bureau Publications

The following publications may be purchased over the counter or by mail from the Bureau offices at 845 N. Park Ave., Tucson, AZ 85719. Orders are shipped via UPS; street address is required for fastest delivery. All orders must be prepaid by check or money order made out to the Arizona Bureau of Geology and Mineral Technology. Shipping and handling charges are listed below. If your total order is

\$1.01 to \$5.00, add \$1.75	40.01 to 50.00, add 7.75
5.01 to 10.00, add 2.25	50.01 to 100.00, add 10.00
10.01 to 20.00, add 4.25	More than 100.00, add 10%
20.01 to 30.00, add 5.50	Foreign mail, add 40%
30.01 to 40.00, add 6.25	

Miscellaneous Map Series

The Miscellaneous Map (MM) series provides an outlet for geologic maps produced by geologists who are unaffiliated with the Arizona Bureau of Geology and Mineral Technology. These maps represent significant contributions to the geologic literature on Arizona. Many are from theses and dissertations and would not be readily available to the public if they were not included in the MM series. The maps are reproduced as blue-line copies made from mylars provided by the authors.

- MM-76-A**—Varga, R. J., 1976, Geologic map and sections of a portion of the western Harquahala Mountains, Arizona, scale 1:12,000; \$2.00.
- MM-76-B**—DeWitt, Ed., 1976, Geologic map and Metamorphic and chemical data map of the Mayer-Crown King area, Yavapai County, Arizona, scale 1:24,000, 2 maps; both maps together: \$7.75.
- MM-77-A**—Suernicht, G. A., 1977, Geologic map and section of the Canada del Oro valley headwaters, Santa Catalina Mountains, Pima-Pinal Counties, Arizona, scale 1:1,000; \$2.00.
- MM-78-A**—Winegar, R. C., 1978, Silver Mountain geology (north half and south half), scale 1:4,800, 2 maps; each map: \$2.00.
- MM-81-A**—Johnson, G. S., 1981, Geologic maps and sample location map of the northern Picacho Mountains, Pinal County, Arizona, scale 1:6,000 and 1:24,000, 3 maps; all 3 maps together: \$7.50.
- MM-83-A**—Bykerk-Kauffman, Ann, 1983, Geologic map of the Buehman Canyon area, Pima County, Arizona, scale 1:6,000; \$3.50.
- MM-84-A**—Hankins, D. D., 1984, Geologic map of a portion of the southern Kofa Mountains, Arizona, scale 1:12,000; \$2.50.
- MM-85-A**—Riggs, Nancy, 1985, Geologic map of the Pajarito Mountains, Santa Cruz County, Arizona, scale 1:12,000; \$3.75.
- MM-85-B**—Stoneman, D. A., 1985, Geologic map of the Plomosa Pass area, northern Plomosa Mountains, La Paz County, Arizona, scale 1:12,000; \$3.00.
- MM-85-C**—Yeats, K. J., 1985, Geologic map and structure section of the northern Dome Rock Mountains, La Paz County, Arizona, scale 1:12,000; \$3.00.
- MM-85-D**—Goodlin, T. C., and Mark, R. A., 1985, Geologic map and Geologic cross sections through the Hot Springs Canyon area, Cochise County, Arizona, scale 1:24,000, 2 maps; both maps together: \$4.00.
- MM-86-A**—Janecke, S. U., 1986, Geologic map of the Geesaman Wash area, Pima and Pinal Counties, Arizona, scale 1:12,000; \$2.00.
- MM-86-B**—Cunningham, W. D., 1986, Geologic map and Geologic cross sections of the northwest Granite Wash Mountains, La Paz County, Arizona, scale 1:10,000, 2 maps; both maps together: \$3.00.

Open-File Reports

Reynolds, S. J., Roddy, M. S., and Welty, J. W., 1986, Map of Paleozoic rocks and conodont-color-alteration indices in Arizona: Open-File Report 86-1, scale 1:1,000,000; \$2.00.

This map shows outcrops of Paleozoic rocks and the locations of more than 100 published conodont-color-alteration indices (CAI) on these rocks. Conodonts are a type of phosphatic microfossil that changes color when heated and retains a color indicative of the highest temperature reached. Paleotemperature information is useful in assessing the petroleum potential of the rocks, in locating heat sources, such as ore-related intrusions, and in evaluating the burial and metamorphic history of specific areas.

Spencer, J. E., and Reynolds, S. J., 1986, Geologic map of the Lincoln Ranch basin, eastern Buckskin Mountains, western Arizona: Open-File Report 86-2, 6 p., scale 1:24,000; \$3.00.

This geologic map covers a 25-square-mile area of the eastern Buckskin Mountains, which are part of the Harcuvar metamorphic core complex. A complexly faulted and folded sequence of Tertiary sedimentary and volcanic rocks, including manganiferous sandstone and conglomerate, forms an upper-plate sheet that is separated from lower-plate mylonitic granitic, gneissic, and metasedimentary rocks by the mid-Tertiary Buckskin-Rawhide detachment fault. The detachment fault is cut and offset by the middle or late Tertiary Lincoln Ranch reverse fault.

Reynolds, S. J., Florence, F. P., Roddy, M. S., and Trapp, R. A., 1986, Preliminary map of K-Ar age determinations in Arizona: Open-File Report 86-3, scale 1:500,000, 2 sheets; both sheets together: \$5.50.

More than 1,200 K-Ar age determinations have been reported for rocks in Arizona. This map, which shows the location of all K-Ar age determinations listed in Open-File Report 85-8, provides an easy method of evaluating which K-Ar age determinations exist for a given area.

McGarvin, T. G., 1986, Index of published geologic maps of Arizona, July 1984-December 1985: Open-File Report 86-4, scale 1:1,000,000; \$2.50.

More than 70 references and the localities they cover are identified on this index map of Arizona. This map is an update of two earlier Bureau publications: Map 17, Index of published geologic maps of Arizona, 1903-1982 (set of six maps), \$6.00; and Open-File Report 84-5, Index of published geologic maps of Arizona, November 1982—June 1984, \$2.00.

Shenk, J. D., and Reynolds, S. J., 1986, Partial list of holdings in the Arizona Bureau of Geology and Mineral Technology library: Open-File Report 86-5, 105 p.; \$12.50.

This report is a partial list of publications on the geology and mineral resources of Arizona that can be found in the Arizona Bureau of Geology and Mineral Technology library. These include Bureau publications and unpublished reports, U.S. Department of Energy publications, most of which are open-file reports, and general publications. Holdings from organizations that issue lists of their own publications, such as the U.S. Geological Survey, U.S. Bureau of Mines, and Arizona Department of Mines and Mineral Resources, are not included in this list.

Reynolds, S. J., Florence, F. P., and Trapp, R. A., 1986, Migration patterns of post-40-Ma magmatism in Arizona: Open-File Report 86-6, 23 p., map; text: \$3.75; map: \$2.00.

Arizona has experienced widespread magmatism since 40 Ma, when volcanism resumed after a 15- to 20-m.y. hiatus. Magmatism during the past 40 m.y. was not evenly distributed, but migrated across the State. The patterns of migration are important because they provide insight into the tectonic setting of magmatism and thus illuminate the processes responsible for the magmatism and related mineral deposits. In addition, documenting the location of recent volcanism is a necessary step toward evaluating the potential for geothermal energy or volcanic hazards.

Computerized compilations of all published K-Ar age determinations in Arizona have been used to generate page-size maps showing the age distribution for different time intervals since 40 Ma. These maps are included in this report, as well as a 1:1,000,000-scale map that shows histograms of age determinations within each 1° x 1° quadrangle. This latter map is especially useful in assessing the post-40-Ma magmatic history of any area within the State.

Reynolds, S. J., and Trapp, R. A., 1986, Computerized databases and database-access programs of the Arizona Geological Survey: Open-File Report 86-7, 66 p.; \$9.50.

The Arizona Geological Survey, which is the Geological Survey Branch of the Arizona Bureau of Geology and Mineral Technology, has been computerizing information on the geology and mineral resources

of Arizona. During the past several years, numerous computerized databases have been created, including those for radiometric age determinations, general and thesis bibliographies, conodont-color-alteration indices, and the mailing list for *Fieldnotes*. Programs have also been written to access, search, and display this information. The databases and programs were created using dBase II, a database-management program from Ashton-Tate, Inc.

This report lists the structures and access programs for the most widely requested geologic databases. All programs, except those that generate graphics-output files, will run on any computer for which dBase II is available. The graphics programs write output files for use with the graphics software GSX-86 from Digital Research, but can be easily modified for other graphics drivers.

Pearthree, P. A., 1986, Late Quaternary faulting and seismic hazard in southeastern Arizona and adjacent portions of New Mexico and Sonora, Mexico: Open-File Report 86-8, 22 p.; \$3.50.

The potential for large earthquakes in southeastern Arizona and adjacent portions of New Mexico and Sonora, Mexico was demonstrated by the Sonoran earthquake of 1887, which measured 7.25 on the Richter scale. With the exception of this one event, however, historical seismicity in the region has been very low.

Quaternary geologic studies provide a chronologic framework for late Quaternary surface-rupturing earthquakes. Preservation of mid-Pleistocene and older surfaces provides a long record of surface displacement, and hence, the evidence needed to estimate long-term rates of fault movement and recurrence of surface rupture. Analysis of fault-scarp morphology also helps in estimating ages of late Quaternary surface ruptures. This report uses these methods to define locations and estimate ages of Holocene and late Pleistocene faulting events, and thus to assess regional seismic hazards and temporal and spatial patterns of faulting during the late Quaternary.

Spencer, J. E., Reynolds, S. J., and Lehman, N. E., 1986, Geologic map of the Planet—Mineral Hill area, northwestern Buckskin Mountains, west-central Arizona: Open-File Report 86-9, 13 p., scale 1:24,000; \$4.00.

This geologic map covers a 56-square-mile area of the northwestern Buckskin Mountains, which are part of the Harcuvar metamorphic core complex. A complexly faulted sequence of Paleozoic carbonates and

New DMMR Publications

The following publications are available from the Arizona Department of Mines and Mineral Resources (DMMR), which has two offices: Mineral Building, Fairgrounds, Phoenix, AZ 85007, telephone (602) 255-3791; and State Office Building, 416 W. Congress, Suite 161, Tucson, AZ 85701, telephone (602) 628-5399.

Directory of Earth Science Clubs in Arizona, 1986, Annual Directory No. 27, 17 p.; \$2.00, plus \$1.00 for postage and handling. This directory lists 78 clubs that are involved in lapidary activities, gold prospecting, rock collecting, mining, and geology. Each listing includes meeting dates, times, and locations; officers; club specialties; and membership restrictions.

Arizona Mineral Potential Map, 1986, scale 1:500,000; \$7.00, plus shipping and handling (\$1.00 for folded copies; \$4.00 for rolled copies). This map, a joint effort by DMMR and the U.S. Bureau of Mines, shows areas within the State that are considered highly favorable, favorable, and less favorable for the future discovery and development of metallic and nonmetallic mineral deposits. Also shown on the map are areas of past mineral production.

Mining Scams, 1986, by M. N. Greeley, Circular No. 11, 8 p.; free except for 30¢ for postage. "A time-honored method to bilk the public of millions of dollars is the ubiquitous mining swindle": so begins this compendium of pitfalls that frequently entrap an unsuspecting investor. The report focuses on the fundamental ingredients of a successful mineral venture and the danger signs of typical mining scams. It is written especially for the person who is considering a first-time investment in a mining or mineral-processing proposal.

quartzites, Mesozoic metasedimentary and metavolcanic rocks, and Tertiary volcanic and sedimentary rocks forms an upper-plate sheet separated from underlying mylonitic granitic and gneissic rocks by the mid-Tertiary Buckskin-Rawhide detachment fault. Upper-plate rocks have been extensively mineralized near and along the detachment fault, especially at the Mineral Hill and Planet mines. Postdetachment basin-fill sediments and basalt are cut and offset, together with older rocks, by the high-angle Mineral Wash fault.

ARIZONA PROFILE

Arizona ranked fourth in the Nation in production of construction sand and gravel during 1985, a gain of two places from the 1984 ranking. California, Texas, and Michigan were the top three producers. According to statistics compiled by the U.S. Bureau of Mines, Arizona produced 38 million tons, valued at \$122.9 million, or 4.7 percent and 5.0 percent, respectively, of the Nation's total production.

Fieldnotes

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