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The 1887 Sonoran Earthquake: It Wasn't Our Fault

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On May 3, 1887 Arizona and the Southwest experienced a major earthquake that had an estimated magnitude of 7.2 on the Richter scale (DuBois and Smith, 1980). The epicenter was in Sonora, Mexico approximately 40 miles south of Douglas, Arizona. The earthquake caused several dozen deaths, damaged buildings as far away as Phoenix, generated rockfalls and fires triggered by rockfalls in the mountains, and caused panic among the population. This year is the 100th anniversary of the only earthquake that caused considerable damage in Arizona in historic times.

Although earth scientists know much more now regarding the mechanisms of earthquakes than they did 100 years ago, reliable earthquake prediction is still in its infancy. It is known that the crust and uppermost mantle of the earth is divided into approximately a dozen major sections or "plates" that are slowly moving. Rates of relative movement range up to several inches per year. It is along the plate boundaries that the most earthquakes occur. The San Andreas fault of California is a plate boundary along which the Pacific plate is moving northwestward with respect to the adjacent North American plate. Because of friction along plate boundaries, plates do not smoothly slip past each other. As a consequence, resistance to movement allows stress to accumulate. When stress builds to the point at which it overcomes the resisting forces, energy is released causing ground motion, or an earthquake.

Although southeastern Arizona is several hundred miles from the San Andreas fault system, it is not immune to earthquakes. No region can be considered completely earthquake free; in fact, worldwide there are approximately 1 million detectable earthquakes annually (Gilluly and others, 1968). The majority of these are small shocks that cause no damage. The large, dangerous earthquakes occur less frequently, on the average of only several per year, and are usually concentrated along plate boundaries. By the time the surface waves of these large events reach southeastern Arizona, the energy has dissipated so that little or no motion is felt except by sensitive recording devices.

The 1887 event was, however, close enough and strong enough to cause major damage and loss of life in the southern portion of the State. The earthquake occurred along a south-trending fault approximately 30 miles in length located south of Douglas, Arizona (Figure 1). This surface rupture, named the Pitaycachi (pronounced Pĭ tī´ kə chē) fault, is one of several surface faults in the region that are thought to have been active during the last 100,000 years (Pearthree, 1986). These faults are located along the margins of south-trending ranges in the southeastern Arizona—southwestern New Mexico border region and extend into Sonora, Mexico.

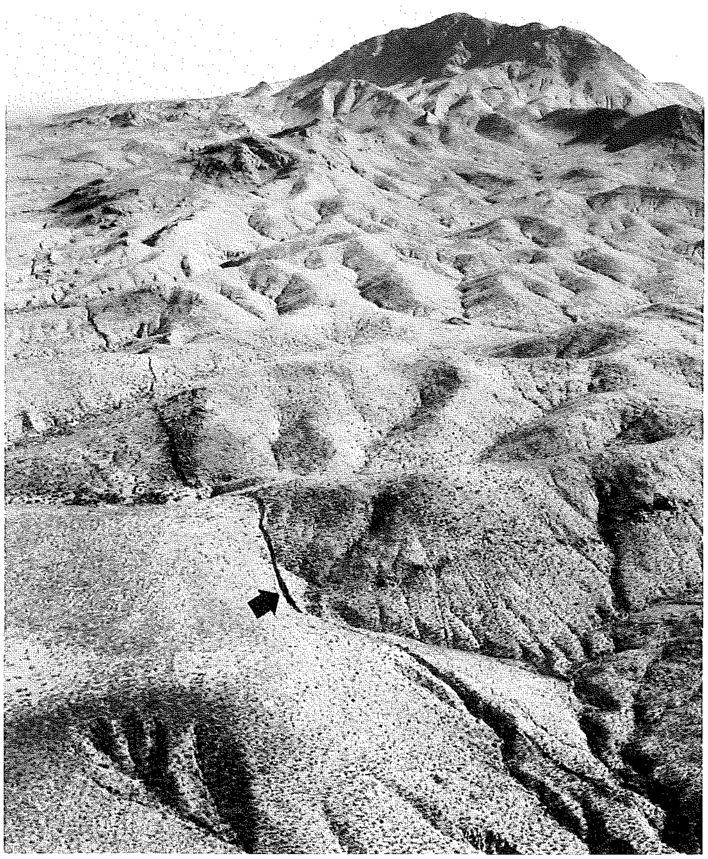

Figure 1. Aerial view, looking northward, of 1887 scarp along Pitaycachi fault, Sonora, Mexico. The fault extends from about 8 kilometers south of the Arizona border for 50 kilometers to and beyond Colonia Morales in the San Bernardino Valley. Photo by Peter Kresan.

It is estimated that the 1887 Sonoran earthquake released twice as much energy as any of the other earthquakes recognized in this region (Pearthree, 1986). Firsthand accounts reported that two violent shocks were preceded by low rumbling noises. This rumbling sound was reported in Tucson and as far away as Phoenix (Figure 2). Estimates of the duration of ground motion vary from a few seconds to approximately 10 minutes, with 1 to 3 minutes being the time most frequently reported. People throughout the region ran into the streets, some fainted, and others were thrown to the ground (DuBois and Smith, 1980). Numerous rockfalls were reported in the mountain ranges of southeastern Arizona and northern Sonora. Sparks from the crashing boulders ignited dry brush and grass, and fires quickly spread to the forests. Nearly all the valleys experienced changes in water conditions. Wells that had been excellent

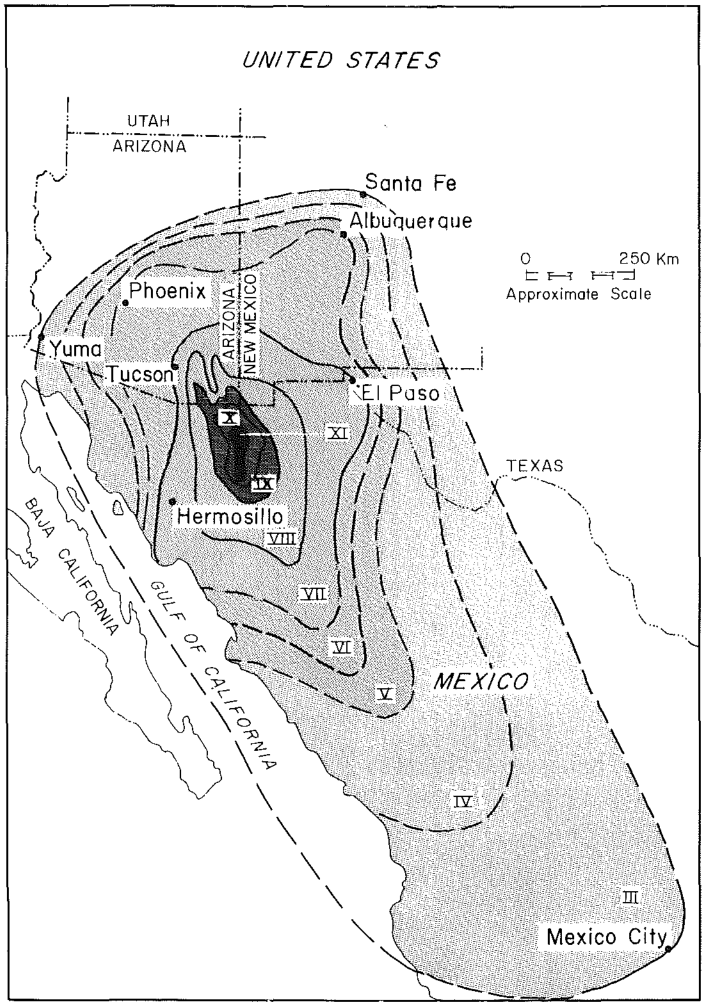

Figure 2. *Isoseismal map of the 1887 earthquake (from DuBois and Smith, 1980). Isoseismal lines connect points on the Earth's surface at which earthquake intensity is the same; they are usually closed curves around the epicenter (the black oval-shaped area shown in the map). The severity of an earthquake can be expressed in two very different ways: by magnitude and by intensity. Magnitude measures the amount of seismic energy released at the focus of an earthquake. It is determined from the logarithm of the amplitude of earthquake waves recorded by seismographs. Magnitude is expressed on the Richter scale in whole numbers and decimal fractions (e.g., 7.2, the magnitude of the 1887 earthquake). Theoretically this scale has no upper limit; however, the largest earthquake ever recorded, in Chile in 1960, had a magnitude of 9.5 (DuBois, 1979).*

Intensity is an arbitrary measure of the observable effects of an earthquake on humans and structures at a specific site. It varies from place to place depending on the strength of the earthquake (magnitude), the distance from the epicenter, and the local geology. The intensity scale currently used in the United States is the Modified Mercalli (MM) Intensity Scale. This scale, composed of 12 levels of intensity that range from imperceptible shaking (I) to catastrophic destruction (XII), is designated by Roman numerals, as shown in the map above. The lower numbers of the MM intensity scale generally deal with the manner in which the earthquake is felt by persons; the higher numbers are based on observed structural damage. For instance, the MM rating of III, recorded in Yuma during the 1887 earthquake, is based on the following MM characteristic: "Felt noticeably indoors, but not always recognized as earthquake." The rating of VI, recorded in Phoenix, is based on these observations: "Felt by all, many frightened and run outdoors; falling plaster, moving furniture; damage slight." Tucson was assigned an MM intensity level of VII during the 1887 earthquake: "Everybody runs outdoors; damage to buildings varies depending on quality of construction." At the epicenter, which was assigned an intensity rating of XI, observers reported the following: "Few structures remain standing; bridges destroyed; fissures in ground; pipes broken; landslides; rails bent."

sources of water went dry, whereas artesian conditions and temporary lakes were created in other areas. One of the more colorful descriptions of the event came from Charleston, Arizona (near Sierra Vista), where "the walls of the saloon did a two-step and the floor did a shimmey" (Weiss, unpub.).

Could such a large earthquake happen again in southeastern Arizona and could it be predicted? It is easier to predict that earthquakes will occur repeatedly along plate boundaries, where movement is well documented, than to predict recurrence in a plate interior, where southeastern Arizona is located. Fortunately, large and destructive earthquakes do not occur frequently in this region. Geologic evidence suggests that the amount of activity along surface ruptures here is very low. During the last 20,000 years, there have been approximately five surface-rupture faulting events with estimated recurrence intervals of 3,000 to 4,000 years in the region of extreme southeastern Arizona, southwestern New Mexico, and northeastern Sonora, Mexico (Pearthree, 1986, p. 7 and fig. 4). Evidence suggests that the Pitaycachi fault, source of the 1887 earthquake, is not likely to be the origin of a large earthquake in the foreseeable future (Bull and others, 1981).

Scientists worldwide are working on concepts that will allow long-range prediction of earthquakes and short-range warning. A variety of methods are being tested; however, a reliable technique is still years away from development. Until that day, earth scientists can only make "educated" guesses as to when another "big one" will occur.

In Arizona, earthquakes are being monitored by the Arizona Earthquake Information Center (AEIC), which was established in Flagstaff in November 1985 (Brumbaugh, 1986). For information on recent tremors in Arizona, write to AEIC, Box 5620, Northern Arizona University, Flagstaff, AZ 86011, or call (602) 523-7197.

The Arizona Bureau of Geology and Mineral Technology has several publications on seismicity and recent faulting in Arizona. Special Paper 3 (DuBois and Smith, 1980) focuses on the 1887 earthquake. It describes the characteristics of the Pitaycachi fault, quotes historical accounts from newspapers and other writings of that period, and analyzes the intensity patterns of the earthquake and its significance in terms of current seismic hazards in Arizona. Bulletin 193 (DuBois and others, 1982) is a compilation of data on the magnitude, source, distribution, and intensity of earth movements in Arizona from 1776 to 1980. Map 22 (Scarborough and others, 1986) identifies the youngest faults, folds, and volcanic rocks in Arizona. Open-File Report 86-8 (Pearthree, 1986) analyzes the scarp morphology and surface displacement of late Quaternary faults, identifies the locations of Holocene and late Pleistocene faulting events, and assesses the seismic hazards in southeastern Arizona, southwestern New Mexico, and northeastern Sonora, Mexico. Two earlier issues of *Fieldnotes* (Sumner, 1976; DuBois, 1979) provide general information about earthquakes such as where they occur, how they are measured, and if they can be predicted. For information on ordering these or other Bureau publications, contact the Bureau offices at 845 N. Park Ave., Tucson, AZ 85719, or call (602) 621-7906.

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The Nonfuel Mineral Industry: 1986 Summary

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In 1986 the value of nonfuel mineral production in the Southwest reached $6.1 billion, an 8-percent increase from the 1985 value of $5.7 billion (Figure 1; Table 1). Production in the Southwest accounted for 26 percent of total output in the Nation, estimated to be $23.5 billion in 1986. For the purposes of this article, the Southwest includes Arizona, California, Colorado, Nevada, New Mexico, and Utah.

These preliminary figures were recently published by the U.S. Bureau of Mines (USBM), which has released State-by-State estimates of nonfuel mineral production for 1986. Excerpts from the preliminary summaries for the Nation and the southwestern States appear below. Additional details on the national statistics are given in the USBM's 1987 *Mineral Commodity Summaries.* Single copies are free from the Publications Distribution Section, U.S. Bureau of Mines, Cochrans Mill Rd., P.O. Box 18070, Pittsburgh, PA 15236. The Mineral Industry Surveys for individual States were prepared by State mineral specialists from the USBM, in cooperation with the respective State mineral agencies. Lorraine B. Burgin, USBM State mineral specialist in Denver, compiled the Arizona summary, in cooperation with the Arizona Department of Mines and Mineral Resources. For copies of the preliminary reports, write to Mineral Industry Surveys, U.S. Department of the Interior, Bureau of Mines, Washington, DC 20241.

U.S. Summary

Production during 1986 by all major mining sectors—oil and gas, coal, industrial minerals, and metals—dropped from 1985 levels. Low mineral commodity prices continued to be a problem for most of the domestic mining industry. Aside from their impact on the oil-and-gas extraction industry, however, low oil prices were helpful to the economy, especially for the energy-intensive nonfuel minerals industry. Although physical output was generally below 1985 levels, the firming of nonfuel mineral prices allowed the current-dollar value of raw nonfuel mineral production to rise slightly. Like output, employment in the nonfuel-mineral mining and processing industries declined. Since 1981 total employment in these industries has dropped by 18 percent, or by about 600,000 jobs.

Mines producing copper kept their output at the 1985 level, but mine production of lead and zinc declined markedly. Domestic smelter and refinery output of these metals showed the same patterns, respectively. Domestic demand for copper and zinc increased, helped by expanding residential construction and automobile production. Demand for lead continued to be adversely affected by environmental regulations to remove lead from gasoline, but overall demand for lead was level. U.S. reliance on imports of these three metals was high, thus continuing the trend of recent years.

In response to low prices and competition from some world producers, major restructuring of the domestic copper industry continued. Significant developments included the reopening of two domestic copper mines under new ownership (both aided with loan guarantees by State and local governments) while the Nation's largest copper mine and several mines that produced byproduct copper remained closed. Other changes included spin-offs of domestic operations, increased foreign investment in U.S. operations, divestiture of foreign operations, and mergers. Some of these actions provided capital for modernization of plants, and the domestic use of lower cost solvent-extraction/electrowinning technology continued to expand. Lower cost contracts between labor and management continued to be an important factor in controlling the domestic production cost of copper.

The Environmental Protection Agency (EPA) determined in July that regulation of mining waste as hazardous waste was not warranted. EPA remained concerned about actual and potential damage from mining waste and planned to establish, by the end of 1989, a mining-waste regulatory program under the nonhazardous solid-waste provisions of the Resources Conservation and Recovery Act. In another action, EPA decided not to proceed with its proposed reinterpretation of the mining-waste exclusion for smelting and refining. Instead, EPA plans to establish criteria for identifying wastes included in the mining-waste exclusion and to begin the studies required to determine the appropriate regulatory regime for smelter and refinery wastes.

Weak demand combined with high inventories held down the price of molybdenum. Those firms that were primarily molybdenum producers were forced to cut production drastically. This was partly the result of continued production of molybdenum from copper operations, which overall did not change significantly from that of 1985.

Structural changes took place in the lead and zinc industry during 1986, but the decline of domestic production capacity for primary and secondary lead in recent years seemed to be related more to uncertainties in the long-term direction of environmental regulations than to price. The price of lead and zinc increased significantly as the year progressed because of worldwide supply shortages that developed toward year-end. Investment in replacement or modernization of domestic lead and zinc operations, however, continued to be limited to those associated with gold and silver production.

Owing mainly to events in the Republic of South Africa, gold prices reached their highest levels in recent years. As a result, gold continued to be a primary target of both domestic and international mineral exploration and development. In 1986, 40 new gold mines began production in the United States alone. Demand for gold in coins, in jewelry, and as a store of wealth also continued to increase, and a number of countries, including the United States, Australia, and Japan, began minting and selling gold coins.

Demand for building materials such as construction aggregate, gypsum, and cement remained strong. Crushed-stone production totaled more than 1 billion short tons for the second consecutive year, and construction sand-and-gravel production was the highest it had been in 6 years. Gypsum wallboard shipments were at a record high level because low interest rates spurred new residential construction.

The depressed state of the agricultural, oil and gas, and steel industries caused significant declines in demand for minerals used in fertilizers, drilling fluids, and steelmaking. Changing technologies and substitution of materials altered demand patterns for industrial minerals, increasing demand for some, often at the expense of others. Substitution of plastics for metals increased demand for filler and reinforcing minerals but decreased demand for refractories and fluxes. Industrial mineral producers continued to work toward higher valued, high-purity products that command a higher price such as high-purity silica sands and calcium carbonate, surface-modified clays, and wollastonite used in the

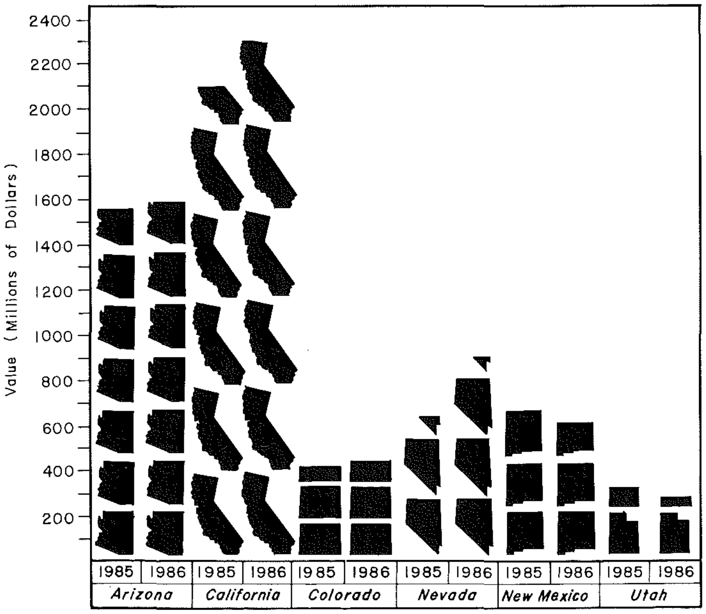


***Figure 1.** Nonfuel mineral production in the Southwest, 1985 and 1986.*

sophisticated glass and filler/extender markets. Environmental issues, market changes, international trade, technology changes, and government legislation all had significant impact on the production of industrial minerals.

Declining oil and gas prices caused a cutback in drilling activities which, in turn, decreased demand for barite and bentonite clay, large quantities of which are used in drilling fluids. The result was a substantial oversupply of these two commodities. Many companies, even the largest, struggled to survive.

The increase in cement imports was the most significant issue confronting the U.S. cement industry. U.S. reliance on imports increased from 4 percent in 1981 to 17 percent in 1986. The industry responded to the lower priced imports by idling clinker production in favor of imported clinker and finished cement and by investing in import facilities. Foreign firms, mostly from western Europe, continued to acquire U.S. cement plants. About 43 percent of U.S. finished cement capacity was foreign owned in 1986 compared with 22 percent in 1981.

Legislation authorizing disbursement of funds to States under the Surface Transportation Assistance Act of 1982 was not enacted for the fiscal year beginning October 1, 1986. Consequently, demand for crushed stone, sand and gravel, and cement may be adversely affected.

In January the EPA proposed an immediate ban on the manufacture, importation, and processing of certain asbestos construction materials. Asbestos and asbestos products not immediately banned will be controlled under a permit system and asbestos use will be phased out within 10 years. The Occupational Safety and Health Administration (OSHA) amended its present standard regulating occupational exposure to asbestos. An administrative stay was placed on that portion of the regulation covering amphiboles following appeals by members of the mineral industry who were concerned that this regulation would adversely affect talc, stone, sand and gravel, and other mineral commodities that sometimes contain amphiboles as trace components.

Table 1. *Nonfuel mineral production in the Southwest, measured by mine shipments, sales, or marketable production, including consumption by producers. All figures are from the U.S. Bureau of Mines; totals for 1986 are preliminary estimates.*

	Value (thousands of dollars)		Percent of Total Value in 1986		
State	1985	1986	Southwest	United States	Major Commodities
Arizona	1,550,085	1,568,435	25.7	6.7	copper, construction sand and gravel, portland cement, molybdenum, silver, crushed stone
California	2,094,796	2,309,517	37.9	9.8	portland cement, construction sand and gravel, boron minerals, gold, crushed stone, diatomite
Colorado	408,178	424,859	7.0	1.8	molybdenum, portland cement, construction sand and gravel, gold, crushed stone, zinc
Nevada	630,883	904,503	14.8	3.9	gold, mercury, construction sand and gravel, crushed stone, gypsum, barite
New Mexico	656,889	608,367	10.0	2.6	copper, potassium salts, portland cement, construction sand and gravel, gold, perlite
Utah	312,359	285,349	4.7	1.2	portland cement, gold, construction sand and gravel, salt, copper, phosphate rock
SOUTHWEST	5,653,190	6,101,030	100.0	26.0	
U.S. TOTAL	23,232,000	23,475,495	----	100.0	

Arizona

The value of nonfuel mineral production in Arizona in 1986 was estimated at $1.57 billion, virtually unchanged from 1985, but about one-half of the 1981 peak output (Table 2). Metals output, which accounted for about 82 percent of the total value, decreased slightly from $1.29 billion in 1985 to $1.28 billion in 1986.

Arizona copper production continued to rank first in the Nation and to contribute nearly three-fourths of the State's nonfuel mineral output. Although copper production remained essentially the same as in 1985, depressed prices, competition with foreign producers, and substitution for copper by aluminum, plastics, and glass in traditional uses for the metal continued to unsettle the industry.

Under the changed economic conditions, copper companies were being restructured, labor unions accepted lower wages, costs were reduced by increasing productivity, and new mining and processing methods were introduced. Construction began on a new solvent-extraction/electrowinning plant that will reportedly yield an additional 100 million pounds of copper per year. Environmental problems, however, continued to plague the industry in 1986, leading to the early closure of one smelter.

The increase in the price of gold brought a 41-percent gain in the value of Arizona's gold output. Gold, as well as lead, molybdenum, and silver, is produced as a byproduct of copper production. One company announced that a new open-pit operation now under construction will yield 60,000 ounces of gold annually, doubling Arizona's gold production.

The value of industrial mineral production was led by construction sand and gravel, portland cement, crushed stone, and lime.

California

California continued as the leading State in the Nation in the production of nonfuel minerals during 1986. Value increased to an estimated $2.3 billion from the $2.1 billion reported in 1985. California led all States in the production of asbestos, boron minerals, diatomite, portland cement, construction sand and gravel, rare-earth metal concentrates, and tungsten ore and concentrates. It was second in the production of natural calcium chloride, calcined gypsum, magnesium compounds from seawater, sodium carbonate, and gold. Gold production nearly tripled from the previous year as new operations were started. Several California mining and mineral processing companies changed ownership during the year.

Colorado

The value of nonfuel mineral production in Colorado in 1986 was estimated at $424.9 million. This represents a modest increase over the 1985 value, but is still much below the peak value of $1.2 billion in 1981. The major factor in this increase was a surge in production and value of gold. The dramatic rise in gold output resulted mainly from the opening of a large

Table 2. *Nonfuel mineral production in Arizona, measured by mine shipments, sales, or marketable production, including consumption by producers. All figures are from the U.S. Bureau of Mines; totals for 1986 are preliminary estimates.*

Mineral	Value (thousands of dollars)	
	1985	1986
Clays	1,503	1,499
Copper	1,175,995	1,165,729
Gem stones	2,700	W
Gold	16,535	23,370
Gypsum	1,926	2,168
Lead	244	W
Lime	21,226	19,403
Molybdenum	63,389	W
Pumice	2	2
Salt	— —	W
Sand and gravel (construction)	118,000*	113,000
Silver	30,007	25,983
Stone (crushed)	23,111	25,100
Other**	95,447	189,970
TOTAL	1,550,085	1,568,435

W Withheld to avoid disclosing company proprietary data; value included in "other" figure.
* Estimated.
** Combined value of cement, diatomite (1986), perlite, pyrites (1985), industrial sand and gravel, dimension stone, and values indicated by symbol W.

new gold mine and the return to operation of a second major gold producer.

Of the nine industrial minerals and eight metals produced, increases in output were seen in all except sand and gravel, lead, zinc, and tin. Although output increased moderately for the State's most important mineral, molybdenum, lower prices resulted in lower total value as demand for this steel-hardening metal continued to be soft. Colorado's rank among nonfuel-mineral-producing States was 19th, compared with 22nd in 1983 and 7th in 1981.

Nevada

Nevada's 1986 nonfuel mineral production was estimated to be valued at $904.5 million, an increase of $273.6 million from that recorded in 1985. This increase resulted from a 40-percent rise in gold production to about 1.9 million ounces. Nevada was the leading State in the Nation in the production of gold and barite and was the sole producer of mined magnesite and mercury. No molybdenum production was reported in 1986. Based on preliminary statistics, Nevada ranked eighth among the States in the value of nonfuel mineral production in 1986.

New Mexico

The value of nonfuel mineral production in New Mexico in 1986 was estimated to be $608.4 million, about 7 percent lower than in 1985. Estimated output and value of portland and masonry cement, clays, copper, gypsum, and silver increased over those of 1985. Estimated output and value of Grade-A helium, molybdenum, potash, construction sand and gravel, and crushed stone declined.

New Mexico received $1.1 million for reclamation work from the U.S. Office of Surface Mining Reclamation and Enforcement. Mine sites to be reclaimed are in Cibola, Grant, Santa Fe, and Socorro Counties.

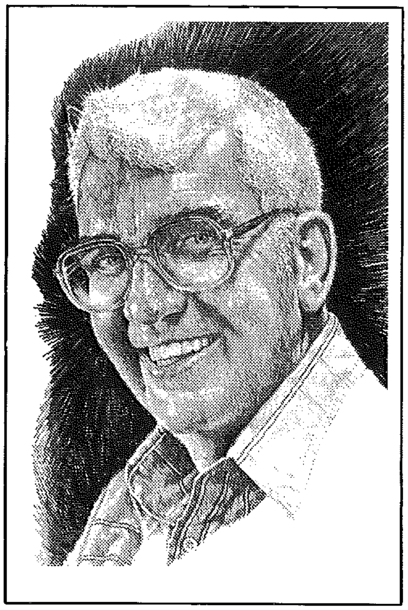
Utah

The value of nonfuel mineral production in Utah in 1986 was an estimated $285.3 million, nearly a 9-percent decline from 1985. Metals output continued its decline from more than half of the total value of nonfuel minerals produced in 1984 to about one-fifth in 1986.

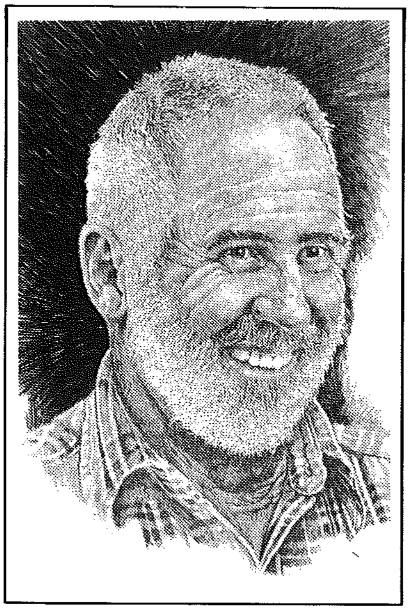
The total value of industrial mineral production fell as declines were posted for portland cement, clays, gilsonite, gypsum, lime, phosphate, industrial sand and gravel, and crushed stone. Commodities rising in value included masonry cement, magnesium compounds, potassium salts, salt, construction sand and gravel, and sodium sulfate.

Industries on the shores of Great Salt Lake continued to be adversely affected by persistent high lake levels, which led to the flooding of solar evaporation ponds.

Key Survey Employees Retire



H. Wesley Peirce



Joseph R. LaVoie

On June 30, 1987 two long-time Arizona Geological Survey employees retired. Dr. H. Wesley Peirce, who began his employment on July 1, 1956 with the Arizona Bureau of Mines, a former name for the survey, served 31 years. As Principal Geologist, Wes cultivated varied interests in the geology of Arizona, but gave special attention to the Colorado Plateau subsurface, the Mogollon Rim, Cenozoic basins, nonmetallic and energy resources, geologic hazards, and earth science education. He wrote several articles, some of which appeared in *Fieldnotes.* Wes received his B.S. degree in geology from the University of Montana in 1949, M.S. from Indiana University in 1952, and Ph.D. from the University of Arizona in 1962.

Joseph R. LaVoie started working for the Arizona Bureau of Mines on March 16, 1965, 22 years ago. Joe supervised the graphics section, which prepares illustrations for all Survey publications including *Fieldnotes* and does photography and darkroom work, drafting, scribing, color separation, and layout. It is through the efforts of Joe and his staff that we were able to prepare such handsome maps and reports. Joe graduated from high school in Michigan and served in the Army during World War II and in the Navy during the Korean War, before moving to Arizona in 1957.

Both Wes and Joe were dedicated, productive employees; we will miss them tremendously. We wish them well in their retirement and in their new jobs as fabricators of fish stories.

RADON UPDATE

by Larry D. Fellows
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Radon gas has been recognized as a geologic hazard to people in homes and other buildings only since the early to mid-1980's. Radon gas, which is a decay product of uranium and is itself radioactive, seeps into homes from underlying soil and rock. It is hazardous in high concentrations because it is inhaled and causes increased radiation exposure to human lung tissue. A recent survey of radon levels in homes in southwestern Tucson, in an area known to contain elevated uranium concentrations, revealed in a few homes radon concentrations above the maximum acceptable level recommended by the U.S. Environmental Protection Agency (EPA). The EPA has set 4 picocuries per liter (pCi/l) as the level above which radon-reduction measures are recommended.

A radon concentration of 2,700 pCi/l was measured in a home in eastern Pennsylvania in December 1984. Before then, radon was not known to accumulate to such high levels within homes built on uraniumrich rock and soil. Because of this startling discovery, other areas in the country where uraniumrich rocks were known to be present became suspect. Before December 1984 uranium-related environmental health concerns had been limited primarily to natural radioactivity (gamma radiation) levels.

In October 1986 the Arizona Geological Survey (AGS), which is the Geological Survey Branch of the Arizona Bureau of Geology and Mineral Technology, initiated activities to help assess the potential for radon in Arizona homes. Dr. Jon Spencer wrote an article on radon and related geologic aspects, which was published in the Winter 1986 issue of *Fieldnotes* (Spencer, 1986). Many articles had already been printed in newspapers and magazines, including some published in Phoenix and Tucson. Spencer's article was mailed in early January 1987 to more than 4,000 subscribers, including most of the television and radio stations in Arizona. Only two or three questions were generated by his article during January and February.

In November 1986 staff of the AGS and the Arizona Radiation Regulatory Agency (ARRA) discussed the location of areas in Arizona within which rocks are known to have elevated uranium content, and, therefore, might have greater potential for indoor radon. The AGS compiled a preliminary map of the State (Spencer and Shenk, 1986) for the ARRA to use in determining where to place charcoal canisters to measure radon levels. The AGS also prepared an estimate of the cost to conduct a gamma-radiation survey of populated areas where uraniumrich rocks are known to be present at the surface. The ARRA, in turn, estimated costs for canisters, laboratory services, and other items required to complete a statewide survey. These figures were incorporated into House Bill 2288, which was sponsored by Senator Greg Lunn and Representative Chris Herstam, introduced in January 1987, and passed by the House Health Committee in February.

A summary article on radon appeared in the *Tucson Citizen* on March 19. Within a few days a reporter from the *Arizona Daily Star* came to our office for information, presumably as a follow-up of the March 19th article. All the information in our files about the uranium-bearing rocks in southwestern Tucson was made available to him. The most detailed map (Grimm, 1978) showed a football-shaped area of "lake-bed limestone," bisected by Cardinal Avenue, approximately 1,500 feet south of Valencia Road. The mapped limestone area is about 875 feet wide and 1,800 feet long (Figure 1a). The *Arizona Daily Star* article, entitled "Cancer-causing radon gas may be threat on southwest side," was published on March 29. It included a map that designated a "potential radon hazard" in the area bounded by south Mission Road, west Valencia Road, south Sorrel Lane, and west Los Reales Road (Figure 1b). Local television stations followed up on the newspaper story. The following week the AGS received hundreds of telephone calls from concerned residents. At that time radon gas had never been measured in any homes in southwest Tucson.

Immediate response was necessary. Dr. Pat Nolan, Director of the Pima County Health Department, and I met on March 31 to discuss procedures for assessing whether an indoor-radon problem existed. We agreed that the AGS would first define the areal extent of the uranium-bearing limestone and then determine the natural radioactivity levels. This information would be provided to Dr. Nolan, who would use it to determine in which homes to place charcoal canisters.

John Welty, a geologist on our staff, reviewed existing literature, went to the field to examine the limestone, and prepared a map showing its area of outcrop. In response to the March 29th newspaper article, Dudley Emer, an independent consultant, called to volunteer his services and equipment to help measure the natural radioactivity levels associated with the limestone. On April 3 Dr. Nolan issued a news release that identified the area of concern and described plans to measure gamma radiation there. On April 6 Emer and Jon Shenk, a graduate research assistant on our staff, began measuring the gamma-radiation levels. Results of their findings were presented to Dr. Nolan and outlined in a news release issued on April 9. The news release included a map that showed the area within which measured radioactivity is two or more times the level of background radioactivity (Figure 1c). On the basis of this information, the Pima County Health Department, with the approval of the Pima County Board of Supervisors, decided to purchase charcoal canisters and place them in every home within the two-times-background boundary. A public meeting was held on April 14 at the Miller Elementary School in that vicinity to explain the origin, occurrence, and health effects of radon, the geologic setting of the site, and plans to measure radon within area homes. Questions were also answered. Canisters were placed in 37 homes the following week.

Radon levels determined from analysis of the charcoal canisters were made available on May 1 at a press conference. The maximum levels detected were 37.3 and 42.9 pCi/l from one home; canisters from two homes recorded 10 to 20 pCi/l; 17 samples were in the 4 to 10 range; and 19 indicated less than 4 pCi/l. On the basis of these results, Dr. Nolan decided to place canisters in 17 adjacent homes to define more fully the extent of elevated radon levels in the area. Two additional homes tested at 4 pCi/l. Results of radon testing were generally consistent with predictions based on gamma-radiation measurements; high radon levels were largely confined to areas with high gamma radiation (Spencer and others, 1987).

One question asked several times by concerned residents was, "Why didn't we know about this before?" As the second paragraph of this article states, until the early 1980's, radon was not known to accumulate to hazardous levels within homes built on uraniumrich rock and soil. Many radon measurements made between 1980 and 1985 provided sufficient data to indicate that hazardous radon levels could be present in many U.S. homes, especially in areas where higher than normal uranium concentrations are present in underlying soil and rock. In the mid-1980's, State and Federal agencies began to respond to this new knowledge with radon surveying programs, especially in States such as Pennsylvania, where radon had been found at very high concentrations.

Geologists and environmental health scientists in Pennsylvania and other States have subsequently learned much about the occurrence of indoor radon. Thousands of charcoal canisters have been placed throughout Pennsylvania. Radon concentrations greater than 100 pCi/l have been measured in many homes. The area of primary concern in Pennsylvania is known as the Reading Prong, which covers about 300 square miles, includes an estimated 22,000 homes, and extends into New Jersey and New York. The State of Pennsylvania has spent about $5 million on radon programs and added 21 full-time employees to implement them.

Elevated radon levels have also been measured in other States, including Alabama, California, Colorado, Connecticut, Florida, Illinois, Kentucky, Maine, Maryland, Montana, New Hampshire, New Jersey, Ohio, and Wyoming. The EPA is currently funding statewide radon surveys in 10 States. Congressional hearings have been held this year to assess the problem and make plans to address it.

Limestone in the Cardinal Avenue area of southwestern Tucson, originally described by Brown (1939), was the target of five uranium claims, referred to as the Dutchess claims, which were filed in 1955 during the uranium "boom." Uranium was never mined from this area because

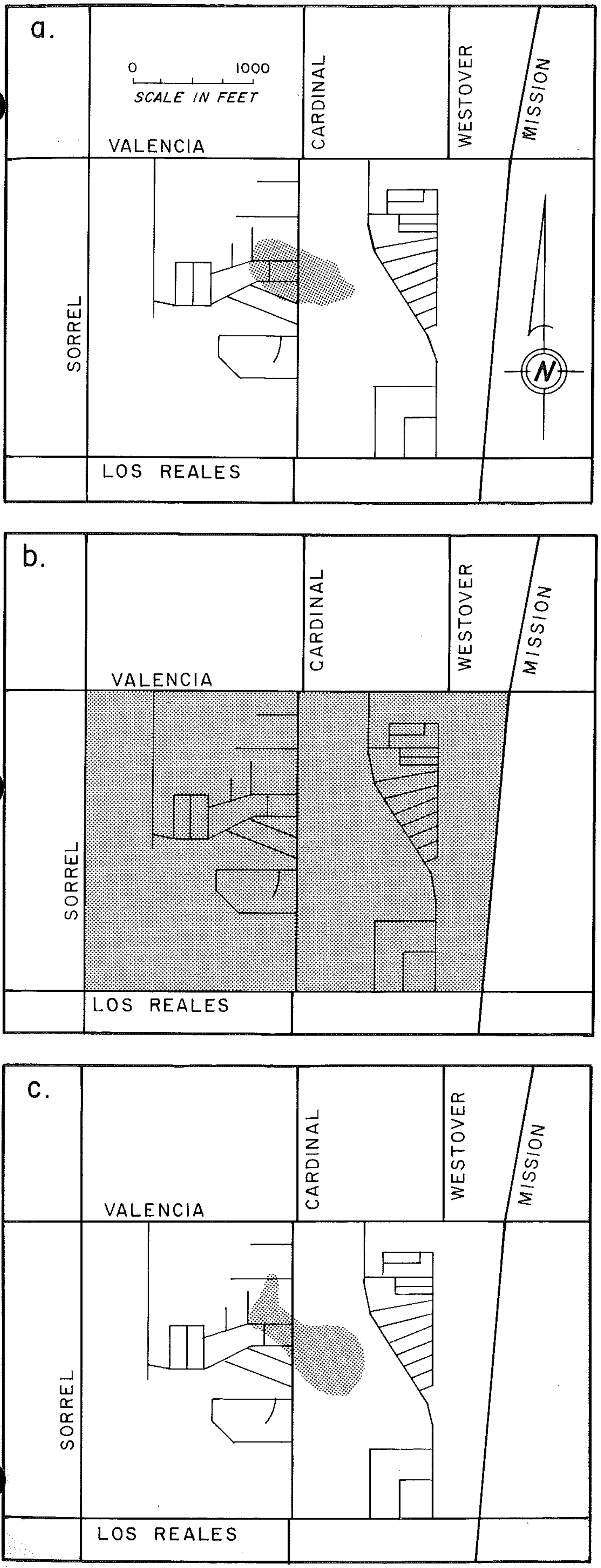

Figure 1 (left). *(a, top) Map showing location of limestone in southwestern Tucson that has small quantities of uranium-bearing minerals. Modified from Grimm (1978, p. 43). (b, middle) Map prepared by* Arizona Daily Star *and included in March 29th issue (p. 1-A) that shows "potential radon hazard" area in southwestern Tucson. (c, bottom) Preliminary map prepared by Dudley Emer, West Tech Geophysics, and Jonathan D. Shenk, Arizona Geological Survey, showing area with two times background radiation due to uranium mineralization. Modified from an AGS news release issued on April 9.*

uranium concentrations were too low. In February 1976 John Vuich, a geologist with the Arizona Bureau of Mines, the former name of the Arizona Bureau of Geology and Mineral Technology, informed the Arizona Atomic Energy Commission (AAEC), now known as the ARRA, about the elevated radioactivity levels associated with the limestone. Two staff persons from the AAEC visited the site and conducted a gamma-radiation survey of the Chastain housing-development property near Valencia Road and Cardinal Avenue, using equipment on loan from the EPA (Figure 2). Radon detection and measurement were not the objectives of this survey. The investigators determined that the background radiation was 12.5 microroentgens per hour on Cardinal Avenue and that the maximum reading on the Chastain property was 25.5 microroentgens per hour (AAEC, 1976). The latter figure was calculated to a yearly total of 0.22380 roentgens per year. Because the AAEC permissible yearly total was 0.5 roentgens per year, no remedial action was recommended by them.

Much more must be learned about the occurrence of radon in homes in Arizona. During the legislative session that ended in May, $58,000 was appropriated to the ARRA for fiscal year 1987-88 to survey areas with elevated radioactivity levels and to purchase canisters for homes within those and other areas. The AGS will receive $8,000 to conduct a reconnaissance analysis of natural radioactivity levels in several areas known to have uraniumrich rocks exposed at the surface. This investigation is planned for completion during late August and September, after the monsoon season has ended (rainwater interferes with radiation measurements). The results of the survey will assist the ARRA in placing charcoal canisters.

Those who would like more information about radon may obtain these free pamphlets from the Environmental Protection Agency (EPA Region 9, 215 Fremont St., San Francisco, CA 94105): (1) A Citizen's Guide to Radon: What It Is and What to Do About It; (2) Radon Reduction Methods: A Homeowner's Guide; and (3) Radon Reduction Techniques

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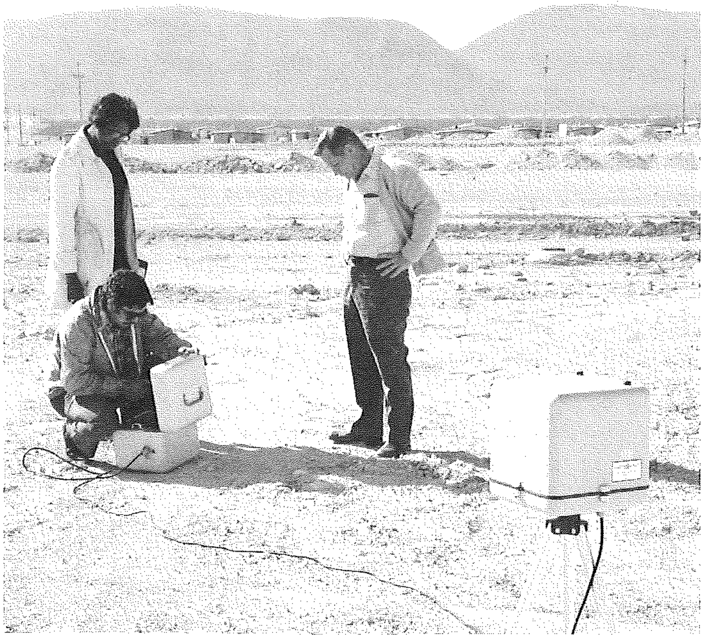

Figure 2 (above). *Gamma radiation being measured by Ralph B. Ochoa (kneeling) and Mattie Coleman (standing, left), both of the Arizona Atomic Energy Commission. Richard T. Moore, Arizona Bureau of Mines (right), observes. Photo taken by John S. Vuich, Arizona Bureau of Mines, February 25, 1976.*

Cooperative Geologic Mapping in Arizona: COGEOMAP Update

by Stephen J. Reynolds
and Jon E. Spencer
Arizona Geological Survey

Accurate and sufficiently detailed geologic maps are essential for understanding the geologic history and character of an area and for making intelligent decisions regarding natural-resource and land management. More specifically, geologic maps are the basis for (1) assessment of mineral and energy potential for exploration and land-management purposes; (2) evaluation of possible geologic hazards such as radon gas and subsidence; (3) determination of suitability of areas for manmade constructions such as buildings, dams, and toxic-waste disposal sites; (4) assessment of ground-water resources; and (5) overall policymaking by land-use planners and managers. Unfortunately, adequate geologic maps do not exist for much of Arizona, especially in the geologically complex Basin and Range Province and adjacent parts of the Transition Zone. Such maps enable one to make informed decisions about the use and management of land and resources.

Because of this, one of the highest priorities of the Arizona Geological Survey (AGS) is geologic mapping, with the goal of publishing a new geologic map of Arizona to replace the current version published in 1969. After consultation with geologists from industry, the U.S. Geological Survey (USGS), and universities, the AGS decided to concentrate its mapping effort in the Phoenix 1° x 2° quadrangle (Figure 1). This quadrangle was almost completely unmapped in detail prior to recent work by AGS and USGS geologists, yet it includes (1) western Phoenix and important manmade features such as the Palo Verde Nuclear Generating Station; (2) proposed sites for hazardous- and toxic-waste disposal and the Superconducting Super Collider; (3) large areas being considered for wilderness status; and (4) areas with substantial past mineral production and unknown, but possibly large, undiscovered mineral resources. In addition to mapping parts of the Phoenix quadrangle, AGS geologists have also completed geologic maps of several areas bordering the north side of the quadrangle.

Since 1985 geologic mapping in the Phoenix quadrangle has been part of the Cooperative Geologic Mapping program (COGEOMAP), a cooperative cost-sharing project undertaken by the USGS and various State geological surveys (Reinhardt and Miller, 1987). For the Arizona COGEOMAP project, the AGS has devoted approximately half of its geologic staff to geologic mapping. The USGS, in turn, has supported USGS geologists involved in geologic mapping in Arizona and has also provided the AGS with funds to hire additional geologists for its mapping effort.

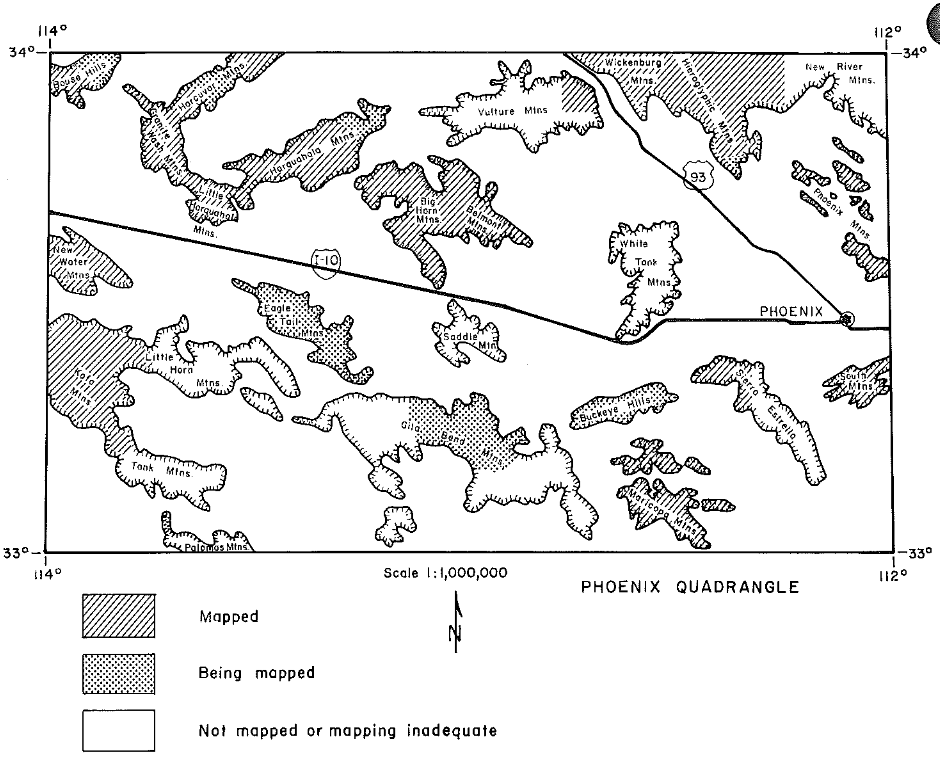

Figure 1. *Status of geologic mapping in the Phoenix 1° x 2° quadrangle.*

Geologic mapping by AGS geologists has been closely coordinated with that of their USGS colleagues, and a spirit of cooperation has developed between AGS and USGS personnel. AGS geologists have volunteered their time to help USGS geologists map several wilderness study areas, and USGS geologists have, in turn, provided geologic and geochronologic support for AGS mapping projects. In addition, AGS geologists have helped to direct geologic mapping by graduate students from all three universities in the State.

RESULTS OF GEOLOGIC MAPPING

Results of the Arizona COGEOMAP project and other AGS mapping projects to date have revealed that the Phoenix quadrangle and adjacent areas are geologically much more complex than previously anticipated and, in fact, contain some of the most complicated geology in the United States. Some of the highlights of our discoveries are presented below, along with references that contain additional information.

Big Horn and Belmont Mountains

As part of the 1985 COGEOMAP project, AGS and USGS geologists mapped the geology of the Big Horn Mountains and contiguous Belmont Mountains (Figure 1) at a scale of 1:24,000 (Capps and others, 1985). A simplified version of the new AGS and USGS mapping is shown in Figure 2, along with depictions of the geology from the 1924 and 1969 State geologic maps, which were based on reconnaissance mapping. This figure illustrates how the geology of any area becomes better understood with additional geologic mapping. The three main reasons for this are as follows: (1) subsequent geologic mapping is generally more detailed than the previous mapping — there is less to gain by remapping the area at the same level of detail; (2) new geologic mapping benefits from and can build upon insights gained from the previous mapping; and (3) the understanding of geologic concepts changes with time as new knowledge is accumulated.

As a result of our mapping efforts, the Big Horn and Belmont Mountains are now known to contain a complexly faulted sequence of middle Tertiary volcanic and sedimentary rocks, previously considered to be Cretaceous in age (Figure 2). The mapping also documented a large, previously unmapped Cretaceous granite and a fluorite-bearing middle Tertiary granite that probably represents the magma chamber for the volcanic rocks (Reynolds and others, 1985). Geologic mapping was coordinated with a geologic, geochemical, and fluid-inclusion study of mineral resources in the area (Allen, 1985). This study describes, for the first time, the geologic setting of gold mineralization at the U.S. Mine, which commenced production after our map results were released.

Bouse Hills

The western Bouse Hills are composed of highly tilted to flat-lying middle Tertiary volcanic rocks. Barite mineralization generally occurs within a specific andesitic(?) unit, whereas manganese mineralization is localized along Tertiary faults. The eastern Bouse Hills are unmapped, but are believed to contain a large middle Tertiary pluton.

Buckskin and Rawhide Mountains

The Buckskin and Rawhide Mountains, located east of Parker and northwest of the Harcuvar Mountains (north of the Phoenix quadrangle), contain major copper-iron deposits related to a regional, gently dipping normal fault, referred to as a detachment fault. To understand better the origin of the fault and the geologic setting and controls of mineralization, we mapped the fault and overlying rocks in detail. Most of this mapping has been released (Spencer and Reynolds, 1986; Spencer and others, 1986) and descriptions of the mineral deposits have been published (Spencer and Welty, 1985, 1986). The mapping and mineral-deposit studies demonstrate that iron-copper mineralization is genetically related to detachment faults and is strongly controlled by both structural and stratigraphic features. In addition, we have recognized rocks above the fault that correlate with the Triassic Moenkopi Formation and other Mesozoic units on the Colorado Plateau (Reynolds and others, 1987a). These rocks contain previously undescribed, stratigraphically controlled deposits of gypsum, an important industrial mineral. One quartzite unit in the Mesozoic sequence preferentially hosts gold mineralization. Most manganese mineralization in the area is now known to be stratigraphically controlled within a specific sequence of middle Tertiary conglomerate and sandstone.

Eagle Tail and Gila Bend Mountains

These ranges contain U.S. Bureau of Land Management (BLM) wilderness study areas, currently being evaluated by USGS geologists. Although our own work in both ranges is limited to reconnaissance, we have discovered that the north-central Gila Bend Mountains contain a regionally unique, previously undescribed sequence of andesitic volcanic rocks and underlying reddish sedimentary rocks that depositionally overlie Precambrian granitic rocks. The andesitic and sedimentary rocks are slightly metamorphosed and cleaved, locally copper stained, and probably Late Cretaceous (Laramide) in age. The possible presence of Laramide volcanic rocks implies that the area may have a previously unappreciated potential for Laramide mineralization. In the southeastern Eagle Tail Mountains, we have examined recently discovered Paleozoic rocks and determined that they are structurally thinned, overturned, and Devonian through Permian in age. Such Paleozoic rocks were generally thought to be absent from the range.

Granite Wash Mountains

The Granite Wash Mountains have been mapped at scales of 1:24,000 and 1:12,000 (Reynolds and others, 1987b). The mapping documented the presence of strongly folded thrust faults that interleave Mesozoic, Paleozo-

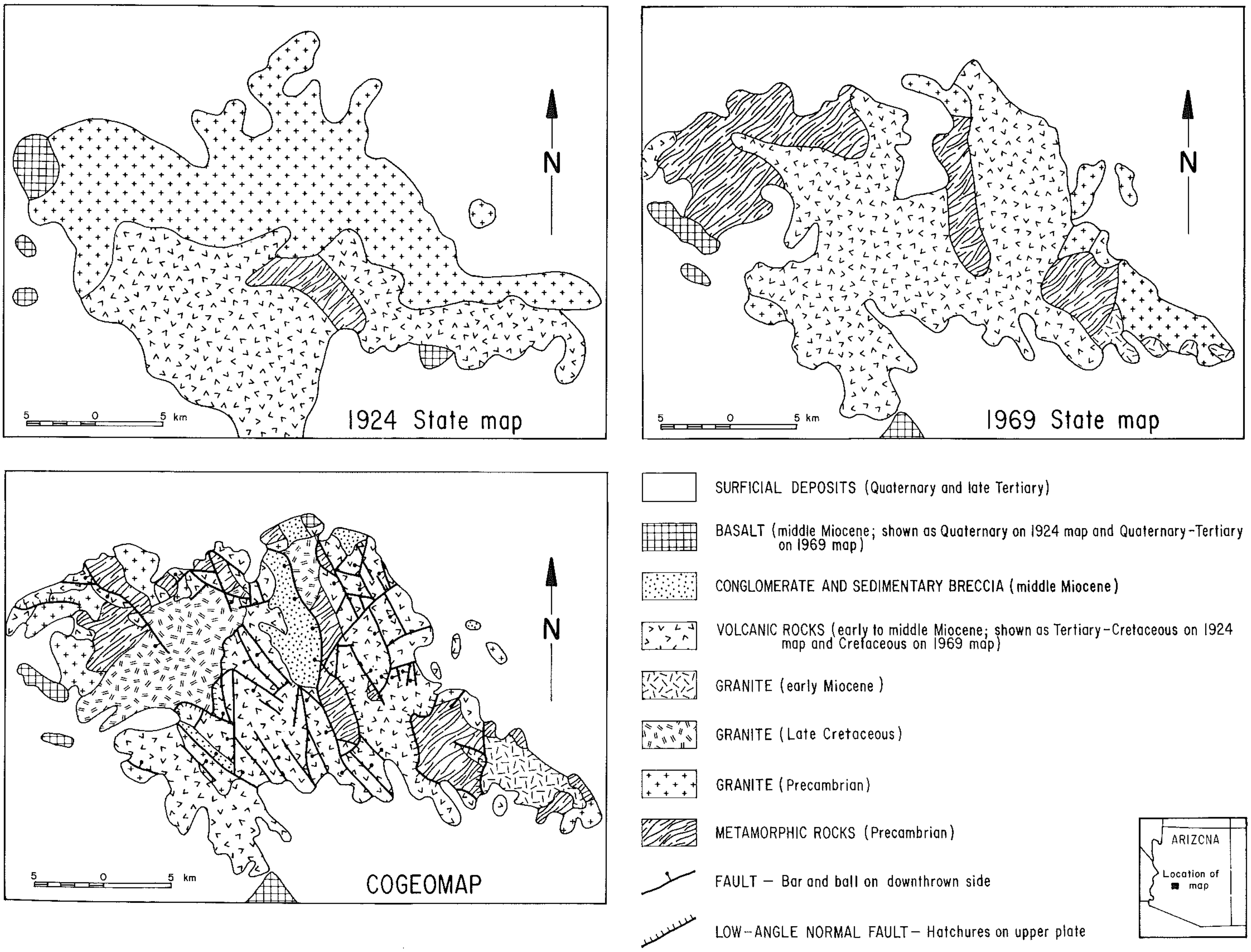

Figure 2. *Evolution of geologic mapping in the Big Horn Mountains, west-central Arizona. Sources of COGEOMAP mapping include Allen (1985), Capps and others (1985), and F. Grey and R. Miller (USGS, unpub. data).*

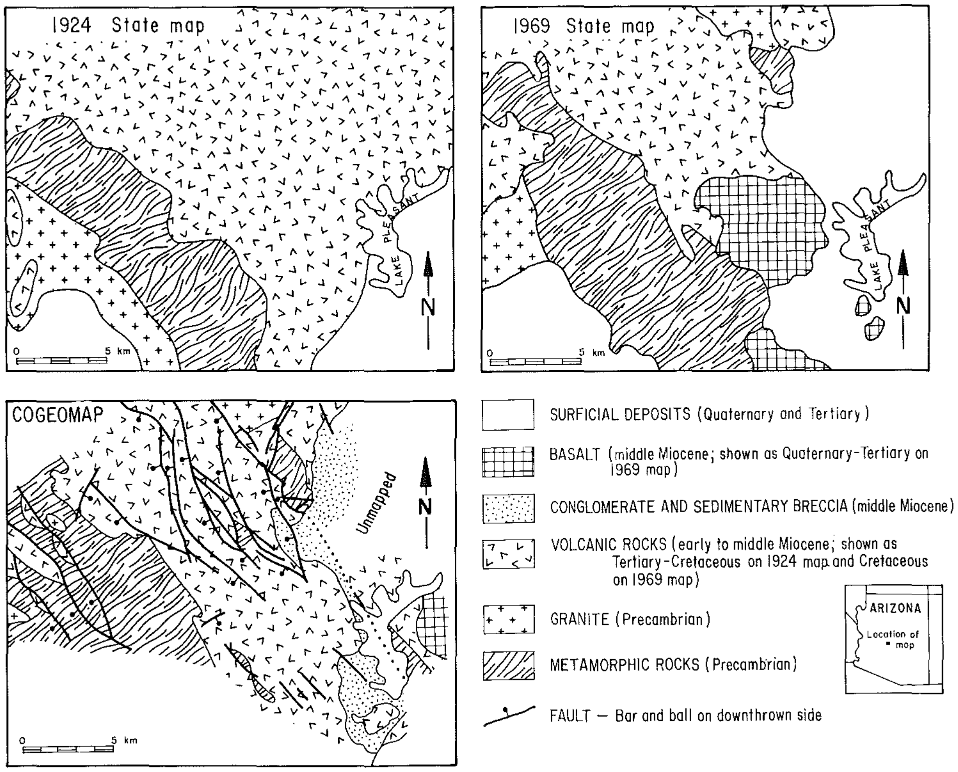

Figure 3. *Evolution of geologic mapping in the Hieroglyphic Mountains, central Arizona. COGEOMAP mapping is largely from Capps and others (1986).*

ic, and Precambrian rocks (Reynolds and others, 1986). Some Paleozoic sections near the thrust faults have been thinned to 1 percent of their normal stratigraphic thickness. Rocks within the thrust zones have been locally affected by alteration and precious- and base-metal mineralization. In addition, stratigraphically controlled gypsum is present in the basal part of the Mesozoic section. We have also discovered several occurrences of massive kyanite and andalusite, two aluminous metamorphic minerals commonly used by industry as refractory material. These aluminous rocks, which are associated with altered and metamorphosed Jurassic volcanic rocks and possible hot-spring-related quartz rocks, represent a new type of mineral deposit in Arizona—one formed by metamorphism of a Jurassic volcanic-related, clayrich alteration zone (Reynolds and others, 1988). Whether these newly discovered aluminous rocks are potential commercial sources of refractory industrial material or are possible indicators of volcanic-related precious-metal mineralization is unknown, but should be evaluated.

Harcuvar Mountains and Merritt Hills

The Harcuvar Mountains, like the Buckskin Mountains, contain a large, gently dipping, normal (detachment) fault that is commonly marked by copper, iron, and gold mineralization. We have mapped and described the main mineralized segments of the fault (Reynolds and Spencer, 1984, 1985a; Spencer and Welty, 1985). In addition, a detailed geochemical, isotopic, and fluid-inclusion study of alteration and mineralization has indicated that the mineralizing fluids were saline basinal waters derived from sedimentary and volcanic rocks above the fault (Roddy and others, in review).

The central Harcuvar Mountains contain a BLM wilderness study area that was recently mapped cooperatively by USGS and AGS geologists. This area contains Precambrian metamorphic and granitic rocks and large sheets of Cretaceous granite, all variably overprinted by Cretaceous metamorphic fabric and middle Tertiary mylonitic fabric related to the overlying detachment fault. Similar geology continues to the southwest into the southwestern Harcuvar Mountains, where Mesozoic thrust faults occur within pendants in a large Cretaceous granitic pluton and where copper mineralization is associated with dioritic dikes.

The Merritt Hills, located east of the Harcuvar Mountains (north of Figure 1), are composed of Precambrian granitic and metamorphic rocks (Reynolds and Spencer, 1985b).

Harquahala and Little Harquahala Mountains

The Harquahala Mountains also contain a BLM wilderness study area currently under evaluation. The main structural features of the range are major Mesozoic thrust faults that complexly interleave Precambrian, Paleozoic, and Mesozoic rocks (Reynolds and others, 1986). The Paleozoic and Mesozoic rocks are strongly folded and metamorphosed and are commonly upside down (S. Richard and Ed DeWitt, 1986, written commun.). Copper, gold, and fluorite mineralization occurs along a detachment fault exposed on the southeastern pediment of the range.

Gently dipping Mesozoic thrust faults and folded and overturned Paleozoic rocks also occur in the adjacent Little Harquahala Mountains (Reynolds and others, 1986). Release of a detailed geologic map of these faults (Spencer and others, 1985b) was instrumental in the discovery and delineation through drilling of previously unknown gold mineralization in the southern part of the range (W. Yarter, 1986, oral commun.).

Hieroglyphic, Buckhorn, Wickenburg, and Vulture Mountains

As part of the 1986 and 1987 COGEOMAP program, AGS geologists mapped all or part of the Hieroglyphic (Figure 3), Buckhorn, and Wickenburg Mountains, and the northeastern part of the Vulture Mountains. Detailed mapping for this area has been or will soon be released (Capps and others, 1986; Grubensky and others, 1987; Stimac and others, 1987). The area contains numerous moderately to gently dipping normal faults that place tilted middle Tertiary volcanic and sedimentary rocks over Precambrian igneous and metamorphic rocks and Cretaceous granite. Other gently dipping normal faults place Precambrian metamorphic rocks over Cretaceous granite. Some of the normal faults have as much as 5 km of displacement. Mineralization in the area is partly middle Tertiary in age and commonly occurs along the gently dipping faults. In addition, the mapping has identified Precambrian quartz- and carbonaterich rocks that were probably formed by volcanic-related hydrothermal fluids.

Maricopa Mountains and Sierra Estrella

The Maricopa Mountains were recently mapped by AGS, USGS, and University of Arizona geologists because the range contains one of two proposed sites in Arizona for the Superconducting Super Collider (Cunningham, 1987). The area is also being considered for hazardous- and toxic-waste disposal. The range is largely composed of a variably foliated Precambrian granite and smaller areas of Precambrian metamorphic rocks and middle Tertiary volcanic and sedimentary rocks (Cunningham and others, 1987).

The adjacent Sierra Estrella have not been completely mapped, but a brief reconnaissance along the crest of the range revealed a diverse assemblage of Precambrian metamorphic and granitic rocks (Spencer and others, 1985a).

South and White Tank Mountains

The South Mountains are one of approximately a dozen mountain ranges in Arizona, including the Buckskin, Harcuvar, and Harquahala Mountains, that have exposures of regional, gently dipping detachment faults. Because the South Mountains represent the most geologically simple occurrence of this type of fault, they have been mapped and studied in detail (Reynolds, 1985). In the South Mountains, structural and isotopic studies have helped constrain the age of faulting and the ole of hot, mineralizing waters in faulting Reynolds and Lister, 1987). Such studies have increased our understanding of how such faults form and how faulting is related to base- and precious-metal mineralization.

Our geologic studies in the White Tank Mountains are restricted to reconnaissance, except for some detailed mapping in the southern part of the range. Most of the range is composed of Precambrian metamorphic and granitic rocks, early Tertiary(?) granite, and middle Tertiary dikes, all locally overprinted by middle Tertiary mylonitic fabric related to a probable continuation of the South Mountains detachment fault. The southern part of the range contains a Precambrian granitic to dioritic pluton that was intruded during the main episode of Precambrian deformation. Laramide(?) copper mineralization has been identified by industry drilling along the northwest flank of the range.

CONCLUDING COMMENTS

Much progress has been made in geologic mapping of the Phoenix 1° x 2° quadrangle, and the resulting discoveries have both scientific and applied implications. The overall geologic complexity of the area, especially near the Mesozoic thrust faults, is bewildering. This complexity has made it difficult to decipher the eologic framework of the area and has no oubt hindered past exploration for mineral deposits. On the other hand, the geologic diversity of the area indicates that additional scientific and mineral discoveries are likely. In particular, there appears to be unassessed potential for new types of metallic and nonmetallic mineral deposits. Those in pursuit of knowledge or mineral wealth would do well to remember our motto for the area: "The only thing to expect is the unexpected."

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New Minerals Director Appointed

Larry Bauer has been selected by D. Dean Bibles, Arizona State Director, U.S. Bureau of Land Management (BLM), to head the agency's Arizona minerals program, which includes management responsibilities for 30 million acres of mineral estate.

As Deputy State Director for Minerals, Bauer will work with Bibles to administer the General Mining Law for 168,000 active mining claims on 12.5 million acres of public land, as well as 17.5 million subsurface acres managed by BLM. Bauer will be responsible for administering mineral leases on lands managed by other Federal agencies in Arizona, including the U.S. Forest Service (11.3 million acres) and U.S. Bureau of Reclamation (1 million acres). He will also supervise leases on 76,000 acres of Indian lands in the State.

Bauer replaces Ray A. Brady, who now serves as district manager of the BLM's Safford (AZ) district.

GSA Meeting to be Held in Phoenix

The 100th annual meeting of the Geological Society of America (GSA) will be held in Phoenix October 26-29, 1987. It is the first time that the GSA has held its annual meeting in Arizona, and thus represents the first formal, comprehensive coverage of the geology of Arizona by one of the world's largest earth science meetings. Twenty-seven symposia will address topics that range from the geology of human origins and cultural evolution to the structure and tectonics of accretionary prisms. Thirty-four field trips before and after the meeting will explore the geologic diversity of the Colorado Plateau, Transition Zone, and Basin and Range physiographic provinces. Eight short courses sponsored by the GSA include such diverse topics as contaminant hydrogeology, paleoseismology and active tectonics, planetary geology and remote sensing, and site characterization for high-level nuclear-waste disposal. For further information, contact The Geological Society of America, P.O. Box 9140, 3300 Penrose Place, Boulder, CO 80301; (303) 447-2020.

Arizona Geological Survey Established

The Arizona Bureau of Geology and Mineral Technology, a State agency administered by the University of Arizona, is composed of the Geological Survey Branch and the Mineral Technology Branch. The Geological Survey Branch functions as the Arizona Geological Survey.

Senate Bill 1102, which was sponsored by Senator Doug Todd, passed by the 38th Arizona Legislature, and signed by Governor Evan Mecham on April 24, 1987, specifies that the Geological Survey Branch will become the Arizona Geological Survey, an independent State agency located in proximity to the University of Arizona in Tucson. The Arizona Geological Survey will be directed by the State Geologist, who is appointed by the Governor. The Mineral Technology Branch will be transferred to the University of Arizona. SB1102 becomes effective on July 1, 1988.

(continued from page 7)

for Detached Houses: Technical Guidance. The first two pamphlets are also available from ARRA, 4814 S. 40th St., Phoenix, AZ 85040; (602) 255-4845.

References

Arizona Atomic Energy Commission, 1976, A radiation survey of Chastain housing development property near Valencia Road and Cardinal Avenue, Tucson, Arizona, February 25, 1976: summary report, 1 p.

Brown, W. H., 1939, Tucson Mountains, an Arizona basin-range type: Geological Society of America Bulletin, v. 50, p. 697-760.

Grimm, J. P., 1978, Cenozoic pisolitic limestones of Pima and Cochise Counties, Arizona: Tucson, University of Arizona, M.S. Thesis, 67 p.

Spencer, J. E., 1986, Radon gas; a geologic hazard: Arizona Bureau of Geology and Mineral Technology Fieldnotes, v. 16, no. 4, p. 1-6.

Spencer, J. E., Emer, D. F., and Shenk, J. D., 1987, Geology, radioactivity, and radon at the Cardinal Avenue uranium occurrence, southwestern Tucson: Arizona Bureau of Geology and Mineral Technology Open-File Report 87-3, 16 p.

Spencer, J. E., and Shenk, J. D., 1986, Map showing areas in Arizona with elevated concentrations of uranium: Arizona Bureau of Geology and Mineral Technology Open-File Report 86-11, scale 1:1,000,000.

Fieldnotes

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State of Arizona .... Governor Evan Mecham
University of Arizona .... President Henry Koffler
Bureau of Geology & Mineral Technology
  Acting Director .... Edgar J. McCullough, Jr.
  State Geologist & Assistant Director,
    Geological Survey Branch .... Larry D. Fellows
  Assistant Director,
    Mineral Technology Branch .... J. Brent Hiskey
  Editor .... Evelyn M. VandenDolder
  Illustrators .... Joseph R. LaVoie, Peter F. Corrao

New Bureau Publications

The following publications may be purchased over the counter or by mail from the Arizona Bureau of Geology and Mineral Technology, 845 N. Park Ave., Tucson, AZ 85719. For price information on these and other Bureau publications, please contact the Bureau offices.

Dickinson, W. R., and Olivares, M. D., 1987, Reconnaissance geologic map of the Mineta Ridge and Banco Ridge area, Pima and Cochise Counties, Arizona: Miscellaneous Map Series MM 87-C, 2 p., scale 1:24,000.

This geologic map of the type area of the Mineta Formation east of Redington Pass was compiled from field reconnaissance by Dickinson and thesis mapping by Olivares, supplemented by previous mapping by earlier workers. The varied internal lithology of the Mineta Formation is depicted in general fashion based on detailed facies analysis by Olivares.

McGarvin, T. G., 1987, Index of published geologic maps of Arizona—1986: Open-File Report 87-1, scale 1:1,000,000.

This index lists 31 references as sources of geologic maps of the State published during 1986. References include publications of the U.S. Geological Survey, Geological Society of America, Arizona Geological Society, Arizona Bureau of Geology and Mineral Technology, and other organizations. The accompanying map identifies the areas within Arizona covered by each reference.

Spencer, J. E., and Reynolds, S. J., 1987, Geologic map of the Swansea—Copper Penny area, central Buckskin Mountains, west-central Arizona: Open-File Report 87-2, scale 1:12,000, with text.

A structurally complex assemblage of Proterozoic through Miocene rocks forms a synformal keel of upper-plate rocks above the Buckskin-Rawhide detachment fault in the central Buckskin Mountains of west-central Arizona. Pre-Tertiary rocks have undergone complex Mesozoic thrust-related deformation and metamorphism. A thick Oligocene(?) to middle Miocene sequence of clastic sedimentary rocks, carbonates, volcanic rocks, and sedimentary breccias is tilted moderately to steeply to the southwest. Cu-Fe mineralization is common along the detachment fault and forms replacement deposits in Paleozoic carbonates at the Swansea mine. This detailed map of approximately 9 square miles is accompanied by descriptions of about 60 map units.

Spencer, J. E., Emer, D. F., and Shenk, J. D., 1987, Geology, radioactivity, and radon at the Cardinal Avenue uranium occurrence, southwestern Tucson: Open-File Report 87-3, 16 p.

Tertiary limestone in an approximately 30-acre area south of the intersection of Valencia Road and Cardinal Avenue in southwest Tucson contains greater-than-average uranium concentrations. A detailed gamma-ray spectrometer survey delineated the extent of the uranium occurrence. Results of the survey are presented in this report, along with a review of the geology of the area and a comparison of background radioactivity to measured indoor-radon levels.

The Bureau of Geology and Mineral Technology is a division of the University of Arizona.

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