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Figure 1. Processing plant for sand and gravel production, operated by the Tanner Companies, near Orange Grove Road and Interstate 10 north of Tucson. The four major steps to sand and gravel mining are site acquisition and clearing, mining, processing, and site reclamation. Strict geologic guidelines govern the selection of sand and gravel aggregate that gives concrete its bulk and strength. The deposit should be poorly sorted, i.e., it should contain a range of grain sizes from cobbles to sand. The particles must be durable; free of reactive alkalies, caliche, organic debris, and trash; and unindurated (not hardened or compacted). Photo by Alyce Pennington.

INDUSTRIAL MINERALS of SOUTHEASTERN ARIZONA

Gold, silver, copper -- When most people think of mining, they think of metallic minerals. Industrial minerals (sand and gravel, crushed stone, etc.), however, provide more dollars to the U.S. economy than do the more celebrated metals. In 1991, U.S. mines produced an estimated \$11.2 billion worth of metals, compared with \$19.6 billion worth of industrial minerals.

Because of the geologic setting of southeastern Arizona, various industrial minerals are exposed in areas that are within easy driving distance of Tucson. In April 1992, the Arizona Geological Society sponsored a 2-day field trip (organized by Brenda B. Houser) to examine several of these deposits, as well as commercial mining and processing operations. The following text is largely excerpted from the technical field-trip guidebook, *Industrial Minerals of the Tucson Area and San Pedro Valley, Southeastern Arizona*, edited by B.B. Houser and featuring the following authors: Daniel T. Eyde, Ted H. Eyde, John M. Guilbert, Robert L. Hockett, Dennis Mackovjak, Ken A. Phillips, and Jonathan D. Shenk. Much of the text is excerpted from the article, "Mineral Economics of Industrial Minerals in Southeastern Arizona," by K.A. Phillips of the Arizona Department of Mines and Mineral Resources. The guidebook may be purchased for \$13.00 (includes shipping) from the Arizona Geological Survey, 845 N. Park Ave., Suite 100, Tucson, AZ 85719.

An industrial mineral is any rock, mineral, or other naturally occurring substance of economic value, excluding metallic ores and mineral fuels. Inhabitants of the Tucson basin have used industrial minerals since prehistoric times. Native Americans built low retaining walls from volcanic boulders on Tumamoc Hill, possibly to create agricultural terraces. In the late 1880's, Mexican laborers quarried the bouldery talus on the southern

and northwestern sides of the hill for the walls and foundations of Tucson houses. Granitic boulders in the foothills of the Santa Catalina Mountains are used today as landscaping materials.

Industrial mineral deposits in southeastern Arizona range in age from Precambrian (more than 570 million years old) to Holocene (less than 10,000 years old). Sand and gravel, portland cement, stone (limestone, dolomite, marble, and landscape rock), clay, diatomite, gypsum, and asbestos have been mined or produced in southern Arizona.

In value, sand and gravel ranks second only to copper among the nonfuel minerals produced in Arizona. In 1991, 23.7 million tons¹ (about 6.5 tons per Arizona resident) of construction sand and gravel, worth \$79.4 million, was produced in the State. (See related article on page 2 of this issue.) The urban areas of Maricopa and Pima Counties support the largest producers of construction sand and gravel in the State.

Sand and gravel is used in concrete aggregate for buildings, highways, dams, and airports, as well as in concrete products, such as blocks, bricks, and pipes. Including the requirements for pavement, pipes, drains, walls, and overpasses, each mile of urban freeway uses 400,000 tons of sand and gravel. A typical 1,600-square-foot house requires 100 tons of sand and gravel, a 24-story office building requires 36,000 tons, and a shopping mall requires 100,000 tons.

In Arizona, sand and gravel is largely produced from floodplains and terraces of the Salt River in Phoenix and the Santa Cruz River and Pantano Wash in Tucson, as well as from alluvial fans in outlying areas. After removal, sand and gravel must be processed -- crushed, screened, washed, and blended -- before it may be sold (Figure 1).

Portland cement is named after the Isle of Portland in southern England because of its resemblance to a limestone found there. Portland cement is a mixture of several industrial minerals, plus an iron additive. A favorite recipe lists the following ingredients and "cooking" instructions for portland cement: Blend 4 c. high-grade limestone, 3 tbl. high-alumina clay or shale, 1 tbl. silica (as sand, sandstone, or high-silica limestone), and

¹ One short ton (abbreviated in this article as "ton") equals 2,000 pounds. One metric ton equals 2,200 pounds.

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\$23 million to clean up mining wastes in Clear Creek and Gilpin Counties, one of the State's oldest mining districts. Superfund-site cleanup plans in Aspen and Leadville continued to draw heated opposition from residents.

The BLM proposed new rules that would expand the reclamation bonding requirements for mining operations that cause 5 acres or less of surface disturbance per year. The Colorado Legislature passed a bill that removes the ceiling on reclamation security-bond requirements from owners of small mining operations and allows local government and the public greater participation in the permitting process.

NEVADA

Nevada's 1991 nonfuel mineral production was estimated to be valued at \$2.5 billion, a decrease of about \$100 million from that of 1990 (Table 1). Gold production rose 4 percent, but silver production dropped nearly 40 percent because of mine closures due to lower prices. Nevada remained the leading State in the production of gold, silver, mercury, and barite; ranked second in the production of diatomite and lithium; and was the sole producer of mined magnesite. Nevada ranked third among the States in 1991 production value of nonfuel minerals.

Nevada's most valuable mineral commodity -- gold -- accounted for 88 percent of the State's total nonfuel mineral value, or about \$2.2 billion. Construction sand and gravel and silver, which accounted for \$63 million and \$55 million, respectively, were the State's next most valu-

able minerals, followed by clays, diatomite, gypsum, lime, and lithium.

Precious-metals exploration declined as many gold producers shifted their exploration activities to foreign countries in response to increased regulations, lower prices, and more favorable conditions offshore. Exploration drilling, however, continued throughout Nevada, with most of the activity centered around known gold-producing properties.

The Nevada Legislature passed several laws in 1991 that affected mining, including the following: Assembly bill 78, which revises mining-reclamation regulations and requires each mining operation to file a yearly report on the status of mining, exploration, and reclamation activities; Assembly bill 351, which provides penalties for violating State hazardous-waste provisions; Assembly bill 535, which imposes annual assessments from \$500 to \$10,000 on developing a body of water that is injurious to wildlife; and Assembly bill 592, which revises requirements for mining-reclamation payments, fees, and verification. Enacted Senate bill 41 authorizes the State's Division of Environmental Protection to develop new rules governing hazardous chemicals. The law requires firms that deal with hazardous chemicals to register with the State, provide an inventory of their chemicals, list safety procedures, and complete a safety and risk evaluation.

NEW MEXICO

The total value of nonfuel mineral production in New Mexico was estimated at \$976 million in 1991, a decrease of

10 percent from the previous year's total (Table 1). The State rose, however, to 10th place nationally in the output of nonfuel minerals.

The metals sector, which included copper, gold, molybdenum, silver, and zinc, contributed nearly \$655 million, or 67 percent of the total value. New Mexico ranked second in the Nation in copper production. Most of New Mexico's gold and silver was produced as byproducts of base-metal output. Significant production of primary gold, however, is planned in 1992 from an area in the Ortiz Mountains south of Santa Fe, where ore reserves containing more than 1 million troy ounces of gold have been identified.

New Mexico's industrial mineral production in 1991 was valued at \$321 million. Potash output furnished more than 24 percent of the total value of nonfuel mineral production in the State and nearly 90 percent of total U.S. output of potash in 1991. New Mexico mines also produced significant quantities of mica, perlite, construction sand and gravel, crushed stone, portland cement, and pumice. Perlite output was the highest in the Nation.

Environmental efforts in 1991 focused on pumice-mining operations at a site near the East Fork of the Jemez River in Sandoval County. To prevent the mine operator from obtaining a patent on its 1,700-acre parcel of mining claims, Congressman Bill Richardson introduced House bill 2502, which would include the mine in a 100,000-acre National Recreation Area. This designation would prohibit the patenting of mining claims and

NONFUEL continued on page 8

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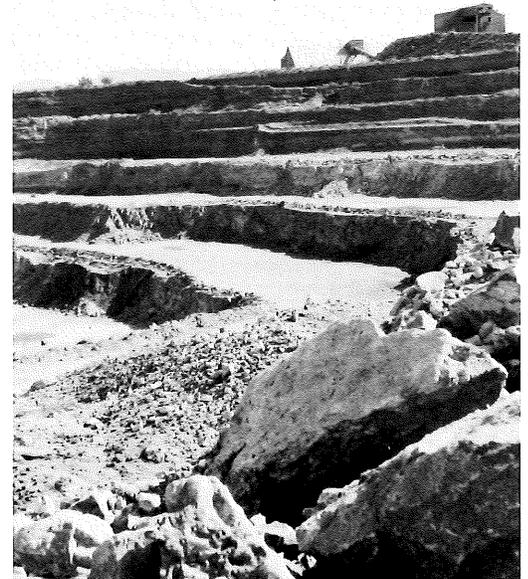
1 tsp. iron ore; grind blended ingredients; bake at 2,700°F for about an hour; add 2 tbl. gypsum to resulting clinker; grind to powder; package for sale.

Portland cement is used for a variety of construction projects. Dry cement is mixed with water and sand and gravel at batch plants to make wet cement (concrete), which is loaded into trucks for immediate transport to construction sites.

Portland cement is produced in only two plants in Arizona: One near Tucson in Pima County supplies the Tucson and south Phoenix areas (Figures 2 and 3); another in Cottonwood in Yavapai County supplies the north Phoenix and Flagstaff areas. The latter also provided the cement for the concrete in the Glen Canyon Dam. Maricopa County, the home of Phoenix, is deficient in limestone deposits that are suitable for portland cement.

Limestone, dolomite, and marble are calcium and calcium-magnesium carbonate rocks that are important to construction, chemical, and other industries. Marble is limestone or dolomite that has been metamorphosed (naturally heated) and recrystallized. These industrial minerals have many uses worldwide. Coarsely crushed stone is used for concrete aggregate, road material, and rail-

Figure 2. Rillito limestone quarry north of Tucson that is used to produce portland cement. Owned by the Arizona Portland Cement Company, this computerized cement operation includes a quarry; primary crusher and storage-surge building (right background); 3.9-mile conveyor-belt system from the quarry to the plant; stacker-reclaimer blending-storage building; kiln-feed composition-adjustment system; kiln; and cement milling, bagging, and shipping system. Photo by Alyce Pennington.



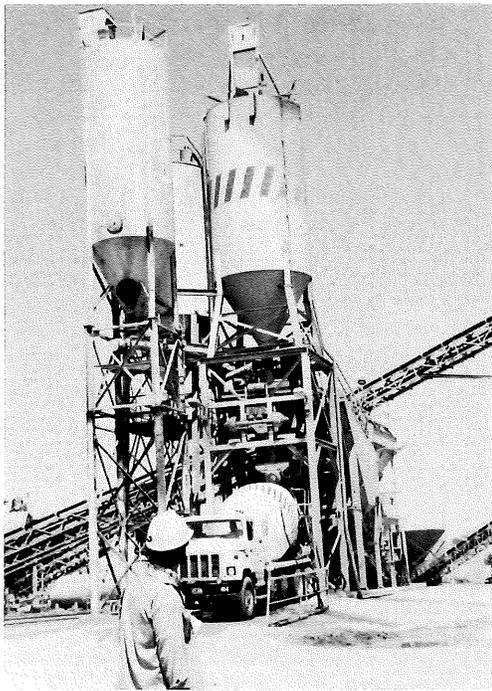


Figure 3. Processing plant for portland cement, operated by the Tanner Companies, near Orange Grove Road and Interstate 10 north of Tucson. The gray crushed cement rock is mixed with sand and gravel and water in the large metal cylinders and loaded into cement trucks. When water is added to cement, microscopic, tubular synthetic minerals quickly begin to grow. These needles intersect one another and bond tightly to the sand and gravel aggregate. Although additives, such as gypsum powder, can retard setting time, the concrete (the mixture of cement and aggregate) must be poured within 90 minutes of being mixed or it will solidify within the trucks. Laboratories, such as the Pima County Materials Testing Laboratory south of Tucson, run elaborate physical, chemical, and mechanical tests on samples to ensure that the concrete meets specifications. Strict quality control can prevent construction disasters. Photo by Alyce Pennington.

road ballast; finely crushed stone is used for poultry grit, livestock feed supplements, stucco, and fillers in paints and plastics. These minerals also serve as fluxing agents for smelting and refining metals; conditioners for acidic soils; raw materials for glassmaking; sources of lime; and decorative, monument, and building stones.

Arizona contains many deposits of limestone, dolomite, and marble, but because of location, size, and quality, only a few support commercial quarries. The best limestones in the State for chemical and industrial use are the Escabrosa and Red-wall Limestones of Mississippian age, which were originally deposited 360 to 320 million years ago in shallow warm seas when the land mass that is now Arizona was near the equator. Two marble quarries in the Santa Rita Mountains south of Tucson supply local and regional markets. The white "scar" on the northwestern slope of the Santa Rita Mountains, which is visible from Interstate 19, is predominantly a natural outcrop of white marbleized Escabrosa Limestone.

Landscape rock includes decomposed, crushed, broken, and quarried blocks of rock as well as natural boulders used outdoors for ground cover and decorative purposes (Figure 4). The major markets for decomposed granite quarried in Arizona are the urban and suburban areas of Tucson, Phoenix, and Las Vegas. As ground cover, these materials control dust and weeds and reduce evaporation and water use. Decomposed granite packs well to make a smooth surface for driveways and play areas. Some "clay" tennis courts are, in fact, covered with finely crushed,

screened, and rolled decomposed granite. In 1991, 5 million tons of crushed stone (limestone, dolomite, marble, and landscape rock), worth \$12.8 million, was produced in Arizona.

Various clays are also produced in the State. One type is used for oil-refining catalysts; other types are used for floor and wall tiles, bricks, and miscellaneous clay products, as well as a portland cement additive. At least 10 companies operate at least 13 clay quarries in Arizona. In 1991, they produced 170,500 metric tons valued at \$1.4 million. A high-alumina clay deposit in Cienega Gap southeast of Tucson supplies almost half of the clay quarried in Arizona (Figure 5). This clay is used as a cement additive and is hauled to Phoenix, where it is used to manufacture red brick.

Diatomite, or "fossil flour," is an unusual sedimentary rock composed of the microscopic siliceous remains of single-celled, water-dwelling plants called diatoms. The skeletons contain holes and channels that make the diatomite porous

and permeable, qualities that are excellent for sophisticated filtration systems. Diatomite deposits worldwide are also used in thermal insulation, absorbents, pesticide carriers, lightweight aggregates, ceramic materials, and anticaking agents. They are also a source of silica for glass and metallurgical applications.

Diatomite deposits are numerous in the western United States, but only a few are commercially quarried because impurities, such as volcanic ash, sand, and clay, affect the potential end uses, processing requirements, and value. In Arizona, diatomite deposits are present in Pinal, Cochise, Yavapai, Graham, and Greenlee Counties. The White Cliffs deposit in the San Pedro Valley has been the focus of the most activity in Arizona and has yet to be adequately investigated (Figure 6). Although this deposit was intermittently quarried for more than 60 years, diatomite is not currently being produced in Arizona.

Gypsum is a hydrous (water-containing) calcium sulfate that forms a soft, compact granular rock; a fine-grained, massive, translucent rock called alabaster; and crystalline minerals, such as selenite. Alabaster has been used for centuries for carved bowls, lamp bases, and similar objects. Crude gypsum is added to portland cement to retard setting time and to alkaline soils to help minimize the accumulation of sodium. Calcining (roasting) gypsum produces either plaster of paris if heated at 250°F to 600°F or "dead-burned gypsum" if heated at 900°F to 1,000°F. When mixed with water, plaster of paris forms a pliant plaster that recrystallizes to gypsum. It may be used directly as plaster or molded into casts or between sheets of heavy paper to form gypsum board (also called wallboard, sheetrock, and plaster board). Plaster of paris is also used as a binder, filler, and chemical agent. Dead-burned gypsum is used



Figure 4. Kalamazoo Materials quarry southwest of Mammoth. This exposure of Oracle Granite has produced 4,000 to 8,000 tons of landscaping materials per month. The quarry overlies an underground copper sulfide deposit that is being mined. Photo by Alyce Pennington.

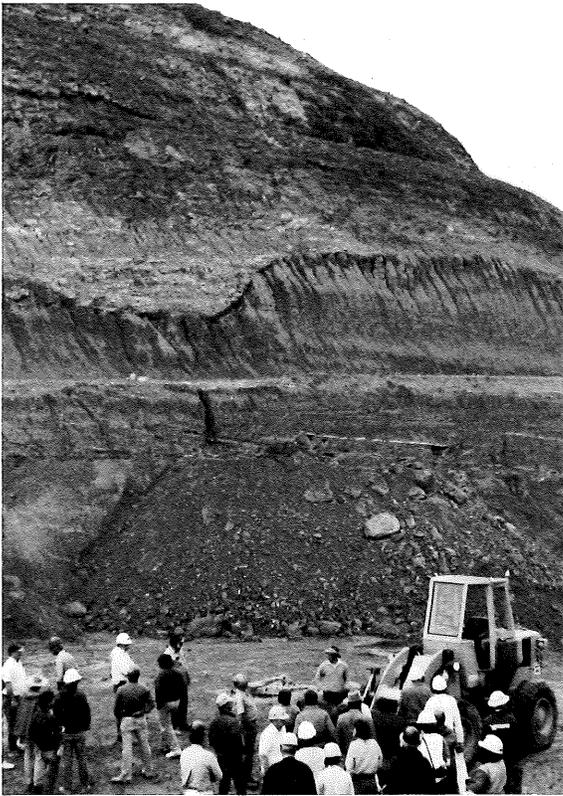


Figure 5. Pantano Clay Pits at Cross Hill southeast of Tucson. This clay deposit, which is enriched in aluminum oxides, is quarried from the Pantano Formation. The Phoenix Brick Yard uses the clay to make bricks and tiles, and the Arizona Portland Cement Company uses the clay as a source of alumina for cement production. Clay is obtained from the beds in the lower half of the outcrop. The upper half of the exposure is a large rock-avalanche deposit that may have slid from the area of the Rincon Mountains when the crust in that area was uplifted and extended 20 to 30 million years ago. Photo by Alyce Pennington.

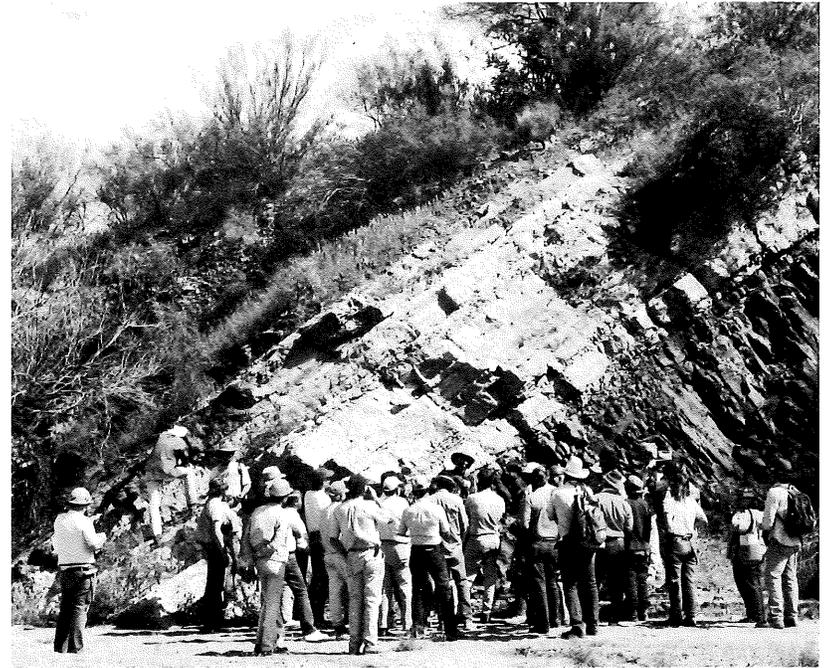


Figure 7. Asbestos outcrop along Putnam Wash opposite the mouth of Aravaipa Creek north of Mammoth. The dark-colored rock at the base of the tilted rock units is a diabase sill, which formed when magma from the Earth's interior was forced upward and intruded preexisting rocks. The light-colored rock above the diabase sill is Mescal Limestone, which was partially metamorphosed by solutions from the hot magma and altered to serpentine and chrysotile. Although this outcrop has never been developed, larger deposits in the Salt River Canyon were extensively quarried because of their exceptionally long (up to 45 centimeters), low-iron fibers. Photo by Alyce Pennington.

as a desiccant and dehydrator and in specialty cements.

Gypsum has been quarried in Arizona since 1880 but increased substantially in commercial value in the mid-1950's, when its demand in agriculture and construction rose with Arizona's population. At least five companies produce gypsum in Arizona from areas near Camp Verde, Littlefield, Winkelman, Mammoth, and the Harquahala Mountains. The National Gypsum Company, the largest

gypsum producer in Arizona, is the only operation in the State that calcines gypsum. Its product supports a wallboard manufacturing plant in Phoenix.

Asbestos is a commercial term applied to a group of highly fibrous, silicate minerals that readily separate into long, thin, strong, flexible fibers. The fibers are heat resistant, chemically inert, and electrically insulating and may be woven together. These qualities make asbestos suitable for manufacturing noncombustible, chemically resistant, and nonconducting materials (e.g., yarn, cloth, paper, paint, brake linings, tiles, insulation, cement, and filters). High-grade deposits of the serpentine mineral chrysotile ("white asbestos") were quarried in the Salt River Canyon and processed in the Globe area for international markets. The chrysotile along Putnam Wash (Figure 7) is a microcosm of the Salt River Canyon chrysotile, although the fibers are shorter than those of the canyon deposits.

Society relies on industrial minerals for making products as diverse and essential as food, medicine, buildings, and computers. Their importance to modern civilization, though generally unappreciated compared with that of metals, is undeniable. As long as humans require food and shelter, human civilizations will require industrial minerals.

Figure 6. Camel Canyon, informally named by University of Arizona paleontologists for the abundant fossilized camel bones discovered there, is the southern limit of the White Cliffs diatomite deposit. This lacustrine (lake) deposit, which consists of interbedded silt, gypsum, marl, diatomite, chert, and volcanic ash, is within the Quiburis Formation. The small quarries in this area were probably not developed until the late 1960's or early 1970's. North of the canyon, however, exposures of the White Cliffs diatomite were quarried as early as the 1920's. Photo by Alyce Pennington.