

## ARIZONA'S METEORITES

by Terri Haag

Aristotle postulated a heavens formed from concentric, crystalline spheres, to which the stars and planets were affixed. According to this hypothesis, the space between the spheres was filled only with clear *aether*, and a celestial origin for rocks or metal that apparently fell from the sky was unthinkable (Burke, 1986).

The heavens, in fact, are filled with all sorts of debris. Rock and metal meteorites that fall to Earth are fragments of larger, interplanetary bodies from within the solar system. Called a **parent body**, the source of a meteorite may be as small as a few meters in diameter or as large as the planet Mars. Most meteorites are fragments of **asteroids**, small celestial bodies that are now in orbit between Mars and Jupiter. Other meteorites that almost certainly came from the surfaces of Mars and the Moon have been found on Earth.

Fragments of broken planets, moons, and asteroids continually wander into Earth's path as it orbits the Sun or are captured by Earth's gravitational pull. As these fragments pass through Earth's atmosphere, frictional heat is generated. Depending on an incoming fragment's size, angle of entry, composition, and speed, a variety of visual phenomena may result. Particles that are smaller than a few microns in diameter can radiate the frictional heat quickly enough to avoid melting or vaporizing and, thus, rarely create visible streaks of light upon entering the atmosphere. Larger fragments, however, may leave brief streaks of light (Hutchison, 1983; Dodd, 1986).

Nearly all incoming celestial fragments, however, incinerate completely without ever landing on Earth. Occasionally, a chunk of rock or metal from outer space is large enough or durable enough to make it all the way through the atmospheric filter and reach the ground. These visitors from space often announce their arrivals with huge, glowing **fireballs** or **bolides**, which can sometimes be seen for hundreds of miles and may be accompanied by smoke and dust trails, sonic booms, detonations, and other visual and audible phenomena. Any objects that actually reach the ground are called **meteorites**, as opposed to **meteoroids**, a name that refers to bodies still in the atmosphere or in space.

*Terri Haag is a Tucson-based freelance writer and an avid mineral, meteorite, and fossil collector.*

Frictional heat during atmospheric entry causes the outer layers of a meteoroid to **ablate**, i.e., to melt, flow back, and "peel" away during flight. Although the friction of entry generates enormous heat, ablation exposes colder, underlying material to the atmosphere. Meteoroids have been "cold soaked" at near-absolute-zero temperatures in outer space for billions of years. This condition, as well as ablation, helps to explain reports that freshly fallen meteorites were "too cold to pick up."

A fiery entry is also responsible for **fusion crust**, one of the primary identifying features of meteorites. Fusion crusts

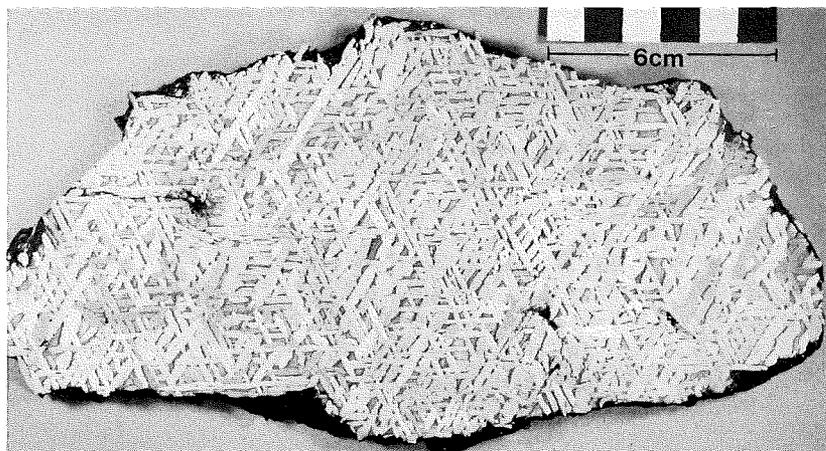


Figure 1. Widmanstätten pattern on etched coarse octahedrite discovered in Augusta County, Virginia, in 1869. Photo © 1992 Dan Britt, Lunar and Planetary Laboratory, University of Arizona.

range in color from a very rare, creamy white to the far more common, glossy, burnt-looking black (Haag and Haag, 1991). Fusion crusts are extremely thin, sometimes only a few microns thick. A good indicator of meteoritic material is a difference in color or texture between the outside (fusion crust) and the inside of a specimen.

### TYPES OF METEORITES

Meteorites are composed of several of the following materials in various combinations: silicates; sulfides; metallic alloys; carbon compounds; trace elements, such as thorium, potassium, and uranium; and rare-earth elements, such as cerium and europium (Wasson, 1985). Based on the relative percentages of these materials, meteorites may be

#### ALSO IN THIS ISSUE

- St. George Earthquake ..... 7
- Exploration Well Near Phoenix ..... 9
- Tucson ESIC Office ..... 11
- AZGS Library ..... 12

divided into three broad categories: iron meteorites (irons), stony meteorites (stones), and stony-iron meteorites (stony-irons). Most meteorites, however, contain enough iron to deflect a strong magnet held on a string (Robert Haag, oral commun., 1992).

Scientists estimate that 94 percent of all meteorites are stones, 4.5 percent are irons, and 1.5 percent are stony-irons (Strahler, 1981). Irons, however, are discovered disproportionately often because they are very heavy, weather slowly, and are quite distinct from Earth rocks.

### Iron Meteorites

Also called nickel-irons, **iron meteorites** are metal alloys of iron and nickel and have approximately the same density and hardness as a blacksmith's anvil. They may also contain other materials, such as sulfides, silicates, phosphates, and carbon-bearing minerals.

Irons are probably fragments of the once-molten cores of large asteroids or small planets. At high temperatures and pressures within the core of the parent body, the nickel-iron was molten. As the core cooled, crystals began to grow, and one of two minerals was preferentially formed, depending on how quickly this cooling took place. At high temperatures, high-nickel **taenite** was prevalent. As the temperature fell and the molten nickel-iron solidified, low-nickel **kamacite** began to form. With a continued drop in temperature, kamacite grew at the expense of taenite and formed bands or **lamellae** oriented like the faces of a regular octahedron. The two minerals etch at slightly different rates when a cut and polished surface of a meteorite is exposed to weak nitric acid, creating a striking crystalline design known as **Widmanstätten structure** or **Widmanstätten pattern** (Wasson, 1985). This pattern is found only in meteorites and, thus, is a diagnostic feature (Figure 1).

Both the nickel/iron ratio and the cooling rate are responsible for the formation, size, and orientation of taenite and kamacite crystals within iron meteorites. Three subcategories of irons -- octahedrites, hexahedrites, and ataxites -- are defined either by the dimensions of their crystalline structures or by the lack of easily discernible patterns in an etched specimen (Dodd, 1986).

**Octahedrites**, named for the eight-sided (octahedral) arrangement of the mineral crystals, come in five varieties: coarsest, coarse, medium, fine, and finest. Coarse and medium octahedrites have wider kamacite lamellae in the Widmanstätten pattern and a larger percentage of iron relative to nickel than do fine octahedrites. **Hexahedrites** are primarily composed of large, six-sided (hexahedral) crystals of nickel-poor kamacite. When etched with acid, hexahedrites typically do not show Widmanstätten patterns. The fine-grained, nickel-rich **ataxites** (a name derived from a Greek word meaning "without order") are primarily

composed of taenite crystals and show no patterns visible to the naked eye when etched (Wasson, 1985). Of the subcategories of irons, medium octahedrites are the most common and ataxites are the rarest.

### Stony Meteorites

Nine out of 10 meteorites are stones. As the name implies, **stony meteorites** are actually rocks. They largely consist of silicate minerals, such as olivine, pyroxene, and plagioclase, as well as other components, including up to 20 percent nickel-iron (Strahler, 1981). A highly diverse group, stony meteorites fall into nearly as many categories as do terrestrial rocks. These categories are based on factors such as the degree of metamorphism, the presence of free visible metal, and the presence of specific minerals or elemental carbon.

The two primary categories of stony meteorites are **chondrites** and **achondrites**. These names refer to the presence or absence of chondrules. **Chondrules** (a name derived from the Greek word for "grain") are extremely ancient and enigmatic silicate spherules that range in size from sand grains to marbles (i.e., from a diameter of about 1 millimeter to 1 centimeter). Precisely how chondrules formed is still unknown, but most scientists believe that they condensed out of the nebular cloud when the solar system was beginning to form approximately 4.5 billion years ago.

A carbonaceous chondrite from Allende, Mexico, contains inclusions of even older and more mysterious compounds called **calcium-aluminum inclusions** (CAI's), which are thought to predate the formation of planets. One hypothesis states that CAI's originated during a supernova explosion before the solar system began to condense (Wasson, 1985).

Chondrites are far more common than achondrites and constitute more than 90 percent of stony meteorites. Ordinary chondrites, which contain the highest percentage of chondrules, may be further classified using letters and numbers. Letters reflect the iron/silica ratio: H (high iron), L (low iron), and LL (low-low iron). Numbers from 3 to 6 reflect the degree of metamorphism

of the chondrules: 3 represents a meteorite with pristine chondrules, whereas 6 indicates a highly metamorphosed chondrite (David Kring, oral commun., 1992; Figure 2).

Achondrites contain no visible chondrules, although they may include rounded clasts of various minerals. They have been highly modified after initial formation by processes such as melting, high-pressure compaction, and impact (Haag and Haag, 1991).

### Stony-Iron Meteorites

**Stony-iron meteorites** are extremely rare. Perhaps the most fascinating of all meteorites, stony-irons contain both



Figure 2. LL-3 chondrite, a low-low-iron stony meteorite with pristine (unmetamorphosed) chondrules (the large white inclusions). This meteorite fell on January 21, 1946, in the Ukraine. Photo © 1992 Dan Britt, Lunar and Planetary Laboratory, University of Arizona.

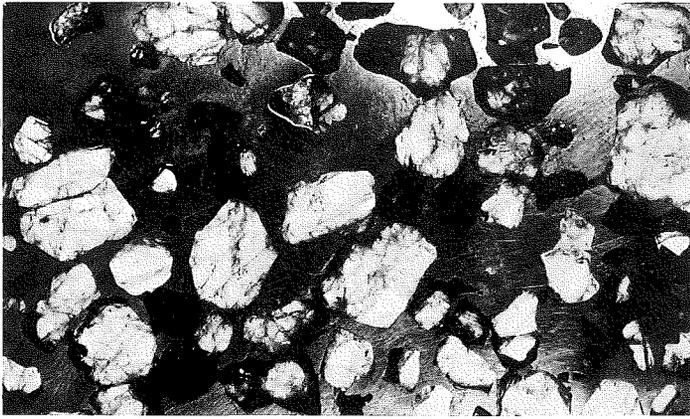


Figure 3. Thin section of Imilac pallasite discovered in the Atacama Desert of northern Chile. Photo © 1991 André Baget, Tucson, Ariz.

silicates and nickel-iron and display characteristics of both stones and irons in the same specimen. The two main types of stony-irons are pallasites and mesosiderites.

**Pallasites**, undoubtedly the most beautiful meteorites, are a striking blend of bright nickel-iron matrix honeycombed with irregular crystals of golden-green olivine (Figure 3). Their origins are still controversial, but most scientists believe that pallasites formed at the interface of the stony mantle and the metal core of a layered planetoid (Bates and Jackson, 1980).

**Mesosiderites** are also a mix of silicates and nickel-iron but generally lack the dramatic appearance of the pallasites because the sizes of the crystals and matrix are smaller and more uniform. Many mesosiderites are **breccias** (rocks formed from pieces of preexisting rocks); some are believed to be the result of mixing due to the collision of two different parent bodies. Like all meteorites, pallasites and mesosiderites may show the effects of metamorphism due to high-energy impacts or reheating within the parent body.

### SIGNIFICANT ARIZONA METEORITES

Meteorites have been discovered worldwide: important finds and falls have occurred from Antarctica to Iceland, and nearly every country on Earth can boast of at least one meteorite. The United States alone has nearly 1,000 meteorites to its credit, and more are discovered every year. Texas, New Mexico, and Kansas are the leaders among States in meteorite "production" (Graham and others, 1985; Robert Haag, oral commun., 1992).

Arizona also has a respectable catalogue of meteorites, including some of considerable historical and anthropological significance (Table 1). Two of the most interesting from an anthropological perspective are the Winona and Navajo meteorites.

The Winona meteorite, a weathered, 53-pound anomalous chondrite, was found buried in a hollowed-out stone cist in the ruins of the Elden pueblo in Winona. The egg-shaped stone was so fragile that it fell to pieces when it was lifted out of its tomb. It had obviously been considered important enough by the Native American residents to have been given a ceremonial burial hundreds, if not thousands, of years before it was discovered by A.J. "Jack" Townsend in 1928 and described in the *American Journal of Science* in 1929 (Heineman and Brady, 1929). This specimen is especially interesting from a meteoritical perspective because it is similar to the silicated portions of a specific type of iron

meteorite. Such varieties are now called **Winona-ites**.

The Navajo meteorite, a 3,306-pound coarsest octahedrite, was found on July 10, 1921, about 13 miles from Navajo. It was buried in talus and carefully covered with large rocks to prevent its discovery. Another 1,508-pound mass was found 5 years later buried nearby in soil. Similar finds have been made in Mexico. The Casas Grandes meteorite, for instance, was discovered in an elaborate burial mound, wrapped in feathered cloth and buried with all the riches and pomp befitting "visiting royalty" (Burke, 1986).

The Tucson Ring, however, is undoubtedly the most famous and most easily recognized of all Arizona meteorites. At 1,517 pounds, it is also one of the largest and heaviest Arizona specimens to have survived intact. Two large pieces of an ataxite, the Tucson Ring and Carleton masses, fell in the Santa Rita Mountains south of Tucson near a pass called "Puerto de los Muchachos." The year of their arrival, however, is unknown. It is also unknown when they were taken to the village of Tucson. Both masses were familiar sights to the residents of this frontier town and served as blacksmiths' anvils for many years (Willey, 1987; Figure 4).

In 1860, Dr. B.J.D. Irwin, an army surgeon, discovered the Tucson Ring half buried in a Tucson alley and realized that it was actually meteoritic iron. He made arrangements to ship the naturally ring-shaped iron mass to the Smithsonian Institution in Washington, D.C., where it arrived in 1863 after a long and hazardous sea voyage. Apparently it was then forgotten because the curator did not mention the specimen in his 1880 catalogue of museum acquisitions. In fact, the magnificent Tucson Ring did not resurface until 10 years later, when a renewed interest in meteorites spurred a better inventory of the museum's outer-space collection (Willey, 1987). The Tucson Ring and Carleton masses still belong to the Smithsonian Institution, despite efforts by the University of Arizona and Arizona State Government to secure their return to home ground.

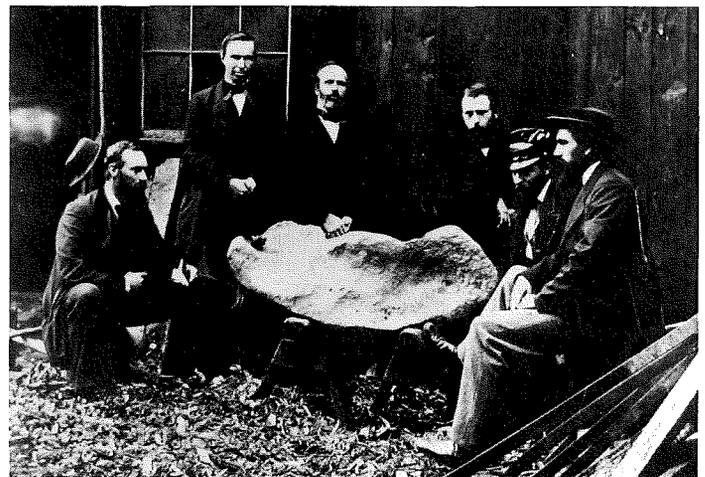


Figure 4. The Carleton mass, the smaller and less famous of the two large pieces of an ataxite found south of Tucson. In June 1862, General James Carleton took possession of this 633-pound fragment from a Tucson blacksmith and had it shipped to San Francisco, where it arrived in November 1862. It remained in California until 1941 and is now in the Smithsonian Institution. This photo, taken in 1862 in San Francisco, also shows members of the California State Geological Survey: left to right, William Brewer, William Ashburner, Josiah Whitney, William Gabb, Chester Averill, and Charles Hoffmann. Photo courtesy of the Arizona Historical Society.

Intense public interest in the **strewn field** (the area of scattered fragments from a meteorite that shattered in the atmosphere) associated with the Tucson Ring and Carleton masses was sparked in 1991, when a nationally syndicated television program called "Missing: Reward" featured a segment on Robert Haag, a Tucson-based meteorite hunter and dealer. Haag offered up to \$100,000 for information leading to the exact location of the meteorite's fall. Since that airing, several tiny pieces of this distinctive, anomalous ataxite have been discovered, but the finder did not locate the actual strewn field or collect the reward money. Dr. John Wasson at the University of California in Los Angeles has analyzed and confirmed the discovery of these new specimens (Robert Haag, oral commun., 1992).

#### OTHER METEORITE DISCOVERIES IN ARIZONA

In February 1985, Thomi Davis and a friend were visiting Udall Park in Tucson when she informed her companion that she was "going to find a meteorite." She was stowing four or five likely candidates in her pockets when she

glanced down and saw a small, brownish-black object by her foot. She promptly picked it up and dumped the others back into the dirt. Convinced that she had found a real meteorite, Davis gave it her stringent "meteorite test": she bounced it off the sidewalk several times, then hit it with a hammer! Miraculously, it did not shatter. Later analysis by more conventional methods revealed chondrules and bright metal grains. Davis could very well be unique in the history of meteorite hunting. She decided to find a meteorite, walked into a city park, and within an hour picked up a beautiful, ordinary chondrite. The park has been thoroughly searched since, but so far no one else has had Davis' incredible luck (Thomi Davis, oral commun., 1992).

This is not to say that no one finds meteorites in Arizona. Practically the entire town of Holbrook found meteorites when a huge fireball dropped about 14,000 small, L-6 chondrites on the startled residents at dusk on July 19, 1912 (Graham and others, 1985). Townspeople combed the surrounding desert and sand dunes and recovered thousands of specimens. The area near Holbrook may still be one of the best regions in the United States for meteorite hunters.

TABLE 1. METEORITES DISCOVERED IN ARIZONA  
(From Graham and others, 1985)

Date	How <sup>1</sup>	Meteorite Name	County	Type	Structure and Composition	Metric Weight <sup>2</sup>	Standard Weight
1959	Find	Bagdad	Mohave	Iron	Medium octahedrite	2.2 kg	4.9 lb
1891	Find	Canyon Diablo	Coconino	Iron	Coarse octahedrite	27 tonnes	30 tons <sup>3</sup>
1954	Find	Clover Springs	Gila	Stony-Iron	Mesosiderite	7.7 kg	17 lb
1905	Find	Coon Butte	Coconino	Stony	L-6 chondrite	2.75 kg	6.1 lb
1955	Find	Cottonwood	Yavapai	Stony	H-5 chondrite	800 g	28.2 oz
1972	Find	El Mirage	Maricopa	Iron	Hexahedrite	598 g	21.1 oz
1909	Find	Gun Creek	Gila	Iron	Anomalous medium octahedrite	22.7 kg	50 lb
1963	Find	Hassayampa	Maricopa	Stony	H chondrite	?	?
1974	Find	Hickiwan	Pima	Stony	H-5 chondrite	1.93 kg	4.3 lb
1912	Fall	Holbrook	Navajo	Stony	L-6 chondrite	218 kg	481 lb <sup>4</sup>
1893	Find	Kofa	Yuma	Iron	Anomalous octahedrite	490 g	17.3 oz
1980	Find	Maricopa	Maricopa	Stony	H chondrite	50 g	1.8 oz
1921	Find	Navajo	Apache	Iron	Coarsest octahedrite	2,184 kg	4,814 lb <sup>5</sup>
1947	Find	Pima County	Pima	Iron	Hexahedrite	210 g	7.4 oz
1920	Find	San Francisco Mts	?	Iron	Fine octahedrite	1.7 kg	3.7 lb
1949	Find	Seligman	Coconino	Iron	Coarse octahedrite	2.2 kg	4.9 lb
1939	Find	Silver Bell	Pima	Iron	Coarsest octahedrite	5.1 kg	11.2 lb
1947	Find	Southern Arizona	?	Iron	Coarse octahedrite	266 g	9.4 oz
1850	Find	Tucson <sup>6</sup>	Pima	Iron	Nickel-rich anomalous ataxite	975 kg	2,149.5 lb
1985	Find	Udall Park <sup>7</sup>	Pima	Stony	H ordinary chondrite	?	?
1927	Find	Wallapai	Mohave	Iron	Fine octahedrite	430 kg	948 lb <sup>8</sup>
1898	Find	Weaver Mts	Maricopa	Iron	Nickel-rich ataxite	38.8 kg	85.5 lb
1940	Find	Wickenburg	Maricopa	Stony	L-6 chondrite	9.2 kg	20.3 lb
1965	Find	Wikieup	Mohave	Stony	H-5 chondrite	372 g	13.1 oz
1928	Find	Winona <sup>9</sup>	Coconino	Stony	Anomalous chondrite	24 kg	53 lb

<sup>1</sup> A **fall** is a specimen found after a meteorite-dropping fireball has been seen; a **find** is a discovered piece that is not associated with a witnessed event.

<sup>2</sup> A 10-gram (0.4-ounce) stony meteorite is the size of a hazelnut, a 100-gram (4-ounce) stone is golf-ball size, and a 1,000-gram (1-kilogram or 2.2-pound) stone is as big as a baseball (Dodd, 1986).

<sup>3</sup> Total weight of numerous pieces that range from tiny fragments to masses of more than 454 kilograms (1,000 pounds).

<sup>4</sup> Total weight of about 14,000 fragments that range from a few grains to 6.6 kilograms (14.5 pounds).

<sup>5</sup> Total weight of two masses: one, found in 1921, weighs 1,500 kilograms (3,306 pounds); the other, found in 1926, weighs 684 kilograms (1,508 pounds).

<sup>6</sup> Includes both the Tucson Ring and Carleton masses. The former weighs 688 kilograms (1,517 pounds); the latter weighs 287 kilograms (633 pounds). The date (1850) refers to the year the meteoritic masses were first described in a published report. Both were known for centuries before this. Dr. Irwin found the Tucson Ring in a Tucson alley in 1860; General Carleton found the Carleton mass in a blacksmith's shop in 1862.

<sup>7</sup> As yet undescribed.

<sup>8</sup> Total weight of two masses: 306 kilograms (675 pounds) and 124 kilograms (273 pounds).

<sup>9</sup> The date (1928) refers to the year A.J. Townsend found the meteoritic mass; it was originally discovered in prehistoric times.



Figure 5. Barringer Meteor Crater. When a large asteroid hit the desert, the main mass was vaporized, but fragments were blown over a huge area and are still being discovered. Photo courtesy of Meteor Crater Enterprises, Inc.

Shifting sands probably buried some of this fall, and pieces may remain covered until shifting winds and determined hunters unveil them.

Other fortunate Arizonans have accidentally stumbled across meteorites. In 1939, a geologist investigating the Silver Bell copper mine northwest of Tucson nearly stubbed his toe on a coarsest octahedrite. The geologist knew that native copper, silver, and even gold were in the area, but he was fairly certain that big lumps of iron were not part of the normal geology. He brought the 11-pound specimen in for analysis, and it was proved to be of extraterrestrial origin (Robert Haag, oral commun., 1992).

The Clover Springs mesosiderite was discovered in 1954 near Strawberry by a rancher who was checking his stock tanks and putting out salt licks for his cattle. As he bent down to replace one of the salt blocks, he saw an unusual rock. Thinking it might be worth investigating, he tossed the 17 pounder into his truck. Sure enough, it was a meteorite, worth thousands of dollars (Haag and Haag, 1991).

Yet another example of meteorite serendipity occurred in 1980. The Maricopa meteorite, an H chondrite, was found virtually by the side of the road when Gordon Nelson stopped his car on a whim to look around on his way to Phoenix. While examining a small **blowout** (a sandy hollow carved by wind erosion), he spotted the 2-ounce stony meteorite (Gordon Nelson, oral commun., 1992).

### BARRINGER METEOR CRATER

East of Flagstaff, near an arroyo called Canyon Diablo, is a big hole in the ground. Now called Barringer Meteor Crater, this striking feature lies in the middle of a high desert plateau, not far from the spectacular Painted Desert. The crater was created about 50,000 years ago, when a nickel-iron asteroid weighing about 100,000 tons barreled into the limestone bedrock at 12 miles per second (about 43,200 miles per hour; Melosh, 1989). Unable to escape, the air in front of the incoming, house-sized asteroid was compressed to the point of ignition, and a blast of burning air seared the desert and everything in it for miles around. As the front of the mass hit the desert floor, still traveling at near-cosmic velocities, it tunneled some 250 feet into the solid bedrock (LeMaire, 1980). Heat and pressure vaporized the front end of the mass while the back end was still falling; the 100,000-ton meteorite turned itself inside out, creating an explosion equivalent to about 10 million tons of TNT. In the process, 300 million tons of solid rock were instantly excavated, leaving a chasm more than a half mile

wide and 500 feet deep (Melosh, 1989; Figure 5). The desert was showered for miles around with a rain of iron fragments ranging in size from microscopic spherules of iron condensate to 1,000-pound pieces (LeMaire, 1980; Graham and others, 1985).

Barringer Meteor Crater was first scientifically investigated in 1891, when Albert Foote, a Philadelphia mineral and meteorite collector, was hired to survey the region on the rumor that it contained a substantial vein of iron ore. Foote found fragments of the Canyon Diablo iron and had them analyzed. After determining that the specimens were not only meteoritic but also full of **carbonados**, dark clusters of microscopic diamonds, Foote tried to sell them.

In 1902, Daniel Barringer, a Philadelphia geologist, learned of the crater, along with the local belief that a huge mass of iron was still buried in the middle of the hole. He invested more than \$120,000 of his life's savings and much of his lifetime into finding commercially minable iron. What he found instead were countless meteorites (Burke, 1986).

Barringer obtained a mining patent under the name of the Standard Iron Company and set about trying to recover the main mass, which he believed lay under the southern rim of the crater. By 1918, despite test holes and intensive exploration, the company had not uncovered any large masses, and the initial stockholders' investments were exhausted. Barringer then entered into a lease agreement with another mining concern, the U.S. Smelting and Refining Company, which poured another \$200,000 into the project with equally fruitless results (Burke, 1986).

Operating on the theory that the buried mass of iron, nickel, platinum, and diamonds approached a market value of \$1 billion, Barringer was not to be deterred. In 1927, with fresh funding and a new company called the Meteor Crater Exploration and Mining Company, he drilled a new exploratory shaft. At 650 feet, however, heavy water flow prohibited further progress. Hoping to shore up the sinking faith of the stockholders, Quincy Shaw, the company president, asked a respected mathematician, Forest Moulton, to estimate the size of the hoped-for mass. Unfortunately for Shaw, Barringer, and the stockholders, Moulton's calculations strongly suggested that the entire mass had volatilized on impact; they were drilling for dreams. All operations were immediately stopped. His health, savings, and confidence shattered, Barringer died of a stroke a few months after Moulton's analysis, still believing that his fortune lay buried in the bottom of a big hole (Burke, 1986).

Canyon Diablo meteorites are well represented in museums and collections around the world. Although private ownership of Barringer Meteor Crater and the surrounding area prevents prospecting, Canyon Diablo specimens may be purchased at the museum on the crater premises.

### ARIZONA METEORITICISTS

Besides harboring a number of interesting meteorites, Arizona is home to a number of interesting **meteoriticists**, scientists who study meteorites. The University of Arizona's (U of A) Lunar and Planetary Laboratory in Tucson has on

staff several internationally known scientists whose work on meteorites has advanced our knowledge of the origins and makeup of the solar system, as well as the history of planet Earth. Dolores Hill and Dr. William Boynton have analyzed meteorites from Antarctica and Australia that came from the surface of the Moon. Along with Dr. David Kring, they are currently analyzing **ureilites** (olivine-rich achondrites) from the Sahara Desert and a new Australian, **ultramafic** (iron- and magnesium-rich) achondrite called Eagles Nest. One of only a handful of specimens of this rare type, Eagles Nest represents a new planetary body about which virtually nothing is known (Dolores Hill, oral commun., 1992).

Neutron-activation analysis, one analytical method employed by U of A scientists, involves bombarding a meteorite sample with neutrons in a nuclear reactor. This allows the scientists to study the radionuclides of elements such as manganese, iron, chromium, and rare-earth elements. By measuring the radiation with gamma-ray spectrometers, the scientists can identify the elements that produced it. The data are carefully analyzed to determine the geochemical makeup of the specimen.

Last year, Dr. Alan Hildebrand (now with the Geological Survey of Canada in Ottawa, but then with the U of A), Kring, Boynton, and other scientists gained international recognition when they discovered an enormous, 110-mile-wide crater partly in the ocean at the edge of the Yucatán Peninsula (Hildebrand and others, 1991; Kerr, 1992). This crater, known as "Chicxulub" (CHEEK-shoe-lube), is of the correct age and size to have been the site of the much-hypothesized, dinosaur-demolishing asteroid impact at the Cretaceous-Tertiary boundary about 65 million years ago. Scientists estimate that the asteroid was about 6 miles wide and that its impact was more forceful than a simultaneous explosion of 10,000 of the largest hydrogen bombs ever tested (David Kring, oral commun., 1992). Towering waves up to 1 mile high would have radiated out from the center of the oceanic impact site at hundreds of miles per hour. Any of these waves that reached the mainland would have continued onshore, flooding hundreds of miles inland and carrying thousands of tons of churning rock and debris (Alan Hildebrand, oral commun., 1991).

Boynton and Kring have analyzed samples of that debris, along with rock extracted from inside the crater by oil-exploration drilling. After examining **polymict breccias** (rocks containing fragments with different compositions that were shattered and mixed during the impact) and rocks that had melted during the impact, they confirmed that Chicxulub is indeed an impact crater and not a volcanic crater. They are also analyzing **shocked quartz grains** (minerals altered by the high-pressure shock waves caused by the impact), as well as platinum-group elements that are rare in the Earth's crust but more abundant in meteorites (David Kring, oral commun., 1992).

#### WHERE TO LEARN MORE

Arizonans have a wealth of information on meteorites available to them. Persons in the Tucson area may visit the Flandrau Science Center and Planetarium on the U of A campus and see a giant, walk-through scale model of an asteroid at the moment of impact with another planetary body. On one side, the "molten" core of the miniature moon is exposed. On the other side, a chasm has opened in the meteoroid, allowing an "alien's-eye view" of the asteroid belt; spinning chunks of meteoroid are flung out into space in front of the visitor's eyes. Set into niches in the "rocky" walls

of the exhibit are actual meteorite specimens, including the one that Thomi Davis found in Udall Park. Associated with this exciting exhibit are the Flandrau Discovery Drawers, which allow closer examination of other meteorites.

Just west of Tucson, the Arizona-Sonora Desert Museum contains a new exhibit, called "Origin of the Earth and Moon," which explains the birth of the solar system. Several meteorites and Moon rocks are on display, including a piece of the Allende chondrite that visitors may touch.

Individuals in the Phoenix area may visit the Center for Meteorite Studies at Arizona State University. This center is home to the third-largest meteorite collection in the world and the largest collection of meteorites at any university. Dr. Carleton Moore, the director, and Chuck Lewis, the assistant curator, are usually on hand to discuss meteorites with aficionados.

Another tremendous resource is the Museum of Northern Arizona in Flagstaff. The Winona meteorite and its stone "sarcophagus" are on display, as well as many other fascinating Arizona meteorites. Deborah Hill, Dr. Eugene Shoemaker, Dr. David Roddy, and other scientists there will share their expertise with meteorite enthusiasts.

Persons wishing to gain a broader knowledge of the subject are encouraged to check out their local library's science section. One well-written and interesting overview of the history and development of the science of meteoritics is *Cosmic Debris*, by John G. Burke. The chapter on myths, folklore, and legends about meteorites is particularly entertaining. Another source, the *Field Guide of Meteorites*, by Robert Haag and this author, includes stories of finds, as well as descriptions and more than 200 full-color photographs of meteorites from around the world. The reference list at the end of this article includes other general-interest publications on cosmic concerns.

Meteorites offer a unique opportunity for scientists to study the makeup of other worlds, without the billions of dollars and monumental difficulties involved in launching space probes. Meteorites are virtually ageless time and space travelers that come to us free of charge from the depths of space. Their value to scientists, collectors, and interested amateurs is incalculable. Arizonans are fortunate to have such a rich heritage, not only of space rocks, but also of the "spacey" people who collect, analyze, and interpret them.

#### SELECTED REFERENCES

- Bagnall, P.M., 1991, The meteorite and tektite collector's handbook: Richmond, Va., Willmann-Bell, Inc., 160 p.
- Bates, R.L., and Jackson, J.A., eds., 1980, Glossary of geology (2d ed.): American Geological Institute, 751 p.
- Burke, J.G., 1986, Cosmic debris: Los Angeles, University of California Press, 441 p.
- Dodd, R.T., 1986, Thunderstones and shooting stars: Cambridge, Mass., Harvard University Press, 196 p.
- Graham, A.L., Bevan, A.W.R., and Hutchison, R., 1985, Catalogue of meteorites (4th ed.): Tucson, University of Arizona Press, 460 p.
- Haag, T.A., and Haag, R.A., 1991, Field guide of meteorites, 10th anniversary edition: Tucson, Wordworks, 60 p.
- Heineman, R.E.S., and Brady, L.F., 1929, The Winona meteorite: American Journal of Science, v. 18, no. 408, p. 477.
- Hey, M.H., 1966, Catalogue of meteorites (3d ed.): London, Alden Press (Oxford) Limited, 637 p.
- Hildebrand, A.R., Penfield, G.T., Kring, D.A., Pilkington, Mark, Camargo, A.Z., Jacobsen, S.B., and Boynton, W.V., 1991, Chicxulub crater: A possible Cretaceous/Tertiary boundary impact crater on the Yucatán Peninsula, Mexico: Geology, v. 19, p. 867-871.

METEORITES continued on page 8

# THE ST. GEORGE EARTHQUAKE OF SEPTEMBER 2, 1992

Philip A. Pearthree  
Arizona Geological Survey

Terry C. Wallace  
University of Arizona

A moderate earthquake that occurred near St. George, Utah, in early September caused considerable damage in southern Utah and was widely felt across northern Arizona, southern Utah, and southern Nevada. The magnitude 5.5 (University of Arizona) to 5.9 (University of Utah) earthquake occurred at 3:26 a.m. PDT on September 2, 1992, about 8 kilometers (5 miles) southeast of St. George (within a few miles of the Arizona border; see Figure 1). The earthquake did not cause any deaths or serious injuries; property damage due to ground shaking was relatively minor. A large landslide triggered by the earthquake, however, destroyed three homes and blocked a state highway in Springdale, Utah, near the southern entrance to Zion National Park (Figure 2). No earthquake-related damage was reported in Arizona, but the tremor was felt strongly in Fredonia, and individuals as far away as Flag-

staff were awakened by the shaking (David Brumbaugh, oral and written commun., 1992). The St. George earthquake is particularly interesting to seismologists and geologists because it occurred in a region with several major active faults that have the potential to generate even larger earthquakes.

The Southern Arizona Seismic Observatory at the University of Arizona analyzed seismic waveforms recorded from the St. George earthquake to determine its characteristics. The earthquake originated at a depth of about 15 kilometers (9 miles). Slip during the earthquake was predominantly normal (vertical, with little horizontal displacement) and apparently occurred on a north-trending fault that dips about 50° to the west. The St. George earthquake is quite unusual because it has had virtually no aftershocks. The seismograph network operated by the University of Utah detected no aftershocks as large as magnitude 2 in the immediate area during the first 3 weeks after the St. George event.

The St. George earthquake is one of the largest historical earthquakes in northwestern Arizona and southwestern Utah. A magnitude 6 event occurred in November 1902, about 30 kilometers (19 miles) north of St. George. Both the magnitude and the location of this event are estimated from reported observations, not from seismic recordings. It is interesting to note that scientists would have placed the **epicenter** (the projection of the earthquake's point of origin onto Earth's surface) of the 1992 St. George earthquake in a similar location had they relied solely on damage reports. **Swarms** of earthquake activity (numerous earthquakes, none of which stands out as a distinct main event) have occurred several times in the Cedar City, Utah, area, in-

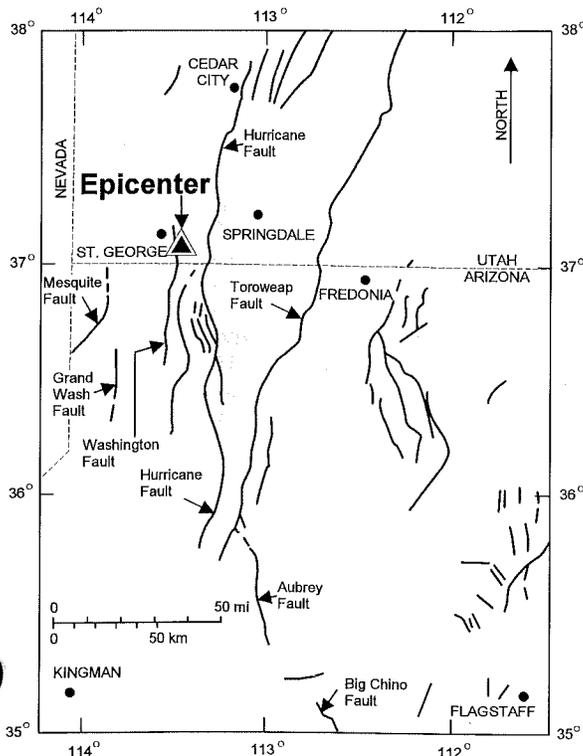
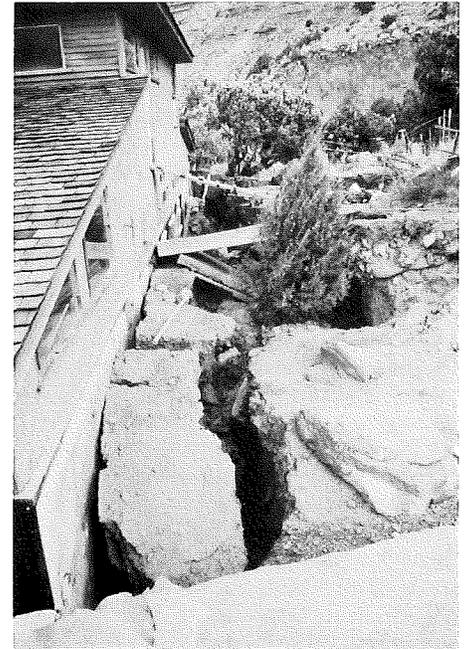


Figure 1. Locations of epicenter of 1992 St. George earthquake and late Quaternary faults in southwestern Utah and northwestern Arizona.

Figure 2. Ground cracks near a home damaged by the Balanced Rock landslide in Springdale, Utah, which was triggered by the St. George earthquake. The headwall scarp, which is about 20 meters (70 feet) high, is visible in the background. This scarp marks where the landslide broke away and shifted down from the rest of the mountain. The landslide measured approximately 490 meters (1,600 feet) from head to toe and was about 1,100 meters (3,600 feet) wide (Black and others, 1992). Photo by Bill Black of the Utah Geological Survey.



cluding late June 1992 (Arabasz and others, 1992). In Arizona, several earthquakes with magnitudes of 6.0 to 6.2 occurred in the Flagstaff area in the early 1900's (David Brumbaugh, oral commun., 1992), and a magnitude 5.5 to 5.75 earthquake occurred near Fredonia in July 1959 (DuBois and others, 1982).

The 1992 St. George earthquake occurred in a region with several major faults that have been quite active during the past 130,000 years and have the potential to generate large earthquakes. The earthquake did not rupture the surface (Black and others, 1992), so it is not certain that it occurred on any of these mapped faults. The epicenter of the earthquake is very near the Washington Fault zone (Figure 1). The fault plane of the earthquake projects to the surface near the Hurricane Fault, a major active fault that trends south from Cedar City to the Grand Canyon. The Hurricane Fault is a normal fault that dips to the west and displaces rocks on the western side downward relative to rocks on the eastern side. Abundant evidence documents the geo-

logically recent activity of the Hurricane Fault, including a 290,000-year-old basalt flow at the town of Hurricane, Utah, that has been displaced about 90 meters (300 feet) by repeated movements on the fault (Hamblin and others, 1981). Fairly young alluvial fans along the fault zone in Arizona have been displaced by a few meters (several feet), suggesting that faulting has occurred within the past 10,000 to 20,000 years (Pearthree and others, 1983; Scarborough and others, 1986). These surface displacements along the Hurricane Fault were most likely produced by paleoearthquakes of magnitude 7+.

The absence of aftershock activity following the 1992 St. George earthquake is intriguing. Typically, an earthquake of magnitude 5.5 to 5.9 would be followed by 10 to 15 aftershocks of magnitude 3 or greater within the first few days after the main event. A magnitude 5 earthquake that occurred near Lake Elsmar, California, in 1988 also had no detectable aftershocks. This event preceded the devastating magnitude 7.1 Loma Prieta earthquake of 1989. Other moderate earthquakes in California with weak aftershock sequences, however, were not followed by a larger earthquake. The absence of aftershocks following the St. George earthquake, therefore, does not necessarily imply that a larger earthquake will occur in that area in the near future.

## REFERENCES

- Arabasz, W.J., Pechmann, J.C., and Nava, S.J., 1992, The St. George (Washington County), Utah, earthquake of September 2, 1992: University of Utah Seismograph Stations, Preliminary Earthquake Report, September 6, 6 p.
- Black, B.D., Mulvey, W.E., Lowe, Mike, and Solomon, B.J., 1992, Investigation of geologic effects associated with the September 2, 1992, St. George earthquake, Washington County, Utah: Utah Geological Survey Report, September 24, 16 p.
- DuBois, S.M., Smith, A.W., Nye, N.K., and Nowak, T.A., Jr., 1982, Arizona earthquakes, 1776-1980: Arizona Bureau of Geology and Mineral Technology Bulletin 193, 456 p., scale 1:1,000,000.
- Hamblin, W.K., Damon, P.E., and Bull, W.B., 1981, Estimates of vertical crustal strain rates along the western margins of the Colorado Plateau: *Geology*, v. 9, p. 293-298.
- Pearthree, P.A., Menges, C.M., and Mayer, Larry, 1983, Distribution, recurrence, and possible tectonic implications of late Quaternary faulting in Arizona: Arizona Bureau of Geology and Mineral Technology Open-File Report 83-20, 51 p.

Scarborough, R.B., Menges, C.M., and Pearthree, P.A., 1986, Map of late Pliocene-Quaternary (post-4-m.y.) faults, folds, and volcanic outcrops in Arizona: Arizona Bureau of Geology and Mineral Technology Map 22, scale 1:1,000,000.

## PROFESSIONAL MEETINGS

**Tucson Gem & Mineral Show.** Annual exhibit, February 11-14, Tucson, Ariz. Contact Tucson Gem & Mineral Show Committee, P.O. Box 42543, Tucson, AZ 85733; tel: (602) 322-5773.

**Arizona-Nevada Academy of Science.** Annual meeting, April 16-17, Las Vegas, Nev. Abstract deadline: January 8. Contact Sandra Brazel, Office of Climatology, Arizona State University, Tempe, AZ 85287-1508; tel: (602) 965-6265.

**Forum on the Geology of Industrial Minerals.** Annual symposium, April 25-30, Long Beach, Calif. Contact Dave Beeby, Chairman, 29th Forum on Industrial Minerals, Division of Mines and Geology, 801 K St., MS 08-38, Sacramento, CA 95814-3531; tel: (916) 323-8562; fax: (916) 327-1853.

**Geological Society of America.** Cordilleran and Rocky Mountain Sections, annual meeting, May 19-21, Reno, Nev. Abstract deadline: January 26. Contact Richard A. Schweickert, Department of Geological Sciences, Mackay School of Mines, University of Nevada-Reno, Reno, NV 89557-0138; tel: (702) 784-6050.

## In Memoriam

Dr. Richard T. Moore, retired Principal Geologist of the Arizona Bureau of Mines, a predecessor of the Arizona Geological Survey, died in August 1992 after undergoing surgery in the Philippines. Dr. Moore spent 26 years as a geologist with the Bureau. He received his B.S. and M.S. degrees from the University of Arizona and his Ph.D. degree from Stanford University. After he retired in 1977, Dr. Moore bought a 42-foot sailboat and cruised the high seas with his wife, Elizabeth. He is survived by his wife, daughter, and two grandsons, all from Tucson.

*METEORITES continued from page 6*

- Hutchison, R., 1983, *The search for our beginning*: London, Oxford University Press, 164 p.
- Kerr, R.A., 1992, Huge impact tied to mass extinction: *Science*, v. 257, p. 878-880.
- LeMaire, T.R., 1980, *Stones from the stars*: Englewood Cliffs, NJ., Prentice-Hall, Inc., 185 p.
- Mark, Kathleen, 1987, *Meteorite craters*: Tucson, University of Arizona Press, 288 p.
- Marvin, U.B., 1986, *Meteorites, the Moon, and the history of geology*: *Journal of Geological Education*, v. 34, p. 140-165.
- McSween, H.Y., Jr., 1987, *Meteorites and their parent planets*: Cambridge, Cambridge University Press, 237 p.
- Meadows, J., 1985, *Space garbage: Comets, meteors and other solar-system debris*: London, Biddles, Ltd., Guildford and King's Lynn, 160 p.
- Melosh, H.J., 1989, *Impact cratering: A geologic process*: New York, Oxford University Press, 245 p.
- Strahler, A.N., 1981, *Physical geology*: New York, Harper & Row, 612 p.
- Wasson, J.T., 1985, *Meteorites: Their record of early solar-system history*: New York, W.F. Freeman & Co., 267 p.
- Willey, R.R., 1987, *The Tucson meteorites; their history from frontier Arizona to the Smithsonian*: Washington, D.C., Smithsonian Institution Press, 47 p.

## Once Upon a Time ...

... two storytellers wrote a fairy tale about minerals. Like all good fairy tales, this one included elements of truth. *Mined It!*, a 54-page book by Jeanette M. Harris and Peter W. Harben, was written for children from ages 8 to 16. The book illustrates, through the use of a fairy tale, the indispensable role of minerals in everyday life. It also includes a glossary and word puzzles. Copies may be customized; e.g., the publisher can add information on minerals that are important to a particular area. Single copies are \$15.95 (includes shipping in the United States and Canada); prices for bulk orders are available on request. Checks should be made payable to Butternut Books and mailed to The Grove, P.O. Box 800, W. Main St., Morris, NY 13808; tel: (607) 263-5070; fax: (607) 263-5356.

## Singing the Mailing List Blues

If you move and want to continue receiving *Arizona Geology*, please send us your new address with your nine-digit zip code. If you want to be deleted from our mailing list, also let us know. This will make everyone happy, especially the folks at the post office.

# EXPLORATION WELL TESTS SALT NEAR PHOENIX

Steven L. Rauzi  
Arizona Geological Survey

In September 1992, Arrowhead Oil and Gas, Ltd., drilled the SunCor-Melange #32-23 well about 20 miles west of Phoenix to test the oil and natural gas potential of a deeply buried deposit of salt near Luke Air Force Base. (Large deposits of subsurface salt and anhydrite are present at several localities in Arizona [Peirce, 1981].) The Luke salt is at least Miocene in age; it is overlain by basalt that has been dated at about 10.5 million years (Eberly and Stanley, 1978). Near the well, the top of the salt deposit lies between 2,500 and 2,600 feet below the surface. The well was drilled to a total depth of 6,650 feet and was completed as a dry hole on September 27, 1992.

The well was drilled in an agricultural and suburban area, which is underlain by a freshwater aquifer that is a primary source of drinking water for nearby communities. Special attention was given to ensure that ground water would not be contaminated during the drilling process. The aquifer in this area is between 400 and 600 feet below the surface, and several water wells produce from it within 0.5 mile of the SunCor-Melange #32-23 well. (The Arizona Geological Survey [AZGS] routinely contacts the Arizona Department of Water Resources for information on the location of water wells and the depth of ground water within 0.5 mile of a proposed exploration well.) The lessor of the oil and gas rights, SunCor Development Corporation, through Litchfield Park Service Company, operates some of these water wells and was therefore especially interested in preventing ground-water contamination.

The procedures used to protect ground water during drilling are based on experience and technology developed over years of drilling in different environments throughout the world. They are employed in both the petroleum and the water-well drilling industries. The most basic method of preventing contamination is **zonal isolation**, sealing off access to all zones so that salt water, oil, and natural gas, if encountered during drilling, cannot mix with ground water. This is accomplished by circulating a viscous mixture of water and clay called **drilling mud** in the **wellbore** (the hole made by the drill bit) to prevent contamination while the well is being drilled. A special pipe called **casing** is then installed and cemented in the wellbore to prevent contamination after drilling has been completed.

## DRILLING

The SunCor-Melange #32-23 well was drilled in two steps: (1) using a freshwater-based drilling mud to a depth just above the salt (about 2,500 feet), where casing was installed and cemented; and (2) using a saltwater-based drilling mud before penetrating the salt to prevent the salt from dissolving, as it would have done if a freshwater-based drilling mud had been used.

As the wellbore is drilled deeper, new joints of drill pipe are added to the drill string (Figure 1). The drill bit is at

the bottom of the drill string, which is rotated at the surface. To improve cutting performance, weight is added to the drill string by placing heavy, thick-walled pipe called **drill collars** just above the bit.

Drilling mud is used to cool the drill bit, lubricate the drill pipe, bring cuttings back to the surface, and prevent contamination of the formations being drilled. It accomplishes the last function by forming a thin, impermeable seal of clay particles on the walls of the wellbore. Drilling mud also prevents the hole from caving in and keeps exposed formation fluids from flowing by exerting hydrostatic pressure against its walls.

To ensure these results, an operator must constantly keep the wellbore full of drilling mud during drilling operations. The drilling mud is pumped through the drill pipe to the drill bit at the bottom of the wellbore, after which the mud returns to the surface with the cuttings through the annular space between the drill pipe and the walls of the wellbore.

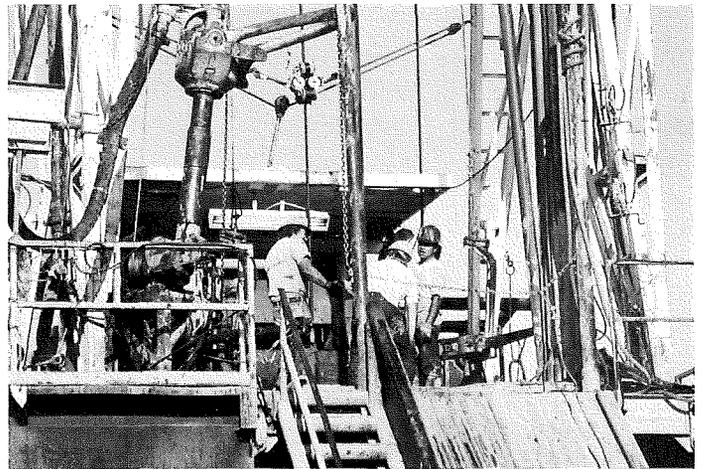


Figure 1. Roughnecks (workers on a drilling rig) connecting another stand to the drill string, which is being lowered into the wellbore. A stand consists of three joints of drill pipe and is approximately 90 feet in length.

At the surface, the mud is routed across a vibrating screen to remove cuttings, sand, and silt that can interfere with the formation of the impermeable clay seal in the wellbore. The mud is then recycled through the drill pipe.

## CASING

The final steps in preventing ground-water contamination in wells are installing casing in the wellbore and cementing it in place (Figure 2). Cementing the casing along its length to isolate each formation penetrated in a well protects ground water, petroleum, and other natural resources by preventing fluid movement between formations. If fluids cannot move from one zone to another, they cannot contaminate each other.

The bottom or **shoe** of the casing is set in a hard, impermeable formation to provide a strong anchor and seal. In addition, centralizers are installed on the casing in several places to keep it in the center of the wellbore and to allow cement to surround it completely. This casing is then cemented throughout its entire length by pumping the cement slurry down the inside of the casing until all of the slurry exits the bottom and fills the annular space between the casing and the walls of the wellbore. The cement slurry thus extends from the bottom of the wellbore to the land

surface. Special rubber plugs are commonly added in front of and behind the cement slurry to prevent it from mixing with the mud it displaces and with the mud used to move it into place, respectively. Fresh water is also typically pumped into the wellbore before the cement slurry is added to clean the viscous drilling mud off the wellbore walls. This cleaning helps establish a more effective cement bond between the casing and the formations along the wellbore walls. The cement prevents fluid movement between formations and supports the weight of the casing.

Once the cement sets, the well is essentially a pipeline from the bottom of the hole to the surface. The wellbore casing is similar to a pipeline that transports natural gas or drinking water into a home, except that the wellbore casing is cemented vertically in place, whereas natural gas and water lines are uncemented and horizontal. Just as a natural gas pipeline confines the gas and prevents it from leaking and contaminating surrounding soil, the wellbore casing confines the fluids traveling within it and prevents them from leaking and contaminating the formations and freshwater aquifers through which it extends.

After drilling to a depth of 2,500 feet, the operator of the SunCor-Melange #32-23 well installed casing in the wellbore. The casing shoe was set just above the salt and just below several beds of hard anhydrite, which provided a strong, impermeable seal (Figure 2). The cemented casing shoe was pressure tested to 1,500 pounds per square inch (psi) and held this pressure for 30 minutes. This proved that the casing had sufficient mechanical integrity to contain the saltwater-based drilling mud and to withstand any unexpectedly high pressures that may have been encountered as the drill bit drilled into the salt. AZGS staff geologists Steve Rauzi and Rick Trapp were present during the cementing process to ensure that the cement was circulated back to the surface and, thus, that the process was properly completed. An AZGS representative witnesses this process on all oil, natural gas, helium, and geothermal wells drilled in Arizona.

The 1,900 feet of cemented casing between the top of the salt and the base of the freshwater aquifer effectively prevented the saltwater-based drilling mud from contaminating the aquifer and would have prevented oil or natural gas contamination had these resources been found and produced. If production had been feasible, the operator would have added another string of casing, called the **production string**, from the surface to the bottom of the oil or natural gas zone to provide additional protection for both the oil or natural gas and the ground water. No oil or natural gas was discovered, however.

#### PLUGGING AND ABANDONMENT

If no oil or natural gas is discovered in commercial amounts in an exploration well, the well is plugged and

abandoned. Information gained while drilling the well is used to plan the plugging operation, which must follow specific regulations that require cement plugs to be placed across certain intervals in the well. In open (uncased) holes, cement plugs are placed across all freshwater zones, any zone containing fluid with a potential to migrate, and any zone containing potentially valuable natural resources. In cased holes, cement plugs are placed across all open perforations, as well as the casing shoe.

The cement plugs are placed by lowering drill pipe to the bottom of the lowest zone to be plugged. The calculated volume of cement is pumped to that zone. The drill pipe is then pulled up to the bottom of the next zone to be plugged. This process is repeated until all of the zones are plugged. The intervals between the cement plugs are filled with a heavy, viscous mud.

In the SunCor-Melange #32-23 well, several cement plugs were placed in the open hole below the casing shoe. Another cement plug was placed 150 feet below the casing shoe up to 100 feet within the casing. Finally, a cement plug was placed inside the casing from a depth of 90 feet up to the ground surface.

#### CONCLUSION

Even though the SunCor-Melange #32-23 well was completed as a dry hole, it provided valuable information on the subsurface geology of Arizona. Each new well, whether completed as a producer or a dry hole, enhances the understanding of Arizona's geologic

history. The better geologists understand this history, the better they can explore for, develop, and manage Arizona's natural resources. These resources include not only oil and natural gas, but also ground water.

The subsurface information obtained on all wells drilled for oil, natural gas, helium, and geothermal resources is maintained at the AZGS. This information includes drilling and production data, sample descriptions, drill cuttings and cores, electric and porosity logs, and formation tops. For any oil or gas exploration well drilled in unproven territory, the subsurface data are kept confidential for 1 year after the well is completed. The well operator has exclusive use of these data during this time. After the period expires, however, these data become public information and may be reviewed at the AZGS office by any individual or group during regular working hours.

#### REFERENCES

- Eberly, L.D., and Stanley, T.B., 1978, Cenozoic stratigraphy and geologic history of southwestern Arizona: Geological Society of America Bulletin, v. 89, p. 921-940.
- Peirce, H.W., 1981, Major Arizona salt deposits: Arizona Bureau of Geology and Mineral Technology Fieldnotes, v. 11, no. 4, p. 1-4. [Available for \$1.00 from the Arizona Geological Survey.]

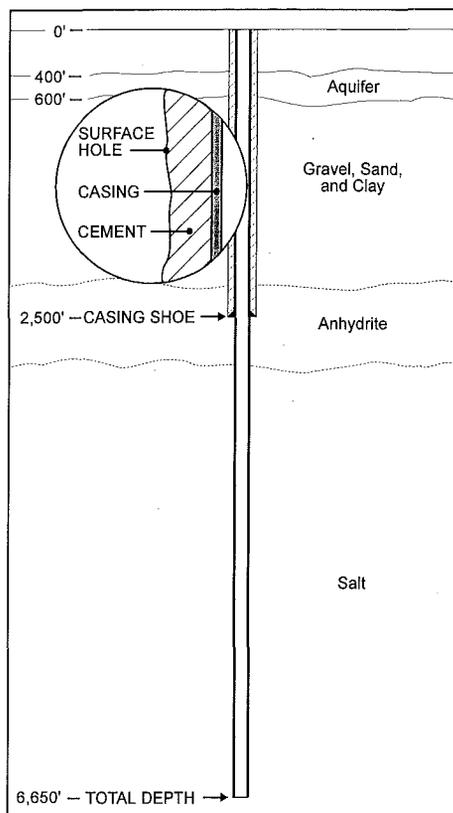


Figure 2. Construction schematic of SunCor-Melange #32-23 well near Phoenix.

# AZGS LIBRARY IS STOREHOUSE OF GEOLOGIC INFORMATION

*Thomas G. McGarvin*  
Arizona Geological Survey

As part of its continuing service to the public, the Arizona Geological Survey (AZGS) maintains a library of maps, reports, and data, with emphasis on the geology of Arizona. The library is open to the public. Frequent users include mineral-exploration geologists, environmental and engineering geologists, representatives of Federal and State agencies, professional and recreational prospectors, consultants, educators, students, and interested members of the public. Materials may not be checked out, but photo-

copying arrangements may be made. Open hours are from 8 a.m. to 5 p.m., Monday through Friday.

The library contains more than 25,000 volumes. Publications by the AZGS and its predecessor agencies, the Arizona Bureau of Mines and the Arizona Bureau of Geology and Mineral Technology, are available for public use. (Many may also be purchased.) The library also includes several major technical journals, reports and maps by the U.S. Geological Survey, reports by the U.S. Bureau of Mines, and quarterly microfiche compilations of unpatented mine claims issued by the U.S. Bureau of Land Management. A microfiche

reader is maintained for library use.

Other library holdings include publications by the geological surveys of States adjacent to Arizona; theses and dissertations on Arizona geology; textbooks; environmental impact statements and reviews; and unpublished maps and reports on the geology and the mineral, water, and energy resources of Arizona. Reports published by the Arizona Department of Water Resources, Arizona Department of Mines and Mineral Resources, and Arizona Geological Society are maintained for reference. The files and publications of the Oil and Gas Conservation Commission, a former State agency, were transferred to the AZGS in 1991.

## Radio Series Links Earth and Sky

"Earth and Sky" is a 2-minute daily radio series that is airing on more than 150 affiliate stations throughout the United States and Canada. Produced in association with the American Geophysical Union, the 1-year-old series is the first to combine earth science and astronomy. In addition to telling listeners what to look for in the night sky, it gives easy-to-understand information about planet Earth. The series is produced by Deborah Byrd and Joel Block, who for 14 years produced the award-winning "Star Date" series. "Earth and Sky" recently received a

National Science Foundation grant enabling public, noncommercial, and university radio stations to obtain the program free of charge. The producers are also developing 1-hour cassette tapes of "Earth and Sky" highlights, which may be ordered for \$10 from Earth and Sky, P.O. Box 2203, Austin, TX 78768; tel: (512) 472-8975. "Earth and Sky" airs in Tucson on community radio station KXCI, 91.3-FM, Monday through Friday at noon; and in Flagstaff on university radio station KNAU, 88.7-FM, Monday through Friday after the 11:30 a.m. news.

### Arizona Geology

Vol. 22, No. 4	Winter 1992
State of Arizona:	Governor Fife Symington
Arizona Geological Survey	
Director & State Geologist:	Larry D. Fellows
Editor:	Evelyn M. VandenDolder
Editorial Asst. & Designer:	Emily Creigh DiSante
Illustrator:	Peter F. Corrao
Copyright © 1992 Arizona Geological Survey ISSN 1045-4802	



Printed on recycled paper



**Arizona Geological Survey**  
845 N. Park Ave., Suite 100  
Tucson, AZ 85719-4816  
Tel: (602) 882-4795

# TUCSON EARTH SCIENCE INFORMATION CENTER OPENS

*Diane Murray*  
Arizona Geological Survey

The Tucson Earth Science Information Center (ESIC) opened for business on August 4, 1992. A joint effort between the Arizona Geological Survey (AZGS) and U.S. Geological Survey (USGS), the Tucson ESIC provides selected earth-science and mineral-resource information from both agencies. The Center is staffed by personnel from the AZGS, with support and coordination provided by members of the USGS Geologic Division (Figure 1).

The Tucson ESIC was established in October 1991 by a Memorandum of Understanding between the AZGS, USGS National Mapping Division, and USGS Geologic Division. The Center is responsible for making multipurpose cartographic, hydrologic, geologic, and mineral-resource data available to the public. These data are maintained in paper (maps and books), CD-ROM, and microfiche formats.

USGS topographic quadrangles, geologic and thematic maps, and selected publications on Arizona are available for sale at the Center. These include Professional Papers, Bulletins, and Water-Supply Papers on general geology as well as the geology of Arizona. USGS Circulars and General Interest Publications are available free of charge at the Center. Some popular AZGS publications and thematic maps are also available for sale.

The Tucson ESIC has complete topographic coverage for Arizona at scales of 1:24,000 (7.5' quadrangle) and 1:250,000 (1° x 2° quadrangle). The Center also has selected maps in the following series: 1:62,500 (15') topographic quadrangles, 1:100,000 (30' x 60') land-status maps, Geologic Quadrangle (GQ) maps, Hydrologic Unit (HUM) maps, Miscellaneous Investigations Series (I) maps, Miscellaneous Field Studies (MF) maps, Mineral Investigations Resource (MR) maps, and National Atlas sheets (at various scales). The Center is planning to expand the publication and map coverage for Arizona and include the border areas of surrounding States



Figure 1. Tucson ESIC team members (left to right): Frances Wahl Pierce (USGS Lead Geologist, Tucson Minerals Information Office), Karen Bolm (USGS Technical Information Specialist), Diane Murray (AZGS Librarian), and Rose Ellen McDonnell (AZGS ESIC Manager).

(California, Colorado, Nevada, New Mexico, and Utah) and northern Mexico.

Information and databases in CD-ROM and other computer formats, on microfiche, and in hard-copy provide ESIC staff members with the resources to answer a wide variety of questions. Coordination with AZGS headquarters ensures complete access to the latest research on Arizona's geology and resources. Visitors who need more detailed information on such topics are referred to geologists or the library at the AZGS headquarters. ESIC staff members are prepared to answer questions about aerial photographs, digital cartographic data, access to geodetic control, geo-

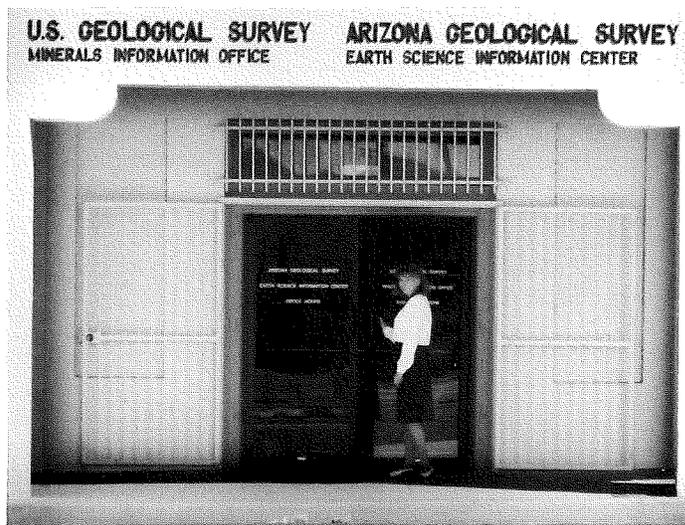


Figure 2. The Tucson ESIC office is located at 340 North Sixth Avenue, Tucson, Arizona 85705-8325.

graphic names, geologic and hydrologic reports, availability of map separates, the National Wetlands Inventory Program, and satellite images. Staff members can also provide information on obtaining other USGS or AZGS publications or data in different formats.

The ESIC office is conveniently situated in the same building as the USGS Minerals Information Office, USGS Center for Inter-American Mineral Resource Investigations, and U.S. Bureau of Mines State Resource Office (Figure 2). The ESIC office, located at 340 N. 6th Ave., Tucson, AZ 85705-8325, is open Monday through Friday, 8:00 a.m. to 4:00 p.m. The phone number is (602) 670-5584; the fax number is (602) 670-5591.

*Diane Murray recently joined the AZGS staff as Librarian for the Tucson ESIC. She has a B.S. degree in geology and an M.L.S. degree, qualifications that make her well suited to answer questions about earth-science information. Diane has worked as a geologist for mineral-exploration and mining companies and for the New Mexico Bureau of Mines and Mineral Resources in Socorro. She has also worked in several libraries.*