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PETRIFIED WOOD: Legacy From a Late Triassic Landscape

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The broad, low-lying flood plain is part jungle, part marsh. It is crossed by numerous meandering streams and rivers; ponds, swamps, and oxbow lakes dot the landscape. The climate is warm and moist, the vegetation lush. The thick growth includes an abundance of ferns, giant rushes, horsetails with diameters as large as 1 foot, and 1- to 4-foot-tall cycads that look like large pineapples capped by coarse leaves. Clams, snails, horseshoe crabs, and crayfish scavenge the lake and river bottoms and muddy banks. Freshwater sharks stalk the waters. Plentiful fish, some as long as 5 feet and weighing as much as 150 pounds, fall prey to giant 10-foot-long, 1,000-pound amphibians that resemble salamanders. Crocodilelike reptiles, up to 1 ton and 30 feet long, snatch fish and unwary animals that venture too close to the water.

In the distant mountains toward the south, near the headwaters of the rivers and streams, 200-foot-tall pinelike trees dominate the scene. Some are carried downstream toward the north after they are killed by insects, lightening, high winds, floods, disease, or old age. A few of these become lodged in shallow areas along the stream bottoms or on sandbars within the flood plain and are eventually covered with successive layers of sand, silt, mud, and volcanic ash.

Although the flood plain resembles the equatorial Amazon or marshy Everglades, the scene actually depicts Arizona and surrounding areas, as they were about 225 million years (m.y.) ago (Dietz and others, 1987). At that time, the landmass now called "Arizona" was part of the supercontinent Pangaea 1,700 miles toward the south near the Equator, and Arizona's petrified logs were still living trees.

Chinle Formation

Paleontologists have pieced together this panorama of Late Triassic (208 to 230 m.y. ago) life from fossils embedded in the sedimentary layers of the Chinle Formation. This formation, one of the most widely distributed Late Triassic deposits in the world, blankets most of the Colorado Plateau, including parts of Utah, Colorado, New Mexico, and Arizona (Stewart and others, 1972). It derives its name from Chinle Valley in northeastern Arizona, where outcrops are extensive. The Navajo term *chinli*, which means "it flows out," probably describes the stream that flows from Canyon de Chelly into Chinle Valley (Gillette and others, 1986).

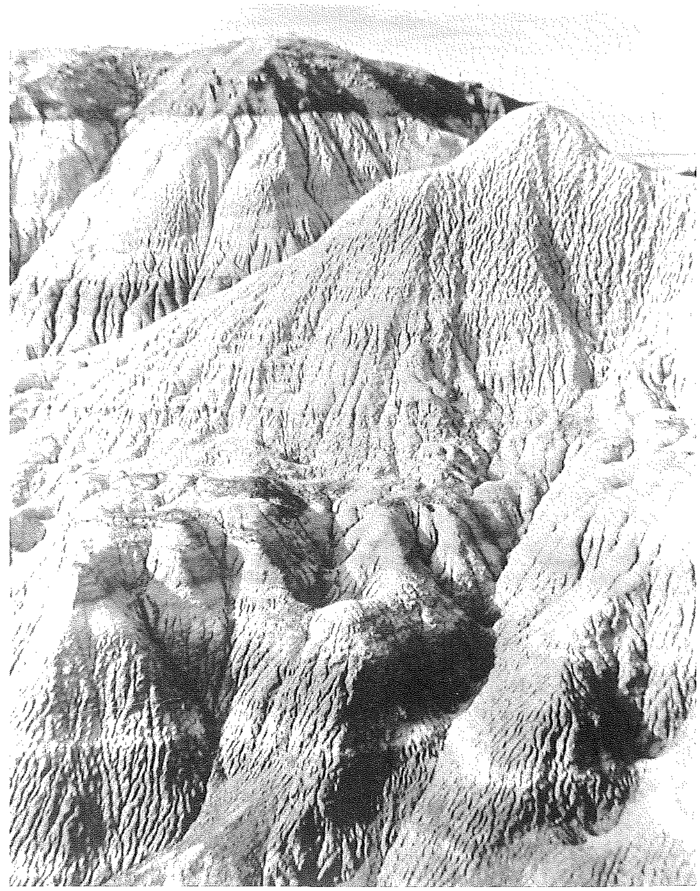

Figure 1. The variegated layers of the Late Triassic Chinle Formation are due to the presence of oxidized iron and manganese minerals (dark bands) and volcanic ash altered to clay (light bands). Photo by Evelyn M. VandenDolder.

The formation's stream deposits of conglomerate, sandstone, siltstone, mudstone, and claystone impart the colorful tints to the Painted Desert of northeastern Arizona (Figure 1). The rainbow hues of the rounded hills were created in a warm, wet, oxidizing environment during the Late Triassic (Ash and May, 1969; Dietz and others, 1987). Faunal differences in units of the Chinle Formation suggest that it was deposited over a long period of time, during which environmental changes occurred (Gillette and others, 1986). In the Petrified Forest, where the Chinle Formation is about 932 feet thick, researchers have discovered 200 genera of fossil plants, as well as 30 species of fossil vertebrates, including dinosaurs (Gillette and others, 1986; Meyer, 1986; Ash, 1987). For this reason, some paleontologists believe that the Petrified Forest is the best place on Earth to study life as it was during the Late Triassic.

The Late Triassic age of the Chinle Formation and fossils embedded within it has been determined through correlation with fossils from other parts of the world. Volcanic cobbles from the Chinle Formation, thought to be rafted in the entangled roots of the conifers that grew in the highlands to the south, yielded K-Ar dates of 196, 210, and 222 m.y. (Peirce and others, 1985). Two of these dates are Late Triassic, but the other date (196 m.y.) is Early Jurassic. These dates apply to the parent rocks, i.e., the rocks from which the cobbles were eroded, and hence are *older* than the Chinle Formation. The apparent conflict between the age based on fossil correlations and the youngest of the K-Ar ages remains unresolved.

Arizona's Petrified Wood

Petrified wood has been found in nearly every county in Arizona; much of it is embedded in deposits that are younger than the Chinle Formation. The most concentrated deposits, however, are within the Chinle Formation in Petrified Forest National Park (Phillips and Bloyd, 1988). The park contains the largest known accumulation of petrified logs in the world (National Park Service, undated; Figure 2).

Early American Indians revered the petrified logs. The Navajos called the logs *Yei bitsin,* "the bones of Yeitso." In Navajo mythology, Yeitso was a monster whose congealing blood formed lava flows. The Paiutes believed the logs were the spears of the wolf god Sinaway that were broken during a terrible battle among the gods (Dietz and others, 1987).

About 90 percent of the petrified wood in the national park is of the species *Araucarioxylon arizonicum,* which is distantly related to the Araucarias that currently grow in South America, Australia, and New Zealand. These include the Norfolk Island pine, the monkey puzzle tree, and the bunya-bunya (Ash and May, 1969; Dietz and others, 1987). Petrified wood from two other trees, *Woodworthia arizonica* and *Schilderia adamanica,* is also present in the park, but is less common.

Some of the petrified logs measure more than 28 inches in diameter and up to 203 feet in length (Ash, 1987). Because the majority of the logs lack branches, roots, and bark and are nearly horizontal in position, researchers believe that most of the original trees did not grow in the area encompassed by the park, but were transported long distances from forested areas by north-flowing streams (Ash and May, 1969; National Park Service, undated). The giant conifers probably thrived in ancestral highlands that may have existed in what is now southern Arizona and Mexico (Peirce and others, 1985; Peirce, 1986). In-situ stumps in growing position, however, are present in the northern part of the park, which suggests that some trees also grew on the flood plain (Ash, 1987).

Figure 2. *Because petrified wood and quartz both contain silica, they have essentially the same hardness. Petrified wood is harder than glass and steel, and as a mass, is considerably harder than granite. It has a specific gravity of 2.6 to 2.8 and can weigh as much as 175 pounds per cubic foot (National Park Service, undated). Because the petrified logs (shown above) are buried at different levels within the Chinle Formation, it is apparent that no sudden catastrophe killed the trees. Some petrified logs show the work of bark beetles; others have scars that resemble fire scars. It is assumed, therefore, that they were killed over a long period by normal forest processes. Photo by Evelyn M. VandenDolder.*

After the trees were transported downstream and became trapped in shallow waters, fluvial deposits of silt, mud, and volcanic ash from volcanoes to the south or west buried the logs and cut off the supply of oxygen; decay was thus retarded. Ground water percolating through the sediments dissolved silica from the volcanic ash. As the silica filtered through the logs, it precipitated from solution as microscopic quartz crystals in the woody tissues where air, water, and sap were originally present in the living tree (National Park Service, undated). In some logs, cell structure remained intact, albeit entombed. Where the logs were hollow, woody tissue did not limit crystal growth; large crystals of rose quartz, smoky quartz, amethyst, and other gemstones or large masses of amorphous (noncrystalline) chalcedony and chert lined the cavity walls (Ash and May, 1969). Originally, researchers believed that minerals replaced the wood fibers. In recent experiments, however, after acid was used to dissolve the minerals, the original woody tissue was visible under a microscope (National Park Service, undated).

As the silica petrified the wood, other elements in the water, such as iron, copper, manganese, and carbon, added tints of red, yellow, orange, brown, blue, green, purple, and black to the fossilized tissues. In some logs, tunnels and galleries are visible, the remains of ancient excavations dug by Triassic insects (Ash, 1987). The high degree of preservation of the logs and other fossils in the Chinle Formation is due to favorable conditions, such as warm temperatures, high moisture, and little or no oxygen, during and after deposition of the sediments (Ash and May, 1969).

Post-Triassic Geologic History

At the time the logs were swept downstream and buried beneath fluvial deposits, the area was flanked by the ancestral Rocky Mountains on the east, ancestral highlands on the south, and a volcanic arc on the west and southwest (Peirce, 1986; Ash, 1987). Pangaea (a Greek word meaning "all earth"), the supercontinent, was still intact at this time. About 205 m.y. ago, in the early Jurassic, Pangaea began to break up and Arizona, as part of the North American continent, slowly drifted northward. Sediments accumulated intermittently throughout the Mesozoic Era (up to about 90 m.y. ago). Some were fluvial deposits left by streams and rivers; others were marine deposits that settled in a shallow, inland sea, which inundated the area. The Chinle Formation became buried beneath 2,000 to 3,000 feet of younger sediments (Ash and May, 1969; National Park Service, undated).

Beginning about 80 m.y. ago, the entire Four Corners area was gradually uplifted, the sea retreated, and erosion began to cut down into the sedimentary layers. The stress of earth movements and the weight of overlying rocks cracked the now petrified logs. Wind and water scoured the sedimentary layers for millions of years. About 6 m.y. ago, a large lake was created, called Lake Bidahochi or Hopi Lake, on the bottom of which sand, silt, and clay accumulated

and others, 1986). Lake Bida-
s later drained to the west and pting of the Grand Canyon Volcanoes in the area erupted, g lava and volcanic ash within op of the Bidahochi Formation ah and Damon, 1986).

n removed the last rocks over- Chinle Formation and exposed ified logs and other fossils.)0 feet of fossil-bearing strata uried in Petrified Forest Nation- (National Park Service, 1981). however, continues to reveal from a past life, including rified wood. An estimated 1/4 oil is removed from the steeper the Painted Desert each year May, 1969).

)ther Petrified Forests

ed Forest National Monument ıblished in 1906 by President Roosevelt to protect this from exploitation by commercial The Painted Desert region ed in 1932 and the monument le into a national park in 1962. now encompasses 93,492 acres Park Service, 1981).

ugh the Petrified Forest of is the most famous, petrified is been found in all 50 States and in many foreign countries (Dietz and others, 1987; National Park Service, undated). The most notable localities are Yellowstone National Park in Wyoming; the Black Hills and Badlands in South Dakota; Florissant Fossil Beds National Monument in Colorado; central and eastern Washington and Oregon; southern Utah; western Nevada; the Catskills in New York; New Albany Forest, Indiana; Red Deer Valley near Calgary, Canada; Joggins, Nova Scotia; Patagonia, Argentina; and Cairo, Egypt (Dietz and others, 1987; National Park Service, undated). Most of these deposits are small and scattered. What distinguishes the Petrified Forest of Arizona from other localities is the large size of the deposits and the spectacular colors in the wood. The Petrified Forest of Arizona is also older than most other petrified forests in the western United States, which are Cretaceous to Tertiary in age (younger than 144 m.y. old; National Park Service, undated).

Arizona's State Fossil

Petrified wood probably ranks third in value as an Arizona gemstone, after turquoise and peridot (Phillips and Bloyd, 1988). Because of its relative abundance in the State, its scientific significance, and its value as a semiprecious stone, petrified wood was made the official State fossil of Arizona in May 1988 (Figure 3). Arizona now joins three other States – North Dakota, Washington, and Louisiana – in revering petrified wood as a State fossil or gem (Dietz and others, 1987). *Araucarioxylon arizonicum,* once the giant of a Late Triassic landscape, is now the giant among Arizona's fossils.

Figure 3. Governor Rose Mofford (center) signs into law Senate bill 1455, making petrified wood (Araucarioxylon arizonicum) *the official State fossil of Arizona. Proponents of the bill are, from left to right, Dr. Robert S. Dietz, Senator Doug Todd (sponsor of the bill), Mitchell Woodhouse, and Dr. Troy L. Péwé. Dietz, Woodhouse, and Péwé are from the Department of Geology, Arizona State University.*

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Conceptualizing Earth History: The (Mis)Use of *Here*

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To enhance public understanding of geologic concepts, geologists should take an active interest in earth-science education and the language best suited to portray geologic history, both simply and accurately. Of special concern is the development and emphasis of concepts fundamental to sharing important geologic insights.

Educators, both formal and informal, are often admonished to practice the KIS principle ("Keep It Simple"). When, however, does keeping it simple become oversimplifying or outright distortion? How sacred is conceptual accuracy? Is a distorted concept better than no concept at all? Keeping it simple -- and accurate -- is, indeed, a tall order for those who must instruct under conditions in which attention spans are short and the volume of subject material is overwhelming. Comedians, cartoonists, and zealots of all types are expected to distort. Are teachers also expected to distort "truth" solely to amuse, captivate, or startle?

Because concepts are expressed in words, the message conveyed is directly related to word selection and implied meanings; this is the essence of communication. A problem word that is often indiscriminately used in conceptualizing earth history is *here*.

It is the use, or misuse, of the common word *here*, meaning "in or at this place," that prompts concern. Used in this way, it conveys a sense of geographic position, and position, with respect to the globe, can be accurately portrayed by measurements of latitude and longitude. Elevation is another parameter that helps to define a place relative to sea level. One example that illustrates the confusion that can arise when *here* is improperly used is an exhibit from the Arizona-Sonora Desert Museum's Earth Science Center near Tucson (Figure 1).

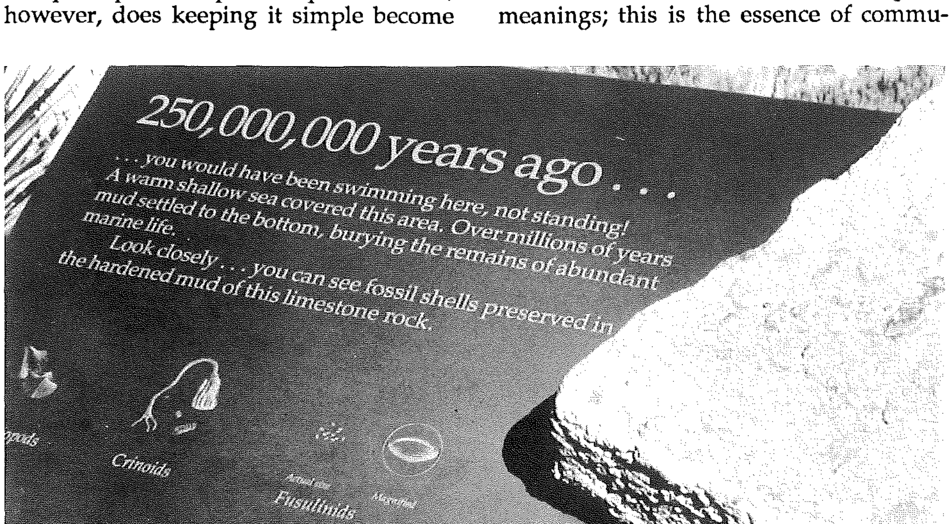

Figure 1. *An example of the misuse of* here, *meaning "in this area," as used in an earth-science exhibit at the Arizona-Sonora Desert Museum. Photo by H. Wesley Peirce.*

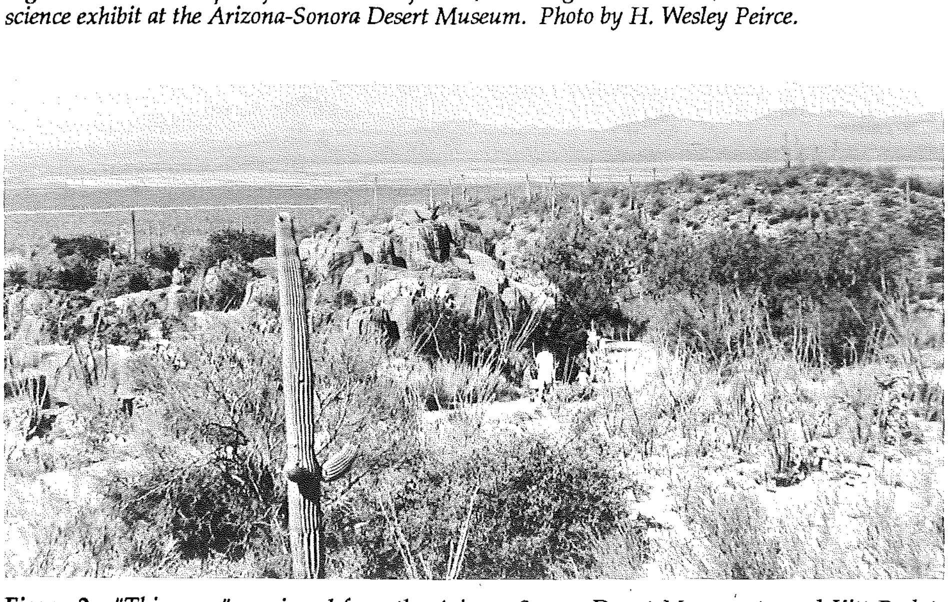

Figure 2. *"This area," as viewed from the Arizona-Sonora Desert Museum toward Kitt Peak to the southwest. Photo by H. Wesley Peirce.*

Here, as used in this exhibit, conveys a sense of place, the place being an undefined region that includes the museum grounds. Figure 2 is a regional view from the museum to the southwest, across Avra Valley toward Kitt Peak. The exhibit prompts the reader to think back 250 million years (m.y.) to a time when a sea was "here." A museum docent leading a 6th grade class might be caught offguard by a question from a very bright student: Does the exhibit mean that a sea once covered Avra Valley and that its waves once pounded against Kitt Peak? If the docent had no in-depth knowledge of regional geologic history, the student and class would be left with a false impression of the conditions that prevailed 250 m.y. ago. The exhibit, although captivating, fails to take advantage of an opportunity to convey clearly a most fundamental earth-science concept: the true nature of geologic change through time.

It is the misuse of *here* in this example that promotes confusion. Because *here* invokes a sense of here and now, a 250-m.y.-old scene is imposed upon the present condition. One could not have been "here" 250 m.y. ago because "here" did not exist. None of the geologic features now visible from the museum grounds (mountains, valleys, desert, rocks, etc.) existed 250 m.y. ago. The sea in which the animals lived and lime-rich sediments accumulated was actually near the Equator, not at 32° north latitude, where some of the fossiliferous limestones that are the basis for the cement industry in Arizona are now located.

These limestones are far from their initial global position, where they were formed, because of continental drifting. Drifting is the actual physical movement of the landmass. Today this part of the evolving landmass is characterized by arid land, whereas 250 m.y. ago it was, as then constituted, in equatorial regions covered by an interior sea in which organisms lived, died, and were buried under accumulations of lime-rich mud. In other words, there *is* a here and now, and there *was* a there and then. Two places and two times are involved, and the environmental conditions associated with each are notably different. As a consequence, the desert now interfaces with rocks formed in an equatorial sea because an evolving landmass has moved thousands of miles northward since 250 m.y. ago. This evolution includes many landscape-changing events.

It is important to impart this sense of a dynamic earth: not only have landmasses moved relative to the poles, but their crustal conditions have also undergone change. Every geologic feature has an age and origin: every rock, mineral, mountain, valley, mineral deposit, fossil, etc. In accurately conceptualizing geologic history, one must recognize the distinction between the mere presence of a rock at a certain location and its actual place of origin. Just because it is "here" today does not necessarily mean that it originated "here." The older the rock, the more likely it is to be out of place with respect to its beginnings. If rocks in Arizona that are 250 m.y. old have drifted thousands of miles, so have the still older rocks.

The exhibit in Figure 1 suggests that local geologic conditions contain evidence of radical environmental change through time. Although the contrast between an ancient sea and a modern desert is implied, the contributory role of drifting is neglected. Instead, a sense of fixedness is conveyed by allowing only time, but not position, to vary.

The educational value of the exhibit could be improved if this change in geographic position were also explained. The exhibit might read as follows: "Had you been on this part of the continental landmass as it was 250 million years ago, you would have been swimming in a warm sea near the Equator. Fossiliferous limestones, now found here at 32° north latitude where a desert prevails today, were carried northward as part of the drifting landmass."

The misuse of *here* is prevalent in earth-science education because its use is easy and almost always dramatic. A lack of forethought might also play a role. The following statements illustrate the inextricable link between word choice and accuracy: (1) Dinosaurs were once "here" in Arizona or (2) Dinosaur fossils have been found in some of Arizona's rocks; and (1) Dinosaurs were "here" in the Tucson Mountains or (2) A dinosaur fossil was recently found in a rock exposed in the Tucson Mountains. In each case, the second statement is the most accurate; to jump to the first statements would be scientifically indefensible. To return to the time of the dinosaurs, one must envision conditions as they might have been more than 100 m.y. ago. Although "Arizona" was in the making, it did not exist in the form that characterizes it today.

In attempting to conceptualize geologic history – "to tell it like it seems to be" – one must encourage interpretive flexibility. Because position as well as time can vary, incautious use of *here* to mean "in or at this place" leads to distortion. *Here* and *now*, must be geologically distinguished from *there* and *then*. When used properly, *here* is a perfectly good word. Today a geologic condition that is the result of all past geologic history prevails "here." How that condition came to be, however, involves many "there"'s. It is of fundamental importance to separate geologic products in both time and space from the processes that made them: the fossiliferous limestone is "here"; the sea in which it began was "there."

Oldest Geologic Map Shows Mines and Quarries

A 3,100-year-old Egyptian papyrus scroll may be the oldest surviving geologic map in the world and the earliest example of geologic thought. The scroll, known as the Turin Papyrus and stored at the Egizio Museum in Turin, Italy, was probably made during the reign of Ramesses IV around 1150 B.C. It shows geologic and topographic features, as well as roads, quarries, gold mines, houses, and a well. The map covers 9 miles of Wadi Hammamat, a ravine between Bir el-Hammamat and Bir Umm Fawakhir in the mountains of the Eastern Desert of Egypt. Ancient and still-used roads connect Qift on the Nile River and Quseir on the Red Sea.

Although the Turin Papyrus has been known to Egyptologists since 1842, its purpose was unknown until two geologists studied its features and compared them to those in the field. James A. Harrell and Max V. Brown of the University of Toledo noted that the colors used on the map reflected actual physical features. The mountains, shown as stylized conical forms on both sides of the ravine, are colored black where dark metasedimentary rocks are prevalent and red where pink granitic rocks outcrop. Multicolored dots on the road may represent the bouldery alluvium from the ravine. Pink and brown streaks on one hill may depict iron-stained, gold-bearing quartz veins that ancient Egyptians mined. The map also notes the locations of the famous *bekhen* stone quarries, the source of building stones used in ancient statues. Annotations on the gold and silver content of surrounding mountains, road destinations, travel distances, and cultural features are also inscribed.

Harrell and Brown announced their discovery at the annual meeting of the Geological Society of America, held in Denver in November 1988.

Satellites Monitor Subsidence

Ground-water depletion has caused the aquifer system to compact and the land surface to subside in many parts of southern Arizona. Land subsidence and resultant earth fissures have caused millions of dollars in damage to engineering structures. Because of the seriousness and extent of these geologic hazards, satellite technology is being used to monitor them. Global Positioning System (GPS) satellites have made vertical and horizontal measurements at bench marks at 43 key sites in Tucson basin and Avra Valley to establish a land-subsidence monitoring network. The study was a cooperative effort among the U.S. Geological Survey, City of Tucson, and National Geodetic Survey.

Land-Subsidence Measurements and Aquifer-Compaction Monitoring in Tucson Basin and Avra Valley, Arizona, by H.H. Schumann and S.R. Anderson, was published by the U.S. Geological Survey as Water-Resources Investigations Report 88-4167. The report documents the design of the land-subsidence monitoring network and presents the results of the first satellite observations. To obtain a copy, send $4.00 to the U.S. Geological Survey, Books and Open-File Reports Section, Western Branch Distribution, P.O. Box 25425, Federal Center, Denver, CO 80225. The report may also be examined at selected U.S. Geological Survey offices: Rm. 5A Federal Bldg., 300 W. Congress St., Tucson; 3738 N. 16th St., Ste. E, Phoenix; 1940 S. 3rd Ave., Yuma; 2255 N. Gemini Dr., Bldg. 3, Flagstaff; and Rm. 5312 National Center, 12201 Sunrise Valley Dr., Reston, Va.

Revenues From State Trust Lands, 1987-88

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The Nonrenewable Resources and Minerals Section of the Arizona State Land Department has had a very active year. The section manages subsurface leasing activities and nonrenewable resources on State Trust land to generate revenue for the 14 State Trust beneficiaries. The beneficiaries and acreage allocated to each are listed in Table 1.

Table 1. *State acreage allocated to State Trust beneficiaries.*

Beneficiary	Acreage
Legislative, Executive, and Judicial Buildings	66,940
State Hospital	78,331
Miner's Hospital	48,776
Miner's Hospital 1929	47,905
State Charitable and Penal Institutions	78,738
Penitentiaries	81,354
Normal Schools	171,951
Agriculture and Mechanical Colleges	135,389
Military Institutes	82,945
School of Mines	133,126
University Land Code	166,249
University of Arizona (Act of Feb. 18, 1881)	59,847
School for the Deaf and Blind	84,135
Common Schools (includes county bonds)	8,362,208
TOTAL	9,597,894

The Land Department places royalties from leasing minerals and selling land and its natural products into a permanent fund. The State Treasurer invests the fund in interest-bearing securities; only the interest earned each year can be transferred to the beneficiaries. Annual revenue from lease and permit rentals and interest from sales contracts are placed into an expendable fund, the entire amount of which is transferred each year to beneficiaries. During the 1987-88 fiscal year (July 1, 1987 through June 30, 1988), beneficiaries received $83,286,863. This included both the interest from the permanent fund and the revenue generated through lease rentals. The Land Department generates revenue mostly from land and right-of-way sales and commercial, grazing, agriculture, and subsurface leasing.

During the past 5 years, several interesting trends have been noted regarding the income from subsurface leasing. Royalties from mineral leasing increased steadily from 1983 to 1986 as the Arizona copper industry recovered from a serious economic slump (Table 2). Impressive gains were realized in 1987-88 as the price of copper skyrocketed. Recently 98 percent of royalties from mineral leases have been generated by two copper mines: Magma's operation at San Manuel and the Mission Pit south of Tucson, currently mined by ASARCO, Inc.

As indicated by prospecting-permit rentals, exploration budgets continued to feel the adverse effects of the mining-industry slump. Matters worsened for exploration on State land in December 1987, when the Arizona Supreme Court declared the fixed mineral-royalty rate for State mineral leases unconstitutional. This undoubtedly fostered a lack of confidence in the investment of exploration funds on State lands.

The court case that resulted in this uncertainty had its beginnings nearly 9 years ago. On April 16, 1981 the Arizona Center for Law in the Public Interest filed a nonclassified civil complaint with the superior court. The action challenged the fixed mineral-royalty rate for State mineral leases (5 percent of the net value of minerals produced) established by A.R.S. § 27-234(B). The petitioners contended that (1) a fixed rate of 5 percent allowed the extraction of minerals without payment of full value to the State Trust and (2) this limitation was contrary to the appraisal- and true-value requirements of the Enabling Act and Arizona Constitution.

The trial court certified the case as a class action and allowed several mining companies to intervene as defendants. The court held that the royalty statute did not violate the Enabling Act or Arizona Constitution. The case was immediately appealed. On December 10, 1987, the Arizona Supreme Court reversed the opinion of the lower court, finding A.R.S. § 27-234(B) unconstitutional. The case was remanded to superior court with instructions to enter summary judgment in favor of petitioners and to further consider the nature and extent of the appropriate legal remedy, e.g., the validity of existing mineral leases. Because of the complexities involved in settling the case, the Land Department and Attorney General's office established a committee of representatives of the plaintiffs, defendants, intervenors, and Attorney General's office to devise a new method of computing mineral royalties for ores from State Trust land. Beginning in January 1988, the committee conducted extensive research on potential methods of ensuring a true-value return to the State Trust.

Although the case has been appealed to the U.S. Supreme Court, it is possible that statutory changes will occur regardless of the outcome. Recent media coverage charging that the current mineral-royalty statutes have caused the Trust to lose hundreds of millions of dollars prompted Governor Mofford to appoint an Oversight Committee to examine Land Department statutes and operations. The committee made several recommendations that could be incorporated into legislation if the law is amended: (1) a new royalty system, with a minimum rate of 1 percent of gross value and appraisals to set rates for individual mines; (2) an appraised land rental for mineral leases; (3) Land Department authority to deny prospecting permits and mineral leases that are not in the best interest of the Trust; and (4) Land Department authority to audit relevant company records to verify royalty payments.

Since the opinion of the Arizona Supreme Court was issued in December

Table 2. *Mineral-leasing revenues (in dollars) for fiscal years 1984-88.*

Fiscal Year	Mineral Royalties	Mineral Rentals*	Prospecting Permit Rentals*	Oil & Gas Rentals*	Mineral Material Royalties**	Mineral Material Rentals*	TOTAL
1983-84	879,053	26,411	654,403	1,547,364	1,078,366	17,670	4,203,267
1984-85	1,246,661	20,070	454,460	1,233,164	1,154,819	16,106	4,125,280
1985-86	1,321,150	20,963	363,873	1,172,877	1,587,699	18,117	4,484,679
1986-87	1,428,097	18,157	172,400	263,570	2,217,764	95,988	4,195,976
1987-88	3,954,469	29,204	120,471	144,594	2,392,699	118,747	6,760,184
TOTAL	8,829,430	114,805	1,765,607	4,361,569	8,431,347	266,628	23,769,386

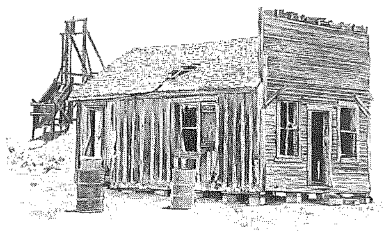
* Land rentals
** Common mineral materials are sold at public auction.

1987, there has been a moratorium on issuing new mineral leases and renewing existing ones. The uncertainty regarding the future royalty rate has been the cause of consternation for the mining industry, as well as the Department, but there is optimism that the situation will soon be resolved.

Oil and gas rental income has dropped markedly during the past 5 years as a result of the industry slump. If oil or gas were ever discovered on State land, the Trust would receive a minimum of 12 1/2 percent of the market value of the oil or gas produced.

Mineral-material royalties have grown steadily during the past 5 years. Resources in this category include sand, gravel, rock, building stone, riprap, cinders, decomposed granite, topsoil, and any other mineral material used in the construction industry. After the Land Department receives an application to purchase mineral materials, it conducts an appraisal and the material is sold at public auction to the highest bidder. Revenue is guaranteed on each lease because the company must pay an annual minimum royalty. Rentals from mineral-material operations greatly increased in 1987-88 when the department began basing the rental figure on a percentage of land value. Total revenue from the sale of mineral materials during the past 5 years is only slightly less than that received from mineral-lease royalties.

Total revenues from subsurface leasing for the current fiscal year are expected to surpass those received in 1987-88. The continuing high price of copper has allowed several companies to increase production. This is excellent news for the industry, as well as the beneficiaries of the State Trust.



NEW AZGS PUBLICATION

The following publication may be purchased from the Arizona Geological Survey (AZGS), 845 N. Park Ave., #100, Tucson, AZ 85719. For price information on this and other publications, contact the AZGS office at (602) 882-4795.

Welty, J.W., and Schnabel, Lorraine, 1989, Bibliography for metallic mineral districts in Gila, Maricopa, Pinal, and Yavapai Counties, Arizona: Open-File Report 89-1, 123 p.

This report is the fourth in a series of county bibliographies for metallic mineral districts in Arizona. The others, Circulars 24, 25, and 26, were published by the AZGS in 1986. Nearly 1,600 citations are included in this compilation. The report has been open-filed to permit timely access to the public. After editing and printing, it will be released as a circular.

AZGS Accepts BOM Diamond-Drill Core

In early March 1989, the Arizona Geological Survey accepted a donation of nearly 32,000 feet of diamond-drill core from the U.S. Bureau of Mines (BOM). The core comes from 13 separate properties across the State (Table 1). The core was shipped from the BOM Twin Cities Research Center, where it had been stored, by the Minnesota Air Guard to Davis-Monthan Air Force Base in Tucson and then trucked to the Mission Unit of ASARCO Inc., where it remains in temporary storage. We thank members of the Minnesota Air Guard; Davis-Monthan personnel; Robert Willard, BOM Twin Cities Research Center; Michael Greeley, BOM State mineral specialist; and James Litchenthan, mine superintendent at the Mission Unit; for their generosity in enabling the AZGS to accept and store this drill core. Information about the geologic setting and logs for each drill hole can be found in the references listed in Table 1. For localities with no listed references, no published information is available. Please call our office (602-882-4795) to make an appointment if you wish to examine any of this core.

Table 1. *Listing of BOM diamond-drill core localities.*

Mineral District	Mine Name	Commodity Sought	Total Footage[1]	Number of Holes	Reference[2]
Ajo	Copper Giant	Cu	1,400	2	Romslo and Robinson (1952)
Apache Iron	Apache Iron	Fe	1,200	15	Stewart (1947)
Artillery Peak	Maggie Canyon	Mn	3,700	69	Kumke and others (1957)
Big Bug	Iron King	Cu	600	4	n.a.
Christmas	Christmas	Cu	3,700	7	Tainter (1948)
Cochise	Keystone	Cu, Zn	10,800	18	Romslo (1949)
Helvetia	King in Exile	Cu	100	1	n.a.
Hualapai	Antler	Cu, Zn	2,100	6	Romslo (1948)
Lakeshore	Lakeshore	Cu	200	1	Romslo (1950)
Pima	Esperanza	Cu	1,450	3	Tainter (1947)
Tiger	Crown King	Cu	1,400	3	n.a.
Wallapai	Cerbat	Pb, Zn	2,800	8	n.a.
Wallapai	Civitation	Cu	3,400	6	n.a.

1 Total footage is rounded off to the nearest 100 feet drilled.
2 "n.a." indicates that no references are available for this core.

References

Kumke, C.A., Ross, C.K., Everett, F.D., and Hazen, S.W., Jr., 1957, Mining investigations of manganese deposits in the Maggie Canyon area, Artillery Mountain region, Mohave County, Arizona: U.S. Bureau of Mines Report of Investigations RI 5292, 87 p.

Romslo, T.M., 1948, Antler copper-zinc deposit, Mohave County, Arizona: U.S. Bureau of Mines Report of Investigations RI 4214, 14 p.

____ 1949, Investigation of Keystone and St. George copper-zinc deposits, Cochise County, Arizona: U.S. Bureau of Mines Report of Investigations RI 4504, 21 p.

____ 1950, Investigation of Lake Shore copper deposits, Pinal County, Arizona: U.S. Bureau of Mines Report of Investigations RI 4706, 24 p.

Romslo, T.M., and Robinson, C.S., 1952, Copper Giant deposits, Pima County, Arizona: U.S. Bureau of Mines Report of Investigations RI 4850, 9 p.

Stewart, L.A., 1947, Apache Iron deposit, Navajo County, Arizona: U.S. Bureau of Mines Report of Investigations RI 4093, 88 p.

Tainter, S.L., 1947, Amargosa (Esperanza) molybdenum-copper property, Pima County, Arizona: U.S. Bureau of Mines Report of Investigations RI 4016, 15 p.

____ 1948, Christmas copper deposit, Gila County, Arizona: U.S. Bureau of Mines Report of Investigations RI 4293, 58 p.

Summary of Earthquake Activity in Arizona for 1988

by David S. Brumbaugh, Director
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The trend of increasing earthquake activity in Arizona during 1987 continued through 1988 (Brumbaugh, 1988). Eighteen events with a local magnitude equal to or exceeding 2.0 ($M_L \geq 2.0$) were recorded in 16 locations. This higher level of activity was also accompanied by an increase of events of $M_L \geq 3.0$. The first and largest of these was on January 2 near Pipe Spring National Monument (Table 1). This event was registered as an M_L of 3.6 at the National Earthquake Information Center (NEIC) in Golden, Colo. This area in northwest Arizona near the Utah border has seen significant activity in the past, including the M_L 5.7 event at Fredonia in 1959. A second event occurred in this area on May 22 near Colorado City. This event was somewhat smaller, with an M_L of 3.13, recorded by the Arizona Earthquake Information Center (AEIC). On July 15 an M_L 3.15 event occurred on Black Mesa near the Peabody Coal Company strip mines. A similar event with an M_L of 3.0 occurred in this area on October 20, 1987. It may be that years of strip-mining activity are releasing stress in this normally aseismic area.

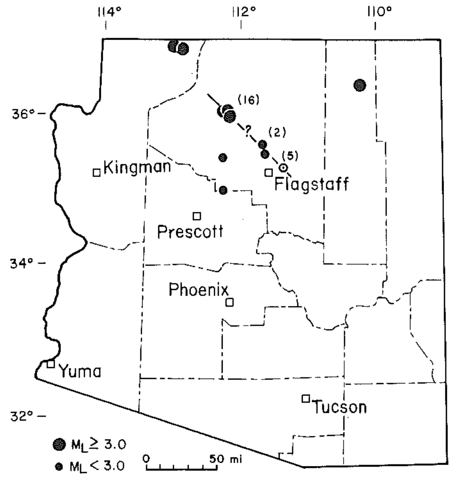

Figure 1. Earthquake activity in Arizona in 1988. Numbers in parentheses indicate number of earthquakes located by the AEIC in each area. Open circle with dot represents a swarm in January 1985 near Sunset Crater. Queried dashed line represents possible seismically active fault system.

Three events of $M_L \geq 3.0$ were part of a swarm of earthquakes that occurred September 6 to 11 near Grand Canyon Village at the South Rim of the canyon. Locations were determined for 16 events, the largest of which were felt at the village and at Phantom Ranch in the bottom of the canyon. Unsubstantiated reports of landslide activity were also received accompanying the largest event on September 7. On September 10 and 11, the AEIC conducted an on-site survey with portable recorders. Nine of the 16 events were located during this survey and had calculated magnitudes of $M_L < 2.0$.

Other activity in the State included microearthquakes in the Perkinsville area (August 21) and north of San Francisco Mountain (February 13 and 14; Table 1).

The Grand Canyon swarm seems to be aligned along a northwest trend similar to that of several mapped surface faults in the area, such as the Phantom-Grandview system. The February events north of San Francisco Mountain and a swarm of events in 1985 near Sunset Crater also line up with the Grand Canyon swarm on a single northwest trend. This activity may represent a northwest-trending fault system that is not well exposed at the surface (Figure 1).

Reference

Brumbaugh, D.S., 1988, Arizona Earthquake Information Center, 1987 progress report: Arizona Bureau of Geology and Mineral Technology Fieldnotes, v. 18, no. 1, p. 6-7.

Table 1. Arizona earthquakes ($M_L \geq 2.0$) detected in 1988 by the AEIC network.

Date	Latitude	Longitude	Depth (km)	Origin Time (UTC)*	M_L**	Epicenter
1-2	36.890° N	112.900° W	1(?)	23:10:51	3.6	Pipe Spring
2-13	35.602° N	111.641° W	3	08:29:53	2.2	San Francisco Mtn.
2-13	35.592° N	111.657° W	1	17:58:12	2.2	San Francisco Mtn.
2-14	35.488° N	111.628° W	13	07:39:49	2.9	San Francisco Mtn.
4-11	57 km from Flagstaff		--	17:34:09	--	?
5-22	36.943° N	112.973° W	17	19:22:47	3.1	Colorado City
6-1	115 km from Flagstaff		--	08:31:58	2.8	?
7-15	36.440° N	110.270° W	1	00:38:10	3.2	Black Mesa
8-21	34.989° N	112.221° W	31	23:24:03	2.6	Perkinsville
9-6	36.031° N	112.174° W	9.5	09:44:00	3.0	S. Rim, Grand Cyn.
9-6	36.002° N	112.196° W	6.8	14:41:26	2.8	S. Rim, Grand Cyn.
9-7	36.007° N	112.142° W	11.7	01:17:40	3.1	S. Rim, Grand Cyn.
9-7	36.021° N	112.199° W	4	01:23:25	2.3	S. Rim, Grand Cyn.
9-7	36.027° N	112.191° W	6.4	03:22:07	3.0	S. Rim, Grand Cyn.
9-7	36.019° N	112.149° W	5	04:15:47	2.1	S. Rim, Grand Cyn.
9-8	35.986° N	112.099° W	5	09:04:08	2.0	S. Rim, Grand Cyn.
10-3	35.426° N	112.245° W	4.1	02:02:50	2.0	north of Williams
10-3	36.021° N	112.199° W	5	15:14:12	2.5	S. Rim, Grand Cyn.

* UTC = Universal Time Coordinated
** M_L = Local magnitude

STAFF NOTES

Larry D. Fellows gave a talk on the geologic aspects of radon in Arizona to the Society of Mining Engineers meeting, held in Las Vegas from February 27 to March 2.

Thomas G. McGarvin gave a talk, titled *What the Rocks Can Tell Us: A Geological History of Arizona,* to 25 persons at the Arizona Historical Society in Tucson on March 1.

Stephen J. Reynolds led a field trip February 9-15 to the Buckskin, Vulture, and South Mountains for faculty members and graduate students from Arizona State University and from Monash and La Trobe Universities in Melbourne, Australia.

Jon E. Spencer coauthored an article, titled *Role of Crustal Flexure in Initiation of Low-Angle Normal Faults and Implications for Structural Evolution of the Basin and Range Province,* which was published in the February issue (v. 94) of the Journal of Geophysical Research.

Pamelia J. West joined the Arizona Geological Survey on March 15 as a clerical assistant. She has worked for Tucson Medical Center, Sun Tran, and Pima Community College and is working on a B.A. in secretarial sciences.

Grand Canyon Earthquake Swarm, September 1988

by Doug Bausch
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On September 6 and 7, 1988, three earthquakes were felt by employees and tourists at the South Rim and on the floor of the Grand Canyon. These three, as well as several smaller earthquakes in the area, were measured and located by the Arizona Earthquake Information Center (AEIC; Table 1). The three largest earthquakes ranged in size from local magnitudes (M_L) of 3.0 to 3.1. There was a report of a minor rock fall that may have been triggered by one of these events, but no property damage occurred. Because of the large crowds at the South Rim during the summer, the earthquakes may have been felt by several hundred people.

Table 1. *South Rim earthquakes located by the AEIC network.*

Date	Local Time	M_L*	Location
8-31-83	1:10am	2.9	36.134°N x 112.005°W
7-18-84	7:29am	2.7	36.200°N x 111.900°W
9-6-88	2:44am	3.0	36.031°N x 112.174°W
9-6-88	7:41am	2.8	36.002°N x 112.196°W
9-7-88	6:17pm	3.1	36.007°N x 112.142°W
9-7-88	6:23pm	2.3	36.021°N x 112.199°W
9-7-88	8:22pm	3.0	36.027°N x 112.191°W
9-7-88	9:15pm	2.1	36.019°N x 112.149°W
9-8-88	2:04am	2.0	35.986°N x 112.099°W
9-10-88	4:21am	1.17	36.063°N x 112.182°W
9-10-88	4:30am	0.81	36.028°N x 112.221°W
9-10-88	10:19pm	1.17	36.030°N x 112.209°W
9-10-88	11:47pm	0.72	36.071°N x 112.206°W
9-10-88	11:55pm	1.52	36.039°N x 112.229°W
9-11-88	4:29am	0.38	36.025°N x 112.275°W
9-11-88	4:58am	1.07	36.039°N x 112.236°W
9-11-88	4:58am	0.67	36.050°N x 112.246°W
9-11-88	5:10am	1.09	36.056°N x 112.253°W
10-3-88	8:14am	2.5	36.021°N x 112.199°W

* Local magnitude

The epicenters of the September swarm seem to follow a northwest trend (Figure 1), which is consistent with the patterns of seismicity in northern Arizona during the past several years. Because of this northwest trend, these earthquakes are probably not related to major northeast-trending structures, such as the Bright Angel and Hermit faults.

For 2 days following the three largest earthquakes, the AEIC positioned six portable seismic stations around the epicentral area. This survey produced enough data to locate nine more events with local magnitudes that ranged from 0.38 to 1.52 (Table 1; Figure 1).

The largest event (M_L 3.1), which occurred on September 7 at 6:17 p.m., was located using data from 54 seismic stations in northern Arizona, southern Nevada, Utah, and Colorado. This may be one of the best constrained Arizona earthquakes to date. It occurred at a depth of 11.7 kilometers and had horizontal and vertical location errors of only 0.5 and 0.8 kilometers, respectively. A first motion study indicates predominantly normal faulting on north-trending nodal planes with a small component of strike-slip motion (Figure 1).

Historically, nine earthquakes had been felt at the South Rim before the September swarm (Table 2). The largest of these shocks occurred on August 18, 1912 and had a local magnitude of 5.5 as determined from seismographs in Denver and Reno (DuBois and others, 1982).

Several other earthquakes that occurred during 1988 had the same signature as those recorded on the South Rim in September (Figure 2). A signature is the trace recorded on a seismograph by the waves from an earthquake. The signatures from these earthquakes showed a *P-S* wave interval of 12.5 to 13.5 seconds. The *P* stands for "primary"; it is the fastest of the seismic waves and is caused by alternating compression and expansion of earth materials. The *S* (secondary) wave is caused by shearing of earth materials. Events that arrive at a seismic station from the same direction with similar time intervals between the *P* and *S* waves probably originated in the same area. The events shown in Figure 2 were recorded at the Williams (WMZ) and Flagstaff (FLAG) stations. The data, however, are insufficient to locate these microearthquakes.

Between 30 and 50 events with the same signature occurred in 1986 and 1987; 96 events were recorded in 1988. Because the latter temporally cluster around the larger September earthquakes (Figure 2), they may indicate microseismicity associated with the South Rim.

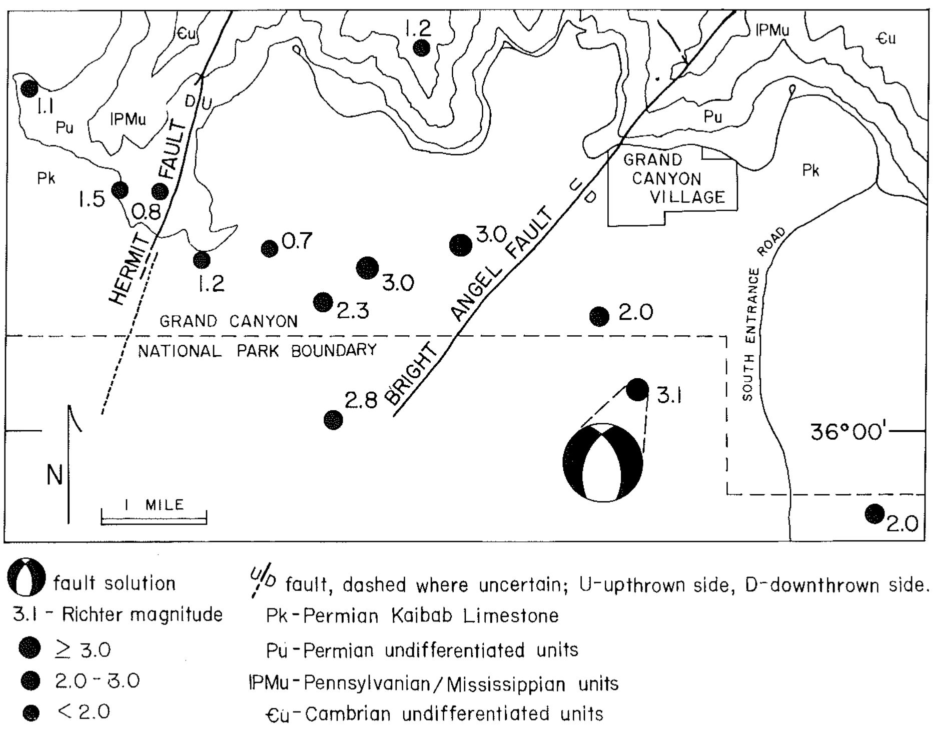

Figure 1. *Grand Canyon earthquake events located by the AEIC, September 6-11, 1988. The fault-plane solution is derived from the first motions on the seismograms of 21 stations surrounding the epicentral area. These first motions, whether compressional (up) or dilational (down) indicate that the landmass movement was either toward or away from, respectively, the seismic station. Plotting the first motions on a stereographic projection and dividing the projection into quadrants of compression and dilation enable seismologists to find the orientation of the fault plane and the state of stress for the event. This solution indicates faulting along a north-trending plane and extension in a roughly northeast-southwest direction.*

Reference

DuBois, S.M., Smith, A.W., Nye, N.K., and Nowak, T.A., 1982, Arizona earthquakes, 1776-1980: Arizona Bureau of Geology and Mineral Technology Bulletin 193, 456 p., scale 1:1,000,000.

***Table 2.** Historical South Rim earthquakes located by felt reports. From DuBois and others, 1982.*

Date	Local Time	M_L or INT*	Location
8-18-12	2:12pm	5.5	35.95°N x 111.95°W
1-1-35	1:50am	VI	36.05°N x 112.14°W
1-5-35	9:25pm	V	36.05°N x 112.14°W
1-10-35	1:10am	VI	36.05°N x 112.14°W
1-15-35	1:50am	II	36.05°N x 112.14°W
1-12-36	n.a.	V	36.05°N x 112.14°W
2-19-39	4:00am	IV	36.05°N x 112.14°W
3-9-39	6:30am	VI	36.10°N x 112.10°W
8-8-48	4:20pm	V	36.80°N x 112.10°W

* The Arabic numeral (5.5, recorded on 8-18-12) refers to local magnitude, as determined on seismographs in Denver and Reno. The Roman numerals (II, IV, etc.) refer to intensity, as measured by damaging effects, on the Modified Mercalli intensity scale.

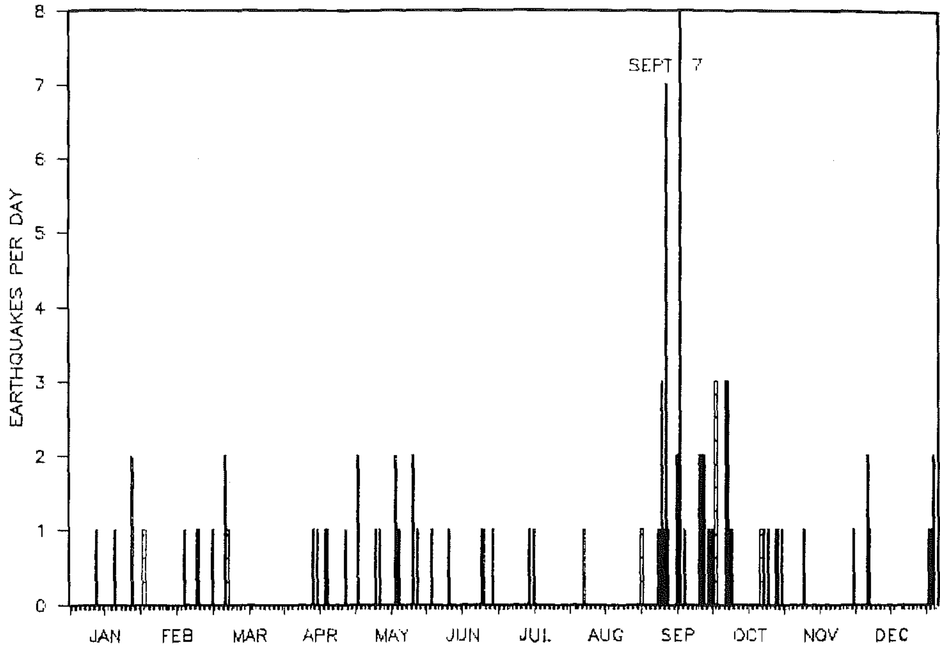

***Figure 2.** Histogram showing possible South Rim events recorded by the AEIC (WMZ and FLAG stations) during 1988.*

Radon Research Underway

The health consequences of exposure to indoor radon are being researched at Pacific Northwest Laboratory in Richland, Washington. The 3-year $6-million study is funded by the U.S. Department of Energy's Office of Health and Environmental Research. This study includes seven separate projects: (1) laser-beam and mass-spectrometry analysis to measure lead-210, a decay product of radon, in the body; (2) identification of the molecular and cellular steps that lead to lung cancer; (3) computer models of lung cells to determine the amount of harmful radiation (alpha particles) emitted from inhaled indoor radon that would initiate lung cancer; (4) computer models to determine how radon travels within the soil and from the soil into the atmosphere, homes, and other structures; (5) tests using microscopic beams directed at simulated lung cells to explain dose-rate effects; (6) investigation of inhalation hazards to uranium miners; and (7) identification of the mechanisms of radon injury. For more information, contact the Public Affairs Office, U.S. Department of Energy, Rm. 8G-048, CP-24, Forrestal Bldg., 1000 Independence Ave., S.W., Washington, DC 20585.

Number of Significant Earthquakes Decreases in 1988

The number of significant earthquakes in the world decreased during 1988, but two devastating shocks that hit Soviet Armenia on December 7 made 1988 the worst year in 12 years for loss of life and property due to earthquakes. The estimate of 25,000 to 60,000 persons killed in Armenia is the highest death toll since 1976, when at least 250,000 persons were killed in an earthquake in China. The earthquake in Armenia also left at least 13,000 persons injured and an estimated 510,000 persons homeless. The devastation in 1988 came nearly on the eve of the International Decade for Natural Disaster Reduction, which begins in 1990. This global effort among 90 nations, including the United States, is focused on reducing the damage caused by earthquakes and other natural disasters, such as volcanic eruptions, storms, floods, and landslides.

The 61 significant earthquakes recorded during 1988 were 15 fewer than the total for the previous year, but 3 more than during 1986, according to the U.S. Geological Survey (USGS). The USGS defines a significant earthquake as one that registers a magnitude of at least 6.5 or one of lesser magnitude that causes casualties or considerable damage.

The main shock of the Armenian earthquake had a magnitude of 6.8 and was followed minutes later by a 5.8-magnitude aftershock. The second and third most deadly tremors of 1988 were a 6.6-magnitude earthquake on the Nepal-India border on August 20 that killed at least 1,000 persons and a 7.3-magnitude shock that hit the Burma-China border on November 6, killing 730 persons.

Three of the significant earthquakes recorded in 1988 occurred in the United States or just off U.S. coasts. These included the world's strongest earthquake during the year, a 7.6-magnitude shock in the Gulf of Alaska on March 6 that caused only minor damage. The other two occurred near Whittier and Pasadena, California on February 11 and December 3 and registered magnitudes of 4.8 and 4.6, respectively. One person died of a heart attack following the Whittier tremor; this was the only death in the United States in 1988 that was linked to an earthquake.

The USGS, using data from seismograph stations throughout the world, annually locates from 10,000 to 12,000 earthquakes with magnitudes equal to or greater than 2.0. Several million earthquakes probably occur each year, but most are so small or occur in such remote areas that they are undetected by even the most sensitive instruments.

Additions to the Arizona Geological Survey Library

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

Beard, R.R., 1989, The primary copper industry of Arizona in 1987: Arizona Department of Mines and Mineral Resources Special Report 14, 75 p.

Jagiello, K.J., 1987, Structural evolution of the Phoenix basin, Arizona: Tempe, Arizona State University, unpublished M.S. thesis, 156 p.

Lienau, P.J., Culver, Gene, and Lund, J. W., 1988, Geothermal direct use sites in the United States, interim report, May 1988: Oregon Institute of Technology, 100 p.

Marvin, R.F., Naeser, C.W., Bikerman, M., Mehnert, H.H., and Ratte, J.C., 1987, Isotopic ages of post-Paleocene igneous rocks within and bordering the Clifton 1° x 2° quadrangle, Arizona-New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin 118, 64 p.

Miller, E.J., 1987, The Buckeye pluton, a peraluminous two-mica granite: Tempe, Arizona State University, unpublished M.S. thesis, 105 p., scale 1:12,000.

Myers, S.M., 1987, Map showing groundwater conditions in the Peach Springs basin, Mohave, Coconino, and Yavapai Counties, Arizona – 1987: Arizona Department of Water Resources Hydrologic Map Series Report 15, scale 1:125,000.

Neet, K.E., 1988, A stable isotopic investigation of the Mazatzal Peak Quartzite, implications for source terranes: Tempe, Arizona State University, unpublished M.S. thesis, 109 p.

Niemuth, N.J., 1987, Arizona mineral development, 1984-1986: Arizona Department of Mines and Mineral Resources, 46 p.

_____ 1988, Arizona mining consultants: Arizona Department of Mines and Mineral Resources Directory 32, 30 p.

Oram, P., 1987, Map showing groundwater conditions in the Butler Valley basin, La Paz County, Arizona, 1986: Arizona Department of Water Resources Hydrologic Map Series Report 13, scale 1:125,000.

Phillips, K.A., 1987, Arizona industrial minerals, 2nd ed.: Arizona Department of Mines and Mineral Resources, 185 p.

Phillips, K.A., and Bloyd, Arthur, 1988, Gemstone production in Arizona: Arizona Department of Mines and Mineral Resources Mineral Report 5, 8 p.

Ross, D.E., 1988, Appraisal manual for producing mines, nonproducing mines, and oil, gas, and geothermal interests: Arizona Department of Revenue, 44 p.

Salt River Project, 1987, Third symposium on artificial recharge of groundwater in Arizona: Proceedings, 239 p.

Sawyer, D.A., 1987, Late Cretaceous caldera volcanism and porphyry copper mineralization at Silver Bell, Pima County, Arizona; geology, petrology, and geochemistry: Santa Barbara, University of California, unpublished Ph.D. dissertation, 383 p.

Schmitz, Christopher, 1987, Geology of the Black Pearl mine area, Yavapai County, Arizona: Tempe, Arizona State University, unpublished M.S. thesis, 154 p.

Schreiber, J.F., Jr., ed., 1987, Lower Cretaceous coral-algal-rudist patch reefs in southeastern Arizona: Geological Society of America Annual Meeting, 100th, Phoenix, Ariz., 1987, supplement volume, field trip 3, 100 p.

Sternberg, B.K., Ryan, T.M., McGill, J.W., and Breitrick, M.E., 1988, The San Xavier geophysics and tunnel-detection test site: University of Arizona Laboratory for Advanced Subsurface Imaging, LASI-88-2, 134 p.

Swift, P.N., 1987, Early Proterozoic turbidite deposition and melange deformation, southeastern Arizona: Tucson, University of Arizona, unpublished Ph.D. dissertation, 134 p.

Tosdal, R.M., 1988, Mesozoic rock units along the Late Cretaceous Mule Mountains thrust system, southeastern California and southwestern Arizona: Santa Barbara, University of California, unpublished Ph.D. dissertation, 365 p.

U.S. Bureau of Land Management, 1987a, Draft environmental impact statement, proposed wilderness program for the Arizona Mohave Wilderness Areas, Greenlee, Maricopa, Mohave, Pinal, Pima, and Yavapai Counties, Arizona and Grant County, New Mexico: 196 p.

_____ 1987b, Draft environmental impact statement, proposed wilderness program for the Yuma District Wilderness EIS Area, La Paz, Mohave, and Yuma Counties, Arizona and Imperial, Riverside, and San Bernardino Counties, California: 235 p.

_____ 1987c, Draft wilderness management plan for the Aravaipa Canyon Wilderness, Arizona: 68 p.

_____ 1987d, Environmental assessment AZ-050-6-33 for oil and gas leasing on public lands in the Yuma district: 40 p.

_____ 1987e, Final environmental impact statement, proposed wilderness program for the Lower Gila South EIS Area, La Paz, Maricopa, Pima, Pinal, and Yuma Counties, Arizona: 322 p.

_____ 1987f, Final environmental impact statement, proposed wilderness program for the Phoenix Wilderness EIS Area, Maricopa, Mohave, Pima, Pinal, and Yavapai Counties, Arizona: 231 p.

_____ 1987g, Final environmental impact statement, proposed wilderness program for the Safford District Wilderness EIS Area, Cochise, Gila, Graham, and Greenlee Counties, Arizona and Hidalgo County, New Mexico: 506 p.

_____ 1987h, Final environmental impact statement, proposed wilderness program for the Upper Sonoran Wilderness EIS Area, La Paz, Maricopa, Mohave, and Yavapai Counties, Arizona: 394 p.

_____ 1987i, Phoenix resource management plan and environmental impact statement, draft: 215 p.

_____ 1988, Environmental assessment, Arizona 1 uranium mine, EA no. AZ-010-88-004, a major modification to the plan of operations for uranium site no. 157, AS-010-84-78P/A: 93 p.

U.S. Bureau of Reclamation, 1987, Seismotectonic investigation for Theodore Roosevelt Dam, Salt River Project, Arizona: 46 p., various scales.

U.S. Department of Agriculture, Forest Service, 1987a, Apache-Sitgreaves National Forests plan: 295 p.

_____ 1987b, Environmental impact statement for the Apache-Sitgreaves National Forests plan: 392 p.

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_____ 1987d, Kaibab National Forest plan: 264 p.

_____ 1987e, Public comments and Forest Service response to the DEIS, proposed Apache-Sitgreaves National Forests plan: 439 p.

_____ 1987f, Summary of the environmental impact statement for the Apache-Sitgreaves National Forests plan: 51 p.

_____ 1987g, Summary of the Kaibab National Forest environmental impact statement and forest plan: 117 p.

_____ 1988, Public comments and Forest Service response to the DEIS, Kaibab National Forest plan: 421 p.

U.S. Fish and Wildlife Service, 1988, Draft environmental assessment, Leslie Canyon National Wildlife Refuge: 11 p.

Wellendorf, C.S., 1987, Regional geology of Tonto basin for the modification of Theodore Roosevelt Dam: U.S. Bureau of Reclamation, 13 p., scale 1:48,000.

State Geological Surveys: Their Histories and Publications

In the early 1800's, as this fledgling Nation expanded its borders and its appetite for raw materials, government officials became increasingly aware of the role that geology plays in the development of the land and its resources. State geological surveys were established to fill the void in geologic understanding. By 1860 some 30 State surveys were operating. Although the 50 surveys today differ in size, name, and detailed functions, each has the basic responsibility to delineate the geologic resources and conditions that affect the economic and environmental well-being of its State.

In recognition of this important role, the Association of American State Geologists (AASG) has published a 499-page collection of individual histories of the State surveys. The book is a record of scientific achievements, human drama, bureaucratic struggles, and public service. Copies of *The State Geological Surveys: A History*, edited by Arthur A. Socolow, are available for $20.00 each from Ernest Mancini, Alabama Geological Survey, P.O. Drawer O, University Station, Tuscaloosa, AL 35486.

The AASG has also released a list of scientific reports and maps published in 1987 by the State geological surveys. This compilation also includes prices and ordering information. To obtain a copy of *List of Publications of the Association of American State Geologists*, send $2.00 to Donald A. Hull, State Geologist, Department of Geology and Mineral Industries, 910 State Office Bldg., 1400 S.W. 5th Ave., Portland, OR 97201-5528.

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Arizona Copper Industry in 1987

During 1987 five companies operated 11 open-pit properties, 1 underground block-caving operation, and 3 smelters in Arizona. They produced 862,034 tons of copper from ore with a weighted average grade of 0.58 percent copper. This represents 61.4 percent of total U.S. copper production in 1987. Of this amount, 19.8 percent (170,921 tons) was produced by leaching oxide ores and low-grade dumps. About 79 percent of the leached copper was extracted by solvent extraction-electrowinning (SX-EW); the remaining 21 percent was extracted by the traditional cementation process. The open-pit operations maintained an average stripping ratio, waste to ore, of 1.21 to 1. The byproducts of copper mining--gold, silver, and molybdenum--were also produced in 1987: approximately 49,000 troy ounces of gold, 3.2 million troy ounces of silver, and 25.9 million pounds of molybdenum.

These figures were excerpted from the 1987 annual report on Arizona's copper industry, published by the Arizona Department of Mines and Mineral Resources. *The Primary Copper Industry of Arizona in 1987*, by Richard R. Beard, covers production, stripping ratios, ore grade, mill recoveries, reserves, employment, wages, and other statistics that pertain to Arizona's copper industry. National and world statistics are included for comparison. The report also reviews each producer's facilities and activities, including acquisitions and restructuring of companies and properties. To obtain a copy of this summary, published as Special Report 14, send $10.00 ($8.00, plus $2.00 for postage and handling) to either office of the Arizona Department of Mines and Mineral Resources: Mineral Building, State Fairgrounds, Phoenix, AZ 85007; or 416 W. Congress St., Rm. 190, Tucson, AZ 85701.

Ground-Water Data Available

The Basic Data Section of the Department of Water Resources collects, compiles, and disseminates groundwater data for Arizona. In cooperation with the U.S. Geological Survey, the section collects general water-quality samples and measures depths to water and discharges from wells and springs. Data are available in both raw and computer format. Out-of-print and recent reports may be reviewed at the Basic Data office. The following reports, which were released in 1988, are available for $3.00 each: *Water resources of the northern part of the Agua Fria area, Yavapai County, Arizona* (Bulletin 5); *Basic groundwater data for the Rillito River Recharge Project* (Open-File Report 5); and *Digital computer model study of Yuma area groundwater problems associated with increased river flows in the lower Colorado River from January 1983 to June 1984* (Open-File Report 6).

The Basic Data office is also the repository of the largest collection of well logs in the State. Logs and construction data, originally compiled by the State Land Department, for some 34,000 wells may be inspected during office hours. Hydrologists are available to answer questions about wells or ground water or to direct inquiries to the appropriate files, reports, or agencies.

The Basic Data office is open from 7:00 a.m. to 4:30 p.m. Monday through Friday at 2810 S. 24th St., Suite 122, Phoenix, AZ 85034; tel: 602-255-1543.