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The 1992 Landers Earthquake Sequence

by Terry C. Wallace
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At 4:58 a.m. (Pacific time) on June 28, 1992, a magnitude 7.4 earthquake occurred in the Mojave Desert of southern California. The epicenter was near the community of Landers, and the earthquake is referred to as the Landers earthquake (Figure 1). The earthquake was the largest to occur in the contiguous United States since the Kern County, California, earthquake (M_s = 7.7*) in 1952. Although the Landers earthquake was significantly larger than the 1989 Loma Prieta earthquake (M_s = 7.1, located in the Santa Cruz Mountains south of San Francisco), the damage was far less. Present estimates put the economic loss at $10 million, compared to $10 *billion* for the Loma Prieta earthquake. The Landers earthquake was widely felt in Arizona, and many residents of Tucson and Phoenix reported that "water had sloshed" out of their swimming pools. (See inset on swimming-pool seiches on page 3.) Many aspects of the Landers earthquake are very unusual and have heightened concerns that a major earthquake will occur on the southern San Andreas Fault in the near future.

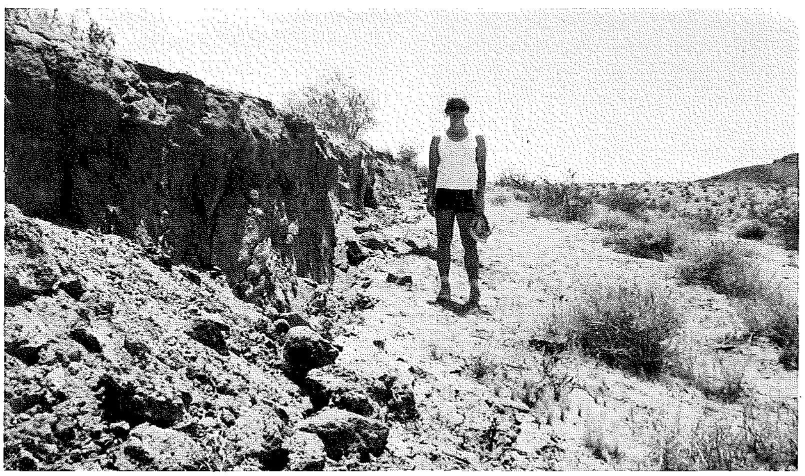

Figure 1. Fault scarp produced during Landers earthquake. Although the sense of motion on the fault is horizontal, large vertical scarps may form on sloping surfaces. Photo by David Wald.

The San Andreas Fault is a major expression of the North American-Pacific plate boundary, where the plates move past one another in a right-lateral sense† at a rate of 3.5 to 5.0 centimeters (1.4 to 2 inches) per year. North of Los Angeles, the San Andreas Fault makes a "big bend" and is oriented much more east-west than in northern California (Figure 2a). The trend of the San Andreas Fault near this bend is oblique to the relative motion of the two plates, resulting in their convergence. The Transverse Ranges (San Gabriel and San Bernardino Mountains) are a topographic expression of this convergence, as is the complexity of faults in southern California. South of latitude 34° N., the boundary between the North American and Pacific plates is distributed among at least three major faults: the San Andreas, San Jacinto, and Elsinore.

Another major fault in southern California is the Garlock Fault, which intersects the San Andreas Fault near latitude 35° N., longitude 119° W. The Garlock Fault is a left-lateral fault. The wedge-shaped region between the Garlock and San Andreas Faults is known as the Mojave Block (Figure 2b). The relative motion of the Garlock and San Andreas Faults requires that the Mojave Block undergo crustal extension. Numerous parallel faults cut the Mojave Block into "slats." These "slat faults" have right-lateral slip and accommodate the extension and rotation of the Mojave Block.

The Landers earthquake ruptured a 60-kilometer- (37-mile-) long segment of one of these Mojave Block faults. The sense of motion on the fault inferred from seismic waves was right-lateral strike-slip. At the epicenter (Figure 3), the surface displacement on the fault trace was approximately 3 meters (10 feet); near the northern end of the fault,

* Seismologists use four different magnitude scales to quantify the size of an earthquake. All of the scales are roughly equivalent and are based on the amplitudes of seismic waves corrected for the distance between the epicenter and recording station. M_s is **surface-wave magnitude,** the most commonly reported magnitude for large earthquakes, and is based on the amplitude of seismic waves that travel along the surface of the Earth. In comparison, **body-wave magnitude** (m_b) is based on the amplitude of seismic waves that travel through the interior of the Earth. M_L is **local magnitude,** the original magnitude scale developed by Charles Richter in the 1930's. M_w, or **moment magnitude,** is the most complete measure of earthquake size because it is directly based on the amount of energy released during an earthquake.

† Faults along boundaries where plates slide horizontally past each other are called **strike-slip faults** because the direction of movement (slip) is horizontal and parallel to the strike of the fault plane, i.e., the direction of its surface trace. **Right lateral** and **left lateral** refer to the two senses of movement on strike-slip faults. If you stand on either block along a right-lateral strike-slip fault and look across the fault, the block on the other side is displaced to the right. If you look across a left-lateral strike-slip fault, the block on the other side is displaced to the left.

ALSO IN THIS ISSUE

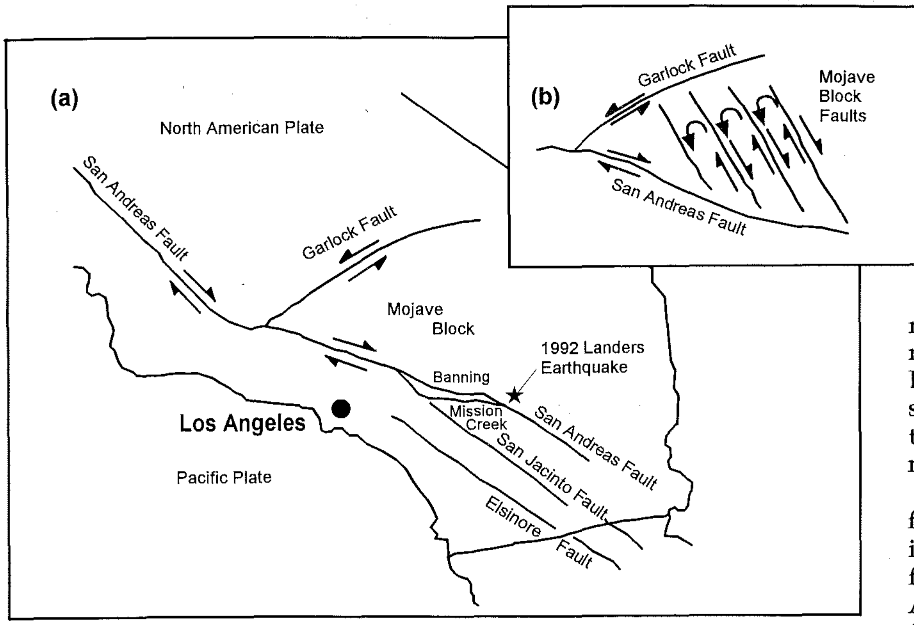

Figure 2. (a) Simplified fault map of southern California. The San Andreas Fault splits into two strands, the Banning and the Mission Creek near Cajon Pass. The 1992 Landers earthquake occurred north of the San Andreas Fault. (b) The Mojave Block is bounded on the north by the Garlock Fault and on the south by the San Andreas Fault. The Mojave Block is cut by a series of "slat" faults with right-lateral slip.

the displacement reached 6 meters (20 feet; Figures 1 and 4). The Landers earthquake **focal depth** (the depth at which the fault rupture began) was very shallow (2 to 3 kilometers or 1 to 2 miles), as were the focal depths of most of the aftershocks along the trend of the fault. These shallow depths are very unusual for strike-slip earthquakes in California, where most focal depths of large earthquakes have been 8 to 10 kilometers (5 to 6 miles). Although movement has occurred within the last 100,000 years along several mapped faults in the epicenter region, surface rupture from the Landers earthquake does not follow the trend of any single existing fault. The surface rupture is arcuate, trending from north-south near the epicenter to northwest at the northern extreme of the fault (Figure 3). Only at the northern end does the rupture merge with existing faults.

Approximately 3 hours after the Landers earthquake, a second large earthquake occurred 30 kilometers (18.5 miles) to the west. This earthquake (M_s = 6.5), known as the Big Bear earthquake because of its proximity to the mountain resort, ruptured a fault plane nearly perpendicular to the Landers Fault. The epicenter and aftershocks (Figure 3) outline a fault trend approximately 30 kilometers (18.5 miles) long. Although the Big Bear earthquake was much smaller than the Landers earthquake, it caused most of the damage during the earthquake sequence because (1) its epicenter was in a more populated region, and (2) many structures weakened by the Landers earthquake failed under the more moderate shaking of the Big Bear earthquake. The sense of slip along the Big Bear Fault was left-lateral. There was no surface rupture associated with this earthquake; the focal depth (9 kilometers or 5.5 miles) was much deeper than that of the Landers earthquake. The trend of the Big Bear Fault crosses numerous known faults, suggesting that the fault is a "new" feature.

As of this writing (August 17), 91 aftershocks with magnitudes larger than 4.0, including 13 with magnitudes larger than 5.0, have occurred in the Landers-Big Bear region. Although the aftershock activity is beginning to decrease, it is likely that several more earthquakes larger than magnitude 4.0 will occur in the next few months.

The relationship among existing mapped faults, the Landers Fault, and the Big Bear Fault is very complex. The Landers and Big Bear Faults form what is known as a **conjugate fault pair.** A simple theory of rock mechanics predicts that fractures on faults will form at an angle that is oblique to the direction of maximum compressive stress. For most rocks, this angle is approximately 60°. Two possible fracture planes can result, depending on whether the 60° angle is measured in a clockwise or counterclockwise direction. These two planes are a conjugate fault pair. This conjugate pairing of faults with opposite senses of motion is very rare in most parts of the world, although it may be the rule in the Mojave Block and along the southern San Andreas Fault. The 1979 Homestead Valley (m_b = 5.7) and 1987 Superstition Hills (M_s = 6.7) earthquakes showed such patterns. On July 5, 1992, a magnitude 5.1 earthquake occurred on the trend of the Big Bear Fault *east* of the Landers Fault. This suggests that the conjugate pattern continues across the Landers Fault. Special conditions may be required for conju-

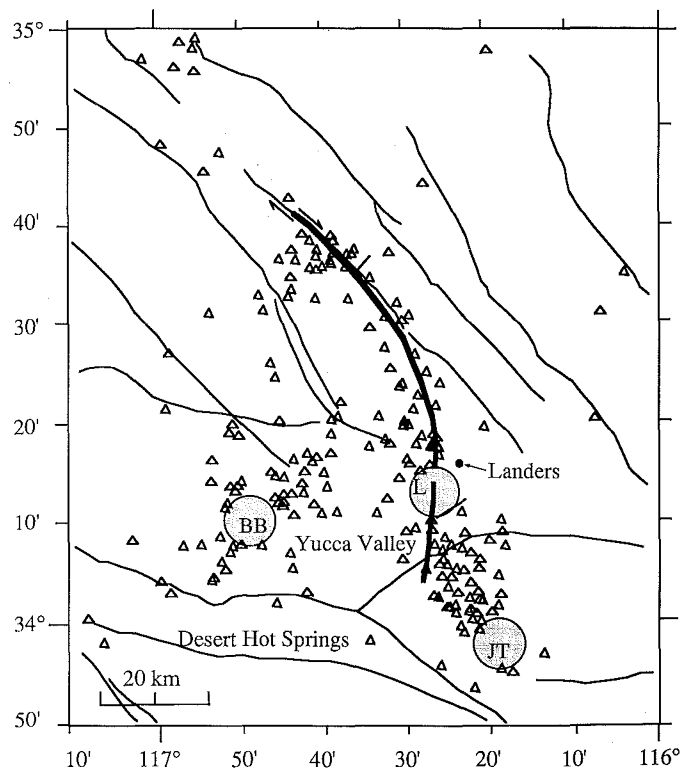

Figure 3. Location of Landers earthquake and significant aftershocks. Epicenters of three events are denoted by letters within large shaded circles: the Landers epicenter is labeled "L"; the Big Bear epicenter is labeled "BB"; and the Joshua Tree epicenter is labeled "JT." Epicenters of aftershocks are shown as triangles. Two trends are evident: the arcuate trace of the Landers Fault and the southwest-northeast trend of the Big Bear Fault. The thin lines signify Quaternary faults; the thick line is the trace of ground breakage associated with the Landers earthquake.

Swimming-Pool Seiches

One of the first things many Arizonans noticed on Sunday morning, June 28, was that the decks of their pools were wet. This is a common observation after large earthquakes have occurred in neighboring States: swimming pools lose water. The cause of this water loss is a wave known as a **seiche** (sāsh).

The ground shaking from a distant earthquake can make the surface of the water in a swimming pool uneven. Gravity causes water to rush from high parts of the surface to low parts. This produces a gravity water wave, which moves back and forth across the pool. If this wave is large enough, water will spill over the pool's edges. The size of a swimming-pool seiche depends on the geometry of the pool (its length, width, and depth) and on the location and size of the earthquake. Swimming-pool seiches can cause spillage of tens to hundreds of gallons of water.

Seiches have also been observed in lakes and partially closed bays after large earthquakes. The great Alaskan earthquake (M_w = 9.2) in 1964 caused a seiche in the Great Lakes in the north-central United States! *Seiche* is a French word coined by Swiss seismologist F.A. Forel, who studied the phenomenon in Lake Geneva and also developed the first earthquake-intensity scale.

gate pairing, such as a large crustal region that is strained everywhere to a point near failure.

The Landers earthquake was preceded by a magnitude 6.1 foreshock on April 23, 1992. Named the Joshua Tree earthquake (Figure 3), it was felt in Las Vegas and Phoenix, although damage was relatively minor. The Joshua Tree aftershock sequence was extremely energetic and protracted. A typical aftershock sequence from a magnitude 6 earthquake would be only a few weeks long, and only four or five events would be larger than magnitude 4.0. Twelve aftershocks larger than magnitude 4.0 followed the Joshua Tree earthquake, however, and aftershocks continued up to the time of the Landers earthquake, more than 9 weeks later. Many of the Joshua Tree aftershocks were very high-stress **drop earthquakes,** meaning that the aftershock faulting process involved more slip than is typical. In hindsight, it is obvious that the Joshua Tree earthquake was a precursor to the Landers earthquake because the Joshua Tree fault zone merges with the southern end of the Landers fault zone. Perhaps the aftershock activity could have been used to issue a warning for the Landers earthquake.

Some of the most interesting phenomena after the Landers earthquake were observed hundreds of kilometers (or miles) from the epicenter. Within minutes after the Landers earthquake, hundreds of small earthquakes occurred near the Mammoth Lakes in north-central California and near Mount Shasta in northern California. Both of these areas are volcanic regions. In addition to the earthquake activity, hydrological phenomena occurred in both regions, including temperature rises in hot springs and increased geyser activity. Conventional theory predicts that the strain change due to the Landers earthquake should be infinitesimal only 100 kilometers (62 miles) away from the epicenter. This unexpected far-flung effect will cause seismologists to reevaluate the correlation of earthquakes. For example, on July 5, 1992, a magnitude 5.5 earthquake occurred on the Nevada-California border south of the Nevada Test Site. Was this earthquake triggered by the Landers sequence? Before June 28, the stock answer would have been "No," but now the answer is "We don't know."

Seismologists are concerned that the Landers earthquake sequence has significantly increased the potential for a major earthquake on the southern San Andreas Fault. The wedge of material defined by the Big Bear Fault, Landers Fault, and Mission Creek strand of the San Andreas Fault moved north on June 28 as a consequence of left-lateral slip on the Big Bear Fault and right-lateral slip on the Landers Fault. This implies that the **normal (perpendicular) stress** *across* the San Andreas Fault decreased. Faults slip in earthquakes when the **shear (tangential) stress** *along* the fault exceeds the frictional resistance of the fault surface. This frictional resistance is directly proportional to the normal stress across the fault. If one assumes that normal stress inhibits fault slip, then the stress that would restrain movement has been reduced along an 80-kilometer (50-mile) section of the San Andreas Fault. The southern 200 kilometers (124 miles) of the San Andreas Fault, from Cajon Pass in the north to the Salton Sea in the south, has not generated a great earthquake ($M \geq 7.0$) for at least 300 years, although the fault was very active between A.D. 1000 and 1700. Sieh (1986) reported that at least 21 meters (69 feet) of right-lateral slip occurred during four large ($M \geq 7.0$) earthquakes within this 700-year interval. His data are consistent with an earthquake-recurrence interval of about 200 to 300 years; it has been about 300 years since the last major earthquake. The conditions appear to be favorable for a magnitude 7.5+ earthquake on the southern San Andreas Fault. Based on the lapse time between the Joshua Tree earthquake and the Landers earthquake (2 months), a window of at least 6 months for "triggering" a large earthquake along the San Andreas Fault is scientifically reasonable.

The 1992 Landers earthquake sequence is causing seismologists to rethink a significant portion of the conventional wisdom about earthquake behavior. For example, why did the Landers earthquake form a new fault instead of causing slip on a preexisting fault? Conventional wisdom would say that much more stress is required to break new rock than to cause slip on an existing zone of weakness. During this century, all

Figure 4. Right-lateral fault 28 miles northwest of Landers. The fault crosses a dirt road and offsets the tracks and line of creosote bushes by 12.8 feet. Photo by David Wald.

strike-slip earthquakes that have occurred in the western United States can be attributed to preexisting faults — all except those in the Landers sequence. Also, why did 3 hours elapse between the Landers and Big Bear earthquakes? Conventional wisdom would say that within seconds after the Landers earthquake, the stress effects should have stabilized in the Big Bear region. Similarly, why didn't the Landers sequence immediately trigger a major earthquake on the San Andreas Fault? Detailed studies of the Landers earthquake sequence will undoubtedly result in a much-improved understanding of fault dynamics and will ultimately result in better predictions of earthquake hazards.

Reference

Sieh, Kerry, 1986, Slip rate across the San Andreas Fault and prehistoric earthquakes at Indio, California: American Geophysical Union Transactions (EOS), v. 67, p. 1,200.

Acknowledgment: SASO Contribution #2. The author wishes to thank Lisa Wald, U.S. Geological Survey, Pasadena, for providing up-to-date information on the earthquake sequence.

Dr. Terry C. Wallace, Jr., seismologist and professor of geosciences at the University of Arizona, received the Macelwane Award from the American Geophysical Union. This annual award is presented to scientists aged 36 or younger who are considered to be the best in their field and who have made significant contributions to the area of geophysics. Wallace received B.S. degrees in geophysics and mathematics and M.S. and Ph.D. degrees in geophysics. He has researched earthquakes in the western United States, China, Africa, South America, the Indian Ocean, and the Mediterranean. Wallace has written several articles for *Arizona Geology* on earthquakes in southern Arizona, northern Sonora, and California.

Southern Arizona Seismic Observatory

The Southern Arizona Seismic Observatory (SASO) is an organized research group in the Department of Geosciences at the University of Arizona. SASO scientists conduct research on different aspects of seismology, fault mechanics, and geodynamics. SASO operates the prototype IRIS/NSN seismic station TAZ in the Santa Catalina Mountains near Tucson. One of the most advanced stations, TAZ is part of the Global Seismic Network (GSN) and the National Seismic Network (NSN). TAZ uses state-of-the-art, very broadband sensors, which can detect ground vibrations with frequencies from .0001 to 20 Hz. The station also uses a 24-bit digitizer to give the signals very wide dynamic range (18 orders of magnitude). The seismometers, digitizer, and data-acquisition module are located at the remote site. The data are transferred to the data-processing center on the University of Arizona campus via a dedicated phone line. At this center, the seismic signals are formatted for various uses, and the data are broadcast in real time via a satellite link to the National Earthquake Information Center in Golden, Colorado. This satellite link is also used to download seismic signals from other NSN stations to SASO.

One of SASO's missions is to disseminate earthquake information rapidly to government agencies, private industry, and the public. SASO is connected via a network link with seismic centers at the U.S. Geological Survey and California Institute of Technology. In the event of a significant earthquake, SASO will produce a scientific update within 12 hours. SASO will also produce a monthly bulletin of earthquakes that occur in or affect Arizona. For more information on SASO and subscriptions to this bulletin, write to or call Terry C. Wallace, SASO, Dept. of Geosciences, Gould-Simpson, Bldg. 77, University of Arizona, Tucson, AZ 85721; (602) 621-4849.

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seismic policy, education, and awareness for which there is no assigned responsibility within the State. The local equivalent of the Advisory Committee for the National Earthquake Hazard Reduction Program, ACES will coordinate government and private-sector seismic-safety practices, evaluate earthquake programs, and monitor compliance with building laws. Short-range plans include developing a charter, defining the organization's structure, and gaining official recognition through an Executive Order. ACES members are also developing a long-term strategy to establish this body as an independent source of credible, technical and nontechnical, seismic information and advice to the public, the private sector, and the executive and legislative branches of State government.

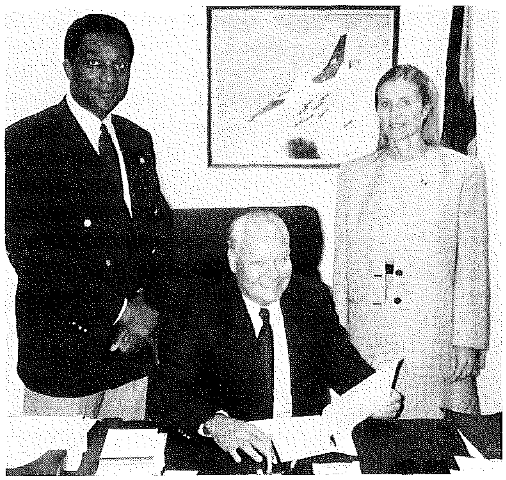
Reference

Menges, C.M., and Pearthree, P.A., 1983, Map of neotectonic (latest Pliocene-Quaternary) deformation in Arizona: Arizona Bureau of Geology and Mineral Technology Open-File Report 83-22, 48 p., scale 1:500,000, 4 sheets.

Arizona Earthquake Preparedness Program

by Reginald A. Yates
Earthquake Program Manager

In June 1991, the Division of Emergency Services (renamed the Division of Emergency Management) in the Arizona Department of Emergency and Military Affairs introduced a program to enhance the State's comprehensive system for emergency management. Several agencies provided information on earthquakes in Arizona: the Arizona Geological Survey (AZGS), Arizona Earthquake Information Center (AEIC) at Northern Arizona University, and U.S. Geological Survey (USGS). Based on this information, the USGS and Federal Emergency Management Agency (FEMA) designated the Yuma area as having high seismic risk. In comparison, California is categorized as having very high seismic risk, whereas Colorado and New Mexico are considered to have moderate seismic risk. Arizona's seismic vulnerability was determined from three criteria: (1) large earthquakes (magnitude [M] 7 to 8) that have occurred outside of, but close to, Arizona; (2) moderate earthquakes (M 5 to 6) that have occurred in Arizona but are unrelated to surface-fault movement (i.e., random earthquakes, such as those recorded in 1906, 1910, 1912, 1959, and 1976); and (3) surface faults in Arizona that have been active in the geologically recent past (within the last 250,000 years) and that could generate a large earthquake (M > 7) in the future.



Arizona Earthquake Preparedness Program administrators, left to right: Reginald A. Yates, Earthquake Program Manager; William D. Lockwood, Director, Division of Emergency Management, Arizona Department of Emergency and Military Affairs; and Ethel DeMarr, Assistant Director, Division of Emergency Management.

The high-risk designation made Arizona eligible for a FEMA grant that will allow the State to develop an effective earthquake-preparedness program. During the first 3 years of the program, funds spent by State agencies on earthquake-related projects will be augmented by Federal funds if those agencies demonstrate progress toward reaching the program's goals. In subsequent years, Federal and State funding for the program will be appropriated and matched on a 50-50 basis. For fiscal years 1991 and 1992, FEMA allocated more than $157,000 for the Arizona Earthquake Preparedness Program (AEPP) and supplemental programs. FEMA supervises the administration and funding of these programs, whereas technical support is coordinated by the USGS, National Science Foundation, and National Institutes of Standards and Technology.

The goal of the AEPP is to establish a foundation for an effective, statewide, earthquake-hazard mitigation and preparedness program. This effort will focus on reducing vulnerability to the effects of major earthquakes within or near Arizona. The AEPP will initially concentrate on hazard identification, vulnerability assessment, and public awareness and education. Mitigation, preparedness planning, and activation of the State Seismic Advisory Council are other key elements of the program.

Program objectives for fiscal year 1992 support the goals listed above and include the following: completing initial hazard analysis, beginning vulnerability studies, and conducting public-awareness and education activities in Flagstaff, Grand Canyon, Phoenix, Prescott, Tucson, Winslow, and Yuma. These communities were selected because of their population density or their proximity to known seismic faults and historical earthquake activity. Other areas of Arizona may be examined as the program evolves.

The program's modest budget and staff (manager and administrative specialist) are being augmented by the activities of individuals from public agencies and the private sector. Experts from many fields, such as the earth sciences, engineering, architecture, construction, education, utilities management, government, and emergency management, are applying their considerable skills to determine the program's direction, develop a statewide seismic-safety policy, create a seismic-resource network, and manage the volumes of data on seismicity in Arizona.

Three agencies have set a lofty standard for cooperation and communication on earthquake issues by providing information, materials, advice, and technical expertise. The AZGS created many of the charts, graphs, and maps used by the Earthquake Preparedness Program. The AEIC developed the proposal and structure for the hazard analysis and provides technical support for workshops and seminars in communities and private organizations. The Structural Engineers Association of Arizona, a private-sector organization, disseminated program information to its members and affiliated associations. Both the Central (Phoenix) and Tucson Chapters have been instrumental in identifying community-based resources and assets that are invaluable at this stage of the program.

The AEPP, in concert with the AZGS and AEIC, will release its first series of maps this year. Prepared at a scale of 1:1,000,000, the first map will illustrate the maximum-intensity ground shaking (based on the modified Mercalli scale) that occurred in Arizona from 1887 through 1987. This map will include information from published isoseismal maps, documented magnitudes of earthquakes in Arizona and earthquakes of $M \geq 6.0$ that occurred near but outside its borders, and unpublished AEIC data.

Historical-seismicity data and paleoseismic information will form the basis of a second map. Estimates of probabilities of future ground acceleration will be extrapolated from studies of neotectonic faults in Arizona (e.g., Menges and Pearthree, 1983). Researchers will also estimate maximum earthquake magnitudes and apply data from studies on attenuation of ground shaking with distance. The resulting map will show the ground acceleration anticipated from the maximum earthquake expected to occur over a given time or exposure interval.

Beginning in December 1991, nearly 40 individuals representing the disciplines mentioned above have been meeting to design a framework for organizing a State Seismic Safety body. The group adopted the name Arizona Council on Earthquake Safety (ACES). ACES will address the issues of

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AZGS Begins New Decade

by Larry D. Fellows
Director and State Geologist
Arizona Geological Survey

On April 29, 1992, Governor Fife Symington signed Senate bill 1055 (Figure 1), which continues the Arizona Geological Survey (AZGS) for another 10 years. This bill marks the successful completion of the Arizona Legislature's Sunset Review of AZGS performance from July 1, 1977, to June 30, 1992. After completing the review, the legislature voted to continue the agency with minor modifications to its enabling legislation.

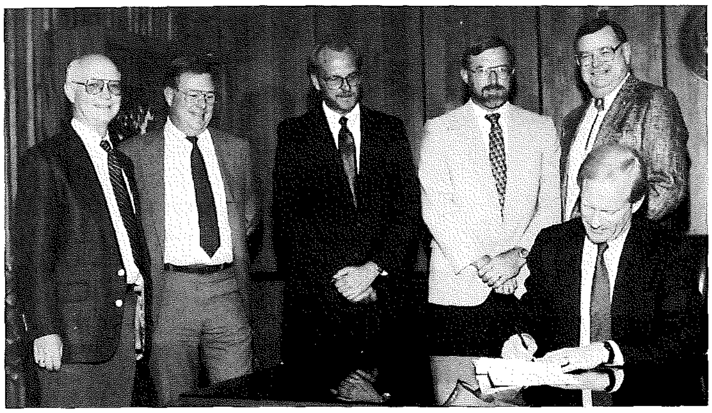


Figure 1. Governor Fife Symington signs Senate bill 1055, which continues the AZGS for another 10 years. Those observing are (left to right) Larry D. Fellows, AZGS Director and State Geologist; James A. Briscoe, JABA, Inc., Tucson; William G. Wellendorf, Water Resources Associates, Inc., Prescott; Frank S. Turek, A-N West, Inc., Phoenix; and State Senator Doug Todd, Tempe. Briscoe, Wellendorf, and Turek are members of AZGS advisory committees.

The AZGS originated as the Office of the Territorial Geologist in 1881. Functions of this office (1881-1912) and the University of Arizona "Bureau of Mines" (1891-1915) were combined in 1915 to form the Arizona Bureau of Mines, a State agency administered by the university. The enabling legislation was later modified, and the agency was renamed the Arizona Bureau of Geology and Mineral Technology in 1977 and the Arizona Geological Survey in 1988.

The Sunset Review process began in 1991 with the selection of the Joint Natural Resources and Agriculture Committee of Reference, cochaired by Senator Gus Arzberger and Representative Susan Gerard. The committee also included Senators Ann Day, John E. Dougherty, Nancy L. Hill, and James J. Sossaman and Representatives Henry Evans, Kyle W. Hindman, Richard "Dick" Pacheco, and Greg Patterson. At the committee hearing in October 1991, the members unanimously recommended to continue the AZGS for another 10 years. This recommendation, together with minor modifications to the enabling act, was incorporated in Senate bill 1055, which was passed by the Senate and House of Representatives and forwarded to Governor Symington for signature.

During the 15-year review period, more than 60,000 persons visited the AZGS office, wrote, or telephoned to obtain geologic information and assistance. Staff members wrote and published 7 bulletins, 11 circulars, 4 special papers, 14 maps, 2 Down-to-Earth series reports, 140 open-file reports, and 58 12-page issues of *Arizona Geology* (formerly *Fieldnotes*). In addition, 4 special papers, 2 geological investigation folios, 17 miscellaneous maps, 37 contributed maps and reports, and 36 open-file reports, completed by non-AZGS authors, were made available to the public. General Revenue appropriations during the 15-year period totaled approximately $5.3 million, publication sales exceeded $350,000, and cooperative projects awarded by Federal, State, and local government agencies brought in $2.8 million.

Other highlights of AZGS history during the review period include the following:

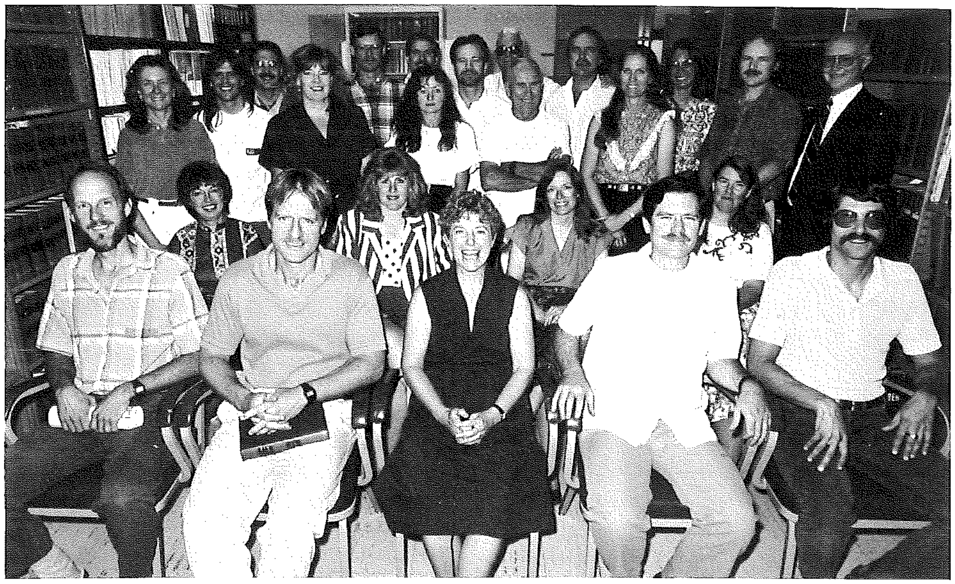
- Celebrating the AZGS centennial;
- Becoming a stand-alone State agency after having been administered by the University of Arizona for 73 years;
- Accepting responsibility for regulating the drilling and production of oil, gas, geothermal, and helium resources;
- Consolidating oil- and gas-well records and samples with existing subsurface samples and data;
- Establishing advisory committees for mineral resources, environmental and engineering geology, and earth-science education;
- Establishing regional and statewide library depository networks for AZGS publications;
- Establishing a computerized database system;
- Publishing a new 1:1,000,000-scale geologic map of Arizona;
- Completing a statewide inventory of historic earthquakes and active faults;
- Nearly completing the geologic map of the Phoenix quadrangle (1:250,000 scale), in cooperation with the U.S. Geological Survey's Cooperative Geologic Mapping Program;
- Developing a surficial geologic mapping program;
- Establishing a new publication series for open-file reports, contributed maps, contributed reports, and nontechnical reports (Down-to-Earth series); and
- Redirecting the earth-science-education program.

Continued population growth in Arizona, accompanied by increased demand for land, water, mineral, and energy resources, magnifies the need for informed land- and resource-management decisions, making the coming decade extremely challenging. To provide the data, reports, maps, interpretations, and assistance that will be requested from the AZGS, the agency will focus on the following activities:

- Working more effectively with State and local land-management agencies and the public;
- Mapping and characterizing bedrock and surficial geologic units;
- Investigating and monitoring known and potential geologic hazards and limitations to land management, including establishing a clearinghouse for land-subsidence and earth-fissure data;
- Developing the capability to do subsurface geologic investigations;
- Preparing interpretive maps in areas with potential for urban development;
- Using computers more extensively and effectively, including establishing a geographic information system and making databases accessible from other locations;
- Strengthening efforts in earth-science education, including publishing more nontechnical reports and establishing a speakers bureau;
- Investigating and characterizing metallic and nonmetallic mineral deposits;
- Expanding the geologic library; and
- Increasing publication sales.

Productivity during the last 15 years has been high and should continue to be throughout the next review period.

Figure 2. Rounding up the (un)usual suspects: AZGS staff members. Seated, front row: Steve Richard, Gary Huckleberry, Pam Lott, Steve Rauzi, and Steve Slaff. Seated, second row: Lauri Colton, Denise Ingram, Evelyn VandenDolder, and Diane Murray. Standing: Emmy Creigh DiSante, Kyle House, John Duncan, Rose Ellen McDonnell, Phil Pearthree, Pete Corrao, Mitzi deMartino, Rick Trapp, Wes Peirce (retired), Joe LaVoie (retired), Tom McGarvin, Cookie Bundy, Donna Moulton, Jon Spencer, and Larry Fellows.



These accomplishments are due, in large part, to the efforts of professional geologists and support staff who are highly qualified, motivated, dedicated, team oriented, and willing to react positively to change. The AZGS embarks on its next review period with a team that meets that description (Figure 2).

New AZGS Publications

The following publications, released since June 1992, may be purchased from the Arizona Geological Survey (AZGS), 845 N. Park Ave., #100, Tucson, AZ 85719. Orders are shipped by UPS; a street address is required for delivery. All orders must be prepaid by check or money order payable in U.S. dollars to the Arizona Geological Survey. Add these shipping charges to your total order:

In the United States:	20.01 - 30.00, add 5.75	50.01 - 100.00, add 10.25
$1.01 - $5.00, add $2.00	30.01 - 40.00, add 6.50	Over 100.00, add 12%
5.01 - 10.00, add 3.00	40.01 - 50.00, add 8.00	Other countries: Request price quotation.
10.01 - 20.00, add 4.50		

Pearthree, P.A., Demsey, K.A., Onken, Jill, Vincent, K.R., and House, P.K., 1992, Geomorphic assessment of flood-prone areas on the southern piedmont of the Tortolita Mountains, Pima County, Arizona: Open-File Report 91-11, 31 p., scale 1:12,000 and 1:24,000, 4 sheets. $16.00

The character of flooding and the extent of flood-prone areas on the southern piedmont of the Tortolita Mountains have been disputed by local and Federal floodplain-management officials since 1987. This report describes the results of a geomorphic analysis of the area that critically evaluates the floodplain designations derived from the alluvial-fan methodology used by the Federal Emergency Management Agency (FEMA). The analysis shows that the extent of active alluvial fans is substantially smaller than the alluvial-fan areas delineated on FEMA's flood-insurance rate maps. The authors recommend ways to minimize discrepancies between model-based predictions and the physical evidence of alluvial-fan flooding on piedmonts.

McGarvin, T.G., 1992, Index to published geologic maps of Arizona -- 1989: Open-File Report 92-6, scale 1:1,000,000. $3.00

This index map lists references for all geologic maps of Arizona published in 1989 and locates their field areas on a map of Arizona. The listing includes geologic, mineral-resource, geologic-hazard, and geochemical maps.

Huckleberry, Gary, 1992, Surficial geology of the eastern Gila River Indian Community area, western Pinal County, Arizona: Open-File Report 92-7, 27 p., scale 1:24,000, 6 sheets. $13.25

Most of the Southwest's urban areas lie on late Cenozoic basin fill. Consequently, the physical properties of the substrata, the distribution of industrial minerals, and the potential for flooding and other geologic hazards have become important areas of study. Surficial mapping provides these types of information, as well as insight into climatic and tectonic mechanisms of landscape evolution and subsurface archaeological potential. This report describes a mapped area that is covered by the Blackwater, Gila Butte, Gila Butte Northwest, Gila Butte Southeast, Sacaton, and Sacaton Butte 7.5-minute quadrangles. The project was completed in cooperation with the U.S. Geological Survey (USGS) COGEOMAP Program.

Pearthree, P.A., and Wellendorf, W.G., 1992, Geomorphic analysis of flood hazards on the northern McDowell Mountains piedmont, Maricopa County: Open-File Report 92-8, 9 p., scale 1:6,000 and 1:12,000, 3 sheets. $6.50

The principal objective of this study was to evaluate the northern piedmont of the McDowell Mountains to determine which areas may be subject to alluvial-fan flooding. Potential flood hazards associated with six drainages that head in the range and cross the piedmont were analyzed using FEMA's alluvial-fan flooding model. Serious discrepancies were discovered between the flood zones shown on FEMA's 1991 flood-insurance rate maps and the geomorphic and geologic evidence of long-term flooding on the northern piedmont. This cooperative study between the AZGS and Water Resource Associates, Inc. was prepared with the support of the cities of Scottsdale and Phoenix, the Flood Control District of Maricopa County, and the USGS COGEOMAP Program.

Chenoweth, W.L., 1992, Geology and production history of the Firelight No. 6 uranium mine, Navajo County, Arizona: Contributed Report CR-92-C, 6 p. $1.25

The Firelight No. 6 Mine (also referred to as the Naschoy or Noschoy Mine) was one of the smaller uranium mines in Monument Valley. This report describes the location, geologic setting, and production history of Firelight No. 6, whose orebody was formed in a channel deposit in the basal portion of the Shinarump Member of the Triassic Chinle Formation. The report includes a map of the mine's underground workings. Most of the information in this report comes from Atomic Energy Commission documents.

Regents Approve Earth Science as Lab Science

by Larry D. Fellows
Director and State Geologist
Arizona Geological Survey

In May 1992, the Arizona Board of Regents amended the laboratory-science admission requirements for the Arizona University System. Earth science with a laboratory component now meets one of the laboratory-science competencies. The Earth Science Education Advisory Committee (ESEAC) to the Arizona Geological Survey (Figure 1) and I commend the Regents for recognizing the importance of earth science and for giving it equal standing with chemistry, physics, and biology, which we believe it rightfully deserves. This decision is consistent with the principles of the national and Arizona environmental education acts and enhances implementation of the Arizona Department of Education's Arizona Science Essential Skills Program. We especially appreciate the support for earth science that Regents Eddie Basha and C. Diane Bishop offered.

Undergraduate admission requirements to the Arizona university system (Section 2-102, A.2.c., of the Regents' policy) now specify that for unconditional admission, an incoming freshman must demonstrate competency in laboratory science "by completing at least one year of study in each of two different laboratory sciences selected from the following: Chemistry, Physics, Earth Science, or Biology. It is strongly recommended that students take a third year of laboratory science in Biology, Chemistry, or Physics or in other laboratory sciences such as Physical Science.

"A laboratory science course is defined as a course in which at least one class period each week is devoted to providing an opportunity for students to manipulate equipment, materials, or specimens to develop skills in observation and analysis, and to discover, demonstrate, or illustrate, or test scientific principles or concepts.

"Competency may be demonstrated by any one or any combination of the following options:

(1) Completes appropriate credits in high school laboratory science courses, or

(2) Completes appropriate four-semester credit hour laboratory science courses from a regionally accredited institution of higher education (one transferable four-semester credit hour course will satisfy the requirement for one year of study), or

(3) Attains at least the following minimum scores on any of the standardized tests listed below:

ATP Achievement Test		ACT	
Chemistry Achievement	575	Natural Science	20
Biology Achievement	550		
Physics Achievement	590		

(Standardized test scores may be used to demonstrate competency in one science only.)"

The ESEAC surveyed high-school earth-science teachers in 1990 and learned that from 1985 to 1990, the number of earth-science sections in the respondent schools declined by 19 percent. College-bound high-school students, aware that earth science was not acceptable as a laboratory-science course, opted to take courses that were accepted. Earth-science teachers reported that, because the universities did not accept earth science as a laboratory-science course, it was perceived by college-bound students as a "dummy" class. Many teachers confirmed that in their schools the earth-science sections that were not eliminated attracted low-ability and poorly motivated students. Consequently, teacher morale was low. The results of this survey were summarized in the Fall 1990 issue of *Arizona Geology* (vol. 20, no. 3, p. 4-6).

After the earth-science-teacher survey was completed, ESEAC members prepared a position paper on earth-science education, which was subsequently endorsed by 29 agencies,

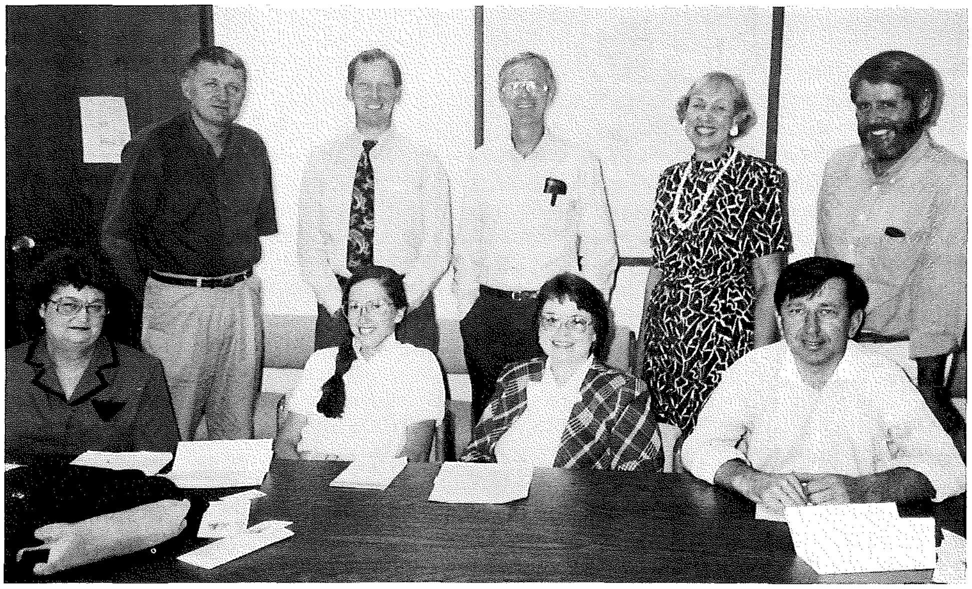


Figure 1. Members of the Earth Science Education Advisory Committee to the Arizona Geological Survey who were present at the August 1992 meeting: seated (left to right), Susan Bollin, Beth Nichols-Boyd, Sue Bachus (visitor), and Alan Morton; standing (left to right), David Harbster, Tony Occhiuzzi, Robert Thompson, Suzanne Cash, and Ray Grant.

professional societies, industries, and other interested groups (Table 1). ESEAC members met in August 1992 to update and modify the position statement (Figure 1).

Why is earth science important to Arizonans? ESEAC members aptly explained its value in their position paper on earth-science education. "Civilization is dependent upon the use and replenishment of Earth's water, energy, mineral, and soil resources. Because earth science is interdisciplinary, i.e., it utilizes laws of physics, reactions of chemistry, and interactions of geology, hydrology, meteorology, oceanography, biology, and astronomy, it provides students with a broad background about their surroundings. This awareness enables them to understand better the resource and environmental issues at the local, state, regional, national, and global levels, as well as the relationship of these factors to domestic and foreign policy and to the economy. More specifically, it gives students the knowledge to make informed decisions about

Table 1. Groups that endorsed the position paper on earth-science education

American Geophysical Union
American Institute of Mining, Metallurgical, and Petroleum Engineers, Tucson Section
American Institute of Professional Geologists (AIPG)
AIPG, Arizona Section
Arizona Alliance for Mathematics, Science & Technology Education
Arizona Geological Society
Arizona Leaverite Rock & Gem Society
Arizona Mineral & Mining Museum Foundation
Arizona Science Teachers Association
Arizona Western College
Chinle Unified School District No. 24
Cyprus Casa Grande
The Geological Society of America
The Geological Society of America, Coordinator for Educational Programs
Groundwater Resources Consultants, Inc., Tucson
Gutierrez-Palmenberg, Inc., Phoenix
Lowell Observatory
Maricopa County Community Colleges, Geology Instructional Council
Maricopa Lapidary Society, Inc.
Mineral Resources Advisory Committee to the Arizona Geological Survey
Mining Club of the Southwest
National Association of Geology Teachers
National Optical Astronomy Observatories
Navajo Community College, Department of Mathematics and Natural Sciences
Northern Arizona University, Department of Geology
Southwestern Minerals Exploration Association
University of Arizona (UA) Department of Geosciences
UA Department of Mining and Geological Engineering
UA Inter-College Science Education Committee

buying property, managing land and resources, and voting on vital resource and environmental issues. Arizona, regarded nationally and worldwide as a state with outstanding, easily observable geologic features and phenomena, could be a leader in educating future citizens. Knowledge of Earth systems and processes is paramount to the development of an informed citizenry relative to their total environment."

Passage of the national and Arizona environmental-education acts in 1990 attested to the importance of knowledge about the environment. Environmental education, of which earth-science education is an integral part, begins at the elementary school level, or even before, and continues throughout adulthood. Students learn about the fundamental concepts, materials, processes, reactions, and interrelationships of the environment through science courses, including chemistry, physics, biology, and geology. They learn that land, water, energy resources, metals, and nonmetals, as well as renewable resources such as wood products, food, and fiber, are essential for human survival. They learn about the origin and character of the land and its resources. They learn that it is imperative to use and manage these resources prudently. With this basic knowledge, students can better understand the total environment, our interactions with it, and our dependency on it and can make *informed* land- and resource-management decisions. Environmental education gives students the tools they need to make *informed* decisions; it does not, however, tell them what decisions they should make.

Water Information

More than 123 million Americans drink ground water from more than 13 million private wells and 100,000 public supply sources. The quality and management of ground water and other water sources are the subjects of several recent publications, some of which are listed below.

Where to Get Free (or Almost Free) Information About Water in Arizona, written by Barbara Tellman for the general public, lists sources of information about water-conservation methods, flood control, legislation, permits, water quality, rainfall, and water supply. Sources include government agencies, professional organizations, nonprofit groups, publications, teaching materials, speakers, videos, and educational films. To obtain a free copy of this 62-page reference, write to or call the Water Resources Research Center, University of Arizona, 350 N. Campbell Ave., Tucson, AZ 85721; (602) 792-9591.

Where to Get Technical Information About Water in Arizona was written by Barbara Tellman for the water professional, research specialist, and consultant. It lists sources of technical publications, databases, maps, and satellite, aerial, and historical photographs. This 36-page reference is also free from the Water Resources Research Center (address listed above).

Proceedings of Conserv '90, the National Conference Offering Water Supply Solutions for the 1990s, was published by the National Ground Water Association (NGWA) as catalog item P710. Conserv '90 was held in Phoenix in August 1990 and was coordinated by nearly 60 national organizations. The conference addressed water-supply issues, such as water reuse, drought management, watershed management, planning, and water transfer. More than 300 papers are included in this single volume. Send $10.00 to the NGWA Bookstore, P.O. Box 182039, Dept. 017, Columbus, OH 43218.

Directory for the Ground Water Industry, compiled by Chris Reimer and published by the NGWA as catalog item K805, is a guide to ground-water information. This 73-page directory includes addresses and phone numbers for government agencies, associations, and industry organizations. Send $12.50 ($10 if NGWA member) to the NGWA Bookstore (address listed above).

The Gila Basin and the Waters of Southern Arizona, by John Folk-Williams, describes water use and management in the Gila Basin and the critical policy issues facing this region. The drainage basin, which includes Phoenix, presents a microcosm of water issues in the arid West. By highlighting efforts to resolve disputes involving Indian water rights, the study clarifies the interplay of history, water use, institutional structure, and interest-group conflict that shapes major decisions about water. This 58-page book is available for $15.00 from Western Network, 616 Don Gaspar Ave., Santa Fe, NM 87501; (505) 982-9805.

A toll-free number, 1-800-423-7748, has been established by the American Ground Water Trust for Americans who use ground water from wells and want to know more about their water supply. Callers may listen to informative recorded messages on water quality, water protection, and water wells and then leave messages of their own to request additional information, which is subsequently mailed to them. The Ground Water Information Line is available 24 hours a day, every day of the year.

Stewart Mountain Dam Safety Modifications Completed

by Larry D. Fellows
Director and State Geologist
Arizona Geological Survey

On April 23, 1992, the U.S. Bureau of Reclamation (BOR) and the Salt River Project (SRP) held a ceremony at Stewart Mountain Dam northeast of Mesa to mark the completion of the Safety of Dams Modification Project. Speakers included John Lassen, SRP President; Joe Hall, BOR Deputy Commissioner; Robert Towles, BOR Regional Director, Lower Colorado River Region; C.M. Perkins, SRP General Manager; and Senator Dennis DeConcini.

Stewart Mountain Dam, constructed on the Salt River by the SRP from 1928 to 1930, forms Saguaro Lake, which has a current capacity of about 69,800 acre-feet. The dam, a multicurvature, thin-arch concrete dam with two gravity-thrust blocks, is about 200 feet high with a crest length of 1,260 feet. Detailed geologic studies of the dam foundation were not made before or during construction. In the mid-1980's, the BOR conducted studies to assess potentially unsafe conditions.

Three such conditions were identified. First, the expansive reaction between cement and siliceous aggregate caused the top of the dam to deflect approximately 6 inches upstream from 1930 until the mid-1960's, when deflection ceased. Second, the Sugarloaf Fault, a northwest-trending normal fault 9 miles north of the dam, was identified in the mid-1980's. Geologists, on the basis of the height and length of the fault scarp and comparisons with other active and inactive faults in the region, estimated that the maximum credible earthquake (MCE) that could be generated by fault movement would be of magnitude 6.75. A dynamic analysis indicated that the dam would be unable to withstand the MCE. Third, hydraulic studies indicated that the dam would overtop during the probable maximum flood (PMF) because of inadequate spillway capacity. The PMF is the estimated hypothetical flood volume and discharge that are considered to be the most severe yet reasonably possible at the site.

To correct these conditions, the BOR made safety modifications. Construction crews rehabilitated and strengthened the arch by installing post-tensioned tendons through it and adding concrete on the downstream side of the thrust blocks. They also built an auxiliary spillway on the right abutment. This addition increased the total spillway capacity from 120,000 cubic feet per second (cfs) to 210,000 cfs, as required by the PMF, and will prevent overtopping.

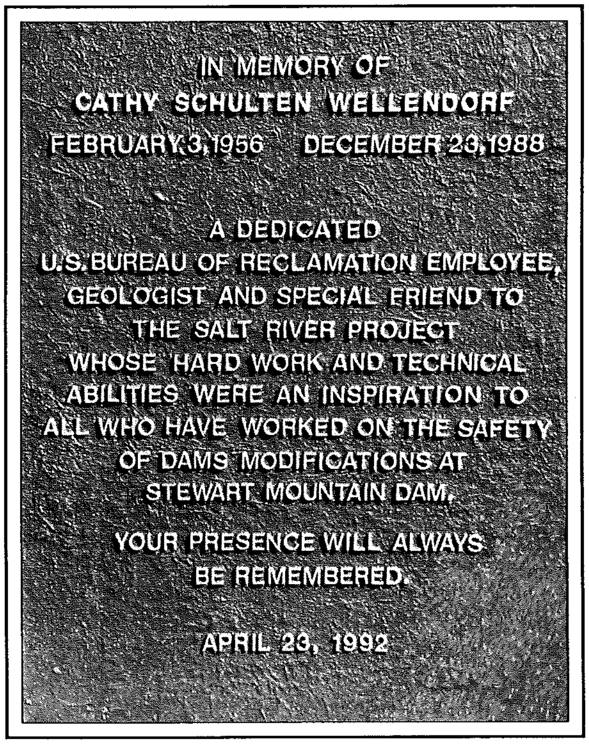


Figure 1. *Plaque presented to Bill Wellendorf during the Safety of Dams Modification ceremony held at Stewart Mountain Dam on April 23, 1992.*

Figure 2. *Mr. Robert Towles (right), Regional Director of the U.S. Bureau of Reclamation's Lower Colorado River Region, presents plaque to members of Cathy Schulten Wellendorf's family (left to right): Al Schulten, Cathy's cousin, El Toro, California; Robert Schulten, Cathy's father, Louisville, Kentucky; Bill Wellendorf, Cathy's husband, Prescott, Arizona; and Lester Wellendorf, Bill's father, Leo, Indiana.*

Beginning in mid-1984, Cathy S. Wellendorf became the BOR's lead geologist on the Stewart Mountain Dam Modification Project. She directed all preconstruction geologic investigations and monitored the geologic and seepage conditions and rock-slope stability of the new auxiliary-spillway excavation. Cathy described this project for *Arizona Geology* readers in the Winter 1986 issue (vol. 16, no. 4, p 8-9, 11). She continued as lead geologist until her death in December 1988.

Throughout her career with the BOR, Cathy planned and carried out numerous special studies and unique projects. She was a gifted, highly respected geologist. In her memory, Cathy's family established the Cathy Wellendorf Memorial Fund with the Arizona Geological Survey. This fund is being used to support projects and activities in environmental and engineering geology.

In recognition of Cathy's contribution, the SRP prepared a bronze plaque (Figure 1), which was presented to her husband, Bill. Cathy's father, Robert Schulten, and Bill's father, Lester Wellendorf (Figure 2), as well as many of Cathy's colleagues and friends, were also present at the ceremony. The plaque has been secured to the Stewart Mountain Dam in her memory.

Theses and Dissertations, 1991

compiled by Emily Creigh DiSante
Arizona Geological Survey

The following list includes theses and dissertations on Arizona geology, geological engineering, hydrology, and related subjects that were awarded in 1991 by Arizona State University, Northern Arizona University, and the University of Arizona. This list, however, is not a complete compilation of theses on such topics. Theses on the geology of other States or countries that were awarded by these universities are not listed, nor are theses on the geology of Arizona that were awarded by out-of-State universities.

Most theses included here are not available in the library of the Arizona Geological Survey. Each thesis, however, may be examined at the main library of the university that awarded it or may be obtained through interlibrary loan. Information may also be obtained from the respective departments, which are indicated in parentheses after each citation according to the codes listed below.

Arizona State University, Tempe, AZ 85287; (602) 965-9011 (Gg-Geography; Gl-Geology).
Northern Arizona University, Flagstaff, AZ 86011; (602) 523-9011 (G-Geology).
University of Arizona, Tucson, AZ 85721; (602) 621-2211 (CEEM-Civil Engineering and Engineering Mechanics; G-Geosciences; HWR-Hydrology and Water Resources; MGE-Mining and Geological Engineering; RNR-Renewable Natural Resources).

ARIZONA STATE UNIVERSITY

Kammerer, Martin, The in-channel dispersion of copper, zinc, and lead in dryland river sediments, Queen Creek, Arizona: M.S. thesis (Gg).

Kenny, Ray, Stable isotopes on chert and carbonate from continental and lowland subaerial exposure surfaces, southwestern United States: Ph.D. dissertation, 204 p. (Gl).

Palais, D.G., Field, analytical, and theoretical studies of low-pressure metamorphism: Ph.D. dissertation, 183 p. (Gl).

NORTHERN ARIZONA UNIVERSITY

Albin, A.L., Structural geology of the Gneiss Canyon shear zone in the Peacock Mountains and southern Grand Wash Cliffs, northwestern Arizona: M.S. thesis, 68 p. (G).

Anderson, P.L., Analysis of gravity data from the Chino Valley area, Yavapai and Coconino Counties, Arizona: M.S. thesis, 119 p. (G).

Barry, P.P., Jr., The mechanics of faulting within the hanging-wall block at the north end of the Verde Fault, north-central Arizona: M.S. thesis, 55 p. (G).

Cook, D.A., Sedimentology and shale petrology of the Upper Proterozoic Walcott Member, Kwagunt Formation, Chuar Group, Grand Canyon, Arizona: M.S. thesis, 158 p. (G).

Doe, M.F., Structural geology of a Proterozoic foreland thrust-system in the vicinity of Barnhardt Canyon, central Mazatzal Mountains, central Arizona: M.S. thesis, 91 p. (G).

Johnson, H.G., A new fish fauna from the Upper Devonian Martin Formation, Mount Elden, northern Arizona: M.S. thesis, 191 p. (G).

Kirby, R.E., A vertebrate fauna from the Upper Triassic Owl Rock Member of the Chinle Formation of northern Arizona: M.S. thesis, 496 p. (G).

UNIVERSITY OF ARIZONA

Armstrong, R.C., Slope stability modeling at the Cyprus Bagdad Mine: M.S. thesis, 102 p. (MGE).

Bazard, D.R., Paleomagnetism of Late Triassic and Jurassic sediments of the southwestern United States: Ph.D. dissertation, 133 p. (G).

Bohannon, S.J., Hydrogeology of the San Xavier mining laboratory and geophysics test site and surrounding area: M.S. thesis, 187 p. (HWR).

Clements, B.P., Precious metal vein mineralization in the Bradshaw Mountains region, Yavapai County, Arizona: M.S. thesis, 150 p. (G).

Cole, K.C., Estimation of mass flux and aquifer properties using global positioning system and micro-gravity in the Tucson basin, southern Arizona: Ph.D. dissertation, 193 p. (G).

Farrand, W.H., Visible and near-infrared reflectance of tuff rings and tuff cones: Ph.D. dissertation, 187 p. (G).

Freitas, R.J., Estimating infiltration parameters from remotely sensed vegetative cover and measured soil properties: M.S. thesis, 161 p. (RNR).

Hall, D.G., Hydrogeologic investigations for a ground-water contamination site, Phoenix, Arizona: M.S. thesis, 176 p. (G).

Hatch, M.A., Global positioning system measurement of subsidence in the Tucson basin, Pima County, Arizona: M.S. prepublication manuscript, 71 p. (G).

House, P.K., Paleoflood hydrology of the principal canyons of the southern Tortolita Mountains, southeastern Arizona: M.S. prepublication manuscript, 21 p. (G).

Klute, M.A., Sedimentology, sandstone petrofacies, and tectonic setting of the late Mesozoic Bisbee basin, southeastern Arizona: Ph.D. dissertation, 268 p. (G).

Kruger, J.M., Seismic crustal structure beneath the Safford basin and Pinaleño Mountains: Implications for Cenozoic extension and metamorphic core complex uplift in southeastern Arizona: Ph.D. dissertation, 158 p. (G).

Lang, J.R., Isotopic and geochemical characteristics of Laramide igneous rocks in Arizona: Ph.D. dissertation, 201 p. (G).

Leblanc, R.P., Transformation of methane and vinyl chloride by methanotrophic bacteria in unsaturated soil columns: M.S. thesis, 123 p. (CEEM).

Neaville, C.C., Hydrogeology and simulation of ground-water and surface-water flow in Pinal Creek basin, Gila County, Arizona: M.S. thesis, 149 p. (HWR).

Rice, G.F., The use of environmental tracers to determine relationships among aquifers in the lower San Pedro River basin, Arizona: M.S. thesis, 65 p. (HWR).

Skirvin, S.M., Use of processed Landsat Thematic Mapper data to detect surface soil moisture over mountain pediments, southeastern Arizona: M.S. thesis, 57 p. (G).

Truebe, H.A., Application of geographic information system technology to the recognition of prospecting targets in the eastern half of the Tucson quadrangle, Arizona: Ph.D. dissertation, 215 p. (MGE).

Wallin, R.W., Ground-water transport of polycyclic aromatic hydrocarbons in association with humic substances in the Pinal Creek basin, Globe, Arizona: M.S. thesis, 108 p. (HWR).

Oil and Gas Notes

A permit was issued in July to Arrowhead Oil and Gas, Ltd., to drill an exploration well 1 mile northeast of Litchfield Park in central Maricopa County. The well, the 32-23 SunCor-Melange, is in T. 2 N., R. 1 W., sec. 23 and has a proposed total depth of 6,000 feet.

On June 3, 1992, Governor Symington appointed Mr. Zed Veale of Flagstaff to succeed Mr. A. Roy Bennett on the Oil and Gas Conservation Commission. Mr. Veale's appointment runs through January 20, 1997. The next regular meeting of the Commission is scheduled for October 23, 1992, in Room 500 of the State Capitol Building in Phoenix.

An error was printed in "Oil and Gas Notes" in the last issue (vol. 22, no. 2, p. 9) of *Arizona Geology*. The abstract by Albert B. Dickas and M.G. Mudrey, Jr. *(The Lake Superior Oronto Group, a Middle Proterozoic Exploration Model for the Late Proterozoic Chuar Group of the Grand Canyon)* was not presented at the 8th McKelvey Forum on Mineral and Energy Resources. It was presented at the Southwest Section Meeting of the American Association of Petroleum Geologists, held April 21-24, 1992, and was published in the April 1992 issue of the *AAPG Bulletin* (p. 574).

Earth Science Information Center Opens in Tucson

The Tucson Earth Science Information Center, a joint effort between the Arizona Geological Survey (AZGS) and U.S. Geological Survey (USGS), is now open at 340 N. 6th Avenue, Tucson, Arizona (tel: 602-670-5544). Topographic maps of Arizona, as well as some for adjacent States, selected USGS geologic maps and reports, and AZGS publications are available for purchase. The center is open Monday through Friday, 8:00 a.m. to 4:00 p.m.

Gold Panning in Arizona

Placer gold consists of mineral grains that have been derived from veins and other deposits in local mountain ranges. These grains become concentrated in weathered materials, such as sand and gravel along stream beds. An estimated 600,000 ounces of placer gold have been mined from streams in Arizona since the 1850's, when gold was first discovered in the State. Placer mining includes gold panning, as well as more sophisticated operations.

Gold Panning in Arizona, a recent 22-page report by Diane Bain, is intended for the recreational gold panner. It includes a brief history of placer gold mining in Arizona; explains the origin of placer gold; identifies the most favorable panning areas; lists placer gold deposits in the State; and supplies panning instructions, prospecting tips, and maps. This entertaining and informative book (Mineral Report No. 7) may be purchased from the Arizona Department of Mines and Mineral Resources, 1502 W. Washington St., Phoenix, AZ 85007; tel: (602) 255-3791. Single copies are $4.50 (including shipping).

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