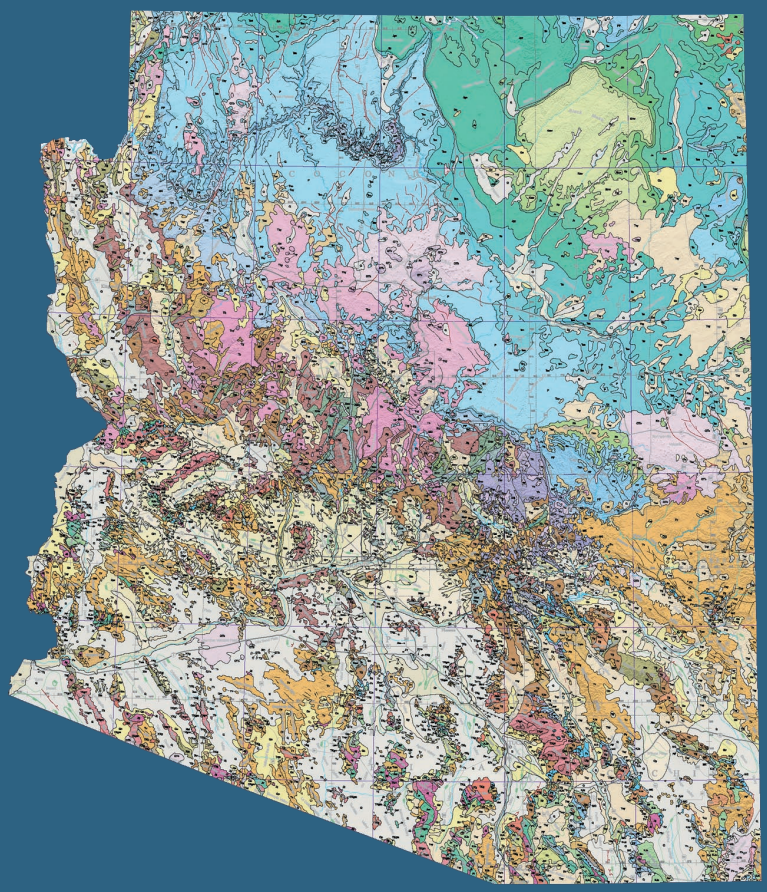

Annual Report of the Arizona Geological Survey

Fiscal Year 2001

(July 1, 2000 to June 30, 2001)

Larry D. Fellows
Director and State Geologist

Arizona Geological Survey
416 W. Congress St., Suite 100
Tucson, Arizona 85701

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On the Cover: A detail from M 35, *Geologic map of Arizona:* Richard, S.M., Reynolds, S.J., Spencer, J.E., and Pearthree, compilers, 2000, Arizona Geological Survey Map 35, scale 1:1,000.000.

EXECUTIVE SUMMARY

Arizona Geological Survey employees collected and archived information and informed and assisted the public in the following ways during Fiscal Year 2001:

Larry D. Fellows
Director and State Geologist

- Answered thousands of requests for geologic information or assistance
- Sold 9,380 geologic reports and maps (Nineteen of every 20 mail orders were returned the same day.)
- Prepared and released 31 new reports and maps on Arizona geology, including

  Geologic Map of Arizona (Map 35)

  Arizona Has Oil and Gas Potential! (Circular 29)

  Guide to Geologic Features at Petrified Forest National Park (Down-to-Earth 10),

  Rocks in the Chiricahua National Monument and Fort Bowie National Historic Site (Down-to-Earth 11)

  Sixteen geologic maps, including eight in the Phoenix-Tucson corridor

  Twelve applied geology studies in population-growth or potential economic-development areas

  Six digital geologic maps and three spatial data products
- Released four 6-page issues of *Arizona Geology,* the quarterly newsletter
- Presented 22 talks, workshops, and fieldtrips
- Expended $196,238 on projects done under contract with federal and other state agencies

MISSION AND DESCRIPTION

MISSION

To inform and advise the public about the geologic character of Arizona in order to foster understanding and prudent development of the State's land, water, mineral, and energy resources.

DESCRIPTION

Informing the public about Arizona's geologic character involves a number of field and office activities. In addition, the AZGS provides administrative and staff support for the Arizona Oil and Gas Conservation Commission (OGCC), which is attached to the AZGS. The OGCC regulates the drilling for and production of oil, gas, geothermal, helium, and carbon dioxide to ensure that sound engineering, environmental, and conservation practices are followed. To carry out the AZGS mission, AZGS staff members conduct the following activities:

- GEOLOGIC MAPPING. Map and describe the origin and character of rock units and their weathering products.
- HAZARDS AND LIMITATIONS. Investigate geologic hazards and limitations such as earthquakes, land subsidence, flooding, and rock solution that may affect the health and welfare of the public or impact land- and resource management.
- ENERGY AND MINERAL RESOURCES. Describe the origin, distribution, and character of metallic, non-metallic, and energy resources and identify areas that have potential for future discoveries.
- OIL AND GAS CONSERVATION COMMISSION. Assist in carrying out the rules, orders, and policies established by the Arizona Oil and Gas Conservation Commission.
- PUBLIC INFORMATION. Inform the public by answering inquiries, preparing and selling maps and reports, maintaining a library and databases, providing a website, giving talks, and leading fieldtrips.

Geologic data users include interested citizens and citizen groups, elected officials and staff, governmental land- and resource-management agencies, environmental and engineering geology companies, hydrologists, energy- and mineral-exploration companies, consultants, attorneys, realtors, insurance companies, teachers, students, libraries, and book dealers.

GEOLOGIC MAPPING

MAPPING PROJECTS

Jon E. Spencer, Senior Geologist

Revised Geologic Map of Arizona. Map 35, the newest version of the Geologic Map of Arizona, was published in 2000. It replaced its predecessor, Map 26, which was printed in 1988 and went out of print after all copies (10,000) were sold. About a quarter of the geologic mapping on Map 35 was completed after 1988. Map units are described in more detail on Map 35, four additional units were added, and depth to bedrock within the major Tertiary basins is shown. A simplified cultural base was used to make the map more legible. Shaded relief was added to enhance the visualization of geology with respect to landforms. AZGS geologists Stephen M. Richard, Jon E. Spencer, Philip A. Pearthree, and Stephen J. Reynolds, Arizona State University, collaborated on the revision.

Phoenix-Tucson corridor. Since the National Geologic Mapping Act was passed in 1992, funding has been available to state geological surveys on a competitive basis through the Statemap program administered by the U.S. Geological Survey. The Act requires that mapping priorities for the Statemap component be determined by advisory committees and that federal funding awarded to a state geological survey is matched equally by State funds. Since 1992 the AZGS has received awards of more than $1,200,000 to do geologic mapping. The federal dollars plus the state matching funds bring the total value of the Arizona mapping program to more than $2,500,000.

The Arizona Geologic Mapping Advisory Committee recommended that mapping be focused in the Phoenix-Tucson corridor, which includes 20 percent of the area of the State and 80 percent of the population. Mapping in the metropolitan Phoenix area has been completed. Work is in progress in the outskirts of Tucson, largely in areas that are being developed or are likely to be developed within the next 10-20 years. Maps in the Phoenix area are being digitized for release on CDs.

The AZGS mapping team included Jon E. Spencer, Philip A. Pearthree, Stephen M. Richard, Tim R. Orr, Thomas H. Biggs, Charles A. Ferguson, Wyatt G. Gilbert, Steven J. Skotnicki, and Ann Youberg.

Charles A. Ferguson, Contracted Geologist

Bullhead City area. The Bullhead City, Arizona – Laughlin, Nevada area is one of the most rapidly expanding areas in the southwestern United States. AZGS geologist Philip A. Pearthree worked with geologists from the Nevada Bureau of Mines and Geology to map the geology of the Davis Dam quadrangle, which straddles the Colorado River and includes parts of both states. This mapping revealed evidence for the extent of flood-prone areas, aggregate resources, and problem soils. In addition, mapping provided some tantalizing hints regarding the development of the Colorado River during the past few million years. The geologic map was submitted to the Nevada Bureau of Mines and Geology for review.

San Bernardino Valley. The AZGS has cooperated with the U.S. Forest Service on several projects to provide geologic mapping and other data to support sustainable range-management practices in the Malpai Borderlands area of southeastern Arizona and southwestern New Mexico. AZGS geologists Ann Youberg and Charles A. Ferguson completed a report on the geology and geomorphology of a small area in the Peloncillo Mountains (Open-File Report 01-05), where prescribed burns are planned in the next few years.

Goldwater Air Force Range. AZGS geologists Philip A. Pearthree, Karen A. Demsey, and Jeanne E. Klawon completed several geologic maps and reports between 1996 and

Tim R. Orr, Geologist II

1998 that cover parts of the Goldwater Air Force Range east of Yuma. After review by Air Force staff, geologic maps in the San Cristobal and Growler Valleys and the western Crater Range were released as Open-File Reports 01-01, 01-02, and 01-03.

DIGITAL MAPPING

North American Geologic Map Data Model. The Association of American State Geologists, U.S. Geological Survey, and Geological Survey of Canada have established a North American Data Model Steering Committee (NADMSC). Stephen M. Richard, AZGS geologist, serves on the Data Model Design Team, which is charged with developing a standardized data model for presenting geologic map information in computer database systems. In addition, Richard is co-chairman of the Science Language Technical Team, which developed a formal scheme for classifying metamorphic rocks in a database system to facilitate lithological querying by users with all levels of expertise. Results of this effort will be used in AZGS geologic map databases.

Richard and AZGS geologist Tim R. Orr are designing and implementing a relational database for geologic information to accompany digital geologic map databases in the AZGS Digital Information Series. The database is being tested and populated in connection with ongoing mapping programs.

Digital geologic map database for the Phoenix metropolitan area. The database design activities described in the preceding paragraph were undertaken primarily to aid in the development of a digital geologic map database for the Phoenix metropolitan area. Orr is digitizing thirteen 7.5' quadrangles (1:24,000 scale) in the northeastern part of the metro area. That work will be completed during FY 2002. In FY 2003 eleven 7.5' geologic maps in the southeastern part of the metro area will be digitized. The databases connected with these maps will initially feature simple text map unit descriptions. The geologic database system will be populated progressively with more in-depth descriptions, which will allow the generation of derivative maps to meet the needs of various users.

- **MAPS RELEASED – PHOENIX-TUCSON CORRIDOR**
  Open-File Reports 00-04, 00-05, 00-06, 00-08, 00-12, and 00-13
  Digital Geologic Maps 02 and 05

(Complete citations of these publications are on p. 13-16.)

- **MAPS RELEASED – OTHER AREAS**
  Map 35, scale 1:1,000,000.
  Open-File Report 00-11, 01-01, 01-02, 01-03, and 01-05
  Digital Geologic Map 01

- **DIGITAL MAPS RELEASED**
  Digital Geologic Map 01, 02, 04, 05, and 06

- **DIGITAL INFORMATION SERIES RELEASE**
  Digital Information Series 18, 19, and 20

PROJECTS

Center for Land Subsidence and Earth Fissure Information (CLASEFI). The AZGS maps, describes, and compiles information about subsiding areas and earth fissures and provides information about them to the public. Meetings are held periodically with other agencies to discuss recent events related to subsidence and fissures. Raymond C. Harris oversees CLASEFI activities.

Philip A. Pearthree, Research Geologist

Colorado Plateau karst study. Work continues on a study of sinkholes and large cracks caused by dissolution of deep salt beds on the southern Colorado Plateau between Snowflake and Winslow. The study is aimed at mapping the distribution of these salt-karst features, which pose a geologic hazard. Of particular concern is the fact that the sinkholes and cracks are hundreds of feet deep and may provide conduits for contaminants to reach an important aquifer.

Hurricane fault. AZGS geologists have studied the recent history of the Hurricane fault in northern Arizona for the past several years in cooperation with Utah Geological Survey geologists. Funding for these investigations have been provided by both state geological surveys and the National Earthquake Hazard Reduction Program of the U.S.Geological Survey (USGS). Philip A. Pearthree represented the AZGS on these projects. Researchers have determined that the Hurricane fault produced several magnitude 6.5 to 7 earthquakes in the past 15,000 years. The fault clearly has potential to cause damage from western Grand Canyon northward to Cedar City, Utah. Scientists from the AZGS, University of Utah, and USGS found evidence that movement on the Hurricane has had a major influence in development of Grand Canyon in past few million years. The final project report was submitted to the USGS via the Utah Geological Survey. A summary article was submitted to the journal *Geology* for publication.

Ann M. Youberg, Contracted Geologist

Jackrabbit Wash. The AZGS is contributing geologic information to a preliminary flood-hazard assessment for Jackrabbit Wash, a large drainage in an undeveloped part of western Maricopa County. A large flood occurred in Jackrabbit Wash during fall 2000. AZGS geologists Philip A. Pearthree and Ann Youberg are comparing satellite images from before and after the flood to detect changes in the landscape caused by flooding. Use of the satellite data and limited field mapping will enable them to delineate areas along Jackrabbit Wash that were inundated in the 2000 flood.

Raymond C. Harris, Geologist II

Oil well plugging. AZGS provided technical assistance for plugging a 1920s era oil-exploration well near Safford. The artesian well was producing hot salty water that drained into the Gila River. Isotope geochemistry studies by the AZGS suggest that this and other artesian wells in the Safford basin are an important source of salinity in the Gila River. Raymond C. Harris conducted geochemical sampling and provided onsite supervision of the plugging. The Water Protection Fund, adminstered by the Arizona Department of Water Resources, provided funding for the project. Nearby irrigation wells will be monitored for several years by AZGS to determine if the quality of groundwater in the area improves after plugging of the artesian well.

Safford Basin ground-water tracing. This pilot study, partially funded by the Arizona Water Protection Fund, was undertaken by Raymond C. Harris to demonstrate the usefulness of using tritium as a tracer of sources of ground water and Gila River water and movement through the Safford Basin. The tritium technique is useful for determining if water was precipitated before the advent of atmospheric atomic bomb testing. Water

Steven J. Skotnicki, Contracted Geologist

originating as precipitation before the late 1950s has no tritium left in it. Many of the seeps in the Gila River channel, springs in the valley, and deep wells have tritium-dead water, indicating this water is not derived from recent Gila River sub flow. This study and previous AZGS isotope geochemistry studies have demonstrated that much of the salinity in the Gila River is coming from natural sources and not from agriculture. Some of this work is described in Open-File Reports 00-9 and 00-10.

Tiger Wash Alluvial Fan. For the past decade the AZGS has cooperated with local floodplain management agencies to provide geologic mapping for use in defining flood-prone areas on desert piedmonts. Active alluvial fans, where floodwater spreads widely and new channels may form during floods, are areas of primary concern. Tiger Wash alluvial fan in westernmost Maricopa County provides an excellent opportunity to integrate geologic studies into flood hazard assessments. In 1999 Philip A. Pearthree and Jeanne E. Klawon mapped the surficial geology of the Tiger Wash alluvial fan and documented widespread inundation and changes in channel patterns that were associated with a large flood in 1997. Delineating flood-prone areas on the basis of distribution of young surficial deposits is very effective. The surficial geologic mapping and inundation mapping were used by JE Fuller Hydrology & Geomorphology to delineate flood-hazard zones for the Flood Control District of Maricopa County. The flood-hazard maps are being reviewed by the Federal Emergency Management Agency as a prototype for alluvial-fan-hazard-delineation standards in Maricopa County.

Verde River floods. AZGS and University of Arizona geologists began investigating the flood history of the Verde River after the large floods of 1993. At Sheep Bridge, a spectacular site above Horseshoe Dam, they documented deposits left by large floods several thousand years ago. Some of those floods were larger than the largest flood of 1993. This work is summarized by P. Kyle House, Philip A. Pearthree, and Jeanne E. Klawon in AZGS Open-File Report 01-04 and in a report that was submitted for publication by the American Geophysical Union.

REPORTS RELEASED

Open-File Report 00-09, 00-10, 01-04, 00-12, and 00-13
(Complete citations of these publications are on p. 13-16.)

ABSTRACTS PUBLISHED

Geological Society of America Abstracts with Programs
v. 32, n. 7, p. A41, A507, A508-09.
(three abstracts)

REPORTS SUBMITTED FOR PUBLICATION

American Geophysical Union, Water Science and Application Series (two manuscripts)
Geology

ENERGY AND MINERAL RESOURCES

PROJECTS

Stephen M. Richard, Research Geologist

Morenci Project. The project, funded by Phelps Dodge Morenci, Inc. (PDM), was initiated in connection with M. Stephen Enders' Ph.D. dissertation at the University of Arizona that focused on supergene copper enrichment in the Clifton-Morenci district. Enders (PDM) and Charles A. Ferguson (AZGS) mapped mid-Tertiary volcanic and sedimentary rocks in the area around the district. Detailed provenance studies of the conglomeratic rocks of the Gila Group, together with $^{40}Ar/^{39}Ar$ dates of important volcanic units, were used to construct a regional time-space diagram that integrated the new work with previously published maps and reports, principally from the U.S. Geological Survey, as well as mapping by several generations of Phelps Dodge geologists. A digital geologic map with multiple structural cross sections (Digital Geologic Map 01), an exhaustive digital database (Digital Information 18), and a report on the mid-Tertiary geochronology and stratigraphy of the region (Open-File Report 00-07) were released.

Ironwood Forest bibliography. The Ironwood Forest National Monument was created by President Clinton in 2000 during his last month in office. Portions of the Silver Bell mineral district were included in the Monument, as were many active mining claims and 55,000 acres of State Trust Land (29 percent of the new monument). Many geologic studies have been completed on the geology and mineral resources in what is now the new Monument. This bibliography lists more than 250 geologic maps and reports that describe the age origin, mineralization, mineral production, and other aspects of the geology of the area.

Oil and gas potential. Because of the increase in the price of crude oil, interest in drilling has escalated. The number of inquiries about the potential for oil and natural gas has increased substantially. To better assist those who are interested in exploring in Arizona, S.L. Rauzi, Oil and Gas Administrator reviewed well records and publications and compiled data that indicate Arizona has oil and gas potential. The AZGS published the results of his findings as Circular 29, entitled *Arizona Has Oil and Gas Potential!*

REPORTS RELEASED

Circular 29
Digital Geologic Map 01
Digital Information 18
Oil & Gas Journal, v. 99
Open-File Report 00-07 and 00-15
(Complete citations of these publications are on p. 13-16.)

OIL AND GAS CONSERVATION COMMISSION

Steven L. Rauzi,
Oil and Gas Administrator

The Arizona Oil and Gas Conservation Commission (OGCC), attached to the Arizona Geological Survey (AZGS), regulates the drilling for and production of oil, gas, helium, carbon dioxide, and geothermal resources. The Governor appoints five members of the Commission. The sixth member, the State Land Commissioner, is *ex officio*. Commissioners are J. Dale Nations, Tucson, chairman; Donald C. Clay, Yuma; Robert L. Jones, Sun City West, vice chairman; Michele Negley, Phoenix; Zed Veale, Flagstaff; and Michael E. Anable, State Land Commissioner.

The AZGS provides administrative and staff support for the OGCC, including issuing permits to drill, monitoring drilling, inspecting completed wells, compiling drilling and production data, and maintaining well files. Steven L. Rauzi is the Oil and Gas Admisistrator. The Commission held three meetings in FY 2000-01.

ACTIVITIES

Production, refining, and storage. Oil production in calendar year (CY) 2000 totaled 57,483 barrels from 21 producing wells, down from 66,483 barrels from 24 wells in 1999. Gas production in CY 2000 totaled 368 million cubic feet from nine producing wells, down from 474 million cubic feet from eight wells in 1998.

Both of Arizona's refineries remained shut down. The refineries, near Fredonia and Coolidge, have been shut down since January 1997 and August 1993, respectively.

Liquefied petroleum gas (LPG) transferred in CY 2000 through storage wells near Luke Air Force Base and Adamana included 108 million gallons in receipts and 97 million gallons in deliveries. In CY 1999, 90 million gallons were received and 104 million gallons were delivered. About 38 million gallons of LPG were in storage at yearend, up from the 26 million gallons the previous year. Fourteen storage wells constructed in subsurface salt are currently in use.

Leasing. In Fiscal Year (FY) 2001, 323,000 acres were under lease for oil and gas exploration. This was up from 303,000 acres in FY 2000 but down from 324,000 in FY 1999.

State Trust Land under lease on June 30, 2001, totaled 234,000 acres, up from 191,000 acres in 2000 and 213,000 acres in 1999.

Public land under lease on June 30, 2001, totaled 89,000 acres, compared with 111,500 in 2000 and 111,000 in 1999.

The State Land Department administers leasing on State Trust Land. The U.S. Bureau of Land Management administers leasing on public lands.

Drilling. A permit was issued to SunCor Development Company for a stratigraphic test of the Luke Salt deposit near Phoenix. The test was drilled to determine the feasibility of storing natural gas in the salt. In March SunCor drilled 4,355 ft of salt from a depth of 880-5235 ft, cut several cores in the salt, and plugged the hole. The operator of the hole near Meteor Crater died and a new operator will take over that hole. Premco Western is drilling below 3,000 ft in the Dutchman Federal hole in northwestern Arizona.

Inspection and enforcement. Staff made semiannual inspections of 14 hydrocarbon-storage wells near Luke Air Base and Adamana. The inspections are conducted to ensure that wellhead valves, safety alarms, and emergency shutdown systems are working properly.

Subsurface samples and data. The OGCC requires drilling operators to submit subsurface data, including rock samples, logs, and all test results, to the AZGS to be filed and archived. The AZGS maintains a series of maps that show the location of oil, gas, and geothermal wells and the types of subsurface data that are available for examination.

Legislation and rules. The OGCC amended three rules: R12-7-101, R12-7-121, and R12-7-125. These rules were changed to bring them in conformance with a recent change in statute, HB 2492, that extended the confidential period for well records from six months to one year. Clarity and understandability were improved and a new shut-in status was added to distinguish between inactive wells that are capable of production (shut-in) and those that are not (temporarily abandoned).

Carbon dioxide update. Ridgeway Arizona Oil Corporation announced a discovery of carbon dioxide (CO_2) in the St. Johns and Springerville areas in southern Apache County in August 1994. By the end of May 1997 the company had drilled 15 wells. At the end of Fiscal Year (FY) 2001 two wells have been completed as gas wells, seven have been temporarily abandoned, and six have been plugged and abandoned. No drilling was done during FY 2001 and the OGCC received no requests for permits to drill.

At a meeting of the House of Representatives Natural Resources Committee in Springerville August 1999, Ridgeway representatives stated that initial development to supply CO_2 for enhanced recovery would require two to three years and about 200 wells. The company informed meeting attendees that as many as 1,195 wells would eventually be drilled over the 25-40 year life of the project. At the May 2000 OGCC meeting a Ridgeway representative announced that the company planned to begin producing carbon dioxide from three wells for a liquid CO_2 plant in about five months. Two of the wells are in Arizona; one is in New Mexico.

At the January 2001 OGCC meeting a Ridgeway representative announced that 14 miles of pipe are ready to be laid to the plant. Work will begin in about three to four months. The plant will produce dry ice instead of liquid CO_2 and start at double its projected starting capacity. At the April 2001 meeting a representative of Ridgeway announced that the company was continuing to work with Tucson Electric Power about the location of the plant and with the State Land Department about right-of-way permits for the pipelines.

MAPS UPDATED

Oil and Gas Publication 2, 11, 12, 15, and 35
(Compete citations of these maps are on p. 13-16.)

PUBLIC INFORMATION

ACTIVITIES

Mary E. Redmon,
Administrative Assistant III

Arizona Geological Survey (AZGS) Information Center. Staff answered thousands of requests for information about Arizona geology and sold reports and maps totaling $45,109. Sales included AZGS and Arizona Geological Society publications. The AZGS has a formal agreement to distribute Society publications. Revenue from sales is used to print and distribute other AZGS publications. Georgeanna L. Meeker, Nancy A. Duffin, Mary E. Redmon, Mary N. Andrade and Rachel A. Aragon sold and distributed publications and answered customer inquiries. Nineteen of every twenty orders were mailed the same day they were received.

Earth Science Information Center (ESIC). The ESIC, a joint venture between the AZGS and the U.S. Geological Survey (USGS), was established to sell maps, reports, general-interest publications, brochures, and other items the USGS publishes. The purpose of the ESIC is to enable geologic data users to obtain information from the state and federal geological surveys from a single location. Revenue from the sale of publications totaled $22,459. This revenue is used to purchase other USGS products for resale and for ESIC operating expenses. Cathy L. Moore was the AZGS liaison with the USGS in maintaining and operating the ESIC.

Rachel A. Aragon,
Secretary

Geology library and databases. The AZGS maintains a non-circulating library, managed by Thomas G. McGarvin, that contains published and unpublished material about Arizona and adjacent states. Among the library's holdings are U.S. Geological Survey publications, maps, and open-file reports. Also included are select theses and dissertations, publications and reports by Arizona state agencies, and publications by the geological surveys of adjacent states. More than 14,000 citations are included in a database searchable by AZGS staff. The library is open to the public for inspection and research.

AZGEOBIB is a database that contains more than 12,500 bibliographic citations dealing with Arizona geology. New citations are added continuously. The database can be searched in a variety of ways and AZGS staff can provide lists of citations for specific requests. This is a popular service for those who are starting new projects and need to know what geologic maps and reports are available within their project area. Richard A. Trapp, IT Manager, maintains the databases.

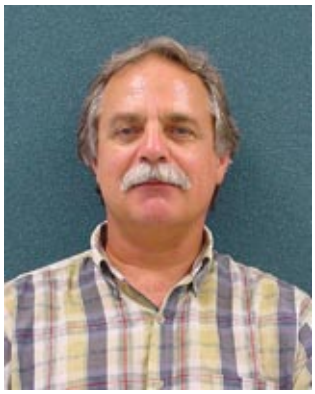
Richard A. Trapp,
Information Technology Manager

Web Site. The AZGS web site (www.azgs.state.az.us) includes information about the agency, geology of Arizona, and publications for sale. The state geologic map, geologic hazards, and links to other geology-related agencies and groups are provided. John A. Birmingham, the AZGS webmaster, redesigned and updated the website.

Arizona Geology. The AZGS published four six-page issues of *Arizona Geology* to describe events related to geology, publicize new geologic maps and reports, and to highlight other activities that pertain to geology in Arizona. Arsenic in ground water, volcanism in Arizona, catastrophic natural disasters in Arizona, and energy resources in Arizona were featured.

Down-to-Earth Reports. The AZGS released two non-technical reports: *Guide to the Geologic Features at Petrified Forest National Park* (Down-to-Earth 10) and *Rocks in the Chiricahua National Monument and the Fort Bowie National Historic Site* (Down-to-Earth 11). The latter superseded Down-to-Earth 8, which went out of print and was updated to include Fort Bowie. Both books were written in non-technical terms under the direction of John V. Bezy, National Park Service, and include descriptions and color photographs of geologic features that can be observed from roads and trails within the preserves.

Earth Science Education. Thomas G. McGarvin, the AZGS' primary contact with science and earth science teachers, assisted teacher groups in incorporating local geology in their courses. The AZGS participated in annual meetings of the Arizona Science Teachers Association and the Arizona Association for Environmental Education. In December 2000 the AZGS participated in the National Science Teachers Association's southwestern area convention in Phoenix.



Thomas G. McGarvin, Geologist II

Rock cuttings and core repository. The AZGS maintains a repository containing cuttings from more than 4,000 oil and water wells, and core from a number of energy and mineral exploration drill holes. The cuttings, core samples, and well logs are available for research and study.

SERVICE TO COMMUNITY AND PROFESSIONAL GROUPS

AZGS geologists participated in a variety of activities sponsored by community and professional groups, including serving as officers or committee members (7), giving talks (10), leading fieldtrips (7), participating in workshops or on panels (5), reviewing applications or proposals for funding or awards (5), and reviewing manuscripts submitted for publication (15). Assistance and service was provided to the following groups:

American Geophysical Union
Amerind Foundation
Arizona Floodplain Management Association
Arizona Geological Society
Association of American State Geologists
Association of Earth Science Editors
Geological Society of America
Gold Prospectors of America
Grand Canyon Association
Journal of Structural Geology
National Science Teachers Association
New Mexico Geological Society
Old Pueblo Lapidary Club
Petroleum Research Fund
South American Journal of Earth Sciences
Tohono Chul Park docents
University of Arizona, Department of Geosciences
United States Geological Survey
Utah Geological Association
Verde River Day
Western States Seismic Policy Council.
Wings Over Willcox
Pima Association of Governments
Pima County Floodplain Management Association
SaddleBrooke Rotary Club

John A. Birmingham, Program and Project Specialist II

NON-TECHNICAL REPORTS RELEASED

Arizona Geology v. 30, n. 3, p. 1-4
v. 30, n. 4, p. 1-4
v. 31, n. 1, p. 1-4
v. 31, n. 2, p. 1-5
Down-to-Earth 10 and 11

(Complete citations of these publications are on p. 13-16.)

OTHER REPORTS RELEASED

Open-File Reports 00-14 and 01-06

OTHER REPORTS SUBMITTED FOR PUBLICATION

Grand Canyon Association
Utah Geological Association Publication 30

CONTRIBUTED MAPS AND REPORTS RELEASED

Contributed Map 00-C
Contributed Reports 00-A and 01-A

PUBLICATIONS RELEASED BY AZGS STAFF AND CONTRIBUTORS FY 2001

ARIZONA GEOLOGY

Arsenic in ground water: Spencer, J.E., 2000, Arizona Geology, v. 30, n. 3, p. 1-4.
Volcanism in Arizona: Fellows, L.D., 2000, Arizona Geology, v. 30, n. 4, p. 1-4.
Catastrophic natural disasters in Arizona?: 2001, Arizona Geology, v. 31, n. 1, p. 1-4.
Energy resources in Arizona: Fellows, L.D., 2001, Arizona Geology, v. 31, n. 2, p. 1-5.

CIRCULARS

C 29. *Arizona has oil & gas potential!:* Rauzi, S.L., 2001, Arizona Geological Survey Circular 29, 40 p.

CONTRIBUTED MAPS

CM 00-C. *Geology of the Los Adobes Rancho area, Sonora, Mexico, and Santa Cruz County, Arizona:* Gilbert, W.G. and Lajack, D.J., 2000, Arizona Geological Survey Contributed Map 00-C, 5 p., scale 1:24,000.

CONTRIBUTED REPORTS

CR 00-A. *Detrital modes of selected sandstone samples from the McCoy Mountains Formation and correlative units in southwestern Arizona:* Dickinson, W.R., 2000, Arizona Geological Survey Contributed Report 00-A, 18 p.

CR 01-A. *Field trip guide to Sabino Canyon and the Mount Lemmon Highway, Pima County, Arizona:* Force, E.R., 2001, Arizona Geological Survey Contributed Report 01-A, 35 p.

DIGITAL INFORMATION

DI 18. *Geologic spatial data for the Clifton-Morenci area, Greenlee County, Arizona:* Ferguson, C.A., Enders, M.S., and Orr, T.R., 2000, Arizona Geological Survey Digital Information 18, 1 CD ROM.

DI 19. *Geologic spatial data for the Roskruge and Waterman Mountains and westernAvra Valley area, Pima County, Arizona:* Ferguson, C.A., Gilbert, W.G., Orr, T.R., Pearthree, P.A., Richard, S.M., Skotnicki, S.J., Spencer, J.E., and Youberg, Ann, 2001, Arizona Geological Digital Information 19, 1 CD ROM.

DI 20. *Digital geographic index of geologic literature for the east half of the PhoenixNorth 30' x 60' quadrangle, Arizona:* Orr, T.R., 2000, Arizona Geological Survey Digital Information 20, 1 CD ROM.

DIGITAL GEOLOGIC MAPS

DGM 01. *Digital geologic map and cross sections of the Clifton-Morenci area, Greenlee County, Arizona:* Ferguson, C.A. and Enders, M.S., 2000, Arizona Geological Survey Digital Geologic Map 01, 1 CD ROM, scale 1:24,000.

DGM 02. *Geologic map of the Waterman Peak 7.5' quadrangle and northern La Tortuga Butte 7.5' quadrangle, Pima County, Arizona:* Richard, S.M., Ferguson, C.A., Spencer, J.E., Youberg, Ann, and Orr, T.R., 2000, Arizona Geological Survey Digital Geologic Map 02, 1 CD ROM, scale 1:24,000.

DGM 03. S*urficial geologic map of the Green Valley-Sahuarita area, Pima County, Arizona:* Pearthree, P.A. and Youberg, Ann, 2000, Arizona Geological Survey Digital Geologic Map 03, 1 CD ROM, scale 1:24,000.

DGM 04. *Geologic map of the Three Points 7.5' quadrangle, Pima County, Arizona:* Pearthree, P.A., Ferguson, C.A., Gilbert, W.G., and Skotnicki, S.J., 2000, Arizona Geological Survey Digital Geologic Map 04, 1 CD ROM, scale 1:24,000.

DGM 05. *Geologic map of the West of Avra 7.5' quadrangle, Pima County, Arizona:* Pearthree, P.A., Youberg, Ann, and Skotnicki, S.J., 2000, Arizona Geological Survey Digital Geologic Map 05, 1 CD ROM, scale 1:24,000.

DGM 06. *Geologic map of the Cocoraque Butte 7.5' quadrangle, Pima County, Arizona:* Skotnicki, S.J. and Pearthree, P.A., 2000, Arizona Geological Survey Digital Geologic Map 06, 1 CD ROM, scale 1:24,000.

DOWN-TO-EARTH

DTE 10. *Guide to geologic features at Petrified Forest National Park:* Bezy, J.V. and Trevena, A.S., 2000, Arizona Geological Survey Down-to-Earth 10, 48 p.

DTE 11. *Rocks in the Chiricahua National Monument and the Fort Bowie National Historic Site:* Bezy, J.V., 2001, Arizona Geological Survey Down-to-Earth 11, 48 p.

MAPS

M 35. *Geologic map of Arizona:* Richard, S.M., Reynolds, S.J., Spencer, J.E., and Pearthree, compilers, 2,000, Arizona Geological Survey Map 35, scale 1:1.000.000.

OPEN-FILE REPORTS

OFR 00-04. *Geologic map of the Oracle Junction 7.5' quadrangle and the eastern third of the Tortolita Mountains 7.5' quadrangle, Pima and Pinal Counties, Arizona:* Skotnicki, S.J., 2000, Arizona Geological Survey Open-File Report 00-04, 19 p., scale 1:24,000.

OFR 00-05. *Compilation geologic map of the Oracle 7.5' quadrangle, Pinal and Pima Counties, Arizona:* Spencer, J.E., Richard, S.M., and Ferguson, C.A., 2000, Arizona Geological Survey Open-File Report 00-05, 30 p., scale 1:24,000.

OFR 00-06. *Geologic map of the southern Roskruge Mountains (the San Pedro and the southern half of La Tortuga Butte 7.5' quadrangles), Pima County, Arizona:* Ferguson, C.A., Gilbert, W.G., Pearthree, P.A., and Biggs, T.H., 2000, Arizona Geological Survey Open-File Report 00-06, 40 p., 2 sheets, scale 1:24,000.

OFR 00-07. *Mid-Tertiary geology and geochronology of the Clifton-Morenci area, Greenlee and Graham counties, and adjacent New Mexico:* Ferguson, C.A., Enders, M.S., Peters, Lisa, and McIntosh, W.C., 2000, Arizona Geological Survey Open-File Report 00-07, 69 p.

OFR 00-08. *Geologic map of the Cocoraque Butte 7.5' quadrangle, Pima County, Arizona:* Skotnicki, S.J. and Pearthree, P.A., 2000, Arizona Geological Survey Open-File Report 00-08, 27 p., scale 1:24,000.

OFR 00-09. *Tritium as a tracer of groundwater sources and movement in the Safford Basin, Graham County, Arizona:* Harris, R.C., 2000, Arizona Geological Survey Open-File Report 00-09, 56 p.

0FR 00-10. *Maps showing surface exposures of salty lacustrine sediments in the Safford Basin, Graham County, Arizona:* Harris, R.C., 2000, Arizona Geological Survey Open-File Report 00-10, 20 p., 11 figures, scale 1:24,000.

OFR 00-11. *Geologic map of the Four Peaks 7.5' quadrangle, Maricopa and Gila Counties, Arizona:* Skotnicki, S.J., 2000, Arizona Geological Survey Open-File Report 00-11, 35 p., scale 1:24,000.

OFR 00-12. *Geologic map and geologic hazards of the Three Points 7.5' quadrangle, Pima County, Arizona:* Pearthree, P.A., Ferguson, C.A., Gilbert, W.G., and Skotnicki, S.J., 2000, Arizona Geological Survey Open-File Report 00-12, 19 p., scale 1:24,000.

OFR 00-13. *Surficial geologic maps and geologic hazards of the Green Valley-Sahuarita area, Pima County, Arizona:* Pearthree, P.A. and Youberg, Ann, 2000, Arizona Geological Survey Open-File Report 00-13, 21 p., 2 sheets, scale 1:24,000.

OFR 00-14. *Annual Report, Fiscal Year 2000:* Fellows, L.D., 2000, Arizona Geological Survey Open-File Report 00-14, 27 p.

OFR 00-15. *Bibliography of the geology and mineral resources of Ironwood Forest National Monument, Pima and Pinal counties, Arizona:* Harris, R.C. and Trapp, R.A., 2000, Arizona Geological Survey Open-File Report 00-15, 18 p.

OFR 01-01. *Surficial geology and geoarchaeology of San Cristobal and Growler Valleys, Barry M. Goldwater Air Force Range, southwestern Arizona:* Pearthree, P.A., Freeman, A.K.L., and Demsey, K.A., 2001, Arizona Geological Survey Open-File Report 01-01, 40 p., 3 sheets, scale 1:100,000 and 1:24,000.

OFR 01-02. *Surficial geology and geoarchaeology of the Daniels Wash area in northern Growler Valley, Barry M. Goldwater Air Force Range, southwestern Arizona:* Pearthree, P.A., Klawon, J.E., and Demsey, K.A., 2001, Arizona Geological Survey Open-File Report 01-02, 33 p., scale 1:24,000.

OFR 01-03. *Surficial geology and geomorphology of the western Crater Range, Barry M. Goldwater Air Force Range, southwestern Arizona:* Klawon, J.E. and Pearthree, P.A., 2001, Arizona Geological Survey Open-File Report 01-03, 19 p., scale 1:24,000.

OFR 01-04. *Paleoflood history of the Lower Verde River, Yavapai County, Arizona:* House, P.K., Pearthree, P.A., and Klawon, J.E., 2001, Arizona Geological Survey Open-File Report 01-04, 33 p.

OFR 01-05. *Geology and geomorphology of 12 small watersheds in the Peloncillo Mountains, central portion of the Malpai Borderlands project area, Hidalgo County, New Mexico:* Youberg, Ann and Ferguson, C.A., 2001, Arizona Geological Survey Open-File Report 01-05, 22 p., scale 1:12,000.

OFR 01-06. *Stratigraphic nomenclature of the Miocene Superstition volcanic field, central Arizona:* Ferguson, C.A. and Trapp, R.A., 2001, Arizona Geological Survey Open-File Report 01-06, 103 p.

OIL & GAS MAPS AND REPORTS UPDATED

OG 2. *Annual oil, gas, and helium production in Arizona 1954-2000:* Rauzi, S.L., 2001, Arizona Geological Survey Oil & Gas 2, 18 p.

OG 11. *Well location map, Colorado Plateau province, Arizona; Apache, Coconino, Navajo, and portions of adjacent counties:* Conley, J.N. and Rauzi, S.L., 2000, Arizona Geological Survey Oil & Gas 11, 48 p. (1975), 4 p., addendum, scale 1:500,000. (OGCC
Country Series Map 9)

OG 12. *Arizona well location map and report:* Rauzi, S.L., 2000, Arizona Geological Survey Oil & Gas 12, 27 p., scale 1:675,000. (2 blueline sheets; OGCC State Series Map)

OG 15. Kineh-Bi-Keyah oil field, Apache County, Arizona: Rauzi, S.L., 2001, Arizona Geological Survey Oil & Gas 15, scale 1:63,360. (OGCC Pool Series Map P-2)

OG 35. Oil and natural gas occurrence in Arizona: Rauzi, S.L., 2001, Arizona Geological Survey Oil & Gas 35, chart (OGCC Chart C-1).

EXTERNAL PUBLICATIONS

Geological Society of America
Quaternary history, slip rate, and rupture characteristics of the Hurricane fault, northwestern Arizona and southwestern Utah: Amoroso, Lee, Pearthree, P.A., Lund, W.R., Arrowsmith, J.R., and Stenner, H.D., 2000, Geological Society of America Abstracts with Programs, v. 32, n. 7, p. A507.

New offset rates on the Toroweap and Hurricane faults in western Grand Canyon, Arizona: Implications for Quaternary downcutting of the Colorado River: Fenton, C.R., Cerling, T.E., Webb, R.H., Pearthree, P.A., and Poreda, R.J., 2000, Geological Society of America Abstracts with Programs, v. 32, n. 7, p. A508-509.

Insights into the character of flooding on alluvial fans from mapping and alalysis of two modern floods: Pearthree, P.A., House, P.K., and Vincent, K.R., 2000, Geological Society of America, v. 32, n. 7, p. A508-509.

MANUSCRIPTS SUBMITTED FOR EXTERNAL PUBLICATION

American Geophysical Union
Mapping hurricane-induced flooding in southwestern Arizona using Landsat TM data: A method for rapid regional flood assessment following large storms: Mayer, Larry and Pearthree, P.A., in press, American Geophysical Union, Paleoflood Volume.

Paleoflood history of the lower Verde River, Arizona: House, P.K., Pearthree, P.A., and Klawon, J.E., in press, American Geophysical Union, Paleoflood Volume.

Geology
Displacement rates on the Toroweap and Hurricane faults: Implications for Quaternary downcutting in the Grand Canyon: Fenton, C.R., Webb, R.H., Pearthree, P.A., Cerling, T.E., and Poreda, R.J., in press, Geology.

Nevada Bureau of Mines and Geology
Geologic map of the Davis Dam 7.5' quadrangle, Nevada and Arizona: Faulds, J.E, House, P.K., Bell, J.W., Pearthree, P.A., and Ramelli, Alan, 2000, Nevada Bureau of Mines and Geology , scale 1:24,000.

PERSONNEL AND BUDGET

PERSONNEL[1]

OFFICE OF THE DIRECTOR

LARRY D. FELLOWS, Director and State Geologist
B.S., Iowa State University; M.A., University of Michigan; Ph.D., University of Wisconsin

ROSE ELLEN McDONNELL,
Assistant Director of Administration
B.S., University of Arizona

GEOLOGISTS

JON E. SPENCER, Senior Geologist
B.S., University of California, Santa Cruz;
Ph.D., Massachusetts Institute of Technology

RAYMOND C. HARRIS, Geologist II
B.S., Oregon State University; M.S., University of Arizona

THOMAS G. McGARVIN, Geologist II
B.A., California Lutheran College

TIM R. ORR, Geologist II
B.S., University of Montana;
M.S., Northern Arizona University

PHILIP A. PEARTHREE, Research Geologist
B.A., Oberlin College; M.S., University of Arizona;
Ph.D., University of Arizona

STEVEN L. RAUZI, Oil and Gas Administrator
B.S. and M.S., Utah State University

STEPHEN M. RICHARD, Research Geologist
B.S. and M.S., University of Arizona;
Ph.D., University of California, Santa Barbara

RICHARD A. TRAPP, Information Technology Manager
B.S., University of Nebraska, Omaha;
M.S., University of Arizona

SUPPORT STAFF

MARY N. ANDRADE,[2] Administrative Assistant I

RACHEL A. ARAGON,[3] Secretary

JOHN A. BIRMINGHAM,[4]
Program and Project Specialist II
B.A., University of Arizona

PETER F. CORRAO,[5] Program and Project Specialist II
B.A., Arizona State University

NANCY A. DUFFIN, Accounting Technician II

GEORGEANNA L. MEEKER,[6]
Administrative Assistant I

CATHY L. MOORE, Geologist I
B.S., University of Wisconsin; M.S., University of Arizona

MARY E. REDMON, Administrative Assistant III

CONTRACTED GEOLOGISTS [7]

Lee Amoroso, M.S.
Thomas H. Biggs, Ph.D.
Charles A. Ferguson, Ph.D.
Wyatt G. Gilbert, Ph.D.
Jeanne E. Klawon, B.S.
Steven J. Skotnicki, Ph.D
Ann M. Youberg, M.S.

(1) Geologists and support staff listed were on the payroll June 30, 2001, except as otherwise noted below. The Arizona Geological Survey is authorized to employ 13.25 full-time-equivalent staff members from the General Fund appropriation.

(2) Hired May 21, 2001

(3) Hired June 18, 2001

(4) Hired July 31, 2000

(5) Resigned July 14, 2000

(6) Resigned May 1, 2001

(7) Employees listed are paid from contracts with other agencies or goups to produce a specific product or products within an agreed-upon period of time.

GENERAL FUND EXPENDITURES

Category	FY 2000 Expended	FY 2001 Expended	FY 2002 Budgeted
Personal Services	518,825	532,040	548,300
Benefits	93,713	97,243	101,200
Professional Services	300		6,500
Operations	192,226	193,349	212,900
In-State Travel	31,103	43,193	46,400
Out-of-State Travel	2,194	2,081	2,000
Capital Equipment	23,848	18,732	**15,500**
Total	**862,209**	**886,638**	**932,800**

PRINTING REVOLVING FUND

Publications	FY 2001 Expended
Arizona Geological Survey	33,046
Arizona Geological Society	1,902
U.S. Geological Survey	25,783
Other Publications	1,938
Total	**62,669**

CONTRACTED PROJECTS

Project (Fund Source)	Principal Investigator	Personal Services	Benefits	Operations	In State Travel	Out State Travel	Equipment	TOTAL
FT HUACHUCA U.S. Army	Pearthree	2,059	338	19				2,416
GEOLOGIC MAPPING U.S. Geologic Survey	Spencer	120,217	26,830	11,374	1,718		621	160,760
PELONCILLO MOUNTAINS U.S. Forest Service	Pearthree	7,612	1,898	242	74			9,826
AGS PUBLICATIONS Arizona Geological Society	McDonnell			1,902				1,902
PD MORENCI-CLIFTON Phelps Dodge, Inc.	Ferguson	661	129	2,658	35			3,483
TRITIUM-WPF Department of Water Resources	Spencer	1,574	295	400				2,269
TIGER WASH JEF, Inc.	Pearthree	516	118	83				717
HURRICANE FAULT State of Utah	Pearthree	3,106	461	108	462			4,137
DAVIS DAM University of Nevada	Pearthree	1,985	253	883	281	405		3,807
GILA OIL Gila Valley Natural Resource Conservation District	Harris	3,475	566					4,041
JACK RABBIT WASH JEF, Inc.	Pearthree	239	65	1,605				1,909
MARSH STATION Statistical Research, Inc	Pearthree	861	111					972
TOTAL		**142,305**	**31,064**	**19,275**	**2,570**	**405**	**621**	**196,239**