Vol. 30, No. 1
Spring 2000

Arizona Geology

Published by the Arizona Geological Survey

ARIZONA GEOLOGICAL SURVEY

THE STATE AGENCY FOR GEOLOGIC INFORMATION

MISSION

To inform the public about geologic processes, materials, and resources in Arizona and assist citizens, businesses, governmental agencies, and elected officials in making informed decisions about managing Arizona's land, water, mineral, and energy resources.

GOALS

- Inform the public about geologic processes, materials, and resources in a timely, courteous manner.
- Map and describe the bedrock and surficial geology of Arizona.
- Investigate and document geologic processes and materials that might be hazardous to the public or have adverse impact on land use and resource management.
- Administer the rules, regulations, and policies established by the Arizona Oil and Gas Conservation Commission.

Earthquake Hazard in Arizona

Larry D. Fellows
Director and State Geologist

In the last hundred years ten earthquakes have each caused more than 50,000 deaths. Last year strong earthquakes shook Turkey (twice), Taiwan, Mexico, Greece, Columbia, and southern California. In the first Turkey quake, 15,000 to 20,000 people died. After each California quake the Arizona Geological Survey (AZGS) receives telephone calls from concerned or potential residents who ask if anything like that could happen here. To respond to such questions and assist those responsible for hazard mitigation, Philip A. Pearthree (AZGS) and Douglas B. Bausch (Arizona Earthquake Information Center) prepared "Earthquake Hazards in Arizona," which the AZGS published in 1999 as Map 34 (described on page 5). The Federal Emergency Management Agency provided partial funding. The Earthquake Preparedness Program in the Arizona Division of Emergency Management, Earthquake Hazards Reduction Program in the U.S. Geological Survey, and Arizona Council on Earthquake Safety also collaborated on the project.

The Earth's brittle, outermost portion has broken into a number of huge fault-bounded plates that are slowly moving relative to one another (Figure 1). Movement between plates causes stresses to build up in the rocks. When stress becomes sufficiently high the crust ruptures along relatively weak zones (faults) and an earthquake is

(continued on page 2)

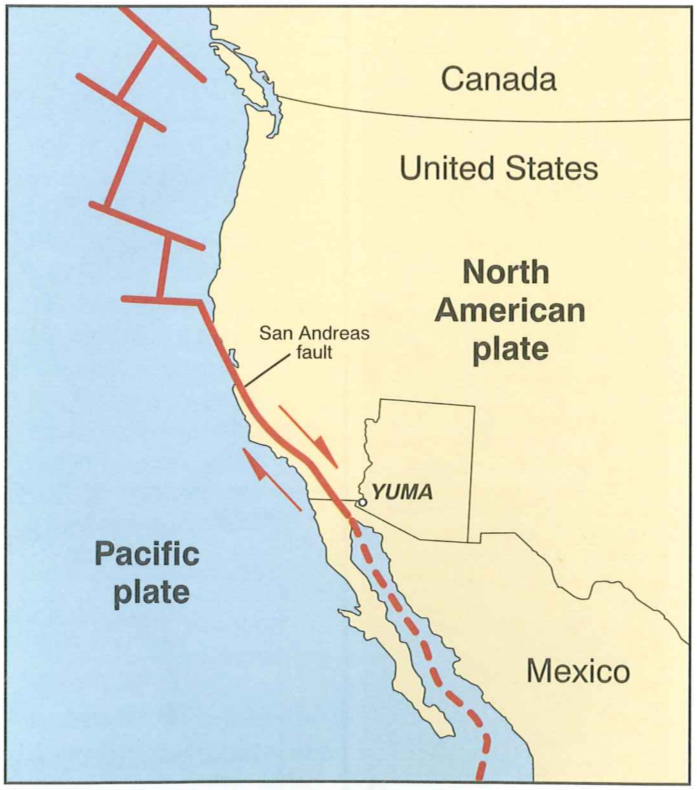

Figure 1. The boundary between the Pacific and North American plates (bold red line) crosses southern California and northern Mexico just west of Yuma, Arizona.

Earthquake Hazard *(continued)*

GOVERNOR
JANE DEE HULL

ARIZONA GEOLOGICAL SURVEY

February 2000

OFFICE OF THE DIRECTOR
Larry D. Fellows, Ph.D.
Director and State Geologist

Rose Ellen McDonnell, B.S.
Assistant Director of Administration

INFORMATION AND PUBLICATIONS
Peter F. Corrao, B.S.
Nancy A. Duffin
Georgeanna L. Meeker
Cathy L. Moore, M.S.
Mary E. Redmon

LIBRARY AND DATABASES
Thomas G. McGarvin, B.A.
Richard A. Trapp, M.S.

MAPPING AND INVESTIGATIONS
Jon E. Spencer, Ph.D.
Senior Geologist

Philip A. Pearthree, Ph.D.
Stephen M. Richard, Ph.D.
Charles A. Ferguson, Ph.D.
Wyatt G. Gilbert, Ph.D.
Raymond C. Harris, M.S.
Tim R. Orr, M.S.
Steven J. Skotnicki, M.S.

OIL AND GAS
Steven L. Rauzi, M.S.

Arizona Geology

Arizona Geology is published quarterly by the Arizona Geological Survey (AZGS), an Executive Branch agency of the State of Arizona. The AZGS headquarters is located at 416 West Congress Street, Suite 100, Tucson, AZ 85701; telephone (520) 770-3500.

Web address
http://www.azgs.state.az.us

Design and layout
PETER F. CORRAO

generated. Earthquakes relieve some of the stress, but stress commonly builds up again and triggers recurrent fault movement and earthquakes.

In places like the Pacific Northwest, plates are colliding head-on with one overriding the other. At the mid-Atlantic ridge, new crust is generated as plates are pulling apart. The Pacific plate is sliding northwestward relative to the rest of North America at a rate of about 2 in/yr along the San Andreas fault system, which extends from the northern Gulf of California through southern and central California.

Historical earthquakes in Arizona. Earthquake hazard is assessed by studying historical earthquakes and mapping and characterizing faults along which movement has occurred in the past 2 million years (the Quaternary Period). The historical record of earthquakes in Arizona dates to about 1776, but records are sparse prior to the late 1800s. These early earthquakes were documented only by reports that described the intensity of shaking that was felt and the type of damage that was caused.

Seismographs, instruments that record earth vibrations, began to be developed in the late 1800s. Useful recordings of Arizona earthquakes date to the early 1900s. The quality of seismograph records improved throughout the past century. Magnitude esti-

Figure 2. More than 20 historic earthquakes with magnitudes greater than 5.0 have occurred in or near Arizona since 1850.

mates are a measure of earthquake size. With each increase of one unit of magnitude, ground motion increases by 10 times and the energy released in the earthquake increases by about 32 times.

More than 20 earthquakes with magnitudes greater than 5 have occurred in or near Arizona since 1850. All of Arizona has experienced some ground shaking (Figure 2). The magnitude 7.4 Sonoran earthquake of 1887, which was centered about 40 miles southeast of Douglas, caused 51 deaths in Sonora and extensive property damage throughout southeastern Arizona. Substantial damage occurred in the Yuma area as a result of the magnitude 7.1 Imperial Valley earthquake of 1940. The Flagstaff area experienced moderate damage three times during the early 1900's because of magnitude 6 earthquakes.

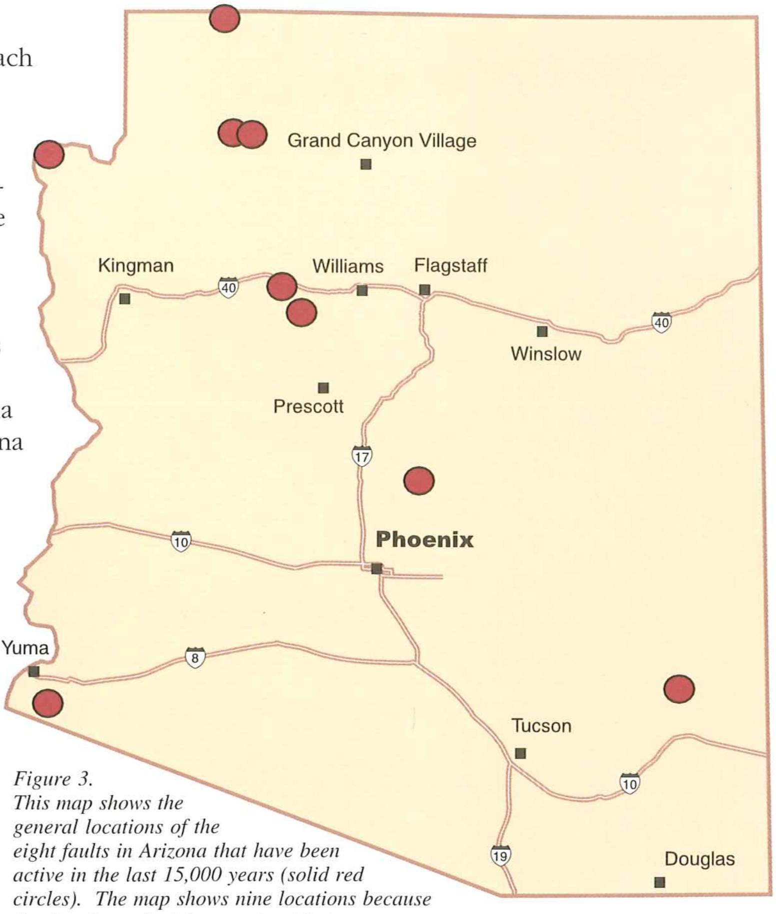

Figure 3.
This map shows the general locations of the eight faults in Arizona that have been active in the last 15,000 years (solid red circles). The map shows nine locations because the Hurricane fault has ruptured in two areas.

Geologic studies of young faults. Geologists contribute to the understanding of earthquake hazard by studying faults that may have generated prehistoric earthquakes. In Arizona, earthquakes larger than about magnitude 6 to 6.5 have probably ruptured the ground surface. Evidence of these surface ruptures may be preserved in the landscape for thousands of years.

Geologists assess the paleoseismic history of a fault by making detailed geologic maps, measuring displacement along the fault, and interpreting strata exposed in trenches excavated across the fault to estimate how recently rupture occurred and how much slip took place. By using these data, geologists may be able to estimate the size of a prehistoric earthquake and how frequently it has been active (recurrence interval).

Geologists have identified nearly 100 faults in Arizona that probably generated earthquakes of magnitude 6 or larger during the Quaternary Period. These faults are not very active, however, when compared with the San Andreas fault. Although the most active faults in Arizona have ruptured every 5,000 to 10,000 years, recurrence intervals of 50,000 to 100,000 years are more typical. The fault that generated the 1887 Sonoran earthquake, for example, probably had not caused a similar earthquake for at least 100,000 years. Geologic studies indicate that rupture occurred on eight faults in Arizona within the past 15,000 years (Figure 3).

Earthquake hazard summary. Geologists and engineers use knowledge about the distribution and character of earthquakes and young faults to assess seismic hazard. Earthquake hazard levels are low to moderate in most of Arizona (Figure 4). Potentially active faults that could generate magnitude 6.5 to 7.2 quakes are scattered throughout southeastern and central Arizona, including much of the Phoenix and Tucson areas. All of those faults have low slip rates, long intervals between rupture, and have had little historic activity. Because of this, these areas are placed in the low to moderate hazard category. The major 1887 Sonoran earthquake proved that large, damaging events can happen, but they do so infrequently.

Although seismic hazard is low in much of Arizona, it is significantly higher in the Yuma and Flagstaff-Grand Canyon areas. Yuma is designated as having a high hazard level because it is close to active faults in the Imperial Valley in southern California and northern Mexico that have generated numerous magnitude 6.5 to 7.0 earthquakes during the last 150 years. There is a reasonable probability that damaging levels of seismic shaking will occur in the Yuma area within the next 50 years. To make things worse, parts of the area have potential for *liquefaction.* Liquefaction happens when the ground shakes and causes shallow, unconsolidated, water-saturated deposits of silt and sand to temporarily lose strength and flow. Structures built on those deposits commonly experience major damage when liquefaction occurs. During the 1940 Imperial Valley earthquake, for example, liquefaction caused bridges to buckle and irrigation ditches to collapse. The potential for liquefaction damage in the Yuma area is increasing because urban development is extending into low-lying areas adjacent to the Colorado and Gila Rivers.

The Flagstaff-Grand Canyon area is considered to have a moderate hazard level. Although the area has not experienced any large, surface-rupturing earthquakes in the last 120 years, quakes in 1906, 1910, and 1912 caused damage in Flagstaff. Much of the area was shaken by the magnitude 4.9 and 5.3 Cataract Creek earthquakes in 1993. Swarms of quakes ranging up to magnitude 4.5 have shaken Grand Canyon Village during the past several decades. The area is broken by many faults that have been active within the past few hundred thousand years and have potential to generate large earthquakes. Average intervals between ruptures on individual faults are long; a large earthquake likely occurs within this region on average every 1,000 to 5,000 years. Because of the frequent historic earthquake activity, together with the presence of many potentially active faults, those in construction and emergency management should give serious consideration to earthquake hazards.

References

Earthquake hazards in Arizona: P.A. Pearthree and D.B. Bausch, 1999, Arizona Geological Survey Map 34, text and map, scale 1:1,000,000.

Quaternary fault data and map for Arizona: P.A. Pearthree, compiler, 1998, Arizona Geological Survey Open-File Report 98-24, 122 p., scale 1:750,000, 1 disk.

Plio-Quaternary faulting and seismic hazard in the Flagstaff area, northern Arizona: P.A. Pearthree and others, 1996, Arizona Geological Survey Bulletin 200, 40 p., 2 sheets, scale 1:50,000 and 1:100,000.

Seismic hazards in Arizona: D.B. Bausch and D.S. Brumbaugh, 1994, Flagstaff, Arizona Earthquake Information Center, 49 p., 2 sheets, scale 1:1,000,000.

Arizona earthquakes: S.M. DuBois and others, 1982, Arizona Geological Survey Bulletin 193, 456 p., scale 1:1,000,000.

The 1887 earthquake in San Bernardino Valley, Sonora: Historic accounts and intensity patterns in Arizona: S.M. DuBois and A.W. Smith, 1980, Arizona Geological Survey Special Paper 3, 112 p.

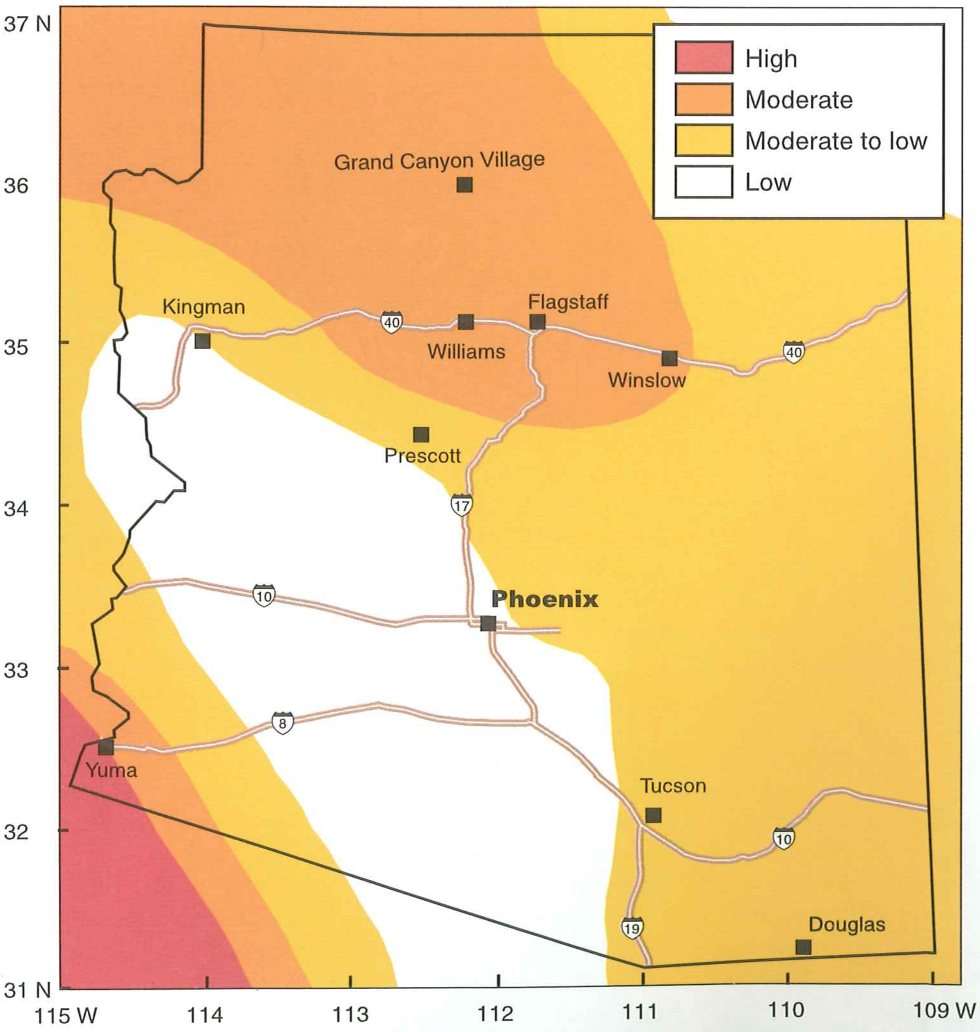

Figure 4. The State has been subdivided into four categories to show interpreted earthquake hazard. The categories are based on rates of historical earthquake activity, number of potentially active faults, and the estimated slip rates for those faults.

Just Released

Earthquake hazards in Arizona: P.A. Pearthree and D.B. Bausch, 1999, Arizona Geological Survey Map 34 (Pub. number M 34), text and map, scale 1:1,000,000. $6.00

Information from this 42 x 42" colored map was paraphrased in the article that begins on page 1 of this issue. The map shows the epicenters, magnitudes, and year of occurrence of earthquakes that have been located instrumentally. In addition, it shows approximate locations, estimated intensities, and year of occurrence of earthquakes described in felt reports. It also shows Quaternary faults that are color-coded to show age of most recent movement and slip rate. Tables include information about selected Quaternary faults in Arizona and notable historical earthquakes in or near Arizona. Inset panels provide information about the following topics: earthquakes and faulting, regional faults and large earthquakes, ground shaking and earthquake damage in Arizona (1887-1999), earthquake hazards in the Yuma area, earthquakes and faults in the Flagstaff-Grand Canyon area, and earthquake hazard summary.

Digital surficial geologic map and geographic database of the northern Tucson basin and Tucson Mountains, Pima County, Arizona: P.A. Pearthree, J.E. Klawon, W.R. Dickinson, T.H. Biggs, and T.R. Orr, 1999, Arizona Geological Survey Digital Information Series 17 (Pub. number DI 17), 1 CD-ROM. $30.00

This is the digital version of the geologic maps included in Open-File Reports 99-21 and 99-22, which cover the eastern flank of the Tucson Mountains and the southern flank of the Santa Catalina Mountains.

Surficial geology and geologic hazards of the northern Tucson basin, Pima County, Arizona (Tucson North and Sabino canyon Quadrangles): J.E. Klawon, W.R. Dickinson, and P.A. Pearthree, 1999, Arizona Geological Survey Open-File Report 99-21 (Pub. number OFR 99-21), 28 p., scale 1:24,000. $8.00

The authors describe the character and general distribution of surficial materials and geologic hazards, include flooding, problem soils, subsidence, and rockfall. Older deposits in the Catalina foothills record Oligocene to Miocene activity on the Catalina detachment fault system. Younger deposits record the development of the modern landscape.

Surficial geology and geologic hazards of the Tucson Mountains, Pima County, Arizona (Avra, Brown Mountain, Cat Mountain, and Jaynes quadrangles): P.A. Pearthree and T.H. Biggs, 1999, Arizona Geological Survey Open-File Report 99-22 (Pub. number OFR 99-22), 19 p., 2 sheets, scale 1:24,000. $9.00

Map units in this area record the recent geologic evolution of piedmonts that surround the Tucson Mountains. The authors describe the character and distribution of the map units as well as geologic hazards in the study area.

Field guide to a dynamic distributary drainage system: Tiger Wash, western Arizona: J.E. Klawan and P.A. Pearthree, 2000, Arizona Geological Survey Open-File Report 00-01 (Pub. number OFR 00-01), 34 p., scale 1:70,000. $9.50

The Tiger Wash system experienced an extreme flood in September 1997, during which much of the piedmont was inundated and substantial channel changes occurred. The authors summarize recent studies of alluvial fan flooding and point out some of the hazards associated.

Map of the volcanic geology of the Castle Butte Trading Post vicinity, Hopi Buttes (Tsézhin Bií), Navajo Nation, Arizona: J.A. Hooten, 1999, Arizona Geological Survey Contributed Map 00-A (Pub. number CM 00-A), scale 1:12,000. $3.50

This map shows the geology of French, Chezhin, and Wide Buttes, which are within the Hopi Buttes volcanic field north of Holbrook. Each butte has a distinctive stratigraphy that includes lava flows, tuffs, crater-filling lake beds, and related sediment.

Ordering Information

You may purchase publications at the AZGS office or by mail. Address mail orders to AZGS Publications, 416 W. Congress St., Suite 100, Tucson, AZ 85701. Orders are shipped by UPS, which requires a street address for delivery. All mail orders must be prepaid by a check or money order payable in U.S. dollars to the Arizona Geological Survey or by Master Card or VISA. Do not send cash. Add 7% sales tax to the publication cost for orders purchased or mailed in Arizona. Order by publication number and add these shipping and handling charges to your total order:

Shipping & Handling
CHARGES
In the United States

Less than	$2.00, add	$1.00
2.00 -	10.00, add	3.50
10.01 -	20.00, add	5.00
20.01 -	30.00, add	6.25
30.01 -	40.00, add	7.00
40.01 -	50.00, add	8.50
50.01 -	100.00, add	10.75
101.01 -	200.00, add	15.00
Over	200.00, call	

Other countries,
request price quotation

Shipping and handling charges include insurance. For rolled maps, add $1.00 for a mailing tube.

If you purchase Open-File Reports, Contributed Maps, or Contributed Reports at the AZGS office, allow up to two days for photocopying.

MAPPING AWARD

The Arizona Geological Survey (AZGS) was awarded $145,535 from the STATEMAP component of the National Geologic Mapping Program to continue preparation of detailed geologic maps in the Tucson urban fringe area in 2001. This funding will be matched by an equal amount from the AZGS' State General Fund appropriation. Mapping will be done in the area between Vail and Benson southeast of Tucson and near Amado south of Green Valley. In addition, some geologic maps in the Phoenix area will be digitized. Mapping is currently underway near Oracle Junction north of Tucson, in the Waterman-Roskruge-Silver Bell mountain area northwest of Tucson, and near Green Valley. The National Cooperative Geologic Mapping Act, which was passed in 1992, was reauthorized in 1999. The purpose of the act is to accelerate the production of detailed geologic maps.

Arizona-Nevada Academy of Sciences

The 44th annual meeting of the Arizona-Nevada Academy of Sciences will be held April 14-15 at the University of Arizona. Details may be obtained online at http://geo.arizona.edu/anas/nl_oc99.html.

Mineral Resource Production and Value

According to figures recently released by the U.S. Geological Survey (USGS), the preliminary estimated value of nonfuel mineral production for Arizona in 1998 was $2.82 billion. The State ranked third in the Nation in total value of nonfuel minerals produced. This was about a 20 percent decrease from the $3.54 billion value of 1997, when Arizona led the Nation.

Most of the State's decrease in nonfuel mineral value was because of a 26 percent drop in copper's unit value. Copper mine production was down only about 4 percent.

Arizona continued in 1998 as the top copper-producing State, accounting for about 65 percent of total U.S. copper mine production and value. Copper, Arizona's leading nonfuel mineral, represented 75 percent of the total nonfuel mineral production value. Production values of lime, gold, crude gypsum, crushed stone, and salt also decreased. Values of all other commodities, especially molybdenum, construction sand and gravel, and portland cement, increased.

In 1998 Arizona rose to first place from second in the production of molybdenum, to second from third in gemstones, to fifth from sixth in construction sand and gravel, and to seventh from ninth in dimension stone. Brucite production began in 1998; Arizona was first of two producing states. The State remained fourth in silver and zeolites, fifth in pumice and pumicite, and eleventh of the 12 gold-producing states. In addition, Arizona was a significant producer of portland and masonry cements, lime, and gypsum.

ARIZONA GEOLOGICAL SURVEY
416 West Congress, Suite 100
Tucson, AZ 85701
(520) 770-3500

Return Service Requested