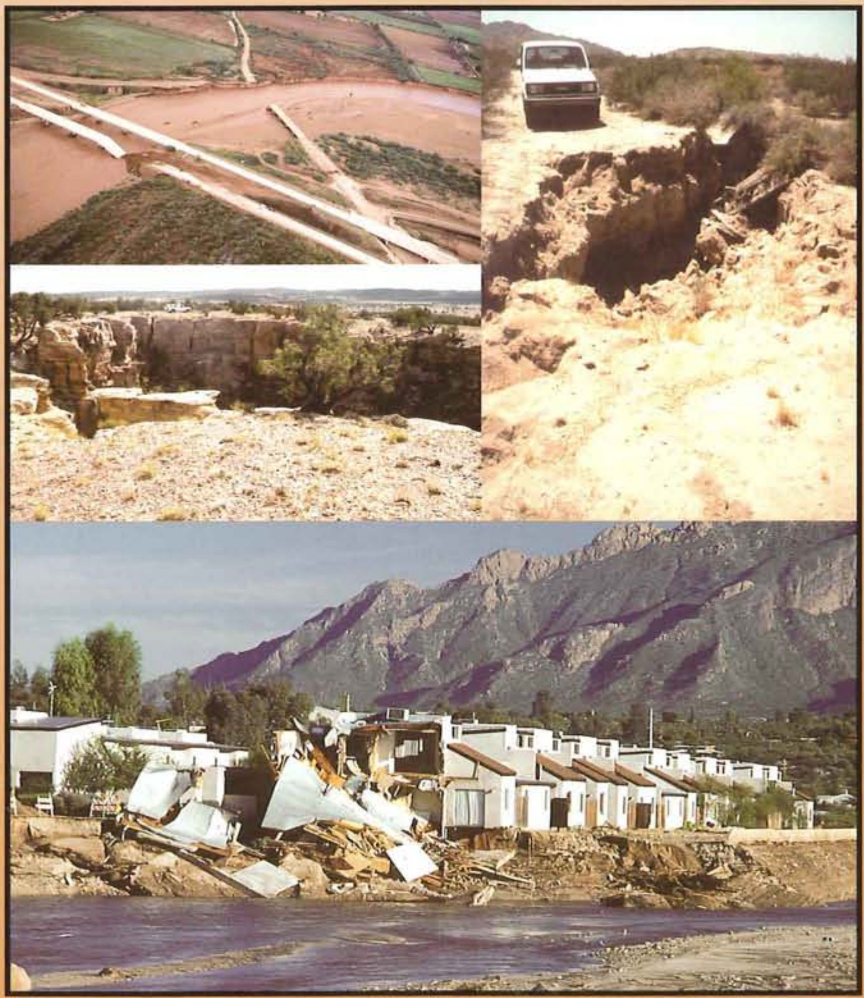
A Home Buyer's Guide to Geologic Hazards in Arizona



Raymond C. Harris
Philip A. Pearthree

Arizona Geological Survey
Down-To-Earth 13
2002

ARIZONA GEOLOGICAL SURVEY

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.

ACTIVITIES

PUBLIC INFORMATION. Inform the public by answering inquiries, preparing and selling maps and reports, maintaining a library, databases, and a website, giving talks, and leading fieldtrips.

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 Commission, which regulates the drilling for and production of oil, gas, helium, carbon dioxide, and geothermal resources.

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Cover photos:

Upper left: Interstate 19 and San Xavier Road, south of Tucson, after flood of October 1983. *Photo © Peter L. Kresan.*
Upper right: Earth fissure crossing road near Queen Creek. *Photo by Raymond C. Harris.*
Bottom: Rillito Creek in Tucson after flood of October1983. *Photo © Peter. L. Kresan.*
Left center: Sinkhole on Colorado Plateau west of Snowflake. *Photo by Raymond C. Harris.*

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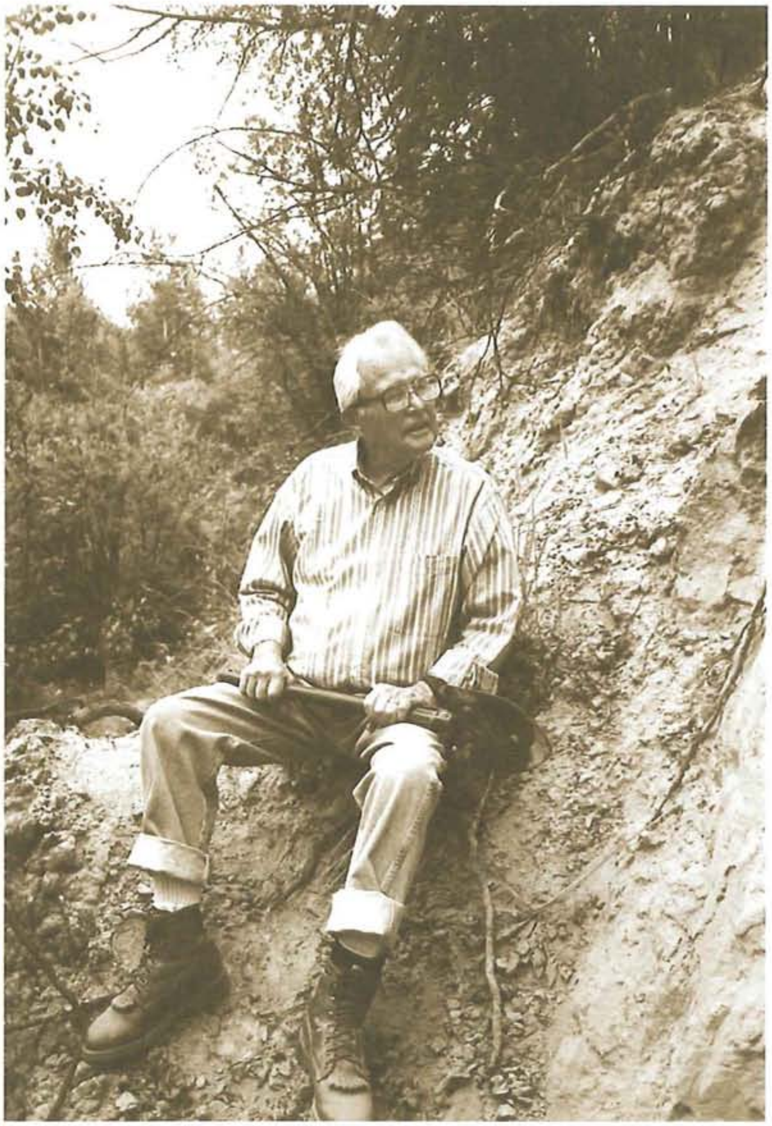

Dr. Troy L. Péwé
1918—1999

Foreword

Dr. Troy L. Péwé spent the last 34 years of his professional career as a faculty member in the Department of Geology at Arizona State University. In addition to teaching and advising graduate students, he served as Department Chairman for a dozen years. Dr. Péwé earned international recognition for work on permanently frozen ground (permafrost) and Ice Age (Pleistocene) geology, which he started before coming to Arizona.

In the mid-1970s Dr. Péwé began to investigate and photograph geologic features, materials, and processes that were impacting urban development in Arizona. Land subsidence and earth fissures, caused by overpumping of groundwater, were among the first problems that attracted his interest. Dr. Péwé advised graduate students on geologic mapping and hazards theses in the Carefree, Cave Creek, Chandler, Phoenix, Scottsdale, and Tempe areas. He worked closely with city officials and with staff at the Salt River Project, Rio Salado Development District, and many other groups, a number of which provided funding for the mapping and investigations.

The Arizona Geological Survey published several of the reports Dr. Péwé and his students produced: *Environmental Geology of the McDowell Mountain Area, Maricopa County, Arizona* (Geologic Investigations Folio 1), *Environmental Geology of the Tempe Quadrangle, Maricopa County, Arizona* (Geologic Investigations Folio 2), and *Geologic and Gravimetric Investigations of the Carefree Basin, Maricopa County, Arizona* (Special Paper 8). The Arizona Legislature provided funds to print the Geologic Folio publications. Dr. Péwé also provided a number of maps for release in the Arizona Geological Survey's Contributed Map series.

Because of Troy Péwé's commitment to investigate relationships between geologic hazards and urban development in Arizona, and to inform the public about them, we dedicate this book in honor of his memory.

Larry D. Fellows
Director and State Geologist
Arizona Geological Survey
June 2002

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Contents

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Raymond C. Harris
Philip A. Pearthree

Introduction

When purchasing a house or property, a largely ignored aspect is the ground that the house sits on and the environment surrounding the property. Before choosing an area in which to buy a home, many people inquire about traffic-noise levels, crime rates, quality of schools, and whether the house is under the flight path of a major airport. It is logically better to obtain this kind of information *before* one buys or builds a home, rather than be surprised the first night by jets taking off from a nearby airport. Similarly, gaining knowledge about geologic conditions in an area will assist prospective homeowners, home builders, developers, and real estate agents to make informed decisions regarding potential problems.

Across Arizona, rocks of all types and ages serve as records of geologic processes that have occurred in the past and are continuing to occur. Some of these processes are merely nuisances to use of the land, whereas others may present serious hazards. We define a *geologic hazard* as any geologic condition or process that poses a risk of injury to humans or damage to structures. Geologic hazards are an unavoidable part of living on planet Earth. From floods to earthquakes to landslides, no place on the Earth is immune from some risk of damage caused by a geologic condition or process. Learning what these conditions are and where they might occur are the first steps toward avoiding them or reducing their effects.

The most widespread and common geologic hazards that should be considered before buying or building in Arizona are

- Floods
- Earthquakes
- Problem soils
- Mass movement
- Subsidence and fissures
- Radon
- Karst
- Abandoned mines
- Volcanic hazards

Virtually every part of Arizona is subject to one or more of these risks, which can be avoided or mitigated, but only with prior knowledge of its existence. Some of these risks, such as radon, are with us every day. Other hazards, such as floods and earthquakes, strike infrequently but with potentially devastating results.

It makes good sense to conduct a thorough inspection of the land before buying a house or property. For home or property buyers, in addition to personal inspection, it might be prudent to find out what information is available regarding geologic hazards in the area. The upfront cost of such inspections is much less than the cost of repairs later. For developers, designing and building with geologic factors in mind may help avoid costly legal battles over damage to structures or loss of property value. For real estate brokers, familiarity with known or potential geologic hazards may help reduce liability if damage occurs on a property.

Our purpose is not to say that any particular parcel of land should not be developed. Rather, in those areas where geologic hazards or limitations are known to be present or where they may potentially exist, knowledge of their existence should help guide planning, design, construction, and maintenance. It remains up to property buyers or owners and local government to determine the level of acceptable risk from geologic hazards. To assist in this evaluation, we have developed this book as a guideline of for home/property buyers. The following pages address the geologic hazards common to Arizona, describe aspects of the geology that should be evaluated before buying or building, present methods to prevent or reduce (mitigate) hazards, and list other appropriate sources of information and assistance.

Floods

(Left) Bank erosion along Rillito Creek in Tucson during the October 1983 flood left the north end of the Dodge Boulevard bridge stranded. *(Photo © by Peter L. Kresan)*

(Above) During the flood of October 1983, the normally dry Santa Cruz River was completely full. This view is from St. Mary's bridge looking south (upsteam) toward downtown Tucson. *(Photo © by Peter L. Kresan)*

Floods In The Desert?

It might seem strange to be concerned about flooding in a dry region like Arizona because deserts, by definition, do not get much precipitation. However, in Arizona a large amount of precipitation can fall in a short period of time. In fact, flooding is probably the most common, widespread, and damaging of all of the geologic hazards discussed in this book. No part of Arizona is immune from hazards associated with flooding. When Arizona was a sparsely populated, predominantly rural state, floods typically were a minor inconvenience. Now that Arizona has large, rapidly expanding metropolitan areas, it is critically important to properly assess and avoid development in flood-prone areas.

Floods cause a tremendous amount of property damage and substantial loss of life in the United States. Even with efforts to improve management of flood-prone areas, damage caused by flooding has continued at a high rate. The Federal Emergency Management Agency (FEMA) estimates that about 4 percent of the total area of the United States is in floodplains. Nine million households and $390 million in property are located in those floodplains.

Although Arizona is dry most of the time, certain weather conditions bring large amounts of moisture into the state. Because of the arid climate, much of the state has sparse vegetation, and hills and mountains are covered with thin and discontinuous soil. With little soil to soak up water and little vegetation to hold water back, much of the precipitation runs off quickly. Flooding can

What are "100-year floods" and floodplains?

The name "100-year flood" implies that over the long term, floods of this size will occur once every 100 years. In this respect, the term is somewhat of a misnomer. In reality, so-called 100-year floods can strike in consecutive years. Actually, the designation of 100-year flood refers to a flood that is believed to have a one percent chance of occurring in any year. Whether or not heavy rain occurs one year does not depend on whether similar rains occurred in previous years (or in previous weeks, for that matter). In more familiar terms, imagine flipping a coin. Although the chance of getting heads is exactly 50-50 for each flip, it is not uncommon to get heads on three or four consecutive flips. The chance of heads or tails on the next flip does not depend on the outcome of the previous flip.

Records of flood events in Arizona go back 150 years at best, and for most streams the flood record is much shorter or nonexistent. It is impossible to assess the true frequency of heavy rains and major floods with a record this short. In looking at the record of major floods in Arizona, it is clear that what hydrologists think is the 100-year flood may change through time. One Safford farmer has remarked that he must be 445 years old because he has lived through *four* 100-year floods on the Gila River!

Hydrologists use a variety of methods to determine the likelihood of rainfall large enough to produce floods of different sizes. Gages that measure flow in streams provide data that can be used to estimate the size of a 100-year flood. Ideally, the largest flood recorded in 100 years of data collecting would be the 100-year flood. Because no stream or river in Arizona has been monitored for a full 100-year span, the size of the largest flood that could occur in 100 years is calculated using statistical methods. As more data are collected through the years, adjustments are made on estimates of the size and frequency of floods. For example, peak flows of the 100-year flood are adjusted upward if it is apparent that what was originally designated as a 100-year flow repeats about every 20 years. Thus, what was originally called a 100-years flood on a stream may actually be a 20-year flood. Most streams in Arizona do not have flow gages, so there is no long-term record of floods. In these cases, hydrologists typically use the record of floods from streams of similar size to estimate the 100-year flood. After the 100-year flood size is estimated, computer models are then used to delineate the extent of inundation in this flood. This area of inundation is the "100-year", or regulatory, floodplain.

Despite all of its potential shortcomings, the "100-year flood" is the standard flood that is used by federal, state, and most local agencies to delineate and manage floodplains. Development is highly regulated, and generally discouraged, in 100-year floodplain areas. If you purchase a home in a 100-year floodplain through a lending agency, you will likely be required to obtain insurance through the Federal Flood Insurance Program administered by FEMA. If you build a new structure in the 100-year floodplain, regulatory agencies typically require that the floor elevation be one foot above the 100-year water surface and that you do not adversely affect structures downstream.

result if the precipitation is sufficiently intense or prolonged. If your property is located along a large stream or river, then you should be most concerned about fall and winter storms. If the property is near a smaller wash, you should be more concerned with intense, localized summer thunderstorms.

Fall/Winter Storms (Rivers and Larger Streams)

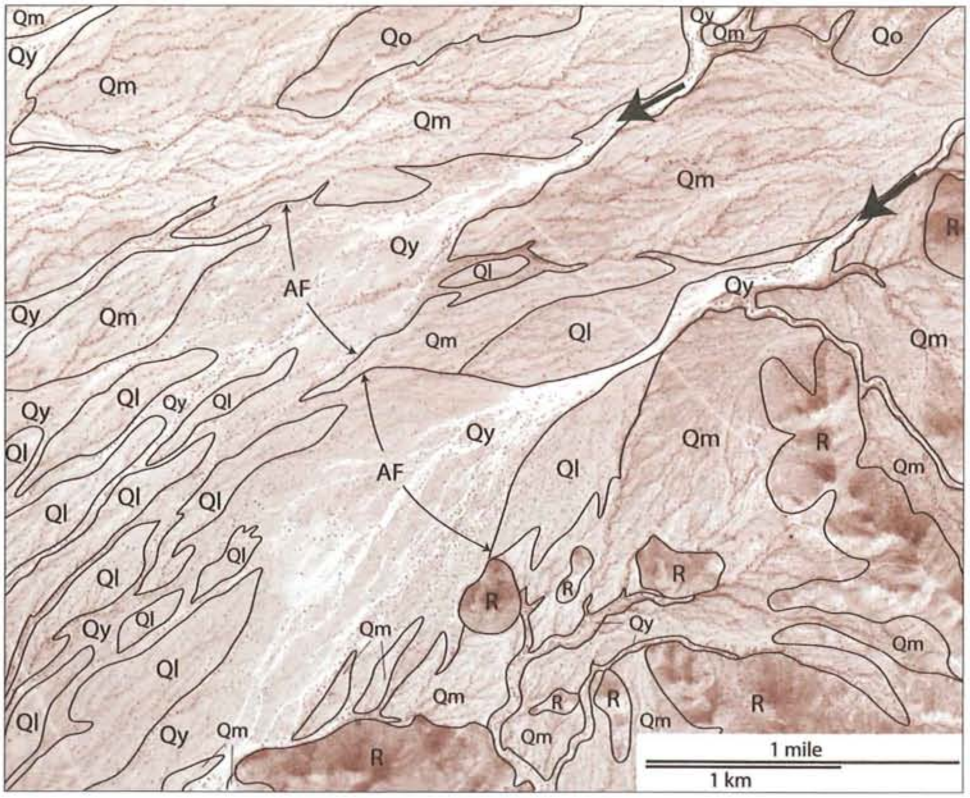
Floods on larger streams and rivers result from regional storms that originate in the Pacific Ocean. In a typical winter, Arizona is affected by numerous storms that do not cause flooding. Occasionally, however, large regional storms lasting for days produce abundant precipitation that can cause flooding. During wet winters, soils become so saturated that runoff increases with each successive storm. Moreover, Arizona is hit periodically by cold storms that produce snow in the high country. If this snow melts too quickly, the runoff can produce floods.

Weather patterns in the late summer or early fall can direct dissipating hurricanes and tropical storms into Arizona. Copious rainfall from these regional-scale systems can generate floods on both small and larger streams.

Summer Storms (Smaller Washes)

Most floods on smaller washes in Arizona occur during the "monsoon" season of the middle and late summer. Intense surface heating results in moisture being drawn into Arizona from the Pacific Ocean and the Gulf of Mexico. Thunderstorms are generated when this relatively moist air is heated and rises, or when it is forced to rise over mountains. Much of Arizona's yearly rainfall comes during this summer rainy season in the form of isolated, occasionally severe afternoon thunderstorms. These storms commonly develop quickly, generate intense wind and lightning, dump their rain, and then dissipate as quickly as they formed.

Floods from monsoon storms typically are highly localized. Unusually intense storms can result in 3 inches or more of rainfall in an hour over small areas. Rainfall of that intensity will generate flash floods on small washes. During these flash floods, normally dry



Aerial photograph of the western piedmont of the White Tank Mountains, which shows alluvial surfaces of different ages. The approximate ages of the deposits in thousands of years (ka) are as follows: Qy, younger than 10 ka; Ql, 10 to 150 ka; Qm, 150 to 800 ka; Qo, older than 800 ka. Areas labeled R are bedrock. The arrows point to relatively large drainages that begin in the mountains and flow from right to left across the piedmont. The areas of recent alluvial-fan flooding (labeled AF) along these drainages are identified by extensive young deposits (Qy). The older fans (units Ql, Qm, and Qo) compose much of the piedmont and have been isolated from floods associated with the larger drainages for more than 10,000 years.

streambeds can fill to their banks and overflow in a few minutes. Flash flooding is particularly dangerous because rain may be falling in only a very small area, with blue sky elsewhere. Because flash floods can travel many miles, people downstream may not be aware that rain is falling upstream. Highly localized, intense flooding may occur on short stretches of a few small washes but nowhere else.

Flood-Prone Areas In Arizona

The most important step that can be taken to minimize property damage by flooding is to avoid building in areas that are prone to flooding. Because of the potential risk to life and property from floods, government agencies restrict development in floodplains. Most floodplains have been delineated solely based on engineering or hydrologic methods. In addition to traditional engineering studies, detailed geologic maps that depict the extent of young deposits along washes and rivers are an extremely useful source of readily available information that can be used to help define the extent of flood-prone land along streams.

Rivers and Streams

Flood-prone areas along rivers and streams include channels and adjacent floodplains. Flood flows in channels are deep, rapid, and obviously hazardous. Floodplains are relatively flat areas adjacent to channels that get flooded occasionally. Flood flows on floodplains are much shallower and less rapid than in channels, and flooding history on floodplains is reflected by the presence of fine-grained, geologically very young material.

In the desert southwest, river and stream floods cause damage in two ways. First, water may overflow the natural confines of a stream channel and inundate low-lying surrounding areas. The second is by widening of the stream channel itself through bank erosion, thereby taking out roads, bridges, and houses on the adjacent floodplain. During the major 1983 flood in Tucson, for example, the banks of the Rillito River migrated laterally as much as 2,700 feet.

Development on floodplains has been an important issue in urban areas in Arizona. Floodplains offer wide expanses of flat land, a seemingly ideal location for development. Before the enactment of floodplain regulations, many developers took advantage of such flat land, and homes and buildings have been constructed within floodplains or near stream banks that were subject to erosion.

Smaller Washes

Flood hazards associated with the thousands of smaller washes in Arizona are as important as the more obvious hazards associated with the larger rivers. As urban areas spread out into the adjacent desert, development increasingly encroaches onto piedmonts (literally, "the foot of the mountains"), which are gently sloping plains between the mountain fronts and the lower, almost flat valley floor. Much of southern, central, and western Arizona consists of piedmonts, which represent

Much of the Floodplain Management in Arizona is done by County Flood Control Districts

- Cochise County Floodplain Division (Highway and Floodplain Department, Bisbee)
- Coconino County Flood Control District (Department of Community Development, Flagstaff)
- Flood Control District of Maricopa County (Public Works Department, Phoenix)
- Pima County Flood Control District (Transportation and Flood Control Department, Tucson)
- Yavapai County Flood Control District (Flood Control Department, Prescott)
- Yuma County Flood Control District (Department of Community Development, Yuma)

Other Sources of Information On Flood Hazards

Arizona Division of Emergency Management
Arizona Floodplain Management Association
Arizona Department of Water Resources (Flood Warning and Dam Safety Division)
Most larger cities in Arizona manage their own floodplains
Federal Emergency Management Agency

Examples of floodplain restrictions (summarized) in various counties around the state include:

- ✓ Buildings must be set back from designated streams or washes because of bank erosion hazard. Setback varies from 30 to 500 feet, depending on size of expected peak flood.
- ✓ Lots must have safe access by standard vehicles.
- ✓ Mobile homes near floodplains must be anchored to the ground so they don't float away.
- ✓ The lowest floor of a built house or the lowest frame of a mobile home must be at least one foot above the expected base flood height (usually the 100-year flood).
- ✓ The natural flow of washes may not be diverted or obstructed without a special permit.
- ✓ Fences may not be placed across washes at wash level because they may trap floating debris, which could form a temporary dam and worsen flooding.
- ✓ Development in a floodplain shall not increase the height of the base flood by more than one foot.
- ✓ Flood insurance may be mandatory in certain areas to obtain federal financing.

most of the land potentially open for development near rapidly growing population centers of the state.

Parts of some piedmonts are subject to alluvial fan flooding, where floodwaters spread out across broad areas and channels may shift during large floods. Piedmonts are typically drained both by a few relatively large streams that begin in adjacent mountains and by many smaller washes that begin on the piedmont. On active alluvial fans, washes commonly fan out into increasingly smaller washes that spread out downstream, in contrast to the normal situation where many small streams come together downstream to form a single, large stream. During alluvial fan flooding, floodwaters spread out and inundate wide areas. New channels can grow quickly if the water takes a new path during flooding. Detailed geologic maps that depict the distribution of young deposits on piedmonts generally are reliable indicators of the extent of flood-prone land along washes and on alluvial fans.

In urban areas, potential for flooding is increased by the amount of land that is covered with buildings and pavement. When the ground is covered, rain has no chance to infiltrate and so must run off. In urban areas, even light rains can fill streets curb-high with runoff. Flooding in cities happens more quickly and with less rainfall than in undeveloped areas.

Preventing Or Reducing Flood Damage

Before purchasing or building a home, it is wise to find out whether the site is in a known floodplain and, if it is, whether it is necessary to purchase flood insurance. This information should be available from county flood-control districts or city floodplain-management agencies. If you are considering building a home in a rural area, avoid areas adjacent to washes, even if the washes seem small and harmless.

Solutions to flooding problems in areas that are already developed are usually difficult and expensive. It is possible to protect property and lives by increasing channel capacity or solidifying channel banks. Such measures have been enacted along the larger streams and rivers in urban areas. If homes are in areas that have experienced repeated or serious flooding, it may be more cost-effective for government agencies to purchase the property than to protect the homes against future flooding.

Because bank erosion is common during floods in Arizona, it is prudent not to build structures immediately adjacent to stream banks. The outside banks of bends in stream channels are particularly vulnerable to erosion. For that reason, floodplain regulations in some counties stipulate that development is not allowed within a certain distance from stream banks. Some houses and developments are exempt ("grandfathered") from parts of floodplain regulations because they were built before the laws were enacted. Older houses may have been built in floodplains and wash bottoms where, today, building would not be allowed.

Where To Go For Information

Most counties, cities, and towns have regulations that govern land use and construction in or adjacent to floodplains. Before building or buying, check with the city or county planning and zoning, community development, or engineering departments to learn of land-use restrictions and building codes. To find out if a property is in a designated floodplain, check with the city or county planning and zoning or community development department, your realtor, your insurance agent, or the Federal Emergency Management Agency (FEMA). Several counties in Arizona have Flood Control Districts, which are special agencies responsible for floodplain management outside incorporated cities. Contact information for federal, state, county, and local agencies is provided on the Arizona Geological Survey (AZGS) website. Finally, geologic maps (available at the AZGS) can provide a useful perspective on flood-prone areas associated with piedmonts and along streams and rivers.

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Environmental Geology of the Tempe Quadrangle, Maricopa County, Arizona, by D.G. Welsh and T.L. Péwé, 1986: Arizona Bureau of Geology and Mineral Technology Geologic Investigations Series GI-2 (Map E - Flooding Map), scale 1:24,000.

Earthquakes

What Causes Earthquakes?

Intense ground shaking caused by large earthquakes can result in widespread damage. Nearly all death and destruction associated with earthquakes is caused by failure of human-built structures. It is critical to understand the potential earthquake hazard in an area to ensure that buildings and other structures are designed and constructed to withstand expected levels of shaking without collapsing.

Earthquakes are concentrated near the boundaries of the great tectonic plates that make up the outer skin of the Earth. In the United States, earthquake activity is greatest along the West Coast because of the plate boundaries that extend through California and near the coast of the Pacific Northwest. Through southern and central California, the Pacific plate is sliding northwestward relative to the rest of North America at a rate of about two inches per year along the San Andreas fault system. Farther north, the North American plate is overriding the Pacific plate. Earthquakes also occur at distances from plate boundaries. In the U.S., damaging earthquakes have occurred throughout the West, in the Mississippi Valley region, New England, and in Charleston, South Carolina.

Faults are zones of the Earth's crust that are weaker than the surrounding rock. As stress increases in the crust because of movement of the tectonic plates, the zone of weakness eventually fails. One side of the fault slips relative to the other side and then stops because of friction. The amount of movement might be as little as a fraction of an inch in a small earthquake or as much as 30 feet in a truly great earthquake. The sudden movement generates vibrations in the Earth (seismic waves) that cause the ground to shake. Earthquakes relieve some of the stress in the crust, but stress eventually builds up again and triggers recurrent fault movement and earthquakes.

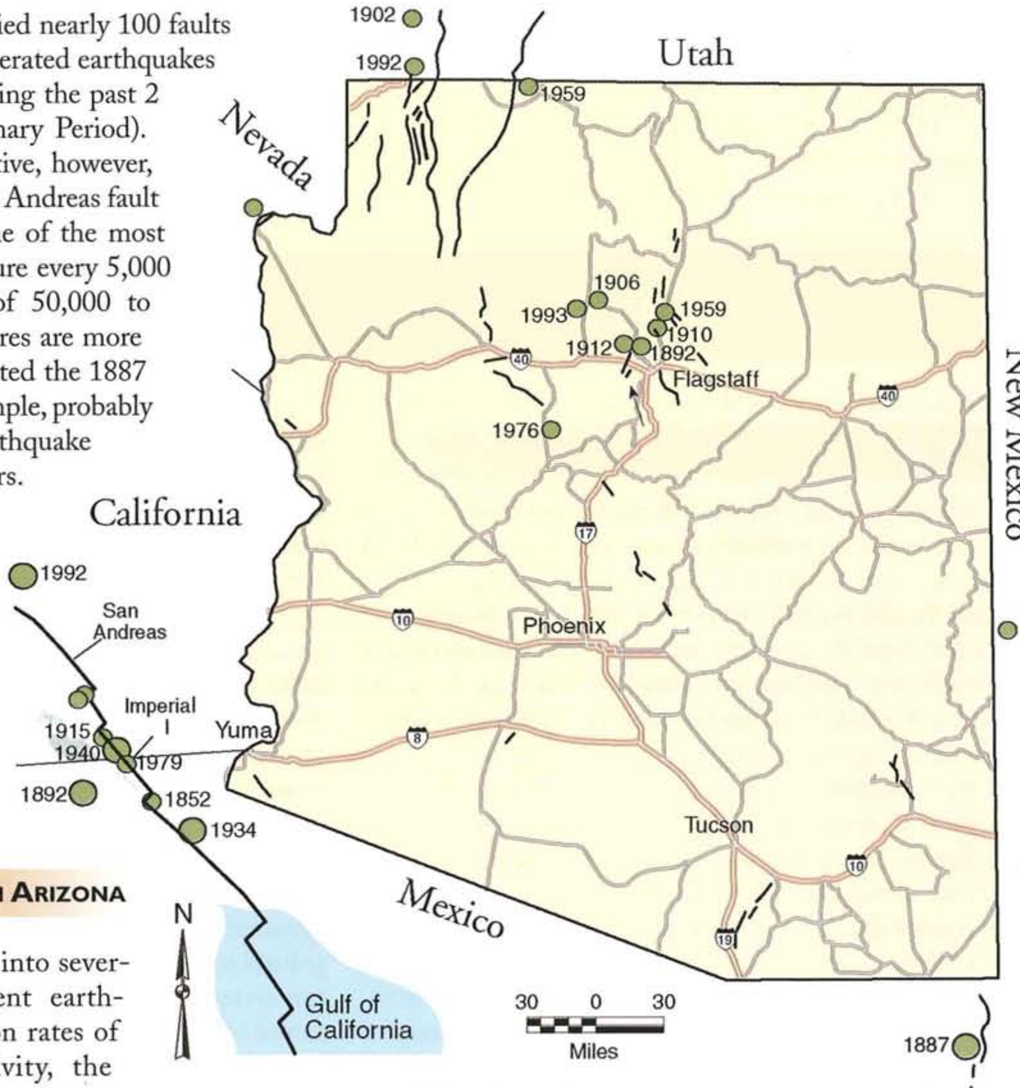
An earthquake's magnitude is related to the amount of energy released into the surrounding earth. The familiar Richter Scale is the most common way to portray the size of an earthquake. Earthquake magnitude depends primarily on the area of the fault plane that ruptures and the amount of movement that occurs during the rupture. Each increase of one unit of magnitude on the Richter Scale represents a 10-times increase in ground motion and about a 32-times increase in the energy released in the earthquake.

Scientists assess earthquake potential by analyzing historical earthquake patterns and studying evidence for prehistoric ruptures along faults. Historical earthquakes provide a wealth of information about the damage that earthquakes cause and some information about where future earthquakes may occur. However, the historical record of earthquakes is extremely short in comparison with the recurrence interval of major earthquakes, and there are many potentially active faults that have not ruptured historically. Large earthquakes that rupture the ground surface along faults leave evidence that geologists can recognize thousands of years later. A much longer record of large earthquakes in a region can be developed by studying these faults and determining the age of large prehistoric earthquakes.

Earthquakes And Young Faults In Arizona

Over the past 150 years, more than 20 earthquakes having magnitudes greater than 5 have occurred in or near Arizona, and all of Arizona has experienced at least moderate earthquake shaking. 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. The Yuma area has experienced repeated damage from earthquakes that occurred in southern California or northern Mexico. The most damaging event was the magnitude 7.1 Imperial Valley earthquake of 1940. The Flagstaff area experienced damage three times during the early 1900's from magnitude 6 earthquakes. A broad area extending from near Winslow through Flagstaff and northwest into Utah continues to experience moderate levels of earthquake activity.

Although no earthquakes in Arizona have ruptured the surface in historic time, many potentially active faults exist. Geologists have identified nearly 100 faults in Arizona that probably generated earthquakes of magnitude 6 or larger during the past 2 million years or so (Quaternary Period). These faults are not very active, however, when compared with the San Andreas fault in California. Although some of the most active faults in Arizona rupture every 5,000 to 10,000 years, intervals of 50,000 to 100,000 years between ruptures 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 on eight faults has probably occurred in Arizona within the past 15,000 years. These studies show that although large earthquakes do occur in Arizona, they do not occur frequently.



Young Faults and Earthquake Epicenters in or near Arizona

Explanation of Symbols

Known young earthquake faults active in the past 130,000 years.

Historical earthquake epicenters; magnitude 5-7 (medium) >7 (large)

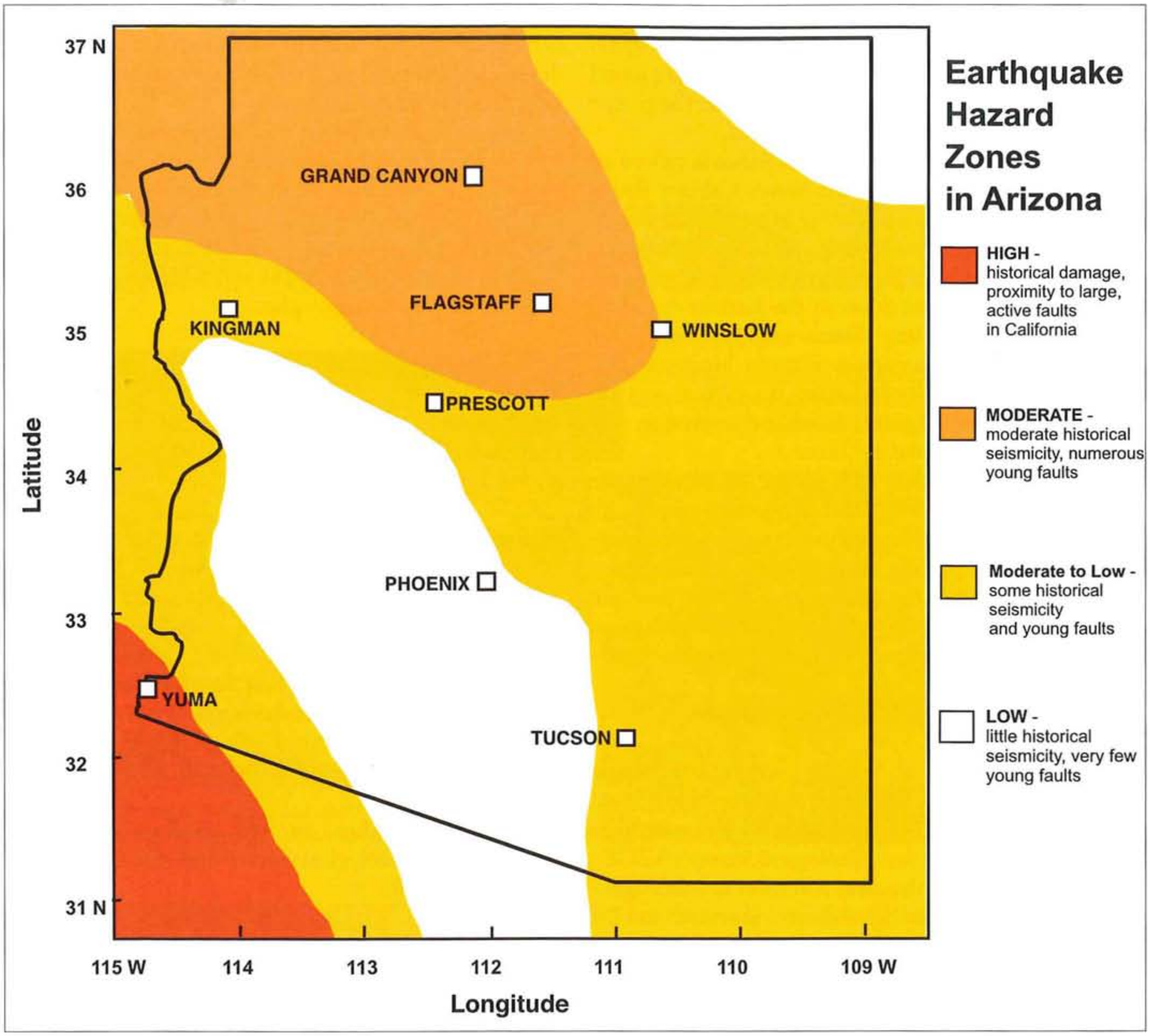
Interstate highway

Earthquake Hazards In Arizona

Arizona can be divided into several zones that have different earthquake hazard levels based on rates of historical earthquake activity, the number of potentially active faults, and the estimated slip rates for these faults. Earthquake hazard levels across the state are generally low to moderate.

Although seismic hazard is fairly low in much of Arizona, it is relatively high in the Yuma area. Yuma 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. To make things worse, parts of the area have potential for liquefaction—that is, when the ground shakes, shallow, unconsolidated, water-saturated deposits of silt and sand may temporarily lose strength and flow. The resulting ground failure can cause major damage to structures. During the 1940 Imperial Valley earthquake, for example, liquefaction caused bridges to buckle and irrigation ditches to collapse in the Yuma area. 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, earthquakes 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 of 1993. Swarms of quakes ranging up to magnitude 4.5 have shaken Grand Canyon Village during the past several decades. The Flagstaff-Grand Canyon region is broken by many faults that have been active within the past few hundred thousand years and have potential to generate large earthquakes. Considering the whole region, large earthquakes may occur on average once every 1,000 to



5,000 years. Because of fairly frequent historical earthquake activity and the presence of many potentially active faults, earthquake hazards should be considered in building construction and emergency-management planning in Flagstaff and the Grand Canyon area.

Earthquake hazard is low in the Sonoran Desert of southern Arizona, where few historical earthquakes have occurred. Because the few Quaternary (young) faults in this region are short, the largest earthquakes that might occur are estimated to be about magnitude 6.5. Earthquake hazard is low to moderate in southeastern and central Arizona, including much of the Phoenix and Tucson metropolitan areas. Many potentially active faults scattered across this region are fairly long and could generate magnitude 6.5 to 7.2 earthquakes. However, these faults have displayed low slip rates and had very long intervals between ruptures. Levels of historical earthquake activity have been low in this region, except for the major 1887 Sonoran earthquake. This event showed that large earthquakes do occur in this region, but the geologic record indicates that they occur infrequently.

Preparing For Earthquakes

Even though the probability of experiencing a large, damaging earthquake is fairly low in most of Arizona, it is wise to be aware of the possibility. Earthquakes may damage structures directly by shaking them, or indirectly by triggering landslides or rockfalls. Homeowners need to be aware of the potential dangers from slope failures triggered by earthquakes, even those centered far away. In steeply sloping areas that have loose boulders, walls or other barriers may be constructed on the uphill side of a property. In areas near rivers where the ground is underlain by unconsolidated, wet sediment, the potential for liquifaction needs to be considered.

Some of the damage from earthquakes is caused by movement of objects within the home. Cabinet doors, appliances, bookshelves, and other loose objects should be secured to prevent movement during an earthquake. Bookshelves and file cabinets may tip over and seriously injure a person. Cabinet doors in the kitchen or pantry may swing open, spilling dishes, small appliances, or canned goods on an occupant. Pictures hung on walls can fall; this is especially dangerous if a picture is at the head of a bed. Water heaters should be secured to prevent rupture of water and gas lines.

Because the location and size of earthquakes are impossible to predict and the damages associated with large earthquakes are great, standard homeowners insurance does not include coverage for earthquakes. Insurance for earthquake damage is available, however. Check with your insurance agent for availability and cost to add coverage to your policy for earthquake damage.

Where To Go For More Information

Several agencies in Arizona provide information about earthquake hazards, preparedness, and mitigation. Reports and maps showing areas that have known faults are available at the Arizona Geological Survey (AZGS). Information about earthquakes and links to other agencies involved with earthquakes are provided on the AZGS website.

The Arizona Earthquake Information Center (AEIC) at Northern Arizona University maintains a regional seismic network in northern Arizona and collects data, distributes information, and conducts research on Arizona earthquakes. AEIC personnel monitor earthquake activity, identify potential hazards to residents and facilities, and maintain an archive of more than 10,000 earthquake records.

Arizona's Department of Emergency and Military Affairs, Division of Emergency Management, in Phoenix, sponsors the Arizona Earthquake Preparedness Program (AEPP). The program seeks to reduce Arizona's vulnerability to damaging earthquakes through public awareness and education programs, and coordination of Federal, State, and local emergency plans.

Selected References

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

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Arizona Earthquakes, by 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, by S.M. DuBois and A.W. Smith, 1980: Arizona Geological Survey Special Paper 3, 112 p.

Problem Soils

(Left) Large cracks in soil indicate extensive drying and shrinking of expansive clay. This type of crack appears during dry seasons. *(Photo by Raymond C. Harris)*

(Right) Repeated shrinking and swelling of clay produces a characteristic "popcorn" texture. *(Photo by Larry D. Fellows)*

How Can Soil Cause Problems?

Damage to structures in Arizona is commonly related to soil characteristics, with expansive (shrink/swell) soils and collapsing soils causing the most problems. Cracking of foundations, walls, driveways, swimming pools, and roads costs millions of dollars each year in repairs. Severe or recurring damage can lower the value of a house or property. According to the American Society of Civil Engineers, about half of the houses built in the United States each year are situated on unstable soil, and about half of these will eventually suffer some soil-related damage.

The causes of soil expansion or collapse are related to the type and amount of clay minerals in the soil, conditions under which the clay originated, and original density of the soil. Clay minerals can form in-place by weathering of rocks, or they can be transported and deposited by water or wind. A change in the moisture content of a soil can cause clay minerals to swell like a sponge or to lose cohesion and collapse.

Expansive (Shrink/Swell) Soils

Many soils have a high content of clay minerals, some of which can act like sponges and absorb large quantities of water, causing the clay mineral to increase substantially in volume. When the clay mineral dries out, it shrinks. Clays that are high in sodium can expand as much as a thousand percent when water is added. Because soils are usually not composed entirely of clay minerals, expansion is typically much less than in pure clay. However, structures may be damaged when a soil expands by as little as five percent.

Expansion of clay minerals can cause walls and foundations to crack and roads and sidewalks to warp, in a manner similar to frost heaving. The first sign of expanding soil beneath a building may be misalignment of doors and windows. Another indication of soil expansion is when patio or driveway slabs buckle or move away from the house. Non-load-bearing walls, which do not have enough weight to resist the pressure produced by expansion, typically crack before load-bearing walls do.

Upon drying, expansive soil shrinks, forming large, deep cracks or "popcorn" texture in surface exposures.

Large cracks in soil indicate extensive drying and shrinking of expansive clay. This type of crack appears during dry seasons. *(Photo by Raymond C. Harris)*

Popcorn texture is the result of repeated shrink/swell cycles, producing marble-sized pellets. In extreme cases, cracks formed by drying clay can be large enough to mimic earth fissures (discussed in the **Subsidence** chapter). However, desiccation cracks are not as long or deep as earth fissures. Expansive clays in Arizona commonly originate from volcanic ash deposits or sediment and alluvium that contain volcanic debris.

Location Of Expansive Soils In Arizona

Phoenix area

Expansive soils are scattered throughout the Phoenix area. Shrink/swell potential is moderate to high in soils in terraces along the Gila and Salt Rivers, old alluvial fan surfaces, and scattered areas in the valley plains. These areas have been delineated on soil survey maps produced by the U.S. Natural Resources Conservation Service (formerly the Soil Conservation Service, part of the U.S. Department of Agriculture). (See map, p. 12)

Tucson area

Expansive soils are found in numerous places in and around Tucson. Many of these areas are associated with exposures of clay-rich beds in the Pantano Formation, mostly in the foothills of the Santa Catalina and Rincon Mountains around the northern and eastern margins of the valley. Tilted strata of the Pantano Formation are exposed prominently along Sunrise Drive and Snyder Road. (See map, p. 13)

Colorado Plateau

Expansive soils are widespread on the Colorado Plateau in northern Arizona. Commonly associated with the Triassic Chinle Formation (famous for the abundant logs in Petrified Forest National Park), clays on the Plateau are composed largely of montmorillinite, which has a high shrink/swell potential. In the Colorado Plateau, exposures of expansive clays are notable for their popcorn textures.

Other areas

Areas where soils have moderate to high shrink/swell potential include parts of the Safford and Duncan valleys, Willcox area, upper San Pedro Valley, upper Santa Cruz River Valley to Nogales, and Yuma. In each of these areas, problem soils are scattered; evaluation of shrink/swell potential must be done on a site-by-site basis.

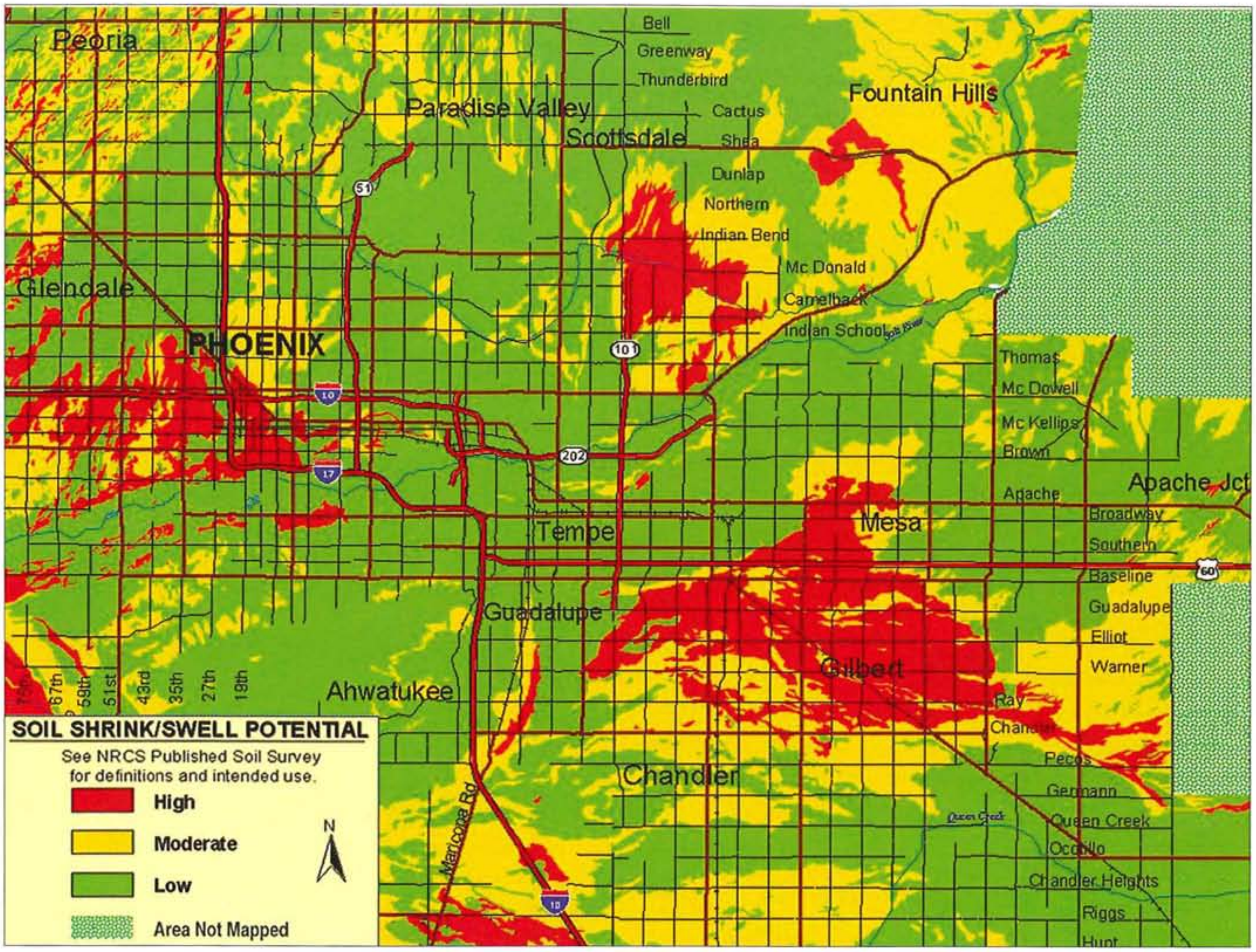
Dealing With Expansive Soil

Identification

The presence of expansive clays can be detected by direct observation: polygonal soil cracking (mudcracks) or popcorn texture in exposures is indicative of shrink/swell clay. Soil survey maps delineate areas of clay-rich soils that are known to have shrink/swell potential. For other areas, laboratory testing of the soil may be the only way to determine if a specific area has shrink/swell soil. Soil engineering laboratories routinely perform tests that evaluate amount of shrink/swell, expansion pressure, and behavior of soil as the water content changes. Although these tests range from $50 to $150 per sample, the up-front cost is considerably less than the cost of repairing cracks in foundations and walls, and the potential decrease in property value.

Mitigation

Mitigation of expanding clay soil can be accomplished in several ways. Application of hydrated lime to swelling soils is a common treatment that is usually effective in preventing or reducing expansion. In this method the sodium in the clay is replaced with calcium, thereby reducing the ability to swell. Another effective method is to remove the expansive soil and replace it with non-expansive fill. This method is practical if the expansive soil is relatively thin and near the surface. Pre-wetting to increase the moisture content before building may help limit future swelling, as long as the moisture content can be held fairly constant. Application or use of protection barriers (coatings, geomembranes) that surround the house foundation



Soil scientists of the Natural Resources Conservation Service (NRCS) have mapped the occurrence of expansive soils. This is a portion of a soils map of the Phoenix region available from NRCS. (*Map courtesy of NRCS*)

help keep soil moisture levels constant and prevent infiltration of surface water. For construction of larger structures, deep piers or footings and specially reinforced or post-tensioned foundation slabs are increasingly common in areas that have expansive soils.

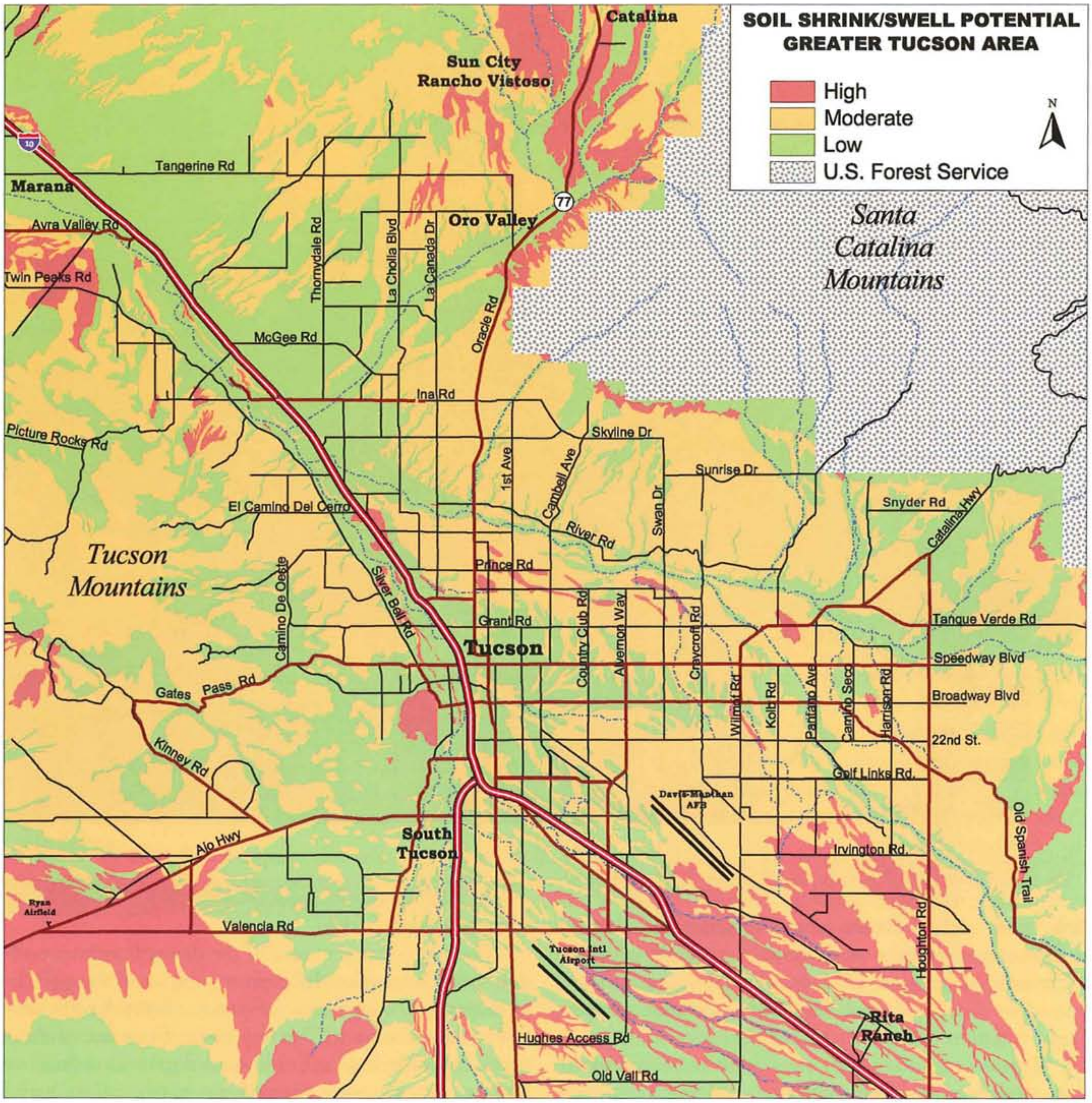
Because expansive soils swell with increased moisture, drainage should be controlled to divert water away from the structure. Poor drainage can result in ponding of water, which allows clays to absorb water, expand, and cause problems. Rain gutter downspouts should direct water away from buildings to prevent infiltration near the foundation. Use of moisture protection barriers surrounding the house help keep soil moisture levels constant and prevent infiltration of surface water. Watering of landscaping plants and lawns, especially deep watering by drip irrigation systems, also can trigger soil expansion. Planting adjacent to foundations should be avoided. Desert-adapted plants are recommended over non-native plants that require more watering, especially near buildings.

Hydrocompaction

Because infrequent rain in the desert Southwest seldom penetrates more than a foot or two and then quickly evaporates, near-surface deposits usually have a very low moisture content. The clay and silt in some of these deposits act like a glue, holding sand grains in place but leaving space between them. Upon wetting, the silt and clay lose their cohesion, and the sand grains move closer together and take up less space. This process, referred to as hydrocompaction, is especially troublesome in soils that have large amounts of silt.

Common events that can trigger compaction include deep watering of plants, ponding of rain runoff, water leaking from pipes, and leaking evaporative coolers. Potential for compaction is increased when a load, such as a house, adds weight to the soil. Hydrocompaction can occur years or even decades after a structure is built.

The problem of hydrocompaction is not to be confused with the common occurrence of settling of fill



Soil scientists of the Natural Resources Conservation Service (NRCS) have mapped the occurence of expansive soils. This is portion of a soils map of the Tucson region available from the NRCS. *(Map courtesy of NRCS)*

material. Any type of fill may later settle if it was not properly compacted during placement. Damage from this type of settling may be prevented by compaction during placement or by waiting a few months before building to allow the fill to compact on its own.

Hydrocompaction can mimic earth fissures (which are caused by subsidence due to groundwater pumping). Damage from hydrocompaction tends to be restricted to a small area, usually smaller than a backyard, and is commonly circular in area; earth fissures are narrow and long, typically extending over several hundred yards. Earth fissures should be suspected only if cracks in structures or in the ground are aligned for a greater distance, such as across a neighborhood.

Distribution Of Hydrocompaction Hazards

Tucson

In Tucson, hydrocompaction has occurred on the floodplains of the Santa Cruz and Rillito Rivers and

Pantano Wash. Soils prone to compaction are also present in a large area of north-central and east-central Tucson known as the Cemetery Terrace. Soils having the potential for hydrocompaction also are present in the Marana area northwest of Tucson.

Benson area

Collapsing soils present a major problem in the Benson area in the upper San Pedro Valley. There, some silty clays and soil formed on alluvium derived from granitic rocks may be subject to significant settling upon wetting or application of loads.

Phoenix area

Floodplain deposits susceptible to compaction are present along the Gila and Salt Rivers in the Phoenix region. Soils formed on the fine-grained lower parts of alluvial fans emanating from mountains and piedmonts also have potential for hydrocompaction.

Preventing Damage From Compacting Soils

Before building, it would be wise to examine published soil surveys or to have a survey or test made of the engineering properties of the soil on the site. It is much easier to take required remedial measures before construction than it is to retrofit. Soil tests can determine the likelihood of compaction based on how much water the soil is capable of holding compared to how much water is needed to lower the strength. Soil may be treated by application of large amounts of water, followed by several weeks or months to allow settling to occur before construction on the site. A large weight, called a preload, can also be applied to fully compact the soil before building. Compaction can be achieved using a vibratory roller or tamper on wetted soil. If the compaction-prone soil is not very deep, removal and replacement with stable soil may be an effective treatment.

Preventative measures for areas that have compacting soils are similar to those that have swelling soils. Rain runoff should be directed away from structures to avoid infiltration. Deep watering of plants may trigger collapse. When landscaping near structures, choose desert-adapted native plants over non-native plants that require extensive watering. Provide for drainage away from structures; ponded water may infiltrate several feet and trigger hydrocompaction. Finally, ensure that walls, footings, and foundations are properly reinforced to withstand minor soil compaction.

Where To Go For More information

The Natural Resources Conservation Service (NRCS) publishes maps and reports showing distribution and properties of soils, and provides information to the public. The NRCS is listed in the blue Government section of the telephone directory under U.S. Department of Agriculture. Soil maps from the NRCS are available for inspection in the AZGS library. AZGS surficial geologic maps contain some soil information.

Consultants specializing in soil properties are listed in the phone book under *Engineers*, subcategories including *civil*, *geotechnical*, and *soils*. Developers commonly perform engineering studies of properties, and their consultants' reports may be available for inspection.

Selected References

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A Guide to Swelling Soils For Colorado Homebuyers and Homeowners, by D.C. Noe, C.L. Jochim, and W.P. Rogers, 1997: Colorado Geological Survey Special Publication 43, 76 p.

So Your Home is Built on Expansive Soils - A Discussion of How Expansive Soils Affect Buildings, Warrren Wray, editor, 1995: New York, American Society of Civil Engineers, 59 p.

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Mass Movements

What Are Mass Movements?

Downslope movement of rock or soil by the force of gravity is one of the most common ways by which the surface of the Earth is shaped over time. These mass movements may be very rapid or imperceptibly slow. Mass movements are practically unstoppable once they are in motion and can damage or destroy roads, railroads, buildings, and houses in their paths. Because they require some topographic relief to get started, mass movements are most common in mountainous or hilly terrain.

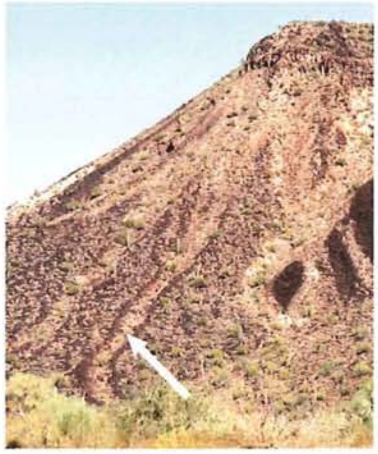
Mass movements occur in every state and cause about $1-2 billion in damages and 25 deaths across the country each year. These hazards cause greater damage and higher monetary losses in the United States, on average, than do earthquakes or hurricanes. For example, in September 1997, dissipating Hurricane Nora traveled across western Arizona from Yuma northeast to the Prescott area. Rainfall amounts of up to 12 inches in the two-day storm triggered numerous landslides and debris flows. Several highways and bridges suffered damage from the mass movements. Because the path of the storm passed through sparsely settled regions, relatively minor property damage occurred. Had a storm like Nora gone through Tucson or Phoenix, however, it might have caused tremendous destruction from flooding and associated landslides and debris flows.

Development has been encroaching onto mountain slopes surrounding many Arizona cities and towns. In addition, because many of our roads are built through steep terrain, excavations associated with road-building may enhance the potential for mass movement. As with all of the geologic hazards discussed in this book, knowledge of the possibility of mass movements can allow people to avoid problematic areas or to develop strategies to mitigate the hazards.

Characteristics Of Mass Movements

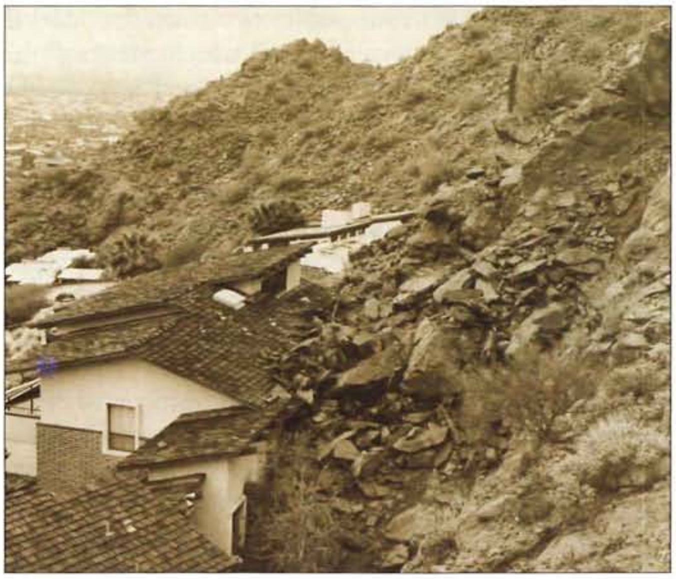
Mass movements are driven by gravity and are usually associated with steep slopes. They may behave quite differently depending on the type of material involved, the proportion of solid material versus water, and the steepness of the slope. Mass movements include debris flows, landslides, and rockfalls.

Debris flows consist of material saturated with water that moves as a fluid mass. They typically flow down valleys, following existing channels. Most of the debris flows that have occurred in Arizona in the past several decades have been restricted to mountain valleys and canyons. In larger debris flows, however, the upper-most part of an active alluvial fan may receive debris flows and is more susceptible to damage than sites lower down or adjacent to the fan. Because their density is much greater than water, debris flows are very effective at transporting large rocks.

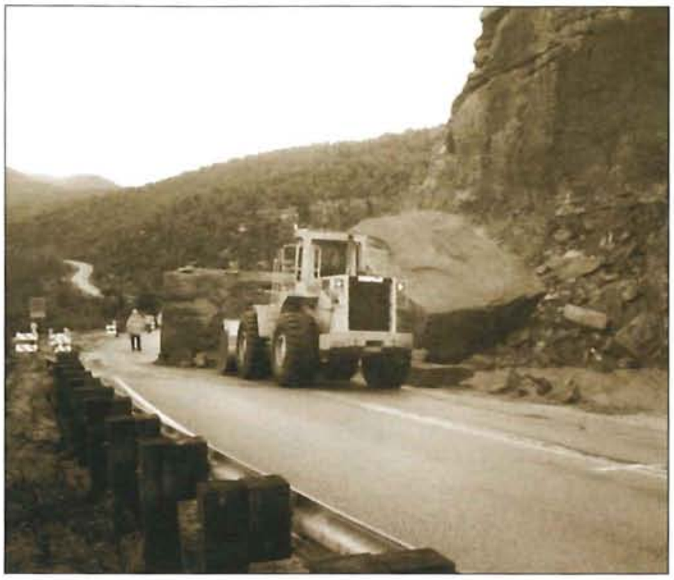


This debris flow (arrow) in southwestern Arizona shows characteristic boulder "levees" on each side of the central scour channel. *(Photo by Larry D. Fellows)*

Landslides are large masses of rock and soil that slide along the ground surface. Although landslides typically move as a single, fairly coherent mass, faster-moving slides may become quite jumbled. Some landslides move very rapidly, whereas others creep at very slow rates and may be active only intermittently. In either case, a landslide can be very destructive to structures built on the landslide itself or in its path. Many landslides in Arizona occur where relatively resistant, coherent rock units such as sandstone or lava flows overlie clay-rich units. When the clay-rich units have abundant moisture in them, they may lose their cohesion, causing the overlying unit to slide down slope.



A rock slide nearly destroyed this home in Phoenix. Steep slopes underlain by highly fractured rock are vulnerable to such landslides. *(Photo by Troy L. Péwé)*



A large rockfall, triggered by heavy rains, temporarily closed this highway. *(Photo courtesy of Arizona Department of Transportation)*

Rockfalls are rocks that fall freely through the air, intermittently bouncing on the ground. Large rocks are obviously more dangerous because the mass of material is greater and they can fall and bounce farther from the source.

Causes Of Mass Movements

Landslides, debris flows, and even rockfalls are commonly triggered by heavy or prolonged rainfall. Water increases the weight of the soil and rock, lowers the cohesive strength of clay, and acts as a lubricant. In colder areas of Arizona, water freezing and expanding in cracks may loosen rocks, making them more susceptible to rockfalls. Slope failure caused by rain may occur during the summer "monsoon" rainy season (July to September) or during unusually wet winters.

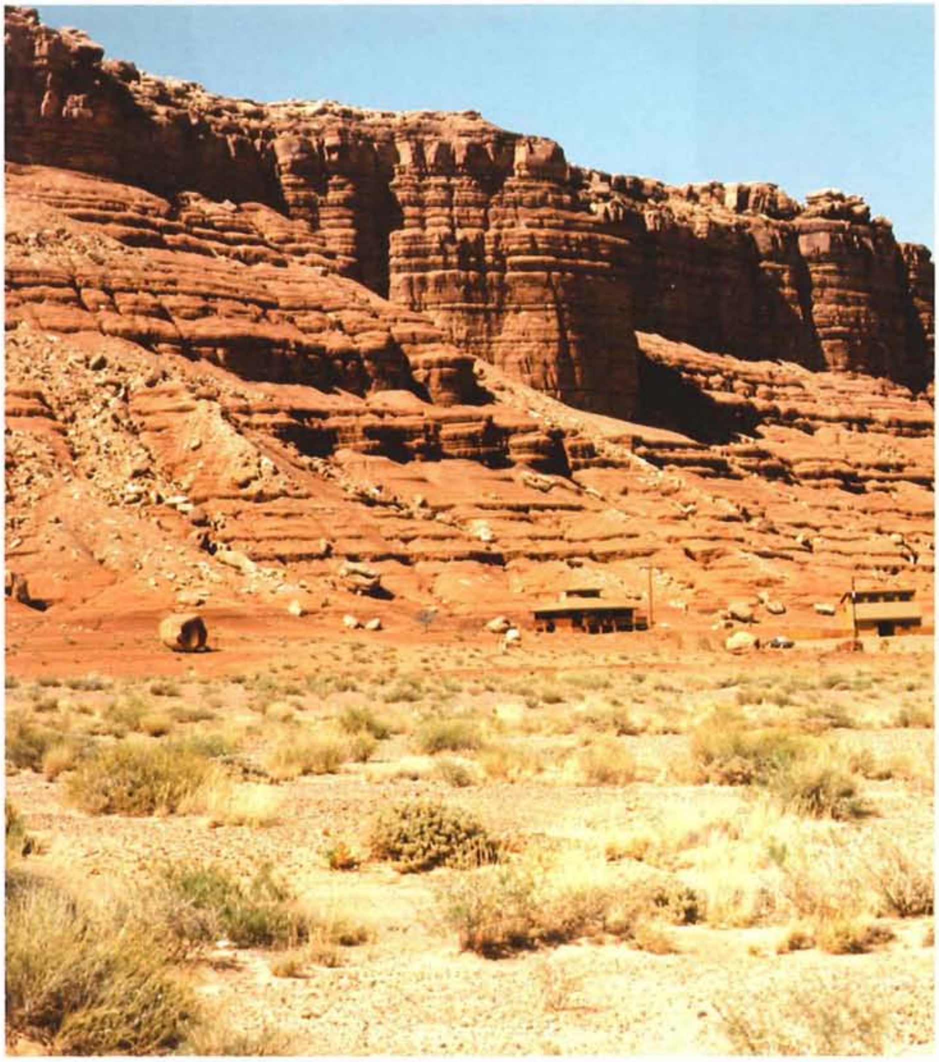
Besides heavy rainfall, other factors that contribute to mass movement include lack of vegetation on steeper slopes, thickness of soil, and expansive clay. Other conditions that can trigger mass movements include earthquake shaking (or other sources of vibrations), number and orientation of bedrock fractures, forest fires, and construction-related slope modification. For example, numerous rockfalls were reported in southeastern Arizona during the 1887 Sonoran earthquake. Some of the most devastating landslides and debris flows that occurred in the world during the past century were triggered by volcanic eruptions. Landslides are more likely to be a hazard where fractures or bedding in the rocks are nearly parallel with the slope. In this situation, the fractures or bedding act as planes of weakness along which water infiltrates and provides lubrication. Weathering takes place more rapidly along fractures and other planes of weakness, providing an easier place for the rock to separate and fall.

Because so many factors control the initiation of slope failure, it is difficult to predict with certainty when and where a slope failure may occur. Steep terrain is an important consideration, as are the geologic units that exist in an area. When considering the possibility of mass movements in an area, one should be aware of evidence of past mass movements, which is sometimes obvious. Fresh scars from landslides and debris flows are lighter in color than the surrounding ground and little or no vegetation is present. Landslides commonly have steep scarps at their upper margins, and the topography of the landslide tends to be lumpy and irregular. Landslides may be quite small (several feet across), or they may be vast. The margins of debris flows are typically higher than the middle (similar to levees) and they commonly leave piles of boulders where they terminate. Large rocks or jumbles of rocks beneath steep slopes or cliffs are evidence of past rockfalls.

Areas At Risk In Arizona

Areas prone to mass movement are widespread in Arizona. As Arizona's population grows and more development takes place near mountain fronts and on steep slopes, the potential for property damage increases as people move into steeper areas more prone to slope failure.

Debris flows are the most common form of mass movement in the mountains of Arizona. Mountain soils



Boulders falling and rolling down slopes below cliffs pose a serious hazard. This hazard is common on the Colorado Plateau. *(Photo by Larry D. Fellows)*

typically are thin, and vegetation is sparse because of the relatively dry climate. Without extensive plant roots to help hold weathered rocks and soil in place, intense rainfalls can cause debris flows.

Rockfalls are a potential threat wherever extremely steep slopes exist. Loose boulders, up to the size of a small house, can tumble an amazing distance down a mountain onto the gentler slopes below.

On the Colorado Plateau and in the rugged mountains of central Arizona, mesas are commonly composed of relatively soft rock that is capped by hard, resistant layers. The underlying soft layers erode easily, leaving the capping layer overhanging with no support. Eventually, the cap rock breaks off and slides or falls to the bottom of the mesa. It is typical to see the lower slopes of mesas littered with large blocks that have fallen from the top. For this reason, buildings should not be constructed at the base of such mesas or cliffs. Areas where soils are thicker, especially those soils having expansive clay, are susceptible to landslides during heavy rains, which weaken the cohesion of the clay. Slopes on the Colorado Plateau are highly susceptible to landslides because of their high clay content of soil and weathered rock outcrops.

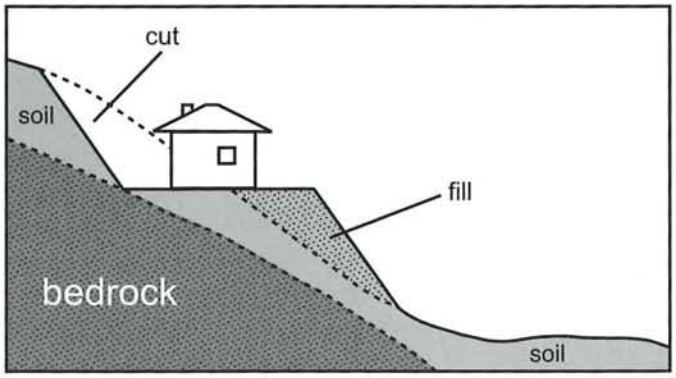
Reduction Of Risks

Debris Flows

Debris flows may be triggered by the same heavy rains that produce flooding and present similar hazards. Forest fires that denude steep slopes may set the stage for debris flows. As with floods, the best method of avoidance is to not build in a floodplain or on the edge of a wash in hilly or mountainous terrain.

Landslides

Because little can be done to mitigate large landslides or slope failures, areas having the potential for landslides should be avoided. Smaller slope failures may be triggered by construction practices. Development on slopes commonly requires construction of a flat site on which to put a house. With the cut-and-fill technique, material is removed from the uphill part of the site and placed on the downhill portion to form a level surface. The fill material may compact and settle later, and cause cracking of foundations and walls. The extra load of a building may trigger a slope failure on unrestrained fill. Retention walls and precompaction of fill may lessen the potential for that type of slope failure.

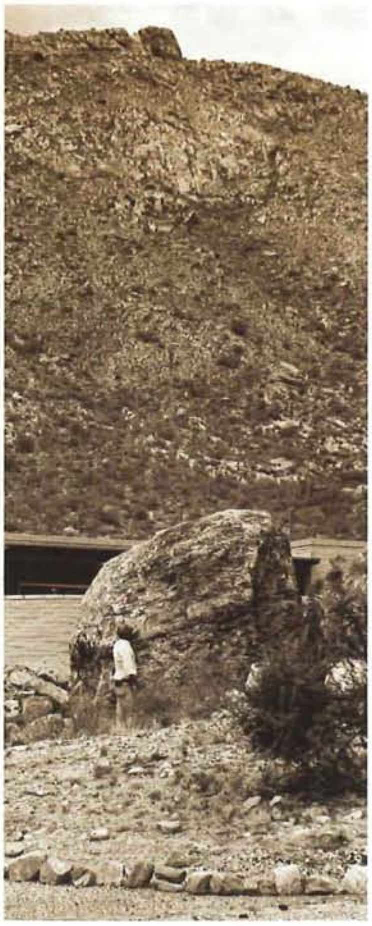


Construction excavation may oversteepen slopes, increasing the chance for slope failure. Fill material may settle, causing cracking in buildings.

Infiltration of water increases the weight and decreases the strength of slopes. Sources of water include rain runoff, leaking pipes or watering systems, deep landscape watering, and septic system drain fields. Preventing infiltration of water into slopes and fill material reduces the likelihood of failure. The stability of soil, weathered bedrock, and landslide deposits containing large amounts of clay may be improved by treating with calcium-bearing chemicals of the same type used to treat expansive soils. This treatment decreases the absorption of water, reduces expansion, and improves the strength of wet clay.

Rockfalls

In areas prone to rockfall, structures should not be built at the base of steep slopes or cliffs. On slopes that have weathered or loose rocks subject to falls or slides, stabilization measures include constructing barriers such as walls, anchoring large boulders with rock-bolts, or removing potentially unstable rocks.



A rock this large could destroy a house. Building on slopes that have large, loose boulders should be done with caution. *(Photo by H.W. Peirce)*

Mitigation considerations

Barriers such as walls, berms, or swales constructed at the upstream end of a property may reduce the risk from slope failure by diverting debris flows and small landslides away from structures. Walls must be reinforced and deeply anchored to withstand the force of a slide or flow. A permit is usually required to construct such a diversion structure. If a landslide, debris flow, or flood enters a neighboring property because of a diversion structure that you built, you could be held liable for damages.

Regular homeowners insurance does not cover debris flows and other events related to floods. Additional flood insurance coverage for mudflows, mudslides, and flood-related erosion (such as mass movement) is available as part of the National Flood Insurance Program. Contact your insurance company, the Federal Emergency Management Agency (FEMA), or the Arizona Division of Emergency Management for information on flood insurance.

Where To Go For Information

Although there has been no systematic compilation of hazards associated with mass movements in Arizona, numerous scientific papers have described mass movements in the state. The Arizona Geological Survey maintains bibliographic and map databases for Arizona. Current or prospective property owners can obtain this information about whether landslides, debris flows, or rockfalls have been recognized in their specific area of interest.

Several counties have adopted planning and zoning restrictions for building on slopes, although these regulations are mostly for aesthetic or environmental reasons, rather than for consideration of hazards. Check with your county Planning and Zoning or Engineering departments about any restrictions or building codes governing construction on slopes. Some information about debris-flow hazards may be obtained from county flood control districts or city floodplain management agencies. These agencies are listed in the blue Government section of the phonebook. Contact information and Internet links to these agencies are found on the AZGS website.

For advice on construction techniques, consult a structural, geotechnical, or geological engineer. Registered engineers are listed in the yellow pages of the telephone directory under "Engineers".

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Subsidence and Fissures

Subsidence near Eloy amounted to 15.4 feet from 1952 to 1985 and continues as more groundwater is pumped. The subsidence at this site has not been measured since 1985. *(Photo courtesy of Herbert Schumann)*

Land Subsidence

Withdrawal of groundwater at rates faster than natural recharge leads to lowering of water tables, eventually causing the land surface to lower or subside. More than 3000 square miles of central and southern Arizona, including parts of the Phoenix and Tucson metropolitan areas, have subsided because of groundwater pumping. Water levels in parts of Tucson's central well field declined by more than 150 feet by 1981. By 1986, more than 300 feet of groundwater lowering had been measured near San Simon, Apache Junction, Queen Creek, Harquahala Valley, and Luke Air Force Base. West of Casa Grande, the water table has dropped nearly 500 feet.

Groundwater produces a buoyancy force that supports part of the weight of the sediments that have been deposited in Arizona's numerous deep basins. Removal of groundwater and the associated buoyancy force results in compaction of the sediment, reduction of pore space, and subsidence at the Earth's surface. In every Arizona basin where substantial groundwater overdraft has occurred, subsidence has followed. The land has subsided more than 15 feet in the Picacho basin near Eloy and 18 feet in the Luke basin, west of Phoenix. In Tucson, subsidence was detected in re-leveling surveys in 1952, but maximum total subsidence was only about 6 inches by 1980. Recent surveys using a satellite-based method (radar interferometry) showed that subsidence is continuing as water levels decline under central Tucson. During the mid- to late-1990s, the Tucson area subsided about 0.6-0.8 inch per year. Based on the amount and rate of past subsidence, parts of the Tucson basin could experience an additional 2 feet of subsidence by the year 2030 if groundwater pumping continues at the current rate.

Subsidence can cause serious problems to infrastructure. Because irrigation canals, storm drainage systems, and sewage systems depend on gravity flow, subsidence can change carefully engineered slopes so the that flow can speed up, stop, or even reverse in extreme cases.

Gradients of streams flowing into a subsiding basin become steeper and cause increased erosion. Storm runoff may flood areas that have sunk and are now lower than their surroundings. Farm fields that are flood-irrigated may need constant re-leveling to ensure that water flows in the right direction. Water well casings can be so badly damaged by compaction from subsidence that new wells must be drilled. Land elevation surveys and contour lines on topographic maps are rendered obsolete when surface elevations change due to subsidence.

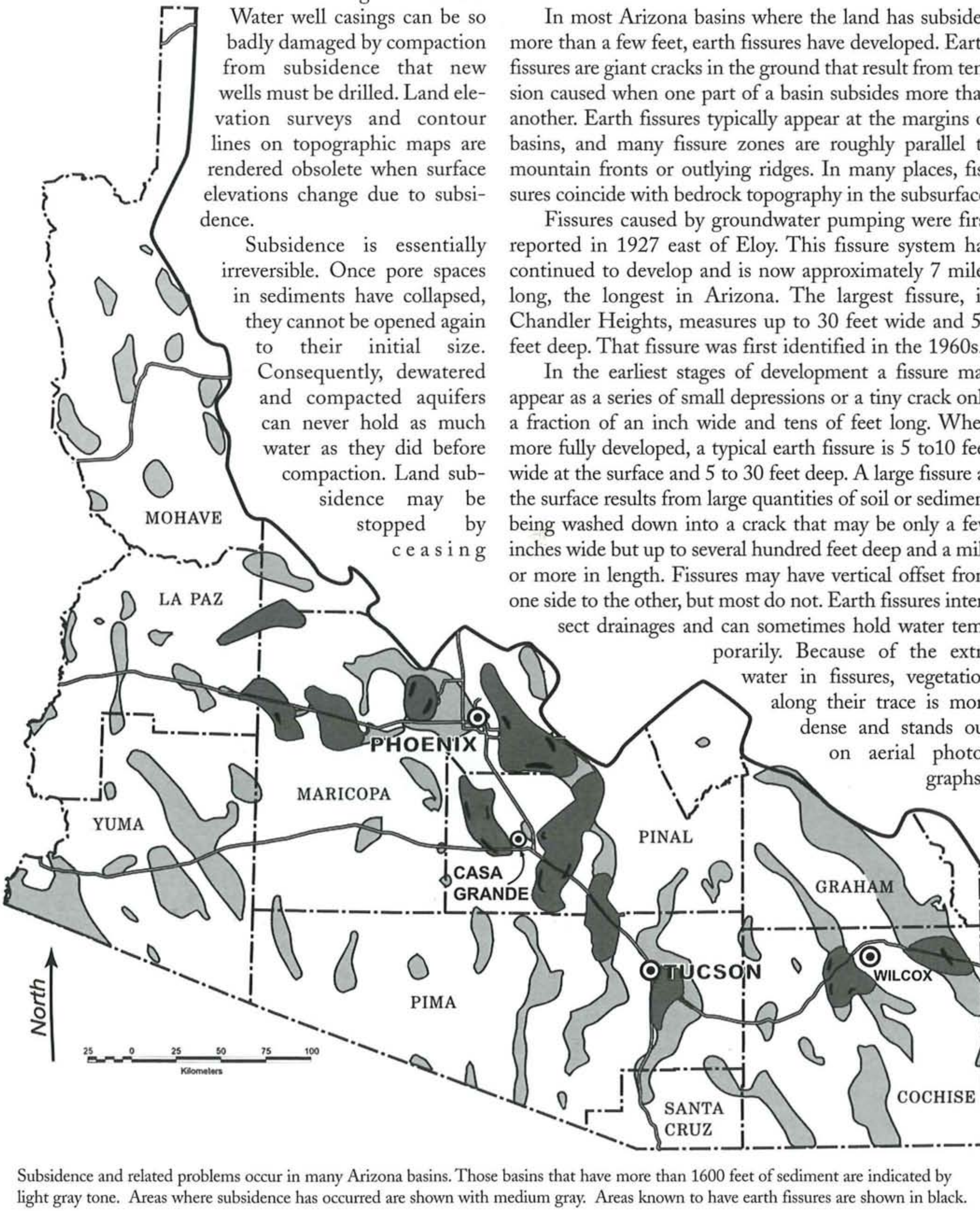
Subsidence is essentially irreversible. Once pore spaces in sediments have collapsed, they cannot be opened again to their initial size. Consequently, dewatered and compacted aquifers can never hold as much water as they did before compaction. Land subsidence may be stopped by ceasing groundwater overpumping, but recovery of groundwater levels does not bring the ground surface back to its original elevation.

Earth Fissures

In most Arizona basins where the land has subsided more than a few feet, earth fissures have developed. Earth fissures are giant cracks in the ground that result from tension caused when one part of a basin subsides more than another. Earth fissures typically appear at the margins of basins, and many fissure zones are roughly parallel to mountain fronts or outlying ridges. In many places, fissures coincide with bedrock topography in the subsurface.

Fissures caused by groundwater pumping were first reported in 1927 east of Eloy. This fissure system has continued to develop and is now approximately 7 miles long, the longest in Arizona. The largest fissure, in Chandler Heights, measures up to 30 feet wide and 50 feet deep. That fissure was first identified in the 1960s.

In the earliest stages of development a fissure may appear as a series of small depressions or a tiny crack only a fraction of an inch wide and tens of feet long. When more fully developed, a typical earth fissure is 5 to10 feet wide at the surface and 5 to 30 feet deep. A large fissure at the surface results from large quantities of soil or sediment being washed down into a crack that may be only a few inches wide but up to several hundred feet deep and a mile or more in length. Fissures may have vertical offset from one side to the other, but most do not. Earth fissures intersect drainages and can sometimes hold water temporarily. Because of the extra water in fissures, vegetation along their trace is more dense and stands out on aerial photographs.



Subsidence and related problems occur in many Arizona basins. Those basins that have more than 1600 feet of sediment are indicated by light gray tone. Areas where subsidence has occurred are shown with medium gray. Areas known to have earth fissures are shown in black.

(Above) At first glance, a typical earth fissure may look like a wash but has steep sides and does not have a flat, sandy bottom. *(Photo by Raymond C. Harris)*

(Above) One of Arizona's newest earth fissures, this one opened in the Harquahala Valley following heavy rain from Hurricane Nora in September 1997. *(Photo by Raymond C. Harris)*

(Right) A young earth fissure near Queen Creek made this road impassable. This fissure is in an area of rapid residential development. *(Photo by Raymond C. Harris)*

(Left) Earth fissures are sometimes used as dumps. Because earth fissures may be hundreds of feet deep and extend down to the water table, they could provide conduits for contaminants to reach aquifers. *(Photo by Larry D. Fellows)*

Earth fissures can cause significant damage to infrastructure such as roads, canals, railroads, and pipelines. Earth fissures may extend through the ground and beneath buildings for hundreds to thousands of feet. Buildings can suffer extensive cracking. Houses have been completely destroyed by fissures that opened up beneath them. The presence of cracks in foundations and walls, however, does not necessarily indicate that subsidence or earth fissures are to blame. Expansive soil, hydrocompaction, and normal settling of fill material can produce cracks similar to fissures that are caused by overdraft of groundwater.

Fissures pose a serious threat to water quality because they may serve as open conduits to the water table (aquifers). Contaminants that enter a fissure may travel almost unimpeded into regional aquifers that supply drinking water. Fissures have commonly been used as illegal dumping sites for household garbage, industrial waste, tires, construction debris, and animal waste. Using fissures for this purpose increases the potential for groundwater contamination.

Fissures also pose a potential safety hazard to humans and animals. A fall into a deep fissure may be life threatening. Some fissures cross roads and are large enough to swallow a motorcycle or car.

What To Do About Earth Fissures

One cannot predict with certainty where new fissures may develop. Fissure development requires that several conditions be met simultaneously: significant lowering of groundwater levels, substantial differential compaction of sediment, sediment of appropriate thickness and grain size, or buried bedrock topography (which aids differential compaction). New fissures commonly form in those areas that have already experienced fissuring. Newer fissures generally tend to form basinward of the older ones as indicated by studies of areas where both new and old fissures are found. Areas of known earth fissures have been well documented by geologists from the U.S. Geological Survey and Arizona Geological Survey, and in master's theses done by students at Arizona universities.

Earth fissures may be mitigated to some degree, but they are better avoided completely. Because fissures commonly open or become larger after heavy rains, runoff should not be allowed to flow into them. Water may be directed away from fissures with ditches, berms, or walls, or over fissures with culverts. Filling an active earth fissure with rock or soil is not an effective solution. Any active fissure that is filled may eventually begin to open again, especially after a large rainfall or application of irrigation water. Remember, a fissure is only a surface indication of a crack that may extend down hundreds of feet and have a length of thousands of feet.

The presence of earth fissures in an area does not mean that development cannot take place. It simply means that knowledge of the existing fissures and the potential for more fissures to develop must be taken into account when planning development to avoid future problems. Knowing where to locate certain types of structures (or more importantly, where *not* to locate them) can help prevent unnecessary repairs and legal costs later.

Where To Go For Information

Groundwater levels in wells are measured periodically by the Arizona Department of Water Resources, which has subsidence data for limited areas in the Phoenix region. The Arizona Geological Survey maintains the Center for Land Subsidence and Earth Fissure Information (CLASEFI), a clearinghouse for information on subsidence and earth fissures in Arizona. For more information, contact CLASEFI or visit the AZGS website.

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Radon

What Causes Radon Gas?

Radon gas is a radioactive element that is produced by the decay of uranium, which is present in virtually all rocks and soils, typically at concentrations of 1-4 parts per million (ppm). During the 1980s, scientists discovered that radon gas can accumulate in homes and other buildings at concentrations that are typically tens of times greater than in outdoor air. Most indoor radon gradually seeps in through cracks or other openings in the ground floor. Houses that have unusually high concentrations of indoor radon are most commonly situated on rock and soil that contain unusually high uranium concentrations.

The concentration of radon is generally measured in picocuries per liter (pCi/L), which is a measure of the number of nuclear decays per minute in a liter of air or water. One picocurie corresponds to about two decays per minute. The U.S. Environmental Protection Agency (EPA) established 4 pCi/L as a guideline for maximum acceptable indoor-radon concentration.

The ability of radon to migrate through soil is strongly dependent upon physical properties of the soil. Highly fractured rock and coarse, well-drained soil are likely to be highly permeable to radon, whereas clay and mud, particularly if wet, do not permit much radon movement. Radon originating from depths greater than a meter or two generally does not reach the surface because it decays before it can get there.

Radon typically diffuses out of underlying soil and into basements, crawl spaces, and lower levels of homes or buildings, eventually reaching upper levels as well. Water pumped from wells in uranium-rich rock and used within a week or two from the time it was pumped from the ground may release significant amounts of radon to the indoor air through a shower or sink.

Probably the most significant factor affecting radon infiltration into homes is the difference in air pressure between outdoor air and indoor air at ground level. If indoor air pressure is lower, soil-gas flows out of underlying soil and into homes. Heating of indoor air causes reduced air pressure in basements and the lowest levels of homes. Consequently, warm indoor air rises to the upper levels of a house, and soil air that may contain radon is drawn in through cracks and other openings in the floor. When evaporative coolers are in use, the indoor air pressure is increased, preventing the influx of soil-gas.

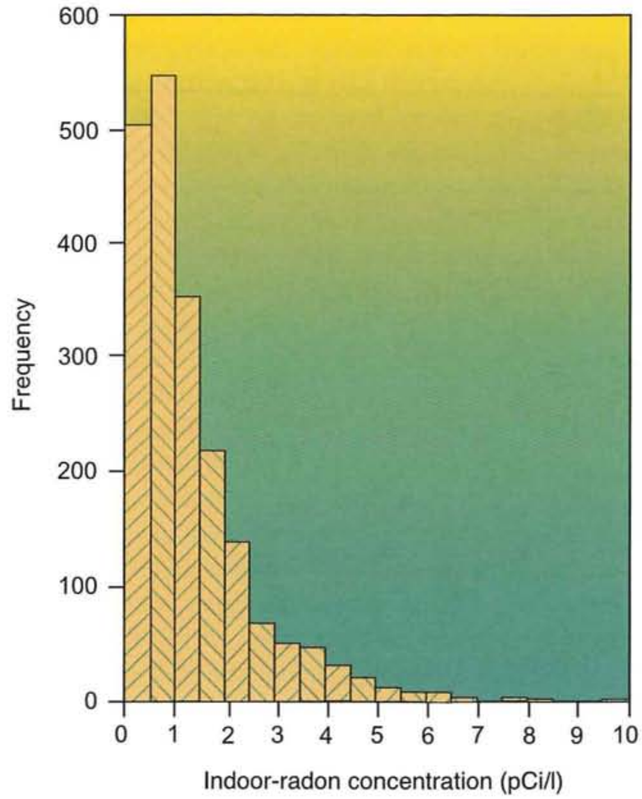
Radon In Arizona

The EPA classifies the entire state of Arizona as "Zone 2", which indicates moderate radon potential. Testing with charcoal canisters (mostly in winter when windows and doors are closed and radon accumulations are highest) showed that 5.4 percent of homes statewide have radon concentrations that are higher than 4 pCi/L. Tests with alpha track detectors, which give a more meaningful long-term average, indicated that only 1.6 percent of houses exceeded 4 pCi/L.

Measuring uranium concentrations in geologic materials is probably the most accurate way to identify areas that are at greatest risk of having elevated indoor radon concentrations. Most rocks have uranium concentrations of 1 to 4 ppm. Some areas that have been identified as having uranium concentrations higher than this are located within or near urban areas. Geologists can identify these areas with moderate uranium concentrations (4 to 40 ppm) as potential radon-hazard areas.

Most homes in the Tucson and Phoenix metropolitan areas, and in many other parts of southern and western Arizona, are built on young, unconsolidated to poorly consolidated alluvial sand, gravel, and derivative soil. High uranium levels are not known for these sediments. Limestone that was deposited in lakes is exposed in many localities in Arizona and is the most common type of rock that has elevated uranium levels in or near popu-

This chapter summarized from *Radon Gas, a Geologic Hazard in Arizona*, by Jon E. Spencer, 1992, Arizona Geological Survey Down-to-Earth 2.



Histogram of radon levels determined using charcoal canisters. This testing was conducted by the Arizona Radiation Regulatory Agency in 1987 and 1988, primarily during winter months under low-ventilation conditions.

lation centers. Some granitic rocks also have anomalously high uranium levels. Homes built on granitic rocks and decomposed granitic rocks seem to have the greatest potential for elevated radon levels even if underlying rocks contain only average uranium concentrations. This may be because fractured and weathered granitic rocks have greater permeability than other common rock types, and a larger proportion of the radon present in the rock can escape.

Tucson Area

The only rock in the entire Tucson metropolitan area that is currently known to contain high concentrations of uranium is limestone in southwestern Tucson near the intersection of Cardinal Avenue and Valencia Road. Chemical analyses indicate that uranium concentrations are as high as 20 ppm at the center of the anomaly. Several dozen houses are built on this limestone. Many of these houses had radon levels greater that the EPA's 4 pCi/L guideline level when they were tested in 1987 by the Pima County Health Department.

Phoenix Area

The only rocks in the entire Phoenix metropolitan area that are currently known to contain high concentrations of uranium are located in the Phoenix Mountains just west of Cave Creek Road. In this area, a volcanic rock unit (basalt or basaltic andesite), exposed over approximately one eighth of a square mile, contains uranium concentrations that are two to four times greater than typical for Arizona rocks.

Cave Creek Area

Limestone in the New River-Cave Creek area contains uranium at concentrations as much as 100 times the regional background. This limestone forms a narrow, discontinuous belt along the north flank of the valley in which the town of Cave Creek is located. Because of their limited outcrop extent, these rocks are not likely to cause above-normal radon levels in many homes, but could potentially be the cause of greatly elevated levels in a small number of homes.

Verde Valley

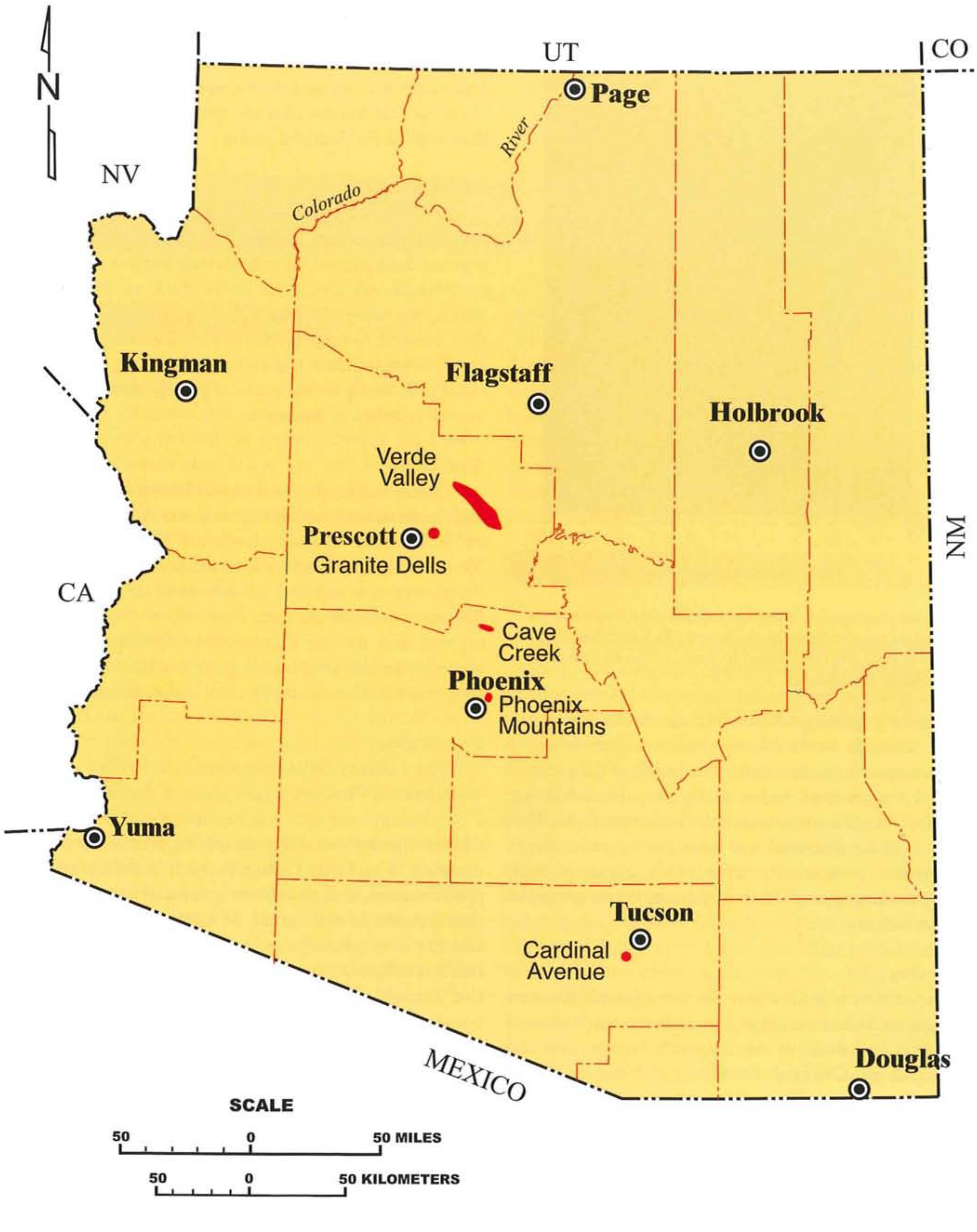
Calcareous mudstone and soft limestone that contain high levels of uranium are exposed over many square miles in Verde Valley. Uranium levels are as high as 40 ppm. These rocks, which underlie much of the town of Camp Verde, are not exposed as far north as Cottonwood. Because of the large area over which these rocks are exposed and the significant urban development that is occurring in the area, buildings throughout Verde Valley have potential for elevated indoor-radon accumulation.

Prescott Area

The Granite Dells, approximately 5 miles northeast of downtown Prescott, is composed of the Dells Granite, a 1.4-billion-year-old granitic intrusion. Many intrusions of this age contain unusually high concentrations of uranium. The Dells Granite, which contains up to 40 ppm uranium, is exposed over an area of approximately 5 square miles. In one survey, 51 homes built on the Dells Granite were tested for radon under minimum air-ventilation conditions (no open windows or running evaporative coolers). Approximately 60 percent of the tested homes had indoor radon levels above the EPA's 4 pCi/L guideline level. Water from wells in the Dells Granite contains unusually high radon concentrations.

How To Detect And Reduce Radon

Testing is the only way to determine whether a home has a high level of indoor radon. Two types of radon monitors are commercially available for use in homes and other buildings. One is the charcoal canister, a small can that is placed in the home for several days and returned to the manufacturer for analysis. Though useful for a quick "spot check," this type of detector does not measure average



Radon potential is low in most of Arizona. Areas in red have higher potential for radon (based on uranium concentrations in underlying bedrock and sediments).

radon levels over longer time periods. Do-it-yourself charcoal canister test kits are available at most hardware stores, in the same section with smoke detectors.

The other type of detector consists of a plastic film that records the tracks of alpha particles that are emitted by atmospheric radon and its decay products. The detector can be placed in a home for months or even a year, to record the long-term average radon concentration, which more accurately reflects health hazard. These detectors are more expensive ($30 to $50) than charcoal canisters ($15) and are not very accurate at determining low radon concentrations. As a result, they are most useful for follow-up measurements where a canister test has indicated concentrations above the 4 pCi/L guideline.

The most common method of reducing indoor-radon levels is to seal the floor so that soil-gas cannot easily enter the home. Other methods include ventilating the basement or crawl space, using fans to suck air from the basement or crawl space to the outside, and placing pipes under the home (sub-slab ventilation) to remove soil gas before it reaches the home. Use of evaporative coolers and electrostatic dust filters also reduces radon levels.

Where To Go For Information

Information about radon gas—such as guidelines for maximum acceptable indoor-radon concentrations, lists of certified commercial vendors for radon measurement and mitigation, methods for lowering radon concentrations in homes, and EPA radon publications—can be obtained from the Arizona Radiation Regulatory Agency in Phoenix. Levels of radionuclides in water supplies are monitored by water companies or utilities and are compiled by the Arizona Department of Environmental Quality.

Information about the distribution of uranium and radon in rocks and soil in Arizona is available at the Arizona Geological Survey (AZGS). Check out the AZGS website for information about the geology of radon, online radon publications, links to other sources of information, and contacts.

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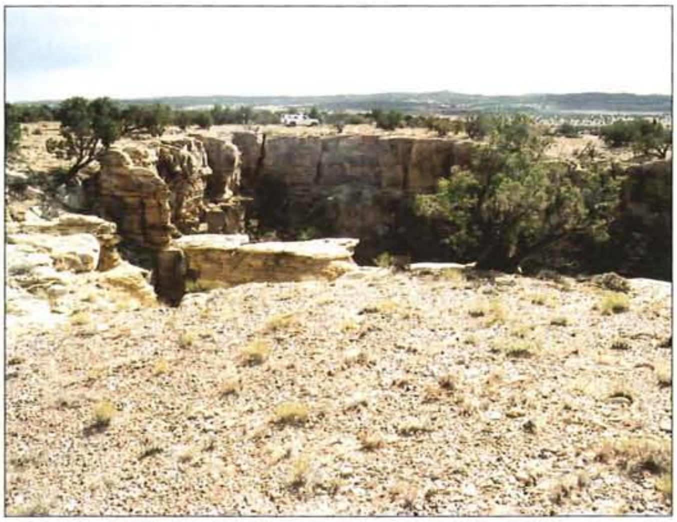
Karst



This giant sinkhole is the result of the dissolution of thick salt layers hundreds of feet below the surface. The size of this sinkhole can be judged by the truck in the background. *(Photo by Raymond C. Harris)*

What Is Karst?

Karst is the name applied to landforms that develop in areas underlain by comparatively soluble rocks such as limestone, gypsum, and salt. Karst terrain is characterized by solution features such as caves, sinkholes, depressions, enlarged joints and fractures, and internal drainage that can have a negative impact on use of the land. The name was derived from the Karst region of Slovenia (part of the former Yugoslavia), which is underlain by limestone.

The passage of water through soluble rocks results in the formation of cavities in the rock. If the ceiling of a cavity collapses, a sinkhole may form at the ground surface. Karst terrain is commonly characterized by highly uneven depths to bedrock; residual red, clay-rich soil; and surface drainages that disappear underground. Voids in bedrock can capture surface-water flow and disrupt the surface drainage system. Soil and other surficial material may be washed into the underground network of cavities.

Hazards from karst include the formation of sinkholes or collapse pits, as well as cracking of walls, foundations, roads, and other structures. Less obvious but equally important are the impacts karst can have on water quality. Networks of interconnected caverns and voids allow contaminants such as sewage, landfill leachate, or hazardous chemicals to travel unimpeded into shallow aquifers that may supply drinking water. The possible presence of solution features must be carefully considered when making land-management decisions, including protecting water supply, locating septic systems, and siting of waste disposal facilities.

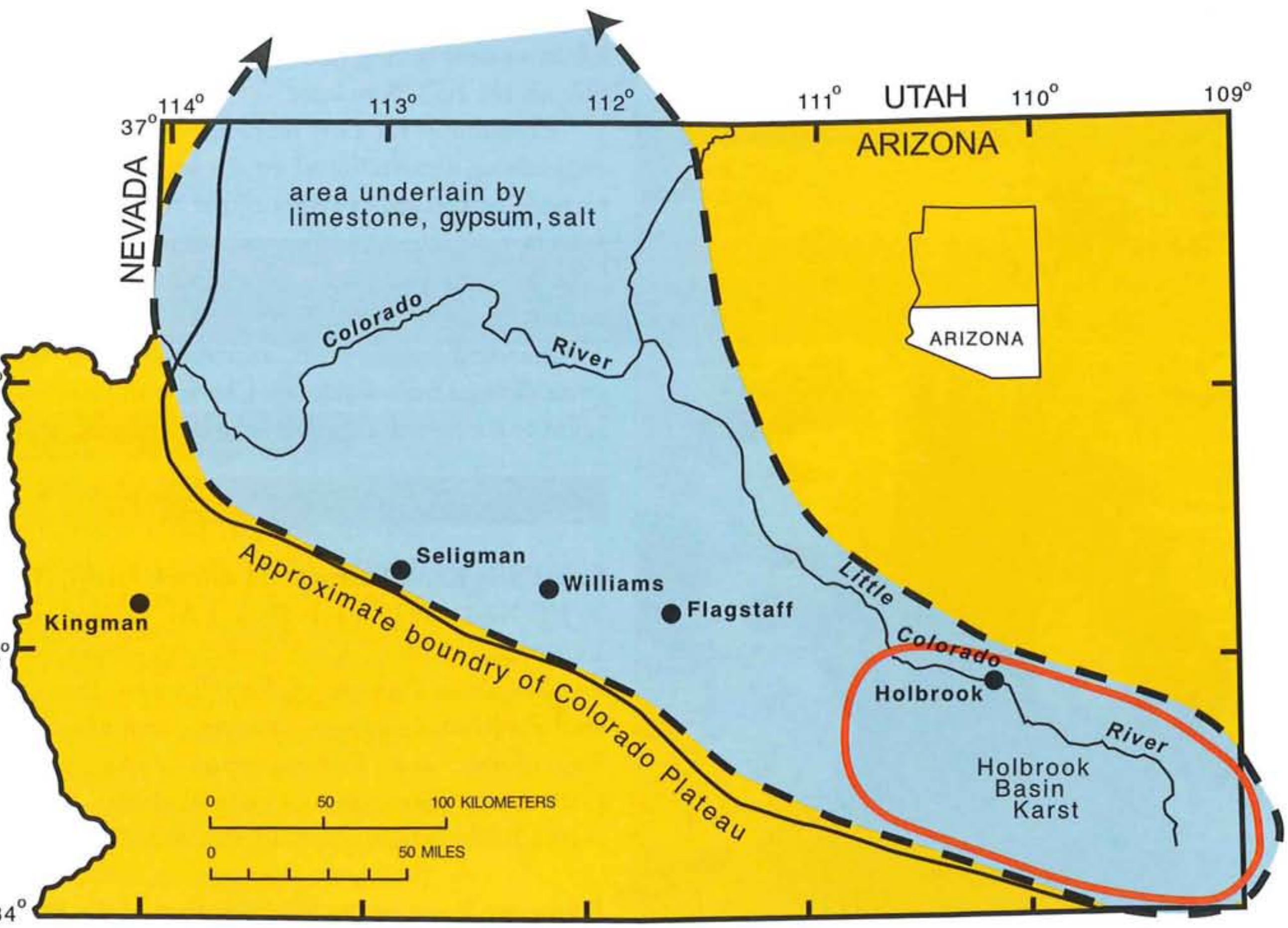
Areas In Arizona Affected By Karst

Karst terrain is common on the Colorado Plateau of northern Arizona. Because the Colorado Plateau has extensive areas of limestone at the surface and gypsum and salt in the subsurface, there is potential for property damage and severe water-quality problems related to dissolution of these soluble rocks. Karst features are particularly common south of Interstate 40, from the Springerville-Saint Johns area northwest to Winslow, and in the Grand Canyon region from Flagstaff to the Utah border.

Karst in the southern part of the Colorado Plateau resulted from the dissolution of salt and gypsum beds. Collapse propagated upward through the overlying sandstone and limestone. Minor karst features are also forming at the surface in limestone. More than 300 sinkholes have been identified in the area between Springerville and Winslow.

On topographic maps, sinks show up as small depressions that have internal drainage and commonly contain small lakes. In limestone terrane in northern Arizona, open caverns are encountered commonly when drilling water wells. In the Sedona area sinkhole collapse has occurred in historic times.

Karst features also are present in southern Arizona in areas underlain by limestone. Examples are Colossal Cave near Tucson, Kartchner Caverns near Benson, and numerous other caves in the mountains of southeastern



The Colorado Plateau of northern Arizona has large areas of karst features. Most of the karst in the Holbrook region is related to dissolution of thick layers of salt at depth. In other parts of the plateau, karst features result from dissolution of limestone exposed at the surface.

Arizona. Because exposures of limestone in southeastern Arizona are not as extensive as on the Colorado Plateau, collapse features are not as common. Solution features such as enlarged joints and small caves are numerous, however, and present the same concerns for water quality as those on the Plateau.

What To Do About Karst

Surface karst features

If you are planning to build in an area that has the potential for karst, we strongly advise that you thoroughly examine a property for signs of karst features before construction. When exposed at the surface, karst features are usually quite obvious. Depressions, holes, and fissures are readily apparent on the ground and, if large enough, can be distinguished on aerial photographs or topographic maps. Geologic maps show areas underlain by limestone.

The simplest method to mitigate a sinkhole or depression is to fill it in. However, this method works only if the sinkhole is inactive and is already mostly filled in at depth. If a sinkhole is still open at depth and connected to other voids, surface material may continue to wash into the voids. Filling an active sinkhole may be only a temporary solution. In any case, surface drainage should be directed away from karst features to avoid piping or collapse.

Hidden karst features

Problems can arise when solution features are hidden or are not obvious at the surface. The additional weight of a building may cause collapse if the roof of a cavern is close to the surface. A septic system installed over unidentified voids may result in water contamination.

To detect the presence of near-surface karst, several geophysical methods can be employed. These include ground-penetrating radar, electrical resistivity, spontaneous potential, gravity, and magnetic surveys. These methods rely on differences in physical properties between the caverns or their filling materials versus the surrounding rock.

Bending of rock layers above voids created by dissolution of salt at depth has caused giant cracks southwest of Holbrook. *(Photo by Raymond C. Harris)*

Differential settling is an indirect problem associated with building on karst. Because karst regions often have variable depth to bedrock, a building may sit partly on soil and partly on solid bedrock. Settling of the soil may occur, causing cracking of foundations and walls. Compounding the potential for fill-related structural damage is the abundance of expansive clay in soils on the Colorado Plateau, which may cause its own problems. (Expansive clay is discussed in the chapter on **Problem Soils**.)

Where To Go For More Information

U.S. Geological Survey topographic maps depict depressions and sinkholes in numerous areas on the Colorado Plateau. Topographic maps may be purchased at outdoor and sporting goods stores, map stores, and Arizona Geological Survey (AZGS). Geologic maps of karst areas are available from the AZGS and USGS. Links to sites having information about karst are available on the AZGS website.

Consultants for karst problems may be found in the engineering (geotechnical or geological), or geologist sections of the yellow pages of the telephone directory. Information about building restrictions in karst terrain may be available from county planning and zoning departments.

Standard homeowners insurance may or may not cover damage from sinkholes. Check with your insurance agent to confirm if karst-related damage is included.

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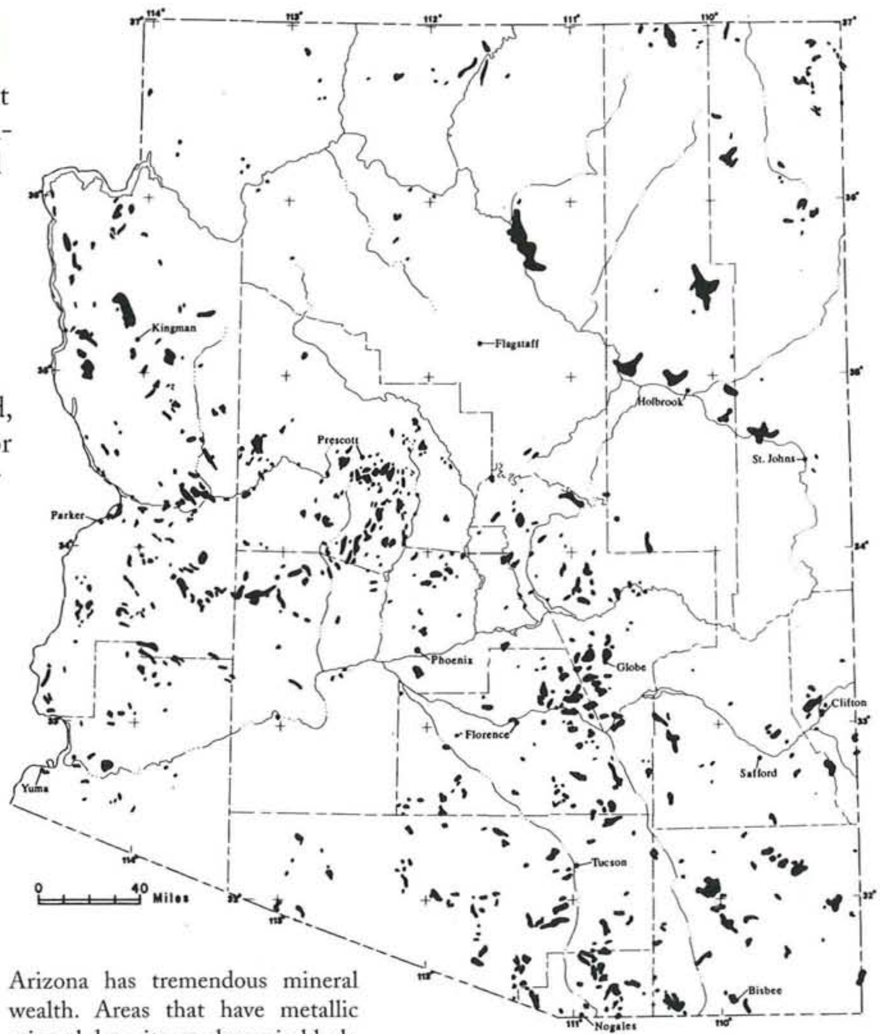
Abandoned Mines

Mineral Deposits And Mines

Arizona is endowed with abundant mineral resources, and for hundreds of years prospectors and geologists have looked for those scattered places where mineral deposits have formed. Our modern standard of living and economic prosperity have been made possible by utilizing natural resources from the earth.

Before resources can be exploited, they must be discovered. In exploring for mineral deposits, prospectors commonly dug holes in the bedrock to determine if mineralization indicated at the surface continued to greater depths. These relatively small holes are called "prospects". The majority of digging by prospectors consists of these prospects, from which no mineral production ever took place. Only if ore was discovered in great enough quantity and rich enough concentration during prospecting would any further digging take place. Larger holes, where valuable material was taken out in commercial quantities, are called mines. In most of these mines, ore eventually ran out or mining became uneconomical for other reasons and the mine was abandoned.



Arizona has tremendous mineral wealth. Areas that have metallic mineral deposits are shown in black.

Thousands of prospects and several hundred mines are scattered across Arizona. In most usage, prospects are lumped together with old mines of every size and all are referred to as "abandoned mines." These mines and prospects are shown on U.S. Geological Survey topographic maps with various symbols. Typically there are many more openings on the ground than are shown on the maps.

Hazards Associated With Abandoned Mines

Most mineral exploration has taken place on public land because private land is predominantly in valley areas where bedrock is not exposed. Until recently, if a valuable ore deposit was discovered, the public land containing the deposit could be converted to private land through a process called patenting. Today, all of Arizona's major mines are on private land, as are many

Mine Symbols used on USGS Topographic Maps

- × prospect
- ⤙ adit (horizontal opening)
- ◩ shaft (vertical opening)
- ⤧ pit or quarry
- waste rock or slag

of the abandoned mines. In many places, these patented areas are prime real estate because they are situated in the mountains, where views are spectacular.

As Arizona's population grows, development is encroaching into the margins of mountain ranges where numerous areas have been heavily prospected for minerals. As more houses are built near mountains, abandoned mines become a potential hazard or liability to property owners. The main concern with abandoned mines and prospects is that of public safety. Most important is the danger of a person falling into an opening and being injured. A fall of 5 to 10 feet can be serious, and a fall of more than 20 feet can be fatal.

In areas where extensive underground mining has occurred, collapse of workings may produce subsidence at the surface. Subsidence from mine collapse has become a problem in Tombstone, for example, where a labyrinth of drifts and stopes were dug directly under the town. Sinkholes have opened in streets where old workings collapsed.

There are many hazards inside abandoned underground mines. Collapse of loose rocks underground can crush a person or close off the opening, stranding the person. Timbers, although they may look like they are in good condition, are usually affected by dry rot and offer little protection against roof collapse. Inside underground mines, workings may include additional shafts, called winzes. A winze that is completely covered by planks is especially dangerous. A person who walks over the planks may not be aware that a shaft is beneath the boards. If the wood is rotten, it can collapse and cause a person to fall down a deep shaft.

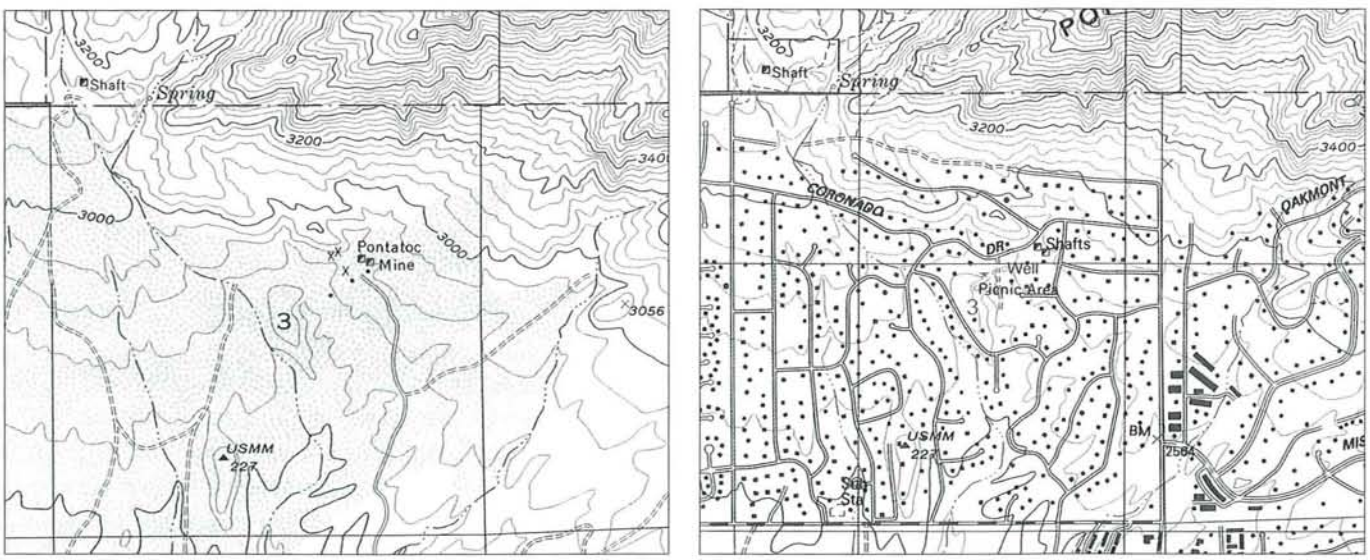
Water in a mine presents a danger from poisonous dissolved gases such as hydrogen sulfide, which can be released to the air by the stirring action from walking through the water. Water can completely fill a winze and make it look like a small puddle. An accidental fall into a water-filled winze can result in drowning.

Gases may accumulate in unventilated underground mines. Some gases, such as carbon dioxide and methane, can displace enough oxygen to make the air deadly. Other gases, such as hydrogen sulfide, are toxic at very low concentrations. By the time you become aware of dangerous gases, it is usually too late.

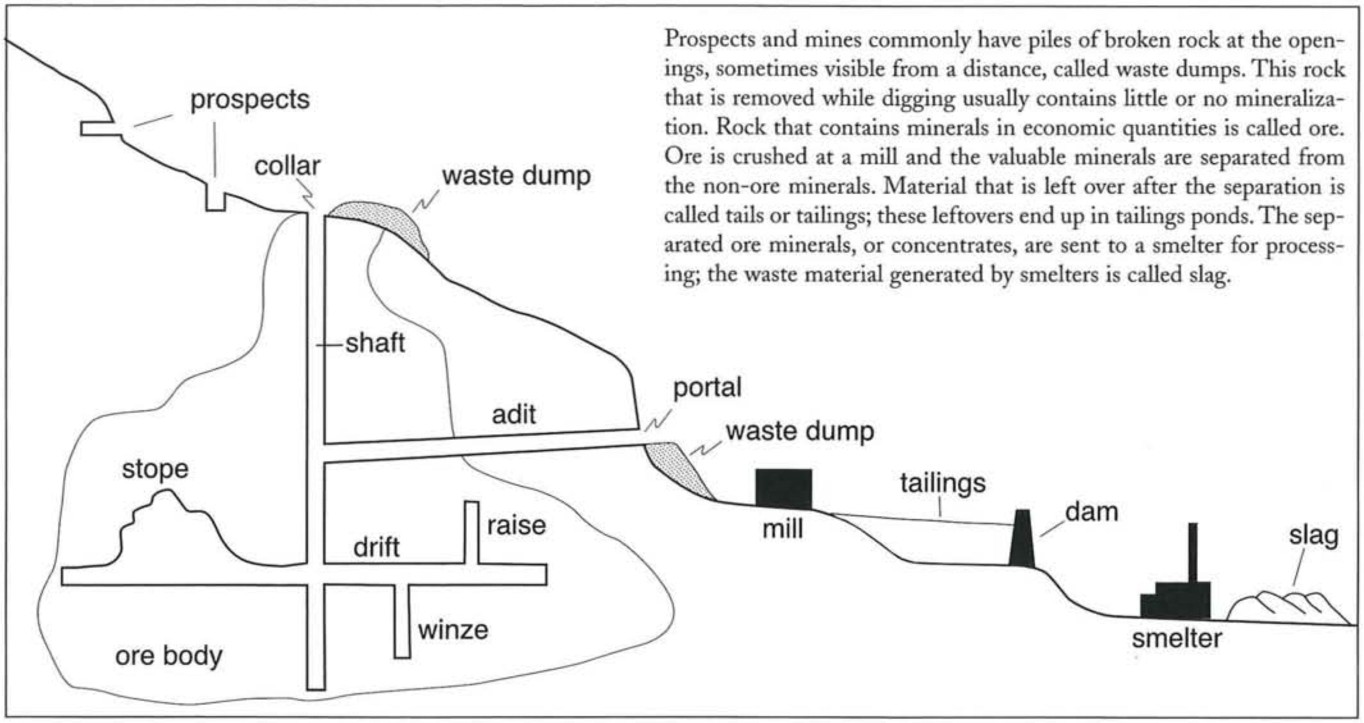
Explosives may be present in old mines. With age, these explosives become increasingly unstable and can explode with the slightest touch or vibration. Old explosives or primers should never be handled, nor should the containers they came in.

What To Do About Abandoned Mines

By Arizona law, landowners or claimants are responsible for maintaining safeguards against accidental injuries to people caused by abandoned mines. Even if a person is trespassing, an injury resulting from an aban-



These maps show encroachment of development into an area of north Tucson where numerous old mines exist. The map on the left is from 1957. The map on the right shows the same area in 1984. Houses are indicated by black dots.



Prospects and mines commonly have piles of broken rock at the openings, sometimes visible from a distance, called waste dumps. This rock that is removed while digging usually contains little or no mineralization. Rock that contains minerals in economic quantities is called ore. Ore is crushed at a mill and the valuable minerals are separated from the non-ore minerals. Material that is left over after the separation is called tails or tailings; these leftovers end up in tailings ponds. The separated ore minerals, or concentrates, are sent to a smelter for processing; the waste material generated by smelters is called slag.

Dangers associated with abandoned mines

Falling into an open shaft or pit
Falling rock or roof collapse
Rotten timbers and ladders
Lack of oxygen or buildup of toxic gases such as hydrogen sulfide
Dangerous animals (mountain lions, javelinas, rattlesnakes)
Explosives

doned mine may result in a lawsuit against the landowner. At a minimum, any opening should be properly fenced or sealed to prevent accidental falls into mine workings, and warning signs should be posted to protect a property owner against liability.

Mitigation is fairly easy for prospects and small mines. Material can be put in the opening to fill up the hole, and the surrounding area can be reshaped to the natural topography. In some cases a cement plug can be placed in the opening to reduce the amount of material needed to fill the hole.

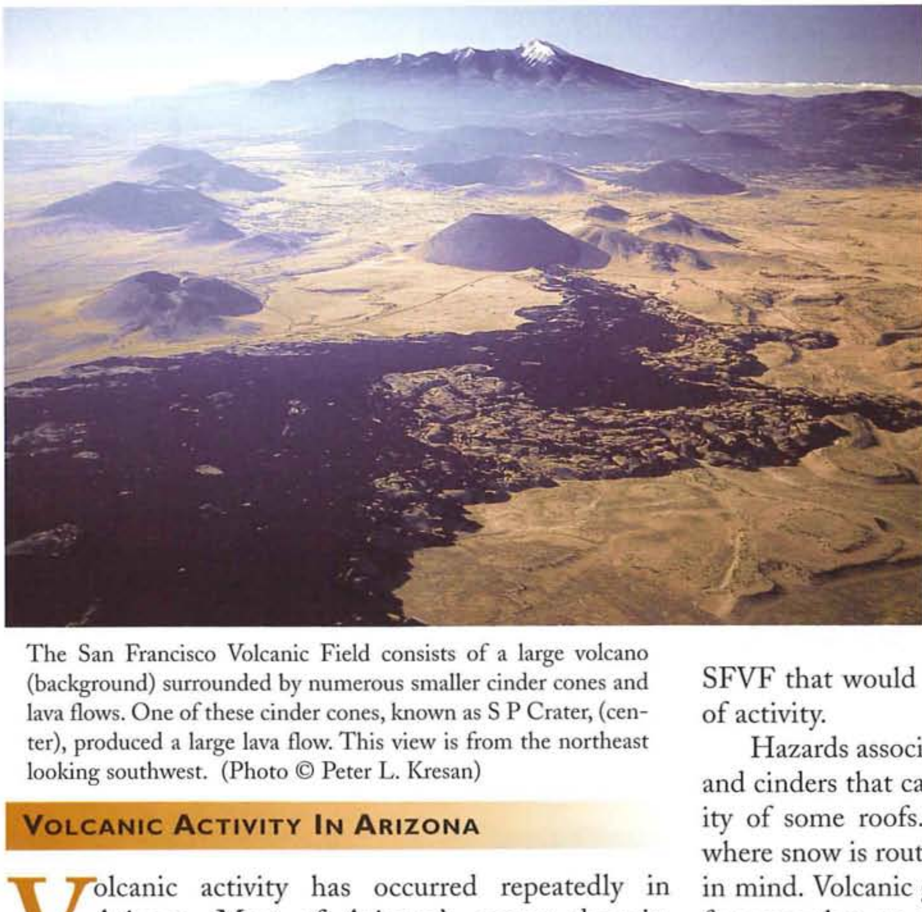
Some prospects and mines are home to a variety of wildlife. Some animals are attracted to these openings because of water that may be present, the cool shade, or the safety of a deep hole in which to make a temporary shelter. Barn owls and bats are the most commons animals inhabiting abandoned mines. Grates or nets may be placed over openings to keep people out but still provide access by wildlife.

Where To Go For Information

The Arizona State Mine Inspector in Phoenix provides information about the location and mitigation of abandoned mines and prospects. For information about mineral resources and mines in Arizona, contact the Arizona Department of Mines and Mineral Resources in Phoenix. For information about the geologic character of mineral resources, contact the Arizona Geological Survey. To find areas where old prospects and mines are located, consult books about rockhounding, mining camps, and ghost towns.

A fall into an abandoned shaft can be fatal. Abandoned mines should be fenced to keep people out. *(Photo by Raymond C. Harris)*

Volcanic Hazards



The San Francisco Volcanic Field consists of a large volcano (background) surrounded by numerous smaller cinder cones and lava flows. One of these cinder cones, known as S P Crater, (center), produced a large lava flow. This view is from the northeast looking southwest. (Photo © Peter L. Kresan)

Volcanic Activity In Arizona

Volcanic activity has occurred repeatedly in Arizona. Most of Arizona's copper deposits formed during intense volcanism 70 to 55 million years ago. Another episode of widespread volcanic activity occurred from about 30 to15 million years ago. Although widespread volcanism decreased markedly about 15 million years ago, some volcanic activity has continued to the present. The San Francisco Volcanic Field (SFVF), in the Flagstaff-Grand Canyon region of northern Arizona, represents some of this 'leftover' volcanism. Lava flows and cinder cones erupted as recently as 800 years ago.

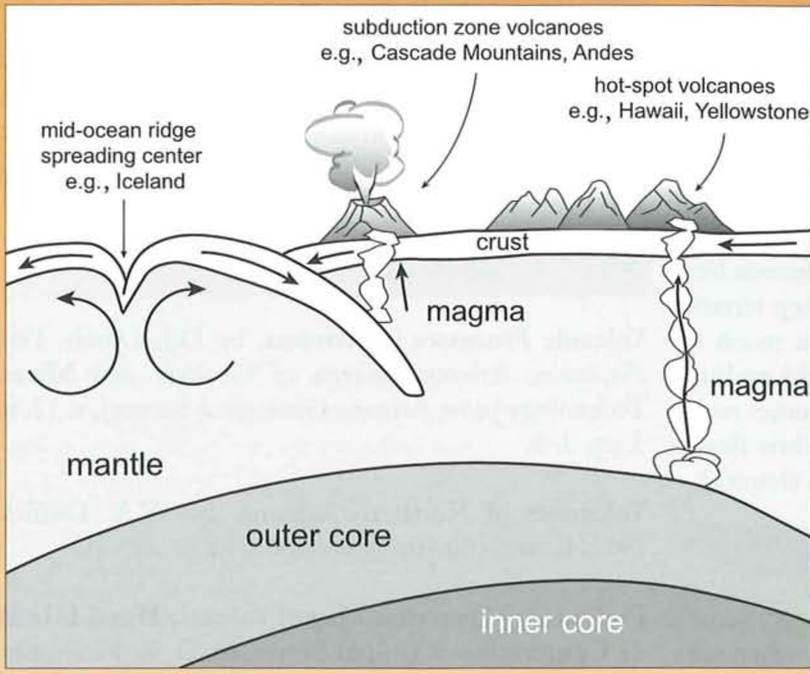
Active Volcanism In Arizona

Although volcanoes have erupted in Arizona numerous times in the geologic past, they pose little risk today. Volcanic eruptions are preceded by swarms of small earthquakes and occasionally by venting of volcanic gases. An eruption without warning is unlikely.

The most active volcanic region in Arizona is the southwestern Colorado Plateau. A zone of volcanic activity migrated slowly northeastward during the past 15 million years from south of the Mogollon Rim in central Arizona to its present position immediately northeast of Flagstaff. Although eruptions in the Grand Canyon-Flagstaff region have occurred as recently as about 800 years ago, there has been no sign of recent magma movement beneath the SFVF that would signal the beginning of a new phase of activity.

Hazards associated with volcanic activity include ash and cinders that can overload the weight-bearing capacity of some roofs. Houses built in the Flagstaff area, where snow is routine, are already designed with loading in mind. Volcanic gases include carbon dioxide and sulfur gases that are sometimes at concentrations that may be harmful to breath. The kind of volcanic eruptions characteristic of the SFVF, however, tend to produce only small quantities of ash and gas.

As with earthquakes, Arizona could be affected by volcanic eruptions in nearby states. Ash clouds from violent volcanic eruptions can travel across the continent, dropping several inches of ash hundreds to thousands of miles away. The closest known active volcanic area that could impact Arizona is the Long Valley caldera region along the east side of the Sierra Nevada in east-central California. The Mammoth Lakes area, part of this volcanic center, has experienced signs of activity recently, including earthquake swarms and venting of gases. Although the likelihood of a volcanic eruption in anoth-



How Magma Forms

Volcanic rocks form in several distinct settings. Along margins where tectonic plates are diverging from each other, igneous rocks erupt in a process called sea floor spreading. The rocks formed there are solidified basalt lava flows. Sea floor spreading centers, or mid-ocean ridges, extend around the globe like seams on a baseball. Some of the oldest rocks at Jerome, in central Arizona, including the large copper deposit there, formed at a sea floor spreading center 1.8 billion years ago.

Another type of volcanic activity is the result of pools of magma, called "hot spots," that form near the Earth's core-mantle boundary. Magma generated there punches its way through the mantle and crust, erupting enormous volumes of lava at the surface. A long chain of large volcanoes that increase in age away from the current volcanic vent are formed as a tectonic plate moves over the hot spot, which is stationary. Chains of volcanoes that formed in this manner include the Hawaiian Islands, Galapagos Islands and volcanic centers of the Snake River-Yellowstone region.

A third setting for igneous activity is above subduction zones, where tectonic plates are colliding. As one plate descends beneath another, the subducted plate heats up and magma forms. This magma rises through the over-riding plate and forms long, narrow volcanic mountain ranges, such as the Cascade Mountains of the Pacific Northwest and the Andes of South America. Volcanic activity related to subduction has occurred repeatedly in Arizona. Most of Arizona's copper deposits formed during volcanism 70 to 55 million years ago. Another episode of widespread volcanic activity occurred from about 30 to 15 million years ago.

Visit the AZGS website for links to online information about volcanoes.

Sunset Crater (upper right) is a 1000-year-old cinder cone in the northeastern part of the San Francisco Volcanic Field. (Photo © Peter L. Kresan) er state significantly affecting Arizona is exceedingly small, ash clouds could cause damage if enough ash fell on roofs not strong enough to support the extra weight. Ash could also pose a danger to aviation by damaging aircraft engines. The impact of ash fall would depend on which direction the wind happened to be blowing when the volcano erupted.

Some of the hazards associated with volcanic peaks in the Flagstaff area are not direct volcanic hazards but, rather, those connected with any high and steep terrain. Because the peaks north of Flagstaff receive much of their precipitation in the form of snow, rapid melting may produce flooding. Steep slopes with loose rocks present the same hazards from landslides, debris flows, and rockfalls (discussed in **Mass Movements** chapter).

Planning for Volcanic Hazards

When will the next volcanic eruption occur? Geologists are unable to predict with certainty when volcanoes will erupt. When "dormant" (temporarily inactive) volcanoes awaken, they typically send signals in the form of earthquake swarms, bulging of the surface, or gas venting. Geologists consider the San Francisco Volcanic Field to be potentially active because eruptions have taken place less than a thousand years ago, which in geologic terms, is practically yesterday. At the present time, however, there are no indications of movement of magma that would herald the beginning of a new eruptive phase. Because there is so little risk in Arizona, special design or construction techniques are not warranted.

Where To Go For More Information

Geologic maps showing young volcanic rocks in Arizona are available from AZGS. General information on volcanic hazards is available from the U.S. Geological Survey Flagstaff Field Center and on the Internet at www.usgs.gov.

Selected References

Volcanic Processes in Arizona, by D.J. Lynch, 1982: *Fieldnotes*, Arizona Bureau of Geology and Mineral Technology [now Arizona Geological Survey], v. 12, no. 3, pp. 1-9.

Volcanoes of Northern Arizona, by W.A. Duffield, 1997: Grand Canyon Association, 68 p.

Preliminary Overview Map of Volcanic Hazards in the 48 Conterminous United States, by D. R. Mullineaux, 1976: U.S. Geological Survey Miscellaneous Field Studies Map MF-768, scale 1:7,500,000.

HISTORY OF ARIZONA GEOLOGICAL SURVEY

The 11th Legislative Assembly of Arizona Territory established the Office of the Territorial Geologist in Prescott in 1881. After the University of Arizona (UA) opened in Tucson in 1891, Territorial Geologists held joint appointments as faculty members in the College of Mines. In 1915, three years after Statehood, the legislature continued the functions of the Office of the Territorial Geologist within the Arizona Bureau of Mines, which was administered by the UA.

Sixty-two years later, in 1977, the legislature modernized the enabling statutes of the Arizona Bureau of Mines and renamed it the Arizona Bureau of Geology and Mineral Technology. In 1988, the legislature transformed the Geological Survey Branch of the Bureau of Geology and Mineral Technology into the Arizona Geological Survey (AZGS), a stand-alone State agency that reports to the Governor. The Arizona Oil and Gas Conservation Commission was attached to the AZGS for administrative and staff support in 1991.