Arizona Geology

Vol. 38, No. 3
Fall/Winter 2008

published by the Arizona Geological Survey

THE STATE AGENCY FOR GEOLOGIC INFORMATION

Tracking Arizona's Ancient Landscapes

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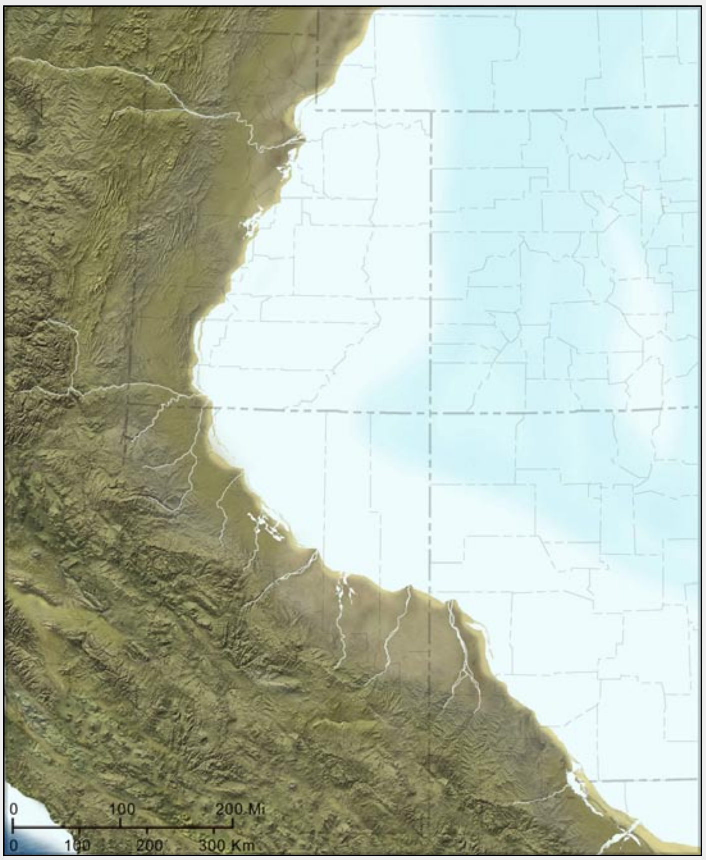
The rocks of Arizona not only yield a wealth of mineral resources but also a wealth of information that provides important clues to the State's varied and complex geologic history. Virtually all knowledge of Earth's past history comes from the rock record; the study of thousands of local rock sections and the orchestration of this information into a cohesive data bank, the geologic literature, provides the foundation for our knowledge of ancient geologic events. The ultimate synthesis of this information can be portrayed in paleogeographic maps – maps of ancient landscapes. Maps are instruments that show the distribution of things across an area, region, or globe. Paleogeographic maps show the distribution of landscapes of the past. The scale and detail of the maps are dictated by the concentration and quality of geologic data. More detailed data results in potentially more detailed maps. Geologic data has been gathered and analyzed across Arizona and adjacent regions for over 150 years. Spurred by economic and academic motives, this data has yielded incredible knowledge concerning the distribution of present and past geologic features.



The greatest extent of the Cretaceous Seaway in Arizona about 93 million years ago. Note that northern Arizona was lower in elevation than areas in the southern part of the state at this time. Modern state and county lines are shown for reference.

Although much communication by professional geologists is presented in technical reports and scientific literature, it is important for professional geologists to also communicate their science to non-geologists. Paleogeographic maps can actually serve both populations because they can simultaneously convey subtle geologic nuances to geologists while also providing a broader pictorial view of ancient landscapes to non-geologists. Our recent book, *"Ancient Landscapes of the Colorado Plateau"* attempts to communicate not only with geologists but also non-geologists—those with little geologic background but with a deep yearning to acquire information about the Earth's past. Although focused on the Colorado Plateau, the geologic province comprising the northern half of Arizona, the numerous maps cover all of Arizona. Each geologic formation in northern Arizona has at least one map that displays the ancient landscape in which that formation was deposited. (*Geologic formation* – a body of rock that consists dominantly of a certain lithologic (re: rock) type or combination of types; e.g., the Coconino Sandstone.)

Arizona's geologic history as represented by the rock record began 1.8 billion years ago when the continental crust (basement rock) was formed in mountains that stretched from Arizona to the Great Lakes. These mountains took form when a series of island arcs and small continents collided with southern North America, the edge of which lay in Wyoming at that time. Eventually those mountains were eroded to near sea level, providing the basement on which the spectacular layered sedimentary rocks of the Colorado Plateau were then deposited. These colorful rock layers formed in the myriad of shallow seas, deserts, rivers, and lakes that would cover Arizona throughout the last billion years of Earth history.

The paleogeographic maps that appear in "Ancient Landscapes of the Colorado Plateau" were prepared using the geologic

Mission

To inform and advise the public about the geologic character of Arizona in order to increase understanding and encourage 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

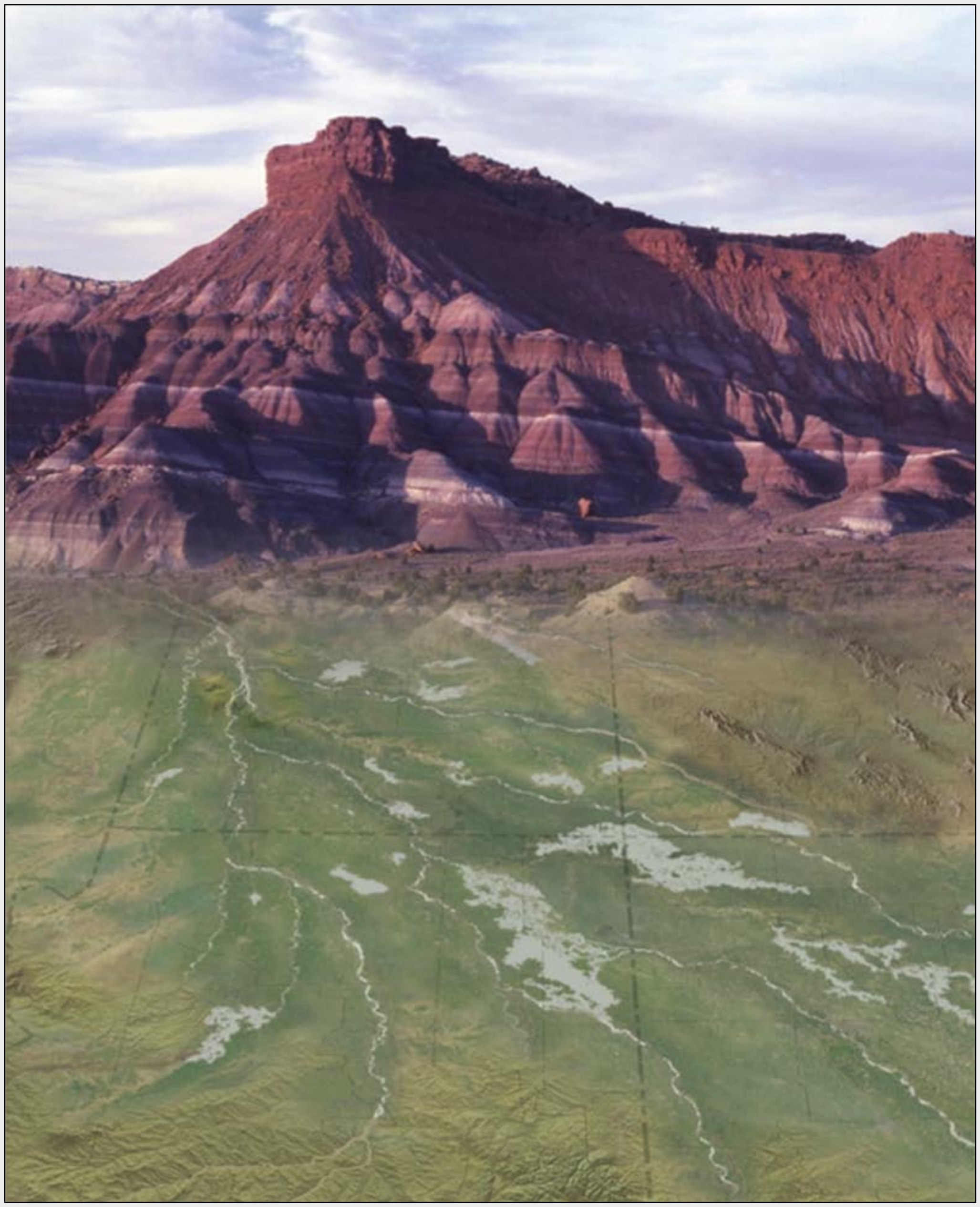
Investigate geologic hazards and limitations such as earthquakes, land subsidence, flooding, and rock solution that may affect the health and welfare of the public or impact land and resource management.

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.



Ordinary strata on the Colorado Plateau (like this outcrop of the Triassic Chinle Formation) allow geologists to reconstruct the ancient landscapes of Arizona and the American Southwest.

Shown is the northern two-thirds of Arizona, as well as large portions of Utah, Colorado and New Mexico.

information referred to above. A base map was selected at an appropriate scale with appropriate political boundaries used as a reference frame, in this case, state boundaries of the Southwest and county lines. For each map, a rough draft is constructed showing the location of seas, shorelines, coastal features, rivers, lakes, dune fields, uplands, mountains, and other features; these sketches can be done digitally on the computer or on paper. After the draft is checked and modified where necessary, the landscape is painted on a computer using the program Adobe Photoshop ®. Much of the landscape, especially mountains and uplands, is cloned from modern digital elevation maps. Because landscapes tend to be fractal, scale is only a minor issue – for example, a large, modern river system covering half of a continent can be scaled down to fit on a small portion of a paleogeographic map. The landscape is painted, using neutral colors for land and medium blue for water bodies. Colors are then adjusted to show water depth (pale blues for shallow, deeper blues for increasing depth) and climate on land (tans and reds for arid regions, greens for humid regions). The resulting maps are rechecked against the available geologic data and maps are compared to each other through time to check the logic of the geologic trends. If

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properly executed, little geologic knowledge is required on the part of the viewer to comprehend the information presented.

The time-slice intervals are selected depending on the scale of the project. For global scales, longer intervals between time slices are used, usually 20-30 million years. For the series of Colorado Plateau maps used in *"Ancient Landscapes"*, each geologic formation is illustrated by at least one map. This number varies greatly by geologic period. For example, for the Cambrian Period (50 million years long) three maps were chosen to show the Cambrian seas at three locations across the map area, corresponding to three formations in Grand Canyon. For the Jurassic, also 50 million years long, 12 maps were needed to illustrate the numerous formations and changing geologic conditions.

A single map represents a snapshot of time; of course, the actual time represented by that snapshot is an average over as short of span of time as possible. That interval is based on our ability to date and correlate rocks across the area of the map. Correlation of some rocks is difficult, especially where fossils are few. And parts of most formations are removed by erosion or buried below younger rocks. In these cases, extrapolation of known trends is used.

Sequences of paleogeographic maps can be used in various ways and at various levels of detail. For a given time slice, the user can compare changes over the area of the map. Trends can be visualized and sizes of topographic features can be measured. Over consecutive time slices, the geologic history of a given area can be evaluated; shoreline trends become apparent and climate changes are clearly portrayed. Professional geologists can use paleogeographic maps to convey complex geologic concepts to non-geologists or students.

Paleogeographic maps clearly illustrate the point that a picture is worth a thousand words. They communicate to a broad and diverse audience the complexities of the geologic history of the Earth.

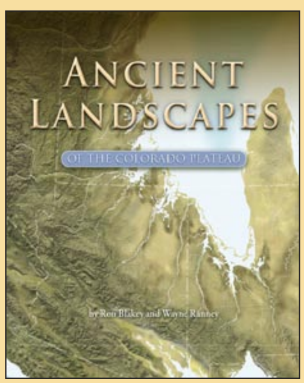
ANCIENT LANDSCAPES OF THE COLORADO PLATEAU: A BOOK REVIEW

by James I. Kirkland, State Paleontologist, Utah Geological Survey.

Ron Blakey and Wayne Ranney (2008).Grand Canyon Association. Grand Canyon, AZ.176 pp.
ISBN-13: 978-1-934656-03-7, $34.95 (alk. Paperback)

Jim Kirkland

The mountains, plateaus, mesas, and canyons of the Colorado Plateau region have attracted the attention of geologists since the earliest surveys of the southwestern United States more than 150 years ago. Nowhere in the world is there such a concentration of geological parks and monuments, each interpreting their portion of the Colorado Plateau's 1.75 billion years of Earth history. Ron Blakey and his many graduate students have been compiling stratigraphic data from the spectacular three dimensional outcrops of this region for more than thirty years. As a lowly paleontologist, I have long credited my own field skills to my time under Ron's influence during the late 1970s. Ron has taken advantage of his intimate knowledge of these rocks in constructing and continuously refining paleogeographic maps, which he has generously put online, permitting scientists and students to benefit from his hard work (http://jan.ucc.nau.edu/~rcb7/). Already acknowledged as having produced some of the finest paleogeographic maps available anywhere, Blakey and Ranney have stepped another light year ahead and set the bar mighty high with this beautiful book.



The 70-plus global views and paleogeographic maps of the southwestern United States in this wonderful oversized (9" x 12") book are no less than simulated satellite photographs of Earth through geologic time. More than 100 photographs of outcrops, rocks, and fossils serve to enlighten the reader as to the basic data the maps are based on, whereas the numerous diagrams illustrate the relationships between outcrops and the development of important geological features on the Colorado Plateau. Of course the book is the state of the art, but there are few areas in the world better understood geologically than the Colorado Plateau. I see a couple of the locales and times that I am most familiar with that I might tweak a bit, and there are still a couple of favorite moments in time I would like to see a paleogeographic map for, but this is nitpicking from a plateau paleontologist, whose love of this portion of the planet rivals that of the authors.

Following a short introduction, the first seven chapters present the paleogeographic maps in the context of the geological history of the Colorado Plateau region. An engaging narrative describes drifting of continents, rising and falling seas, an evolving biota, and changing paleoclimates reflecting the vast changes in the landscape over the Colorado Plateau in the context of the region's geology and modern landscapes across the world today. The last two chapters describe 17 specific sites on the Colorado Plateau where most of the geological history discussed may be observed. Finally, a short appendix explains in simple terms how these paleogeographic maps were made.

This book will be an often referred to resource for geologists, students, and for that matter, anyone who loves maps or is interested in geology or the southwestern United States in general. It should be in all major libraries as well as high school libraries, at least in the southwestern United States. I predict there will be many printings and hopefully future editions of this marvelous book.

James I. Kirkland
State Paleontologist
Utah Geological Survey

A primer on historical concepts on the origin and age of the Colorado River and the Grand Canyon

The origin of the Colorado River and the age of the Grand Canyon have piqued the interest—and imagination—of generations of geologists.

In 1946, in the American Journal of Science, Chester Longwell asked, "How old is the Colorado River?" Longwell was not the first to pose that question, as Powell, Dutton, Davis, Lee, and Blackwelder all got there before him. Dutton and Powell, working without detailed geologic maps or radiometric age dates, got it wrong; Dutton (1882) concluded the river was a wholly antecedent stream, "older than the structural features of the country", whose roots lay in the Eocene. Davis (1901), ruminating on the Grand Canyon portion of the Colorado River, largely accepted Dutton's idea of an antecedent stream, but concluded that the river formed not on an Eocene lake floor but on a "great peneplain," in the mid-Tertiary. In either case, an antecedent Colorado River would have flowed approximately along its present course before the land beneath the river was uplifted and the river cut downward as the land was elevated (thus forming the Grand Canyon). Blackwelder (1934) boldly interpreted the age of sedimentary deposits along the Colorado River drainage as entirely Recent- to Pleistocene-age. In the absence of older river deposits, he proposed an early Pleistocene age for both river and canyon. (He was careful to note that his interpretation was "frankly theoretical" and that science advanced "not only by the discovery of facts but also by the proposal and consideration of hypotheses, provided always that they are not disguised as facts".). Longwell (1946), while adopting some of Blackwelder's ideas, notably the role of a string of basins that were connected by downcutting during the formative years of the river, rejected Blackwelder's estimate of an early Pleistocene age. In a masterful display of insight and bravura, Longwell placed the earliest age of the river in the earliest Pliocene—at the time the start of the Pliocene was placed roughly at 10 Ma.

Fast forward to the latter part of the 20th century, when ideas on the origin and age of the Grand Canyon and the Colorado River were much better informed by geologic mapping, structural and tectonic analysis, sedimentological and geomorphic studies of the Grand Canyon and surrounding basins, and estimates of incision rates in the Grand Canyon were constrained by radiometric age dates.

New data confirm young age of the Grand Canyon

Jon Spencer & Phil Pearthree

The Grand Canyon is a spectacular gorge eroded into western margin of the Colorado Plateau highland by the Colorado River. The deep valleys, massive cliffs, and abrupt margins of the Grand Canyon attest to its relative geologic youth, as over geologic time such features are altered by weathering, erosion, and deposition to produce broad valleys with more gentle margins. Geologists also have inferred a young age for the canyon because 6-11 million year old (Ma) lake deposits at the mouth of the Grand Canyon show no sign of voluminous sand and gravel deposits like those transported by the Colorado River (Lucchitta, 1989). Deposits farther downstream in the lower Colorado River Valley indicate that the Colorado River arrived abruptly in the low desert areas about 5 Ma, and filled several closed basins with water before spilling over divides and incising the modern river course (House et al., 2005, 2008; Spencer and Pearthree, 2005; Dorsey et al., 2007; Spencer et al., 2008).

A recent study done at the University of New Mexico that used minute quantities of uranium and its radioactive-decay products to calculate the age of limestones from caves inferred a much older age (17 Ma) for the inception of Grand Canyon development (Polyak et al., 2008). The cave limestones, which coat the walls of caves, are called "speleothems". The type of speleothem analyzed consists of calcium carbonate that was precipitated when the cave was only a few meters to tens of meters below the water table. When the top of the water table is near,

Overview of the Grand Canyon (31 Dec. 2000) shown in this true color, Multi-angle Imaging Spectroradiometer (MISR) image. The northern part of the San Francisco volcanic field, including the San Francisco Peaks, appear at the bottom of the image. North is to the top. (Image courtsey of NASA's Earth Observatory.)

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Ivo Lucchitta (1989) distilled the principal hypotheses of the origin and age of both the Colorado River and the Grand Canyon down to two schools of thought. The first, the work of geologists who studied there from the 1880s to the 1940s, maintained that the river formed along most of its length simultaneously – more or less – and that the river system we see today is much the same as when it formed in the mid-Tertiary.

The second, the work of geologists who worked there from the 1930s onward—U.S. Geological Survey geologists Edwin McKee and Charles Hunt pioneered this group—held that the Colorado River was a complex and integrated system whose upper and lower sections formed at different times and whose evolution – both changes in course and direction of flow – responded to perturbations in crustal structure, tectonics and climate. According to Lucchitta's summary, the lower Colorado River was in place between 5 to 6 Ma, and incision of the Grand Canyon began about that time. How linkage between the Colorado River above Grand Canyon and the lower Colorado River occurred remains an area of controversy.

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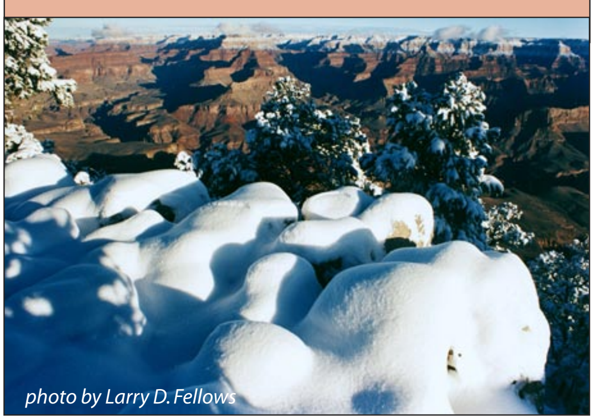

photo by Larry D. Fellows

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exchange of gasses between groundwater and the atmosphere triggers accelerated precipitation of a distinctive coating on the walls of the underwater cave. These caves in and near the Grand Canyon subsequently dried out as the water table dropped further, so no more carbonate coatings accumulated in the caves. Dating the youngest speleothems thus dated the time when the local water table fell below the level of each cave.

The isotope analyses from speleothems in caves within the Grand Canyon gave ages of 0.8 to 4 Ma. This is consistent with previous studies that indicated canyon incision began at about 5 Ma. The inference of early Grand Canyon development was based on speleothems from two caves outside the Grand Canyon, including Grand Canyon Caverns in western Coconino County, for which they obtained dates of 7.5 and 17 Ma. We and other geologists interpret their data for these two caves to represent water table changes unrelated to Grand Canyon incision (Pearthree et al., 2008; Pederson et al., 2008; Karlstrom et al., 2008). It is certainly possible that small canyons were eroded in the Grand Wash Cliffs (now the west end of the Grand Canyon) prior to the arrival of the Colorado River (Young, 2008), and that the cave with the 7.5 Ma date dried out as a result, but their linkage to the river and Grand Canyon is not clear.

The explanations for the abrupt arrival of the Colorado River through the Grand Canyon area remain controversial (Peterson, 2008). The scenario we favor involves filling of a large lake east of the Kaibab uplift (in the area where the Colorado River and Little Colorado River now meet, but before canyon incision) by the upper Colorado River in the late Miocene. When this lake filled, it overtopped the Kaibab uplift in the area north of Flagstaff where the Grand Canyon is now deepest and most often visited. Water from the lake then spilled down to the west through the region that is now the Grand Canyon, possibly filling small basins and exploiting whatever valleys existed in the region. First arriving waters that reached the western Grand Canyon may have flowed down a small, pre-existing canyon through the Grand Wash Cliffs, or perhaps produced spectacular waterfalls as this torrent of muddy water fell in a cascade thousands of feet down to the floor of Grand Wash Trough. In any case, rapid erosional incision of the Grand Canyon during its early development likely added huge amounts of sediment to the new-born Colorado River as it found its way to the Gulf of California.

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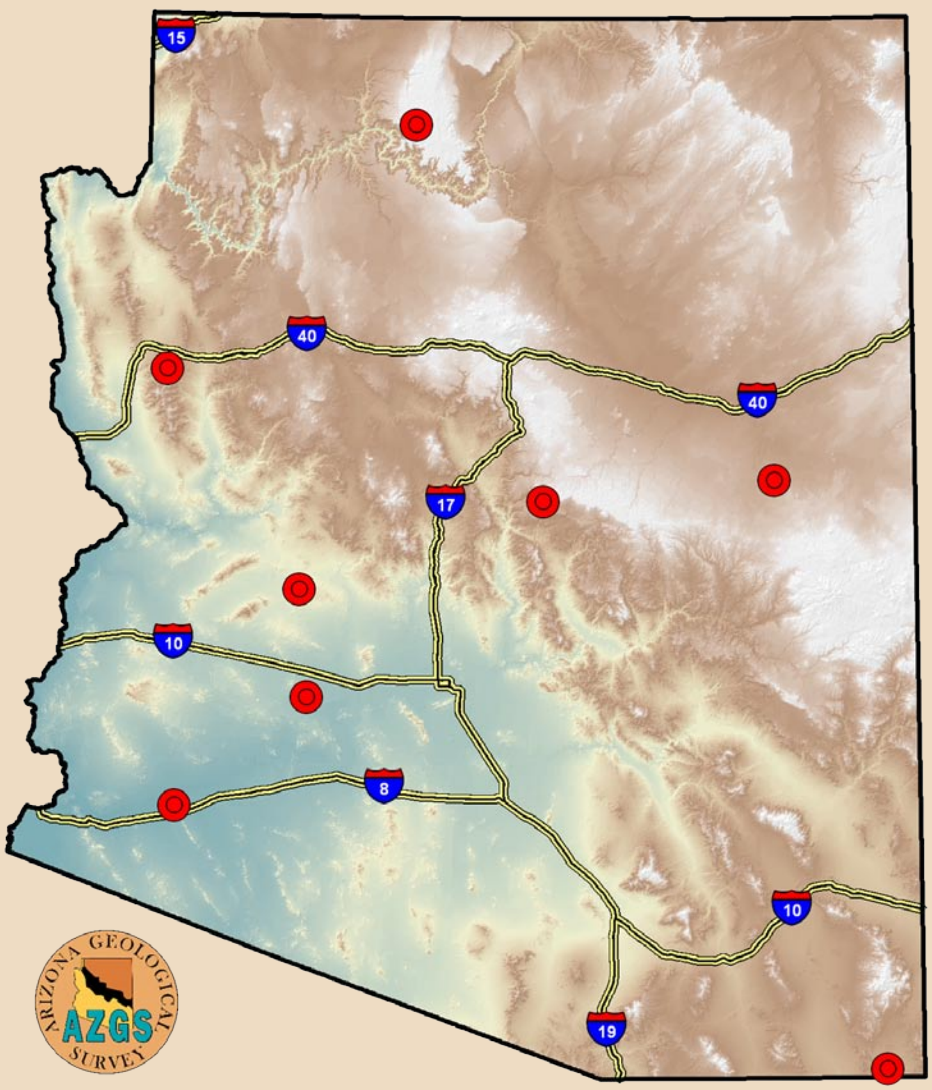
Earthquakes in Arizona?

When it comes to earthquakes, Arizona is overshadowed by its more tectonically active neighbor to the west, California. But earthquakes do occur in Arizona. How frequently, on which faults, and the recurrence time of potentially damaging quakes are questions of great interest to Earth scientists and civil authorities alike.

Those questions may soon find an answer. In July 2008, AZGS and our three university partners, Arizona State University, Northern Arizona University and the University of Arizona were awarded $493,678 from the Federal Emergency Management Agency (FEMA) to improve earthquake monitoring and revisit seismic hazard assessment in Arizona.

The award provides for the purchase and maintenance of eight broadband seismometer stations—see location map—that, until November 2008, were part of a larger seismic array temporarily deployed in Arizona as part of EarthScopes' USArray Program (http://www.iris.washington.edu/USArray/index.html). AZGS takes possession of the seismometers in January 2009.

Small earthquakes that are generally undetected in Arizona now, may offer clues to where larger earthquakes could



Distribution of seismometers (red bullseyes) in Arizona's first dedicated broadband network.

A Guralp broadband seismometer at time of deployment.

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occur in the future. Dr. Matthew J. Fouch (ASU School of Earth and Space Exploration) noted that this new network "provides us with a fundamentally improved ability to see deep inside the crust and mantle beneath the state … and provide the key evidence we need to better understand the geology we observe at the surface".

The Earth science teams at ASU, NAU and UA are responsible for analysis and interpretation of seismic data that should provide new insight into Arizona's earthquake hazards. Mimi Diaz (AZGS) is coordinating science outreach and will work with local jurisdictions to update their hazard mitigation plans.

Broadband seismometer station near Pine, Arizona.

Visit http://www.azgs.az.gov/fema_award for additional information and images of a broadband station.

Note: We feel strongly that a State-dedicated seismic network is in the best interest of Arizona and its people. But maintaining this equipment is expensive. If you are interested in assisting AZGS fund the seismic network beyond the two years of the grant, contact Arizona Geological Survey's Mimi Diaz (602.708.8253).

New Publications

OFR-08-05—Geology and Geological Hazards Field Trip of Sabino Canyon: Results of the July 2006 Storms, by A. Youberg and J.P. Cook, 2008 13 p., available online at www.azgs.az.gov

OFR-08-06—Geological Mapping of Debris-Flow Deposits in the Santa Catalina Mountains, Pima County, Arizona, by A. Youberg, M.L. Cline, J.P. Cook, P.A Pearthree and R.H. Webb, 2008, 42 p., with 11 sheets (1:6000 scale) on accompanying CD-ROM. $20.00

OFR-08-08—Delineating Post-Wildfire Debris Flow Hazards For Pre-Fire Mitigation, Pine and Strawberry, Arizona: A FEMA 5% Initiative Study, by Ann Youberg, 2008. (available online at azgs.az.gov)

DI-39—Locations of Mapped Earth Fissure Traces in Arizona, by T.C. Shipman et al., 1:12,000 to 1:24,000- scale ESRI shapefiles of Earth Fissure Study area, V. 11/26/08

Note: The Arizona Geological Survey is introducing a new Digital Map (DM) series for maps with a strong environmental geology component. Our first maps in the series involve debris flow deposits in the Santa Catalina Mountains and earth fissures in Pinal and Maricopa County.

Earth fissure maps of the DM series, e.g., DM-EF-4, are available online at azgs.az.gov.

DM-EF-4—Earth Fissure Map of the Mesa Study Area: Maricopa County, AZ, 2008

DM-EF-5—Earth Fissure Map of the Scottsdale Study Area: Maricopa County, AZ, 2008

DM-EF-6—Earth Fissure Map of the Toltec Buttes Study Area: Pinal County, AZ, 2008

DM-EF-7—Earth Fissure Map of the Pete's Corner Study Area: Pinal County, AZ, 2008

DM-EF-8—Earth Fissure Map of the Luke Study Area: Maricopa County, AZ, 2008

The following maps accompany OFR-08-06, Geological Mapping of Debris-Flow Deposits in the Santa Catalina Mountains, Pima County, Arizona.

DM-DF-1A—Debris-Flow Deposits at the Mouths of Molino, La Milagrosa and Agua Caliente Canyons, Pima County, AZ, 2008 $7.00

DM-DF-1B—Debris-Flow Deposits at the Mouth of Soldier Canyon, Pima County, AZ, 2008 $4.00

DM-DF-1C—Debris-Flow Deposits at the Mouth of Gibbon Canyon, Pima County, AZ, 2008 $3.75

DM-DF-1D—Debris-Flow Deposits at the Mouths of Sabino and Bear Canyons, Pima County, AZ, 2008 $4.50

DM-DF-1E—Debris-Flow Deposits at the Mouths of Esperero and Bird Canyons, Pima County, AZ, 2008 $4.50

DM-DF-1F—Debris-Flow Deposits at the Mouth of Ventana Canyon, Pima County, AZ, 2008 $7.00

DM-DF-1G—Debris-Flow Deposits at the Mouths of Finger Rock and Pontatoc Canyons, Pima County, AZ, 2008 $5.50

DM-DF-1H—Debris-Flow Deposits at the Mouth of Cobblestone Canyon, Pima County, AZ, 2008 $4.75

DM-DF-1I—Debris-Flow Deposits at the Mouth of Pima Canyon, Pima County, AZ, 2008 $8.75

DM-DF-1J—Debris-Flow Deposits at the Mouth of Pusch Canyon, Pima County, AZ, 2008 $3.00

DM-DF-1K—Debris-Flow Deposits at the Mouth of Linda Vista Canyon, Pima County, AZ, 2008 $3.00


photo by Larry D. Fellows

AZ Geology is Going Digital!
www.azgs.az.gov

In March 1971, the Arizona Bureau of Mines—predecessor of today's Arizona Geological Survey—published the first issue of Fieldnotes. For nearly 40 years, Fieldnotes, and its successor, Arizona Geology, showcased all things geologic in Arizona.

From the onset, the quarterly magazine printed topical pieces on Arizona's mineral resources, energy potential, and environmental geology. In fall-1988, Fieldnotes became Arizona Geology, and the newsletter was retailored to meet the needs of Arizona's exploding population. There was increased focus on articles describing geologic phenomena—flash floods and regional floods, earthquakes, landslides, volcanism, swelling and shrinking soils, earth fissures, and more—with the most immediate and adverse impact on the lives and properties of our fellow Arizonans.

But that was then and this is now! As print publication costs rise through the stratosphere, we simply can no longer afford to print and mail 4100 copies of Arizona Geology quarterly.

Arizona Geology is going digital. We are suspending the print publication immediately and we are moving from a quarterly schedule to three times annually.


M. Lee Allison, Director and State Geologist

We eagerly accept the challenge of transforming Arizona Geology into a web-based publication. We'll add new features and resurrect some old ones that were shunted aside to accommodate growing costs and reduced page numbers. There will be more illustrations, streaming video and links to geologic news – local, national, and international - that affects Arizona.

Get automatic notice of each issue by subscribing to the Arizona Geology RSS feed at azgs.az.gov.

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