# Arizona Geology

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THE STATE AGENCY FOR GEOLOGIC INFORMATION


## 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, nonmetallic, 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.*

## THE ICE AGE AND IMPACTS ON ARIZONA

**The Ice Age.** A farmer from the Midwest asked a visiting geologist how all the rocks got in his corn field. The geologist explained that a glacier brought them. The farmer, with a puzzled look, asked "Where's the glacier now?" The geologist replied, "Back after more rocks." After the Ice Age (Pleistocene Epoch) began about two million years ago, thick ice sheets spread repeatedly across much of the midwestern and northeastern United States (Figure 1). In the West, glaciers moved slowly down mountain valleys, grinding off the bedrock and smoothing out the valley floors as they went. Although what is now Arizona was not covered by ice sheets, mountain glaciers did develop on San Francisco Mountain near Flagstaff and Mt. Baldy in the White Mountains. Even though there was not extensive glaciation in Arizona, Ice Age events impact our lives daily. A brief summary of the Ice Age is in order before I mention its impacts.

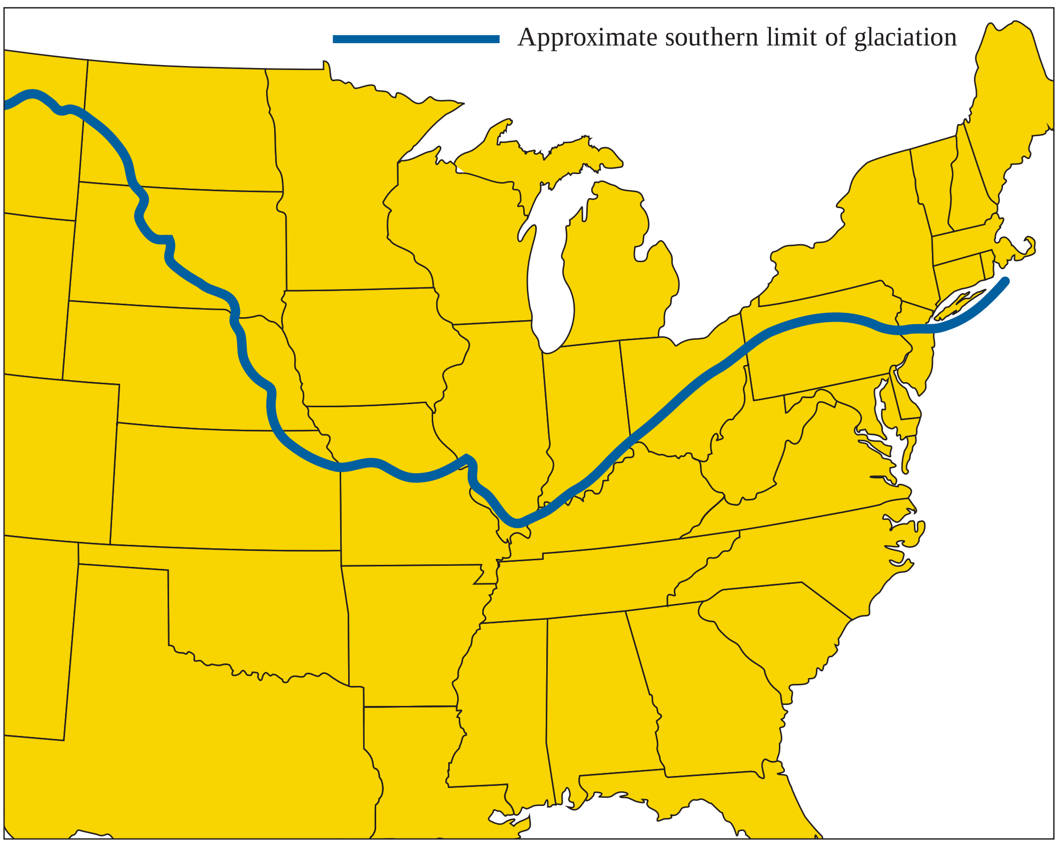


**Figure 1.** Glaciers extended as far south as the Missouri and Ohio rivers in the Midwest and covered most of New England

Geology is about change. Studies of the Ice Age show that temperature, precipitation, and composition of the atmosphere changed repeatedly. Many scientists have done, and continue to do, research on ancient climates using a variety of different and independent approaches. Studies have shown that the mean annual temperature in central Europe, and presumably the rest of the world, cooled 15-20$^{o}$ C (27-36$^{o}$ F) in the last 60 million years. An additional 10$^{o}$ C (18$^{o}$ F) decline likely occurred during the Ice Age. During the cool periods, snowfall was compacted and changed to ice, which accumulated and formed continental glaciers as much as a mile thick. (The weight of the ice caused Earth's crust to be depressed). When glaciers formed, huge quantities of water remained on the land as ice. As a result, sea level fell by as much as 400 feet. When the climate warmed sufficiently, the ice melted and sea level rose accordingly. In the West, meltwater and runoff from rains flowed into large areas that had no outlets and formed gigantic lakes.


**Figure 2** Silt (A) and sand and gravel (well sorted [B] and poorly sorted, clay rich [C and inset]) deposited by the Santa Cruz River.

**Figure 3** Sand and gravel being sorted by particle size.

Glaciers covered the upper Midwest at least four times and extended as far south as the Ohio and Missouri rivers. Periods of glacial advance lasted 100,000 to 200,000 years and were separated by shorter, warmer periods that lasted 8,000 to 12,000 years. We are living in the most recent of many such "interglacials." Advancing glaciers smoothed the landscape and left thick deposits of gravel, sand, silt, and clay when they receded. Those deposits form the parent material for the productive, fertile, black soil in the upper Midwest – some of the best in the world.

Ice Age temperatures sometimes rose and fell abruptly. Studies of ice cores from Greenland reveal that two times between 135,000 and 110,000 years ago the mean annual temperature dropped about 7$^{o}$ C (12$^{o}$F)in less than a few centuries; one time it fell 14$^{o}$ C (25$^{o}$F) in 10 years and returned to its former level 70 years later. The Vostok ice core, taken in Antarctica, provided a continuous record of ice accumulation during the past 420,000 years. Scientists who studied the core identified four warming/cooling cycles, each of which lasted 90-135,000 years. Each cycle began abruptly with an extremely rapid increase in temperature. After the temperature peaked it cooled unevenly until an abrupt increase took place and the next cycle began. The carbon dioxide content in the atmosphere very closely parallels the temperature curve. A new cycle began about 15,000 years ago and near-peak temperatures are being recorded. If these cyclical changes continue as they did the past 420,000 years, a long, uneven period of cooling is about to begin.

**The Holocene.** The Holocene Epoch, the name given to the latest interglacial interval, began after a rapid increase in temperature (and carbon dioxide) took place about 15,000 years ago. Ice began to melt. By about 8,000 years ago continental glaciers had melted from what is now the United States. Mountain glaciers, periodically replenished by snowfall, are either melting or advancing, depending on the area. The World Glacier Monitoring Service indicates that more than 71,000 glaciers exist; fluctuation data are available for fewer than 2,000 of them.

Those who study ancient climates (paleoclimatologists) have shown that extended periods of stable climate are rare - the climate is usually either getting warmer or cooler. The global temperature fluctuated during the Holocene as well as the Ice Age, although not to the extremes as during the Ice Age. For example, from about A.D. 1200-1350 the temperature warmed significantly. This interval is commonly referred to as the "Medieval Warm Event." The Vikings established agricultural colonies in Greenland, which was warmer than it is today. That warming was followed by a period of cooling known as the "Little Ice Age (LIA)" that lasted until the mid 1800s. (European society prospered during the warm event, but living conditions during the Little Ice Age were much more difficult.) The climate has been warming, in general but not uniformly, since then. From about 1940-1980, cooling took place. When I began studying geology in the 1950s many geologists were discussing the possibility that ice sheets might form during our lifetimes. The current warming trend ended those fantasies.

Fluctuations in temperature, atmospheric composition, and rainfall occurred repeatedly because of natural processes. Not enough people lived during the Ice Age to have had any impact on any changes that took place then.

**Impacts on Arizona.** Even though Arizona and much of the Southwest were not glaciated extensively, events that happened during the Ice Age (and Holocene) impact our daily lives. All of these events can be attributed to the availability of water. During the last couple million years Arizona probably received substantially more winter precipitation than it does today. Sediment deposited by rivers and streams soaked up water like a giant sponge; **groundwater recharge** took place at an accelerated rate. Springs and flowing streams were common. When settlement of Arizona began, good quality groundwater was available for residents, cattle, and crops.

The structural basins that characterize southern and western Arizona (and large areas west of the Rocky Mountains and

**Figure 4** (Left) Sand and gravel being mixed with cement to produce concrete. **Figure 5** (Above) Sand and gravel being mixed with hot oil to produce asphalt.

east of the Pacific coast ranges) formed largely 15-5 million years ago during the "Basin and Range" event. Although this happened long before the Ice Age began, accelerated weathering and erosion continued into the Ice Age and Holocene. During wetter intervals, streams transported more runoff than they do today. At the same time, they also transported and deposited more sediment (sand, gravel, silt, and clay) in their channels and on floodplains. The sediment was derived from the weathering of rock in the adjacent mountains.

At first, many basins were closed (had no outlets) and deposition was entirely internal. When water eventually found an outlet from a basin, a through-flowing stream and tributary system began to develop. While streams were transporting sediment, the sediment particles became rounded, sorted, and reduced in size; the least stable fragments did not survive. Running water in those streams, most of which no longer flow, left valuable deposits of sand and gravel. The deposits are sources of **construction aggregate**, a commodity that is essential to sustain development (Fig. 2,3).

Aggregate is a primary ingredient in concrete (Fig. 4) and asphalt (Fig. 5). Asphalt is used primarily in road construction. Concrete, also used on highways and streets, is used in the construction of homes, shopping centers, apartment and office buildings, factories and warehouses, hospitals, schools, water treatment and waste disposal facilities, canals, runways, and many other types of construction. Every growing urban area requires nearby sources of aggregate of suitable quality.

Much of the modern **topography was modified** during the Ice Age and the Holocene when the rate of precipitation was higher than it is today. River valleys and floodplains were widened during times when streams carried more water than today. In southern Arizona, many small, intermittent or dry streams and washes appear to occupy disproportionately large valleys.

**Summary.** The Ice Age was a time of repeated temperature, precipitation, and atmospheric changes that were caused by natural processes. The Holocene Epoch, which began after rapid warming started about 15,000 years ago, is the most recent of many interglacial periods. The Holocene climate fluctuated too, but not as much as during the Ice Age.

During the Ice Age and the Holocene, aquifers were filled with groundwater, sand and gravel were deposited by rivers and streams, and the modern landscape was modified, largely by the action of runoff.

On the basis of paleoclimate studies, one can conclude that irrespective of any human influence that may be happening today the global climate will continue to change. At some unknown time in the future, cooling will begin. That could trigger another "Little Ice Age" – or the next "big one". Based on the experiences of those who lived in central Europe during the Little Ice Age, I hope warming continues at least another few decades.

*Larry D. Fellows*

### SELECTED READINGS


Bluemle, J.P., 1999, **Global warming: A geological perspective**: Arizona Geology, v. 29, no. 4, p. 1-4.
This is a non-technical summary of the technical paper listed below.

Bluemle, J.P., Sabel, J.M., and Karlén, Wibjörn, 1999, **Rate and magnitude of past global climate changes**: Environmental Geosciences, v. 6, no. 2, pp. 63-75.
Authors discuss the geologic and anthropologic records of climatic fluctuation, as well as direct climate measurements.

Gerhard, L.C., Harrison, W.E., and Hanson, B.M., editors, 2001, **Global perspectives on global climate change:** American Association of Petroleum Geologists Studies in Geology #47, 372 p.

This book, which includes 18 technical articles on various aspects of global climate change, is available from the AAPG Bookstore (http://bookstore.aapg.org/). The book has four parts: 1) climate drivers, 2) methods of estimating ancient temperature, 3) natural variability and studies of past temperature, and 4) policy drivers. Most of the authors of papers included in the book are academicians who design and conduct their individual research programs without regard for potential policy implications of their work.

# FRIENDS AND NEIGHBORS

**STATE GEOLOGICAL SURVEYS** were established by state legislatures to map and characterize the geology of their respective states and provide objective, scientific geologic information and assistance that is needed by governmental agencies, industry, and the public. Many of you have dealt with state geological surveys in states other than Arizona. If not, the following information about state geological surveys that adjoin Arizona may be useful. Additional information may be found on the Association of American State Geologists website: http://www.kgs.ukans.edu/AASG/AASG.html.

**Directors of state geological surveys in the Southwest**.

Back row left to right: Jonathan G. Price (Nevada), Richard G. Allis (Utah), and Vincent Matthews (Colorado). Front row left to right: Larry D. Fellows (Arizona) and Peter A. Scholle (New Mexico).

### NEVADA BUREAU OF MINES AND GEOLOGY

University of Nevada, Reno, Mail Stop 178,
Reno, NV 89557-0088
(775) 784-6691 (775) 784-1709 fax
www.nbmg.unr.edu

**State Geologist and Director:** Jonathan G. Price, Ph.D., appointed September 1988

**Mission:** To provide the State's needs for geological and mineral-resource information and research.

**Description:** The Nevada Bureau of Mines and Geology (NBMG) is a research and public service unit of the University of Nevada, Reno (UNR) and is the state geological survey. The NBMG, part of the Mackay School of Earth Sciences and Engineering within the College of Science, is one of the Statewide Programs at the UNR. The Board of Regents appoints the NBMG director.

NBMG scientists conduct research and publish reports that focus on the economic development, public safety, and quality of life in urban and rural Nevada. Major research programs include addressing issues of urban growth, particularly natural hazards and economic stability; mineral, energy, and water resources vital to economic expansion; and environmental concerns. The NBMG has no regulatory responsibilities and no branch offices.

### UTAH GEOLOGICAL SURVEY

1594 West North Temple, Salt Lake City, UT 84114-6100
(801) 537-3300 (801) 537-3400 fax
www.geology.utah.gov

**Director and State Geologist:** Richard G. Allis, Ph.D., appointed September 2000

**Mission:** To create, interpret, and provide information about Utah's geologic environment, resources, and hazards to promote safe, beneficial, and wise use of land.

**Description:** The Utah Geological Survey (UGS), a division of the Department of Natural Resources (DNR), is an applied scientific agency. The director of the UGS serves at the pleasure of the Governor.

The UGS comprises five technical programs: Energy and Minerals, Geologic Hazards, Geologic Mapping, Environmental Sciences (groundwater and paleontology sections), and Geologic Information and Outreach. The UGS, which operates the DNR Bookstore and Library, owns a 12,000-square-foot warehouse for archiving rock core and cuttings collected largely from oil and gas exploration in Utah. The UGS is largely non-regulatory, with the exception of issuing permits to collect fossils on state land. All UGS staff are located in the DNR Salt Lake City office, except for two who work in the Cedar City branch office.

### COLORADO GEOLOGICAL SURVEY

1313 Sherman Street, Room 715, Denver, CO 80203
(303) 866-3028 (303) 866-4445 fax
www.geosurvey.state.co.us

**Director and State Geologist:** Vincent Matthews III, Ph.D., appointed March 2004

**Mission:** To help reduce the impact of geologic hazards on the citizens of Colorado, to promote the responsible economic development of mineral and mineral fuel resources, to provide geologic insight into water resources, and to provide geologic advice and information to a variety of constituencies.

**Description:** The Colorado Geological Survey (CGS) is an agency of state government within the Department of Natural Resources (DNR). The Executive Director of the DNR appoints the CGS director after a competitive process.

The CGS provides a multitude of services and information to federal, state, and local government agencies, mineral and energy industries, and private citizens, including media, researchers, teachers, and students. CGS staff prepare geologic maps, provide information and services regarding geologic hazards, water resources and underground storage potential, and economic development of mineral and energy resources. In addition, they conduct school-site and land-use reviews. The CGS is also the home of the Colorado Avalanche Information Center, which provides snow avalanche hazard monitoring, education, and research. The CGS has no branch offices.

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## FRIENDS AND NEIGHBORS—*continued from page 4*

**NEW MEXICO BUREAU OF GEOLOGY AND MINERAL RESOURCES**

New Mexico Tech, 801 Leroy Place, Socorro, NM 87801
(505) 835-5302 (505) 835-6333 fax
http://geoinfo.nmt.edu/

**Director and State Geologist:** Peter A. Scholle, Ph.D., appointed September 1999

**Mission:** To contribute to the teaching, advising, research, and outreach activities of the New Mexico Institute of Mining & Technology (NM Tech) and also serve as a non-regulatory governmental agency (the state's geological survey) that conducts scientific investigations leading to responsible economic development of the state's mineral, water, and energy resources.

**Description:** The New Mexico Bureau of Geology and Mineral Resources (NMBG&MR) is a state agency and a division of NM Tech. The NM Tech President and Board of Regents appoint the NMBG&MR director, who serves at their pleasure.

Major programs include geologic mapping, mineral, energy and water resource investigations, and public information and service. The NMBG&MR has no regulatory responsibilities, although the director is, by law, a member of several regulatory boards.

The NMBG&MR has a substantial branch office in Albuquerque, a small office in Carlsbad, and, in addition, operates a mineral museum in Socorro.

## OIL AND GAS ACTIVITY IN 2004

The Arizona Oil and Gas Conservation Commission issued eight permits to drill. Operators drilled four wells. Ridgeway Arizona Oil Corporation drilled a $CO_2$ test near St. Johns in May and tested the well during the summer and fall. The Ridgeway well is currently shut in waiting on additional tests and availability of equipment.

Holbrook Energy LLC drilled a helium test in the old Pinta Dome field in September. The well is currently shut in waiting on a slim-hole completion attempt.

Gruy Petroleum drilled two helium test wells south of Sanders in November. Those wells are shut in pending additional drilling to determine if there is enough helium to justify rebuilding a helium extraction plant in the area.

Acreage leased for oil and gas in Arizona declined from 481,000 acres in 2003. Leases on State Trust land totaled 256,000 acres and leases on federal land totaled 97,000 acres.

## JUST RELEASED

**Geologic map of the Vulture Mine 7.5' quadrangle, Maricopa County, Arizona:** Grubensky, M.J., and Shipman, T.G., 2004, Arizona Geological Survey Digital Geologic Map 41, v. 1.0 (DGM 41), 1 CD-ROM that includes a 1:24,000-scale map. $15.00 plus tax (Arizona residents) and shipping charges. A color paper copy of the map is available for $12.00 (Arizona residents) and shipping charges.

**Geologic map of the Rincon Valley area, Pima County, Arizona:** Richard, S.M., Spencer, J.E., Youberg, Ann, and Ferguson, C.A., 2005, Arizona Geological Survey Digital Geologic Map 44, v. 1.0 (DGM 44), 1 CD-ROM that includes an 11-p. text and a 1:24,000-scale geologic map. $15.00 plus tax (Arizona residents) and shipping charges. A color copy of the map plus the text is available for $15.00 plus tax (Arizona residents) and shipping charges.

**Geologic map of the Davis Dam SE 7.5' quadrangle, Mohave County, Arizona and Clark County, Nevada:** Pearthree, P.A., and House, P.K., 2005, Arizona Geological Survey Digital Geologic Map 45, v. 1.0 (DGM 45), 1 CD-ROM that includes a 1:24,000-scale geologic map. $15.00 plus tax (Arizona residents) and shipping charges. A color paper copy of the map is available for $12.00 (Arizona residents) and shipping charges.

**Geologic spatial data (1:24,000-scale) for the southern San Pedro River area, Cochise County, Arizona:** Richard, S.M., and Moore, E.M., compilers, 2005, Arizona Geological Survey Digital Information 31, version 0.5 (DI 31), 1 CD-ROM. $30.00 plus tax (Arizona residents) and shipping charges.

**Oil and gas wells in the State of Arizona, updated January 2005:** Rauzi, S.L., and Richard, S.M., compilers, 2005, Arizona Geological Survey Digital Information 33, v. 1.0 (DI 33), 1 CD-ROM. $30.00 plus tax (Arizona residents) and shipping charges.

**Inundation mapping and hydraulic reconstructions of an extreme alluvial fan flood, Wild Burro Wash, Pima County, southern Arizona:** Vincent, K.R., Pearthree, P.A., House, P.K., and Demsey, K.A., 2004, Arizona Geological Survey Open-file Report 04-04 (OFR 04-04), 1 CD-ROM, 51 p., 2 sheets, scale 1:6,000 and 1:15,000. Maps and GIS data are on CD-ROM. $18.00 plus tax (Arizona residents) and shipping charges. A copy of the CD-ROM, color copies of the maps, and the text are available for $33.00 plus tax (Arizona residents) and shipping charges.

**A field guide to the overlooks of Fish Creek Canyon, Superstition Mountains, Pinal County, Arizona:** Ferguson, C.A., 2005, Arizona Geological Survey Open-file Report 05-01 (OFR 05-01), 16 p. $5.00 plus tax (Arizona residents) and shipping charges.

## Publication Ordering Information

You may purchase publications at the AZGS office or by mail. Address mail orders to AZGS Publications, 416 W. Congress St., Suite 100, Tucson, AZ 85701. Orders are shipped by UPS, which requires a street address for delivery. All mail orders must be prepaid by a check or money order payable in U.S. dollars to the Arizona Geological Survey or by Master Card or VISA. Do not send cash. Add 7.6% sales tax to the publication cost for orders purchased or mailed in Arizona. Order by publication number and add these shipping and handling charges to your total order:

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