FIELDNOTES

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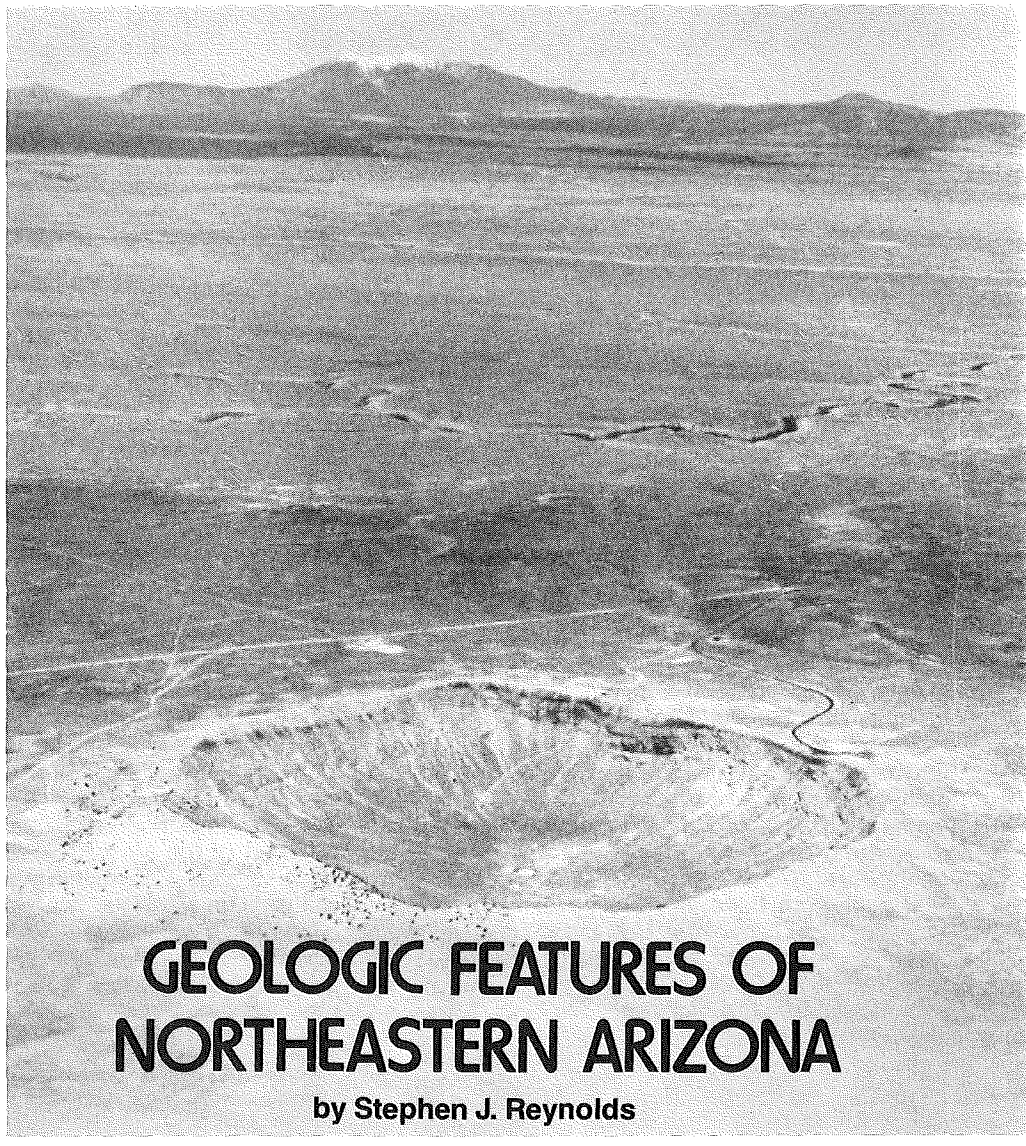


GEOLOGIC FEATURES OF NORTHEASTERN ARIZONA

by Stephen J. Reynolds

Figure 1. Aerial photograph of Meteor Crater with San Francisco Mountains in background. Photo: Meteor Crater, Northern Arizona.

Introduction

Northeastern Arizona has long been famous for its rich endowment of scenic beauty and natural wonders, such as the Grand Canyon, Monument Valley, and Meteor Crater (Figure 1). How did such features form? What is the geologic story behind the scenery? Geologists and park naturalists are often asked these and other questions. Most answers are not simple. Behind every landscape are hundreds of subtle and not-so-subtle geologic controls. An entire geologic story exists within every pinnacle, canyon, and rock layer. What concerns us here is not the detailed script of the geologic story, but the overall plot.

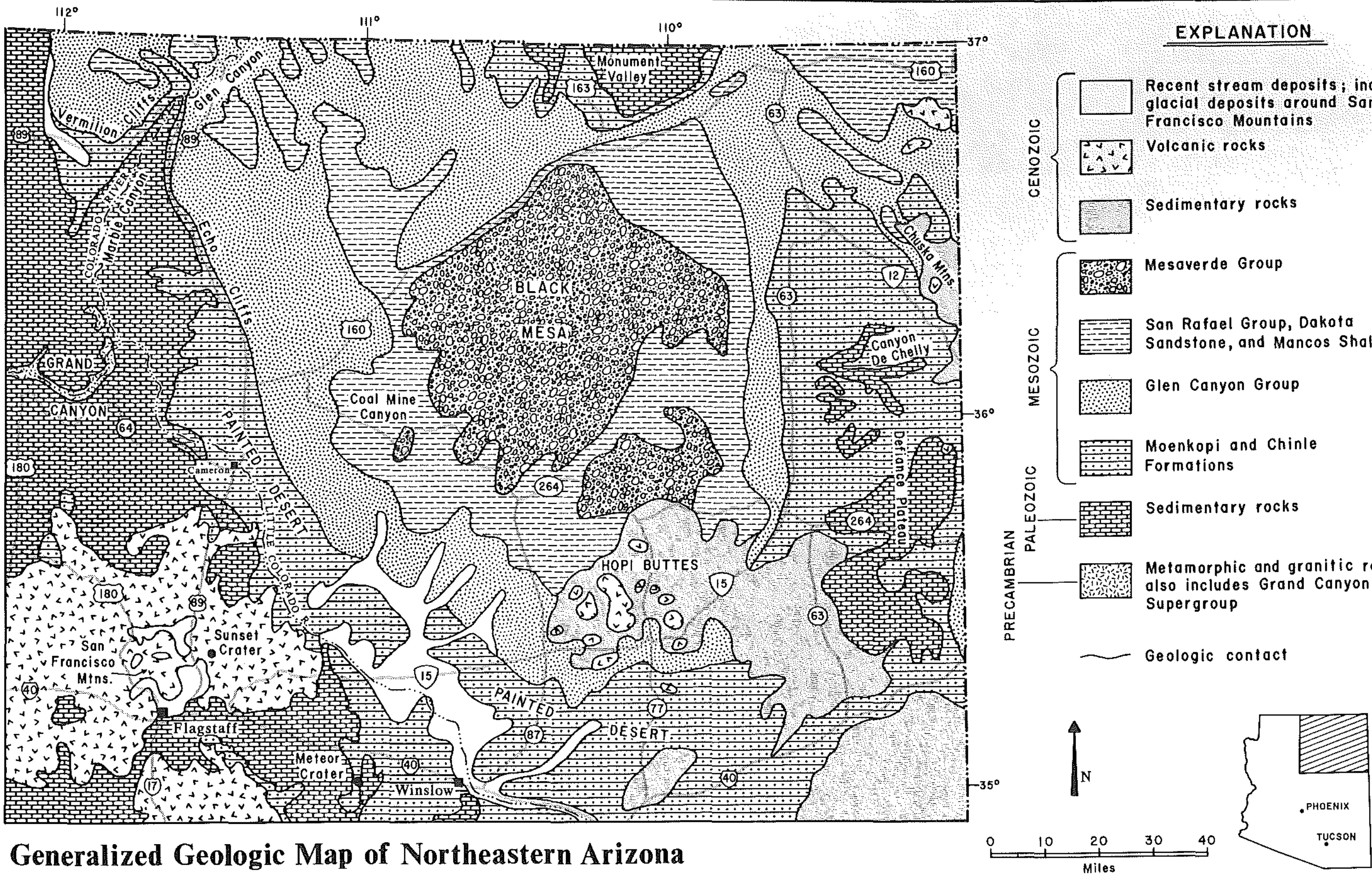
This article contains a short summary of the geology of northeastern Arizona, followed by a "character sketch" of the area's best known geologic features. A list of general references is included for those interested in learning more about the geology of this fascinating region.

Geologic History of Northeastern Arizona

Northeastern Arizona is part of the Colorado Plateau physiographic province, a region of wide-open spaces and breath-taking vistas. Landscapes of the Colorado Plateau are dominated by broad plains or plateaus that are interrupted by a series of mesas, cliffs, and deep canyons. The spectacular scenery of the region is mostly due to erosion of a sequence of flat-lying sedimentary formations. Differences in color and resistance to erosion between adjacent sedimentary layers create the colorful, stair-stepped appearance that is so typical of the region.

The geologic history of northeastern Arizona began in the Precambrian Era nearly two billion years ago (see Figures 2–4), when sediments and volcanic rocks were deposited in oceans and scattered volcanic archipelagos. These deposits were buried to great depths and converted into metamorphic rocks by high temperatures and pressures. They were intruded by magma (molten rock) that solidified into granite. These ancient metamorphic and granitic rocks represent the first step in the long process of building the continental crust of Arizona. They have been buried by thousands of feet of younger sedimentary rocks and are presently exposed only in the bottom of the Grand Canyon and in small areas of the Defiance Plateau. Drill holes by oil companies indicate that Precambrian metamorphic and granitic rocks underlie essentially all of northeastern Arizona.

Around 1.1 billion years ago, parts of the region were invaded by shallow seas, in which sedimentary rocks of the Grand Canyon Supergroup were deposited. Sedimentation was locally accompanied by emplacement of basaltic intrusions and by eruption of basaltic lavas. Episodes of



Generalized Geologic Map of Northeastern Arizona

Figure 2. Geologic map (modified from Cooley, 1967).

faulting occurred during and after deposition of the Grand Canyon Supergroup.

After a prolonged period of erosion that lasted about 500 million years, early Paleozoic seas invaded most of Arizona and resulted in the deposition of limestone, shale, and beach sands. Within northeastern Arizona, these sedimentary rocks are exposed only in the lower walls of the Grand Canyon. However, they reappear from beneath their cover of younger rocks along the Mogollon Rim to the south and the Grand Wash Cliffs to the west.

In the latter half of the Paleozoic Era, about 300 million years (m.y.) ago, northeastern Arizona was the site of shallow seas, extensive mud-flats, and large fields of sand dunes. The resulting sequences of limestone, shale, siltstone, and sandstone are exposed in the upper walls of the Grand Canyon and are partially exposed in Monument Valley, Canyon de Chelly, the Defiance Plateau, and the Mogollon Slope.

In the early part of the Mesozoic Era (225 m.y. ago), the region consisted of a broad coastal plain on which the Triassic Moenkopi Formation was deposited. Subsequent mountain building and volcanism to the south contributed steam-carried debris and volcanic ash that were deposited as the Chinle Formation. The Chinle Formation is exposed in the Painted Desert and in brightly colored lower slopes of the Vermilion Cliffs, Echo Cliffs, and Paria Canyon. The next sedimentary formations deposited, those of the Glen Canyon Group, consist of red, orange, and white sandstone and siltstone that represent ancient sand dunes and river deposits. They form the upper parts of the spectacular Vermilion Cliffs, Echo Cliffs, and Paria Canyon and are also widely exposed around Glen Canyon, Navajo National Monument, and the northern Chinle Valley. These formations locally contain numerous dinosaur footprints and bones.

During the middle part of the Mesozoic Era (180–110 m.y. ago), more sandstone, siltstone, and shale were deposited by streams, wind, and ocean currents. These rocks, assigned to the San Rafael Group, Dakota Sandstone, and Mancos Shale, are most widely exposed around the periphery of Black Mesa, such as in Coal Mine Canyon. In Black Mesa, they are overlain by late Mesozoic sandstone, siltstone, and shale of the Mesaverde Group, which contains important coal resources. These rocks were deposited in deltas and shallow, retreating seas.

Near the end of the Mesozoic, the Colorado Plateau and the rest of Arizona were subjected to stresses that folded the sedimentary layers and caused some areas to be uplifted relative to others. By

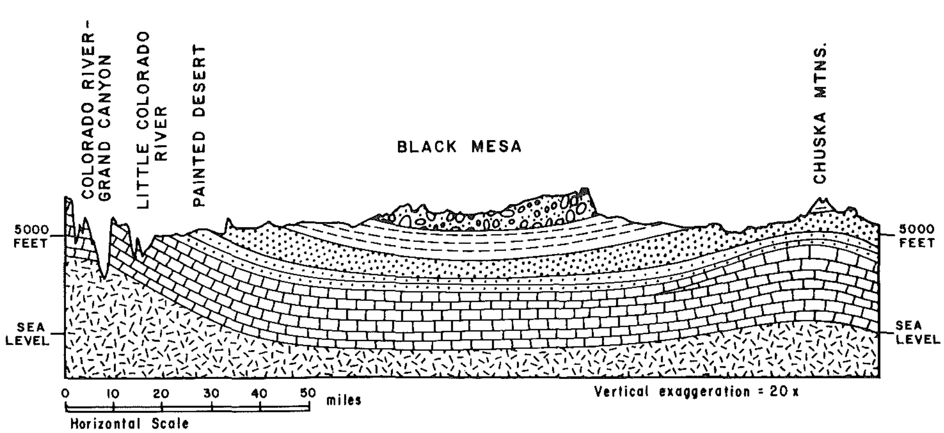


Figure 3. Geologic cross-section from Grand Canyon to Chuska Mountains (modified from Oetking and others, 1967).

the start of the Cenozoic Era (65 m.y. ago) the seas had completely retreated from northeastern Arizona, never to return. The oldest Cenozoic rocks are igneous intrusions and wind-deposited sandstones, found in and around the Chuska Mountains. Much younger lake beds, stream deposits, and volcanic rocks accumulated south of Black Mesa and the Defiance Plateau. In latest Cenozoic time, intense volcanism constructed the San Francisco Mountains near Flagstaff. Volcanism has continued until very recently, as evidenced by the formation of Sunset Crater in 1065 A.D. The present episode of canyon cutting probably started within the last 10 million years.

Grand Canyon

Any discussion of geologic features of northeastern Arizona should include the Grand Canyon (Figure 5). The canyon is perhaps the most magnificent erosional feature on earth. It is a remarkable 277 miles long, up to 18 miles wide, and approximately one mile deep. The canyon was carved by the Colorado River and its tributaries, and widened by landslides, rockfalls, and various other types of erosion. Within the geologist's conception of time, the canyon is a relatively young feature formed within the last 5 to 10 m.y. However, rocks exposed in the canyon walls are much older, ranging in age from almost two billion years to less than 250 m.y.

As in most geologic settings, the oldest rocks are at the bottom. The dark, inner gorge of the canyon has been incised into Precambrian metamorphic and granitic rocks that are nearly two billion years old, almost half as old as the earth itself. The metamorphic rocks represent sedimentary and volcanic rocks that were buried to great depths and metamorphosed by high temperatures and pressures. Some granitic rocks were probably formed when the metamorphic rocks were melted.

The top of the Precambrian rocks is marked by an unconformity, a surface that represents a period of erosion that, in this case, lasted up to 500 m.y. The unconformity is overlain by Paleozoic sedimentary rocks that form the conspicuous layering in the canyon walls. The sedimentary rocks were deposited between 600 m.y. and 250 m.y. ago in shallow seas, deserts, and meandering rivers. They consist of resistant sandstone and limestone that form major cliffs, and easily eroded siltstone and shale that form gentle slopes. This sequence of sedimentary rocks is not restricted to the Grand Canyon, but extends beneath most of the Colorado Plateau of northern Arizona. Rocks of similar age reappear at the surface along the Mogollon Rim, Monument Valley, and near Canyon de Chelly.

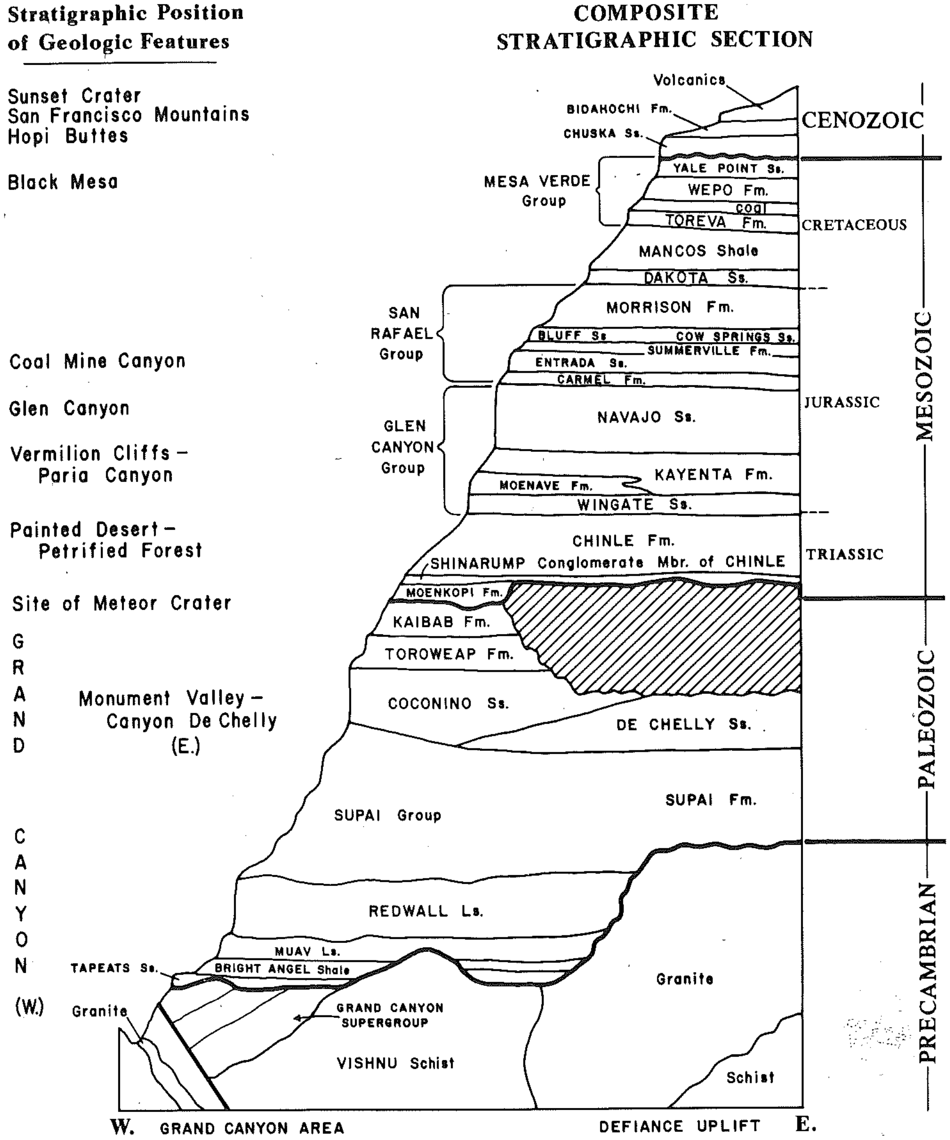


Figure 4. Composite stratigraphic section of northeastern Arizona (modified from Petrified Forest Museum Association, 1980, geologic cross-section along Interstate 40).

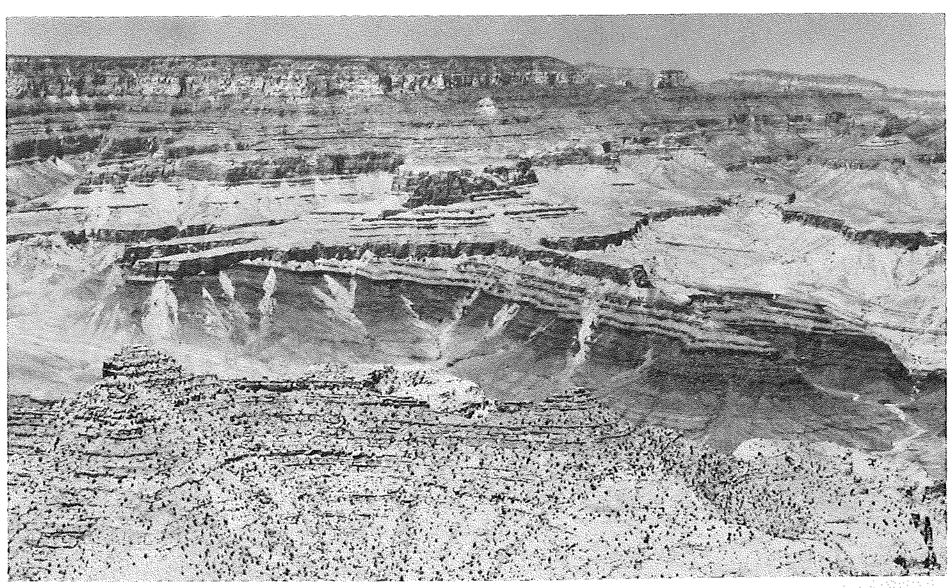


Figure 5. Eastern Grand Canyon. Note unconformity between tilted strata of Grand Canyon Supergroup (of late Precambrian age) and overlying sedimentary rocks of Paleozoic age. Photo: S. Reynolds.

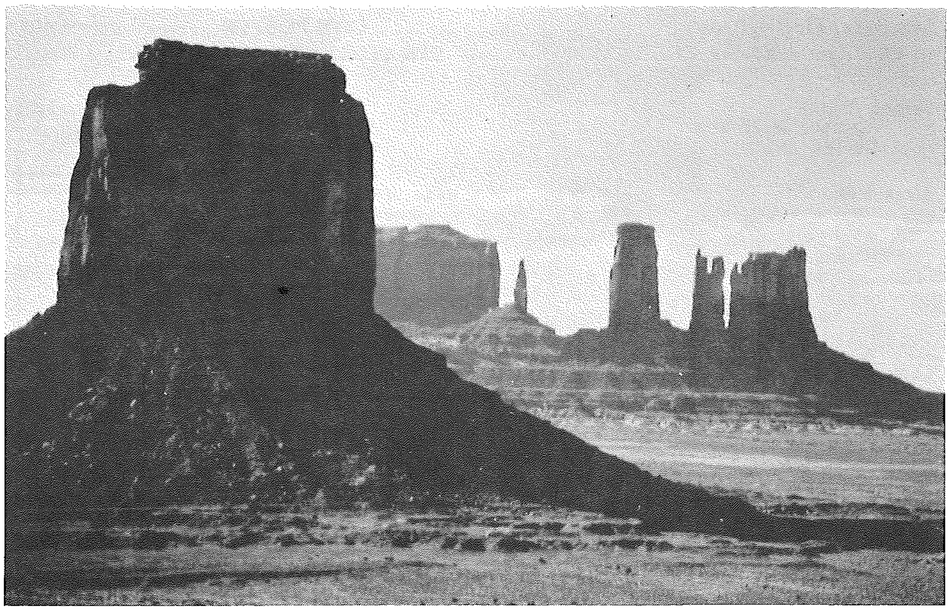


Figure 6. Monument Valley at sunset. "Monuments" are composed of slope-forming shale, cliff-forming De Chelly Sandstone, and cap-rock of Shinarump Conglomerate. Photo: S. Reynolds.

Monument Valley

Monument Valley is another of nature's masterpieces of erosion (Figure 6). The trademarks of Monument Valley are spectacular, steep-sided mesas, buttes, and pinnacles that rise abruptly from a nearly featureless plain. The scenery of the valley is dominated by three main sedimentary layers that are similar in age to those exposed in the upper walls of the Grand Canyon. The lowest layer is composed of easily eroded shales and mudstones that occur on the gently sloping pedestals around each monument. The middle and most prominent layer, referred to as De Chelly Sandstone, forms a brightly colored orange and red cliff. The sandstone was originally deposited as sand dunes approximately 270 m.y. ago. It is overlain by a thin, protective cap of Triassic Shinarump Conglomerate that represents ancient stream deposits. All three layers once extended continuously over the entire Monument Valley region, but they

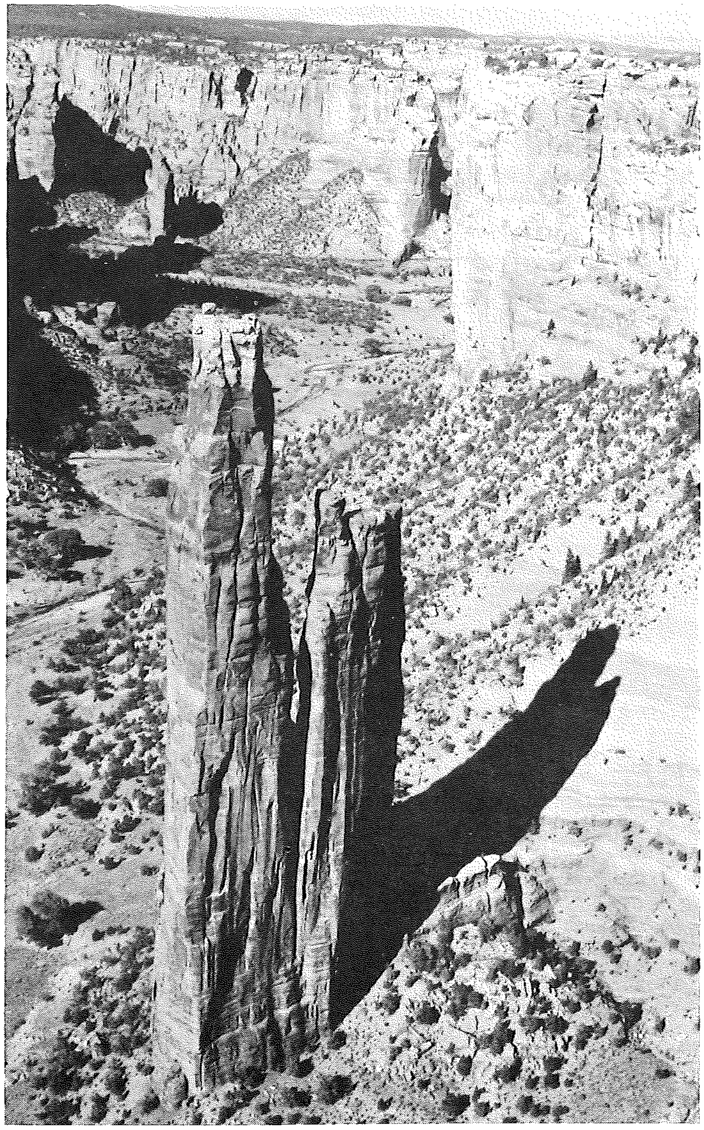


Figure 7. Canyon de Chelly and Spider Rock. Photo: S. Reynolds.

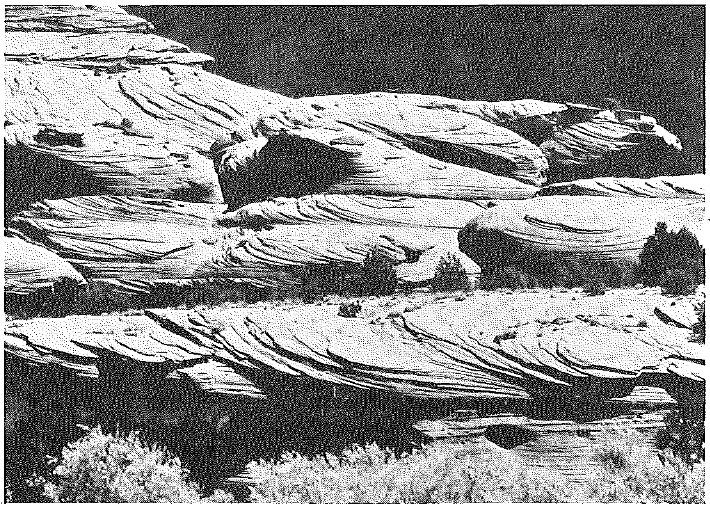


Figure 8. Cross-beds in De Chelly Sandstone, Canyon de Chelly. Photo: S. Reynolds.

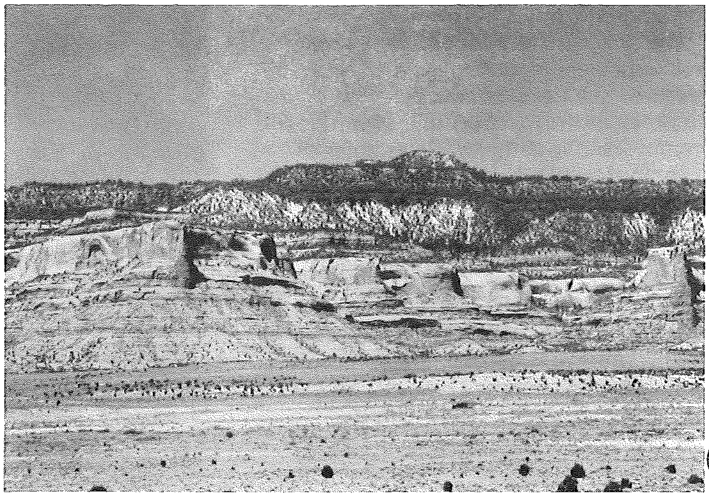


Figure 9. Chuska and Lukachukai Mountains. Strata low on the flanks of the mountains are mostly sandstones of Mesozoic Glen Canyon Group. Overlying rocks are younger sedimentary and volcanic rocks of Mesozoic and Cenozoic age. Photo: S. Reynolds.

were gradually removed from most areas by erosion within the last 10 m.y. The "monuments" are remnants of the layers that erosion left behind.

Canyon de Chelly

Beautiful Canyon de Chelly (pronounced de-shay) is the topographic opposite of Monument Valley. Whereas Monument Valley contains isolated monuments rising above a low-relief plain, Canyon de Chelly is a deep cleft within a gently inclined plain (Figure 7). The steep-sided canyon was formed as streams eroded down through a sequence of resistant rocks that are partly the same sedimentary formations that comprise Monument Valley. Canyon de Chelly contains a lower, slope-forming layer, a middle cliff of brightly colored De Chelly Sandstone, and an upper protective cap of tan and brown Shinarump Conglomerate. The middle sandstone was formed as a part of the same field of sand dunes as the middle sandstone of Monument Valley. The original forms of the sand dunes are preserved in the rocks as a series of gently sloping layers or cross-beds (Figure 8). The cross-beds represent the fronts of ancient sand dunes and can be used to determine which way the wind was blowing when the sand was deposited 275 m.y. ago.

The actual canyon was not formed until much more recently, probably within the last several million years. At famous Spider Rock (Figure 7) the canyon is over 1,000 feet deep and 3,000 feet wide. The canyon walls become progressively lower downstream to the west because the resistant cap rock and underlying layers gently slope in that direction. The prehistoric Anasazi Indians constructed White House and other dwellings within recesses and alcoves in the sheer vertical walls.

Chuska and Lukachukai Mountains

The Chuska and Lukachukai Mountains, some of Arizona's least publicized scenic attractions, are familiar to many geologists as the site of Arizona's largest oil field. Both mountain ranges are located in northeastern Arizona, near the New Mexico border. The Chuska Mountains are an impressive, mesa-like range that reaches elevations of over 9,700 feet and affords excellent views of Shiprock and Canyon de Chelly. The rugged and colorful flanks of the range are composed of red- and orange-colored sandstone and siltstone of early Mesozoic age (see Figure 9). These strata are successively overlain by younger, light-colored sedimentary rocks and a dark-colored cap of Cenozoic volcanic flows. Rocks beneath the Lukachukai Mountains were found in 1967 to contain significant oil deposits. This oil field has accounted for nearly 90 percent of Arizona's total oil production. Since its discovery, it has yielded over 16 million barrels of oil, which is less petroleum than Arizona presently consumes in four months.

Black Mesa

Black mesa is one of the largest geological entities of Arizona (Figure 2). It is a more-or-less circular feature approximately 60 miles in diameter, with an area of 3,200 square miles. The mesa is a saucer-like erosional remnant of sedimentary rocks of the Cretaceous Mesaverde Group that once covered much of northeastern Arizona (Figure 3). These rocks overlie and are significantly younger than the Paleozoic sedimentary layers of the Grand Canyon, Monument Valley, and Canyon de Chelly. In fact, drilling by oil companies indicates that Paleozoic rocks are buried nearly a mile below the surface of Black Mesa. Imagine the walls of the Grand Canyon with yet another mile of rocks on top!

Sedimentary rocks of the Mesaverde Group are not as brightly colored as the older rocks that surround Black Mesa. The Mesaverde Group is composed of tan and gray sandstone, siltstones, and shales that were deposited in shallow seas, along beaches, and by streams (Figure 10). These rocks contain Arizona's largest known deposits of coal. The coal was formed from plants that accumulated in swampy or marshy environments. The plant-rich layers were buried by younger stream and beach deposits, and were gradually converted into coal. Black mesa coal was first used for fuel by prehistoric Indians and will be a major energy source for the southwest U.S. many years into the future.

Coal Mine Canyon

Some extremely beautiful landscapes occur in and around Coal Mine Canyon, west of Black Mesa. Scenic badlands topography has been formed in varicolored sandstone and siltstone of the Mesozoic San Rafael Group (Figure 11). A coal seam within the sedimentary layers was evidently ignited by lightning and burned to produce brightly colored rocks resembling slag from a furnace. Locally, shale layers directly above the coal seam display exotic colors and abundant oyster fossils. The somewhat eerie aspect of the landscape is accentuated by legends of a silvery ghost that haunts the area during full moons.

Hopi Buttes

Landscapes south of Black Mesa are dominated by dark-colored buttes that stand above a surrounding red- and tan-colored terrain (Figure 12). The oldest rocks exposed near the Hopi Buttes are red-colored sandstone and siltstone of Mesozoic age. These rocks are overlain by light colored layers of Late Cenozoic sandstone, siltstone, and mudstone that were deposited in ancient Lake Bidahochi approximately 5 m.y. ago. The lake beds locally contain fossil fish and larger vertebrates such as antelope, camels, and mastodons. These rocks are in turn overlain by dark-colored volcanic rocks that were erupted onto the floor of the lake. The volcanic rocks are mostly basaltic lava flows and pyroclastic deposits composed of ash, cinders, and larger fragments. Sedimentary layers derived from the volcanic rocks are relatively common. Some buttes are true volcanic vents, whereas others are simply capped by thin lava flows. The Hopi Buttes exist because the

Figure 10. Mesaverde Group, Mancos Shale, and older strata on east flank of Black Mesa. Photo: D. Nations.

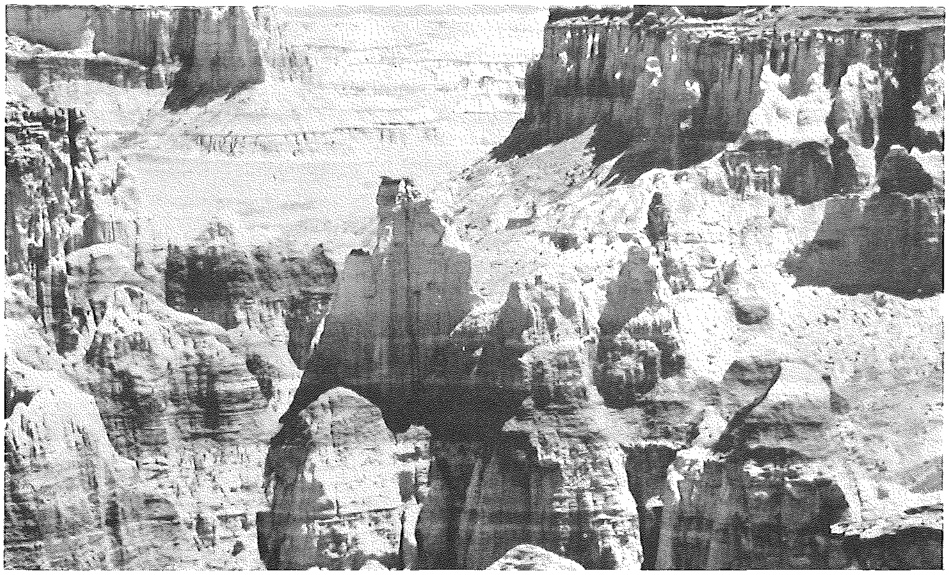


Figure 11. Coal Mine Canyon, west of Black Mesa. Badlands topography is developed in sedimentary strata of the San Rafael Group of Mesozoic age. Photo: S. Gillatt.

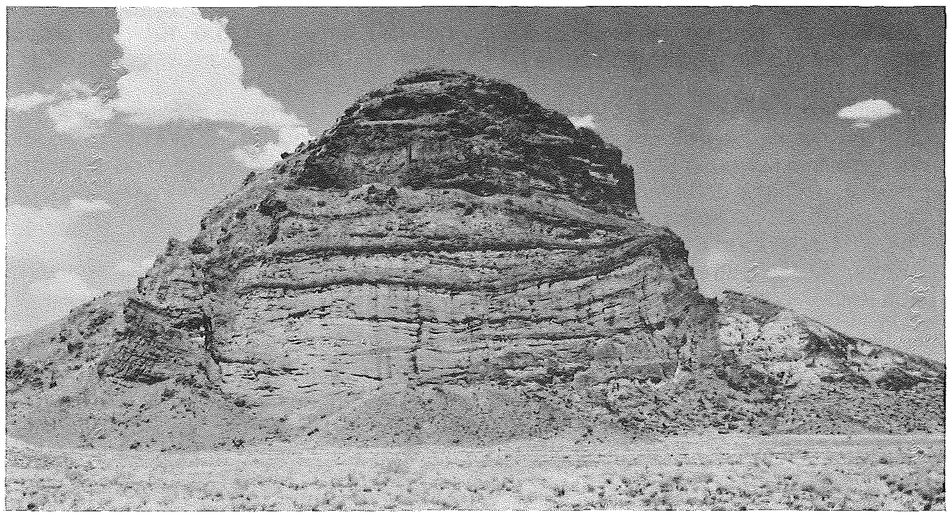


Figure 12. Typical Hopi Butte. Dark-colored butte is composed of late Cenozoic volcanic rocks that overlie, and are flanked by Mesozoic sandstones of the Glen Canyon Group. Photo: S. Reynolds.

Figure 13. Typical landscapes developed in Chinle Formation of early Mesozoic age, Painted Desert. Photo: S. Reynolds.

volcanic rocks are more resistant to erosion than are the surrounding and underlying sedimentary rocks.

Painted Desert—Petrified Forest

Colorful landscapes of the Painted Desert lie mostly south and west of Hopi Buttes and extend along the Little Colorado River Valley from east of Holbrook to north of Cameron. This region is characterized by extensive, low-relief plains and a series of small cliffs, ledges, and rounded hills (Figure 13). Most of the Painted Desert is underlain by variably colored sandstone, siltstone, and shale of the early Mesozoic Chinle Formation. These sedimentary rocks were deposited by meandering streams that flowed north across the region some 200–250 m.y. ago. The red, orange, pink, and purple colors in the rocks are due to oxidized iron and manganese minerals. Many of the white and gray layers contain clays that were formed by the weathering and alteration of volcanic ash. The volcanic ash was evidently blown into the area from erupting volcanos to the west.

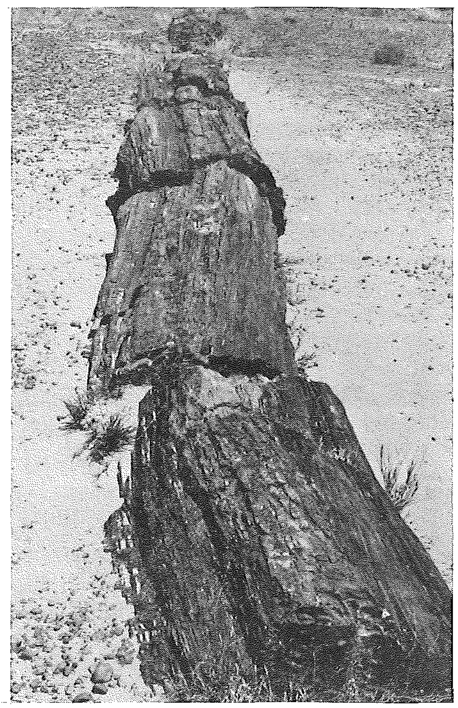


Figure 14. Petrified log in Chinle Formation, Petrified Forest. Log is several feet in diameter and over 30 feet long. Photo: S. Reynolds.

The Chinle Formation locally contains brightly colored petrified wood (Figure 14). The Petrified Forest is one of the world's greatest concentrations of large, petrified logs. The logs were originally transported northward into the area by flooding streams and were buried by successive layers of ash, mud, and sand. Ground water percolating through the sediments dissolved silica from the volcanic ash and redeposited it in the buried logs, turning them to stone. Impurities of iron, copper, and manganese in the silica give the petrified logs their splendid color.

Meteor Crater

The tranquil appearance of the Painted Desert and Little Colorado River Valley is interrupted west of Winslow by a large, circular crater (Figures 1 and 15). This feature, well known as Meteor Crater, is over 4,000 feet wide and 550 feet deep. It is one of the most spectacular meteorite impact craters in the world. The crater was formed approximately 20,000 years ago when a nickel-iron meteorite crashed onto the flat surface of the Colorado Plateau at over 30,000 miles per hour. The meteorite is calculated to have been over 80 feet in diameter and to have largely vaporized upon impact. Sedimentary layers along the rim of the crater were upturned by the force of impact and were covered by debris blasted out of the crater. Numerous fragments of the meteorite have been found below the floor of the crater and on the surrounding plateau surface.

Sunset Crater

A different type of crater lies east of the San Francisco Mountains, approximately 30 miles northwest of Meteor Crater. Sunset Crater was produced by a volcanic eruption a little more than 900 years ago. The eruption, which occurred around 1065 A.D., marks the most recent volcanic activity in the San Francisco volcanic field. The 1,000-foot-high crater was formed when hot volcanic cinders were blown into the air, and then settled around the vent (Figure 16). Formation of the main cinder cone was accompanied by eruption of a dark, basaltic lava flow that occurs in Bonito Canyon. At the end of the volcanic episode, hot springs and vapors escaped from the vent and deposited brightly colored minerals near the top of the crater. These yellow, red, and orange minerals give the crater its color of a perpetual sunset.

Needless to say, the volcanic eruption had a profound impact on the local Indians. Prior to the eruption, Indians, now referred to as the Sinagua, lived around the San Francisco Mountains in pithouses. The spectacular, but ominous eruption prompted many Sinagua to flee the area. After the eruption, neighboring Indians, including the Anasazi, migrated into the area to farm on the moisture-retentive volcanic ash. Multi-room dwellings, such as those preserved at Wupatki National Monument, were constructed at this time. Relentless winds eventually stripped the soil of its beneficial volcanic ash, and the Indians abandoned Wupatki and neighboring villages.

Figure 15. Meteor Crater. Walls of crater are composed of limestone and sandstone of late Paleozoic age. Rocks below floor of crater are shattered. Photo: Meteor Crater, Northern Arizona.

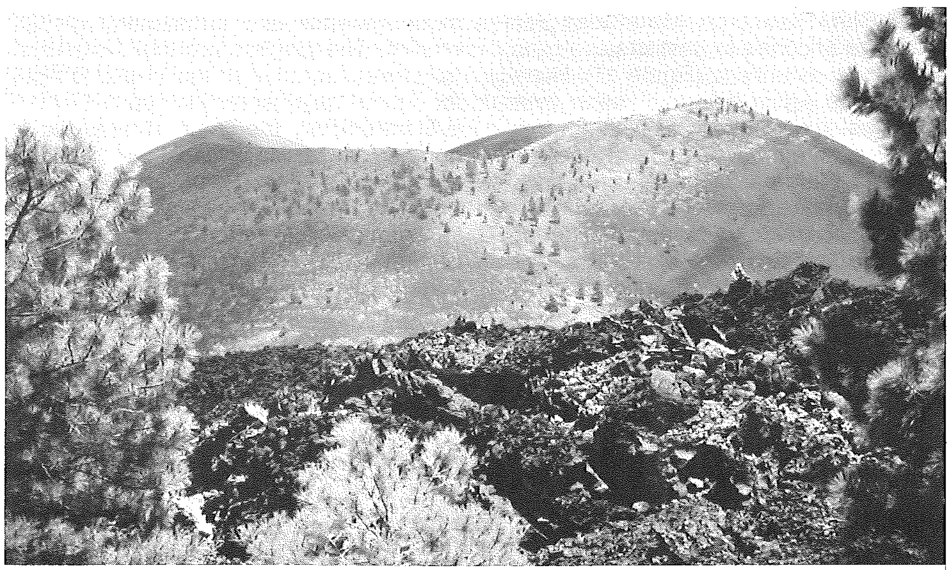


Figure 16. Sunset Crater with Bonito Lava Flow in foreground. Photo: S. Reynolds.

Figure 17. San Francisco Mountains from northwest. Photo: K. Matesich.

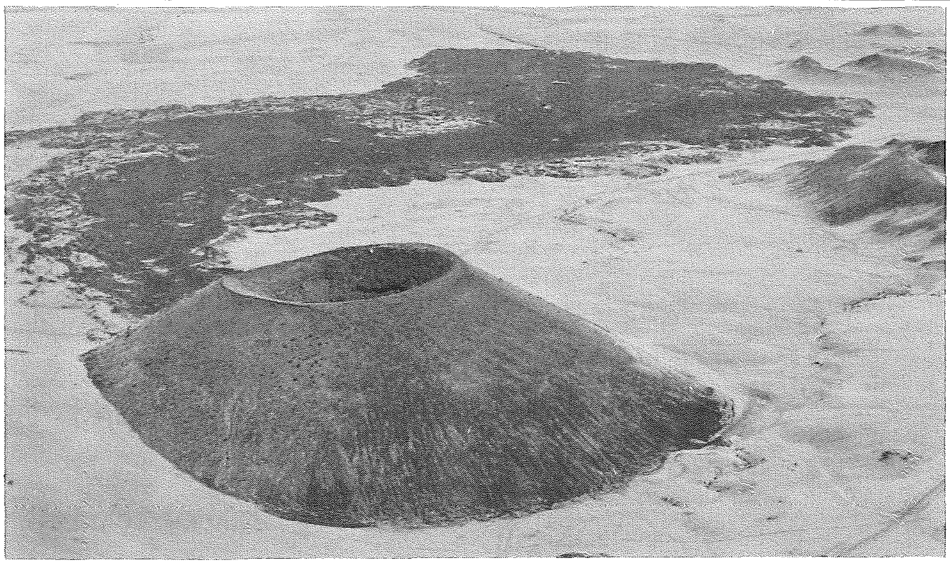


Figure 18. Aerial photograph of S P Crater and lava flow. Photo: D. Nations.

San Francisco Mountains

The San Francisco Mountains (or Peaks) are Arizona's largest stratovolcano and highest mountains (Figure 17). Humphreys and Agassiz Peaks reach over 12,000 feet in elevation and stand approximately a mile above the surrounding Colorado Plateau. The San Francisco Mountains were formed by successive eruptions of lava and pyroclastic debris within the last two m.y. The top of the volcano, which may have once been as high as 15,000 feet above sea level, has been lowered substantially by volcanic collapse and subsequent glacial erosion. The glaciers probably extended from near the crest of the peaks to near the floor of the adjacent plateau.

Surrounding the main peaks are a number of smaller volcanic vents. Elden Mountain, O'Leary Peak, and Kendrick Peak are volcanic domes similar in origin to the one presently forming in the crater of Mount St. Helens in southwestern Washington state. Numerous, small cinder cones are scattered around the higher peaks. Some of these, such as S P Crater, Sunset Crater, and Merriam Crater are recent and well preserved. Photographs of S P Crater and its accompanying lava flow appear in most introductory geology textbooks (Figure 18).

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ARIZONA OIL AND GAS CONSERVATION COMMISSION 1981 Activity Report

by A. K. Doss Executive Director, Arizona Oil and Gas Conservation Commission

Considerable exploration-related activity occurred during 1981, as reflected in the number of drilling permits issued by the state and by the total footage drilled (see table below). However, one exploration drill hole, of particular interest to industry, proved to be a major disappointment. The Phillips Petroleum No. 1 State, near Tombstone, was abandoned after reaching a total depth of 10,561 feet. In spite of this casualty, the following table indicates a striking comparison between the years 1980 and 1981:

	1980	1981
Number of drilling permits issued	14	73
Total number of wells drilled	8	51
Total footage drilled	32,775	65,400
Number of oil test dry holes	7	9
Number of oil producers	0	6

The 51 holes drilled in 1981 represented oil and gas tests (15), geothermal resource tests (34), underground storage cavity well (1), and re-entry (1).

The six new oil producers are on the Navajo Indian Reservation. Five new development wells, drilled by Kerr-McGee Corporation in the Dineh-bi-Keyah field, produced an average of 200 barrels of oil per day. The sixth well is a wildcat drilled by Kenai Oil and Gas in Section 7, T. 40 N., R. 29 E. This well indicated a pump potential of 56 barrels of oil per day.

Geothermal gradient holes represented the largest number drilled, accounting for approximately 7,600 feet of drilling.

The increase in activity and production during 1981 will also be reflected in an increase of state revenues through taxes, rentals and commercial sales, as indicated in the following table (estimated on an annual basis for the next few calendar years):

OIL AND GAS REVENUES TO ARIZONA

Direct	
1. Advalorem taxes (10¢/ dollar on the gross sales of oil and gas production)	$1,312,500
2. Sales tax (2½% of the gross sales of oil and gas production)	400,000
3. Rentals to the state (state lands and ½ on federal lands)	16,000,000
	$17,712,500
Indirect	
Commercial sales (rent, food, clothing, fuel, trucking fees, trucking charges, recreation, etc), conservatively estimated	$600,000
Total Revenue	$18,312,500

The prognosis for 1982 is even better than 1981. Conceivably, footage drilled could exceed 100,000 feet. Phillips Petroleum has a six-well drilling program outlined, and other major companies, as well as large and small independents, have indicated interest in exploration drilling activity. This interest is scattered from the northwest corner to the southeast corner of the state.

BUREAU OF GEOLOGY AND MINERAL TECHNOLOGY
Summary of Activities during 1981

by Larry D. Fellows
Assistant Director and State Geologist
Bureau of Geology and Mineral Technology

Geologic mapping, CRIB*, salt, "young" faults, earthquakes, potential geothermal resources, COSUNA**, geologic road and river logs, and uranium resources: these subjects, and more occupied the staff at the Bureau of Geology and Mineral Technology (BGMT) during 1981. In addition, geologic data and general assistance were provided to hundreds of persons.

The BGMT, charged by statute to do scientific investigations and to provide information, functions as the state geological survey of Arizona. Forty-five states have geological surveys and no two are identical. In Arizona our mission is to do research and provide information about: 1) the state's geologic setting, 2) its mineral and energy resources, and 3) the overall impact of things geologic on land use and society.

INFORMATION AND ASSISTANCE

We endeavor to provide timely, accurate, geologically related information based on geologic mapping, field observations, research investigations, and data compilations and synthesis.

BGMT staff supply information and furnish assistance by:

1. Publishing and selling geologic studies, either over-the-counter or by mail order. (A list of available publications may be obtained free of charge.)
2. Maintaining a specialized geologic library for public and staff use. The library includes:
   a. Unpublished maps and reports prepared by BGMT and other agencies
   b. Maps and reports published by the BGMT, the U.S. Geological Survey (USGS), the U.S. Bureau of Mines, state geological surveys from adjacent states, and other state and federal agencies
   c. Selected theses on Arizona geology
   d. Index of theses on Arizona geology (1891–1978)
   e. Abstracts of talks and articles on Arizona geology (1960–1981)
   f. Some major geological bulletins, journals, and newsletters
3. Publishing *Fieldnotes,* our quarterly newsletter, which is available by subscription (free) or over-the-counter
4. Giving talks on various aspects of geology on request
5. Identifying rocks and minerals from Arizona
6. Storing drill cuttings from selected exploration holes for examination
7. Disseminating information by telephone, correspondence, and office visits

Projects Completed:

—BGMT open-file series established
—Index of geologic road and river logs (1950–1980) published as Circular 22

Projects in Progress:

—Index of theses on Arizona geology
—Index of published geologic maps

RESEARCH

Geologic Setting

To better understand the geologic setting, or framework, of Arizona, BGMT geologists study the earth's surface and subsurface to learn the distribution and characteristics of rocks and other earth materials. They also identify the earth processes that have been active, or may still be active (e.g., folding, faulting, erosion, metamorphism, intrusion, volcanism, etc.).

Projects Completed:

—Characteristics and correlation of rocks of Mississippian and Pennsylvanian age in Arizona; prepared as part of USGS project and published as BGMT Circular 21
—Four composite stratigraphic sections in the Basin and Range Province, completed as part of COSUNA project and placed on open file at BGMT
—Report on the 1887 earthquake, San Bernardino Valley, Sonora: summarizes intensities in various parts of the state, and other related phenomena such as rockfalls and liquefaction; funded by USGS, U.S. Nuclear Regulatory Commission (NRC), and BGMT; published by BGMT as Special Paper 3
—Final report to USGS and NRC on historical seismicity in Arizona; project funded by USGS, NRC, and BGMT; report placed on open file by BGMT; copies available for purchase
—Compilation of existing gravity control points at 1:250,000 scale and two milligal contour interval; work done by University of Arizona, Department of Geosciences, as part of BGMT geothermal assessment project; partial funding provided by U.S. Department of Energy (DOE); maps available for examination or purchase at BGMT; 1:500,000 scale map may be obtained from the Department of Geosciences
—Geologic mapping along the Salt River from Roosevelt Dam downstream to Granite Reef Dam; project funded by U.S. Bureau of Reclamation; maps on open file at BGMT

Projects in Progress:

—Geologic mapping in Harquahala, Little Harquahala, and South Mountains
—Mapping of faulting and volcanic activity during past 15 million years; funded by USGS and BGMT
—Mapping of earth materials of Quaternary age (last 3 million years); final product will be 1:1,000,000 scale map of state; project funded by USGS and BGMT
—Map showing rock outcrops of Laramide age (70–50 million years ago)
—Comprehensive catalog of earthquakes that occurred or were felt in Arizona; project funded by USGS, NRC, and BGMT; being prepared for publication by BGMT

Mineral and Energy Resources

BGMT staff conduct studies on the occurrence, characteristics and origin of mineral and energy resources and provide information useful in mineral exploration, mining, and processing.

Projects Completed

—Occurrence of radioactive minerals in Arizona; funded by DOE; placed on open file at BGMT with copies available for purchase

Projects in Progress:

—Assessment of potential geothermal resources in Arizona; final report being prepared
—Map showing geothermal anomalies and data; will be printed by the National Oceanic and Atmospheric Administration
—Geothermal bibliography and index in Arizona; to be published by BGMT as Circular 23
—Occurrence and production of molybdenum in Arizona; project funded by USGS; data entered in CRIB; in technical review

continued on page 12

*Computerized Resources Information Bank
**Correlation of Stratigraphic Units of North America

Earth Science Information

Federal Agencies in Arizona

Data and information about Arizona's earth materials, mineral and water resources, and earth processes are available from various state and federal agencies. A list of state agencies and some of the services and products they provide was included in the June 1981 issue of *Fieldnotes*. Some federal agencies are listed here to guide those who might need additional information or assistance about these and related matters.

DEPARTMENT OF AGRICULTURE

FOREST SERVICE—Regional Office

Office of Information
517 Gold Ave., S.W.
Albuquerque, NM 87102
505/766-2444
There is no state office. Contact should be made with specific Forest Headquarters or District Ranger offices, listed below.

Services and products:

Provide information on
—Resources on national forest lands
—Mineral exploration and leasing
—Lands closed for mineral entry
Sells forest maps

National Forest Headquarters:

Apache-Sitgreaves National Forest
Box 640
South Mountain Ave.
Springerville, AZ 85938
602/333-4301
Nick W. McDonough, Forest Supervisor
District Ranger Offices in Alpine, Clifton, Lakeside, Overgaard, Snowflake, and Springerville

Coconino National Forest
2323 E. Greenlaw Lane
Flagstaff, AZ 86001
602/779-3311, ext. 1441
Neil R. Paulson, Forest Supervisor
District Ranger Offices in Flagstaff, Happy Jack, Rimrock, and Sedona

Coronado National Forest
301 W. Congress
Federal Building
Tucson, AZ 85701
602/792-6483
Robert L. Tippeconnic, Forest Supervisor
District Ranger Offices in Douglas, Nogales, Safford, Sierra Vista, and Tucson

Kaibab National Forest
800 South Sixth Street
Williams, AZ 86046
602/635-2681
Leonard A. Lindquist, Forest Supervisor
District Ranger Offices in Fredonia, Tusayan, and Williams

Prescott National Forest
344 South Cortez Street
P.O. Box 2549
Prescott, AZ 86302
602/445-1762
Donald H. Bolander, Forest Supervisor
District Ranger Offices in Camp Verde, Chino Valley, and Prescott

Tonto National Forest
102 S. 28th Street
P.O. Box 29070
Phoenix, AZ 85038
602/261-3205
James L. Kimball, Forest Supervisor
District Ranger Offices in Carefree, Globe, Mesa, Payson, Roosevelt, and Young

SOIL CONSERVATION SERVICE

3008 Federal Building
230 North First Ave.
Phoenix, AZ 85025
602/261-6711

Verne M. Bathurst, State Conservationist
Donald R. Phillips, Assistant State Conservationist—Programs
Douglas S. Pease, State Soil Scientist

Services and Products:

Library of soil maps and reports (available for examination; no checkout)
Published soil surveys available for distribution
Generalized soil maps for each county in Arizona
Major land resource areas and sub-resource areas in Arizona (maps)
Farmland maps for portion of Maricopa County
Information on soils and soil-mapping projects

Area Offices:

Flagstaff Area
Soil Conservation Service
2717 North Fourth, Suite 140
Flagstaff, AZ 86001
602/779-3311 or 779-1392
Charles R. Adams, Area Conservationist

Tucson Area
Soil Conservation Service
3241 Romero Rd.
Tucson, AZ 85705
602/792-6602
Joseph L. Knisley, Jr., Area Conservationist

DEPARTMENT OF INTERIOR

BUREAU OF LAND MANAGEMENT

Arizona State Office
2400 Valley Bank Center
Phoenix, AZ 85073
602/261-3706
Thomas J. Allen, Acting State Director

Services and Products:

Records of unpatented mining claims on federal lands in Arizona
Land ownership maps and other maps for sale (price list available)
Maps showing wilderness inventory information on Bureau of Land Management (BLM)-administered lands
Information on how to obtain leases and information about BLM-administered lands open or closed for mineral entry
Watershed characteristics of some BLM-administered lands

District Offices:

Arizona Strip District Office
Federal Building
196 E. Tabernacle
P.O. Box 250
St. George, UT 84770
801/673-3545
Billy R. Templeton, District Manager

Phoenix District office
2929 W. Clarendon
Phoenix, AZ 85017
602/241-2501
William K. Barker, District Manager

Yuma District Office
2450 Fourth Ave.
Yuma, AZ 85364
602/726-6300
H. Max Bruce, District Manager

Safford District office
425 E. Fourth Street
Safford, AZ 85546
602/428-4040
Fritz Rennebaum, District Manager

Kingman Resource Area of Phoenix District
2475 Beverly
Kingman, AZ 86401
602/757-4011
Roger G. Taylor, Area Manager

Lake Havasu Resource Area of Yuma District
P.O. Box 685
2049 Swanson Ave.
Lake Havasu, AZ 86403
602/855-8017
James May, Area Manager

BUREAU OF MINES

Intermountain Field Operations Center
Denver Federal Center
Building 20
Denver, CO 80225
Joseph B. Smith, Chief, 303/234-3918
Jimmie E. Jinks, Assistant Chief, 303/234-3740
George R. Schottler, Chief, Minerals Availability Section, 303/234-4161
Karl E. Starch, Chief, State Services Section, 303/234-6866
Lorraine B. Burgin, State Minerals Specialist for Arizona
Homer C. Stewart, Chief, Resource and Environmental Studies Section, 303/234-3930
Robert G. Dickinson, Chief, Mineral Land Assessment Section, 303/234-6755

Services and Products:

Information on the location and potential of mineral resources, exploration, development, and processing
Computerized system for assessing worldwide information on mineral resources through systematic engineering and cost evaluations for selected mineral properties
Identification and location of significant domestic operating, developing, and explored mines for selected commodities
Library of periodicals, state and federal reports, open-file reports, technical books and maps on mineral resources, mining, and processing.
Data files on mines and mining districts
Statistical information on state mineral production and mining activities

BUREAU OF RECLAMATION

Geology and Materials Branch
505 South 43rd Avenue
P.O. Box 6972
Phoenix, AZ 85005
602/261-4450
Rex A. Motsenbocker, Chief

Services and Products:

Information on
—Engineering properties of earth materials
—Subsidence due to groundwater withdrawal
—Ground-water levels along the Central Arizona Project aqueducts and storage dams
—Geologic setting and related factors in the Central Arizona Water Control Study Area
—Geologic factors related to safety of dams along Salt and Verde Rivers

GEOLOGICAL SURVEY—Geologic Divison

Western Region
345 Middlefield Road
Menlo Park, CA 94025
415/323-8111
G. Brent Dalrymple, Assistant Chief Geologist, Western Region

Services and Products:

Information about Western Region (Geologic Division) projects and activities in Arizona

GEOLOGICAL SURVEY—Geologic Division

Flagstaff Office
2255 N. Gemini Drive
Flagstaff, AZ 86001
602/779-3311
Gordon Swann, Deputy Assistant Chief Geologist

Services and Products:

Geologic library includes most U.S. Geological Survey (USGS) publications, as well as other geologic maps and reports
Information about status of geologic projects being done by geologists at Flagstaff office
Planetary data facility and library
Information about ordering lunar and planetary images and USGS publications

GEOLOGICAL SURVEY—National Mapping Division

Western Mapping Center
345 Middlefield Road, M.S. 31
Menlo Park, CA 94025
415/323-8111
Gene Napier, Acting Chief, Program Management

Services and Products:

Topographic maps, orthophoto quadrangles, and other related maps
Base maps and separates at various scales
Digital mapping
Information about status of mapping projects
Information on cost and availability of maps (address inquiries to National Cartographic Information Center, Menlo Park)

GEOLOGICAL SURVEY—Water Resources Division

Arizona District Office
Federal Building
301 W. Congress
Tucson, AZ 85701
602/792-6671
Robert MacNish, District Chief

Services and Products:

- Basic water resources data (stream flow, ground-water levels, flood-prone areas, water use, springs, water quality)
- Reports on earth fissures and subsidence related to ground-water withdrawal, surface and ground-water interaction, floods, consumptive use of water by vegetation, and ground-water supply and availability
- Prepares data for flood warning
- Maintains formal cooperative programs with Arizona Department of Water Resources and other state and federal agencies
- Provides loan copies of published USGS water studies in Arizona

Subdistrict Offices:

Flagstaff Field Center (USGS)
Water Resources Division
2255 N. Gemini Drive
Flagstaff, AZ 86001
602/779-3311, ext. 1429
G. W. Hill, Field Office Chief

Phoenix Subdistrict office (USGS)
Water Resources Division
1880 Valley Bank Center
Phoenix, AZ 85073
602/261-3188
E. G. Nassar, Subdistrict Chief

Tucson Subdistrict Office (USGS)
Water Resources Division
Federal Building
301 W. Congress
Tucson, AZ 85701
602/792-6671
H. W. Hjalmarson, Subdistrict Chief

Yuma Subdistrict Office (USGS)
Water Resources Division
1940 South 3rd Avenue
P.O. Box 5774
Yuma, AZ 85364
602/783-2133
L. L. Werho, Subdistrict Chief

Bureau Activity Summary continued

—Occurrence and production of base and precious metals being introduced into CRIB; funded by USGS and BGMT

Impact of Things Geologic

In order to evaluate the impact of things geologic, one must first understand the geologic setting—earth materials, resources, and processes. Some processes (e.g., flooding, faulting, landslides, rockfalls, etc.) may be hazardous to inhabitants and destructive to structures. Certain other factors (steep slopes, thin soil cover, subsidence, shrinking and swelling clay, presence or absence of resources, etc.), although not hazardous, may limit use of land.

During 1981 BGMT geologists reviewed and evaluated reports on the potential for mineral resources in wilderness study areas, the geologic framework in proposed hazardous and toxic waste disposal areas, geologic factors along proposed Central Arizona Project canal routes, and the impact of various geologic factors on land use in Coconino County.

Projects Completed:

—Report on 1887 earthquake in San Bernardino Valley, Sonora; includes discussion on implications for seismic hazard in Arizona and recommendations to minimize earthquake losses

—Final report to USGS and NRC on historical seismicity in Arizona; includes commentary on seismic risk

Projects in Progress:

—Comprehensive catalog of earthquakes that occurred or were felt in Arizona; funded by USGS, NRC, and BGMT; will be published by BGMT

—Assessment of geologic hazards in Arizona; funded by USGS and BGMT; will include identification of areas in which potentially hazardous geologic factors occur

REGIONAL EVENTS

Illinois State Museum—Field Trip, Geology of the Grand Canyon, Colorado Plateau, Arizona and Utah; Springfield, June 28–July 9, 1982.

Geological Society of America—Penrose Conference
- Origin of Fluids and Metals in Porphyry and Epithermal Mineral Deposits, Dillon, Colo., August 8–13, 1982 (Deadline: April 20).
- Laramide Deformation of the Rocky Mountain Foreland, Billings, August 22–28, 1982.
- Sonoma Orogeny and Permian to Triassic Tectonism in Western North America, Winnemucca, Nev., September 8–14, 1982.

Utah Geological Association—Field Trip, Central Utah, Salt Lake City, September 20–22, 1982.

Fieldnotes

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State of Arizona .... Governor Bruce Babbitt
University of Arizona .... President John P. Schaefer
Bureau of Geology & Mineral Technology
Acting Director .... William P. Cosart
State Geologist .... Larry D. Fellows
Editor .... Anne M. Candea
Illustrators .... Joe LaVoie, Ken Matesich and Jenny Laber

State of Arizona
Bureau of Geology and Mineral Technology
845 N. Park Ave.
Tucson, Arizona 85719
602/626-2733