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Geology of Side Canyons of the Colorado, Grand Canyon National Park

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The majesty of the Grand Canyon emanates from the magnitude of its impressive dimensions. The Colorado River has cut a mighty gorge; its tributaries are no less spectacular. Trails from the rim are few, the hike is lengthy, and access to much of the canyon from above is limited; however, a river trip through the Grand Canyon, with ample time for hiking, enables one to explore many side canyons with relative ease. Unlike a view from the rim, a view from the river gives one an inside-out perspective (Figure 1). The rim view paints an overall picture of the grand-scale geologic scene. In the side canyons, one can further examine the details of geologic features and relationships that tell a more complete story.

The sequence of rocks in the Grand Canyon can be divided into four groups, each separated by a major unconformity (time break) that indicates a significant erosional episode and thus a major gap in the geologic record (Figure 2). The two oldest groups consist of Precambrian igneous and metamorphic crystalline rocks [Vishnu Group, about 1.8 billion years (b.y.) old], overlain by a tilted sequence of sedimentary rocks (Grand Canyon Supergroup, 1.4 to 1.0 b.y. old). Extensive erosion of these Precambrian rocks formed a conspicuous planar surface on which the canyon's characteristic, horizontally stratified Paleozoic rocks were deposited 550 to 250 million years (m.y.) ago. The fourth group includes a veneer of late Cenozoic sediments and volcanic rocks that were deposited during and after the period of canyon cutting, mostly 6 m.y. ago to the present. The topographic signature of the Cenozoic Era is punctuated by canyonlands and broad pediments, features sculpted by the agents of erosion that responded to the gentle uplifting of the region to about 2 miles above sea level.

From its source in northeastern Colorado to its mouth at the Gulf of California, the Colorado River crosses four major physiographic provinces: the Rocky Mountain region, the Colorado Plateau, the Transition Zone, and the Basin and Range Province. On the final leg of its long journey across the Colorado Plateau, the river follows a sinuous course in northern Arizona through the Grand Canyon. The Grand Canyon, Transition Zone, and Colorado Plateau end abruptly at the Grand Wash Cliffs, where the river flows into the Basin and Range Province near Lake Mead. The canyon is 277 miles long, up to 18 miles wide, and a mile deep through much of its length. It passes through five structural provinces of the Colorado Plateau, each bounded by a major fault or monoclinal fold. An unusual aspect of the Colorado River is that it actually follows these structural weaknesses only twice and for a mere one-fifth of its length. Elsewhere, it boldly crosscuts these structures and flows against the regional dip of the strata (Figure 3).

In contrast, side canyons are more strongly influenced by structural and geomorphic controls such as faults, regional dip of strata, and rock hardness. Fault-controlled canyons are recognized by distinct linear trends. Side canyons that flow down the regional dip tend to be longer than those that drain into the river against the dip. Many of the larger canyons drain source areas of higher elevation and thus greater rainfall. Canyons formed in softer shales and mudstones are generally wider than those confined to the harder sandstone, limestone, and crystalline rocks. The length of time over which these controls have operated contributes to the wide variety of side canyons. The unique architectural style and attractive features of each side canyon are thus determined by a combination of factors. The nine canyons shown in Figure 3 have been

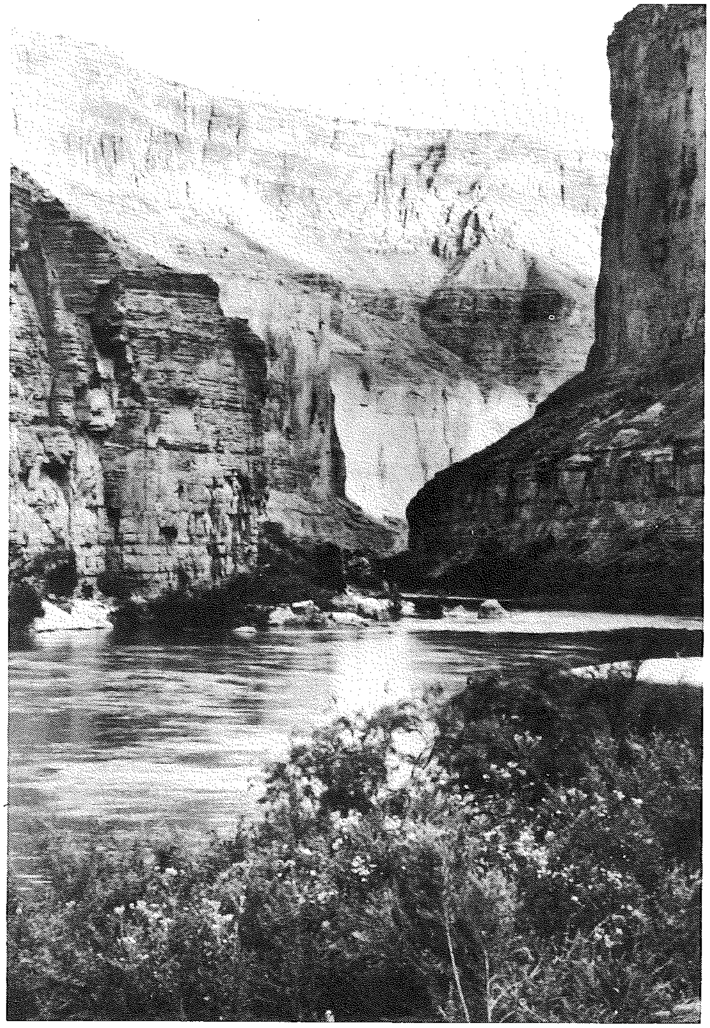

Figure 1. The Colorado River within Marble Canyon, as seen from Saddle Canyon. Photo by S. Reynolds.

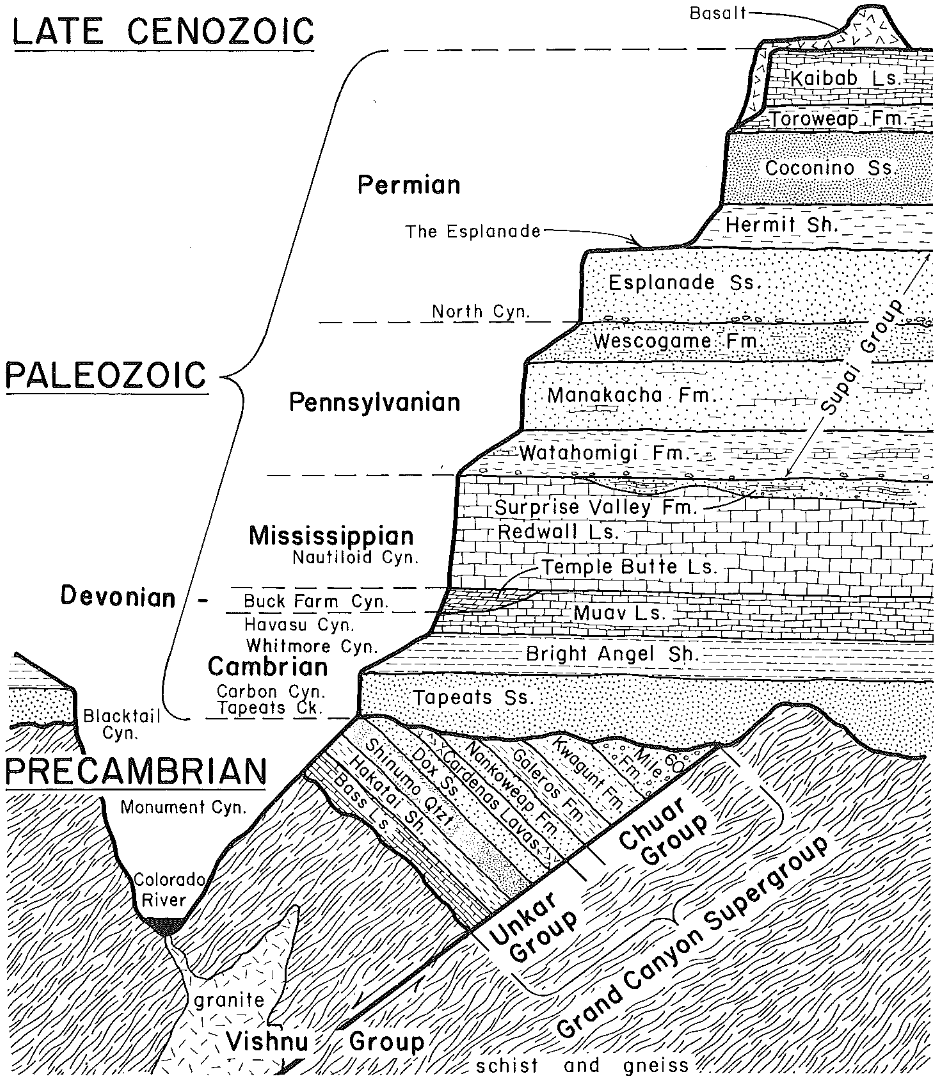

Figure 2. Generalized stratigraphic section of rock units revealed within the Grand Canyon.

chosen for this discussion because a wide range of geologic features are clearly displayed in a variety of settings.

North Canyon

In the first 20 miles below Glen Canyon Dam, the Colorado River cuts down through the red-colored Mesozoic rocks of the Vermilion and Echo Cliffs into the underlying cream-colored Permian rocks that form the familiar rim of the Grand Canyon. By North Canyon (mile 20 from Lees Ferry), the river has also deeply incised the underlying, rust-colored, Permian Hermit Shale and Permian-Pennsylvanian Supai Group. A hike up North Canyon reveals sculptured formations of the Supai Group, including a gray conglomerate that marks the base of the Esplanade Sandstone. The canyon walls are steep and high, textures are soft and gentle, colors are warm and soothing, and the acoustics are those of a cathedral. Only minor vegetation survives on the scoured bedrock floor, but the sacred, night-blooming Datura bush grows in abundance near the mouth of the canyon. Nearly a mile of hiking leads to a sanctuary with smooth, concave walls formed by dramatic, curved fractures in the sandstone (Figure 4). A serene plunge pool cannot be passed without a swim, intentional or otherwise (Figure 5).

Nautiloid Canyon

Not far downstream from North Canyon, gray- and cream-colored strata form a small cliff along the river's shores. Through the next 12 miles, the river's course becomes confined within the towering walls of the canyon's single most formidable barrier to river-rim hiking: the Redwall Limestone. This fossiliferous carbonate rock was deposited in a vast shallow sea that inundated much of western North America during Mississippian time more than 300 m.y. ago. In 1869 John Wesley Powell named Marble Canyon for the beautiful marblelike polish of the Redwall Limestone flanking the river. The limestone's true ivory and gray colors, exposed by running water or recent rockfalls, are usually concealed by a red iron-oxide stain derived from the overlying Supai Group and Hermit Shale.

The 500-foot vertical walls of nearly pure limestone and dolomite are highly resistant to erosion in the semiarid climate of the inner canyon. Numerous solution caverns, however, were dissolved by the ground water of a more humid climate during an earlier geologic period. Many large caverns developed along vertical joints or cracks in the limestone and are particularly conspicuous near mile 35, where a large set of joints bisects the canyon.

In this vicinity, a narrow cleft called Nautiloid Canyon enters from the east (Figure 6). A short, 100-yard climb into this canyon reveals numerous fossilized remains of the chambered nautiloid (Figure 7). Discovered by William Breed in 1969, these fossils were the first of their kind to be found in the Grand Canyon. The polished limestone floor of Nautiloid Canyon bears many cross sections of these ancient cone-shaped creatures, which can be up to 20 inches in length. The tentacle-like appendages on some specimens may be preserved soft parts. These fossils, found in the Thunder Springs Member of the Redwall Limestone, are but one of several animals preserved in this cherty rock.

Buck Farm Canyon

Small rapids and riffles occasionally punctuate the shady serenity of Marble Canyon as the river cuts into older Paleozoic strata downstream from Nautiloid Canyon. Only the keenest observer will notice where the river intersects the inconspicuous horizontal contact between the Mississippian Redwall Limestone and underlying Cambrian Muav Limestone. The parallel layering and similar appearance of these two red-stained limestones belies the staggering difference in their ages. Rocks representing Late Cambrian through Early Mississippian time, nearly 200 m.y. of earth history, are missing at this stratigraphic boundary. A clue to these vanished pages of time is evident in the canyon walls upstream from Buck Farm Canyon, where purplish lenses of sandy limestone 50 feet high and hundreds of feet long are sandwiched between the Redwall and Muav Limestones (Figure 8). A hike in Buck Farm Canyon near mile 40 affords an opportunity to examine closely one of these Devonian Temple Butte Limestone lenses.

The bowl-shaped cross section of these lenses suggests the following scenario of events. After deposition of the Muav Limestone in Cambrian time, vertical forces uplifted the continent above sea level, and streams carved channels into the landscape. Subsequent transgression of a Devonian sea filled these channels with impure limestone, which accumulated to even greater thicknesses in the western Grand Canyon. Both Temple Butte Limestone and Muav Limestone were then eroded down to a peneplain as the landmass once again emerged from the sea in Late Devonian time. This second erosional period so thoroughly leveled the landscape that the Temple Butte Limestone in the eastern Grand Canyon was preserved only at the bottom of channels in which it had first accumulated. A third marine advance from

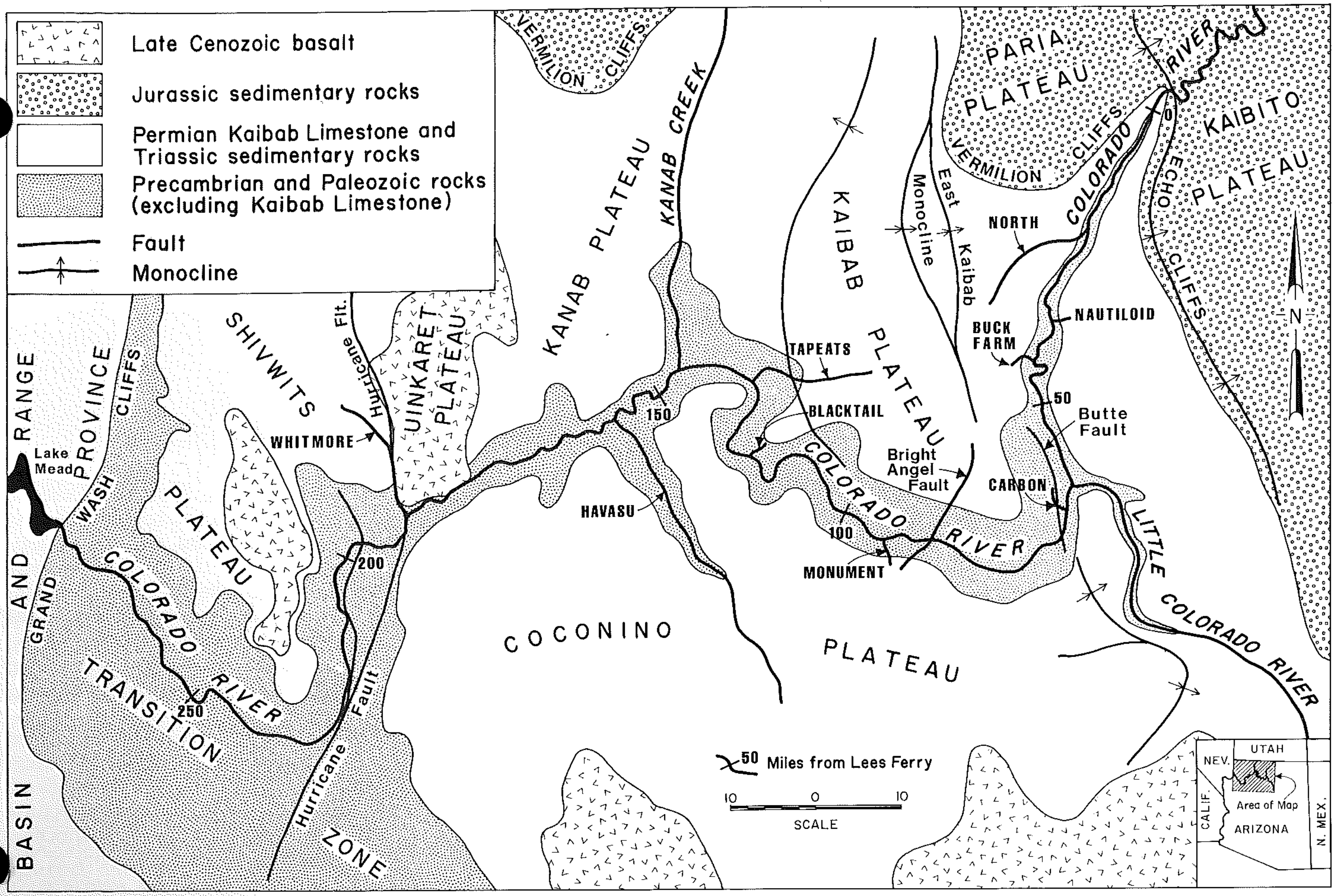

Figure 3. Simplified geologic map of the Grand Canyon region.

the west blanketed the region with the Redwall Limestone in middle Mississippian time, preserving the channel infillings in the geologic record. The relatively recent cutting of the Grand Canyon affords cross-sectional views of these channels, which were originally cut some 400 m.y. ago.

How did the landscape appear during the erosional intervals and what lived in the

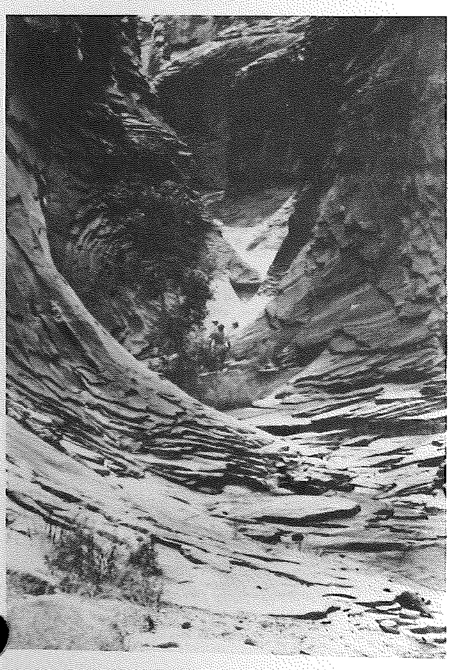

Figure 4. *North Canyon. Curved fractures and bedding surfaces occur in the Permian Esplanade Sandstone of the Supai Group. Photo by A. Potochnik.*

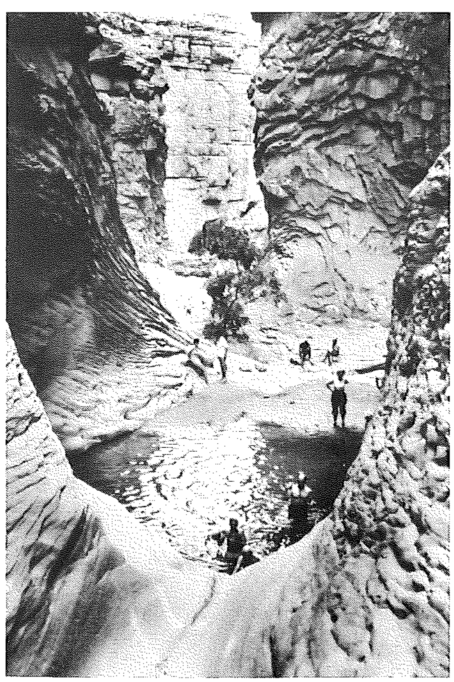

Figure 5. *Plunge pool within North Canyon. Photo by A. Potochnik.*

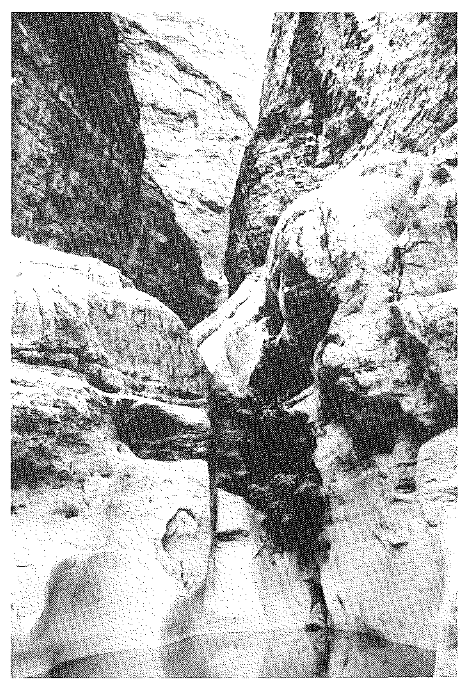

Figure 6. *A pool and dry waterfall near the mouth of Nautiloid Canyon. Photo by S. Gillatt.*

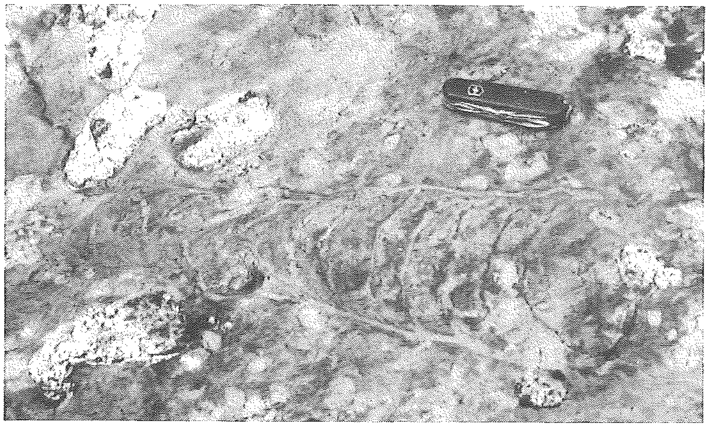

Figure 7. Fossil nautiloid on stream-polished outcrop of Mississippian Redwall Limestone. Photo by S. Reynolds.

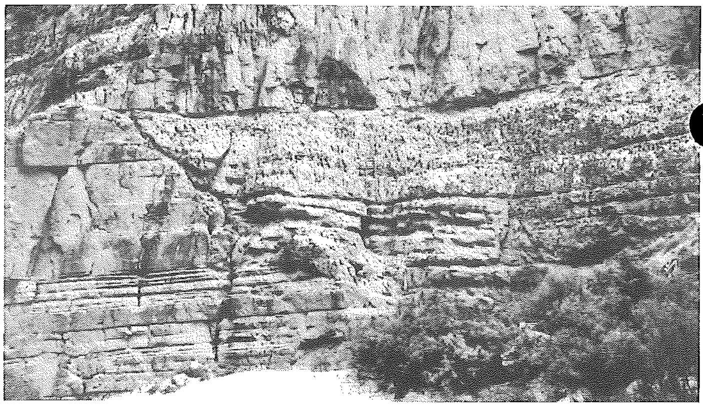

Figure 8. Lens of Devonian Temple Butte Limestone that was deposited in a channel cut into the underlying Cambrian Muav Limestone. The lens is overlain by Mississippian Redwall Limestone. Photo by S. Reynolds.

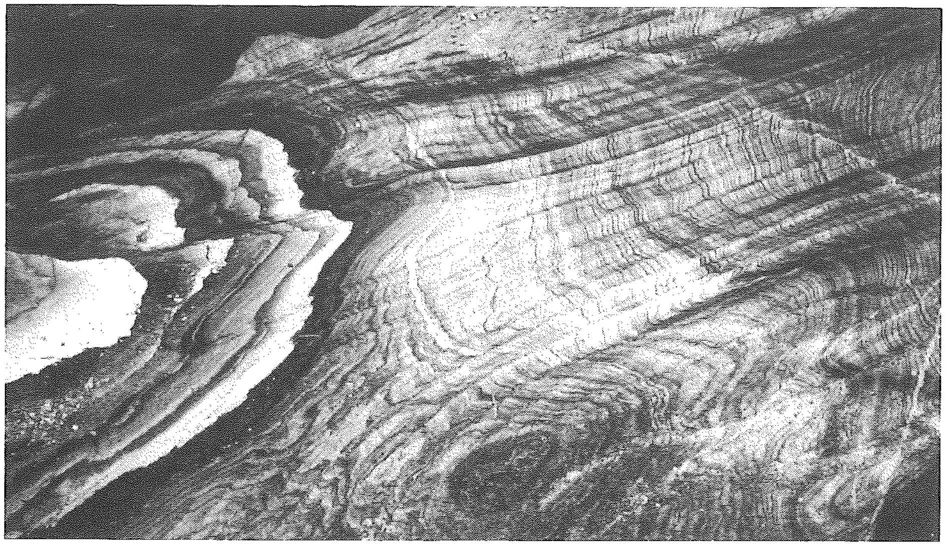

Figure 9. Liesegang banding in Cambrian Tapeats Sandstone, Carbon Canyon. Bedding dips to the left. Photo by S. Reynolds.

Devonian sea? The flat-lying, undisturbed nature of the Paleozoic rocks tells us that dynamic crustal activity such as mountain building, faulting, and volcanism were absent. During the first erosional episode, one can imagine a bleak, featureless landscape of Muav Limestone incised by local stream channels. Probably no plants or animals lived on land, but early, bony-plated fishes first made their appearance in the Devonian sea that inundated this landscape. The landmass once again emerged from the sea and the earliest land plants took root. The subsequent inundation by the Mississippian sea brought a much greater abundance and diversity of marine life including corals, sponges, shellfish, echinoderms, and nautiloids.

Carbon Canyon

The Marble Canyon segment of Grand Canyon ends a few miles downstream from the confluence of the Colorado River with its major tributary, the Little Colorado River. The configuration of the canyon changes dramatically here as it cuts through a broad upwarped region called the Kaibab Plateau, or "mountain lying down" (Paiute). The nearly vertical walls of Marble Canyon give way to the characteristic stair-stepped profile of a far wider and deeper Grand Canyon. Carbon Canyon, a lateral gorge entering the river from the west at mile 65, provides a fascinating structural and geomorphic perspective of the eastern boundary of the uplifted Kaibab Plateau.

The canyon walls in the lower portion of Carbon Canyon consist of purple sandstones and siltstones of the Precambrian Dox Formation and buff-colored, coarse-grained arkose of the overlying Cambrian Tapeats Sandstone. The latter exhibits striking examples of honeycomb weathering and purple- and rust-colored parallel bands that form graceful, curving patterns throughout the rock (Figure 9). These Liesegang bands or "picture sandstone" effects were caused by precipitation of iron oxides in the ground-water-saturated matrix of the porous sandstone.

Evidence of the forces that uplifted the Kaibab Plateau relative to areas to the east is dramatically displayed a short distance above a large rockfall that chokes the channel. The bedding planes in the Tapeats Sandstone become tilted gently upward as one walks upcanyon until, at one point, they are abruptly bent vertically (Figure 10). The narrow gorge opens into a wide valley of rolling hills with many small tributaries that drain the soft shales of the Precambrian Chuar Group. The Kaibab Plateau, underlain by the entire Paleozoic sequence, is seen on the western skyline some 5 miles distant and 2,000 feet higher than the elevation of the same formations along the river. The sharp upturn in the strata in Carbon Canyon is a local fold caused by the Butte fault. This fault parallels a broad structural upwarp called the East Kaibab monocline, which forms the eastern boundary of the Kaibab Plateau. A structural weakness of great antiquity, the Butte fault was a normal fault (west side down) in the Precambrian but

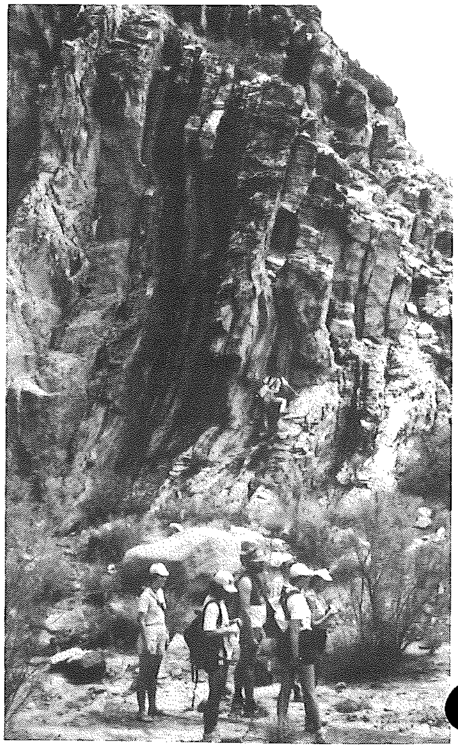

Figure 10. Upturned bedding along Butte fault, Carbon Canyon. Photo by S. Reynolds.

Figure 11. Granite Gorge. Dark-colored walls are Precambrian metamorphic and igneous rocks. Photo by S. Reynolds.

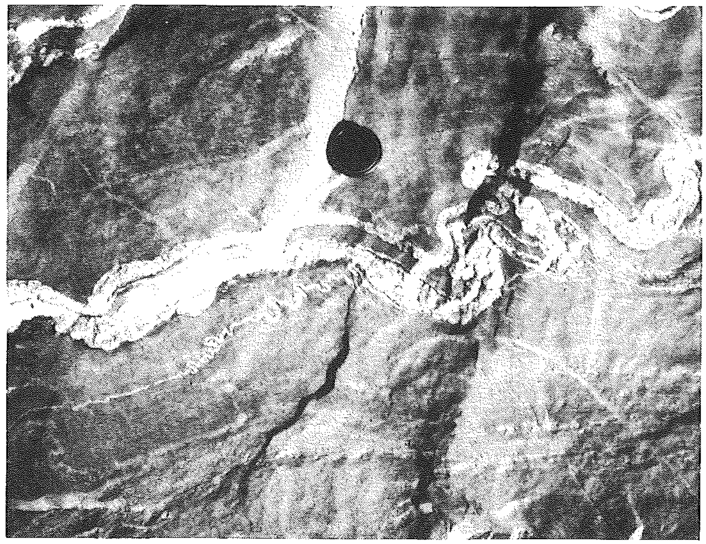

Figure 12. Folded granitic layers within dark-colored Precambrian metamorphic rocks in Monument Canyon. Photo by A. Potochnik.

was reactivated as a reverse fault (west side up) in late Mesozoic or Cenozoic time during uplift of the Kaibab Plateau. Cenozoic erosion has breached the monocline, causing removal of the entire Paleozoic sequence and exposure of the underlying Chuar Group shales.

Monument Creek

Near mile 93, Monument Creek enters the Colorado River from the south side in the deepest section of the Grand Canyon and Inner Granite Gorge. Within the walls of this side canyon are exposures of older Precambrian metamorphic and granitic rocks, whose resistance to erosion is responsible for the steep-walled, "V" shape of the Inner Gorge (Figure 11). The steep metamorphic layering and numerous convoluted folds within the rocks recall a time when the rocks flowed like warm asphalt, as high temperatures and large horizontal stresses accompanied the collision of crustal blocks some 100 kilometers wide (Figure 12). The mountains that formed during this collision were eroded away before the Cambrian sea encroached on the landscape and buried it beneath beach sand that later became lithified or compacted to form the Tapeats Sandstone. The unconformity between the steeply dipping metamorphic rocks and the overlying, gently inclined Tapeats Sandstone is well exposed within Monument Canyon. Called the Great Unconformity, this erosional surface represents the absence of more than 1 b.y. in the geologic record.

In the more recent geologic past, boulders carried down the present canyon of Monument Creek and deposited at its mouth have partially dammed the Colorado River, causing the major rapid of Granite Falls (Figure 13). Monument Canyon, which contains remnants of a mudflow deposited in 1984, has the characteristics that a side canyon needs to form a large rapid in the river. These include a steep stream gradient, a narrow canyon with a flat floor, a sufficient supply of large boulders, and a source of fine-grained material to generate mudflows or debris flows. (Large boulders are more easily transported in a medium that is thicker than water). Monu-

Figure 13. Wooden dory within Hermit Rapid. Talus slope in background is derived from Precambrian rock. Photo by S. Reynolds.

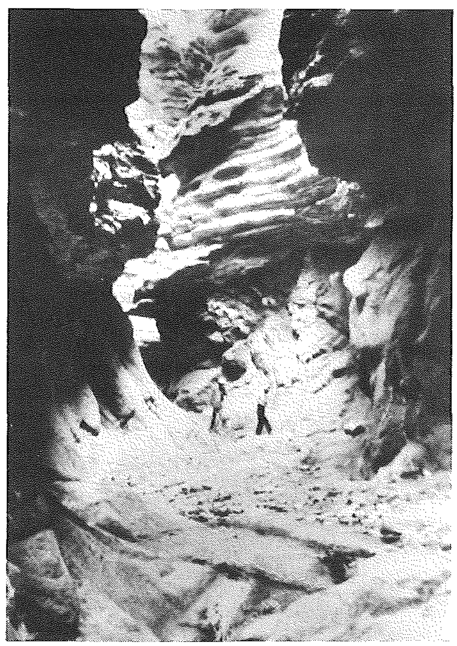

Figure 14. Blacktail Canyon. Horizontal beds of Cambrian Tapeats Sandstone unconformably overlie the nearly vertical Precambrian Vishnu Group. Photo by A. Potochnik.

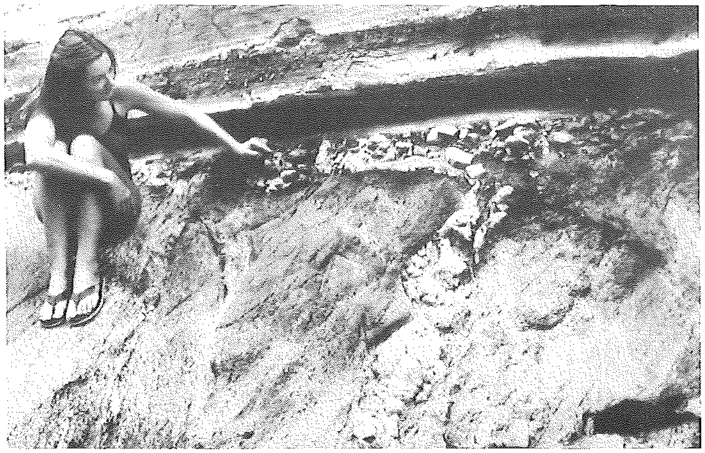

Figure 15. The Great Unconformity between Tapeats Sandstone and the underlying Precambrian Vishnu Group, Blacktail Canyon. Material from the light-colored layer within the schist has been incorporated into the thin, basal conglomerate of the overlying sandstone. The unconformity represents the erosion of more than 1 b.y. from the geologic record. Photo by A. Potochnik.

Figure 16. Precambrian diabase (dark ledge at river level) and slope-forming units of the Precambrian Unkar Group along the Colorado River near Tapeats Creek. Tilted units of Unkar Group are unconformably overlain by Cambrian Tapeats Sandstone. Photo by J. Blaustein.

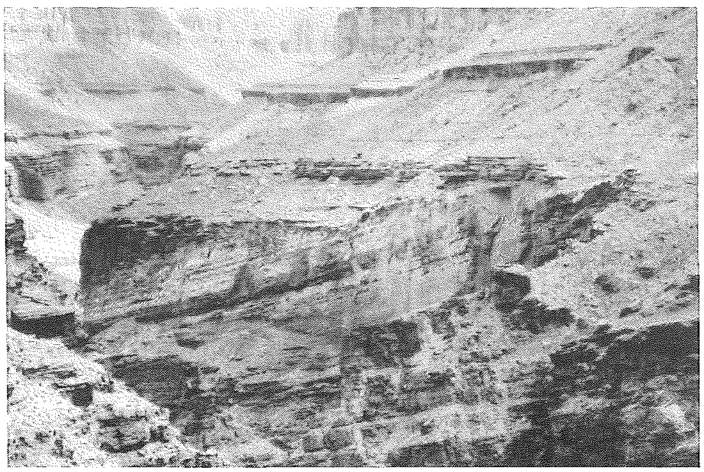

Figure 17. Tilted Precambrian Shinumo Quartzite (Unkar Group) unconformably overlain by flat-lying Cambrian strata, Tapeats Creek. The resistant quartzite was once a craggy island. Along its flanks, Cambrian seas deposited the sands of the Tapeats, which forms the dark ledge shown in the left center of the photograph. The island was later buried by marine muds, which were compacted into the overlying, slope-forming units of the Cambrian Bright Angel Shale. Photo by S. Reynolds.

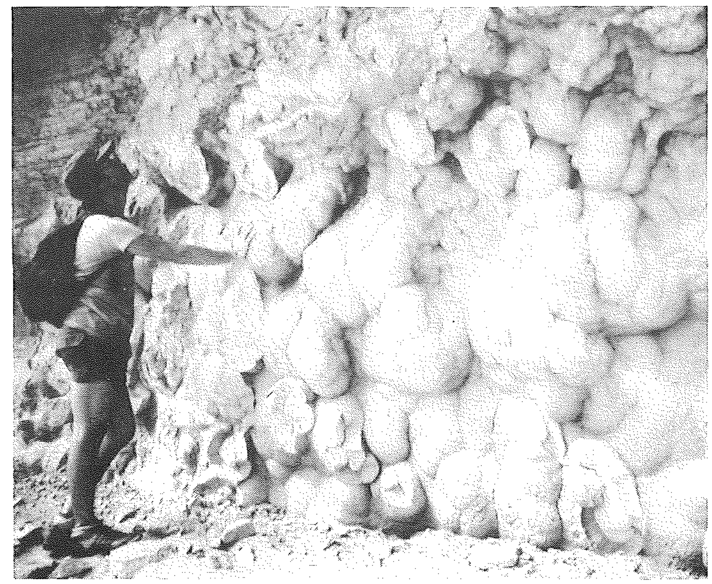

Figure 18. Travertine along the canyon walls of Havasu Creek. Photo by S. Gillatt.

ment Creek does not have a large drainage area compared to other canyons; apparently this factor is of secondary importance in creating a large rapid.

Blacktail Canyon

Inner Granite Gorge ends near Blacktail Canyon, where the regional westward dip of the strata causes the Tapeats Sandstone to descend to river level. Blacktail Canyon near mile 120 is a narrow, somewhat tubelike notch cut along the Great Unconformity between the sandstone and underlying Precambrian Vishnu Schist (Figure 14). The details of the unconformity, which is exposed along the polished walls of the canyon, are incredibly clear (Figure 15). The vertical metamorphic layering in the schist is abruptly overlain by sandstone and conglomerate derived from weathering and erosion of the schist. Thin vertical quartz veins in the schist were resistant to weathering and were eroded into small quartz pebbles now found in the basal sandstone. One can easily imagine the waves of the Cambrian sea, 600 m.y. ago, crashing onto jagged hills of schist and churning the metamorphic rock into sandy beaches as the sea advanced across the barren landscape.

Tapeats Creek

A few miles downstream from Inner Granite Gorge near mile 134, a cold and clear-flowing perennial stream called Tapeats Creek enters the Grand Canyon. The lowest rock formations of the Precambrian Unkar Group are exposed near river level (Figure 16). The characteristic tilt of these rocks readily distinguishes them from the more flat-lying Paleozoic rocks. A creekside path through ancient ruins and garden sites of the Anasazi Indians leads to a trail along Tapeats Creek that traverses upward through these Precambrian strata into the Paleozoic rocks. Here, Thunder Springs bursts from a cavern high in the Muav Limestone wall.

The Bass Formation, the oldest unit in the Precambrian Grand Canyon Supergroup, contains wavy, fossilized algal mats, the oldest preserved evidence of life revealed in the Grand Canyon. Bright reddish-orange shales and siltstones of the overlying Hakatai Shale contain ripplemarks and mudcracks, features that suggest deposition in a tidal-flat environment. A gradational contact between these shales and the underlying Bass Limestone indicates that Hakatai mudflats gradually displaced the algal marine environment as the Bass sea retreated from the area. The tidal flats were in turn covered by a thick sequence of sand deposited near the shoreline of a sea. Consolidation of these sands formed the overlying Shinumo Quartzite, a cliff-forming unit that forms the steep-walled, narrow canyon of upper Tapeats Creek. A sill of dark-colored diabase was formed as molten rock intruded between layers of the Bass

Formation more than 1 b.y. ago. The layers in the Bass Formation were forcibly pushed apart to accommodate these lavas and reacted with the magma to form thin layers of green serpentine and fibrous chrysotile asbestos.

An upcanyon view from high on the Thunder River switchbacks reveals the angular unconformity between the Shinumo Quartzite and overlying Cambrian rocks (Figure 17). The Tapeats Sandstone, a beach sand of the advancing Cambrian sea, was deposited on the shores of a Shinumo Quartzite island that stood as a large remnant of late Precambrian erosion. As the sea deepened, the island became submerged, and offshore muds of the Bright Angel Shale were deposited across the top of the former island.

Havasu Creek

Downstream from Tapeats Creek, the regional tilt of the rock layers causes the cliff-forming Paleozoic limestones, once again, to appear at river level. The confluence of Havasu Creek with the Colorado River near mile 157 is easily missed. A narrow Muav Limestone gorge obscures the enormity of this large tributary, second only to the Little Colorado River in size. A well-beaten path and gentle stream gradient encourage a hike along the 8-mile trail to the Havasupai Indian village. Havasu Creek is known for its spectacular waterfalls, and the verdant banks of this perennial, aqua-blue stream are lined with velvet ash, cottonwood, and wild grape.

Travertine deposits are perhaps the most fascinating geologic feature of Havasu Creek (Figure 18). This peculiar rock is formed by the precipitation of calcium carbonate as the creek courses through the thick Paleozoic limestones. Precipitation is augmented by warming and evaporation during the long flow to the Colorado. The travertine thus tends to encrust and take the form of any object over which the creek passes.

Distinctive features of travertine cementation are the flat-topped and sinuous "dams" so commonly seen in the creek (Figure 19). These dams form by a self-enhancing process. An obstruction tends to catch sticks and leaves, which become encrusted with calcium carbonate, thereby increasing the size of the obstruction. When the obstruction becomes large enough, mosses colonize it and provide an additional substrate that increases its width and size. Eventually a dam will form across the channel with perhaps one or two spillways through which the stream flows. The process becomes self-restricting in the spillways because water velocity is sufficient to prevent accumulation of debris, growth of moss, and precipitation of travertine.

Whitmore Wash

Near mile 188, below the notorious Lava Falls rapids, Whitmore Wash preserves evidence of a time even more tumultuous than that experienced by the river traveler while navigating the rapids. Whitmore Wash and the area around Lava Falls contain remnants of dark basalt lava flows that once filled the Grand Canyon to a depth of more than 1,500 feet (Figure 20). The lava erupted from volcanic vents, such as Vulcan's Throne, that pierce the Esplanade, a widespread erosional surface approximately 3,000 feet above the canyon bottom. The Esplanade formed at the top of resistant red sandstones of the Supai Group as the overlying, less resistant Hermit Shale was removed by erosion.

Many vents occur near the Hurricane Fault, a major, recently active, north-south fault that may have served as a conduit for the ascending lavas. Upon eruption, the flows of molten lava cascaded over the walls of the Grand Canyon into the Colorado River 3,000 feet below, creating enormous clouds of steam and filling tributary canyons that drained into the Grand Canyon prior to volcanism. The lava-filled canyon of "old" Whitmore Wash is visible from river level where the main Whitmore trail climbs the north wall of the Grand Canyon into Toroweap Valley. Less than one-half mile downstream from the trail is the "new" Whitmore Wash, a narrow side canyon that drains the same extensive watershed as the former wash. The new wash, however, has cut into the Paleozoic limestones instead of excavating the more erosionally resistant lava that fills the old channel. In the main Grand Canyon, the dams formed by lava flows were more transient, probably surviving less than 10,000 years.

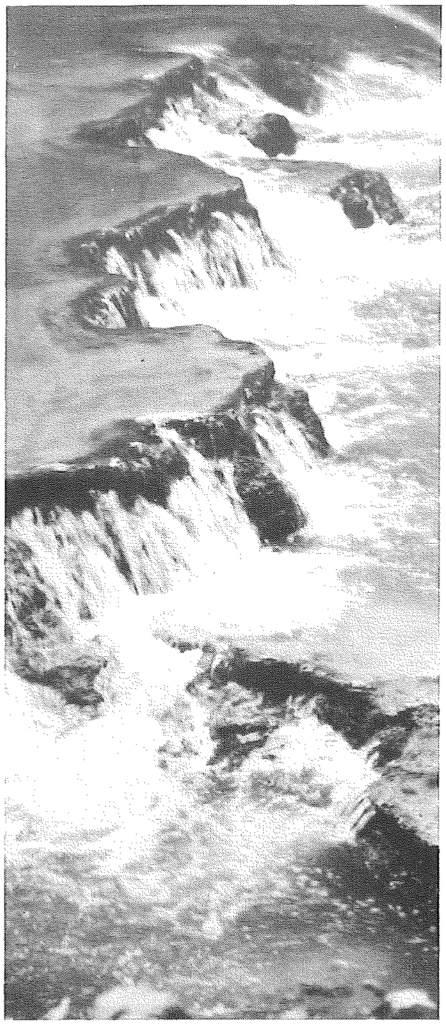

Figure 19. *Travertine terraces in Havasu Creek show sinuous character and spillways. Photo by S. Reynolds.*

Figure 20. *Late Cenozoic basalt flows and cinder deposits were erupted into and partially filled the Grand Canyon along the Hurricane fault near Whitmore Wash. Lighter colored Paleozoic rocks that formed the walls of the canyon are visible in the distance. Photo by S. Reynolds.*

Final Comments

The canyons described above represent just a small sample of the geologic wonders and natural beauty found within side canyons of the Colorado River. Each canyon is unique, both in scenery and in the array of exposed geologic features. Short hikes within these canyons complement the river-running, which alternates between the relaxing tranquility of long, slow-moving stretches and the bursts of apprehension, excitement, and chaos within the rapids. The entire experience is difficult to describe, but impossible to forget.

Selected References

Breed, W. J., and Roat, E. C., 1974, Geology of the Grand Canyon: Museum of Northern Arizona and Grand Canyon Natural History Association, 185 p.

Hamblin, W. K., and Rigby, J. K., 1968, Guidebook to the Colorado River, part 1; Lees Ferry to Phantom Ranch in Grand Canyon National Park: Brigham Young University Geology Studies, v. 15, pt. 5, 84 p.

______ 1969, Guidebook to the Colorado River, part 2; Phantom Ranch in Grand Canyon National Park to Lake Mead, Arizona-Nevada: Brigham Young University Geology Studies, v. 16, pt. 2, 126 p.

Péwé, T. L., 1968, Colorado River guidebook; a geologic and geographic guide from Lees Ferry to Phantom Ranch, Arizona: Arizona State University Department of Geology, 78 p.

Rabbit, M. C., McKee, E. D., Hunt, C. B., and Leopold, L. B., 1969, The Colorado River region and John Wesley Powell: U.S. Geological Survey Professional Paper 669, 145 p.

Bureau Receives New Rock-and-Mineral Collection

The foyer of the Bureau of Geology and Mineral Technology has been transformed into a minimuseum. Cyprus Pima Mining Co. in Tucson recently donated 150 rock and mineral specimens that some of its employees collected during its 27 years of operation (Figure 1). The collection was started by A. A. (Del) Friedman and George A. Komadina, both of whom served as vice president and general manager of the company. Numerous examples of Arizona's minerals, such as those of copper and molybdenum, are on display. The collection also contains "exotics" from other States and countries, such as whaleback shale from western Australia and diamond "blue ground" from Kimberly, South Africa. The company received the "exotics" as gifts from foreign mining officials who toured its facilities.

Cyprus Pima Mining Co. started stripping the orebody in 1955; in 1957 the concentrator was processing 3,000 short tons of ore per day (stpd). After four expansions and process improvements, production increased to 57,000 stpd. In 1977 the company ceased operations for economic reasons. Copper and molybdenum prices rose enough by 1979 to warrant a resumption of mining. Processing started at 18,000 stpd and, when ore became available, was increased to 32,500 stpd, a rate that was maintained until 1982, when a shutdown was again enforced. Subsequent years of low metal prices convinced senior management officials to liquidate the company.

From January 1957 to September 1982, the company delivered 226.5 million tons of ore to the mill crushers. From this ore, 4.1 million tons of copper concentrate containing 1.1 million tons of contained copper and 13.2 million ounces of silver were produced, as well as 20.4 million pounds of molybdenum.

Figure 1. *George A. Komadina, former vice president and general manager, Cyprus Pima Mining Co., (left) presents new rock-and-mineral display to William P. Cosart, associate director, Arizona Bureau of Geology and Mineral Technology.*

Oil and Gas Conservation Commission Hires New Director

Dr. Daniel J. Brennan has been appointed executive director of the Arizona Oil and Gas Conservation Commission as of January 1986. His experience includes 15 years in exploration and development geology and 14 years in university teaching. He has worked for Shell Oil Co., Sunray DX Oil Co., Coastal Corp., Coquina Oil Corp., and ANR Production Co. He was an assistant and associate professor of geology at Wichita State University and a full professor and chairman of the geology department at State University of New York, College at Cortland. His research has focused on topics such as strata-bound ore deposits, petrology of carbonate facies, and basin analysis.

Dr. Brennan received his B.S., M.S., and Ph.D. degrees in geology from the University of Notre Dame, the South Dakota School of Mines and Technology, and the University of Arizona, respectively. He is a fellow of the Geological Society of America and a member of the American Association of Petroleum Geologists.

Dr. Brennan succeeds Mr. A. K. Doss, who served as executive director from June 1981 through August 1985. From September 1985 until January 1986, Mr. Rudy Ybarra served as acting executive director. Mr. Ybarra remains on the commission staff.

MAPS AVAILABLE

The U.S. Geological Survey (USGS) recently published a series of seven maps, Water-Resources Investigations Report 83-4114, A through G, on the Basin and Range Province, Arizona:

- A - Ground-water units and withdrawal
- B - Ground-water levels, springs, and depth to ground water
- C - Distribution of dissolved solids and dominant chemical type in ground water
- D - Outcrops of granitic rocks
- E - Outcrops of thick, dominantly argillaceous sedimentary and metasedimentary rocks
- F - Outcrops of pre-Quaternary ash-flow tuffs and volcaniclastic rocks
- G - Outcrops of pre-Quaternary basaltic rocks

The maps were completed as part of a project entitled "Geologic and hydrologic characterization and evaluation of the Basin and Range Province relative to the disposal of high-level radioactive waste." The project, a cooperative effort by the USGS and seven Basin and Range States, was described in *Fieldnotes*, vol. 15, no. 2. Similar maps were also prepared for the other six States.

The Arizona Bureau of Geology and Mineral Technology has a limited supply of the Arizona maps for distribution. The series is free if picked up in person from the Bureau offices (845 N. Park Ave., Tucson, AZ 85719). If a mail order is requested, prepayment of $5.00 is required to cover postage and handling. Orders are shipped via UPS; street address is required for fastest delivery. Only complete sets will be distributed.

An Oil Rig at the Grand Canyon?

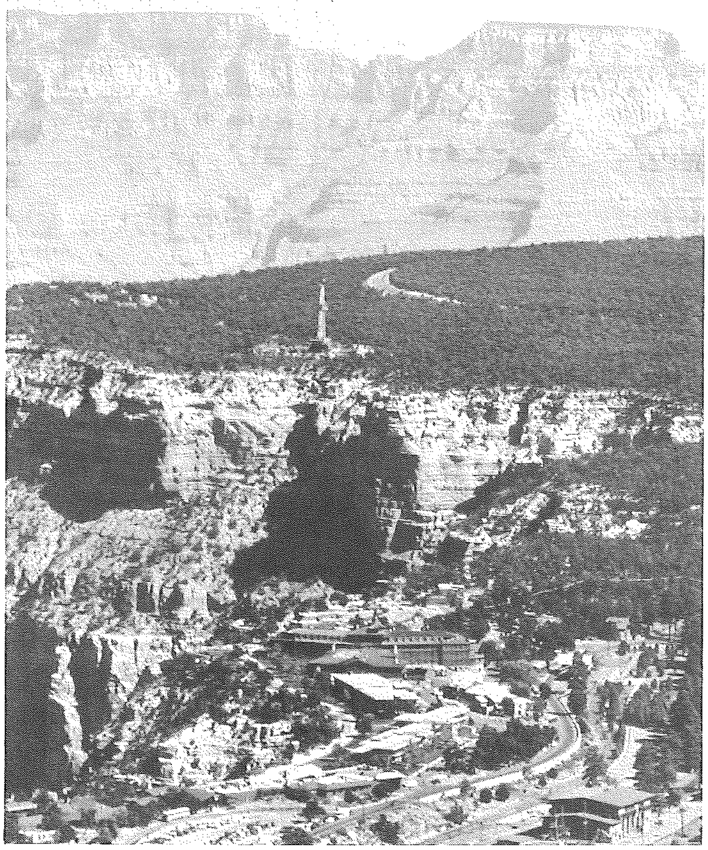

Figure 1. *Oil rig at Yavapai Point (center) provides solution to water-supply problem at Grand Canyon Village (foreground). Photo courtesy of Texas Eastern Corp.*

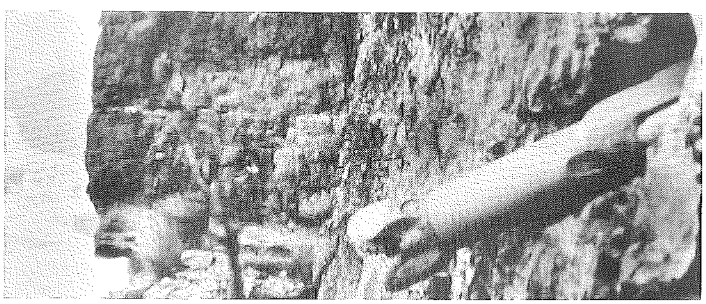

Figure 2. *Bit and reamer at breakout point in Cambrian Muav Limestone on canyon's south wall. Photo by Marcia Lattimore.*

Oil and water usually don't mix, but on the South Rim of the Grand Canyon, the National Park Service has blended both in a solution to a long-standing problem. The Federal agency asked the oil industry to use its drilling technology and expertise to increase the water supply to Grand Canyon Village. The problem was not lack of a water source, but rather difficulty in bringing the water from the Indian Gardens pump station—2,800 feet down in the canyon—up to the canyon rim.

Roaring Springs, a natural spring that gushes from the rocky North Rim of the canyon, is the source for Bright Angel Creek, which flows through a chasm high on the canyon's north wall. Water from the creek flows mostly by gravity through a pipeline that extends some 12 miles down the north face to the Indian Gardens pump station on the south face. The North Rim is about 1,000 feet higher in elevation than the South Rim.

From Indian Gardens, water had been pumped up to the South Rim through an old pipe system built in the 1930's. Because it was exposed along the canyon wall, the system was subject to silting, freezing, and damage from rock slides. It also provided an inadequate supply of water.

The Park Service had considered rebuilding the old system or trucking water to the village, but a feasibility study by McLaughlin Water Engineers recommended drilling a directional hole near the canyon face that would emerge near the pump station. The study found that this alternative would not only provide the best, most efficient means of transporting water, but would also be less hazardous for workers, have less impact on the environment, and be less expensive than other proposals. The report noted, however, that conventional water-well drillers could not provide the technology and expertise required for such a project; oil industry drilling methods were needed to meet specifications.

Last year the Park Service asked Grace, Sheursen and Moore, an Oklahoma City petroleum engineering group, to develop plans for a high-angle directional hole. Brinkerhoff-Signal, a drilling subsidiary of Texas Eastern Corp., was then hired to erect an oil rig and begin drilling 250 feet from the canyon's edge (Figure 1).

Drilling the 14¾-inch borehole took 49 days. The biggest challenge was drilling at a 65° angle using air, rather than mud, to remove cuttings and to cool and lubricate the downhole motors and equipment. The conventional use of drilling mud would have led to lost circulation because of the highly fractured limestones and large solution cavities in the canyon wall. Drilling with air usually leads to torque and drag build-up on the drillstring. This problem was alleviated by the use of a soap, water, and polymer mist to cool the downhole motor and lubricate the bottomhole assembly.

The borehole penetrated a Paleozoic sequence, from the Permian Kaibab Limestone at the rim to the Cambrian Muav Limestone near the pump station. The hole, just a few feet off target, emerged at an advantageous position to the station (Figure 2). Gyroscope and magnetic single-shot methods were used to guide the direction of drilling. The hole encountered no structural features or faults in its path, which totaled 5,075 measured feet. True vertical depth of the hole is 2,800 feet, with horizontal displacement of 3,800 feet (Figure 3).

The hole has already been set with 10¾-inch casing, into which an 8⅝-inch water line will be installed. The line will be coated inside to prevent rusting.

The project, which should be completed during the summer, will furnish water for the ranger station, tourist lodges, restaurants, and associated services in Grand Canyon Village. The Park Service estimates that between 2 and 3 million persons visit the village each year.

—Excerpted from "High tech delivers results; oil patch helps in Grand Canyon," by Mary Fritz. Published in the February 1986 issue (vol. 7, no. 2) of *Explorer*, the monthly newsletter of the American Association of Petroleum Geologists (AAPG). Used with permission.

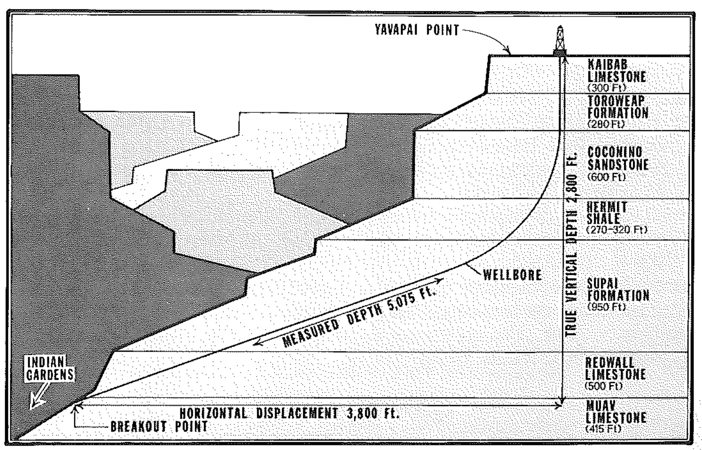

Figure 3. *Grand Canyon drilling project.*

Theses and Dissertations, 1985

The following list includes theses and dissertations on Arizona geology, mineral technology, hydrology, and related subjects that were awarded in 1985 by Arizona State University, Northern Arizona University, and the University of Arizona. This list, however, is not a complete compilation of theses on such topics. Theses on the geology of other States are not listed, nor are theses awarded by out-of-State universities.

Most of the theses included here are not available in the Bureau library. Each thesis, however, may be examined at the main library of the university that awarded it. More detailed information may also be obtained from the respective departments, which are indicated in parentheses after each citation using the following codes:

Arizona State University, Tempe, AZ 85287; (602) 965-9011.
C—Chemistry; Gg—Geography; Gl—Geology; ME—Mechanical Engineering

Northern Arizona University, Flagstaff, AZ 86011; (602) 523-9011.
G—Geology

University of Arizona, Tucson, AZ 85721; (602) 621-2211.
AE—Agricultural Engineering; ChE—Chemical Engineering; CE—Civil Engineering; G—Geosciences; HWR—Hydrology and Water Resources; MGE—Mining and Geological Engineering; MS—Materials Science; RNR—Renewable Natural Resources; SWS—Soil and Water Science

Arizona State University

Bales, James, Environmental geology of the Tempe quadrangle, Maricopa County, Arizona; part II: M.S. Thesis, 103 p., 12 plates. (Gl)

Brittingham, P. L., Structural geology of a portion of the White Tank Mountains, central Arizona: M.S. Thesis, 107 p. (Gl)

Canepa, J. A., The behavior of fluorine, chlorine, and sulfur in basalts: Ph.D. Dissertation. (C)

Chandrasekar, Srinivasan, Comparison of residual stresses induced when grinding and lapping ferrites and metals: Ph.D. Dissertation. (ME)

Davis, G. M., Geology of the southern Plomosa Mountains: M.S. Thesis, 159 p. (Gl)

Ross, N. L., A thermochemical and lattice vibrational study of high pressure phase transitions in silicates and germanates: Ph.D. Dissertation. (C)

Spinnler, G. E., HRTEM study of antigorite, pyroxene-serpentine reactions, and chlorite: Ph.D. Dissertation, 249 p. (Gl)

Stuart, J. A., The crystal chemistry of the clinoptilolite-heulandite zeolite series: Ph.D. Dissertation. (C)

Sykes, M. L., Ascent of granitic magma; constraints from thermodynamics and phase equilibria: Ph.D. Dissertation, 311 p. (Gl)

Verville, H. J., Channel change, process, and cross-sectional flow distribution in an arid-region braided river, Agua Fria River, Arizona: M.A. Thesis, 127 p. (Gg)

Northern Arizona University

Cunion, E. J., Jr., Analysis of gravity data from the southeastern Chino Valley area, Yavapai County, Arizona: M.S. Thesis, 110 p. (G)

Duffield, J. A., Depositional environments of the Hermit Formation, central Arizona: M.S. Thesis, 82 p. (G)

Edwards, D. P., Controls on deposition of an ancient fluvial-eolian depositional system; the Early Jurassic Moenave Formation of north-central Arizona: M.S. Thesis. (G)

Espegren, W. A., Sedimentology and petrology of the upper Petrified Forest Member of the Chinle Formation, Petrified Forest National Park and vicinity, Arizona: M.S. Thesis. (G)

Glotfelty, M. F., Hydrogeology of the Camp Verde area, Yavapai County, Arizona: M.S. Thesis, 142 p. (G)

Ismail, Razimah, Stratigraphy, mineralogy, and depositional environments of the mudrock facies of the Verde Formation, central Arizona: M.S. Thesis, 88 p. (G)

Martin, D. L., Depositional systems and ichnology of the Bright Angel Shale (Cambrian), eastern Grand Canyon, Arizona: M.S. Thesis, 365 p. (G)

Peterson, R. R., Jr., The geology of the Buckhorn Creek area, Yavapai County, Arizona: M.S. Thesis, 109 p. (G)

University of Arizona

Allen, G. B., Economic geology of the Big Horn Mountains of west-central Arizona: M.S. prepublication manuscript, 116 p. (G)

Almasmoum, Ali, Classification system for excavating caliche in Tucson, Arizona: M.S. Thesis, 108 p. (CE)

Azevedo, L. O. R., Infra-red spectrophotometry and X-ray diffractometry as tools in the study of nickel laterites: M.S. Thesis, 118 p. (G)

Barua, S. L., Application of conditional simulation model to run-of-mine coal sampling frequency determination and coal quality control at the power plant: Ph.D. Dissertation, 152 p. (MGE)

Beard, L. S., Precambrian geology of the Cottonwood Cliffs area, Mohave County, Arizona: M.S. Thesis, 115 p. (G)

Cai, Wenlong, Zero-one programming analysis of mine production scheduling problems: M.S. Thesis, 103 p. (MGE)

Cook, E. R., A time series analysis approach to tree ring standardization: Ph.D. Dissertation, 171 p. (RNR)

Currier, D. A., Structures and microfabrics of a zone of superposed deformation, foothills fault zone, east flank of the Huachuca Mountains, southeast Arizona: M.S. Thesis, 167 p. (G)

Davey, James, The mixing of waters of the Salt and Verde Rivers: M.S. Thesis, 126 p. (CE)

Depner, J. S., Estimation of the three-dimensional anisotropic spatial covariance of log permeability using single-hole and cross-hole packer test data from fractured granites: M.S. Thesis, 92 p. (HWR)

Dickey, Juliana, The effects of selected nitrogen and sulphur applications on soil pH, water soluble sulfate, DTPA extractable iron, manganese, copper, and zinc on selected Arizona soils: M.S. Thesis, 47 p. (SWS)

Dietz, D. D., Geophysical investigation of concealed bedrock pediments in central Avra Valley, Pima County, Arizona: M.S. Thesis, 75 p. (G)

Ely, L. L., Reconstructing paleoflood hydrology with slackwater deposits, Verde River, Arizona: M.S. prepublication manuscript, 49 p. (G)

Er, Cevat, Analysis of muramic acid in Holocene microbial environments by gas chromatography, electron impact, and fast atom bombardment mass spectrometry: M.S. prepublication manuscript, 32 p. (G)

Esposito, D. M., Criteria and methods of analysis for regulation of interference between wells: M.S. Thesis, 90 p. (HWR)

Ethington, E. F., Resistivity and induced-polarization modeling for a buried resistive dike and buried resistive chamber: M.S. Thesis, 150 p. (G)

Field, J. J., Depositional facies and Hohokam settlement patterns on Holocene alluvial fans, north Tucson basin, Arizona: M.S. prepublication manuscript, 68 p. (G)

Flynn, T. J., Water temperature as a groundwater tracer in fractured rock: M.S. Thesis, 67 p. (HWR)

Fowler, S. D., Copper solvent extraction from chloride-sulfate media: M.S. Thesis, 127 p. (MS)

Franks, C. D., Temperature, moisture, and albedo properties of Arizona soils: M.S. Thesis, 132 p. (SWS)

Fuenkajorn, Kittitep, Experimental assessment of borehole drilling damage in basaltic rocks: M.S. Thesis, 267 p. (MGE)

Gajam, S. Y., Some aspects of hydrochloric acid-leaching of kaolinite clay: Ph.D. Dissertation, 110 p. (MS)

Genniwa, A. M., The physical, chemical, and spectral characteristics of soils at Page Ranch International Center, Pinal County, Arizona: M.S. Thesis, 75 p. (SWS)

Goodlin, T. C., Stratigraphic and structural relations of the area south of Hot Springs Canyon, Galiuro Mountains, Arizona: M.S. Thesis, 100 p. (G)

Hall, D. L., Stratigraphy and sedimentary petrology of the Mesozoic rocks of the Waterman Mountains, Pima County, Arizona: M.S. Thesis, 92 p. (G)

Hassan, H. M., Estimation of evapotranspiration and irrigation uniformity from subsoil salinity: Ph.D. Dissertation, 191 p. (SWS)

Hauck, W. R., Correlation and geochemical zonation of the mid-Tertiary volcanic and intrusive rocks in the Santa Teresa and northern Galiuro Mountains, Arizona: M.S. Thesis, 140 p. (G)

Henkel, A. F., Regionalization of southeast Arizona precipitation distributions in a daily event-based watershed hydrologic model: M.S. Thesis, 122 p. (RNR)

Herndon, R. L., Hydrogeology of Butler Valley, Arizona; an artificial recharge and ground-water storage prefeasibility study: M.S. Thesis, 106 p. (HWR)

Hess, A. A., Chertification of the Redwall Limestone (Mississippian), Grand Canyon National Park, Arizona: M.S. Thesis, 132 p. (G)

Hirschboeck, K. K., Hydroclimatology of flow events in the Gila River basin, central and southern Arizona: Ph.D. Dissertation, 335 p. (G)

Jacobson, E. A., A statistical parameter estimation method using singular value decomposition with application to Avra Valley aquifer in southern Arizona: Ph.D. Dissertation, 315 p. (HWR)

Jeffrey, R. G., Jr., Rockbolt analysis for reinforcement and design in layered rock: Ph.D. Dissertation, 290 p. (MGE)

Kelzieh, Amer, An application of the principles of flow through partially saturated porous media to problems of agglomerated heap leaching: M.S. Thesis, 107 p. (CE)

King, N. E., A decision-support system for mine evaluations: M.S. Thesis, 143 p. (MGE)

Law, C. S., An experiential assessment of the Arizona landscape: Ph.D. Dissertation, 132 p. (RNR)

Levine, S. J., Genesis of typic paleorthids and petrocalcic paleargrids on the same far terrace in the Avra Valley near Tucson, Arizona: M.S. Thesis, 93 p. (SWS)

Linak, William, The effect of coal type residence time and combustion configuration on the submicron aerosol composition and size distribution from pulverized coal combustion: Ph.D. Dissertation, 589 p. (ChE)

Mark, R. A., Structural and sedimentary geology of the area north of Hot Springs Canyon, southern Galiuro Mountains, Cochise County, Arizona: M.S. Thesis, 96 p. (G)

May, S. R., Paleomagnetism of Jurassic volcanic rocks in southeastern Arizona and North American Jurassic apparent polar wander: Ph.D. Dissertation, 214 p. (G)

Merz, August III, Mountain-front recharge from the Santa Rita Mountains to the Tucson basin: M.S. Thesis, 122 p. (HWR)

Monreal, Rogelio, Lithofacies, depositional environments, and diagenesis of the Mural Limestone (Lower Cretaceous), Lee Siding area, Cochise County, Arizona: M.S. Thesis, 100 p. (G)

Morris, Robert, The control of sulfur dioxide emissions during the roasting of metal sulfides: M.S. Thesis, 225 p. (ChE)

Nasser-Rafi, Rahbar, Fluid flow and permeability of solidifying lead-20 weight percent tin alloys: M.S. Thesis, 100 p. (MS)

Partridge, J. B., Magnitude-frequency relationships of large floods utilizing geologic evidence on the Salt River, Arizona: M.S. Thesis, 54 p. (G)

Postillion, F. G., Evaluating alternatives for groundwater quality management in Green Valley-Sahuarita, Arizona: M.S. Thesis, 167 p. (RNR)

Pradhan, L. C., Design, construction, and evaluation of small-scale structures for controlling concentrated flow erosion: M.S. Thesis, 215 p. (AE)

Rahman, Mohammad, Laboratory evaluation of existing filter criteria for geofabrics: M.S. Thesis, 169 p. (CE)

Reely, Blaine, Effects of flyash content on strength and durability characteristics of Pantano soil-cement mixes: M.S. Thesis, 118 p. (CE)

Riggs, Nancy, Stratigraphy, structure, and mineralization of the Pajarito Mountains, Santa Cruz County, Arizona: M.S. Thesis, 102 p. (G)

Roberts, M. C., Theory and practice of the intensity of use method of mineral consumption forecasting: Ph.D. Dissertation, 350 p. (MGE)

Roth, F. A., Implications of stratigraphic completeness analysis for magnetic polarity stratigraphic studies: M.S. Thesis, 67 p. (G)

Sale, T. C., Model for prediction of seepage from small unlined water impoundments: M.S. Thesis, 75 p. (RNR)

Schaffer, Andrew, Permeability testing and grouting of fractured rock: M.S. Thesis, 148 p. (MGE)

Schlesinger, M. E., PbO solubility in lead blast furnace slags: M.S. Thesis. (MS)

Stevens, W. R., Pore water pressure in rock slopes and rockfill slopes subject to dynamic loading: M.S. Thesis, 101 p. (MS)

Sylvia, D. A., Depositional, diagenetic, and subsidence history of the Redwall Limestone, Grand Canyon National Park, Arizona: M.S. Thesis, 243 p. (G)

Thomson, K. A., Vertical diffusion of selected volatile organic contaminants through unsaturated soil from a water table aquifer; field and laboratory studies: M.S. Thesis, 73 p. (HWR)

Tomida, Yukimitsu, Small mammal fossils and correlation of continental deposits, Safford and Duncan basins, Arizona: Ph.D. Dissertation, 253 p. (G)

Winstanley, D. J., Application of hydrogeochemistry to delineate flow in fractured granite near Oracle, Arizona: M.S. Thesis, 67 p. (HWR)

Yang, Hsien-Min, Principal components and texture analysis of the NS-001 thematic mapper simulator data in the Rosemont mining district, Arizona: M.S. Thesis, 78 p. (MGE)

Yeats, K. J., Geology and structure of the northern Dome Rock Mountains, La Paz County, Arizona: M.S. Thesis, 123 p. (G)

QUATERNARY GEOLOGY

Soils and Quaternary geology of the southwestern United States, D. L. Weide, ed., 1985, 150 p. Five papers explore the pedogenic (soil-forming) process of carbonate and clay accumulation and show how soils can be used to date surficial deposits and recent movement on major faults. Three papers, including one on Arizona, are regional studies that focus on Quaternary alluvial stratigraphy, soils, landscape ages, and recent tectonic history. Available from the Geological Society of America, 3300 Penrose Place, P.O. Box 9140, Boulder, CO 80301 ($20.00).

Pliocene/Quaternary geology, geomorphology, and tectonics of Arizona, R. B. Morrison, 1985, 24 p. Regional study of Arizona, reprinted from volume listed above. Copies available from R. B. Morrison, Morrison and Associates, 13150 W. 9th Ave., Golden, CO 80401 ($2.00, plus postage).

Arizona Earthquake Information Center

In November 1985, the Arizona Board of Regents authorized the establishment of the Arizona Earthquake Information Center (AEIC), to be housed on the campus of Northern Arizona University (NAU). The purpose of the AEIC is to conduct research, collect data, and distribute information on Arizona earthquakes. These activities increase the understanding of the causes and potential hazards of earthquakes in the State.

Collection and distribution of earthquake data are handled by two branches of the AEIC: the seismic archive and the Sherman Mifflin Smith seismic observatory.

The seismic archive catalogs, stores, and distributes information on earthquakes. Archival records dating back to 1966 are found nowhere else and thus provide a valuable data source to scientists and historians. The archive contains 10,000 paper records of earthquakes, as well as microfilm, microfiche, and original seismograph logbooks.

The Sherman Mifflin Smith seismic observatory, the operations center for the northern Arizona seismic network, monitors and collects data on earthquakes throughout northern and central Arizona. The network began in Flagstaff in 1967, when the U.S. Geological Survey (USGS) established a research station as part of the astrogeology program. This station (FLG) was closed in 1972. The equipment was transferred to NAU, where a new station (FLAG) was established in 1977 and continues to operate today.

In 1970 the USGS in Flagstaff helped to establish station SCN at Sunset Crater National Monument. Affiliation and support of this station has continued with NAU since 1973.

January 1986 marked the operational debut of the first radio telemetry station in northern Arizona, located west of Williams (WMZ). A second radio telemetry station at the Grand Canyon (GCN) was added in February. Immediate plans for the network call for the addition of another station within the next 6 months, with others to be added as funding becomes available.

Dr. Davis Named Vice Provost

Dr. George H. Davis was named vice provost of the University of Arizona, effective January 1986. He joined the university in 1970 as assistant professor in the geosciences department, was promoted to associate professor in 1975, and became full professor and department chairman in 1982.

Dr. Davis received his B.A., M.A., and Ph.D. degrees from the College of Wooster in Ohio, the University of Texas, and the University of Michigan, respectively. A prolific writer, he authored and coauthored two books on structural geology, wrote five encyclopedia articles, published 22 abstracts, and collaborated on three maps. He is secretary-treasurer for the structural geology division of the Geological Society of America.

Dr. Davis succeeds Dr. Laurel L. Wilkening, who was named vice president for research in mid-1985.

New Bureau Publications

The following open-file reports may be purchased over the counter or by mail from the Bureau offices at 845 N. Park Ave., Tucson, AZ 85719. Orders are shipped via UPS; street address is required for fastest delivery. All orders must be prepaid by check or money order made out to the Arizona Bureau of Geology and Mineral Technology. Shipping and handling charges are listed below. If your total order is

$1.01 to $5.00, add $1.75	40.01 to 50.00, add 7.75
5.01 to 10.00, add 2.25	50.01 to 100.00, add 10.00
10.01 to 20.00, add 4.25	More than 100.00, add 10%
20.01 to 30.00, add 5.50	Foreign mail, add 40%
30.01 to 40.00, add 6.25	

Realmuto, V. J., 1985, Preliminary map of selected mass movement events in Arizona: Open-File Report 85-16, 10 p., scale 1:500,000, 2 sheets; text: $1.50; maps: $3.00 each.

The primary sources of information for this map were maintenance-activity records for the years 1980-85, provided by the Arizona Department of Transportation Highways Division. Data from two highway maintenance activities were included: Activity 164, minor slide removal; and Activity 180, major damage and disaster maintenance. Other agencies, such as the U.S. Forest Service, National Park Service, and U.S. Bureau of Reclamation, also provided landslide data. Only those landslides with maintenance costs exceeding $1,000 were plotted on the map. Accompanying tables list the location (in township and range designations), date, cost, slide type, number of miles of affected highway, and reporting agency for each event plotted on the map. The listing is organized alphabetically by county. The U.S. Geological Survey provided funding for this project.

Allen, G. B., 1985, Economic geology of the Big Horn Mountains of west-central Arizona: Open-File Report 85-17, 140 p.; $12.50.

This study complements recent geologic mapping of the Big Horn and Belmont Mountains, the results of which have been released as Bureau Open-File Report 85-14 (see *Fieldnotes*, vol. 15, no. 4). The study and mapping are part of the Cooperative Geologic Mapping Program (COGEOMAP), which is jointly funded by the U.S. Geological Survey and the Arizona Bureau of Geology and Mineral Technology.

The Big Horn Mountains are a geologically complex range that covers more than 500 sq km in west-central Arizona. Three major lithologic terranes outcrop: (1) Proterozoic amphibolite, phyllite, schist, gneiss, and granite; (2) Mesozoic monzonite to diorite intrusives; and (3) Cenozoic mafic to silicic volcanic rocks and clastic rocks. The entire area is in the upper plate of a detachment fault, and consequently contains many low- to high-angle normal faults.

Each lithologic terrane has its associated mineral occurrences. Most mineral occurrences are middle Tertiary in age and occur in three districts: the Tiger Wash barite-fluorite district, the Aguila manganese district, and the Osborne base- and precious-metal district.

Florence, F. P., and Reynolds, S. J., 1985, Compilation of Rb-Sr, fission-track, isotopic-lead, and lead-alpha age determinations in Arizona: Open-File Report 85-18, 89 p.; $10.50.

This information was compiled from original references and organized using database-management software. In format and intent, the compilation is designed to complement Bureau Open-File Report 85-8, "Compilation of K-Ar Age Determinations in Arizona" (see *Fieldnotes*, vol. 15, no. 3).

The compilation consists of five parts. Part 1, the heart of the database, is a master list of information on each date, including dating method, material dated, rock type, rock unit, location, geologic setting, and significance of the date. Parts 2, 3, and 4 are cross indexes: part 2 arranges dates by geographic area such as mountain range; part 3 lists all dates on a particular formation or rock unit such as the Galiuro Volcanics; and part 4 arranges dates by original sample number. Part 5 lists cited references.

PROFESSIONAL MEETINGS

Remote Sensing for Arid Lands Hydrology. Meeting, June 9-12, 1986, Page, Ariz. Contact Frank J. Wobber, Office of Energy Research, U.S. Dept. of Energy, Washington, DC 20545; (301) 353-5549.

Southwestern Ground Water Issues. Conference, October 20-22, 1986, Tempe, Ariz. Contact Barbara J. Graves, National Water Well Assoc., 500 W. Wilson Bridge Rd., Worthington, OH 43085; (614) 846-9355.

Fieldnotes

Vol. 16, No. 1 — Spring 1986

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University of Arizona .... President Henry Koffler
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