Arizona Bureau of Geology and Mineral Technology

FIELDNOTES

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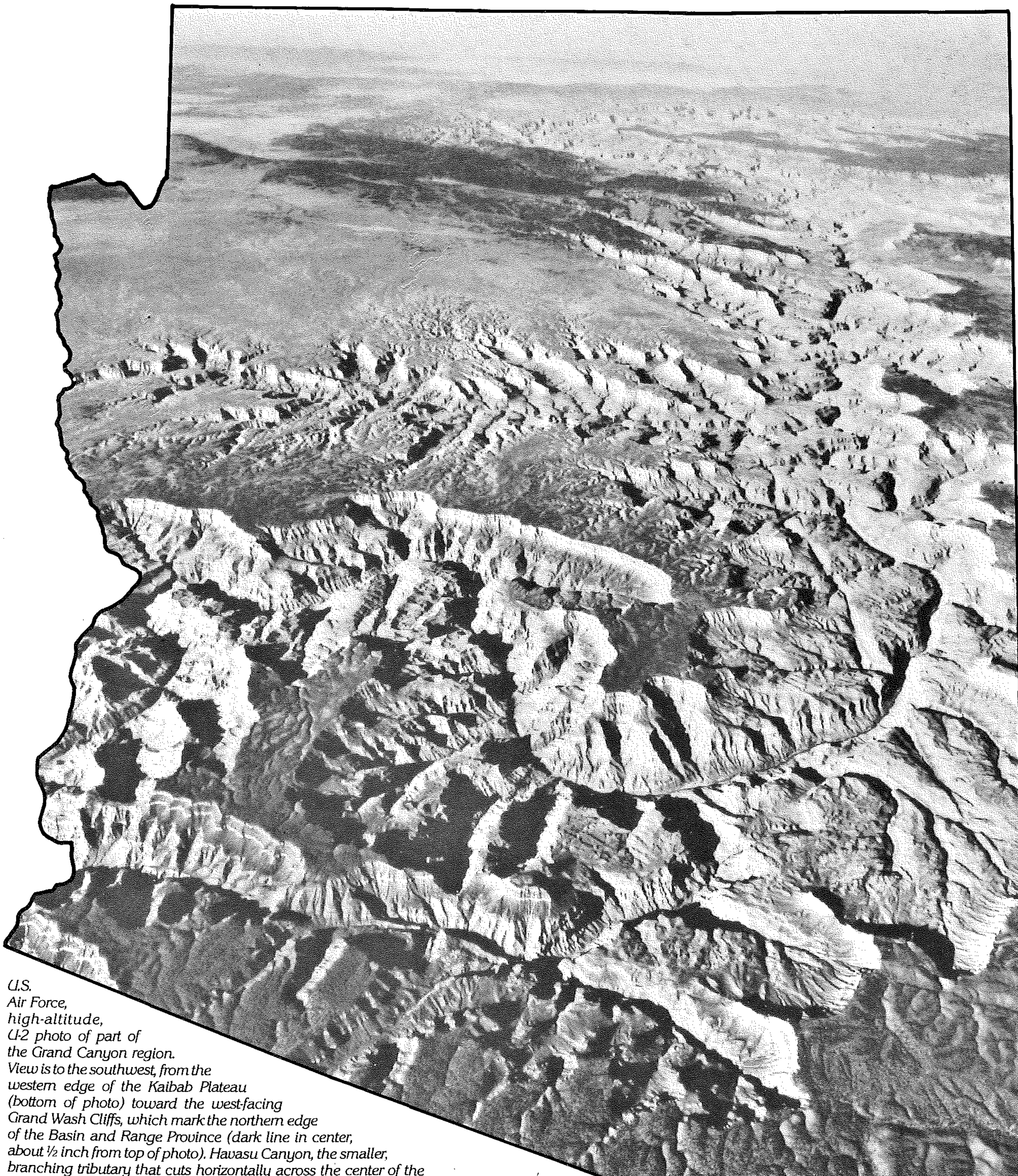

U.S. Air Force, high-altitude, U-2 photo of part of the Grand Canyon region. View is to the southwest, from the western edge of the Kaibab Plateau (bottom of photo) toward the west-facing Grand Wash Cliffs, which mark the northern edge of the Basin and Range Province (dark line in center, about ½ inch from top of photo). Havasu Canyon, the smaller, branching tributary that cuts horizontally across the center of the photo, is incised into the Coconino Plateau. The dark area in the upper right corner is the Shivwits Plateau; Lake Mead is just beyond it, but not in view.

Arizona Geology: An Aerial Tour

by Peter L. Kresan
University of Arizona

From the air, the geologic fabric of Arizona is visible as "landprints" woven into beautiful and impressive designs. Patterns reflect structure, rock type, and the geologic history written in stone. This photo essay takes you on an annotated journey over Arizona's diverse landscapes. It is by no means a complete tour, but it will introduce you to the incredibly rich geologic heritage of this region, as revealed from above. Figure 1 is an index map that identifies areas depicted in the photographs; numbers on the map correspond to figure numbers.

Figure 2. In Marble Canyon, the Colorado River cuts into the ledgy Supai Formation beneath the slope-forming Hermit Shale and

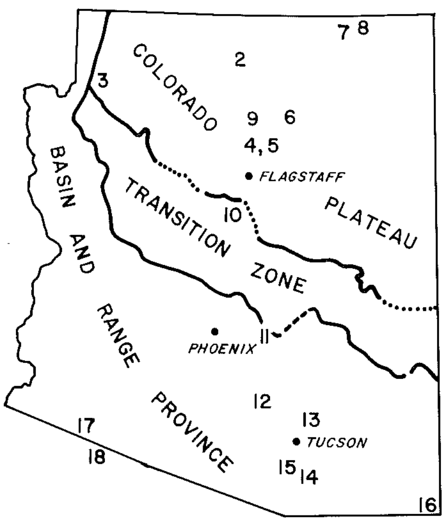

Figure 1

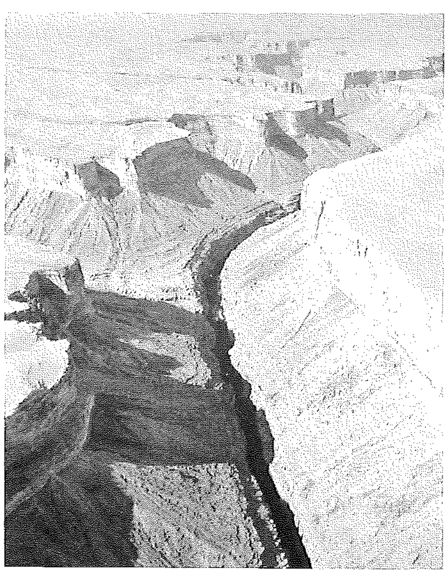

Figure 2

Figure 3a

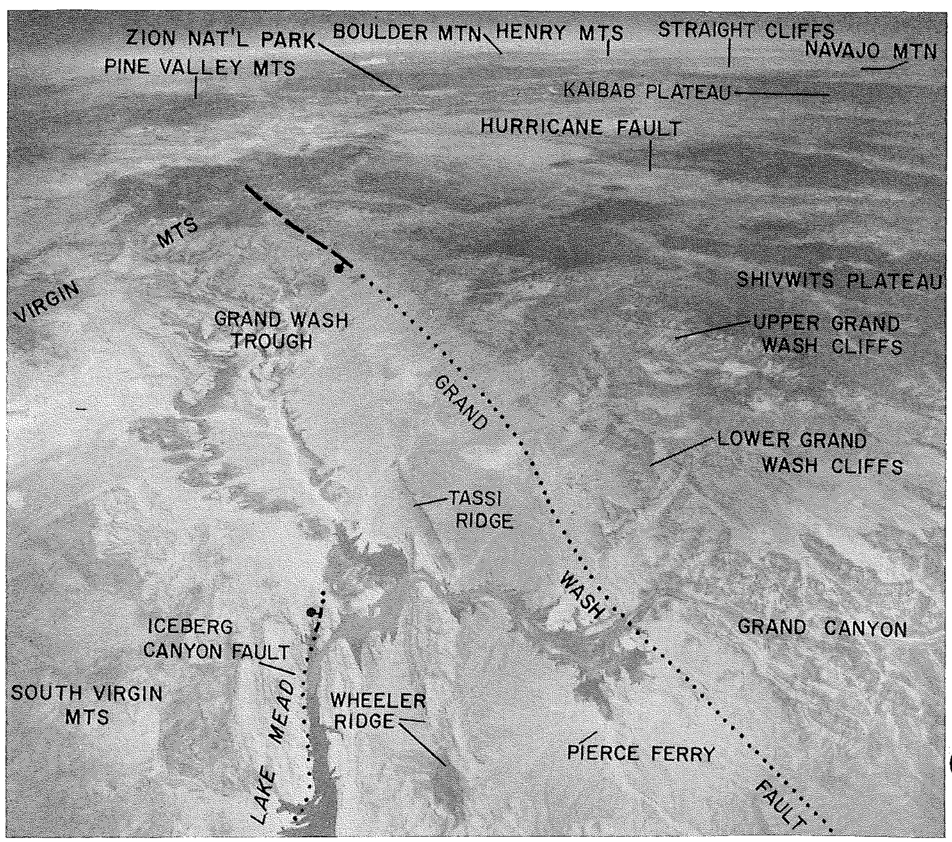

Figure 3b

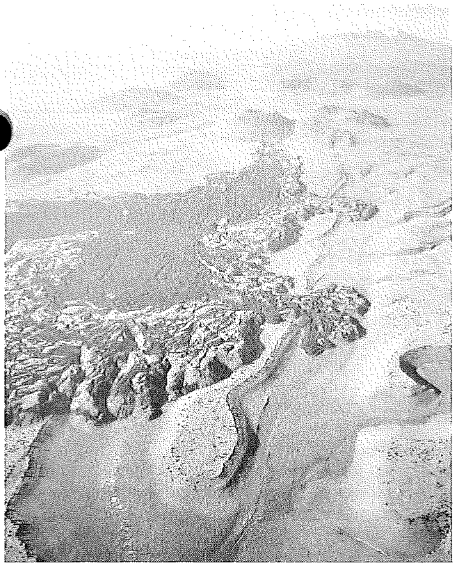

Figure 4

overlying massive cliffs of Coconino Sandstone, Toroweap Formation, and Kaibab Limestone. Sheer Wall Rapids (river mile 14.4 from Lee's Ferry) lie at the mouth of Tanner Wash, which merges with the Colorado River (left, center). The view is to the south across the Marble platform.

Figures 3a and 3b. The western edge of the Colorado Plateau in northwestern Arizona is shown in this U.S. Air Force, high-altitude, U-2 view to the north-northeast. The Colorado Plateau to the east (right) is structurally simple, with nearly horizontal Paleozoic strata cut by normal faults. The Grand Wash fault consists of a system of en-echelon, high-angle, down-to-the-west normal faults. Displacement along the fault varies from a throw of several hundred feet at the Utah border to the north to about 16,000 feet (5,000 meters) at the mouth of the Grand Canyon and as much as 20,000 feet (6,000 meters) in the Red Lake area to the south (Lucchitta and Young, 1986).

Figure 4. The Pleistocene basalt flow from SP cinder cone spilled onto a multiple graben floor that was partially filled by a flow from Crater 160, south of SP Crater and in line with San Francisco Mountain. The overall thickness of the SP flow ranges from 15 to 60 meters. Crater 160 is a cinder, tuff, and spatter cone noted for the abundance and variety of xenoliths (Moore and others, 1974).

Figures 5a and 5b. The Mesa Butte fault, SP Crater and flow, and San Francisco Mountain are prominent features in this U.S. Air Force, high-altitude, U-2 photo of the San Francisco volcanic field north of Flagstaff on the Colorado Plateau; the view is to the south. Bill Williams Mountain, Sitgreaves Mountain, and Kendrick Peak are silicic to intermediate eruptive centers along or near the Mesa Butte fault. Red Mountain, Mesa Butte, and Shadow Mountain (not shown on photo) are prominent basaltic eruptive centers along the fault (Shoemaker and others, 1974).

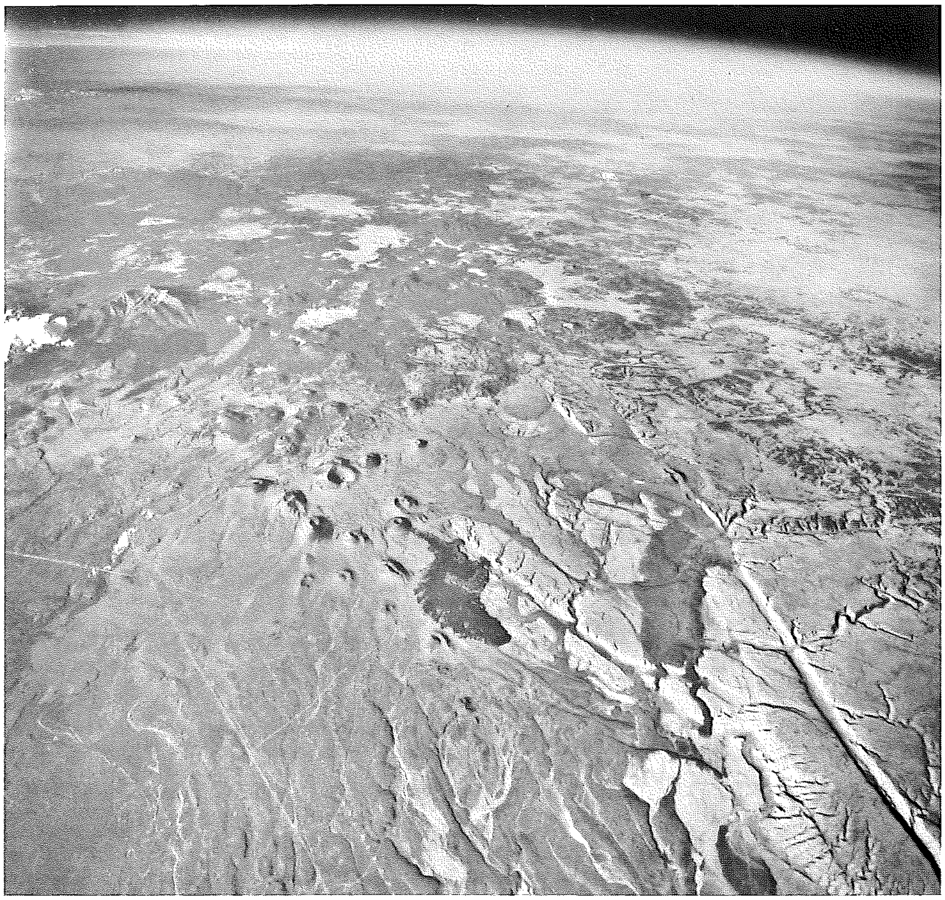

Figure 5a

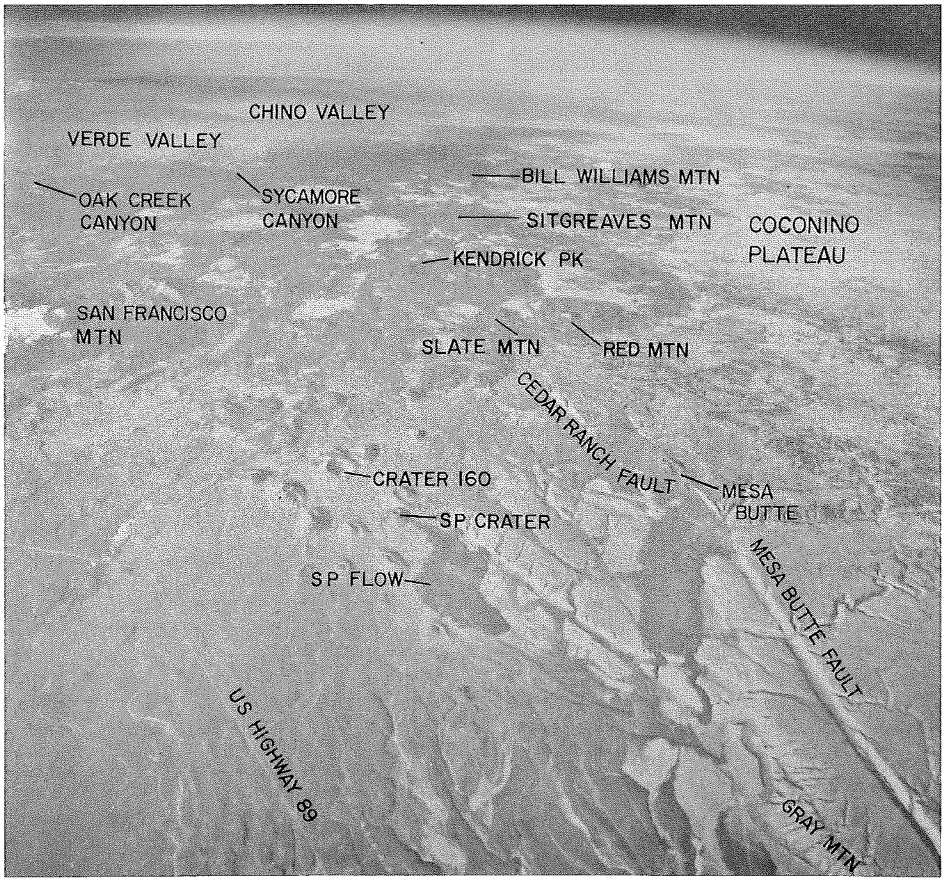

Figure 5b

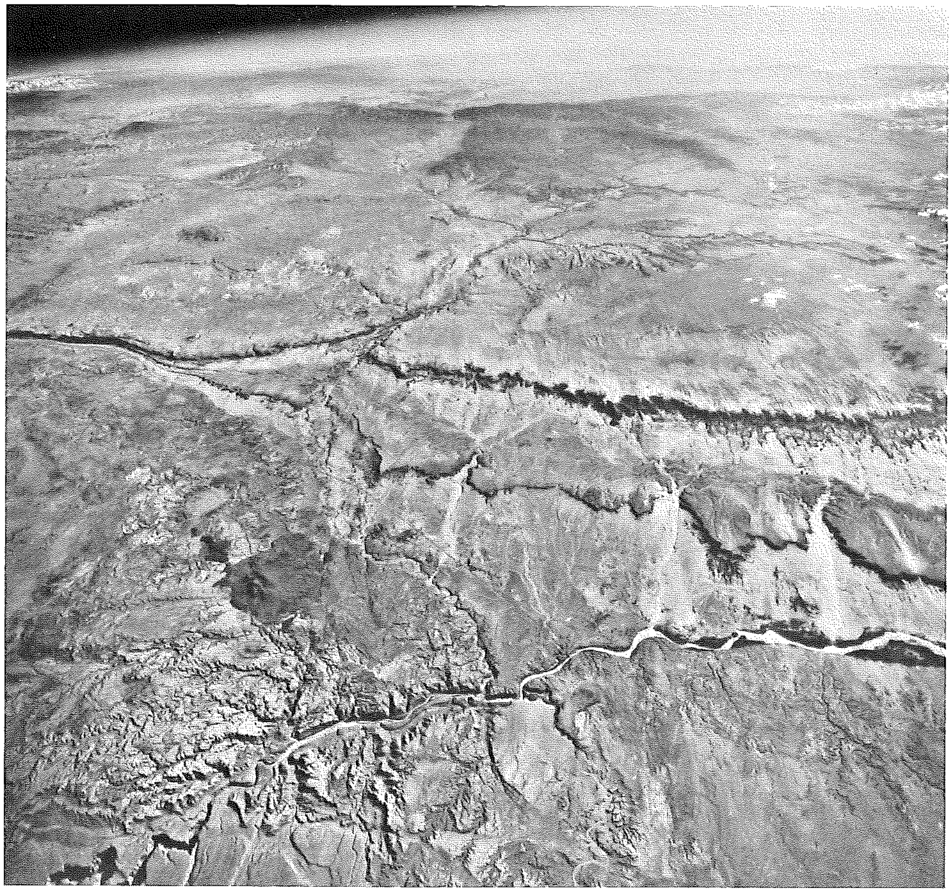

Figure 6a

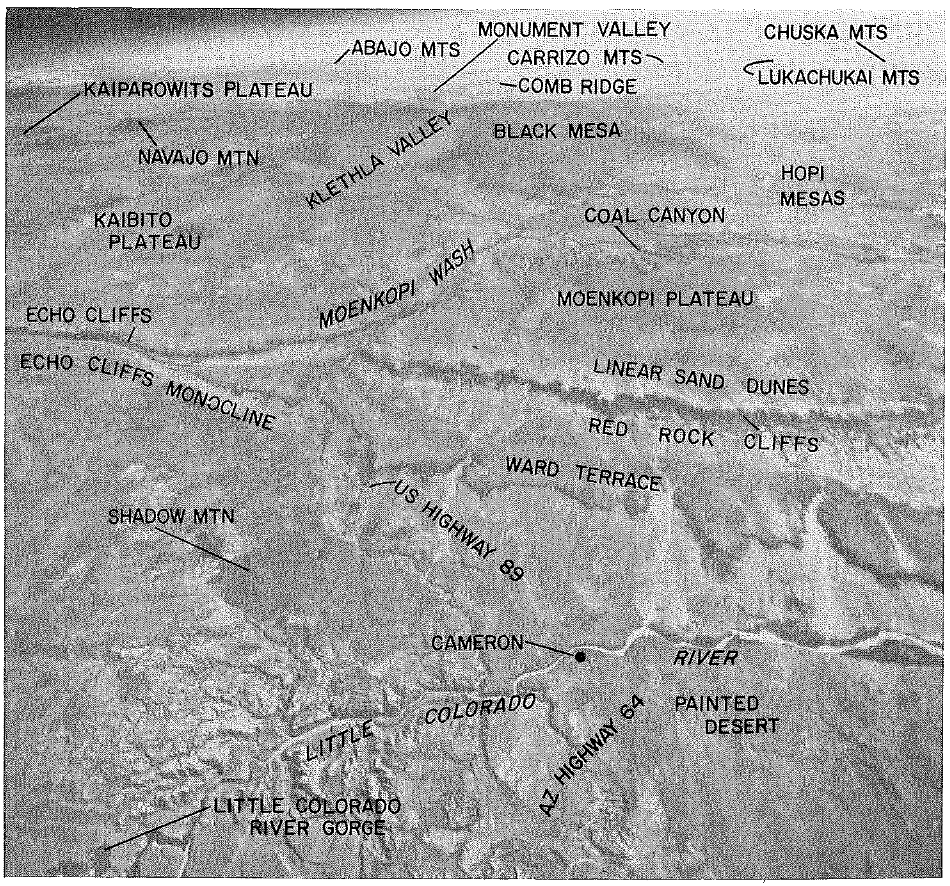

Figure 6b

The San Francisco volcanic field on the southern margin of the Colorado Plateau is composed of Quaternary and upper Tertiary basaltic rocks erupted from vents marked by cinder cones. A series of intermediate to silicic eruptive centers also produced volcanoes of considerable relief. The highest of these composite volcanoes is the 12,670-foot Humphreys Peak.

Figures 6a and 6b. Mesozoic sedimentary rocks predominate in this U.S. Air Force, high-altitude, U-2 view across northeastern Arizona from above Cameron. Lying at the northern end of the Mesa Butte fault, Shadow Mountain cinder cone is the northernmost isolated eruptive center of the San Francisco volcanic field. One of the basalt flows has been dated by K-Ar at 0.62 ± 0.23 m.y. B.P. Flows are penecontemporaneous with faulting in the underlying Chinle Formation, the varicolored Triassic mudstone that forms the Painted Desert (Condit, 1974).

Unobstructed by topographic barriers and driven by strong, year-round, west-southwest wind, sand climbs the Red Rock Cliffs and forms a pattern of linear dunes, which streak across the Moenkopi Plateau (Breed and others, 1984). The entire Glen Canyon Group is exposed in the Echo Cliffs. Coal Canyon is incised into units of the Jurassic San Rafael Group and Upper Cretaceous coal-bearing Dakota Sandstone. Cretaceous Dakota Sandstone, Mancos Shale, and Mesa Verde Group are widely exposed in Black Mesa, the location of Arizona's major coal resources.

Figure 7. About 200 meters of erosion exposed the plumbing of the approximately 30-m.y.-old Agathla Peak diatreme near Kayenta in northeastern Arizona. The volcanic neck chiefly consists of breccia with branching dikes and sheets of igneous rock. There are several hundred well-exposed diatremes in Arizona, most of which are in the Navajo and Hopi volcanic fields. The edge of Black Mesa

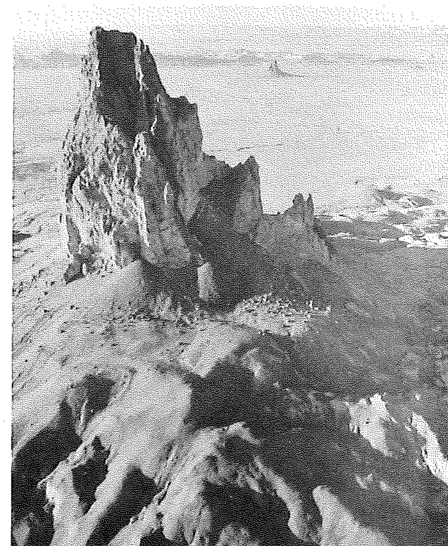

Figure 7

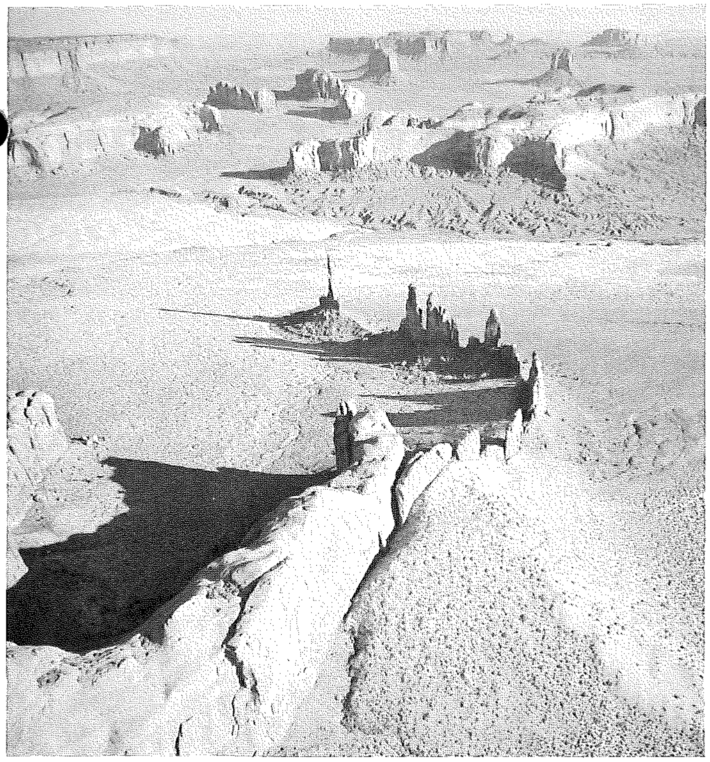

Figure 8

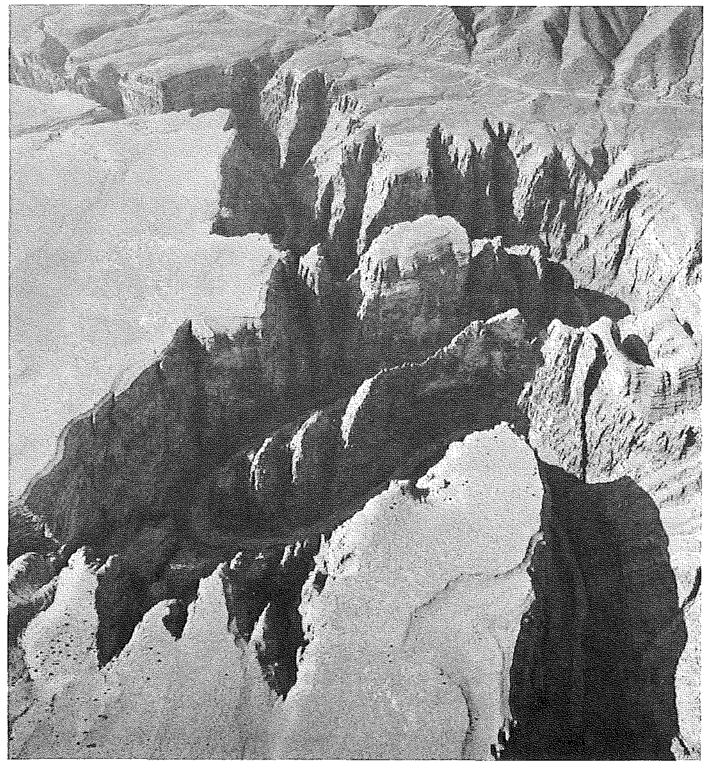

Figure 9

cuts across the horizon in this low-altitude, aerial oblique view to the south (Fitzsimmons, 1973; Sheridan, 1984).

Figure 8. Sculptured from mostly Permian sedimentary rocks involved in the Monument upwarp, these spires, buttes, and mesas constitute Monument Valley north of Kayenta in northeastern Arizona. This low-altitude, aerial oblique view pans north across the Totem Poles and Spearhead Mesa to the Mittens area. De Chelly Sandstone forms the magnificent cliffs. The slopes beneath the massive cliffs are Organ Rock Shale. The very uppermost caps of many of the buttes north of the Totem Poles are composed of thin remnants of Moenkopi Formation overlain by the Shinarump Member of the Chinle Formation; both are of Triassic age (Baars, 1973).

Figure 9. Entrenched meanders of the Little Colorado River form a spectacular gorge west of Cameron. Arizona State Highway 64 and the slope of the Grand View monocline cut across the upper right (west) corner of this aerial view to the south. Permian Kaibab Limestone is the rimrock, underlain by Toroweap Formation and Coconino Sandstone deep in the gorge.

Figure 10. The erosionally embayed Mogollon Rim at Oak Creek Canyon near Sedona marks the southern edge of the Colorado Plateau. Oak Creek Canyon in the upper left (west) corner extends north toward San Francisco Mountain near Flagstaff. The light-colored cliffs in the foreground are Permian sedimentary rocks of the Supai Group, Coconino Sandstone, Toroweap Formation, and Kaibab Limestone. Late Tertiary flows at the southern margin of the San Francisco volcanic field cap the Permian sedimentary rocks along the rim. On the east side of Oak Creek Canyon and exposed in Munds Canyon (cutting diagonally across the upper center of the photo), the flows form a significantly thicker sequence. One interpretation is that the flows and underlying late Tertiary gravels filled a large erosional reentrant carved into the ancestral plateau, one margin of which was marked by the preexistent Oak Creek fault (Peirce and Nations, 1986).

Figure 11. Weaver's Needle, a flow remnant in the Superstition Mountains east of Phoenix, is shown in this aerial view to the north. The highly jointed rock in the foreground is the 22-

Figure 10

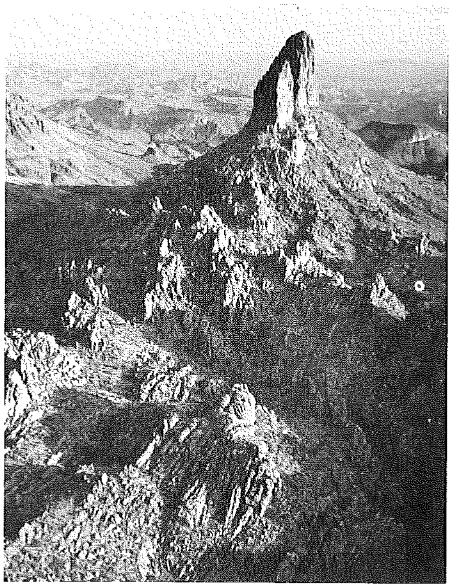

Figure 11

to 25-m.y.-old Superstition welded tuff. The spire is composed of glassy latitic lava. Between these two units is a stratified laharic breccia. Three volcanic centers are identified in the western part of this volcanic field. Remnants of middle Tertiary ash-flow sheets blanket a large area of central and southeastern Arizona (Sheridan, 1987; oral commun., 1987).

Figure 12. Picacho Peak, a prominent landmark in southeastern Arizona, is a tilted (dipping to the left or northeast) and faulted remnant of a lower Miocene volcanic complex. The volcanic rocks are potassium rich because of postvolcanic alteration and are locally interlayered with conglomerate (Shafiqullah and others, 1976).

Interstate Highway 10 cuts diagonally across the center of view. The Tortolita Mountains are in the background and the Santa Catalina Mountains are on the horizon. This aerial view is to the southeast.

The Picacho Peak rocks are a remnant of the deformed upper plate of a detachment fault that separates them from lower-plate rocks exposed in the Picacho Mountains to the north (left, but not in view).

Figure 13. This view is to the northeast along the Santa Catalina core complex near Tucson. The relatively planar slope along the southern (right) flank of the mountain expresses the dip slope of Tertiary mylonitic foliation. The mylonitic fabric was formed by top-to-the-southwest shear.

Pusch Ridge in the foreground is composed of layers of the early Tertiary leucocratic Wilderness granite and darker layers of mylonites derived from the 1.4-b.y.-old Oracle Granite. Further along Pusch Ridge, Alamo Canyon marks the gradational lower boundary of the mylonitic zone. The Catalina detachment fault follows a sinuous trace along the southern (right) edge of the mountain front and has a shallow dip to the south and west.

Mount Lemmon in the upper left at the crest of the range consists of Cambrian and Precambrian metasedimentary rocks that dip to the northeast. The Pinaleno Mountains (left horizon) are another metamorphic core complex. The Galiuro Mountains between the Santa Catalina and Pinaleno Mountains contain middle Tertiary volcanic rocks.

Figure 14. The incised Madera Canyon alluvial fan skirts the west flank of the Santa Rita Mountains south of Tucson. This aerial view is to the east. Sonoita basin is in the upper left corner and the Huachuca Mountains are on the horizon just left of center.

The lighter, less dissected slope is considered to be middle Pleistocene. The more dissected center portion of the fan is older. The dark lines that cut the younger left edge of the fan are Quaternary fault scarps. Based on scarp morphology and soils, the youngest rupture may have occurred 8,000 to 15,000 years ago (Ely and Baker, 1985, p. 55).

Figure 15. This aerial view is to the southeast across the community of Green Valley, south of Tucson. The Pima-Mission open-pit copper mine and tailings piles sit perched on the broad bajada surrounding the Sierrita Mountains. The copper is disseminated in skarn associated with a Laramide porphyritic intrusive. The Madera Canyon alluvial fan at the base of the Santa Rita Mountains is in the upper right (south) corner. The Huachuca Mountains are visible in the center of the horizon.

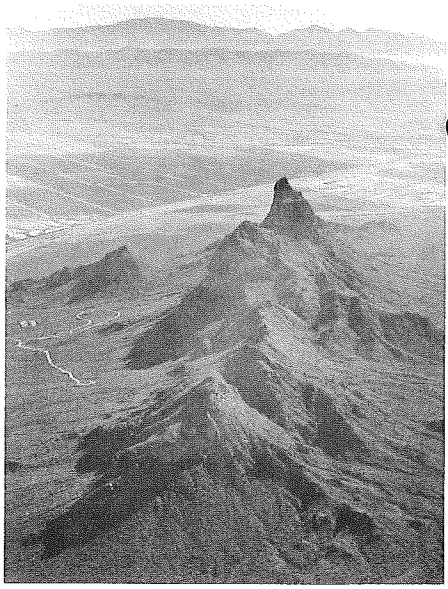

Figure 12

Figure 16. In this aerial view toward the north along the southeastern Arizona-southwestern New Mexico border, the San Bernardino Valley joins the southern end of the San Simon Valley. This valley is bounded by relatively uplifted mountain blocks of the Perilla-Pedregosa-Chiricahua Mountains on the west (left) and the Peloncillo Mountains on the east (right).

Paramore Crater (center) with the tuff ring is one of five steam-blast explosion features in the

Figure 13

Figure 14

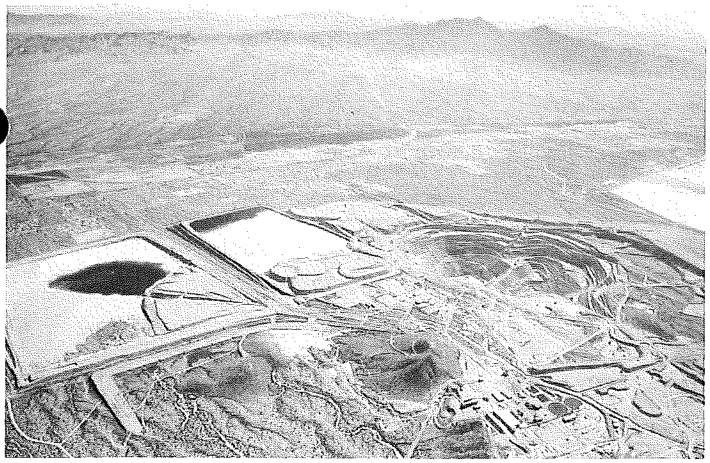

Figure 15

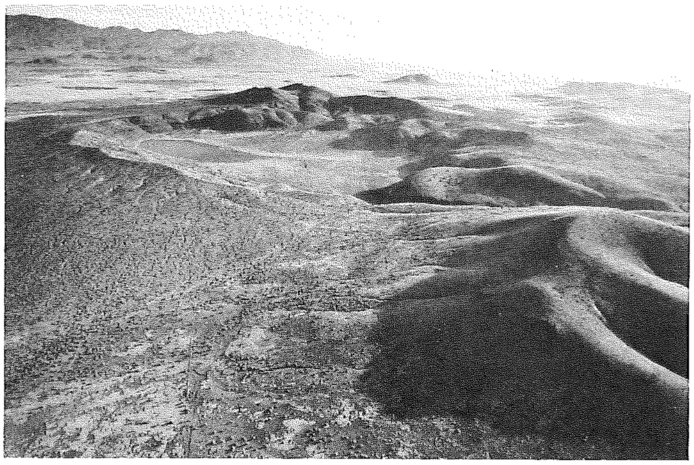

Figure 16

San Bernardino volcanic field. The alkali olivine basalts in this field contain large amounts of xenolithic material, including lherzolite and pyroxenite nodules. San Bernardino basalts have been radiometrically dated as late Pliocene or Pleistocene (Lynch, 1978).

Figure 17. This low-altitude aerial view to the south shows exposures of the light-colored, lower Tertiary Gunnery Range granite being exhumed from beneath a faulted cover of 16- to 17-m.y.-old dark andesites of the Cabeza Prieta Mountains in southwestern Arizona. In the foreground, the granite outcrops in A-1 basin. Cabeza Prieta Peak is the andesite-capped peak just below the horizon in the upper right corner. The broad shield of the Pinacate volcanic field in northwestern Sonora, Mexico is in the center of the horizon (Shafiqullah and others, 1980).

Figure 17

Figure 18. The Pinacate volcanic field in northwestern Sonora, Mexico is one of the youngest and most spectacular lava fields in North America. This low-altitude aerial view to the north shows the central peaks area. Pinacate Peak (left of center) is the highest point.

The volcanic complex consists of a small shield-type volcano with some 500 eruptive centers, including more than 300 cinder cones, along its flanks. Volcanic activity has been continuous but episodic during the last 1.2 m.y. and consisted of two distinct periods of volcanism. First, the Volcan Santa Clara trachyte shield volcano was built by successive eruptions through a central summit vent complex. Second, smaller, individual basaltic cones and lava flows were erupted on the slopes of Santa Clara and extended out onto the desert surrounding the central vent complex (Lynch, 1981).

Figure 18

Acknowledgments

The author thanks John Sumner, whose talents as a pilot made these photos possible; Dan Lynch and Tad Nichols for their assistance

(continued on page 10)

Geologic Highlights of the Phoenix Region

by Stephen J. Reynolds
Arizona Geological Survey

The Phoenix region contains a diverse and spectacular array of geologic features, most of which are easily accessible by short trips in a passenger car. Such features vary from unusual divergent Holocene terraces along the Salt River to Proterozoic volcanic rocks that represent the initial construction of the continental crust of the region. In addition, the area contains classic examples of middle Tertiary volcanic centers, detachment faults, and metamorphic core complexes. This article summarizes the geologic history of Arizona and briefly discusses some of the more interesting and accessible geologic features near Phoenix.

GEOLOGIC HISTORY OF ARIZONA

Arizona encompasses parts of three geologic-physiographic provinces: the Colorado Plateau, Basin and Range Province, and intervening Transition Zone (Figure 1). The Colorado Plateau in northeastern Arizona is characterized by flat-lying Paleozoic and Mesozoic sedimentary rocks that form broad plateaus and mesas, locally interrupted by deeply incised canyons cut by drainages of the Colorado River system. In the bottom of the Grand Canyon, the Paleozoic and Mesozoic rocks have been eroded, exposing the underlying Proterozoic basement. The topography of the Colorado Plateau commonly mimics regional structural features, especially uplifts bounded by monoclinal folds or by faults. The highest topographic features in the region are partially eroded late Cenozoic volcanoes that form San Francisco Mountain near Flagstaff and the White Mountains of east-central Arizona.

The Basin and Range Province in southern and western Arizona contains a series of north- to northwest-trending mountain ranges separated by broad alluvial valleys. The ranges include a diversity of Proterozoic to Cenozoic rocks with complex structural and metamorphic histories. The intervening basins contain variable thicknesses of upper Cenozoic clastic detritus and locally thick, nonmarine evaporite deposits; they are the primary ground-water reservoirs of the region.

The Transition Zone, as the name implies, has geologic and physiographic characteristics intermediate between those of the Colorado Plateau and Basin and Range Province. In this region, pre-Miocene erosion has stripped away much of the Paleozoic and Mesozoic sedimentary cover, leaving wide expanses of exposed Proterozoic crystalline rocks. The Proterozoic rocks are commonly overlain by middle to upper Cenozoic sedimentary and basaltic rocks. The structural continuity of these rocks is disrupted by northwest-trending late Cenozoic basins that are narrow analogs of those in the Basin and Range Province.

The geologic history of Arizona began with an Early to Middle Proterozoic (1.8 to 1.4 b.y. ago) period of crustal construction and eventual stabilization via volcanism, sedimentation, deformation, metamorphism, and plutonism. During Late Proterozoic (1.4 to 1.1 b.y. ago) and Paleozoic time, carbonate and clastic rocks accumulated in a stable cratonic environment close to sea level.

In Late Triassic to Early Jurassic time, southern Arizona became tectonically active in response to subduction and deformation along the southwestern margin of North America. A pulse of volcanism and associated plutonism occurred in southern Arizona during Early to Middle Jurassic time and was followed by a period of continental to shallow-marine sedimentation during Late Jurassic to mid-Cretaceous time. The Colorado Plateau remained tectonically stable during this time, but periodically received influxes of orogenic detritus from the south. In Late Cretaceous to early Tertiary (Laramide) time, intense compressional deformation caused folding and basement-involved thrusting in southern Arizona and formed monoclines as Paleozoic and Mesozoic strata were draped over reactivated Proterozoic faults in the Colorado Plateau and Transition Zone. Deformation was accompanied by locally extreme metamorphism and by granitic plutonism associated with large porphyry-type copper deposits.

Laramide tectonism was followed by a period of widespread early Tertiary uplift and erosion that denuded southwestern Arizona of all shallow-level rocks. This erosion was succeeded by a tremendous outpouring of volcanic rocks during middle Tertiary time (38 to 15 m.y. ago). Volcanism was accompanied by granitic plutonism and by crustal extension that formed regional, gently dipping normal faults, termed detachment faults, and associated mylonitic fabrics within metamorphic core complexes. Subsequent to middle Tertiary tectonism, late Cenozoic block faulting formed many, but not all, of the present-day basins and ranges. Some present-day basins are relics from the middle Tertiary period of extensional faulting. Faulting was concurrent with late Cenozoic, fundamentally basaltic volcanism in the Transition Zone and along the margins of the Colorado Plateau. In late Tertiary and Quaternary time, previously unconnected basins with interior drainage became integrated into the Colorado and Gila River drainage system.

GEOLOGIC SETTING OF PHOENIX

Phoenix is in the Basin and Range Province, 50 kilometers southwest of the Transition Zone. Like most of central Arizona, the Phoenix region lacks Paleozoic and Mesozoic rocks, which were eroded from the area before middle Tertiary time (Figure 1). Most mountain ranges in the area consist of Proterozoic crystalline rocks overlain by middle Tertiary volcanic and sedimentary rocks. Early and middle Tertiary granitic plutons are exposed in the South and White Tank Mountains south and west of Phoenix. These same two mountain ranges are termed metamorphic core complexes because they contain mylonitic fabrics formed by middle Tertiary ductile shearing along a regional, gently dipping normal fault (or detachment fault). This fault dips gently to the northeast off the South and White Tank Mountains, projecting beneath rocks exposed closer to Phoenix. Rocks above the detachment fault, such as those at Camelback Mountain, Papago Park, and Tempe Butte, were broken into tilted fault blocks as they were transported to the northeast relative to rocks beneath the fault.

After middle Tertiary detachment faulting, the Phoenix region was the site of late Tertiary normal faulting that created deep basins filled with several kilometers of nonmarine clastic rocks and evaporite deposits (Peirce, 1976). Examples are the Luke basin west of Phoenix and the Higley basin near Chandler. By Pliocene time, the previously closed basins became integrated with the Salt and Gila River drainage network.

GEOLOGIC FEATURES NEAR PHOENIX

Camelback Mountain, Papago Park, Tempe Butte

Camelback Mountain, in the northeastern part of metropolitan Phoenix, is an erosional remnant of a large fault block tilted during the middle Tertiary episode of crustal extension. The mountain is composed of Proterozoic granite, overlain to the southwest by west-dipping, middle Tertiary sedimentary breccia and other clastic rocks (Cordy, 1978). The basal contact of sedimentary rocks is generally a fault that probably formed while the beds were tilted to the west. The middle Tertiary sedimentary rocks are well exposed near Echo Park and along residential roads on the south side of the "Camels Head," where they are cut by spectacular clastic dikes of remobilized fault gouge.

Similar middle Tertiary sedimentary breccias and clastic rocks form the reddish buttes and hills at Papago Park, near the City of Phoenix Zoo (Péwé and others, 1987). Here, the sedimentary rocks are in depositional contact with underlying Proterozoic granite (such as on the east side of Hole in the Rock north of the zoo) and dip moderately to steeply to the southwest. Large, well-exposed sheets of megabreccia, which represent shattered landslide blocks of Proterozoic granite and metarhyolite, are present within the tilted sequence of sedimentary breccias northwest of the zoo (Reynolds and Lister, 1987).

A stratigraphically higher sequence of finer grained reddish clastic rocks is present on the north flank of Tempe Butte near Arizona State University (Péwé and others, 1987). These rocks contain well-preserved sedimentary structures, including small folds formed during sedimentation, and are capped by a 17-m.y.-old volcanic flow.

South Mountains

The South Mountains, easily accessed via Central Avenue and other roads south of Phoenix, are a simple, but elegant example of a middle Tertiary detachment zone or metamorphic core complex (Reynolds, 1985; Reynolds and Lister, 1987). The eastern half of the range is composed of a middle Tertiary granodioritic to granitic pluton, whereas the western half consists of Proterozoic gneiss. Both rock types are overprinted by a gently to moderately dipping mylonitic fabric and younger breccia. The mylonitic fabric and superimposed breccia were formed by top-to-the-northeast normal displacement along a gently dipping shear zone, or detachment zone, that progressively evolved from ductile to brittle levels of the crust. The detachment fault and associated breccia zone, exposed in the eastern and southern South Mountains, projects beneath and probably truncates the tilted fault blocks of Tertiary sedimentary rocks at Papago Park, Tempe Butte, and vicinity.

White Tank Mountains

The White Tank Mountains west of Phoenix are geologically very similar to the South Mountains in that they contain mylonitic fabric and superimposed breccia formed below an east-dipping detachment zone (Rehrig and Reynolds, 1980). The mylonitic fabrics cut Proterozoic metamorphic rocks and Tertiary intrusive rocks and are well exposed near paved roads in a regional park on the east side of the range.

Lake Pleasant Area

Spectacular Proterozoic and middle Tertiary geology forms the scenery around Lake Pleasant and the Hieroglyphic Mountains northwest of Phoenix. Exposed on the west shore of Lake Pleasant and to the north along the dirt road to Castle Hot Springs are east-dipping middle Tertiary volcanic rocks overlain by conglomerate and sedimentary breccia deposited in half grabens formed during middle Tertiary crustal extension (Capps and others, 1986). Silicic flow breccias compose the high, sheer walls of Crater Canyon, directly west of the Castle Hot Springs resort. The large construction project downstream from Lake Pleasant is the planned New Waddell Dam, part of the federally funded Central Arizona Project.

Phoenix Mountains

The Phoenix Mountains consist of isolated hills and mountains in northern metropolitan Phoenix. Squaw Peak, the most prominent mountain, contains well-traveled hiking trails that traverse a sequence of Proterozoic metavolcanic and metasedimentary rocks, including andalusite-bearing and quartz-kyanite rocks (Thorpe and Burt, 1978). The peculiar silica- and alumina-rich composition of these rocks probably reflects hydrothermal alteration by acidic fluids that leached all mobile elements, such as potassium and sodium, either before or during regional metamorphism.

Salt River Area

The Salt River, one of the major rivers in Arizona, flows westward across the Phoenix basin from the high country to the east. The Salt River is flanked by well-preserved terraces that are close in elevation near Tempe, but diverge in elevation upriver to the east (Péwé, 1987). South of the Salt River, near Chandler, are excellent examples of earth cracks: large open fissures formed by differential subsidence due to ground-water withdrawal.

Superstition and Goldfield Mountains

The main geologic attraction in these mountain ranges, besides the famed Lost Dutchman mine, is a thick sequence of middle Tertiary volcanic rocks and overlying conglomerate and volcanic-sedimentary breccia (Sheridan, 1987). The volcanic rocks, like many in the region, are commonly tilted and cut by steeply to gently dipping normal faults. The region contains one or more volcanic centers and is best accessed via the Apache Trail (Arizona State Highway 88), a scenic, winding, partly unpaved road that passes from Apache Junction through Tortilla Flat to Roosevelt Lake.

CONCLUSION

The Phoenix region is endowed with a diverse assemblage of rock types and geologic features that are, partly because of the arid climate, very well exposed. Many spectacular exposures are within short walking distance from paved roads. Examining a small selection of these exposures provides an appreciation of the general geologic framework of central Arizona. It is an opportunity that should not be missed.

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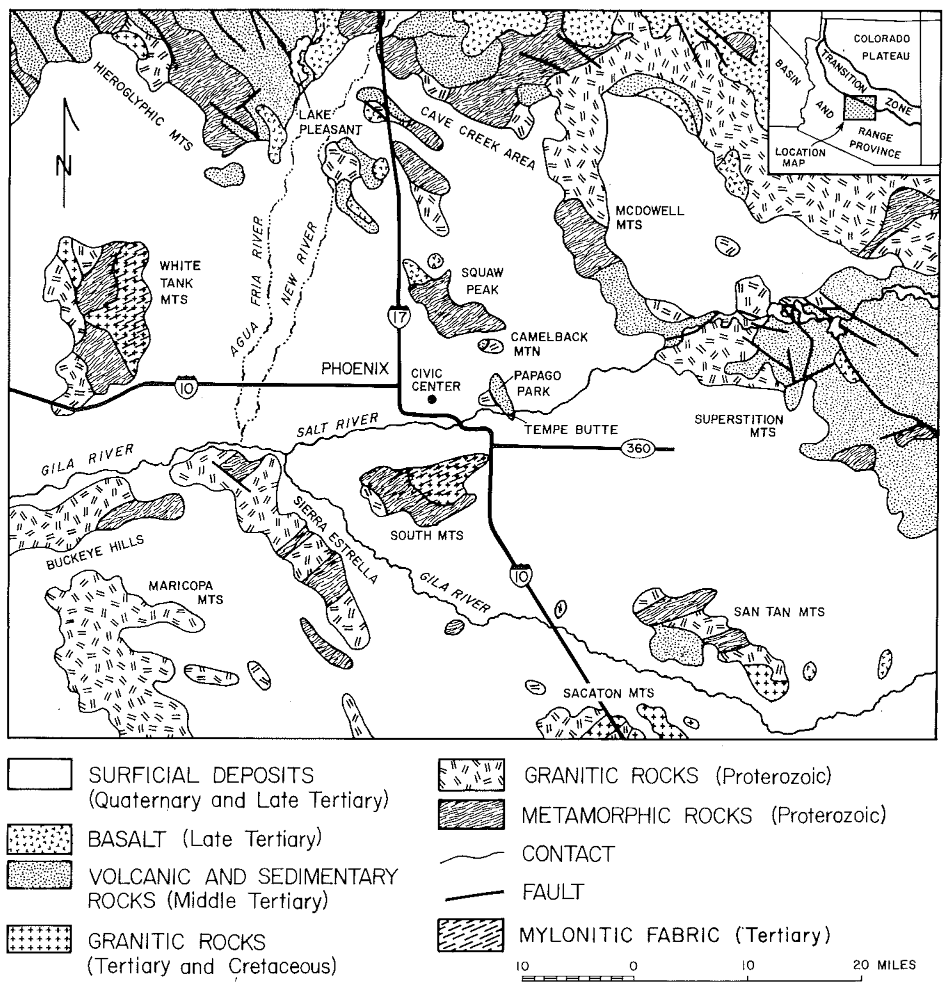

Figure 1. Generalized geologic map of the Phoenix area, central Arizona.

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(continued from page 7)

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Selected Publications of the Arizona Geological Survey

The following list is a selection of publications released by the Arizona Geological Survey (Geological Survey Branch of the Arizona Bureau of Geology and Mineral Technology). The AGS will have an exhibitor's booth at the 100th annual meeting of The Geological Society of America (GSA), to be held in Phoenix, Arizona October 26-29. A complete price list of AGS publications, as well as several publications for purchase, will be available at the AGS booth in the GSA Exhibitors Hall.

Bulletins

182—Coal, oil, natural gas, helium, and uranium in Arizona, 289 p.

193—Arizona earthquakes, 1776-1980, 456 p., scale 1:1,000,000.

194—Metallic mineral districts and production in Arizona, 58 p.

195—Geology of the South Mountains, central Arizona, 61 p., scale 1:24,000.

196—Mine index for metallic mineral districts of Arizona, 92 p.

197—Compilation of radiometric age determinations in Arizona, 258 p.

Circulars

Bibliographies for metallic mineral districts in the following counties in Arizona:

24—Cochise, Graham, and Greenlee, 38 p.

25—La Paz, Mohave, and Yuma, 45 p.

26—Pima and Santa Cruz, 44 p.

Maps (scale 1:1,000,000)

18—Metallic mineral districts of Arizona (also included in Bulletin 194).

19—Map of outcrops of Laramide (Cretaceous-Tertiary) rocks in Arizona and adjacent regions.

20—Map of mid-Tertiary volcanic, plutonic, and sedimentary rock outcrops in Arizona.

21—Map of post-15-m.y. volcanic outcrops in Arizona.

22—Map of late Pliocene-Quaternary (post-4-m.y.) faults, folds, and volcanic outcrops in Arizona.

23—Land subsidence, earth fissures, and water-level change in southern Arizona.

24—Map of K-Ar and Ar-Ar age determinations in Arizona (also included in Bulletin 197).

25—Map of fission-track, Rb-Sr, and U-Pb age determinations in Arizona (also included in Bulletin 197).

Special Papers

4—Proceedings of the 21st Forum on the Geology of Industrial Minerals, 134 p.

5— Geologic diversity of Arizona and its margins; excursions to choice areas, 422 p.

The AGS also places geologic maps, research results, and compilations on open-file. Open-file maps cover several mountain ranges in Arizona including the Big Horn, Buckskin, Hieroglyphic, Little Harquahala, northern Plomosa, and Vulture Mountains. Open-file reports cover a variety of subjects including geothermal studies in Arizona, land-use issues, geologic hazards, and metallogenic studies.

Water: Lifeblood of Civilization in the Salt River Valley

by James P. Lombard
University of Arizona

In the Sonoran Desert of southern Arizona, a dependable water supply is difficult to maintain. Rainfall is scarce and unpredictable: the Phoenix area receives an average of less than 10 inches per year (Sellers and Hill, 1974). Most streams are ephemeral. Prehistoric communities in the Salt River Valley depended on canals to convey water from the seasonally variable Salt River to fields and houses (Masse, 1981). Today ground water is pumped to augment the supply from the dammed Salt and Verde Rivers, and even part of the Colorado River has been rerouted to satisfy a growing thirst. For more than 2,000 years, the inhabitants of the Salt River Valley have managed to maintain a constant water supply; how they accomplished this feat is a fascinating story.

Geographic Setting and Climate

The Salt River Valley is in the Basin and Range province just south of the mountainous terrain of the Transition Zone. The valley floor is a broad area of gently sloping alluvial soils that are well suited for irrigated agriculture and the construction of gravity-fed canals. Thick sediments containing much of the Salt River Valley's ground water have accumulated between the partially buried bedrock mountains and hills that protrude from the valley floor.

The Salt River, joined by the Verde River east of Phoenix, flows westward until it meets the Gila River southwest of the city. Today the Salt River rarely flows through Phoenix except during large floods because much of its water is diverted upstream for irrigation and any remaining river water evaporates or quickly soaks into the sediments of the valley floor (University of Arizona, 1972).

The headwaters of the Salt River are in the Mogollon Rim region, where springs and precipitation runoff supply numerous streams that converge to form the river. Because precipitation in this area is seasonal, the Salt River provided a dependable water supply only during certain months, until storage dams were built to contain the flow. Using tree-ring data from both live trees and archaeological sites in the upper Salt and Verde drainage basins, scientists have determined seasonal streamflow in the Salt River from 740 to 1370 A.D. and from 1800 to 1979 A.D. (Graybill and others, 1987). This reconstruction has allowed them to assess the difficulties that early inhabitants of the valley may have had in maintaining their principal water supply.

Prehistoric Use of the Salt River

It is believed that the Hohokam people migrated from Mexico into the Salt River Valley about 300 B.C. and lived there until about 1450 A.D., when their culture inexplicably declined (Haury, 1976). The Hohokam were riverine farmers who used an extensive network of hundreds of miles of hand-dug canals (Figure 1) to divert water from the Salt River for irrigation and for settlements as far as 10 miles from the river. The Hohokam were evidently adapted to seasonality of the Salt River because they built the most complex urban civilization outside of Mexico in pre-Columbian time, with an estimated population of 50,000 to 60,000 (Haury, 1976).

Despite their impressive lengths, Hohokam canals were technologically simple and relatively inefficient. Canal intake structures on the river's edge were not permanent and probably could not withstand floods. The canals were rarely lined with clays to prevent water loss. The lack of techniques for canal construction across steeper terrain limited the area of land that could be irrigated within the valley (Graybill and others, 1987). The reconstructed streamflow record of the Salt River suggests that the Hohokam spent considerable energy repairing or rebuilding intakes and other parts of their canals after floods (Graybill and others, 1987). Tree-ring data indicate that in the middle of the 14th century the Salt River flooded heavily, which may have caused irreversible damage to canal systems and been a major factor in the decline of the Hohokam civilization (Graybill and others, 1987).

Historic Settlement of the Salt River Valley

Several thousand Pima individuals lived close to the banks of the Salt River when

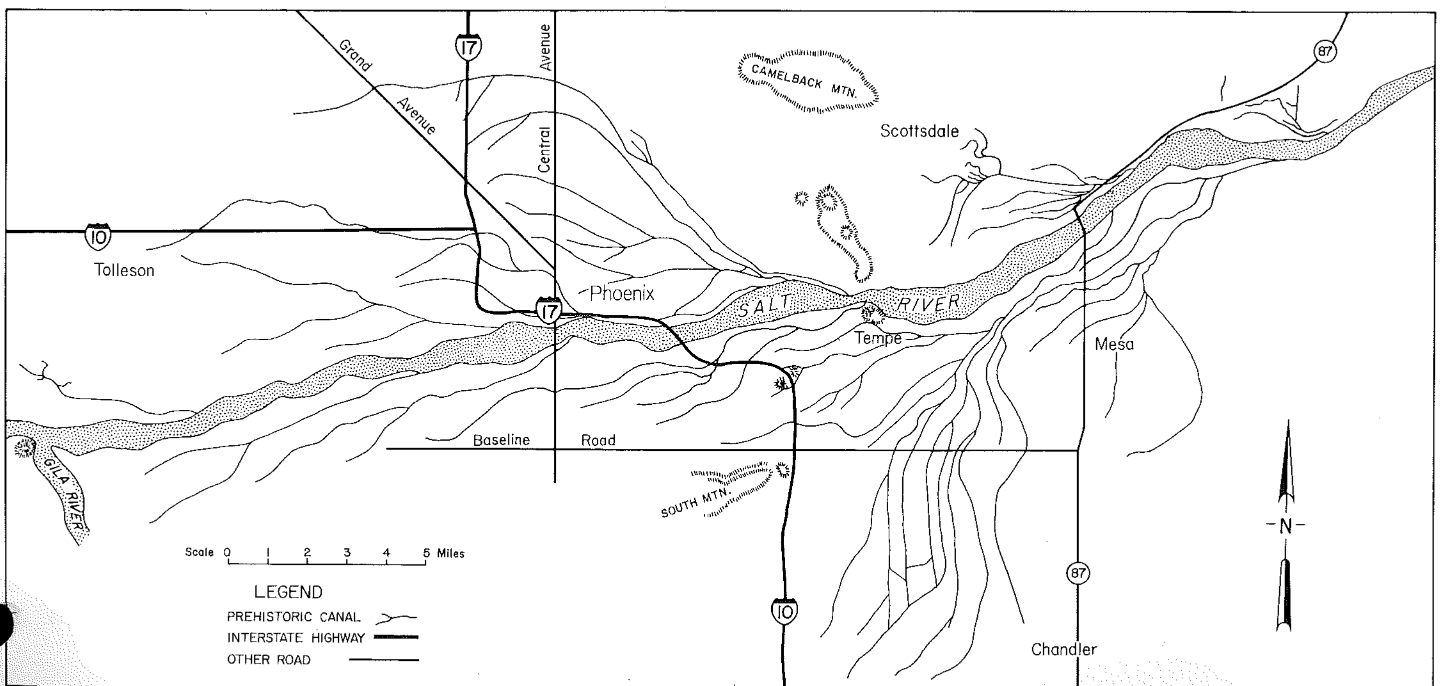

Figure 1. Prehistoric canal network in the Salt River Valley (adapted from Midvale, 1968).

Spanish missionaries arrived in the late 17th century. The Pima used irrigated agriculture to cultivate the same types of crops that the Hohokam raised. Although they did not build or maintain long canals, evidence suggests that they may have used the portions of the Hohokam canals that were closest to the river. The small abandoned cities of the Hohokam were replaced by the scattered farming settlements of the Pima. Pima oral tradition maintains that the Hohokam were their ancestors, but includes no record of the causes of the Hohokam decline (Haury, 1976).

New settlers arrived in the Salt River Valley after the establishment of Fort McDowell in 1865. Large-scale irrigation farming began in 1867 after completion of the Swilling Irrigation Canal Company ditch, which occupied portions of the prehistoric canal network (Johnson, 1982). At first, the settlers essentially used prehistoric irrigation technology, but they soon constructed sturdy intakes on the river using concrete and built canals across steeper terrain to areas unfarmed by the Hohokam (Graybill and others, 1987). Even with improved canal systems, however, farmers experienced enough difficulty coping with dry years that by the turn of the century they lobbied Congress to build a large dam on the Salt River to store water and generate power. Roosevelt Dam was completed in 1911, followed by other dams on the Salt River; these solved the water needs of valley residents, at least for a time.

An unusual problem occurred in the early 1920's when the fields in some parts of the valley became waterlogged from too much irrigation. Large water wells were drilled for the first time in the Salt River Valley to lower the water table by pumping the excess water and piping it further to the west to irrigate more land (University of Arizona, 1972). This was the beginning of the ever-increasing use of large wells to pump ground water for irrigation in the valley, a practice that has depleted the ground-water supply (University of Arizona, 1972). As a result, the land has subsided in several areas and the resulting earth fissures pose problems to current and future development (Schumann and Genualdi, 1986).

Current and Future Water Sources

With a population of 1.8 million, Phoenix and its suburbs constitute the largest desert metropolitan area in the United States (Rand McNally, 1987). Because of skyrocketing urban growth in the Salt River Valley, water demand is expected to double during the next 40 years (Lindsey, 1987). To fill this increasing need, the valley's water supply from the Salt River and diminishing ground-water reserves is being augmented by water from the Colorado River. The Central Arizona Project (CAP), a multibillion-dollar system of canals, pumps, and aqueducts, carries the water from Lake Havasu on Arizona's western border to Phoenix and will soon service Tucson when the project is completed. This extra water, however, will sustain growth in the Phoenix metropolitan area only until the turn of the century, at which time Phoenix will require yet another source. City planners in Mesa, Scottsdale, and Phoenix are exploring other sources outside the city limits. The City of Phoenix recently bought 14,000 acres of farmland 100 miles west of the city to use as a source of ground water for several hundred thousand new residents sometime early in the 21st century (Lindsey, 1987).

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Publications of the Arizona Geological Survey

Staff members of the Arizona Geological Survey (Geological Survey Branch of the Arizona Bureau of Geology and Mineral Technology) conduct research, do geologic mapping, and collect and compile data. The results of these efforts are published (as bulletins, maps, etc.) or are placed on open file. *Fieldnotes* is the survey's quarterly newsletter; subscriptions are free to U.S. residents. A complete price list of survey publications is available on request.

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