U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

TO ACCOMPANY MAP MF-2343

GEOLOGIC MAP OF THE UPPER PARASHANT CANYON AND VICINITY, MOHAVE COUNTY, NORTHWESTERN ARIZONA

By George H. Billingsley

INTRODUCTION

The geologic map of the upper Parashant Canyon area covers part of the Colorado Plateau and several large tributary canyons that make up the western part of Arizona’s Grand Canyon. The map is part of a cooperative U.S. Geological Survey and National Park Service project to provide geologic information for areas within the newly established Grand Canyon/Parashant Canyon National Monument. Most of the Grand Canyon and parts of the adjacent plateaus have been geologically mapped; this map fills in one of the remaining areas where uniform quality geologic mapping was needed. The geologic information presented may be useful in future related studies as to land use management, range management, and flood control programs for federal and state agencies, and private concerns.

The map area is in a remote region of the Arizona Strip, northwestern Arizona about 88 km south of the nearest settlement of St. George, Utah (fig. 1). Elevations range from about 1,097 m (3,600 ft) in Parashant Canyon (south edge of map area) to 2,145 m (7,037 ft) near the east-central edge of the map area. Primary vehicle access is by dirt road locally known as the Mount Trumbull road (fig. 1); unimproved dirt roads and jeep trails traverse various parts of the map area. Travel on the Mount Trumbull road is possible with 2-wheel-drive vehicles except during wet conditions. Extra fuel, two spare tires and extra food and water are highly recommended when traveling in this remote area.

The map area includes about 26 sections of land belonging to the State of Arizona, about 40 sections of private land, and a small strip of the Lake Mead National Recreation Area (southeast edge of the map area). The private land is mainly clustered around the abandoned settlement of Mt. Trumbull, locally known as Bundyville (figs. 1 and 2), and a few sections are scattered in the upper Whitmore Canyon area just south of Bundyville.

Lower elevations within the canyons support a sparse growth of sagebrush, cactus, grass, creosote bush, and a variety of desert shrubs. Sagebrush, grass, cactus, cliffrose bush, pinyon pine trees, juniper trees, and some ponderosa pines thrive at higher elevations.

Surface runoff in the north half of the map area drains northward towards the Virgin River in Utah via Hurricane Wash. In the south half of the area, it drains towards the Colorado River in Grand Canyon via Parashant and Whitmore Canyons. Upper Parashant and Whitmore Canyons are part of the physiography of the western Grand Canyon, but are not included within Grand Canyon National Park. The entire map area is now within the newly established Grand Canyon/Parashant Canyon National Monument (January, 2000), and is jointly managed by the Lake Mead National Recreational Area, Boulder City, Nevada, and the Bureau of Land Management, Arizona Strip District, St. George, Utah.

PREVIOUS WORK

Regional reconnaissance photogeologic mapping of this area was compiled onto Arizona State geologic map by Wilson and others (1969) and by Reynolds (1988). A photogeologic map of this area was produced by Lucchitta (1975) using remote sensing techniques. Geologic mapping of adjacent areas includes: (1) the Hurricane Fault zone and vicinity by Huntoon and others (1981); (2) the upper Hurricane Wash and vicinity by Billingsley (in press a); and (3) the Vulcan's Throne and vicinity by Billingsley and Huntoon (1983).

MAPPING METHODS

This map was produced by interpretation of 1976 infrared 1:24,000-scale aerial photographs followed by extensive field checking. Many of the Quaternary alluvial deposits that have similar lithology, but different geomorphic characteristics, were mapped almost entirely by photogeologic methods. Stratigraphic position and amount of erosional degradation were used to help determine relative ages of young and old alluvial deposits having similar lithologies. In the field, each map unit and structure was investigated in detail to insure accuracy of description.

GEOLOGIC SETTING

The map area lies within the Shivwits and Uinkaret Plateaus, subplateaus of the Colorado Plateaus physiographic province (fig. 2). The boundary between the Uinkaret Plateau and the Shivwits Plateau is marked at the top of the Hurricane Cliffs fault scarp (fig. 2; Hamblin and Best, 1970). The physiographic boundary of the Grand Canyon is the canyon rims of Parashant and Whitmore Canyons (fig. 2).

The Shivwits and Uinkaret Plateaus are characterized by nearly flat-lying Paleozoic and Mesozoic sedimentary strata warped by minor folds. These strata have an average regional dip of about 1° east, except along the downthrown side of the Hurricane Cliffs, Main Street Fault, and Dellenbaugh Fault, where dips are as steep as 15° east into the faults. The near vertical Hurricane Fault in the northeast quarter of the map area is the principal structure offsetting the sedimentary rocks. Vertical displacement across the Hurricane Fault is estimated to be more than 390 m (1,280 ft; down to the west) at the north edge of the map area. Smaller, but significant structures are the Main Street and Dellenbaugh Faults, which aligned along a common structural strike in the western quarter of the map area. Vertical displacement across the Dellenbaugh Fault is estimated to be as much as 122 m (400 ft), and across the Main street Fault, as much as 85 m (280 ft), both down to the west.

Tertiary and Quaternary volcanic rocks and Quaternary surficial deposits are widely distributed in the map area. The volcanic rocks consist of basaltic dikes, flows, and pyroclastic deposits; surficial deposits include terrace gravels, alluvial fans, talus, and landslide deposits. Artificial fill and quarries are also mapped. Map contacts between most surficial deposits are intertonguing or gradational, both laterally and vertically.

The subdivision of Quaternary surficial units on the map is intentionally detailed because these units provide the basic geologic information for the construction of roads, flood control, vegetation management, soil erosion, and planning of resource conservation projects.

All alluvial deposits in the map area are Quaternary age because they contain clasts derived from Quaternary basalts (Billingsley, in press a, b, c). Relative vertical and lateral stratigraphic relations among the surficial deposits are set forth in the description of map units.

PALEOZOIC AND MESOZOIC SEDIMENTARY ROCKS

About 668 m (2,190 ft) of Permian strata and about 600 m (1,970 ft) of Triassic strata are exposed in the map area. The Paleozoic and Mesozoic rocks, in order of decreasing age, are the Hermit, Toroweap, and Kaibab Formations (Lower Permian), and the Moenkopi Formation and Chinle Formations (Lower and Middle Triassic).

About 275 m (900 ft) of red siltstone and sandstone of the Hermit Formation is exposed in Parashant Canyon. Along the base of the Hurricane Cliffs, about 20 m (65 ft) of the upper part of the Hermit Formation is exposed on the upthrown side of the Hurricane Fault. The lower 7 m (23 ft) of the Hermit Formation and the underlying Esplanade Sandstone of Permian age are not exposed in the map area, but crop out about 2 km farther south.

The tan and yellowish-white Coconino Sandstone (Lower Permian) crops out as an intermittent, crossbedded, cliff-forming sandstone in parts of Parashant and Whitmore Canyons. The Coconino Sandstone clearly intertongues with the lower part of the Seligman Member of the Toroweap Formation and is well demonstrated laterally and vertically within the Parashant and Whitmore Canyon areas (Fisher, 1961; Schleh, 1966; and Rawson and Turner, 1976). The Coconino Sandstone forms a cliff as much as 6 m (20 ft) thick but is too thin to show at map scale. The Coconino Sandstone thins to the north and west, but thickens east and southeast of the map area forming a mappable cliff unit. The Toroweap Formation unconformably overlies the Hermit Formation.

Gray siltstone, sandstone, gypsum, and limestone of the Toroweap Formation are well exposed in the lower steep slopes and ledges of the Hurricane Cliffs and in the upper cliffs of Parashant and Whitmore Canyon areas. Thickness of the Toroweap Formation averages about 160 m (520 ft) in the map area (including the Coconino Sandstone); it gradually thins to the north and east of the map area, and thickens slightly to the south and west.

Unconformably overlying the Toroweap Formation is a cliff-forming gray cherty limestone and a slope-forming, pale-red and gray gypsifereous sandstone of the Kaibab Formation. Within the map area, the Kaibab Formation averages about 200 m (650 ft) thick, gradually thinning southward and eastward, and gradually thickening northward and westward. The regional unconformity between the Toroweap and Kaibab Formations is

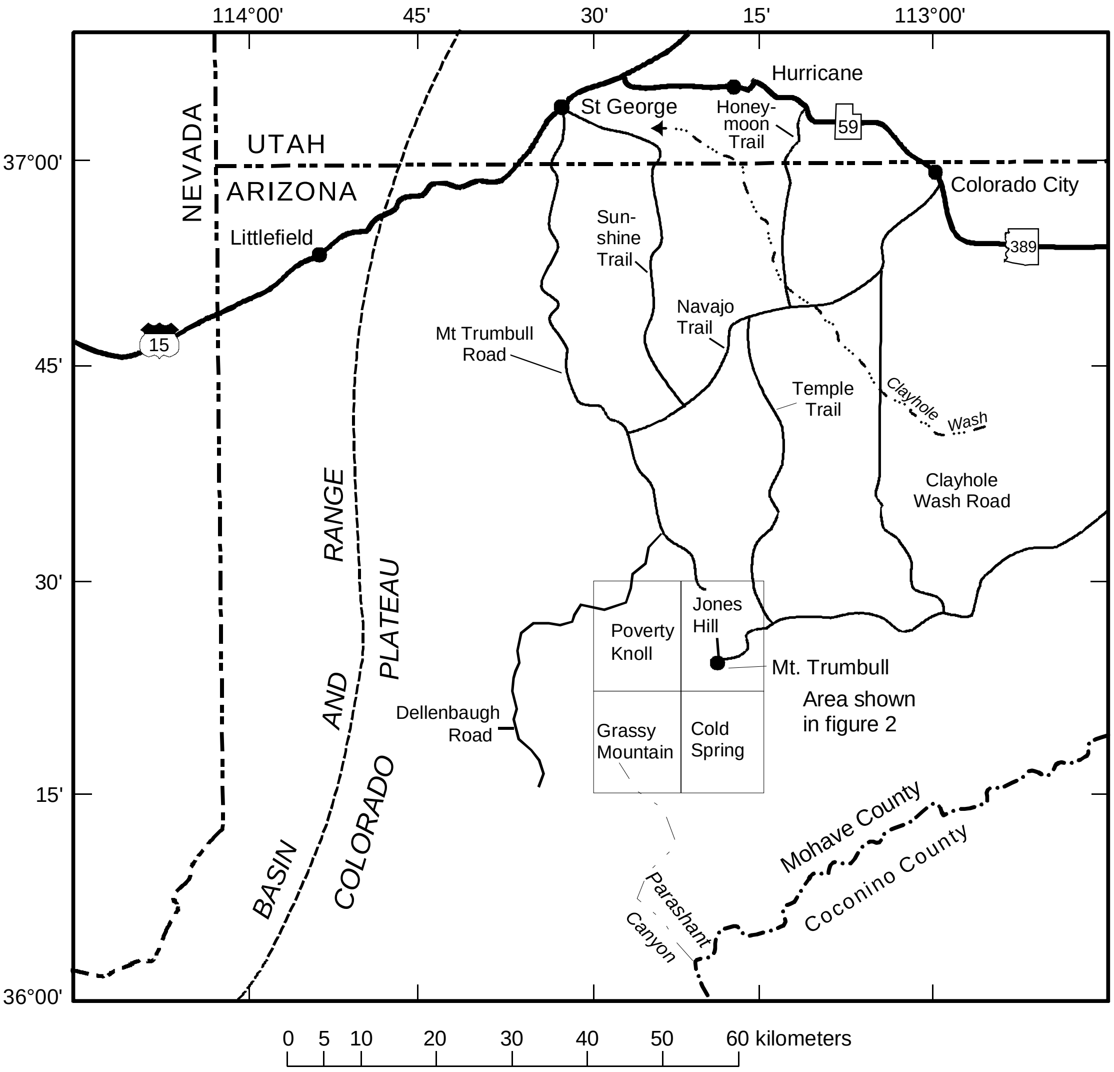

Figure 1. Index map showing 7.5-minute quadrangles mapped in this report in the upper Parashant Canyon and vicinity, northern Mohave County, northwestern Arizona.

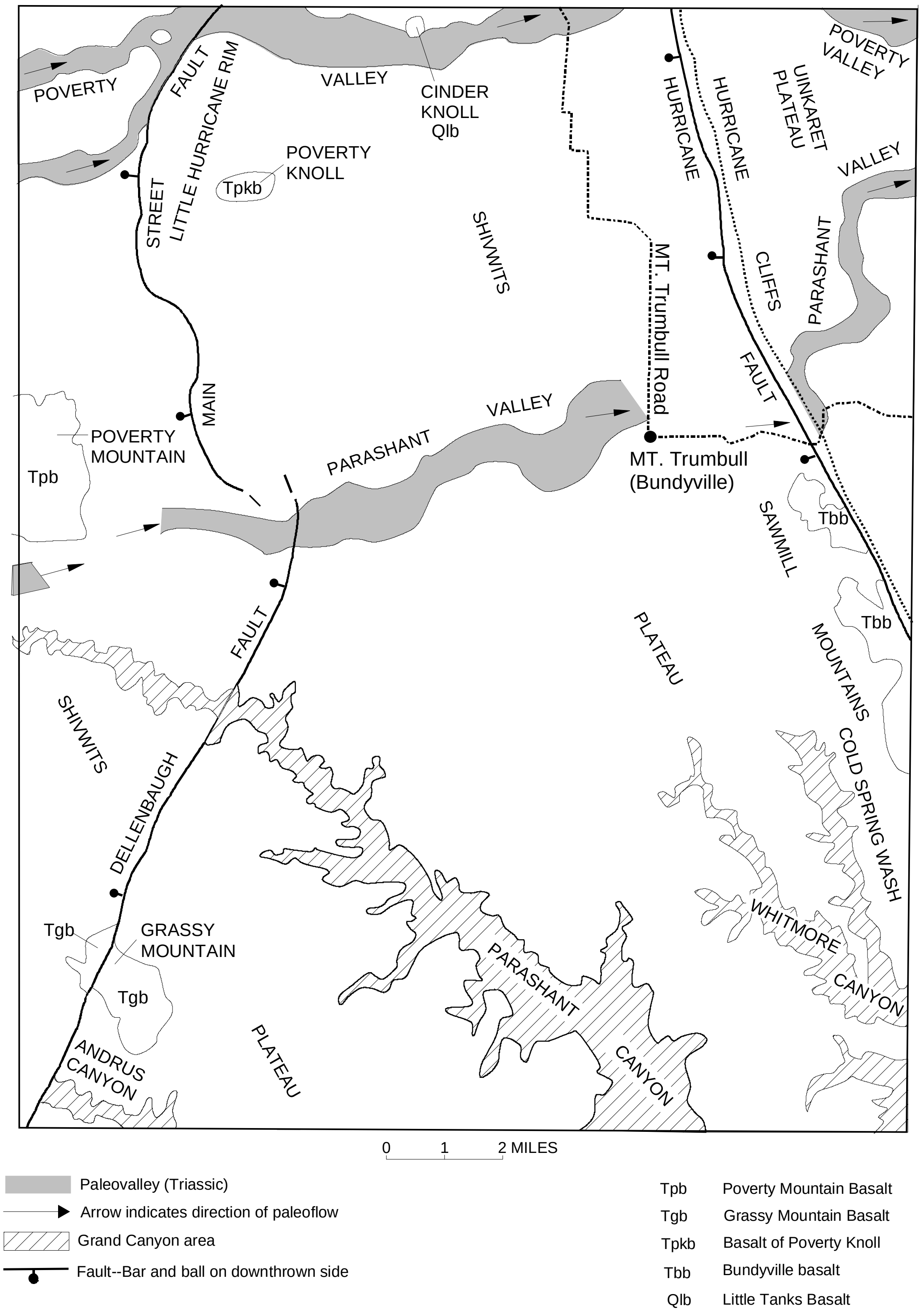

Figure 2. Selected geographic and geologic features of the upper Parashant Canyon and vicinity, northwestern Arizona.

locally very subtle with erosional relief as much as 3 m (10 ft) and is mostly covered by talus. However, at some locations in the western Grand Canyon and within this map area, the Kaibab Formation fills large bowl-shaped depressions, possibly erosion channels, up to as much as 3 km (2 mi) wide and about 45 m (150 ft) deep. Thus, the Kaibab Formation is thicker in the erosional basins and channels where the Woods Ranch Member of the Toroweap Formation is eroded away. Overall, the Kaibab Formation gradually thickens north and west of the map area, and gradually thins south and east. Much of the upper part of the Kaibab Formation (Harrisburg Member) is eroded where not directly overlain by strata of the Moenkopi Formation. The carbonate and gypsifereous strata of the Kaibab Formation forms the bedrock surface of the upper Hurricane Cliffs and the rims of Parashant and Whitmore Canyons, as well as much of the exposed bedrock surface of the map area.

A major regional unconformity separates the Permian and Triassic strata in the Grand Canyon area. After deposition of the Harrisburg Member of the Kaibab Formation, erosion of the Harrisburg was mainly confined to paleoriver valleys and their associated tributaries. Two large paleovalleys were cut into the Harrisburg and Fossil Mountain Members of the Kaibab Formation of the map area during Early Triassic time. The paleovalleys were filled with gray conglomerate and sandstone of the Timpoweap Member of the Moenkopi Formation. Imbrication of pebbles in the conglomerate beds of the Timpoweap Member indicate deposition was from streams that flowed eastward. The conglomerate and sandstone material is locally derived from the Kaibab Formation.

For location and descriptive purposes on this map (fig. 2), the northern Triassic paleovalley is called Poverty valley, named for nearby Poverty Knoll. Poverty valley averages about 1 km (0.5 mi) wide and about 60 m (200 ft) deep. Strata of the Timpoweap Member in Poverty valley are exposed along the Little Hurricane Rim east of the Main Street Fault, in the flatland south of Poverty Knoll, and on the Uinkaret Plateau in the northeast corner of map area (fig. 2). Poverty valley can be traced west and northwest of this map area for about 13 km (8 mi; Billingsley, 1994). East of Poverty Knoll and towards the Hurricane Cliffs, Poverty valley is mostly covered by surficial deposits and younger Moenkopi Formation strata. Poverty valley joins another paleovalley called Sullivan valley in the vicinity of the Hurricane Cliffs (Billingsley, in press a, c). Sullivan valley becomes progressively wider and shallower east of the Hurricane Cliffs and is largely covered by Quaternary basalt flows.

A second large paleovalley, herein called Parashant valley (fig. 2), is exposed between Poverty Mountain and the settlement of Mt. Trumbull (Bundyville). The paleovalley is buried by younger strata of the Moenkopi Formation at Poverty Mountain, but is partly eroded by modern tributary erosion in the upper reaches of Parashant Canyon on the southwest side of Poverty Mountain. Parashant valley is partly covered by Cenozoic surficial deposits between Poverty Mountain and the settlement of Mt. Trumbull, becoming mostly covered by alluvium and younger strata of the Moenkopi Formation near the base of the Hurricane Cliffs. At the top of the Hurricane Cliffs, along the Mt. Trumbull road, Parashant valley can be traced northward across the Uinkaret Plateau to where it joins Poverty and Sullivan valleys near Moriah Knoll north of the map area (Billingsley, in press a, c). Parashant valley has not been mapped west of the map area, and its westward extent is unknown. Parashant valley averages about 1 km (0.5 mi) wide and about 60 m (200 ft) deep.

Gray conglomerate and sandstone, light-brown to red siltstone and sandstone, gray gypsum, and gray limestone of the Triassic Moenkopi Formation unconformably overlie the Permian Kaibab Formation. About 475 m (1,560 ft) of the Moenkopi Formation is partly exposed beneath Tertiary basalt flows in the Sawmill Mountains at the east edge of the map area (fig. 2) and forms the down-faulted area adjacent to the Hurricane Cliffs. Strata of the Moenkopi Formation are also partly exposed beneath Tertiary basalt flows at Grassy Mountain, Poverty Mountain, and Poverty Knoll. The Moenkopi Formation, as a whole, gradually thins east and south, but thickens north and northeast of the map area. About 120 m (400 ft) of the Chinle Formation is exposed in the downthrown block of the Hurricane Fault beneath the Tertiary basalt flows in the Sawmill Mountains. The Chinle Formation unconformably overlies the Moenkopi Formation. The basal Shinarump Member of the Chinle Formation intertongues with the soft purple shale and siltstone of the Petrified Forest Member of the Chinle Formation and rests unconformably on red sandstone and siltstone of the upper red member of the Moenkopi Formation. Locally, white coarse-grained sandstone, which may be equivalent to the Shinarump Member of the Chinle Formation, unconformably overlies the red sandstone of the Moenkopi Formation. Erosion has removed an unknown thickness of the upper Chinle Formation and other strata above the Chinle before deposition of Tertiary basalts.

VOLCANIC ROCKS

Most of the volcanic rocks in this map area are Tertiary basalts that form a protective caprock over the soft strata of the Moenkopi Formation at Grassy Mountain, Poverty Mountain, and Poverty Knoll. Tertiary basalts also overlie soft strata of the Chinle Formation in the Sawmill Mountains along the downthrown block of the Hurricane Cliffs (fig. 2), and at Mount Logan 3 km (2 mi) east of this map area. The soft Moenkopi and Chinle Formation strata are easily eroded around the edges of the resistant basalt flows, and seepage of water through the basalt forms minor springs in landslide blocks of basalt.

A small outcrop of Quaternary basalt at Cinder Knoll at the north-central edge of the map area overlies lower strata of the Moenkopi Formation and strata of the Harrisburg Member of the Kaibab Formation (fig. 2). The basalt flow and pyroclastic deposits at Cinder Knoll are part of the Little Tanks Basalt as described north of this map area by Billingsley (1993a).

There are four whole-rock conventional K-Ar ages obtained from basalts in or near this map area: (1) 1.0±0.1 Ma for the Little Tanks Basalt just north of this map (Billingsley, 1993a), (2) 2.63±0.34 Ma for a basalt flow on Mount Logan just east of this map area (Reynolds and others, 1986), (3) 3.6±0.18 Ma, for the Bundyville basalt (this map, just east of Mt. Trumbull, fig 2; Reynolds and others, 1986), and (4) 4.75±0.26 Ma, for the Shivwits basalt (Best and others, 1980), introduced here as the Poverty Mountain Basalt. The Poverty Mountain sample was taken at the west end of Poverty Mountain, just west of this map area.

Most of the basalt flows erupted from intrusive dikes or vent areas that were partly buried by subsequent flows, pyroclastic deposits, or landslide masses. Several of the basaltic flows and associated volcanic rocks are relatively isolated from one another and are mapped and described as separate units. Each volcanic area is a unique contribution to the geomorphic development of that part of the landscape of the Arizona Strip. The basaltic rocks are briefly described below:

Shivwits basalt

The Shivwits basalt, informally named by Best and others (1980) and Reynolds and others (1986), includes a widespread mass of basaltic flows and associated pyroclastic vents on the Shivwits Plateau, mainly south of this map area. The Shivwits basalt included several volcanic mountains on the Shivwits Plateau such as Mount Dellenbaugh, Blue Mountain, Yellow John Mountain, Grassy Mountain, and Poverty Mountain (Best and others, 1980; Lucchitta and McKee, 1974). Poverty and Grassy Mountains, within the map area, are volcanic areas that are separate and isolated from the main Shivwits volcanic area centered on Mount Dellenbaugh south of this map area. The basalt flows that cap Grassy Mountain and Poverty Mountain were included in the Shivwits basalt nomenclature by Reynolds and others (1986) probably because of their regional proximity to the Mount Dellenbaugh and Yellow John Mountain basaltic masses. Because of this separation, however, the volcanic rocks at Poverty and Grassy Mountains are herein mapped separately from the Shivwits basalt.

The whole-rock K-Ar ages reported from the Shivwits basalt south of this map area are 6.20±0.30 Ma and 7.64±0.30 Ma near Mount Dellenbaugh (Lucchitta and McKee, 1974); 6.78±0.15 Ma at Mount Dellenbaugh, informally named the Dellenbaugh basalt by Reynolds and others (1986); 7.06±0.49 Ma at Mount Dellenbaugh, informally named the Mount Dellenbaugh basalt by Best and others (1980); and 8.2±0.1 Ma at Price Point (southeast of Mount Dellenbaugh), informally named the Price Point basalt by Wenrich and others (1995). The samples were not adequately located and presumably were collected from the upper flows of the general area around Mount Dellenbaugh. It is not clear that the age range represents the length of volcanism or episodes of volcanic activity between 6 to 8 m.y. because of the margin of error in the K-Ar ages. More data is required from these volcanic rocks to better establish a chronological order of volcanic events for this region.

Poverty Mountain Basalt

The basaltic rocks at Poverty Mountain form a topographic highland and mappable unit that is separate from other basaltic rocks on the Shivwits Plateau. The basalt flows and associated pyroclastic deposits of Poverty Mountain (west-central edge of map area) are herein formally named the Poverty Mountain Basalt for Poverty Mountain, the type area, northern Mohave County, Arizona (secs. 29 and 32, T. 35 N., R. 11 W.). The Poverty Mountain Basalt is comprised of one or more alkali-olivine basalt flows and associated pyroclastic deposits that came from local dikes and vent areas. Only the eastern part of the Poverty Mountain Basalt is within this map area. Most of the Poverty Mountain Basalt extends west of this map area for about 8 km (5 mi) to the Hidden Canyon drainage (USGS 7.5' Poverty Spring quadrangle, Arizona). A whole-rock sample of the Poverty Mountain Basalt collected by Best and others (1980) at the west end of Poverty Mountain (sec. 22, T. 35 N., R. 12 W.) yielded a K-Ar age of 4.75±0.26 Ma.

Poverty Mountain is a conspicuous, flat-topped mountain that forms a regional landmark for this part of the

Shivwits Plateau. The mountain is mainly comprised of Triassic strata of the Moenkopi Formation having a regional dip of about 2° east. The Moenkopi Formation was beveled by Tertiary erosion that drained west, opposite to the regional dip. The Poverty Mountain Basalt erupted onto this beveled erosion surface and flowed west towards an ancestral Hidden Canyon drainage that flowed northwest. Erosion on the west side of Poverty Mountain had already removed much of the Moenkopi strata and part of the upper strata of the Harrisburg Member of the Kaibab Formation prior to deposition of the Poverty Mountain Basalt. The Hidden Canyon drainage has eroded 100 m (330 ft) deeper into the Kaibab strata since deposition of the Poverty Mountain Basalt. Sometime after the 4.7 Ma Poverty Mountain Basalt flows, headward erosion of Parashant Canyon drainage captured the Hidden Canyon drainage about 4 km (2.5 mi) south of Poverty Mountain (just west of this map area). The headward erosion of Parashant Canyon and its tributaries have removed much of the soft strata of the Moenkopi Formation from the south and east side of Poverty Mountain, steepening the slopes and enhancing the development of large landslide masses. Headward erosion by landslide sapping is slowly eroding into the basalt cap of Poverty Mountain and will eventually demolish Poverty Mountain.

Grassy Mountain Basalt

Grassy Mountain is about 10 km (6 mi) south of Poverty Mountain, and like Poverty Mountain, is comprised of east-dipping Triassic strata overlain by Tertiary basalt flows. The gently east-dipping strata at Grassy Mountain were beveled by Tertiary erosion to an almost flat, but slightly west-dipping surface similar to that of Poverty Mountain (fig. 3A). The basalt flows and associated pyroclastic deposits of Grassy Mountain (southwest corner of map area) are herein formally named the Grassy Mountain Basalt for Grassy Mountain, the type area, northern Mohave County, Arizona (secs. 3, 4, and 10, T. 33 N., R. 11 W.).

The Grassy Mountain Basalt was extruded from fissure vents onto the Tertiary surface and generally flowed out in a radial pattern with a westerly component. Pyroclastic deposits accumulated on the basalt flows near fissure dikes and vent areas, and some of these deposits were partly buried by more basalt flows. Today the aerial extent of basalt flows on Grassy Mountain covers about 3 square kilometers (1.5 sq mi).

The Grassy Mountain Basalt is similar to that of Poverty Mountain because they (1) are alkali-olivine basalts, (2) occupy similar stratigraphic levels, (3) overlie a west-sloping beveled erosion surface cut into the east-dipping Moenkopi Formation, and (4) flowed in a radial pattern and slightly westward and northwestward. Grassy and Poverty Mountains are only about 10 km (6 mi) apart. There are no K-Ar age determinations for the Grassy Mountain Basalt, but for the reasons stated above, it is assumed that they are of a similar age to those of Poverty Mountain, about 4.7 Ma.

Basalt of Poverty Knoll

The basaltic rocks at Poverty Knoll are informally named basalt of Poverty Knoll for Poverty Knoll, a 245 m (800 ft) high isolated mesa or knoll about 6.5 km (4 mi) northeast of Poverty Mountain (northwest quarter of map area). The basalt consists of a single intrusive dike and basalt flow that formed a caprock over soft Triassic strata similar to that of Poverty and Grassy Mountains. The basalt overlies slightly east-dipping strata of the Shnabkaib Member of the Moenkopi Formation. The basalt flow at Poverty Knoll flowed in a radial pattern, with an overall flow direction towards the east about 1 km (0.5 mi). The aerial extent of the basalt is about one quarter of a section (sec 2, T. 36 N., R. 11 W.).

There are no K-Ar age determinations for the basalt at Poverty Knoll. The basalt is similar in composition to other Tertiary alkali-olivine basalts of this region and overlies strata of the Moenkopi Formation. Poverty Knoll lies between Poverty Mountain (southwest of Poverty Knoll) and Diamond Butte, a landmark butte about 11 km (7mi) northeast of Poverty Knoll (northeast of this map area). The K-Ar age of the Diamond Butte Basalt is 4.3±0.6 Ma (Billingsley, 1993a, in press a) and overlies upper strata of the Moenkopi Formation similar to that of Poverty Mountain and Poverty Knoll. Therefore, the basalt of Poverty Knoll is probably about 4.3 to 4.7 Ma in age because of similar geologic setting, petrologic characteristics, and proximity to the basalts at Poverty Mountain and Diamond Butte. Landslide debris surrounds Poverty Knoll as they do at Poverty Mountain, Grassy Mountain, and Diamond Butte.

Bundyville basalt

Hamblin (1970) first described the basaltic rocks east of the town of Mt. Trumbull (Bundyville) and informally referred to them as the Bundyville basalt. There the basalt is on a downthrown block along the west side of the Hurricane Fault (fig. 2). The basalt was sampled for a whole rock K-Ar age determination in 1968 by Paul Damon, University of Arizona, and yielded an age of 3.6±0.18 Ma (Reynolds and others, 1986). The name Bundyville basalt was also used informally by Reynolds and others (1986) and is informally used in this report.

At this location, thick basalt flows overlie soft strata of the Moenkopi and Chinle Formations, although the Chinle was not recognized in early reports. As with other Tertiary basalts of this region, the hard basalt flows have preserved the underlying soft Triassic strata of the Chinle and Moenkopi Formations from extensive erosion (fig. 3B). The Bundyville basalt unconformably overlies about 122 m (400 ft) of the Petrified Forest Member of the Chinle Formation.

The Bundyville basalt overlies gently east-dipping strata of the Chinle Formation reflecting a possible Hurricane Monocline structure and reverse fault drag on the west side of the Hurricane Fault (fig. 3B). The Chinle Formation was eroded to a nearly flat surface before the eruptions of the Bundyville basalt. Basalts having the same general characteristics as the Bundyville basalt occur just east of this map area. Those at Mount Logan overlie flat-lying strata of the Chinle Formation, and those at Mount Trumbull overly nearly flat-lying to slightly east-dipping strata of the Chinle and Moenkopi Formations. The Mount Logan basalt yielded a whole-rock K-Ar age of 2.63±0.34 Ma (Reynolds and others, 1986), and the Mount Trumbull basalt, an age of 3.67±0.09 Ma (Best and others, 1980). About 10 km (6 mi) south of Mt. Logan and southeast of this map, is another outcrop of similar age basalt just north of Mount Emma (Stage I of Hamblin, 1970). The basalt flows at Mount Logan might be younger than those of the Bundyville basalt as suggested by the K-Ar age determinations. However, the Mount Logan basalt overlies the same 122 m (400 ft) of Chinle Formation east of the Hurricane Fault (fig. 3B) as does the Bundyville basalt on the west side of the Hurricane Fault. Therefore, it is likely that the Bundyville and Mount Logan basalts are one and the same. Both basalts flow away from the Hurricane Fault area, suggesting a common high point near Death Valley Lake.

Sometime after extrusion of the Bundyville basalt, erosional undercutting and oversteepening of the Moenkopi and Chinle Formations initiated the development of landslide masses. When the Hurricane Fault became active sometime after deposition of the Bundyville basalt, earthquake shaking probably contributed to the development of several landslide masses. The earthquake shaking was probably responsible for severely disrupting and distorting the Bundyville basalt flows because the flow surfaces are lumpy and hummocky. In wet conditions, the landslide masses may become unstable allowing the landslide blocks to resume downslope movement. As the landslide masses slowly descend, they disintegrate and form thick blocky talus deposits. The basaltic debris at the bottom of landslide and talus deposits is gradually eroded into local alluvial-fan deposits.

Little Tanks Basalt

Just north of this map area is a 60-m-high pyroclastic cone and associated basalt flow of the Little Tanks Basalt (Billingsley, 1993a; in press a). Cinder Knoll in the northern part of the map area is the southern extension of the Little Tanks Basalt. The hill was formed by a basalt lava flow that was later partly covered by pyroclastic deposits and subsequently overlain by another basalt flow (sec. 29, T. 36 N., R. 10 W.; this map). A whole-rock K-Ar age of the Little Tanks Basalt yielded a 1.0±0.4 Ma age (Billingsley, 1993a). The Little Tanks Basalt overlies the Timpoweap Member, lower red member, and Virgin Limestone Member of the Moenkopi Formation.

STRUCTURAL GEOLOGY

High-angle to nearly vertical normal faults and gently tilted strata characterize the Shivwits and Uinkaret Plateaus. The east-dipping Hurricane, Main Street, and Dellenbaugh Monoclines, and lesser east-dipping monoclines, overlie deep-seated west-dipping reverse faults that folded the strata up-to-the-west during Late Cretaceous and early Tertiary time (Huntoon, 1990). Pliocene and Pleistocene extension reactivated the deep-seated faults producing down-to-the-west normal faults along monoclines and reversed the Cretaceous and Tertiary offsets.

The Hurricane Fault, whose fault scarp forms the Hurricane Cliffs, separates the lower Shivwits Plateau

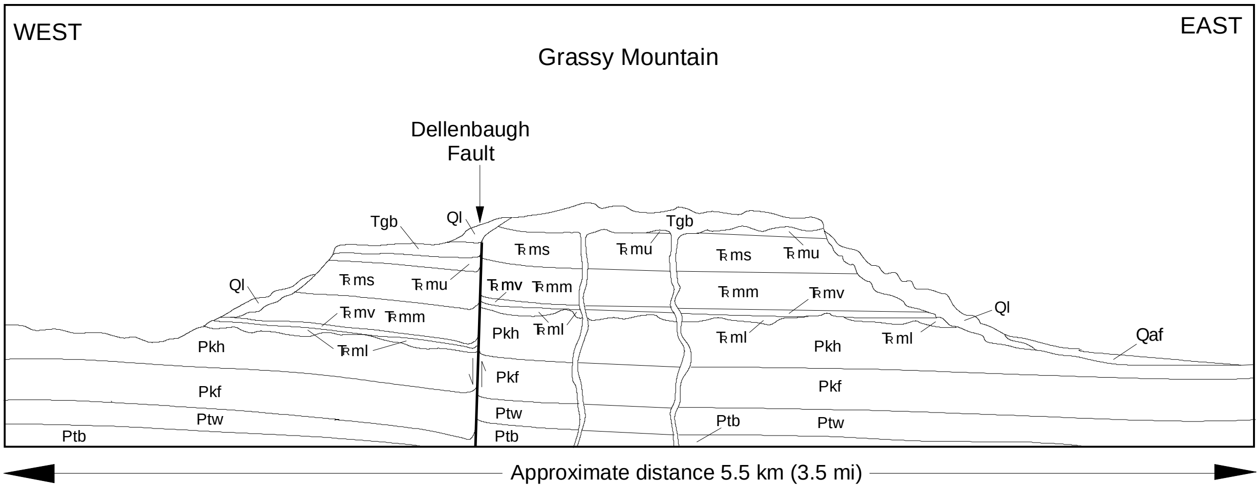

Figure 3A. Schematic east-west cross section through Grassy Mountain, northern Mohave County, Arizona. Thickness of units and vertical scale are approximate. Qaf=alluvial fan; Ql=landslide deposits; Tgb=basalt flows of Grassy Mountain Basalt; Moenkopi Formation, TRmu=upper red member, TRs=Shnabkaib Member, TRmm=middle red member, TRmv=Virgin Limestone Member, TRml=lower red member; Kaibab Formation, Pkh=Harrisburg Member, Pkf=Fossil Mountain Member; Toroweap Formation, Ptw=Woods Ranch Member, Ptb=Brady Canyon Member.

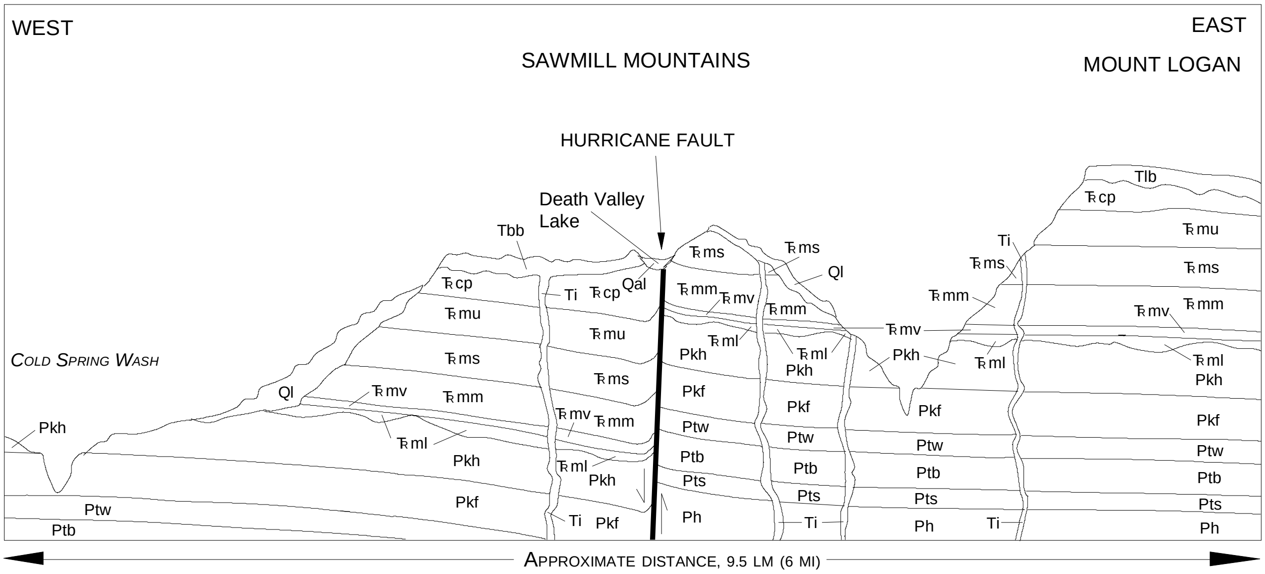

Figure 3B. Schematic northeast-southwest cross section from Cold Spring Wash to Mount Logan (east of study area), northern Mohave County, Arizona. Thickness of units and vertical scale are approximate. Qal=alluvium; Ql=landslide deposits; Tbb=Bundyville basalt; Tlb=Mount Logan basalt; Ti=intrusive dike; Chinle Formation, TRcp=Petrified Forest Member; Moenkopi Formation, TRmu=upper red member, TRms=Shnabkaib Member, TRmm=middle red member, TRmv=Virgin Limestone Member, TRml=lower red member; Kaibab Formation, Pkh=Harrisburg Member, Pkf=Fossil Mountain Member; Toroweap Formation, Ptw=Woods Ranch Member, Ptb=Brady Canyon Member, Pts=Seligman Member; Ph=Hermit Formation.

from the higher Uinkaret Plateau (fig. 2 and 3B). Maximum displacement along the Hurricane Fault is about 610 m (2,000 ft) near the east edge of map. Equal offset of the 3.6 Ma Bundyville basalt and underlying Mesozoic strata in this part of the Colorado Plateau indicate that extension along the Hurricane Fault began after extrusion of the Bundyville basalt. Even though the Hurricane Fault can be accurately traced on aerial photographs, extensive landslide and talus debris on both sides of the fault almost completely obscure the Moenkopi and Chinle Formations in the field and on aerial photographs.

A few kilometers southeast of this map area, the Hurricane Fault splits into at least two, and possibly three, major fault segments that gradually decrease overall displacement of strata to about 550 m (1,800 ft) in upper Whitmore Canyon. In the southeastern third of the map area, a zone of northwest-trending faults and grabens parallel the strike of the Hurricane Fault. These parallel faults and folds are also coincident with the nearly vertical joints in the bedrock of the Parashant and Whitmore Canyon areas.

Regionally, the bedrock strata have an eastward dip averaging about 1°, which increases to an average of about 5° east along the Hurricane Monocline and locally reaches as much as 12 °. The axis of the Hurricane Monocline is a few hundred meters west of and approximately parallel to the Hurricane Fault according to Huntoon and others (1981) and Wenrich and others (1986). Strata within a few hundred meters of the downthrown side of the Hurricane Fault dip west owing to normal fault drag. It is not certain that the Hurricane Monocline exists within this map area because almost all of the folding of strata is on the downthrown side of the Hurricane Fault, which can be explained by reverse fault drag as suggested by Hamblin (1965).

The Main Street Fault and Monocline, in the western third of the map area, are structurally similar to the Hurricane Fault and Monocline. However, the probable monoclinal axis associated with the Main Street Fault is plotted on the east side of the Main Street Fault because most of the dipping strata are on that side. The easterly dip along the Main Street Monocline averages about 8° east with a maximum dip of as much as 15°.

The Hurricane and Main Street structures have a similar structural history, but the Main Street is lesser in magnitude. About 38 km north of this map area, the Main Street Fault equally offsets the 2.4 Ma Segmiller Mountain Basalt and the underlying Triassic and Permian strata (Billingsley, 1993b). Thus, north of the map area, the Main Street Fault is younger than 2.4 Ma, but there is no evidence of Holocene displacement in alluvial deposits along the Main Street Fault in the map area.

Although not directly connected, the Main Street and Dellenbaugh Faults are closely related, and probably represent a single structure that is not continuous at the present level of erosion. Both faults have the same structural strike. The name Dellenbaugh Fault is retained on this map to where it ends en echelon with the Main Street Fault east of Poverty Mountain (secs. 35 and 36, T. 35 N., R. 11 W.). A weak monocline is associated with the Dellenbaugh Fault but is not shown on the map and appears to die out just south of the map area.

The Dellenbaugh Fault offsets the Grassy Mountain Basalt about 85 m (280 ft) down-to-the-west. The fault scarp in the basalt is poorly defined because of talus and landslide debris that cover the scarp (fig. 3A). The landslide masses that cover the fault and surround Grassy Mountain are probably the results of shaking and liquefaction of the softer strata beneath the basalt during earthquakes along the Dellenbaugh Fault. The landslide masses are in soft gypsifereous siltstone and sandstone and may become unstable in wet conditions.

Low amplitude short, doubly plunging anticlines and synclines in the map area have a general northwest or northeast trend. These folds, like others elsewhere on the Colorado Plateaus, are probably related to early Laramide compression (Huntoon, 1990).

Warped and bent strata too localized to show at map scale are the result of Pleistocene and Holocene solution of gypsum in the Harrisburg Member of the Kaibab Formation. These warped and bent strata are commonly associated with solution of gypsum along drainages or joints, especially in the northwest quarter of the map where strata of the Kaibab Formation are heavily disrupted.

Gypsum dissolution in the Harrisburg Member of the Kaibab Formation has also produced small sinkholes and caves on the Shivwits and Uinkaret Plateaus. The sinkholes are most common in the north-central part of the map area on the Shivwits Plateau. This karsting is Holocene and Pleistocene in age on the basis of local drainage disruption, and some sinkholes with steep walls indicate recent collapse. Hundreds of unmapped sinkhole depressions are breached by drainages on the plateau surfaces. Locations of sinkholes that form enclosed basins or depressions are indicated on the map by a triangle symbol.

Landslides

Landslide masses are most common around Tertiary basalt flows where they cover strata of the Chinle and Moenkopi Formations. A few landslide blocks and rockfall masses from Paleozoic units also occur along the rims of tributary canyons to Grand Canyon. These masses fail because of dissolution of gypsum within the Woods Ranch Member of the Toroweap Formation and local surface erosion that undercut limestone cliffs of the Fossil Mountain Member of the Kaibab Formation.

The landslide masses around the Tertiary volcanic rocks provide an important resource for this region, water in the form of springs. Springs are usually found either at the base of basalt flows, or at the base of landslide masses, or within landslide areas where local drainages have eroded headward into the landslide/strata boundary. The contact between landslide masses and the underlying Triassic strata form local impermeable zones because of the claystone, siltstone, and gypsum in the Chinle and Moenkopi Formations. This impermeable zone is a steep undulating surface caused by the erosion of landslide masses. Precipitation falling on the basalt flows and landslide surfaces seeps down and encounters the basalt/strata boundary, or the landslide/Triassic strata boundary, and forms springs. The area of recharge determines how large and how long a spring will last during the year. The smaller the recharge area, the smaller the spring, and in dry years many small springs dry up. Larger springs dry up within a few years during long periods of little or no rainfall.

Breccia pipe structures

Circular collapse structures, minor folds, and other surface irregularities are due to dissolution of gypsum and gypsifereous siltstone not only in the Kaibab, but also in the Toroweap and Moenkopi Formations. Some bowl-shaped depressions in the Kaibab Formation, characterized by inward-dipping strata, may be the surface expression of breccia pipes originating from dissolution of the deeply buried Mississippian Redwall Limestone (Wenrich and Huntoon, 1989; Wenrich and Sutphin, 1989). Such features are characterized by inward dipping strata and are marked on the map by a dot and the letter C.

Some deep-seated breccia pipes are overlain by gypsum collapse features related to thinning by dissolution of gypsum within the Woods Ranch Member of the Toroweap Formation (Wenrich and others, 1986). However, breccia pipes cannot be distinguished with certainty on the plateau surface from shallow collapse structures caused by the dissolution of gypsum. The deep-seated breccia pipes are potential hosts for economic deposits of copper and uranium oxide minerals, whereas the shallow structures are unlikely to be mineralized (Wenrich, 1985). Two breccia pipes are well exposed in the western wall of Parashant Canyon, and provide an excellent cross-sectional view of these structures (southeast quarter of the map area; secs. 11 and 14, T. 33 N., R. 10 W.).

Several uranium claims are associated with breccia pipes throughout the map area, particularly in and near Parashant Canyon. A breccia pipe in the southwest wall of Parashant Canyon (east half of section 11, T. 33 N., R. 10 W.) was prospected for copper in the late 1890's or early 1900's and abandoned because only trace amounts of the copper minerals malachite and azurite are present. However, during the 1970's and 80's, uranium became a commodity of interest and breccia pipes are known to have hosted uranium deposits elsewhere on the Colorado Plateau (Wenrich, 1985). All breccia pipes in the Parashant Canyon area, including the surrounding plateaus, were staked with hundreds of uranium claims that literally covered the territory. Several of the breccia pipes were drilled and found to contain variable amounts of uranium minerals, but none contained enough to warrant the costs of mine development. The uranium claims have remained untouched for the last 10 years or so and their potential as future uranium mines is uncertain. The cost of mine development and the price of uranium are key economic factors for mining these deposits.

There is one prospect in the map area that is not associated with a breccia pipe. A claim for copper was located on a small ridge near the center of section 13, T. 34 N., R. 10 W. (southeast corner of the map area) by Elmer Bundy, a local rancher who lived at Mt. Trumbull. Mr. Bundy discovered and named the claim "Copper Nat" in 1957 as noted on a claim notice in a rusty tin can within a rock cairn at the prospect. One small shaft and one small tunnel on the property are dug less than 3 m (10 ft) into the sandy limestone strata of the Harrisburg Member of the Kaibab Formation. The author inspected the abandoned prospect and found no copper minerals in the area, although a green mineral known as celadonite, an iron/magnesium mineral, which resembles in appearance the green copper mineral malachite, is present. Thinking the celadonite was a copper mineral was probably the reason Mr. Bundy worked the claims, then soon abandoned the claim when the truth became known.

ACKNOWLEDGMENTS

I appreciate the advice, revisions, and information of the following U.S. Geological Survey individuals: Fred Miller, L. Sue Beard, Susan Priest, Charles L Powell, Debra Block, Darlene Casebier, Jane S. Ciener, and Jan Zigler. Their scientific assistance in the preparation of the map and text are invaluable.

REFERENCES CITED

Best, M.G., McKee, E.H., and Damon, P.E., 1980, Space-time composition patterns of late Cenozoic mafic volcanism, southwestern Utah and adjoining areas: American Journal of Science, v. 280, p. 1035-1050.

Billingsley, 1993a, Geologic map of the Little Tanks quadrangle, northern Mohave County, Arizona: U.S. Geological Survey Open-File Report 93-682, scale 1:24,000, includes pamphlet, 17 p.

___1993b, Geologic map of Wolf Hole Mountain and vicinity, Mohave County, northwestern Arizona: U.S. Geological Survey Miscellaneous Investigations Series Map I-2296, scale 1:31,680, includes text and cross sections.

___ 1994, Geologic map of Sullivan Draw and vicinity, Mohave County, northwestern Arizona: U.S. Geological Survey Miscellaneous Investigation Series Map I-2396, scale 1:31,680, includes text and cross sections.

___ 1997, Geologic map of the Mount Logan quadrangle, northern Mohave County, Arizona: U.S. Geological Survey Open-File Report OF-97-426, scale 1:24,000, includes pamphlet, 19 p.

___ in press a, Geologic map of the upper Hurricane Wash and vicinity, northwestern Arizona: U.S. Geological Survey Miscellaneous Investigations Map Series I-2539, scale 1:31,680.

___ in press b, Geologic map of the lower Hurricane Wash and vicinity, northwestern Arizona: U.S. Geological Survey Miscellaneous Investigations Map Series I-2481, scale 1:31,680.

___ Unpub. data, Geologic map of Clayhole Wash and vicinity, northwestern Arizona: U.S. Geological Survey Miscellaneous Field Studies Map MF-, scale 1:31,680.

Billingsley, G.H., and Huntoon, P.W., 1983, Geologic map of the Vulcan's Throne and vicinity, western Grand Canyon, Arizona: Grand Canyon, Arizona, Grand Canyon Natural History Association, scale 1:48,000.

Fisher, W., 1961, Upper Paleozoic and lower Mesozoic stratigraphy of Parashant and Andrus Canyons, Mohave County, northwestern Arizona: Unpublished Ph.D. thesis, University of Kansas, Lawrence, Kansas, 345 p.

Fitton, J.G., 1989, Petrology and geochemistry of Late Cenozoic basalt flows, western Grand Canyon, Arizona, *in* Elston, D.P., Billingsley, G.H., and Young, R.A., eds., Geology of Grand Canyon, northern Arizona (with Colorado River guides): 28th International Geological Congress, Field Trip Guidebook T115/T315, Washington D.C., American Geophysical Union, p. 186-189.

Hamblin, W.K., 1965, Origin of “reverse drag” on the downthrown side of normal faults: Geological Society of America Bulletin, v. 76, p. 1145-1163.

Hamblin, W.K., 1970, Late Cenozoic basalt flows of the western Grand Canyon, *in* Hamblin, W.K., and Best, M.G., eds., The western Grand Canyon district: Utah Geological and Mineralogical Survey, Guidebook to the geology of Utah, no. 23, p. 21-37.

Hamblin, W.K., and Best, M.G., 1970, The western Grand Canyon district: Utah Geological and Mineralogical Survey, Guidebook to the Geology of Utah, no. 23, 156 p.

Huntoon, P.W., 1990, Phanerozoic structural geology of the Grand Canyon, *in* Beus, Stanley S., and Morales, Michael, eds., Grand Canyon geology: New York Oxford, Oxford University Press, p. 261-310.

Huntoon, P.W., Billingsley, G.H., and Clark, M.D., 1981, Geologic map of the Hurricane Fault zone and vicinity, western Grand Canyon, Arizona: Grand Canyon, Arizona, Grand Canyon Natural History Association, Grand Canyon, Arizona, scale 1:48,000.

___1982, Geologic map of the Lower Granite Gorge and vicinity, western Grand Canyon, Arizona: Grand Canyon, Arizona, Grand Canyon Natural History Association, scale 1:48,000.

Lucchitta, Ivo, 1975, The Shivwits Plateau, *in* Application of ERTS images and image processing to regional geological problems and geological mapping in northern Arizona: California Institute of Technology, Jet Propulsion Laboratory, Technical Report 32-1597, p. 41-73.

___1979, Late Cenozoic uplift of the southwestern Colorado Plateau and adjacent lower Colorado River region: Tectonophysics, v. 61, p. 63-95.

Lucchitta, Ivo, and McKee, E.H., 1974, New geochronologic constraints on the history of the Colorado River and its Grand Canyon: Geological Society of America Abstracts with Programs, v. 7, p. 342.

Rawson, R.R., and Turner, C.E., 1974, The Toroweap Formation; A new look, *in* Karlstrom, T.N.V., Swann, G.A., and Eastwood, R.L., eds., Geology of Northern Arizona with notes on archaeology and paleoclimate: Part 1, Regional Studies, Geological Society of America Rocky Mountain Section Meeting, Flagstaff, Arizona, p. 155-191.

Reynolds, S.J., 1988, Geologic map of Arizona: Tucson, Arizona, Arizona Geological Survey, Map 26, scale 1:1,000,000.

Reynolds, S.J., Florence, F.P., Welty, J.W., Roddy, M.S., Currier, D.A., Anderson, A.V., and Keith, S.B., 1986, Compilation of radiometric age determinations in Arizona: Arizona Bureau of Geology and Mineral Technology, Geological Survey Branch, Bulletin 197, 258 p.

Schleh, E., 1966, Stratigraphic section of Toroweap and Kaibab Formations in Parashant Canyon, Arizona: Arizona Geological Society Digest, v. 8, p. 57-64.

Sorauf, J.E., and Billingsley, G.H., 1991, Members of the Toroweap and Kaibab Formations, Lower Permian, northern Arizona and southwestern Utah: Rocky Mountain Geologist, v. 28, no. 1, p. 9-24.

Stewart, J.H., Poole, F.G., and Wilson, R.F., 1972, Stratigraphy and origin of the Triassic Moenkopi Formation and related strata in the Colorado Plateau region: U.S. Geological Survey Professional Paper 691, 195 p.

Wenrich, K.J., 1985, Mineralization of breccia pipes in northern Arizona: Economic Geology, v. 80, no. 6, p. 1722-1735.

Wenrich, K.J., Billingsley, G.H., and Huntoon, P.W., 1986, Breccia-pipe and geologic map of the northeastern Hualapai Indian Reservation and vicinity, Arizona: U.S. Geological Survey Miscellaneous Investigation Series Map I-2440, scale 1:48,000, includes pamphlet, 60 p.

Wenrich, K.J., and Huntoon, P.W., 1989, Breccia pipes and associated mineralization in the Grand Canyon region, northern Arizona, *in* Elston, D.P., Billingsley, G.H., and Young, R.A., eds., Geology of Grand Canyon, Northern Arizona (with Colorado River Guides): 28th International Geological Congress Field Trip Guidebook T115/315, Washington, D.C., American Geophysical Union, p. 212-218.

Wenrich, K.J., and Sutphin, H.B., 1989, Lithotectonic setting necessary for formation of a uranium-rich, solution-collapse breccia-pipe province, Grand Canyon region, Arizona: U.S. Geological Survey Open-File Report 89-0173, 33 p.

Wenrich, K.J., Billingsley, G.H., and Blackerby, B.A, 1995, Spatial migration and compositional changes of Miocene-Quaternary magmatism in the western Grand Canyon: Journal of Geophysical Research, v. 100, no. B7, p. 10,417-10,440.

Wilson, E.D., Moore, R.T., and Cooper, J.R., 1969, Geologic map of the State of Arizona: University of Arizona, Arizona Bureau of Mines, scale 1:500,000.

DESCRIPTION OF MAP UNITS

SURFICIAL DEPOSITS

Surficial deposits (Holocene)—Surficial deposits are differentiated from one another on the basis of morphologic character and relative physiographic position chiefly by interpretation of 1976 aerial photographs. Older alluvial-fan and terrace-gravel deposits generally exhibit extensive erosion, whereas younger deposits either are actively accumulating material or are lightly eroded

Qaf **Artificial fill and quarries (Holocene)**—Alluvial and bedrock material removed from pits, trenches, and quarries to build stock tanks and drainage diversion dams

Qs **Stream-channel alluvium (Holocene)**—Interlensing silt, sand, and pebble to boulder gravel; unconsolidated and poorly sorted. Locally overlaps alluvial-fan (Qa_1), terrace-gravel (Qg_1), upper part of valley-fill (Qv), and floodplain (Qf) deposits. Inset against older alluvial-fan (Qa_2 and Qa_3) and older terrace-gravel (Qg_2) deposits. Stream channels subject to intermittent high-energy flows and flash floods. Little or no vegetation in stream channels except salt cedar (tamarisk) trees. Contacts with other alluvial deposits approximate. About 1 to 2 m thick

Qf	**Floodplain deposits (Holocene)**—Light-gray or tan silt, sand, and lenses of pebble to cobble gravel; unconsolidated. Locally contain cinder and basalt fragments. Intertongue with or overlap valley-fill (Qv) deposits. Form relatively flat surfaces having little or no vegetation. Subject to frequent flooding or ponding, mainly in dammed drainages or natural sink depressions. About 1 to 4 m thick
Qg$_1$	**Young terrace-gravel deposits (Holocene)**—Light-brown, pale-red, and gray silt, sand, and pebble to boulder gravel composed about equally of well-rounded limestone and sandstone clasts and angular to subrounded chert clasts derived from the Kaibab Formation. Include well-rounded to subangular basalt clasts. Form benches about 1 to 3 m above modern streambeds; locally inset into intermediate terrace-gravel (Qg$_2$ and Qg$_3$) deposits. About 1 to 4 m thick
Qa$_1$	**Young alluvial-fan deposits (Holocene)**—Gray-brown silt and sand. Contain lenses of coarse gravel composed of subangular to rounded pebbles and cobbles of limestone, chert, and sandstone locally derived from Permian and Triassic strata; locally contain well-rounded to sub-angular basalt clasts and pyroclastic debris. Contain some gypsum and calcite cement. Overlapped by or intertongue with stream-channel alluvium (Qs) and upper part of valley-fill (Qv) deposits. Intertongue with young terrace-gravel (Qg$_1$); overlap intermediate alluvial-fan (Qa$_2$ and Qa$_3$) deposits; form below older alluvial fans (Qa$_4$). Subject to extensive erosion by sheet wash and flash-flood debris flows and minor arrow erosion. Support sparse growth of sagebrush, cactus, and grass. 1 to 4 m or more thick
Qc	**Colluvial deposits (Holocene and Pleistocene)**—White to gray silt and fine-grained sand, and black and reddish, fine-grained, cinder, scoria, and basalt clasts; locally, on basalt flows, consolidated by gypsum and calcite cement to form calcrete. Common in enclosed basins or depressions in landslide areas and on basalt flows. Similar to floodplain (Qf) deposits, but limited to local accumulations generally not associated with stream drainages. Subject to temporary ponding. Support sparse growths of grass. About 1 to 3 m thick
Qv	**Valley-fill deposits (Holocene and Pleistocene)**—Gray and light-brown silt, sand, and lenses of pebble to small-boulder gravel; partly consolidated; include well-rounded clasts of limestone, sandstone, and angular chert fragments. Intertongue with or overlap talus (Qt), terrace-gravel (Qg$_1$, Qg$_2$, and Qg$_3$), and alluvial-fan (Qa$_1$ and Qa$_2$) deposits. Represent a relatively low-energy, low-gradient alluvial stream-channel or shallow-valley drainage deposit. Subject to sheetwash flooding and temporary ponding; cut by arroyos as much as 3 m deep in larger valleys. Support moderate growths of sagebrush, grass, and cactus. About 1 to 5 m thick
Qt	**Talus deposits (Holocene and Pleistocene)**—Unsorted breccia debris composed of small and large angular blocks of local bedrock on steep to moderately steep slopes below outcrops. Include redeposited silt, sand, and gravel eroded from local bedrock; in places, partly cemented by calcite and gypsum. Intertongue with alluvial-fan (Qa$_1$ Qa$_2$, and Qa$_3$), valley-fill (Qv), terrace-gravel (Qg$_1$ and Qg$_2$), and landslide (Ql) deposits. Support sparse growth of sagebrush, cactus, and grass. Only thick or extensive deposits shown. Some talus deposits in Parashant Canyon are derived from older remnants of landslide debris. About 2 to 6 m thick
Ql	**Landslide deposits (Holocene and Pleistocene)**—Unconsolidated masses of unsorted rock debris. Include detached blocks that have rotated backward and slid downslope as loose incoherent masses of broken rock and deformed strata, in places partly surrounded by talus (Qt). Found principally below Tertiary basalt flows at Poverty Knoll, Poverty Mountain, Grassy Mountain, and the Sawmill Mountains. Large angular blocks of basalt are as much as 3 m across. Support sparse to moderate growth of sagebrush, cactus, grass, oak brush, juniper, and pinyon pine trees. Unstable when wet. Thickness ranges from 3 to 45 m, averaging about 12 m
Qg$_2$	**Young intermediate-age terrace-gravel deposits (Pleistocene)**—Similar to young terrace-gravel deposits (Qg$_1$) but partly consolidated. Composed mainly of light-red, fine-grained sand and silt together with gray silt and clay. Locally contain angular to rounded basalt clasts 12 cm or more in diameter. Form flat benches about 2 to 8 m above modern stream floors, and about 1 to 5 m above young-terrace gravel (Qg$_1$) deposits. Intertongue with or locally overlain by talus (Qt) and young alluvial-fan (Qa$_1$) deposits. Locally inset into intermediate alluvial-fan (Qa$_2$) deposits. Approximately 2 to 4 m thick

Qa$_2$	**Young intermediate-age alluvial-fan deposits (Holocene and Pleistocene)**—Similar to young alluvial-fan (Qa$_1$) deposits, but partly cemented by calcite and gypsum. Commonly overlapped by young alluvial-fan (Qa$_1$) or young terrace-gravel (Qg$_1$) deposits; intertongue with or overlap valley-fill (Qv) and talus (Qt) deposits. Include abundant subrounded to subangular basalt clasts. Support sparse growth of sagebrush, cactus, and grass. Ranges from 2 to 8 m thick
Qg$_3$	**Older terrace-gravel deposits (Pleistocene)**—Similar to both younger terrace-gravel units (Qg$_1$ and Qg$_2$); partly cemented by calcite and gypsum. Deposit usually isolated as remnants of older ancestral drainages of Parashant Wash and its tributaries, and Hurricane Wash. In Parashant Wash, deposit usually 10 to 60 m above modern drainages; in Hurricane Wash, 1 to 25 m above modern drainage. As much as 1 to 10 m thick
Qa$_3$	**Older intermediate-age alluvial-fan deposits (Pleistocene)**—Similar to young and young intermediate-age alluvial-fan deposits (Qa$_1$ and Qa$_2$); partly cemented by calcite and gypsum. Commonly overlapped by young and young intermediate-age alluvial-fan deposits (Qa$_1$ and Qa$_2$) and intertongue with landslide (Ql) deposits. Often dissected by erosion and arroyos as deep as 2 m. Include abundant basaltic clasts near landslide masses (Ql). Usually have light-gray thin soil developed on surface; support moderate grass, cactus, and sagebrush. Ranges from 2 to 4 m thick
Qa$_4$	**Older alluvial-fan deposits (Pleistocene)**—Similar to younger alluvial-fan (Qa$_1$, Qa$_2$, and Qa$_3$,) deposits, but basalt pebbles, cobbles, and boulders are more abundant than in younger alluvial fans. Basalt clasts form thin desert pavement surface. Partly consolidated by calcite and gypsum. Minor deposits preserved near Grassy, Poverty, and Sawmill Mountains. Form benches as much as 30 m above local terrain. Support moderate growths of grass. Average thickness, 2 m

VOLCANIC ROCKS

	Little Tanks Basalt (Pleistocene)—Named for local stock tank labeled "Little Tanks reservoir", the type area, in northern Mohave County, Arizona (sec. 5, T. 36 N., R. 10 W.; Billingsley, 1993a), north of this map area. Basalt and associated pyroclastic deposits at Cinder Knoll (sec. 29, T. 36 N., R. 10 W.), at northern edge of map area represent the youngest volcanic rocks in the map area. K-Ar whole-rock age, 1.0±0.4 Ma (Billingsley, 1993a). Divided into pyroclastic rocks and basalt flows, described below
Qlp	**Pyroclastic deposits**—Red-brown and reddish-black basaltic scoria and cinder deposits; partly consolidated. Unit forms low pyroclastic cone (Cinder Knoll) about 15 m high capped by basalt flow
Qlb	**Basalt flows**—Dark-gray, finely crystalline to glassy, alkali-olivine basalt. Groundmass composed of plagioclase, olivine, and augite (Fitton, 1989). Unit contains abundant olivine phenocrysts 0.25 to 1 mm in diameter. Unit unconformably overlies Harrisburg Member of Kaibab Formation, Timpoweap Member and lower red member of Moenkopi Formation, and old intermediate alluvial-fan (Qa$_3$) deposits. About 1 to 3 m thick
	Bundyville basalt (Pliocene)—Informally named for abandoned settlement of Bundyville (Mt. Trumbull) on Shivwits Plateau in east-central part of map area (secs. 23, 24, 25, and 26, T. 35 N., R. 10 W.). Includes basalt flows on downthrown side of Hurricane Fault in Sawmill Mountains, 5 to 10 km (3 to 6 mi) southeast of Bundyville. K-Ar whole-rock age, 3.6±0.18 Ma (Reynolds and others, 1986)
Tbb	**Basalt flows**—Dark-gray, finely crystalline, alkali-olivine basalt containing olivine phenocrysts averaging 1 to 2 mm grain size. Unit consist of several basalt flows that form caprock over purple and white mudstone and sandstone beds of Petrified Forest Member of Chinle Formation, and red sandstone beds of upper red member of Moenkopi Formation. Flow surfaces locally distorted by landslides and distortion of underlying soft mudstone. Source of flows assumed to have originated from local fissure dikes that may parallel the strike of the Hurricane Fault; fissure dikes are now covered by basalt or landslide and talus debris. Thickness about 10 to 55 m, averages about 30 m
	Basalt of Poverty Knoll (Pliocene)—Informally named for Poverty Knoll, a 245 m high isolated mesa or knoll on the Shivwits Plateau in northwestern part of map area (sec. 2, T. 35 N., R. 11 W.). Divided into two units, a flow and a dike
Tpki	**Intrusive dike**—Light-gray, finely crystalline, alkali-olivine basalt

Tpkb	**Basalt flow**—Light-gray, finely crystalline, alkali-olivine basalt containing plagioclase laths and olivine phenocrysts 1 mm in diameter in glassy groundmass. Unit composed of about 35 percent olivine phenocrysts. Flow overlies Shnabkaib Member of the Moenkopi Formation. Averages about 37 m thick
	Poverty Mountain Basalt (Pliocene)—Informally named Shivwits basalt by Best and others (1980) and Reynolds and others (1986) in conjunction with other basalt flows south of this map area. Formally named here for Poverty Mountain, the type area, on Shivwits Plateau at west-central edge of map area (secs. 29 and 32, T. 35 N., R.11 W.). K-Ar whole rock age is 4.75±0.26 Ma (Reynolds and others, 1986). Divided into three units described separately
Tpi	**Intrusive neck**—Medium-gray, finely crystalline, alkali-olivine basalt that forms small neck
Tpp	**Pyroclastic deposits**—Reddish-black and red fragments of scoria, cinders, and small ribbons deposited on basalt flows. Form small cone about 25 m (80 ft) high, interbedded with basalt flows; unconsolidated
Tpb	**Basalt flows**—Medium-gray to light-gray, finely crystalline, alkali-olivine basalt. Include augite and olivine phenocrysts less than 1 mm in diameter in glassy groundmass. Basalt overlies gently east-dipping (2° average) upper red member and Shnabkaib Member of Moenkopi Formation. Basalt flowed in radial pattern with a mostly westward component on nearly flat erosion surface. Ranges from 30 m to 92 m thick
	Grassy Mountain Basalt (Pliocene)—Formally named here for Grassy Mountain, the type area, on Shivwits Plateau (secs. 3, 4, 9, 10, T. 33 N., R. 11 W.). Divided into three separately described units
Tgi	**Intrusive dikes**—Dark-gray, finely crystalline, alkali-olivine basalt. Source areas for associated basalt flows and pyroclastic deposits. Dikes align with nearly vertical east-west joints and fractures of this area. Dike widths, 0.5 to 2 m
Tgp	**Pyroclastic deposits**—Red to reddish-black, angular, scoriaceous cinder fragments and ash deposits; unconsolidated. Spatially associated with intrusive dikes; overlie basalt flows of Grassy Mountain and in turn are overlain by basalt in some areas. Include interbedded pyroclastic deposits between basalt flows near dikes. Variable thickness, 1 to 6 m
Tgb	**Basalt flows**—Dark-gray, finely crystalline, alkali-olivine basalt; olivine phenocrysts averaging 1 mm in diameter make up about 25 percent of rock sample from interior of basalt flow. One or more flows are interbedded with pyroclastic deposits near dikes; basalt flowed generally west and northwest. Basalt overlies upper red member and Shnabkaib Member of Moenkopi Formation. Thickness ranges from 12 m to as much as 60 m
Ti	**Intrusive dikes (Pliocene)**—Gray, finely crystalline, alkali-olivine basalt; south-central edge of map area. Dikes do not protrude above ground surface; highly altered and weathered. Dikes align with local northwest-southeast joints in bedrock and are presumably associated with dike swarm in Parashant Canyon about 3 km south of map area. Whole-rock K-Ar age, 6.34±0.1 Ma (Wenrich and others, 1995)

SEDIMENTARY ROCKS

	Chinle Formation (Upper Triassic)—Only Petrified Forest Member is present in map area. Shinarump Member is missing or has undergone local facies change into sandstone lithology, which is here, included as part of Petrified Forest Member
TRcp	**Petrified Forest Member**—White, blue-gray, pale-red and purple, slope-forming mudstone, siltstone, and coarse-grained sandstone; contains small very well rounded pebbles of yellow and red quartzite. At some outcrops, includes white, coarse-grained, ledge-forming sandstone at base that may be equivalent to Shinarump Member of Chinle; contains brown or red petrified wood fragments. Contains bentonitic clays derived from decomposition of volcanic ash. Unconformable contact with overlying Bundyville basalt not exposed; erosion has removed unknown portion of upper part. Unit mostly covered by landslide debris (Ql). Unconformably overlies slope-forming upper red member of Moenkopi Formation; erosional relief less than 2 m where contact exposed. About 122 m thick

Moenkopi Formation (Middle? to Lower Triassic)—Divided into, in descending order, upper red member, Shnabkaib Member, middle red member, Virgin Limestone Member, lower red member, and Timpoweap Member as used by Stewart and others (1972)

TRmu **Upper red member (Middle? and Lower Triassic)**—Red, thin-bedded, cliff- and slope-forming siltstone and sandstone. At Grassy and Poverty Mountains, upper part is absent due to Tertiary erosion and is overlain by Tertiary basalt flows; in the Sawmill Mountains, the Chinle Formation overlies unit. Gradational lower contact is placed at top of uppermost thick white or light-gray calcareous siltstone and dolomite of Shnabkaib Member of the Moenkopi Formation. Average thickness about 120 m

TRms **Shnabkaib Member (Lower Triassic)**—White, laminated, slope-forming, aphanitic dolomite interbedded with light-gray, calcareous, silty gypsum. Upper part is unconformably overlain by Tertiary basalt flows at Poverty Knoll. Gradational lower contact with middle red member placed at base of lowest thick white or light-gray calcareous silty dolomite of the Shnabkaib Member. Unit thins south and west, thickens north. Average thickness about 130 m

TRmm **Middle red member (Lower Triassic)**—Red-brown, thin-bedded to laminated, slope-forming siltstone and sandstone. Includes white and gray gypsum beds, minor white platy dolomite, green siltstone, and gray-green to red gypsifereous mudstone. Gradational lower contact with the Virgin Limestone Member is placed at top of highest gray limestone bed of Virgin Limestone. Unit thins west, south, and east, thickens north. Average thickness about 120 m

TRmv **Virgin Limestone Member (Lower Triassic)**—Consists of two light-gray, thin-bedded to laminated, ledge-forming limestone beds, 0.5 to 2 m thick, separated by white, pale-yellow, red, and bluish-gray, thin-bedded, slope-forming gypsifereous siltstone in northeast quarter of map area. Thins south and west to only one limestone bed at Grassy and Poverty Mountain areas, about 0.5 m thick. At eastern edge of map area, lowest limestone bed contains star-shaped crinoid plates and poorly preserved *Composita* brachiopods in upper part. Unconformable contact with underlying lower red member of Moenkopi Formation has erosional relief as much as 2 m. Lower limestone bed thickens and thins as channel-fill deposit and locally pinches out onto or unconformably overlies paleohills of Harrisburg Member of the Kaibab Formation. Thickness ranges from 0 to 20 m

TRml **Lower red member (Lower Triassic)**—Red, fine-grained, thin-bedded, gypsifereous, slope-forming, sandy siltstone; and gray, white, and pale-yellow laminated gypsum and minor sandstone. Lower part contains redeposited gypsum and siltstone of Harrisburg Member of the Kaibab Formation and includes marker bed of reddish-gray, coarse-grained, thin-bedded, cross-stratified, calcareous, ledge-forming sandstone 1 to 2 m thick. Gradational contact with underlying Timpoweap Member of the Moenkopi Formation placed at base of lowermost red siltstone bed. Where Timpoweap strata are absent, unconformably overlies Harrisburg Member of the Kaibab Formation. Locally thickens in paleovalleys, pinches out onto eroded paleohills of underlying Harrisburg. Ranges from 0 to 20 m thick

TRmt **Timpoweap Member (Lower Triassic)**—Light-gray, slope- and ledge-forming conglomerate in lower part and light-gray to light-red, slope-forming calcareous sandstone in upper part. Conglomerate composed of subangular to rounded pebbles and cobbles of gray and dark-gray limestone, white and brown chert, and gray sandstone in matrix of gray to brown, coarse-grained sandstone. Upper part includes beds of low-angle cross-bedded, calcareous sandstone, conglomerate, and minor siltstone. Includes calcite and gypsum cement. All detritus in the Timpoweap Member derived from the Kaibab Formation. Occurs in and defines paleovalleys 1,500 m wide and as much as 70 m deep eroded into Harrisburg Member of the Kaibab Formation (fig. 2). Imbrication of pebbles in conglomerate show general eastward flow of depositing streams. Ranges from 0 to 50 m thick

Kaibab Formation (Lower Permian)—Divided into, in descending order, Harrisburg Member and Fossil Mountain Member as defined by Sorauf and Billingsley (1991)

Pkh **Harrisburg Member**—Upper, middle, and lower part are distinctive from one another, but not subdivided. Upper part consists mainly of slope-forming, red and gray, interbedded gypsifereous siltstone, sandstone, gypsum, and thin-bedded gray limestone. Includes caprock of resistant, pale-yellow or light-gray, fossiliferous (mollusks and algae), sandy limestone averaging about 1 m thick that weathers black or brown. Upper part of unit mostly eroded away in southern quarter of map area; gradational into middle part of unit. Middle part consists mainly of two cliff-forming limestone beds as much as 4 m thick: upper bed is gray, thin-bedded, cherty limestone that weathers dark brown or black and commonly forms geomorphic bedrock surface of exposed Harrisburg Member; lower bed is light-gray, thin-bedded, sandy limestone. Both beds thicken and thin locally, but regionally thicken eastward. Minor erosional unconformity separates middle from lower part. Lower part consists of slope-forming, light-gray, gypsifereous siltstone and fine- to medium-grained calcareous sandstone; gray, medium-grained, thin-bedded sandy limestone; and gray, massive-bedded gypsum. Solution of gypsum in lower part has locally distorted limestone beds of middle part, causing them to slump or bend into local drainages. Gradational into underlying Fossil Mountain Member. As much as 92 m thick

Pkf **Fossil Mountain Member**—Light-gray, fine- to medium-grained, thin-bedded, fossiliferous, cliff-forming, cherty limestone. Unit characterized by black-weathering chert bands. Unconformable contact with underlying Woods Ranch Member of the Toroweap Formation marked by solution and channel erosion locally having relief averaging about 2 m to as much as 12 m (40 ft) near southeast corner of map area; contact locally obscured by talus and minor landslide debris. About 106 m thick

Toroweap Formation (Lower Permian)—Divided into, in descending order, Woods Ranch, Brady Canyon, and Seligman Members as defined by Sorauf and Billingsley (1991)

Ptw **Woods Ranch Member**—Gray, slope-forming gypsifereous siltstone and pale-red silty sandstone interbedded with white laminated gypsum. Beds are locally distorted due to gypsum solution. Lower contact gradational. Thickness varies from 55 to 80 m owing to solution of gypsum and erosion of upper beds

Ptb **Brady Canyon Member**—Gray, cliff-forming, medium-bedded, fine- to coarse-grained, fetid, fossiliferous limestone; weathers dark dray. Includes thin-bedded dolomite in upper and lower parts. Limestone beds average about 0.5 m thick and include chert lenses and nodules. Lower contact gradational. Contact commonly covered by minor slump or talus debris. Approximately 60 m thick

Pts **Seligman Member**—Gray, thin-bedded, slope-forming dolomite and gypsifereous sandstone. Middle part includes gray to red, thinly interbedded siltstone, sandstone, and gypsum; lower part includes brown, purple, and yellow, fine- to medium-grained, thin-bedded, low-angle crossbedded and planar-bedded sandstone; locally includes high-angle, cross-bedded, fine- to medium-grained sandstone of the Coconino Sandstone. Lower contact is unconformable with as much as 1 m of erosional relief; contact mostly covered by talus and alluvial deposits. About 37 m thick

Ph **Hermit Formation (Lower Permian)**—Light-red and yellowish-white, fine-grained, thin- to thick-bedded, slope- and ledge-forming sandstone and siltstone. Sandstone beds as much as 3 m thick are separated by beds of dark-red, slope-forming siltstone and silty sandstone as much as 1 m thick. Reddish sandstone beds commonly contain yellowish-white bleached spots; all beds are partly or completely bleached yellowish-white near breccia pipes. Lower 2 m is red soft siltstone, which fills erosional channels as much as 7 m deep cut into the underlying Permian Esplanade Sandstone in places; otherwise, siltstone forms unconformable contact with the Esplanade Sandstone with as much as 2 m relief. About 275 m thick

U.S. DEPARTMENT OF THE INTERIOR
U.S.GEOLOGICAL SURVEY

TO ACCOMPANY MAP MF-2343

METADATA FOR GEOLOGIC MAP OF THE UPPER PARASHANT CANYON AND VICINITY, MOHAVE COUNTY, NORTHWESTERN ARIZONA

Digital Database by Michelle L. Harr and Jessica L. Wellmeyer

INTRODUCTION

This is a digital geologic map database. This pamphlet describes what is in this database and gives instructions for obtaining the data. The report does include PostScript plot files containing images of the geologic map sheet and an explanation sheet as well as the accompanying text describing the geology of the area. For those interested in a paper plot of information contained in the database or in obtaining the PostScript plot files, please see the section entitled “For Those Who Don’t Use Digital Geologic Map Databases” below.

This digital map database, compiled from previously published and unpublished data, and new mapping by the authors, represents the general distribution of bedrock and surficial deposits in the Parashant Canyon area. Together with the accompanying text it provides current information on the geologic structure and stratigraphy of the area covered. The database delineates map units that are identified by general age and lithology following the spatial resolution (scale) of the database to 1:31,680 or smaller. The content and character of the database, as well as three methods of obtaining the database, are described below.

FOR THOSE WHO DON’T USE DIGITAL GEOLOGIC MAP DATABASES

Two sets of plotfiles containing images of much of the information in the database are available to those who do not use an ARC/INFO compatible GIS. Each set contains an image of a geologic map sheet and the accompanying explanatory pamphlet. There is a set available in PostScript format, and another in Acrobat PDF format. (See sections below) Those who have computer capability can access the plotfile packages in either of the two ways described below, however, these packages do require gzip and tar utilities to access the plot files. Requests for a tape copy of the digital database or plotfiles can be made by sending a tape with request and return address to: Database Coordinator; U.S. Geological Survey; 345 Middlefield Road, M/S 975; Menlo Park, CA 94025. Plot files can also be acquired online at http://geopubs.wr.usgs.gov/map-mf/mf2343

Those without computer capability can obtain plots of the map files through USGS Plot-On-Demand service for digital geologic maps. To obtain plots of the map sheet and accompanying pamphlet, contact the USGS Information Services office at the following address: USGS Information Services; Box 25286; Denver Federal Center; Denver, CO 80225-0046. Or by phone (303)202-4200, fax (303)202-4695, or e-mail: infoservices@usgs.gov. Be sure to include the map reference MF-2343.

DATABASE CONTENTS

This digital database package consists of the geologic map database and supporting data including base maps, map explanation, geologic description, and references. A second package consists of PostScript plot files of a geologic map, explanation sheet and geologic description.

Digital Database Package

The first package is composed of geologic map database files for the Parashant Canyon area. The coverages and their associated INFO directory have been converted into ARC/INFO export files. These export files are uncompressed and are easily handled and compatible with some Geographic Information Systems other than ARC/INFO. The export files included are:

ARC/INFO export file	Resultant Coverage	Description
para_poly.e00	para_poly/	Faults and contacts
para_dip.e00	para_dip/	Strike and dip information and annotation, point data and annotation
para_fold.e00	para_fold/	Fold axes
para_anno.e00	para_anno/	Unit annotation, fault and fold names, fault separation values

The database package also contains the following other export files with extraneous data used in the construction of the database

ARC/INFO export file	Resultant File	Description
geo.lin.e00	geo.lin	Lineset
geo.mrk.e00	geo.mrk	Markerset
color524.shd.e00	color524.shd	524 color shadeset

para_lut.txt	Textfile with lookup table input data
paradrg.tif.gz	Zipped background hypsography image
paradrg.tfw	World file accompanying paradrg.tif

PostScript Plotfile Package

The second digital data package available contains the PostScript images described below:

Mf2343a.eps	Encapsulated PostScript plottable file containing complete map composition with geology, symbology, annotation, and base map of the Parashant Canyon quadrangle
para_geol.eps	A Post Script plot file of this report and the report containing detailed unit descriptions and geological information plus sources of data and references cited

This package also contains the Adobe Acrobat (.pdf) portable document format files described below:

PDF file	Description
Mf2343b.pdf	Parashant Canyon map figure

The Acrobat files were created from corresponding .eps files and are compatible with Adobe Acrobat version 3.0 and higher.

ACCESSING DATABASE CONTENTS

ARC/INFO Export Files

ARC export files are converted to their proper ARC/INFO format using the ARC command ‘import’ with the option proper for the format desired. To ease conversion and preserve naming convention, an AML is enclosed that will convert all the export files in the database to coverages and graphic files and will also create an associated INFO directory. From the ARC command line type:

```
ARC: &run import.aml
```

ARC export files can be read by other Geographic Information Systems. Refer to your documentation for proper procedure for retrieval of data.

PostScript and Portable Document Format Files

These files are packaged separately. PDF files come as is and can be downloaded or copied directly to your hard drive with no conversion aside from opening the file from Adobe Acrobat. The Post Script documents are zipped and compressed to a smaller file size. They can be decompressed using gzip.

DATABASE SPECIFICS

Procedure Used

Stable-base maps were scanned at the Flagstaff USGS Field site using the Optronics 5040 raster scanner at a resolution of 50 microns (508 dpi). The resulting raster file was in RLE format and converted to the RLC format using the “rle2rlc” program written by Marilyn Flynn. The RLC file was subsequently converted to an ARC/INFO Grid in ARC/INFO. The linework was vectorized using gridline. A tic file was created in lat/long and projected into the base map projection (Polyconic) using a central meridian of -113.125W. Tics are defined in the four extreme corners of the map area in the geologic coverages corresponding with quadrangle corners both in base maps and digital maps. The tic file was used to transform the grid into UTM. ARC/INFO generated a RMS report after transforming the original grid into transverse UTM.

```
Scale (X,Y) = (1.585,1.586)  Skew (degrees) = (-0.017)
Rotation (degrees) = (-1.028)  Translation = (299756.961,4010121.758)
RMS Error (input,output) = (2.119,3.361)

Affine  X = Ax + By + C
        Y = Dx + Ey + F
 A =        1.585   B =         0.028   C =      299756.961
 D =       -0.028   E =         1.586   F =     4010121.758
```

```
tic id      input  x        input  y
           output x        output y              x error        y error
------ ---------------- ---------------- ---------------- ---------------- ----------
    1      -1254.544        2309.914
           297834.227      4013824.430         -0.562         -3.307
    2      -15433.769       2407.332
           275367.256      4014375.431          0.562          3.309
    3      -15290.173       19893.924
           276085.494      4042113.039         -0.564         -3.319
    4      -1155.041        19803.127
           298480.527      4041560.539          0.564          3.318
```

Lines, points, polygons and annotation were edited using the ARCEDIT modules.

Following editing and annotation, the individual coverages were projected into UTM projection

Map Projection:

Parameter	Description
Projection	UTM
Units	Meters on the ground
Zone	12
Datum	NAD 1927

The content of the geologic database can be described in terms of the lines and the areas that compose the map. Descriptions of the database fields use the terms explained below.

Database Fields:

Parameter	Description
Item name	name of database field
Width	maximum number of characters or digits stored
Output	output width
Type	B - binary integer; F- binary floating point number, I - ASCII integer, C - ASCII character string
N.dec.	number of decimal places maintained for floating point numbers

LINES

The arcs are recorded as strings of vectors and described in the arc attribute table (AAT). They define the boundaries of the map units, faults, and map boundaries in PARA_POLY. These distinctions and the geologic identities of the boundaries are stored in the LTYPE field according to their line type.

Arc Attribute Table Definition:

```
DATAFILE NAME: PARA_POLY.ATT 10 ITEMS: STARTING IN POSITION
1 COL  ITEM NAME        WDTH          OPUT    TYP      N.DEC    ALTERNATE NAME
   1  FNODE#                    4     5          B           -
   5  TNODE#                    4     5          B           -
   9  LPOLY#                    4     5          B           -
```

13	RPOLY#	4	5	B	-	
17	LENGTH	8	18	F	5	
25	PARA_POLY#	4	5	B	-	
29	PARA_POLY-ID	4		5	B	-
33	LTYPE	35	35	C	-	
68	PTTYPE	35	35	C	-	
103	SYMBOL	3	3	I	-	

The AAT defined above represents the AAT in PARA_POLY.

Description of AAT Items:

Item	Description
FNODE#	Starting node of the arc
TNODE#	Ending node of the arc
LPOLY#	Polygon to the left of the arc
RPOLY#	Polygon to the right of the arc
LENGTH	Length of the arc in meters
PARA_POLY#	Unique internal number
PARA_POLY-ID	Unique identification number
LTYPE	Line type
PTTYPE	Point type for arc markers
SYMBOL	Field not used

The geologic line types relate to geologic line symbols in the line set GEO.LIN according to the lookup table GEOLIN.LUT.

Domain of Line Types recorded in LTYPE field:

ANTICLINE_ CERTAIN _RED
ANTICLINE_CONCEALED_RED
MONOCLINE_ CERTAIN _RED
MONOCLINE_ CONCEALED _RED
SYNCLINE_ CERTAIN _RED
SYNCLINE_ CONCEALED _RED
BASALT_FLOW_DIRECTION
CONTACT_CERTAIN
HIGH_ANGLE_FLT_CERTAIN
HIGH_ANGLE_FLT_CONCEALED
HIGH_ANGLE_FLT_APPROX
LANDSLIDE_SCARP

Domain of Markers recorded in PTTYPE field:

FAULT_BALL_FILL
SYNCLINE_RED
ANTICLINE_RED
MONOCLINE_RED

POLYGONS

Map units (polygons) are described in the polygon attribute table (PAT). This identifies the map units recorded in the PTYPE field by map label. Individual map units are described more fully in the accompanying text.

Definition of Polygon Attribute Table:

```
DATAFILE NAME: PARA_POLY.PAT, 7 ITEMS: STARTING IN POSITION
1 COL  ITEM NAME     WDTH     OPUT     TYP     N.DEC
   1  AREA              8        18       F       5
   9  PERIMETER         8        18       F       5
  17  PARA_POLY#        4        5        B       -
  21  PARA_POLY-ID      4        5        B       -
  25  PTYPE             5        5        C       -
  30  PATTERN           3        3        I       -
  33  ORIGPTYPE         5        5        C       -
```

Description of Item Names:

Item Name	Description
AREA	Area of polygon in square meters
PERIMETER	Perimeter of polygon in meters
PARA_POLY#	Unique internal number
PARA_POLY-ID	Unique identification number
PTYPE	Unit label
PATTERN	Designated fill pattern for polygons
ORIGPTYPE	(Not used)

Domain of PTYPE (map units):

Qaf	Qs	Qg1	Qg2	Qg3	Qa1
Qa2	Qa3	Qa4	Qc	Qv	Qt
Ql	Qlp	Qlb	Tbb	Tpki	Tpkb
Tpi	Tpp	Tpb	Tgi	Tgp	Tgb
Ti	TRcp	TRmu	TRms	TRmm	TRmv
TRml	TRmt	Pkh	Pkf	Ptw	Ptb
Pts	Ph	xxx			

C represents Cambrian strata, D represents Devonian strata, M represents Mississippian strata, MP represents Pennsylvanian/Permian strata, P represents Permian strata, T represents Tertiary strata, TR represents Triassic strata, Q represents Quaternary strata and ‘xx’ is a code for any undefined strata. Polygons were assigned colors based on their geologic unit. The colors were assigned from the shadeset COLOR524.SHD and are related to the lookup table MASTER.LUT

POINTS

Strike and dip information is recorded as coordinate data with related information. This information is described in the Point Attribute Table (PAT). ARC/INFO coverages cannot hold both point and polygon information, thus PARA_DIP has only a point attribute table, and PARA_DIP has only a polygon attribute table.

Definition of Point Attribute Table:

```
DATAFILE NAME: PARA_DIP.PAT 7 ITEMS:  STARTING IN POSITION
1 COL  ITEM NAME    WDTH    OPUT   TYP    N.DEC
   1  AREA              8       18     F      5
   9  PERIMETER         8       18     F      5
  17  PARA_DIP#         4       5      B      -
  21  PARA_DIP-ID       4       5      B      -
  25  PTTYPE            35      35     C      -
  60  DIP               3       3      I      -
  63  STRIKE            3       3      I      -
```

Description of item names:

Item Name	Description
AREA	Area
PERIMETER	Perimeter
PARA_DIP#	Unique internal number
PARA_DIP-ID	Unique identification number
PTTYPE	Point type
DIP	Dip angle in azimuth degrees
STRIKE	Strike angle in degrees

The coverage PARA_DIP contains strike and dip data and other pertinent structural data represented by point symbology, including collapses, sinkholes and domes. PARA_POLY has point types defined in the AAT, which correspond to the defined linetype for an arc. These point types are related to the lookup table GEOMRK.LUT and are from the symbolset GEO.MRK.

Domain of PTTYPE:

VERTICAL_JOINT
BEDDING
APPROXIMATE_BEDDING
DOME
PROBABLE_BRECCIA_PIPE
VOLCANIC_VENT
SINKHOLE

ANNOTATION

The coverage PARA_ANNO contains all annotation for the polygon coverage. It is defined somewhat differently from the polygon and dip coverages. The arc attribute table is of negligible importance. Arcs in this coverage are merely leaders from a unit annotation to the related polygon. PARA_ANNO contains annotation with unit labels, fault separation, and monocline names. All annotation was in feature subclass “anno.unit.”

The textset used for all annotation was geofont.txt, specifically symbolset 30. Use of this textset allows for proper symbol notation for unit symbols. The default ARC/INFO textset does not allow for a proper geologic symbol indicating ‘Triassic.’ By using this alternate text set, the character pattern ‘^m’ prints instead as TRm.

BASE MAP PROCEDURE

The base map was prepared by downloading four 1:24,000 DRGs, converting them to grid format, clipping their boundaries, and piecing them together seamlessly to create one large raster image. The DRGs used are the Cold Spring quadrangle, Grassy Mountain quadrangle, Jones Hill quadrangle, and Poverty Knoll quadrangle. These raster images were imported as georeferenced TIFF (GeoTIFF) graphics, and were drained of all color except brown, black and blue. Once clipped and joined together, the grid was colored with a colormap file producing a graphic with all linework in gray. Following this procedure the image was re-scaled to a resolution of 1:31,680. No editing of the topography, text, or cultural features shown on the map was done.

SPATIAL RESOLUTION

Use of this digital geologic map database should not violate the spatial resolution of the data. Although the digital form of the data removes the constraint imposed by the scale of a paper map, the detail and accuracy inherent in map scale are also present in the digital data. This database was created and edited at a scale of 1:31,680; means that higher resolution data is generally not present. Plotting at scales of larger than 1:31,680 will not yield greater real detail, but may reveal fine-scale irregularities below the intended resolution.

COVERAGES

PARA_POLY/ - polygon coverage of geologic units and faults, corresponding annotation
PARA_DIP/ - point coverage of bedding and structural features, corresponding annotation
PARA_ANNO/ - annotation coverage
PARA_FOLD/ - line coverage with fold structures

OTHER FILES

Lineset	GEO.LIN	GEOLIN.LUT
Markerset	GEO.MRK	GEOMRK.LUT
Shadeset	COLOR524.SHD	MASTER.LUT
Textset	GEOFONT.TXT	