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Geologic map of the Mount Logan quadrangle, northern Mohave County, Arizona

by
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GEOLOGIC MAP OF THE MOUNT LOGAN QUADRANGLE, NORTHERN MOHAVE COUNTY, ARIZONA

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INTRODUCTION

This report of the Mount Logan quadrangle of the Colorado Plateau is part of a cooperative U.S. Geological Survey and National Park Service project to provide geologic information of areas in or near the Grand Canyon of Arizona. Most of the Grand Canyon and parts of the adjacent plateaus are geologically mapped at the 1:500,000 scale. This map contributes detailed geologic information to a previously inadequately mapped area. The geologic information presented here will assist in future geological studies related to land use management, range management, and flood control programs by federal and state agencies and private enterprises.

The nearest settlement to this map area is Colorado City, Arizona, about 96 km (60 mi) north in a remote region of the Arizona Strip, northwestern Arizona (fig. 1). Elevations in the map area range from about 1,195 m (3,920 ft) in Whitmore Canyon (southwest corner of map) to 2,398 m (7,866 ft) at Mount Logan (northwest corner of the map). Primary vehicle access to this area is by dirt road locally known as the Mount Trumbull Road (fig. 1); unimproved dirt roads, such as the road to Woods Ranch in Whitmore Canyon and jeep trails, lead to various locations within the map area. Travel on the Mount Trumbull road and into Whitmore Canyon is possible with 2-wheel-drive vehicle, except during wet conditions. Four-wheel drive vehicles are recommended for all other roads and trails in the map area. Extra fuel, two spare tires, extra food and water are highly recommended when traveling in this remote area.

The map area is managed by the U.S. Bureau of Land Management, Arizona Strip District, St. George, Utah, and includes about 3 sections of land belonging to the State of Arizona, and about 2.5 sections of private land. A small strip of land along the south edge of the map lies within the Lake Mead National Recreation Area, and about 12 or 13 sections are within Grand Canyon National Park (originally Grand Canyon National Monument; Grand Canyon National Park since 1975). The private land is near Woods Ranch in Whitmore Canyon, and the Arkansas Ranch, northeast corner of the map area. Mount Logan and the Sawmill Mountains were originally established in 1904 as part of the Dixie National Forest. In 1924 the Dixie National Forest became the Kaibab National Forest. On February 13, 1974, this part of the Kaibab National Forest was transferred to the Bureau of Land Management (Personal communication, Becky Hammond, Bureau of Land Management, Spring, 1997). Mount Logan and Hells Hole are now part of a designated wilderness area (not shown on map). Lower elevations within Whitmore Canyon support a sparse growth of sagebrush, cactus, grass and a variety of desert shrubs. Sagebrush, grass, cactus, cliffrose bush, pinion pine, juniper, ponderosa pine, and oak forest thrive at elevations above 1,830 m (6,000 ft).

Surface runoff is mainly south towards the Colorado River, about 11 km (7 mi) south of this map. Whitmore Canyon is part of the western Grand Canyon, but is not included within the Grand Canyon National Park or the Lake Mead National Recreational Area because of local ranching and mining interests.

PREVIOUS WORK

Reconnaissance photo geologic mapping of this area was compiled onto Arizona state geologic maps by Wilson and others (1969) and revised by Reynolds (1988). A preliminary geologic map of this area was produced by Billingsley and Huntoon (1983). Geologic mapping of adjacent areas include: (1) the upper Hurricane Wash and vicinity, which adjoins the northwest corner of this map (Billingsley, in press a), (2) the Clayhole Valley and vicinity, which adjoins the north edge of this map (Billingsley, in press b), and (3) the upper Parashant Canyon and vicinity, which borders this area on the west (Billingsley in press c; fig. 1).

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 having similar lithology, but different geomorphic characteristics, were mapped almost entirely by photogeologic methods. Stratigraphic position and amount of erosional degradation helped determine differences between young and old alluvial deposits of similar lithology. Each map unit and structure was investigated in detail in the field to insure accuracy and consistency of description.

GEOLOGIC SETTING

The map area lies within the Shivwits and Uinkaret Plateaus, subplateaus of the Colorado Plateaus physiographic province, and the western Grand Canyon. The boundary between the higher Uinkaret Plateau and the lower Shivwits Plateau is marked by the Hurricane Fault (Billingsley and others, in press). The physiographic boundary of the Grand Canyon is arbitrarily marked along the rim of Whitmore Canyon. Whitmore Canyon has eroded headward into the Shivwits Plateau and into a small part of the Uinkaret Plateau at Hells Hole.

The Shivwits and Uinkaret Plateaus are characterized by nearly flat-lying Paleozoic and Mesozoic sedimentary strata that are warped by minor folds. These strata have an average regional dip of about 1° east, except along the base of the Hurricane Fault, where dips are as steep as 15° east. The steep east-dipping strata reflect the reverse fault drag along the Hurricane Fault and, in part, the east-dipping Hurricane Monocline. The Hurricane Monocline is not clearly defined in this map area, but is defined north (Billingsley, in press b) and south (Billingsley and Huntoon, 1983) of this map area. The Hurricane Fault offsets both sedimentary and overlying volcanic rocks. Vertical displacement across the Hurricane Fault is estimated at about 610 m (2,000 ft, down to the west) at the northwest edge of the map, and about 400 m (1,315 ft, down to the west) in the south half of the map. The Hurricane Fault splits into several faults in Whitmore Canyon that align along a north-south strike. Vertical

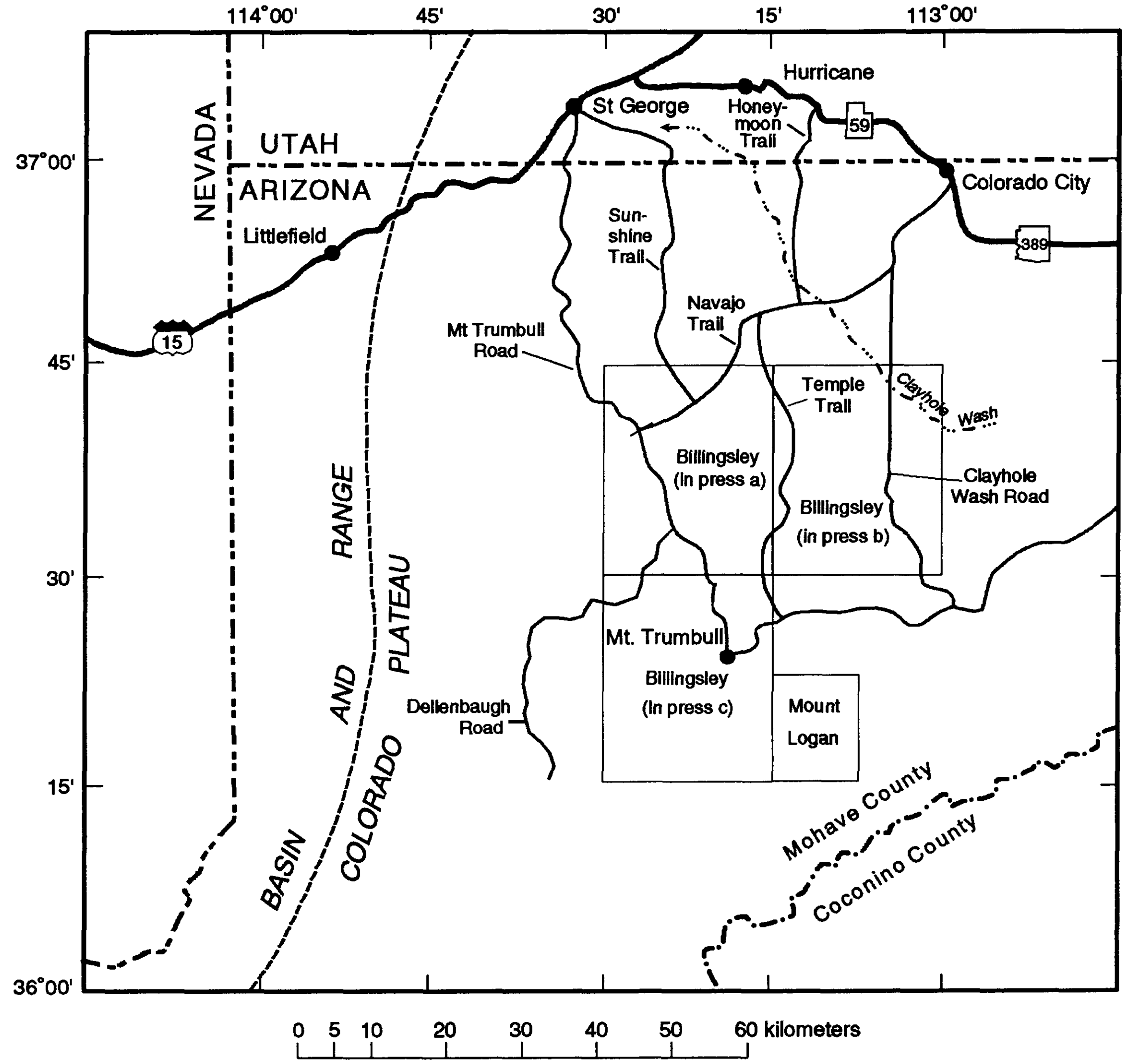

Figure 1. Index map for the Mount Logan quadrangle and vicinity, northern Mohave County, northwestern Arizona.

overall displacement across the various segments of the Hurricane Fault in Whitmore Canyon may be more than 400 m (1,315 ft), but total displacement is difficult to estimate because of thick alluvial cover and basalt flows.

Tertiary and Quaternary volcanic deposits cover about 2/3 of the map area and are part of the Uinkaret Volcanic Field consisting of olivine basalt dikes, flows, and pyroclastic deposits (Hamblin, 1994). The Quaternary alluvial deposits in the map area include artificial fill and quarries, terrace-gravels, alluvial fans, talus, and landslides. Map contacts between various surficial deposits are intertonguing and/or gradational, both laterally and vertically. All alluvial deposits in the map area are assigned a Quaternary age because the alluvial units contain clasts derived from Quaternary and older basaltic rocks of this map, as they do in adjacent areas (Billingsley, in press a, b, and c). The subdivision of alluvium on the map is intended to be useful for planning of roads, flood control, vegetation studies, soil investigations, erosion control, and other environmental land management decisions.

PALEOZOIC AND MESOZOIC SEDIMENTARY ROCKS

About 550 m (1,800 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 Formation, Coconino Sandstone, Toroweap Formation, and Kaibab Formation (Lower Permian); the Moenkopi and Chinle Formations (Lower and Middle Triassic). About 230 to 240 m (750 to 800 ft) of red siltstone and sandstone of the Hermit Formation is present on the east side of Whitmore Canyon, but is largely covered by alluvial fan and talus debris. The Esplanade Sandstone, not exposed in the map area, crops out below the Hermit Formation about 0.4 km (0.25 mi) south of this map on the east side of Whitmore Canyon. The tan and white Coconino Sandstone also crops out on the east side of Whitmore Canyon as a small cliff of cross-bedded sandstone, and thins rapidly north and west. In Whitmore Canyon, the Coconino Sandstone is a cross-bedded sandstone within the basal part of the Seligman Member of the Toroweap Formation. North and west of this map area, the Coconino rapidly thins and pinches out or forms lenses within the lower Toroweap. East and south of the map area, the Coconino rapidly thickens forming a mappable cliff unit at the base of the Toroweap Formation and unconformably overlying the Hermit Formation.

Gray siltstone, sandstone, gypsum, and limestone of the Toroweap Formation are well exposed in the upper steep slopes and ledges on the east side of Whitmore Canyon, and partly exposed on the west side. The type section for the Woods Ranch Member of the Toroweap is just east of Woods Ranch in Whitmore Canyon, southwest corner of this map area (Sorauf and Billingsley, 1991). Thickness of the Toroweap Formation averages about 160 m (520 ft) in the map area.

Unconformably overlying the Toroweap is a gray cherty limestone and pale-red and gray gypsiferous sandstone of the Kaibab Formation averaging about 160 m (530 ft) thick. Overall, the Kaibab gradually thickens north and west of this map, and gradually thins south and east. In the western Grand Canyon region, the top part of the Woods Ranch Member of the Toroweap Formation is locally eroded as small solution channels about 3 or 4 m deep. However, in some areas, large bowl-shaped depressions or channels are eroded as deep as 45 m (150 ft) into the Woods Ranch Member. The Fossil Mountain Member of the Kaibab thickens to as much as 45 m (150 ft) in these eroded bowl-shaped area at the expense of the Woods Ranch Member of the Toroweap. Much of the Harrisburg Member of the Kaibab is removed by Early Tertiary and Quaternary erosion where not unconformably overlain by strata of the Moenkopi Formation.

A major regional unconformity separates the Permian and Triassic strata. After deposition of the Harrisburg Member of the Kaibab Formation, stream channels were eroded into the Harrisburg forming paleoriver valleys and associated tributaries as deep as 45 m (150 ft) in this map area. One large paleovalley has eroded into the Harrisburg Member and just into the Fossil Mountain Member of the Kaibab Formation on the east rim of Whitmore Canyon, southwest corner of the map and filled with sediments of the Timpoweap Member of the Moenkopi Formation. This paleovalley is present at Whitmore Point, a few kilometers southwest of this map. Imbrication of pebbles in the conglomerate beds of the Timpoweap indicate deposition was from streams that flowed northeast. The conglomerate and sandstone material is locally derived from the Kaibab Formation.

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 (1,570 ft) of the Moenkopi Formation is exposed at Hells Hole, northwest corner of the map area. Elsewhere, strata of the Moenkopi are mostly covered by talus and landslide debris or basalt flows. At Hells Hole, about 120 m (400 ft) of the Chinle Formation is exposed and unconformably overlies the Moenkopi Formation. The unconformable contact is one of low relief, less than 3 m (10 ft). The Shinarump Member of the Chinle Formation is locally absent within the map area allowing the soft purple shale and white siltstone and sandstone of the Petrified Forest Member of the Chinle, to fill erosion channels cut into the red sandstone and siltstone of the upper red member of the Moenkopi Formation. Early Tertiary and Quaternary erosion has removed an unknown thickness of the upper part of the Chinle Formation and all younger strata above the Chinle that may have been present in this area before deposition of the Tertiary basalts.

VOLCANIC ROCKS

More than 30 basaltic cinder cones of Tertiary and Quaternary age dot the landscape in this map area, representing part of the Uinkaret Volcanic Field. The Tertiary basalt flows form a protective caprock over the soft strata of the Chinle and Moenkopi Formations, mainly along the downthrown block of the Hurricane Fault, at Mount Logan, and just north of Mount Emma. The Moenkopi and Chinle strata are easily eroded around the edges of the basalt flows, and seepage of water through the basalt flows towards the edges have helped to induce landslides rooted in the soft strata.

There are three whole-rock K-Ar ages obtained from the Tertiary basalt flows in or near this map area: (1) a 3.67 ± 0.09 Ma age from the Mount Trumbull Basalt, just north of this map (Best and others (1980); (2) a 3.6±0.18 Ma age from the Bundyville basalt just northwest of this map (Reynolds and others, 1986); and (3) a 2.63±0.34 Ma age from the Mount Logan basalt of this map area (Reynolds and others, 1986). No age determinations were obtained from any of the younger basalt flows in the map area. However, Jackson (1990) reported a whole rock K-Ar age of 0.635±0.24 Ma from a basalt flow about 10 km (6 mi) northeast of this map near the head of Toroweap Valley, and Billingsley (1994) reported a whole rock K-Ar age of 0.83±0.28 Ma age from the Antelope Knoll Basalt about 29 km (18 mi) north of this map. There are several K-Ar ages between 1.2 and 0.17 Ma from basalts within the Grand Canyon about 9.6 km (6 mi) south of this map (Hamblin, 1994). The youngest basalt flow is near the Arkansas Ranch and east of Little Spring, northeast corner of the map. This basalt flow appears to be only a few thousand years old at most, and as comparable to the thousand year old basalt flows of Sunset Crater near Flagstaff, Arizona.

Most of the basalt flows erupted from dikes or vent areas identified by cinder cones. Several dikes are suspected of being buried by subsequent flows, pyroclastic deposits, or landslide masses. The volcanic rocks have preserved a unique view into the past as to the geomorphic development and setting of the landscape of this part of the Arizona Strip.

Most of the volcanic rocks in this map area are assumed to be Quaternary age. The Quaternary basalt flows and pyroclastic deposits of Slide Mountain, Petty Knoll, and Mount Emma are the most prominent landmark volcanoes in the map area. Lava flows from these volcanoes have formed extensive basalt cascades westward into Whitmore Canyon and eastward into Toroweap Valley. The basaltic rocks are briefly described as follows; oldest to youngest:

Bundyville basalt

Hamblin (1970) was the first to talk about the basaltic rocks east of the town of Mt. Trumbull (Bundyville, 6.4 km [4 mi] northeast of this map area) and informally referred to them as the Bundyville basalt. The basalt is on a downthrown block along the west side of the Hurricane Fault (northwest corner of this map). The basalt was sampled for a whole rock K-Ar age determination in 1968 by Paul Damon, University of Arizona, that yielded a 3.60±0.018 Ma age (Reynolds and others, 1986). The name Bundyville basalt was used informally by Reynolds and others (1986), by Billingsley (in press c), and is informally used in this report.

The thick Bundyville basalt overlies about 122 M (400 ft) of soft strata of the Petrified Forest Member of the Chinle Formation about 4 km (2.5 mi) northwest of this map (Billingsley, in press c). The gently east-dipping strata of the Chinle Formation reflect the Hurricane Monocline structure. The Chinle strata were eroded to a nearly flat surface with a northwesterly drainage before the eruption and deposition of the Bundyville basalt.

Landslide debris and talus covers most of the Moenkopi and Chinle strata around and below the Bundyville and Mount Logan basalt. The landslide masses may be the result of earthquake shaking by periodic movement along the Hurricane Fault. Earthquakes may have helped initiate the distortion of the Bundyville basalt flow surfaces into a lumpy and hummocky expression because they overlie soft mudstone and shale of the Chinle. Earthquakes and wet conditions probably initiate landslide masses to creep downslope around the edges of the flows. Older landslide masses that have slid far downslope have disintegrated into blocky talus deposits.

On aerial photos, Death Valley Lake (northwest corner of the map area) appears to be a volcanic crater because of a circular ridge of small peaks surrounding the lake. The Hurricane Fault trace goes right through Death Valley Lake. However, the ridges on the east side of the lake and fault are rocks of the Shnabkaib Member of the Moenkopi Formation, while the Bundyville basalt crops out on the west side. The uptilted, west-dipping lavas on the west side of Death Valley Lake may be dikes that parallel the Hurricane Fault, or basalts that have been bent up along the fault. Most of the Bundyville basalt probably came from dikes that parallel the Hurricane Fault trace and are now buried by subsequent flows, or landslide and talus debris. Several basalt dikes are exposed in Hells Hole just east of the Hurricane Fault that may be some of the source dikes for part of the Bundyville basalt. However, the dikes in Hells Hole may be of Quaternary age because they are also aligned in a more north-south direction not quite parallel to the Hurricane Fault, and may be the source dikes for Quaternary basalt flows just north of Hells Hole. There are no age determinations of these dikes. Most of the Bundyville basalt appears to have flowed north and west from the Death Valley Lake area.

Offset along the Hurricane Fault, based on the Chinle/Moenkopi contact, and the basalt/Chinle contact on both sides of the fault, is about 610 m (2,000 ft). Displacement of the basalt and underlying strata are equally offset along this segment of the Hurricane Fault, making the fault younger then the 3.6 Ma Bundyville basalt.

Mount Logan basalt

In the northwest quarter of this map area and east of the Hurricane Fault and Hells Hole, is a Tertiary age basalt at Mount Logan overlying the Chinle Formation. The name Mount Logan basalt was informally introduced by Reynolds and others (1986), but was sampled by Paul Damon in 1968 which yielded a 2.63±0.34 Ma whole-rock K-Ar age.

The 2.6 Ma age suggests that the Mount Logan basalt is younger than the Bundyville basalt. However, the basalt flows at Mount Logan overlie 122 m (400 ft) of the Chinle Formation. West of Mount Logan, the Bundyville basalt overlies the same 122 m (400 ft) of the Chinle Formation. Therefore, based on stratigraphic position and the close proximity of both basalts, it is likely that the Bundyville and Mount Logan basalt are probably the same age, if not the same basalt. Hand specimens of basalt from either locations have the same characteristics, but chemical analysis were not done. Further analysis is needed to determine if both basalts are the same.

Tertiary basalt north of Mount Emma

About 6.5 km (4 mi) south of Mt. Logan and just north of Mount Emma, is another outcrop of Tertiary age basalt that Hamblin (1970) called a Stage I basalt, which represents the oldest basalt flows in the Uinkaret Volcanic Field. The Stage I basalt north of Mount Emma remains unnamed and unsampled for K-Ar age determination and other analysis. Hamblin (1970) suggests that the Stage I basalt flows of Mount Trumbull, Mount Logan, Bundyville basalt, and the Tertiary basalt just north of Mount Emma, were all once part of a continuous lava field. The Tertiary flows of this region flowed east and downslope across eroded strata of the Chinle and Moenkopi Formations toward Toroweap Valley and the Bundyville basalt flowed west and northwest of the Hurricane Fault. The four Stage I Tertiary basalt flows of this part of the Uinkaret Volcanic Field appear to be separate flows, but may have erupted at about the same time. Future analysis may suggest that they were all once connected to one another. Younger volcanic rocks have erupted within the Grand Canyon south of this map area and discussed by Hamblin (1994).

STRUCTURAL GEOLOGY

High angle to nearly vertical normal faults and gently tilted strata are the structural characteristic of the Shivwits and Uinkaret Plateaus. The east-dipping Hurricane Monocline overlies deep-seated 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 normal down-to-the-west faults along the monoclines, reversing the Cretaceous and Tertiary offsets.

Equal offset of the 3.6 Ma Bundyville basalt and underlying Mesozoic and Paleozoic strata along this segment of the Hurricane Fault began after deposition of the Bundyville basalt. The Hurricane Fault trace can be identified on aerial photos and from topographic relief, but most of the fault is covered by landslide and talus debris. Near the center of the map, the Hurricane Fault divides into at least two, and possibly three segments that have an overall offset of strata as much as 550 m (1,800 ft).

The regional dip increases to an average of about 5° east along the west side of the Hurricane Fault, and has a maximum dip of as much as 15 ° east. North and south of this map area, the Hurricane Monocline axis is well defined and is just west of and parallel to the Hurricane Fault (Huntoon and others, 1981; Wenrich and others, 1986; Billingsley, in press a). The axis of the Hurricane Monocline is uncertain and poorly defined in this map area, therefore it is not indicated on the map. There is Holocene displacement to as much as 10 m (30 ft) of the alluvial deposits along the Hurricane Fault in Whitmore Canyon, southwest quarter of this map area.

Locally 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 bent strata are commonly associated with the solution of gypsum along drainages or joints in the Whitmore Canyon area.

DESCRIPTION OF MAP UNITS

SURFICIAL DEPOSITS

(Surficial deposits are differentiated from one another chiefly by photogeologic techniques on the basis of difference in morphologic character and physiographic position. Older alluvial fans and terrace-gravel deposits generally exhibit extensive erosion whereas younger deposits are either actively accumulating material, or are lightly eroded as observed on 1976 aerial photographs. Surficial units on this map may have slightly different names and descriptions than units with the same map symbols on adjoining maps, but are characteristically the same)

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

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), and upper part of valley-fill (Qv) deposits. Inset against intermediate alluvial fan (Qa_2) and older terrace-gravel (Qg_2) deposits. Stream channels subject to high-energy flows and flash floods. Little or no vegetation in stream channels. Contacts with other alluvial deposits approximate. About 1 to 2 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. Includes abundant well-rounded to subangular basalt clasts. Forms benches about 1 to 3 m above modern stream beds; locally inset into older terrace-gravel (Qg_2) and intermediate alluvial fan (Qa_2) deposits. About 1 to 3 m thick

Qa_1 **Young alluvial fan deposits (Holocene)**--Gray-brown silt and sand. Includes 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 includes well-rounded to sub-angular basalt clasts; partly cemented by gypsum and calcite in Whitmore Canyon area. Composed mainly of pyroclastic debris and basalt fragments in volcanic areas. In Whitmore Canyon, overlapped by or intertongues with stream-channel alluvium (Qs) and upper part of valley-fill (Qv) deposits; intertongues with young terrace-gravel (Qg_1), overlaps intermediate and older alluvial fan (Qa_2, Qa_3) deposits. Subject to extensive erosion by sheet wash and flash flood debris flows and minor arroyo erosion. Supports sparse growth of sagebrush, cactus, and moderate growths of grass. 1 to 4 m or more thick

Qc **Colluvial deposits (Holocene and Pleistocene)**--Black and reddish, coarse grained, fragmentary, cinder, scoria, ash, and basalt clasts; locally consolidated by gypsum and calcite cement. Common in enclosed basins or depressions in landslide areas. Limited to local accumulations generally not associated with stream drainages. Subject to temporary ponding. Supports sparse growths of grass and juniper trees. 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; includes well-rounded clasts of limestone, sandstone, and angular chert fragments derived from local outcrops of Paleozoic rocks. Intertongues or overlaps talus (Qt), terrace-gravel (Qg_1 and Qg_2), and alluvial fan (Qa_1 and Qa_2) deposits. Represents relatively less-active, low-gradient, alluvial stream-channel or shallow valley drainage deposits. Subject to sheetwash flooding; locally cut by arroyos as much as 2 m deep. Supports 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. Includes silt, sand, and gravel; partly cemented by calcite and gypsum. Intertongues with alluvial fan (Qa_1 Qa_2, and Qa_3), valley-fill (Qv), terrace-gravel (Qg_1 and Qg_2), and landslide (Ql) deposits. Supports sparse growth of sagebrush, cactus, and grass. Only thick or extensive deposits shown. Some talus deposits on east side of Whitmore Canyon are older remnants of landslide debris. About 2 to 6 m thick

Ql **Landslide deposits (Holocene and Pleistocene)**--Unconsolidated masses of unsorted rock debris. Includes detached blocks that have rotated backward and slid downslope as loose incoherent masses of broken rock and deformed strata, often surrounded by talus (Qt). Found principally below Tertiary basalt flows in upper Whitmore Canyon, Mount Logan, and the Sawmill Mountains. Includes large angular blocks of basalt that are as much as 3 m in diameter. Supports 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 thick

Qg_2 **Older-age terrace-gravel deposits (Holocene and 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 contains angular to rounded basalt boulders as much as 1 m or more in diameter. Forms benches about 2 to 8 m above modern stream floors, and about 1 to 5 m above young-terrace gravel (Qg_1) deposits. Intertongues 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 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; intertongues with or overlaps valley-fill (Qv) and talus (Qt) deposits. Inset against older alluvial fan (Qa_3) deposits. Includes abundant subrounded to subangular basalt cobbles and boulders. Supports sparse growth of sagebrush, cactus, grass, and juniper trees. Ranges from 2 to 25 m thick

Qa_3 **Older-age alluvial fan deposits (Pleistocene)**--Similar to young and intermediate alluvial fan (Qa_1 and Qa_2) deposits, partly cemented by calcite and gypsum. Commonly overlapped by young and intermediate alluvial fans (Qa_1 and Qa_2) and intertongues with talus (Qt) deposits. Often dissected by erosion with arroyos as deep as 2 m. Usually has thin soil developed on surface; supports moderate grass, cactus, and sagebrush. Ranges from 2 to 6 m thick

VOLCANIC ROCKS

Little Spring basalt (Holocene)--Informally named for Little Spring (SE 1/4, Sec. 16, T. 34 N., R. 8 W.), just west of Arkansas Ranch, northern Mohave County, Arizona (northeast quarter of this map). The olivine basalt and associated cinder cone represent the youngest volcanic rocks in the map area as well as the Uinkaret Volcanic Field. Whole-rock K-Ar age determinations have not been done, but based on the freshness of basalt flow surfaces, and the similarity to basalt flow freshness at Sunset Crater near Flagstaff, Arizona, this basalt deposit is probably less than 2,000 years old. Divided into:

Qlsp **Pyroclastic deposits**--Red-brown and reddish-black basaltic scoria, bombs, and uncemented cinder and other scoriaceous ejecta deposits. Consists of two areas that are part of a cinder cone about 41 m (135 ft) high on basalt flow surface (elevation 7,015 ft). Only eastern half of cone is present; western half may not have been formed. About 41 m thick

Qlsb **Basalt flow**--Dark-gray, finely crystalline to glassy, alkali olivine basalt. Groundmass composed of plagioclase and olivine. Forms clinker and highly broken aa surface. Includes one flow going north about 1.8 km, and one flow going southeast about 2.4 km. Overlies older Quaternary basalt flows, pyroclastic deposits, and alluvial fan (Qa_1) deposits. Ranges about 3 to 7 m thick

Qi **Basalt dikes (Pleistocene)**--Greenish-black olivine basalt, forms near versicle ridges surrounded by associated basalt flows north of Hells Hole. Widths of dikes shown on map are approximate and not clearly defined. Dikes within Hells Hole area may be of similar age

Qp **Pyroclastic deposits (Pleistocene)**--Reddish-black, red, and gray tuff, ash, scoria, cinder, bombs, and other scoriaceous ejecta; mostly unconsolidated except partly consolidated as gray welded tuff at Slide Mountain, Petty Knoll, and Mount Emma. Most deposits overlie local basalt flows as cones or thick cinder sheet deposits. Deposits form 31 cinder cones, some have two or three associated vents forming a common cone; includes about 6 lesser cones. Basalt flows at base of cinder cones intertongue or coalesce to form massive flows from several adjacent cones, suggesting a similar eruptive episode erupting simultaneously along north-south linear fissures, such as Petty Knoll, Slide Mountain, and Mount Emma. Other north-south pyroclastic cone alignments probably represent fissure-like eruptions that may be slightly younger or older than adjacent north-south cone alignments. No whole rock K-ar ages are available for cinder cones or flows in this map area, except for one sample from the middle part of Mount Logan that may or may not represent oldest basalt of Mount Logan. Map contact is arbitrary and encloses thickest deposits, not all thin deposits shown. Most prominent deposits are Slide Mountain, 183 m (600 ft) high, Petty Knoll, about 110 m (360 ft) high, and Mount Emma about 150 m (500 ft) high. Several other cinder cones in map area average about 60 m (200 ft) high

Qb **Basalt flows (Pleistocene)**--Medium-gray to light-gray, finely crystalline, alkali olivine basalt. Includes phenocrysts of augite, olivine, and, in some areas, hornblende, less than 1 mm in diameter in glassy groundmass. Includes large clusters of massive red or green olivine crystals, as much as 145 cm (6 in) in diameter, in southern part of volcanic field. Basalt flows overlie Tertiary basalts and east-dipping (1 to 2° average) lower units of Moenkopi Formation and Harrisburg Member of Kaibab Formation. Includes numerous basalt flows from cinder cones that lap onto themselves, or merge, intertongues, or coalesce into other multiple basalt flows from several common north-south aligned cinder cones. Ranges from 30 m to 92 m thick

QTi **Basalt dikes at Hells Hole (Pleistocene? and Pliocene?)**--Medium-gray to green-black, finely crystalline, alkali olivine basalt dikes; average widths, about 0.5 m (1 to 2 ft). Forms near vertical dikes exposed in Kaibab and Moenkopi Formations. Dikes align parallel to near vertical north-south joints (N. 10° W) in Paleozoic and Mesozoic rocks. Dikes also align parallel to Quaternary cinder cones north, east, and southeast of Hells Hole, but they are also close to the Tertiary Bundyville and Mount Logan basalts

Tmlb **Mount Logan basalt (Pliocene)**--Informally named for Mount Logan (Reynolds and others, 1986), a 2,400 m (7,866 ft) high mountain on the Uinkaret Plateau, northern Mohave County, Arizona (sec. 12, T. 34 N., R. 9 W.). K-Ar whole rock age 2.63±0.34 Ma obtained from basalt near middle of Mount Logan. Because younger basaltic rocks overly older basalts on Mount Logan, new K-Ar age determinations are needed to help determine sequence of basaltic events at Mount Logan

Basalt flow(s)--Light-gray, finely crystalline, alkali olivine basalt; contains red and green olivine phenocrysts 1 mm in diameter in glassy groundmass; includes pligoclase laths in glassy groundmass. Plagioclase masses form white spotted blotches in some basalt flows. Basalt flows overly Petrified Forest Member of Chinle Formation at Hells Hole (west half of sec 12, T. 34 N., R. 9 W., northwest quarter of map area); eastern extent of basalt may overlie upper red member and Shnabkaib Member of Moenkopi Formation. Basalt dikes below summit of Mount Logan in Hells Hole may be source for Mount Logan basalt, but dikes may also be Quaternary age and source for Quaternary basalt flows just north of Hells Hole. Basalts flowed east about 5.3 km (3.3 mi) from summit of Mount Logan descending about 335 m (1,100 ft). Average thickness, about 67 m

Tbb **Bundyville basalt (Pliocene)**--Informally named for abandoned settlement of Bundyville (Mt. Trumbull; Hamblin and Best, 1970; Hamblin, 1970), Shivwits Plateau, northern Mohave County, Arizona, (secs. 23, 24, 25, and 26, T. 35 N., R. 10 W.), exposed in northwest quarter of map area. Basalt flow(s) on downthrown side of Hurricane Fault. Whole-rock K-Ar age, 3.6±0.0.18 Ma (Reynolds and others, 1986)

Basalt flow(s)--Dark-gray, finely crystalline, olivine basalt. Groundmass contains olivine. Consists of several basalt flows forming caprock overlying purple and white mudstone and sandstone beds of Petrified Forest Member of Chinle Formation. Flow surfaces locally distorted by landslide and soft sediment deformation of underlying soft mudstone. Source of flows assumed to have originated from local dikes, now mostly covered by basalt or landslide and talus debris. Ranges from about 30 to 55 m thick

Basaltic rocks just north of Mount Emma (Tertiary?)--Gray-black alkali-olivine basalt; includes several basalt flows, pyroclastic deposits, and intrusive necks and dikes. Largely covered by Quaternary pyroclastic deposits of Mount Emma and other similar age north-south aligned cinder cone deposits, and associated basalt flows. Unit is offset by fault, about 200 m (650 ft). No age determinations done on these deposits, but assumed to be Tertiary age based on similarities of flow directions and elevation to Mount Logan basalt and Mount Trumbull basalt. Divided into:

Ti **Intrusive rocks**--Gray-black alkali-olivine basaltic neck. Only part of intrusive neck exposed and offset by fault. Most of unit covered by landslide debris. Width of neck, unknown. Source for associated Tertiary basalt flows north of and covered by Mount Emma

Tc **Pyroclastic deposits**--Reddish-black cinder, scoria, ash, and other scoriaceous ejecta; heavily eroded. Associated with intrusive neck (Ti) on downthrown side of fault. About 12 m thick

Tb **Basalt flows**--Gray-black alkali-olivine basalt, plagioclase laths common in glassy ground mass. Consists of several basalt flows that flowed east and south from neck area. Underlying strata concealed, but because of similar elevation as Mount Logan basalt, it is assumed these basalt flows overly strata of the Chinle Formation, or upper strata of the Moenkopi Formation. About 122 m thick

SEDIMENTARY ROCKS

Chinle Formation (Middle Triassic)--Includes Shinarump and Petrified Forest Members. Shinarump Member locally missing or has undergone local facies change to become sandstone lithology similar to Petrified Forest Member lithology; included as Petrified Forest Member this report

Ŧcp **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, brown, and red quartzite. Includes white, coarse-grained, ledge-forming sandstone at base in some outcrops that may be equivalent to Shinarump Member of Chinle; contains brown, yellow, white, and red petrified wood fragments. Contains bentonitic clays derived from decomposition of volcanic ash. Unconformable contact with overlying Bundyville basalt, not exposed in this maps area; erosion has removed unknown thickness of upper part. Unit mostly covered by Bundyville basalt (Tbb) and landslide debris (Ql). Unconformable contact with underlying slope-forming upper red member of Moenkopi Formation; erosional relief less than 2 m at Mount Logan. About 122 m thick

Moenkopi Formation (Lower Triassic)--Includes, in descending order, the upper red member, Shnabkaib Member, middle red member, Virgin Limestone Member, lower red member, and Timpoweap Member as used by Stewart and others (1972). Divided into:

Ŧmu **Upper red member**--Red, thin-bedded, cliff- and slope-forming, siltstone and sandstone. Unconformably overlain by Chinle Formation at Hells Hole and Sawmill Mountains. Gradational lower contact placed at uppermost thick white or light-gray calcareous siltstone and dolomite of Shnabkaib Member of Moenkopi Formation. Unit thins south and east, thickens north. Average thickness about 120 m

Ŧms **Shnabkaib Member**--White, laminated, slope-forming, aphanitic dolomite interbedded with light-gray, calcareous silty gypsum. Gradational and arbitrary lower contact with middle red member placed at lowest thick white or light-gray calcareous silty dolomite of Shnabkaib Member. Unit thins south and west, thickens north. Average thickness about 135 m

₮mm **Middle red member**--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 gypsiferous mudstone. Gradational and arbitrary lower contact with Virgin Limestone Member placed about 10 m above gray limestone bed of Virgin Limestone. Unit thins west, south, and east, thickens north. Average thickness about 120 m

₮mv **Virgin Limestone Member**--Consists of one light-gray, thin-bedded to thinly laminated, ledge-forming limestone bed, 0.5 to 2 m thick, and overlying, pale-yellow, red, and bluish-gray, thin-bedded, slope-forming gypsiferous siltstone. Thins south and west, thickens north to include two limestone beds just north of map area, and as many as 4 limestone beds near St. George, Utah. Erosional contact with underlying lower red member of Moenkopi Formation placed at base of limestone bed that locally pinches out onto or unconformably overlies paleohills of Harrisburg Member of Kaibab Formation. Thickness ranges from 0 to 20 m

₮ml **Lower red member**--Red, fine-grained, thin-bedded, gypsiferous, 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 Kaibab Formation. Gradational contact with underlying Timpoweap Member of Moenkopi Formation placed at lowermost red siltstone bed. Locally, unconformably overlies Harrisburg Member of Kaibab Formation where Timpoweap is absent. Locally thickens in paleovalleys, and pinches out onto eroded paleohills of underlying Harrisburg. Ranges from 0 to 20 m thick

₮mt **Timpoweap Member**--Light-gray, slope and cliff-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 yellowish sandstone, conglomerate, and minor red siltstone. Includes calcite and gypsum cement. All detritus in Timpoweap derived from Kaibab Formation. Fills paleovalley about 1,500 m wide and as much as 70 m deep that eroded into Harrisburg Member of Kaibab Formation (fig. 2). Imbrication of pebbles in conglomerate show general northeastward flow of depositing streams. Ranges from 0 to 50 m thick

Kaibab Formation (Lower Permian)--Includes, in descending order, Harrisburg and Fossil Mountain Members as defined by Sorauf and Billingsley (1991). Divided into:

Pkh **Harrisburg Member**--Includes an upper, middle, and lower part. Upper part consists mainly of slope-forming, red and gray, interbedded gypsiferous siltstone, sandstone, gypsum, and thin-bedded gray limestone. Upper part mostly eroded from southern quarter of map area because of paleovalley. Gradational contact with middle part. Middle part consists mainly of two, thin, cliff-forming limestone beds as much as 2 m thick: upper bed is gray, thin-bedded, cherty limestone that weathers dark brown or black often forming bedrock surface of exposed Harrisburg Member; lower bed is light-gray or yellow, thin-bedded, sandy limestone. Both beds thicken and thin locally, gradually thickening east and north and thinning west. Minor erosional unconformity separates middle from lower part. Lower part consists of slope-forming, light-gray, gypsiferous 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 west side of Whitmore Canyon. Gradational and arbitrary contact with underlying Fossil Mountain Member at top of cherty limestone cliff of Fossil Mountain. As much as 76 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 Toroweap Formation marked by solution and channel erosion with relief as much as 5 m; contact locally obscured by talus and minor landslide debris. About 85 m thick

Toroweap Formation (Lower Permian)--Includes, in descending order, Woods Ranch, Brady Canyon, and Seligman Members as defined by Sorauf and Billingsley (1991). Type section for Woods Ranch Member just east of Woods Ranch in Whitmore Canyon, this map. Divided into:

Ptw **Woods Ranch Member**--Gray, slope-forming gypsiferous siltstone and pale-red silty sandstone interbedded with white laminated gypsum. Beds are locally distorted due to gypsum solution. Lower contact gradational and marked by topographic break from slope-forming Woods Ranch to cliff-forming limestone of Brady Canyon Member. Thickness varies from 55 to 60 m owing to solution of gypsum or channel erosion in upper part

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. Contact with Seligman Member at recess in cliff or top of slope-forming gypsifereous sandstone; gradational. Contact commonly covered by minor slump or talus debris. Approximately 60 m thick

Pts **Seligman Member**--Gray, thin-bedded, slope-forming dolomite and gypsiferous sandstone. Upper part includes gray to red, thinly-interbedded siltstone, sandstone, and gypsum; lower part includes mostly brown, purple, and yellow, fine- to medium-grained, thin-bedded, low- to high-angle crossbedded and planar-bedded sandstone. Includes high-angle fine- to medium-grained, cross-bedded Coconino Sandstone that thins and thickens in lower part. Coconino Sandstone is 1 to 9 m thick, pinches out west and north, thickens east and south. Coconino interbedded with yellow, flat, thin-bedded sandstone and siltstone of basal part of Seligman Member. Seligman Member unconformably overlies Hermit Formation; 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, yellowish-white, fine-grained, thin- to medium-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. Lower contact with Esplanade Sandstone is covered, elsewhere, contact is erosional unconformity with as much as 25 m (80 ft) of relief. Hermit mostly covered by talus and alluvial deposits east side of Whitmore Canyon. About 250 m thick

Contact

Fault--Dashed where inferred or approximately located; dotted where concealed; bar and ball on downthrown side. Number is estimated dip-slip displacement in meters. Number in parenthesis is offset of alluvial deposits in meters

Landslide scarp--Headward scarp of landslide; hachures point in direction of slide

Strike and dip of beds

Inclined--Measured in the field

Approximate--Estimated from aerial photographs

Implied--Interpreted from aerial photographs, dip amount not determined

Flow direction of basalt--Interpreted from aerial photographs of flow channels, collapsed lava tubes, marginal flow levees, and frontal lobes

Volcanic vent area

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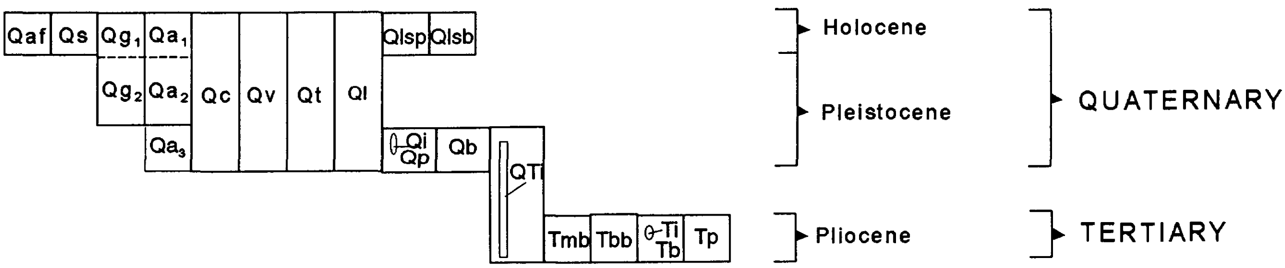
CORRELATION OF MAP UNITS

SURFICIAL DEPOSITS AND IGNEOUS ROCKS



SEDIMENTARY ROCKS