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GEOLOGIC MAP OF PART OF THE UINKARET VOLCANIC FIELD, MOHAVE COUNTY, NORTHWESTERN ARIZONA

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INTRODUCTION

The geologic map of part of the Uinkaret Volcanic Field is one product of a cooperative project between the U.S. Geological Survey, the National Park Service, and the Bureau of Land Management to provide geologic information about this part of the Grand Canyon-Parashant Canyon National Monument of Arizona. The Uinkaret Volcanic Field is a unique part of western Grand Canyon where volcanic rocks have preserved the geomorphic development of the landscape. Most of the Grand Canyon, and parts of adjacent plateaus have already been mapped. This map completes one of the remaining areas where uniform quality geologic mapping was needed. A few dozen volcanoes and lava flows within the Grand Canyon are not included in the map area, but their geologic significance to Grand Canyon development is documented by Hamblin (1994) and mapped by Billingsley and Huntoon (1983) and Wenrich and others (1997). The geologic information in this report may be useful to resource managers of the Bureau of Land Management for range management, biological, archaeological, and flood control programs.

The map area lies within the Shivwits, Uinkaret, and Kanab Plateaus, which are subplateaus of the Colorado Plateaus physiographic province (Billingsley and others, 1997), and is part of the Arizona Strip north of the Colorado River. The nearest settlement is Colorado City, Arizona, about 58 km (36 mi) north of the map area (fig. 1). Elevations range from about 2,447 m (8,029 ft) at Mount Trumbull, in the northwest quarter of the map area, to about 732 m (2,400 ft) in Cove Canyon, in the southeast quarter of the map area. Vehicle access is via the Toroweap and Mount Trumbull dirt roads (fig. 1). Unimproved dirt roads traverse other parts of the area except in designated wilderness. Extra fuel, two spare tires, and extra food and water are highly recommended for travelers in this remote area.

The U.S. Bureau of Land Management, Arizona Strip Field Office, St. George, Utah manages most of the area. In addition, there are 12 sections belonging to the State of Arizona, about 12 sections are private land, and several sections are within the Grand Canyon National Park and Lake Mead National Recreational Area (U.S. Department of the Interior, 1993). The private land is in Potato Valley and Lake Valley, southwest and west of Mount Trumbull, and in Whitmore Canyon and Toroweap (Tuweap) Valley. Portions of the Sawmill Mountains, Mount Logan, and Mount Trumbull areas were originally established as part of the Dixie National Forest in 1904. In 1924, Dixie National Forest land became part of the Kaibab National Forest. Then on February 13, 1974, management of this part of the Kaibab National Forest was transferred to the Bureau of Land Management, Arizona Strip Field Office (personal commun. Becky Hammond, Bureau of Land Management, 1997). Mount Logan and part of the Sawmill Mountains are now designated as the Mount Logan Wilderness Area, and Mount Trumbull is designated as the Mount Trumbull Wilderness Area. Most of the map area is now part of the new Grand Canyon-Parashant Canyon National Monument established January 11, 2000.

Lower elevations within Hells Hollow, Whitmore Canyon, Toroweap Valley, and Cove Canyon support a sparse growth of sagebrush, cactus, grass, and a variety of desert shrubs. Sagebrush, grass, cactus, cliffrose bush, pinion pine, and juniper trees thrive at elevations above 1,830 m (6,000 ft). Ponderosa pine and oak forests thrive at higher elevations in the Mount Trumbull and Mount Logan areas.

Surface runoff within the map area drains south towards the Colorado River through Hells Hole, Hollow, Whitmore Canyon, Toroweap Valley, and Cove Canyon. Upper Toroweap Valley, upper Hells Hollow, and Whitmore Canyon are part of the physiographic area of Grand Canyon, but are not within Grand Canyon National Park (Billingsley and others, 1997). As of January 11, 2000, these areas are now part of the new Grand Canyon-Parashant Canyon National Monument.

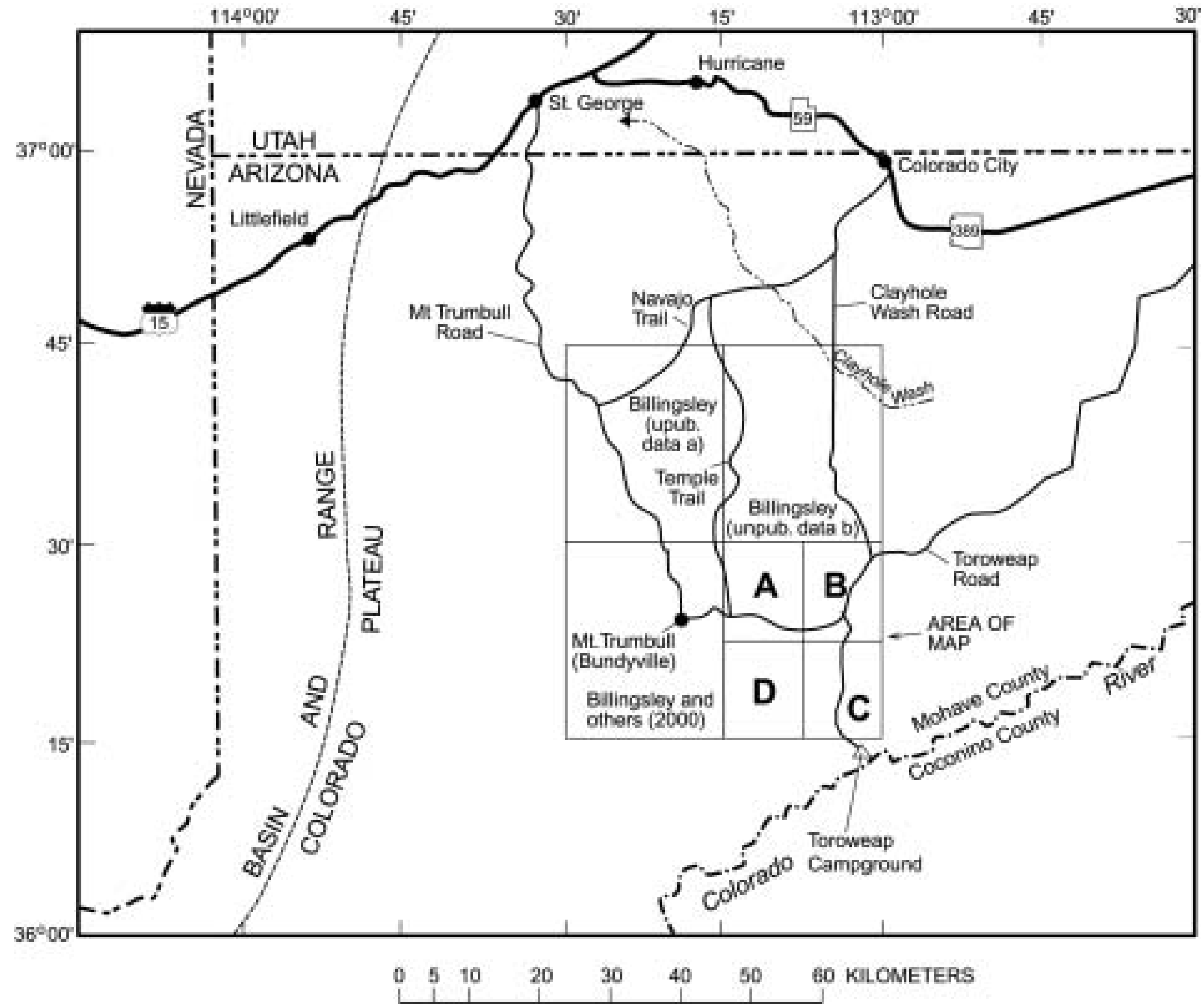

Figure 1. Map showing the Mount Trumbull NW (A), Mount Trumbull NE (B), Mount Logan (C), and Mount Trumbull SE (D), U.S. Geological Survey 7.5-minute quadrangles and adjacent mapped areas, northern Mohave County, northwestern Arizona.

PREVIOUS WORK

Dutton (1882) made the earliest geologic map of the Uinkaret Plateau. A reconnaissance photogeologic map was produced by Koons (1945), and later compiled onto a state geologic map of Arizona by Wilson and others (1969), and then recompiled to a different scale by Reynolds (1988). The first recorded survey of the Uinkaret Volcanic Field was by Powell (1875) in 1869-72. Powell named the Uinkaret Plateau and applied the names of Mount Trumbull, Mount Logan, and Mt. Emma to prominent peaks. He discovered the Toroweap Fault and estimated its displacement to be about 244 m (800 ft) (Powell, 1875). Geologic maps of the Mount Logan and Mount Trumbull NW quadrangles (Billingsley, 1997a, b) are compiled into the western half of the map area. Geologic mapping of adjacent areas (fig. 1) include upper Hurricane Wash and vicinity, which adjoins the northwest corner of this map (Billingsley, unpub. data a); upper Parashant Canyon and vicinity bordering the western edge of this map (Billingsley and others, 2000); and

Clayhole Valley and vicinity, which borders the northern edge of this map (Billingsley, unpub. data b). A geologic map by Wenrich and others (1997) borders the southern edge of the map area.

MAPPING METHODS

This map was produced using 1:24,000-scale 1976 aerial photographs followed by extensive field checking. Volcanic rocks were mapped as separate units when identified on aerial photographs as mappable and distinctly separate units associated with one or more cinder cones and flows. Several basalt flows and associated cinder cones at similar stratigraphic levels could not be distinguished as separate units with certainty and were mapped as general Quaternary basalt units (Qp and Qb south of Mount Trumbull, Qp1 and Qb1 north of Mount Trumbull) based on stratigraphic relations and coalescing basalt flows. Textural and mineral characteristics are not distinctive enough to separate individual basalt units.

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 determine relative ages of alluvial deposits having similar lithologies. Each map unit and structure was investigated in detail in the field to insure accuracy of description.

GEOLOGIC SETTING

The boundary between the lower Shivwits and higher Uinkaret Plateaus is the Hurricane Fault. The Shivwits Plateau is west of the Hurricane Fault on the downthrown side, and the Uinkaret Plateau is east of the fault on the upthrown side. The boundary between the Uinkaret and Kanab Plateaus is the Toroweap Fault; the Uinkaret Plateau is west of the Toroweap Fault on the downthrown side, and the Kanab Plateau is east of the fault on the upthrown side.

Nearly flat-lying Paleozoic and Mesozoic sedimentary strata that have an average regional dip of about 1º ENE characterize the Shivwits, Uinkaret, and Kanab Plateaus, except near the Hurricane and Toroweap Faults. Strata along the downthrown side of these faults are largely covered by alluvium, basalt flows, or landslide debris, but exposures in the Grand Canyon 5 km (3 mi) south of this map area show Paleozoic strata dipping east toward the fault planes about 14º along the Hurricane Fault and about 4º along the Toroweap Fault. These dips may reflect a weak monoclinal structure associated with both faults as suggested by Huntoon (1990) and indicated by Billingsley and Huntoon (1983) and Wenrich and others (1997), but the monoclinal axis is not shown on the map because the monoclines are weakly present along these segments of the Toroweap and Hurricane Faults. Tilted strata west of the faults illustrate a reverse fault drag as suggested by Hamblin (1965). Maximum vertical separation of strata across the Hurricane and Toroweap Faults is estimated at about 610 m (2,000 ft) and 198 m (650 ft), respectively.

Tertiary and Quaternary volcanic rocks and surficial deposits are widely distributed in the map area. The volcanic rocks are mostly alkali-olivine basalt flows and pyroclastic deposits of the Uinkaret Volcanic Field. These rocks cover about two-thirds of the map area. At least 154 pyroclastic cones are present in the map area. An additional 35 pyroclastic cones are just south of the map area (Billingsley and Huntoon, 1983; Wenrich and others, 1997) and 24 more are just north of the map area (Billingsley and Workman, 1999) bringing the total number of volcanic cones in the Uinkaret Volcanic Field to about 213. Tertiary age volcanoes began erupting about 3.6 Ma at four separate areas within the Uinkaret Volcanic Field and later became surrounded or covered by numerous Pliocene and Pleistocene volcanic deposits.

Mapped surficial deposits include stream channel, floodplain, terrace gravels, alluvial fans, talus debris, valley-fill, colluvial, and landslide deposits. Artificial fill and quarry deposits are also mapped. Map contacts between Quaternary deposits are arbitrary because of intertonguing and (or) gradational lateral and vertical changes. The subdivision of Quaternary surficial units on the map is intentionally detailed because these units strongly influence the management of rangeland, flood control, biological studies, soil erosion, and the planning of road construction. All surficial deposits in the map area are Pleistocene or younger, because they contain materials derived from Quaternary volcanic deposits (Billingsley, 1997a, b; unpub. data a, b; Billingsley and others, 2000).

PALEOZOIC AND MESOZOIC SEDIMENTARY ROCKS

There are about 1,220 m (4,000 ft) of Cambrian, Devonian, Mississippian, Pennsylvanian, and Permian strata exposed in the map area and about 600 m (1,970 ft) of Triassic strata. The Paleozoic and Mesozoic rocks are sedimentary and are, in order of decreasing age, the Muav Limestone (Cambrian), the Temple Butte Formation (Devonian), the Redwall Limestone (Mississippian), the lower Supai Group undivided (Pennsylvanian and Mississippian), the Esplanade Sandstone of the Supai Group (Permian), the Hermit Formation, Coconino Sandstone, Toroweap Formation, and Kaibab Formation (Permian), the Moenkopi Formation (Triassic), and the Chinle Formation (Triassic). The Coconino Sandstone is mapped as a separate unit as with current Grand Canyon nomenclature because it forms a mappable unit, but the Coconino Sandstone intertongues within the lower part of the Seligman Member of the Toroweap Formation as suggested by Fisher (1961), Schleh (1966), Rawson and Turner (1974), Billingsley (1997a), and Billingsley and others (2000).

All Paleozoic rocks are well exposed in Cove Canyon, in the southeast quarter of the map area, and Permian strata form the walls of Toroweap Valley and Whitmore Canyon. Whitmore Canyon was originally called Queantoweap Valley (Koons, 1945), and it is not known when the name was changed. Gray to red or reddish gray interbedded siltstone, sandstone, limestone, and gypsum of the Harrisburg Member of the Kaibab Formation form the bedrock surface of all the plateaus where not covered by Mesozoic strata, volcanic rocks, or alluvial deposits.

The Mesozoic rocks consist mainly of red siltstone and sandstone of the Moenkopi Formation and mudstone of the lower part of the Chinle Formation. A complete section of these rocks is well exposed in Hells Hole, a steep-walled amphitheater that drains into Whitmore Canyon. The Chinle Formation is exposed west of Mount Logan (Hells Hole) and west of the Hurricane Fault. Most of the Triassic Moenkopi strata are covered by Quaternary basalt flows and landslide debris in the Sawmill Mountains, Mount Logan, and Mount Trumbull areas. Early Tertiary and Quaternary erosion removed an unknown thickness of the upper part of the Chinle Formation and all subsequent younger strata before deposition of the Tertiary basalts. An unknown thickness of Chinle Formation is present under the Tertiary basalt flows that cap Mount Trumbull because Chinle float material occurs in landslide debris on the western and northern flanks of Mount Trumbull.

A regional unconformity separates the Permian and Triassic strata. After deposition of the Harrisburg Member of the Kaibab Formation, streams eroded valleys as deep as 50 m (160 ft). These paleovalleys are now filled with sediments of the Timpoweap Member of the Moenkopi Formation (Triassic). The chert, limestone, sandstone, and gypsum clasts within the Timpoweap Member are derived from the Kaibab Formation. Pebble imbrications in the Timpoweap Member indicate that east- and northeast-flowing streams deposited these clasts.

VOLCANIC ROCKS

QUATERNARY VOLCANIC ROCKS

Quaternary basalt flows are more widespread than Tertiary basalt flows and generally surround the Tertiary flows at lower elevations. The Quaternary basalt flows are generally associated with a late-stage eruptive phase that resulted in the formation of numerous pyroclastic cinder cones. There are about 154 Quaternary cinder cones within the map area. Fissure eruptions along north-south fractures and joints in the bedrock have allowed for extensive simultaneous eruptions of basalt flows and pyroclastic cones that form several aligned cones such as Mt. Emma, Petty Knoll, and Slide Mountain. In most cases, the dying stages of gaseous vents appear to have formed large pyroclastic cones on top of associated basalt flows as lava spread out and coalesced with flows from other nearby eruptive centers. However, in some cases the basalt flow appears to have been the last stage when basalt flows rafted away parts of the cone. In either case, basalt flows and associated pyroclastic cones in this map and report are treated as a same-time, single, eruptive phase, even when map contacts show pyroclastic cones are younger than the basalt flows. Many of the basalts carry mantle derived peridotite inclusions indicating that the magma originated from the upper mantle (Best and others, 1970). Dutton (1882) and Koons (1945) observed the tendency for cones on the Uinkaret Plateau to align parallel to faults but to occur in the areas between them. Area mapping and adjacent mapping (Billingsley and others, 2000) show that volcanic cones and dikes align to local bedrock joint and fracture systems that predate faulting.

K-Ar ages have been determined for some of the basalt flows. Jackson (1990) reported a 0.635±0.24 Ma age from a basalt flow in the upper reaches of Toroweap Valley. The location of his sample was not reported, but Jackson mentioned an offset of the flow of about 36 m (118 ft) along the Toroweap Fault. The road into Toroweap Valley (this map area) parallels the Toroweap Fault and is built on the basalt of Graham Ranch flow that entered Toroweap Valley from the east. The basalt of Graham Ranch is offset by the Toroweap Fault about 34 to 36 m (110 to 118 ft) and is likely the same basalt from which Jackson (1990) obtained the 0.63 Ma date.

Billingsley (1994a) reported a K-Ar age of 0.83±0.28 Ma for the Antelope Knoll Basalt about 29 km (18 mi) north of the map area at the north margin of the Uinkaret Volcanic Field. There are several K-Ar ages between 1.2 Ma and 0.44 Ma reported by Hamblin (1994) from basalt flows along the south edge of the Uinkaret Volcanic Field within the Grand Canyon (about 9.6 km [6 mi] south of the map area). Wenrich and others (1995) reported a K-Ar age of 0.76±0.08 Ma for a basalt flow in Tuckup Canyon about 9.6 km (6 mi) east of the map area and a 0.407±0.07 Ma age for a dike about 17.6 km (11 mi) east of the map area. Anderson and Christensen (1989) reported a K-Ar age of 0.203 Ma for basalt in the lower reaches of Toroweap Valley (southeast edge of the map area), but did not specify a site or range of age error. The youngest basalt flow in the Uinkaret Volcanic Field is about 1,000 years old as determined by cosmogenic ^{3}He dating methods (Fenton, 1998). This young volcano is about 3 km (2 mi) south of Mount Trumbull and east of Little Spring and is informally named the basalt of Little Spring (this report). This basalt is comparable in surface characteristics and texture to the 1,000-year-old Sunset Crater Volcano near Flagstaff, Arizona.

The cosmogenic ^{3}He dating technique identifies other very young basalt flow surfaces in the map area. According to Fenton (1998), basalt flow surfaces south of Mt. Emma that cascaded into Toroweap Valley and Whitmore Canyon are about 0.100 Ma. Some of these basalt flows and associated pyroclastic deposits form mappable units in the northwest quarter of the map area. The basalt flows and pyroclastic deposits of Slide Mountain, Petty Knoll, and Mt. Emma are among the most prominent and impressive Quaternary volcanoes and appear to have erupted at about the same time. Lava from many of the volcanoes in the Mt. Emma chain form flows that coalesced and cascaded down drainages and over the general landscape westward into Whitmore Canyon and eastward into Toroweap Valley (Canyon) to the Colorado River south of the map area (Hamblin, 1994; Billingsley and Huntoon, 1983; Wenrich and others, 1997; Fenton, 1998).

Toroweap Valley is about 5 km (3 mi) wide and contains as much as 100 m (300 ft) of basalt and alluvium in the upper reaches and as much as 670 m (2,200 ft) in the down-stream part of the valley. Toroweap Valley was at grade with the Colorado River before basalt flows began filling the canyon approximately 0.150 to 0.200 Ma (Fenton, 1998) as evidenced by the nearly 860 m (2,820 ft) of basalt fill overlain by only a few meters of alluvium at the confluence of Toroweap Valley and the Colorado River, 5 km (3 mi) south of the map area. There may have been a few Tertiary flows that partially filled Toroweap Valley before Quaternary flows filled the canyon. Further studies of the volcanic rocks are needed to determine the sequence of basaltic events that filled Toroweap Valley. The Toroweap Valley is now filled with basalt, and only recently has alluvium begun to accumulate in low areas. A younger basalt flow and pyroclastic cone, Vulcan's Throne 3 km (2 mi) south of the southeast corner of the map (average cosmogenic age of 0.074±.04 Ma), is deposited on top of the 0.200 Ma Quaternary flows at the mouth of Toroweap Valley (Fenton, 1998). The alluvium and basalt near Vulcan's Throne are offset as much as 5 m (15 ft) by Holocene movement along the Toroweap Fault; this offset clearly defines the Toroweap Fault in Toroweap Valley. Faulting along the Toroweap Fault in Prospect Valley south of the Colorado River occurred as recently as 0.038 Ma or earlier based on cosmogenic ^{3}He dating of the volcanic flows in Prospect Valley south of Vulcan's Throne (Fenton, 1998).

Most of the Quaternary basalts are combined into general undifferentiated map units based on the coalescing of basalt flows from several vent areas that erupted at about the same time north and south of Mount Trumbull. Some of the Quaternary basalt units are formally or informally named for nearby geographic locations or the elevation of the highest cinder cone associated with a mappable flow. Based on stratigraphic position, the basalt flows that spread into Toroweap Valley from the west in the north half of the map appear to be older than those that flowed from the west in the south half. However, the timing of these westerly flows reaching Toroweap Valley may be a factor of distance from the source, rather than a difference in age. The basalt of Graham Ranch entered upper Toroweap Valley from the east and appears to be slightly older than the flows that came from the west, because it is overlain by flows from the west.

But the flow from the east traveled a much shorter distance than those from the west traveled, which suggests a possible similar age for basalts east and west of the Toroweap Fault. The basalt of Larimore Tank in the upper reaches of Toroweap Valley originated north of the map area and is probably the second youngest basalt in the map area based on stratigraphic position and freshness of flow surfaces (the Cave Basalt of Billingsley, 1994b; Billingsley and Workman, 1999). The youngest basalt in the map area is the basalt of Little Spring south of Mount Trumbull.

Quaternary basalt flows preserved the geomorphic history of landscape development in Toroweap Valley, but further study and accurate age determinations of the basalts are needed. The chronologic age of volcanic events in the map area is based on stratigraphic position of flows, freshness and weathering of flow surfaces, and geomorphic relation to alluvial deposits. Quaternary basalts are briefly described from youngest to oldest.

BASALT OF LITTLE SPRING

The youngest volcanic rocks in the Uinkaret Volcanic Field consist of a partially formed double cinder cone and lava flow about 3 km (2 mi) south of Mount Trumbull. The basalt flow and cinder cone are informally named the basalt of Little Spring for Little Spring, Uinkaret Plateau, northern Mohave County, Arizona (SE1/4 sec. 16, T. 34 N., R. 8 W.). Little Spring is about a kilometer southwest of the vent area for the basalt of Little Spring in landslide debris near the base of the basalt of Mount Logan on the east side of Mount Logan. Little Spring is one of three permanent springs in the south half of the Uinkaret Plateau. Cosmogenic dating methods of the flow surface of the basalt of Little Spring indicate that the flows are about 1,000 years old (Fenton, 1998). Other criteria supporting this age are the freshness of the basalt flow surface, roughness, character, degree of weathering, and characteristics similar to the 1,000-year-old basalt flows at Sunset Crater National Monument near Flagstaff, Arizona.

The basalt of Little Spring originated from two closely associated vents and coalesced into one large pool of lava that spread in a northerly and southerly direction. A red pyroclastic cone was formed on top of the lava, but the lava continued to flow north and south rafting away the southern and northern part of the pyroclastic cone material. When the eruption finally ended, only the east half and part of the southwest edge of the pyroclastic cone remained. Rafted remnants of the pyroclastic cone are scattered at various locations on the basalt flow. There is no soil cover and very little vegetation on the flow surface. Vegetation grows only on scattered remnants of the pyroclastic material rafted farther south and north from the vent area.

BASALT OF LARIMORE TANK

This unit was originally named Cave Basalt by Billingsley (1994b) and Billingsley and Workman (1999) for numerous sinkholes in the basalt flow. The name was incorrectly used on those two maps because the authors were unaware that the name Cave Basalt was already in use. Therefore, the name is herein informally changed to basalt of Larimore Tank, a stock tank labeled “Larimore Tank” on the U.S. Geological Survey Hat Knoll 7.5-minute quadrangle just north of the map area, Uinkaret Plateau, northern Mohave County, Arizona (sec. 16, T. 37 N., R. 7 W.). The basalt of Larimore Tank consists of five unnamed pyroclastic cones that are aligned in a northwest-southeast orientation just north of the northeastern corner of the map area. Lava flows from each vent coalesced into one thin flow indicating that the five vents were erupting simultaneously. Most of the basalt flowed north towards Clayhole Valley (Billingsley, 1994b), but some basalt spread south into the uppermost reaches of Toroweap Valley (this map).

Numerous sinkholes pit the basalt of Larimore Tank, some as much as 18 m (60 ft) deep. The sinkholes are the result of solution weathering of gypsum in the underlying Harrisburg Member of the Kaibab Formation. The jointed and fractured nature of the basalt flow probably allowed water to gradually seep down into the underlying gypsum allowing for a more consistent dissolution of the gypsum. Where gypsum is exposed at the surface near the basalt of Larimore Tank, water was not able to penetrate and quickly ran off. The basalt of Larimore Tank flowed south into upper Toroweap Valley and around an older flow mapped as the basalt of Graham Ranch.

BASALT OF GRAHAM RANCH

The basalt of Graham Ranch is found near the Graham Ranch in upper Toroweap Valley, Kanab Plateau, in the northeast corner of the map area (the type area, Uinkaret Volcanic Field, northern Mohave County, Arizona, sec. 3, T.

35 N., R. 7 W.). Billingsley and Workman (1999) inadvertently named this basalt the Sage Basalt before it was known that the name Sage was already in use. The name Sage Basalt is also incorrectly used by Billingsley and Hampton (2000).

The basalt of Graham Ranch is an alkali-olivine basalt with three associated pyroclastic cones. All three cones are aligned north-south just east of the Toroweap Fault. Basalt from the cones coalesced into one flow that traveled in several directions. The radial pattern and coalescing of flows indicate that the three vent areas erupted at about the same time. Most of the basalt flowed 2.5 km (1.5 mi) west into the upper reaches of Toroweap Valley near Graham Ranch.

The largest, northernmost cone of the basalt of Graham Ranch is offset down-to-the-west by the Toroweap Fault. The offset is estimated to be as much as 26 m (85 ft), based on topographic expression. Offset is visible on aerial photos, but the fault line is difficult to locate in the field due to erosion of the pyroclastic deposits. Displacement of the underlying Kaibab Formation is estimated to be about 67 m (220 ft) down-to-the-west based on exposures of marker beds on both sides of the fault in the Harrisburg Member of the Kaibab Formation. The middle pyroclastic cone is about 70 m (230 ft) high. Some of the basalt from this cone may have flowed over the Toroweap Fault into Toroweap Valley, but the flow is not exposed on the downthrown side because it is covered by alluvium. The southern pyroclastic cone is comprised of two vents that coalesced into one, forming a 67 m (220 ft) cone. The basalt flow from this cone is alkali-olivine basalt like the others; olivine phenocrysts make up about 30 percent of the rock. Most of the basalt from this southern cone flowed west and descended into Toroweap Valley over the Toroweap Fault scarp. The basalt was later offset 36 m (120 ft) by movement on the Toroweap Fault. Thus, about half of the 67 m (220 ft) of separation along this part of the Toroweap Fault occurred since the eruption of the basalt of Graham Ranch, about 0.635±0.34 Ma. The basalt of Graham Ranch flowed at least another 2.5 km (1.5 mi) down Toroweap Valley after cascading over the Toroweap Fault.

UNDIFFERENTIATED BASALTS

Volcanic rocks north and south of Mount Trumbull are informally referred to as undifferentiated alkali-olivine basalt flows and pyroclastic deposits that erupted from several vent areas at about the same time. Most of the vents have formed large pyroclastic cones aligned in a general north-south orientation that reflect local bedrock fracture and joint systems. These deposits are collectively assumed to be Quaternary age (Billingsley, 1994b, 1997a, b). Basalt flows north of Mount Trumbull are labeled Qb1, and basalts south of Mount Trumbull are labeled Qb because the flows south of the mountain may be slightly different in age based on geomorphic relationships in Toroweap Valley. Fenton (1998) suggests that the flows south of Mount Trumbull are in the 0.150 to 0.100 Ma age range. Additional work is needed to determine the chronological order of deposition for Quaternary volcanic rocks in this part of the Uinkaret Volcanic Field.

A large pyroclastic cone in upper Toroweap Valley (hill 5579) is one of three vents in Toroweap Valley that formed near the Toroweap Fault. Two vents are in the southern reaches of Toroweap Valley. There are no basalt flows visibly associated with hill 5579; if basalt flows are present, they are totally covered by alluvium or younger basalt flows from south of Mount Trumbull.

Just southwest of hill 5579 is a large intrusive dike within the Harrisburg Member of the Kaibab Formation that includes pyroclastic deposits around its perimeter. No trace of the cone is present.

OTHER QUATERNARY BASALTS

Some of the Quaternary volcanic rocks in the northwest quarter of the map area have formed isolated mappable units that abut or overlap basalt flows of similar age. For descriptive purposes, the mappable volcanic units of this area are informally named for nearby ranches or the highest elevation of an associated pyroclastic cone, such as basalt of Kendrick Ranch or basalt of hill 6375. These alkali-olivine basaltic rocks are so similar in texture and characteristics that they may have erupted at or about the same time. Hand samples have very similar compositional and textural characteristics and cannot be distinguished from one another with certainty. Future studies of these rocks may suggest a chronologic order of the eruptions that shaped this remarkable landscape. These mappable volcanic units are not listed in chronologic order.

BASALT OF CRAIGS KNOLL AND BERRY KNOLL

The basalt of Craigs Knoll and Berry Knoll is informally named for the flows and pyroclastic deposits associated with Craigs Knoll (sec. 4, T. 35 N., R. 8 W.), Berry Knoll (sec. 24, T. 36 N., R. 9 W.), and the unnamed pyroclastic cone between them (sec. 30, T. 36 N., R. 8 W.), Uinkaret Plateau, northern Mohave County, Arizona, in the northwest quarter of the map area. Craigs Knoll is a 300-m-high (1,000 ft) cinder cone about 5 km (3 mi) northeast of Mount Trumbull. Berry Knoll is a 110-m-high (360 ft) pyroclastic cone in the northwest corner of the map area. These three volcanoes may have erupted simultaneously and the resultant basalt flows now form a combination of one or more flows informally mapped as the basalt of Craigs Knoll and Berry Knoll (Billingsley, 1994b).

Craigs Knoll has been extensively eroded on its east side revealing at least two eruptive phases. The first phase is the eruption of a basalt flow onto a nearly flat bedrock surface of low, hilly terrain of the Harrisburg Member of the Kaibab Formation. The extents of the first-phase flows are not known because they were subsequently covered by younger basalt flows during a second eruptive phase. A gray and tan pyroclastic cone, Craigs Knoll, formed on top of the first basalt flow before the second eruptive phase began.

The second eruptive phase, a fissure-type eruption on the north flank of Craigs Knoll, began shortly after Craigs Knoll pyroclastic cone was formed. The time interval of this hiatus is unknown but was likely only a few months or years. The second eruptive phase produced a thick series of basalt lavas that flowed in a radial pattern on the north flank of Craigs Knoll and covered the north half of the cone and surrounding landscape west, north, and east of Craigs Knoll. This eruptive phase formed a small cone on the north flank of Craigs Knoll that became partly buried by subsequent basalt flows. The second phase of basalt flows at Craigs Knoll flowed north about 8 km (5 mi), (Billingsley, 1994b and unpub. data b).

After the second eruptive phase ended, the basalts were offset about 60 m (200 ft) along a north-south fault on the west flank of Craigs Knoll. Displacement of the basalt and underlying Kaibab Formation strata are the same, indicating that the fault is younger than the basalt flows (Billingsley 1994b). There are no age determinations for either the first or second eruptive phases of Craigs Knoll.

TERTIARY VOLCANIC ROCKS

There are four outcrops of Tertiary basalt flows in the map area. These Tertiary flows form a protective caprock over soft strata of the Chinle and Moenkopi Formations at Mount Trumbull and Mount Logan, along the downthrown block of the Hurricane Fault (west-central edge of the map area), and just north of Mt. Emma. The Tertiary basalts flowed over a relatively flat erosional surface of tilted strata of the Chinle and Moenkopi Formations. The Mesozoic and Paleozoic strata have a regional dip of about 1º to 2º east, and the basalts erupted before faulting began. There are very few pyroclastic deposits associated with the Tertiary basalts except near Mt. Emma.

A period of erosion occurred between the Tertiary and Quaternary eruptions that may have lasted about 2.6 Ma. During this interval, the Moenkopi and Chinle strata were eroded from any area not capped by Tertiary basalt flows. Capped area quickly became buttes or mesas because underlying Triassic strata easily eroded along flow margins. Today, the Tertiary flows form basalt capped mountains.

Resultant erosion around the Tertiary basalts allowed steep unstable hillside failures to develop. Mass movement of these landslide blocks is a major erosional component, making the Tertiary basalt capped areas smaller to become isolated mountains today.

About 6.5 km (4 mi) south of Mt. Logan and just north of Mt. Emma (southwest quarter of map area) is an outcrop of Tertiary basalt that Hamblin (1970) called a Stage I basalt (the oldest basalt of the area). This basalt remains unnamed and unsampled for age determination and other analyses. Hamblin (1970) suggests that the Stage I basalt flows of Mount Trumbull, Mount Logan, Bundyville basalt, and the basalt north of Mt. Emma were all once part of a continuous lava field. The Stage I flows appear to be separate flows as mapped, but they may have similar eruptive times.

TERTIARY BASALTS NORTH OF MT. EMMA

The Tertiary basalts north of Mt. Emma are largely buried by Quaternary basaltic eruptions of Mt. Emma and associated volcanoes. The basalt erupted from a single large vent area and accumulated to about 183 m (600 ft) thick. The bulk of the lava seems to have accumulated in a local basin or valley and flowed east and northeast about 2 km (1.3 mi). A small portion of the lava flowed west but thinned rapidly as if it were flowing uphill. A southern extension of the Hurricane Fault system cuts the Tertiary basalt north of Mt. Emma offsetting these rocks about 250 m (820 ft) down-to-the-west.

BASALT OF MOUNT LOGAN

East of the Hurricane Fault at Hells Hole is a Tertiary basalt that forms Mount Logan. The basalt overlies about 122 m (400 ft) of the Chinle Formation. Reynolds and others (1986) informally introduced the name Mount Logan basalt. Paul Damon sampled basalt on Mount Logan in 1968 but did not specify a location other then Mount Logan. The sample yielded a K-Ar age of 2.63±0.34 Ma. This age is about 1 million years younger than the nearby basalt of Bundyville (3.60±0.018 Ma) to the west, but the basalt of Mount Logan and the basalt of Bundyville overlie the same 122 m (400 ft) of the Chinle Formation, separated by Hells Hole and the Hurricane Fault. The age of the basalt of Bundyville has a smaller margin of error than the Mount Logan age and is assumed to be the age for the basalt of Mount Logan. Based on stratigraphic position, thickness, and close proximity, about 2 km (1 mi) apart, the basalt of Bundyville and the basalt of Mount Logan are likely one and the same (fig. 2). Hand specimens from either basalt have the same general characteristics and textural composition, but chemical analyses have not been done. Further analysis is needed to verify whether both basalts are really the same.

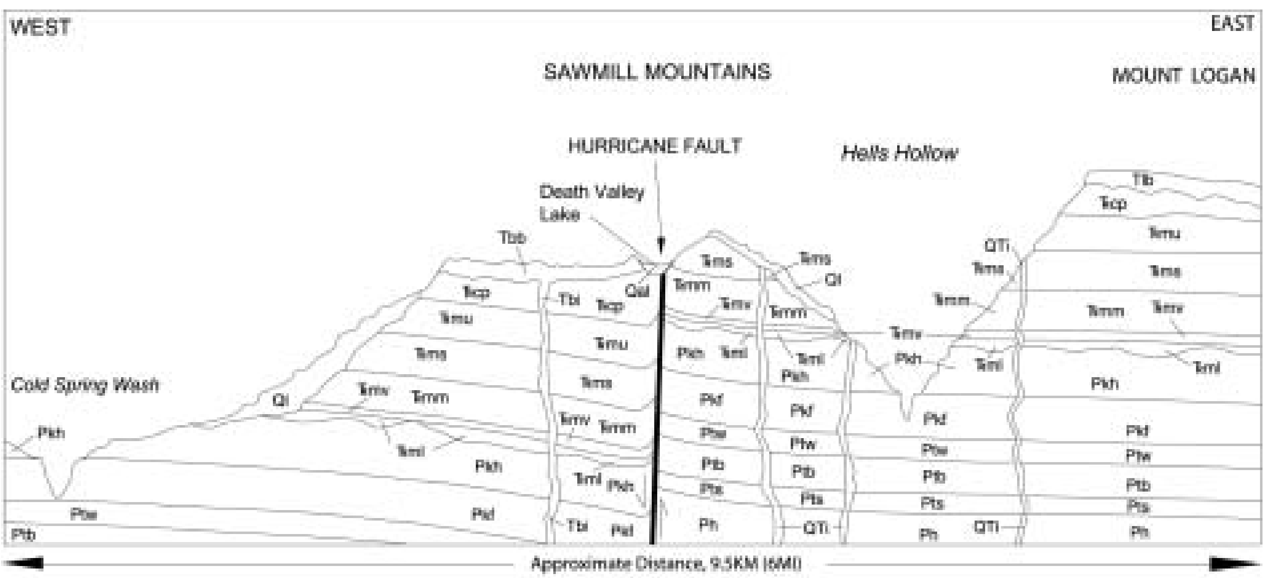

Figure 2. Schematic west-east cross section from Cold Spring Wash (tributary of upper Whitmore Canyon) through Hells Hole to Mount Logan, northern Mohave County, Arizona. Thickness of units and vertical scale are approximate. Surficial and volcanic units: Qal, alluvium; Ql, landslide; Tbb, basalt of Bundyville; Tlb, basalt of Mount Logan; QTi, intrusive dikes. Chinle Formation; Ŧcp, Petrified Forest Member. Moenkopi Formation; Ŧmu, upper red member; Ŧms, Shnabkaib Member; Ŧmm, middle red member; Ŧmv, Virgin Limestone Member; Ŧml, 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.

The source of the basalt of Mount Logan is uncertain, but may have originated from dikes exposed in Hells Hollow about several hundred meters west of the western edge of the basalt flows at the highest point of Mount Logan. These dikes are oriented in a north-south trend similar to the Quaternary basalt vent areas of this region, and may be associated with those basalts instead of Mount Logan. The basalt of Mount Logan flowed east about 5.5 km (3.5 mi) descending about 305 m (1,000 ft) towards Toroweap Valley over an eroded surface of the Chinle and Moenkopi Formations. The rate of descent was about 87 m/km (285 ft/mi). The flow would have, and perhaps did, reach the Toroweap Valley or Fault.

BASALT OF BUNDYVILLE

Hamblin (1970) was the first to report on the basaltic rocks 6.4 km (4 mi) east of the town of Mt. Trumbull (Bundyville) along the east-central edge of the map area and informally referred to them as the Bundyville basalt. The name Bundyville basalt was again used informally by Reynolds and others (1986) and Billingsley and others (2000) and is informally used as the basalt of Bundyville in this report because of its uncertain relationship to the basalt of Mount Logan. The basalt of Bundyville is present along the west side of the Hurricane Fault on the downthrown side and overlies the Petrified Forest Member of the Chinle Formation about 4 km (2.5 mi) west of the map area.

The basalt of Bundyville was sampled for a K-Ar age determination in 1968 by Paul Damon, University of Arizona, and yielded a 3.60±0.018 Ma age (Reynolds and others, 1986). The basalt of Bundyville overlies about 122 m (400 ft) of soft strata of the Petrified Forest Member of the Chinle Formation (Billingsley and others, 2000). The Chinle was eroded to a nearly flat surface and may have been the northerly extent of the Whitmore Canyon drainage when the basalt of Bundyville erupted. Sometime after deposition of the basalt of Bundyville, the Hurricane Fault became active, offsetting both the basalt and underlying strata about 610 m (2,000 ft).

The basalt of Bundyville probably came from fissures that parallel the Hurricane Fault and are now buried by subsequent flows or landslide and talus debris (fig. 2). Several basalt dikes exposed in Hells Hole may represent some of the source dikes for the basalt of Bundyville; however, the dikes are aligned in a north-south direction not parallel to the Hurricane Fault but parallel to the general north-south Quaternary volcanoes in this part of the map area. There are no K-Ar ages for these dikes and, because of their relations to both Tertiary and Quaternary basalts; they are labeled as Quaternary (QTi). Landslide and talus debris cover most of the Moenkopi and Chinle strata around and below outcrops of the basalt of Bundyville. Periodic movement along the Hurricane Fault may have distorted the flow surface of the basalt of Bundyville into a lumpy, hummocky expression, because it overlies soft mudstone and shale of the Chinle Formation (fig. 2). More recently, perhaps in the last several tens of thousands of years, earthquakes and wet conditions have probably caused landslide masses to creep downslope around the flow edges. The landslide masses disintegrate into blocky talus deposits at their distal ends.

On aerial photos, Death Valley Lake (west-central edge of the map area) resembles a volcanic crater because of a circular ring of small rocky peaks that surround the lake. The Hurricane Fault goes through Death Valley Lake. The ridges on the east side of the lake and fault are rocks of the Shnabkaib Member of the Moenkopi Formation, and rocks on the west side of the lake and fault are those of the basalt of Bundyville. West-dipping basalt ridges on the west side of Death Valley Lake may either be dikes that parallel the Hurricane Fault or basalt flows that have been bent upward by fault drag.

BASALT OF MOUNT TRUMBULL

Koons (1945) first mentioned the basaltic rocks on top of Mount Trumbull and informally referred to them as the Mount Trumbull basalt as did Hamblin (1970) and Billingsley (1997b). The basalt of Mount Trumbull caps Mount Trumbull, the highest mountain in the Uinkaret Volcanic Field, Uinkaret Plateau, northern Mohave County, Arizona (sec. 27, T. 35 N., R. 8 W., elev 8,029 ft; north-central part of map area). The K-Ar age of the basalt of Mount Trumbull is 3.67±0.09 Ma and 3.47±0.63 Ma (Hamblin and Best, 1970; Best and others, 1980; Reynolds and others, 1986).

The basalt came from a large dike or neck on the north side of the mountain, which forms the highest point on the mountain. Some basalt flowed west about 1.5 km (1 mi) onto an eroded surface of the Shinarump or Petrified Forest

Member of the Chinle Formation. Most of the basalt flowed east and southeast and descended over 300 m (1,000 ft) in about 2.5 km (1.5 mi), a scenario similar to the basalt of Mount Logan. The basalt of Mount Trumbull preserves the Triassic strata of this area. The steep soft slopes around Mount Trumbull have subsequently been covered by landslide and talus debris similar to those of other nearby Tertiary basalt outcrops.

Near the top of Mount Trumbull on the south edge of the mountain is a 60-m-high (200 ft) pyroclastic cone (elev 7,847 ft) that is probably Quaternary age. This volcano (7847) erupted onto the basalt of Mount Trumbull surface and flowed down the south flank of Mount Trumbull over landslide debris. This flow was later subjected to further landslide disruption. Cone 7847 is aligned with other north-south oriented Quaternary pyroclastic cones both north and south of Mount Trumbull and for this reason is considered Quaternary in age.

STRUCTURAL GEOLOGY

Gently tilted Paleozoic and Mesozoic strata offset by near-vertical normal faults constitute the major structural elements of this part of the Uinkaret Volcanic Field. The regional dip of the Paleozoic and Mesozoic strata increases from about 4º east on the west side of the Toroweap Fault in Toroweap Valley to about 14º east on the west side of the Hurricane Fault in Whitmore Canyon (Hamblin, 1965; Billingsley and Huntoon, 1983; Wenrich and others, 1997). Huntoon (1990) documented that the Toroweap and Hurricane Faults overlie deep-seated reverse faults that produced east-dipping monoclines with strata up-to-the-west during Late Cretaceous and early Tertiary time. Pliocene and Pleistocene extension has reactivated these deep-seated faults producing normal down-to-the-west fault separations along the Toroweap and Hurricane Monoclines, reversing the Cretaceous and Tertiary offset. However, the monoclinal flexure, although present as a minor fold in the map area, is not present everywhere along the Toroweap and Hurricane Faults in the map area. Most of the monoclinal development is in the Grand Canyon and within the lower part of Whitmore Canyon of this map area.

Reverse drag along the Hurricane and Toroweap normal faults is common in the map area. Reverse drag along normal faults is defined by Hamblin (1965) as a sag-induced infolding of the rocks toward the fault plane within the hanging wall. The infolding fills space created at depth as displacement occurs along normal fault surfaces that dip less steeply with increasing depth. The result is that reverse drag exacerbates the displacement along those faults. It also accentuates preexisting monoclinal dips on the downdropped western blocks within the fault zones. Reverse drag is prevalent in the Paleozoic and Mesozoic strata along the Hurricane and Toroweap Faults (Billingsley and others, 2000).

Toroweap Valley and Whitmore Canyon appear to have been partially established before volcanism and faulting began along weak trends of the Hurricane and Toroweap Monoclines. Tertiary basalt flows may have reached parts of Toroweap Valley before faulting began. Activation of the faults likely accentuated the headward erosion from the Colorado River along these faults into Toroweap Valley and Whitmore Canyon.

The Toroweap Fault separates the Uinkaret Plateau (west side) from the Kanab Plateau (east side). The maximum separation of Paleozoic and Mesozoic strata along the Toroweap Fault is about 198 m (650 ft) at the south edge of the map area, decreasing to about 67 m (220 ft) in the upper reaches of Toroweap Valley. About half of the offset along the northern part of the Toroweap Fault took place after deposition of the basalt of Graham Ranch during the Pleistocene, approximately 630,000 years ago. Based on data from this and other mapping west and north of the area (Billingsley, 1997a, b; unpub. data a, b; Billingsley and others, 2000), the Toroweap Fault probably became active sometime during the past 2 to 2.5 m.y. The Toroweap Fault trace can be determined accurately on aerial photos because of relatively recent offset of basalt flows and alluvial deposits in Toroweap Valley.

The Hurricane Fault separates the Uinkaret Plateau (east side) from the Shivwits Plateau (west side). The maximum separation of Paleozoic and Mesozoic strata along the Hurricane Fault in the map area is about 610 m (2,000 ft) in the northwest corner of the map (Billingsley and others, 2000). Fault separation decreases to about 550 m (1,800 ft) in upper Hells Hole. The fault trace shows visible displacement of relatively recent basalt flows and alluvial fan deposits in Whitmore Canyon. Estimated offset of strata along the Hurricane Fault is based on the Chinle/Moenkopi contact and the basalt/Chinle contact on both sides of the fault. Separation of the basalt of Bundyville and underlying strata are equally offset along this segment of the Hurricane Fault, making the fault younger than the 3.6 Ma basalt of

Bundyville or the 2.6 Ma basalt of Mount Logan. Separation of Quaternary basalts along the Hurricane Fault is as much as 34 m (112 ft) just south of the southwest corner of the map and displacement of alluvium is as much as 3 m (10 ft).

A southern extension the Hurricane Fault near Mt. Emma rapidly dies out southward and may reach the Grand Canyon about 5 km (3 mi) south of the map area. Other faults south of the map area, all down-to-the-west, may be southern extensions or splays of the Hurricane Fault system (Billingsley and Huntoon, 1983). These faults are largely covered by Quaternary basalt flows, but where they are exposed, they bend southwestward and rejoin the Hurricane Fault near the Colorado River.

Locally warped and bent strata, too localized to show at map scale, are the result of Pleistocene and Holocene dissolution of gypsum in the Harrisburg Member of the Kaibab Formation. Distorted strata in the Harrisburg Member are common along drainages or joints on the plateaus, especially in upper Toroweap Valley. Gypsum dissolution in the Harrisburg Member has also resulted in several small and large sinkholes and caves on the Kanab and Uinkaret Plateaus. The karst is Holocene and Pleistocene in age based on several sinkholes that have developed in the basalt of Larimore Tank in upper Toroweap Valley. Locations of sinkholes forming enclosed basins or depressions are indicated on the map by a triangle symbol.

BRECCIA PIPE STRUCTURES

Circular collapse structures, minor folds, and other surface irregularities are due to dissolution of gypsum and gypsiferous siltstone in the Kaibab or Toroweap Formations. Some bowl-shaped depressions in the Kaibab Formation, characterized by inward-dipping strata, may be the surface expression of a breccia pipe originating from dissolution of the deeply buried Mississippian Redwall Limestone (Wenrich and others, 1997; Wenrich and Sutphin, 1989). Collapse features are marked on the map by a dot and the letter C.

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DESCRIPTION OF MAP UNITS

SURFICIAL DEPOSITS

Surficial deposits (Holocene and Pleistocene)—Surficial deposits are differentiated from one another chiefly on the basis of difference in morphologic character and physiographic position observed on aerial photographs. Older alluvial fans and terrace-gravel deposits generally exhibit extensive erosion whereas younger deposits are actively accumulating material or are lightly eroded as observed on 1976 aerial photographs

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

Qs **Stream-channel alluvium (Holocene)—**Interlensing silt, sand, pebbles, and boulder gravel; unconsolidated and poorly sorted. Locally overlaps alluvial fan (Qa1 and Qa2), terrace-gravel (Qg1), upper part of valley-fill (Qv), and floodplain (Qf) deposits. Inset against some young-intermediate alluvial fan (Qa1) and old terrace-gravel (Qg2) deposits. Stream channels subject to intermittent high-energy flows and flash floods. Little or no vegetation in stream channels except some sagebrush. Contact with other alluvial deposits is approximate. Thickness 1 to 3 m (3 to 10 ft)

Qf **Floodplain deposits (Holocene)—**Light-gray or tan silt, sand, and interlensing pebbles, cobbles, and gravels; unconsolidated. Locally contain cinder and basalt fragments. Intertongue with or overlap valley-fill (Qv) and young alluvial fan (Qa1) deposits. Form relatively flat surfaces that have little or no vegetation and have some drainage outlet. Subject to frequent flooding or ponding. Thickness 1 to 3 m (3 to 10 ft)

Qg1 **Young terrace-gravel deposits (Holocene)—**Light-brown, pale-red, and gray silt, sand, and pebble to boulder gravel composed of well-rounded limestone and sandstone and angular to subrounded chert clasts locally derived from the Toroweap and Kaibab Formations; include rounded to subrounded basalt clasts derived from locally exposed basalt flows or other alluvial deposits and landslide debris. Form terraces about 1 to 3 m (3 to 10 ft) above modern streambeds in Hells Hollow, Whitmore Canyon, and Langs Run drainages and lower Toroweap Valley. Locally inset into old terrace-gravel (Qg2) deposits in Hells Hollow and Whitmore Canyon area. Thickness 1 to 4 m (3 to 12 ft)

Qa1 **Young alluvial fan deposits (Holocene)—**Gray-brown silt, sand, gravel, and boulders. Include interlensing coarse gravel composed of subangular to rounded pebbles and cobbles of limestone, chert, and sandstone clasts locally derived from the Kaibab and Toroweap Formations. Locally includes well-rounded to sub-angular basalt clasts and pyroclastic debris on and near Quaternary volcanoes north and south of Mount Trumbull, often mixed with clasts from the Toroweap and Kaibab Formations on west side of Toroweap Valley and upper Whitmore Wash. Partly cemented by gypsum and calcite. Overlapped by or intertongue with upper part of valley-fill (Qv) and floodplain (Qf) deposits. Intertongue with or overlap young-intermediate alluvial fan (Qa2) deposits. Subject to extensive erosion by sheet wash, flash flood debris flows, and minor arroyo erosion. Support moderate growth of sagebrush, cactus, and grass. Thickness 1 to 10 m (3 to 30 ft) or more

Qc **Colluvial deposits (Holocene and Pleistocene)—**White to gray silt and fine-grained sand, black and red, fine-grained cinder, scoria, and basalt clasts. Locally confined to basins, playas, or depressions in landslides around Mount Trumbull and Mount Logan areas. Similar to floodplain (Qf) deposits, but limited to local internal accumulations generally not associated with stream drainages. Subject to temporary ponding. Support sparse growth of grass. Thickness 1 to 3 m (3 to 20 ft)

Qv **Valley-fill deposits (Holocene and Pleistocene)—**Gray and light-brown silt, sand, and lenses of pebble to small-boulder gravel; partly consolidated by gypsiferous siltstone and calcite. Contain well-rounded clasts of limestone, subrounded to angular chert fragments, and subrounded to angular basalt pebbles and pyroclastic gravel mixture. Intertongue with or overlap alluvial fan (Qa1 and Qa2) deposits. Represent relatively less active, low-gradient alluvial stream-channel or shallow valley drainage deposits, mainly on plateau surfaces and in Toroweap Valley. Subject to sheetwash flooding and temporary ponding; cut by arroyos as much as 2 m (6 ft) deep. Support moderate growth of sagebrush, grass, and cactus. Thickness 1 to 4 m (3 to 12 ft)

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 bedrock outcrops. Include silt, sand, and gravel partly cemented by calcite and gypsum. Intertongue with alluvial fan (Qa1, Qa2, and Qa3) deposits and commonly associated with landslide (Ql) deposits. Support sparse growth of sagebrush, cactus, grass, pinion, juniper, and oak. Only thick or extensive deposits shown. Thickness 2 to 6 m (6 to 20 ft)

Ql **Landslide deposits (Holocene and Pleistocene)—**Unconsolidated masses of unsorted rock debris. Include detached bedrock blocks that have rotated backward and slid downslope as loose incoherent masses of broken rock and deformed strata. Found principally below Esplanade Sandstone in Cove Canyon area, below the canyon rim of Cove Canyon and Toroweap Valley, and below Tertiary basalt flows. Support sparse to moderate growth of cactus and grass at elevations below 5,000 ft and moderate forest of oak, juniper, ponderosa pine, and pinion trees at higher elevations. May become unstable in wet conditions. Thickness 3 to 18 m (10 to 60 ft)

Qg2 **Old terrace-gravel deposits (Holocene and Pleistocene)—**Similar to young terrace-gravel deposits (Qg1) but partly consolidated by gypsiferous siltstone and calcite. Composed mainly of gray to brown, fine-grained sand and silt matrix mixed with subangular to rounded pebbles and boulders of basalt and limestone as much as 1 m in diameter in Hells Hollow and Whitmore Canyon areas. Form terraces about 2 to 4 m (6 to 12 ft) above modern streambeds and about 1 to 2 m (3 to 6 ft) above young terrace gravel

(Qg1) deposits. Locally inset into young-intermediate alluvial fan (Qa2) deposits in Hells Hollow and Whitmore Canyon drainages. Intertongue or locally overlain by talus (Qt) and young alluvial fan (Qa1) deposits. Thickness 2 to 25 m (6 to 80 ft)

Qa2 **Young-intermediate alluvial fan deposits (Holocene and Pleistocene)—**Similar to young alluvial fan (Qa1) deposits, but partly cemented by calcite and gypsum. Surfaces are rocky and eroded by arroyos as much as 10 m (30 ft) deep. Commonly overlapped by young alluvial fan (Qa1) deposits. Intertongue with or overlap valley-fill (Qv) and talus (Qt) deposits. Contain abundant subrounded to subangular Quaternary basalt clasts and cinders on west side of Toroweap Valley and east side of Hells Hollow and Whitmore Canyon drainages. Support moderate growth of sagebrush, cactus, grass, and some juniper trees. Thickness 2 to 30 m (6 to 100 ft)

Qa3 **Old alluvial fan deposits (Pleistocene)—**Similar to young and young-intermediate alluvial fan (Qa1 and Qa2) deposits, partly cemented by calcite and gypsum. Surface has thin soil development forming a smooth texture on aerial photos; often exhibits arroyo erosion averaging about 1 to 2 m (3 to 6 ft) deep on east side of Mount Trumbull. Commonly overlapped by or intertongue with talus (Qt) and landslide (Ql) deposits. Contain abundant Quaternary and Tertiary basaltic clasts that form thin desert pavement near landslide (Ql) masses. Support moderate growth of grass, cactus, sagebrush, juniper, and pinion pine trees. Thickness 2 to 10 m (6 to 30 ft)

VOLCANIC ROCKS

Quaternary deposits

Basalt of Little Spring (Holocene)—Informally named herein for Little Spring (SE 1/4, sec. 16, T. 34 N., R. 8 W.), just southwest of Mount Trumbull, Uinkaret Plateau, northern Mohave County, Arizona (northeast quarter of map area). The olivine basalt flows and associated double cinder cone represent the youngest volcanic rocks in the Uinkaret Volcanic Field based on 3-He cosmogenic dating methods (Fenton, 1998), the freshness of flow surfaces, and similarities to basalt flow surfaces at Sunset Crater National Monument near Flagstaff, Arizona; the basalt of Little Spring is about 1,000 years old. Divided into:

Qlsp **Pyroclastic deposits**—Red-brown, gray, and reddish-black basaltic scoria, bombs, cinder, and scoriaceous ejecta deposits. Consists of two deposits that may have been part of a double pyroclastic cone formed from two closely associated vent areas. Eastern part of pyroclastic cone is about 41 m (135 ft) high and deposited on associated basalt flow surface (elev 7,015 ft). Only east half and southwest part of cone is present; the rest of cone has been rafted away on lava flows from the vent area toward the northwest and southeast. Support a few ponderosa pine and oak trees. Thickness 41 m (135 ft)

Qlsb **Basalt flows**—Dark-gray, finely crystalline to glassy, alkali olivine basalt. Groundmass composed of plagioclase and olivine. Forms clinkery broken aa surface. Splatter debris common near both vent areas. Basalt flowed northwest about 1.8 km (1.1 mi) and spread out into local valley and southeast about 2.4 km (1.5 mi) down a steep gradient into another local valley. Overlies older Quaternary basalt flows (Qb), pyroclastic (Qp) deposits, and young alluvial fan (Qa1) deposits. Thickness 3 to 7 m (10 to 23 ft)

Basalt of Larimore Tank (Pleistocene)—Informally named for Larimore Tank, a stock tank just west of the basalt flow on U.S. Geological Survey Hat Knoll 7.5' quadrangle, Uinkaret Volcanic Field, northern Mohave County, Arizona (sec. 16, T. 37 N., R. 7 W.). Incorrectly named the Cave Basalt in Billingsley (1994b) and Billingsley and Workman (1999) before it was known that this name was already in use

Qltb **Basalt flows**—Dark-gray to black, finely crystalline alkali-olivine basalt. Basalt has coalesced from five pyroclastic vents aligned along northwest-southeast fracture or joint system of underlying Permian strata. Contain abundant olivine phenocrysts 0.25 to 1 mm in diameter. Overlain by valley fill (Qv), and young to young-intermediate alluvial fan (Qa1 and Qa2) deposits. Sinkholes have developed under basalt flow in gypsum or gypsiferous siltstone units of the Harrisburg Member (Pkh) of the Kaibab Formation causing basalt to collapse into sinkholes as deep as 18 m (60 ft). Sinkholes are partly filled with ponded alluvium similar to localized floodplain (Qf) and colluvial (Qc) deposits. Basalt flowed south into upper part of Toroweap Valley when eruptions ceased. Most of the basalt flowed north (Billingsley, unpub. data a). Thickness 1 to 12 m (3 to 40 ft)

Basalt of Graham Ranch (Pleistocene)—Informally named for Graham Ranch in upper Toroweap Valley, (sec. 3, T. 35 N., R. 7 W.); the type area, Uinkaret Volcanic field, Uinkaret Plateau, northern Mohave County, Arizona. Incorrectly named the Sage Basalt by Billingsley and Workman (1999) and Billingsley and Hampton (2000) before the name Sage Basalt was already in use. Divided into:

Qgrp **Pyroclastic deposits**—Red-brown and reddish-black scoriaceous basalt, ash, and cinder deposits; partly consolidated. Consist of three pyroclastic cones that include six vent areas aligned along north-south oriented, near-vertical bedrock-fracture or joint systems in underlying Paleozoic rocks. Three vent areas form northern cone, one vent forms a central cone, and two vents form southern cone. Deposits overlie associated basalt flows. Toroweap Fault offsets the northern pyroclastic cone and basalt flow about 26 m (85 ft). The northern cone is about 134 m (440 ft) high, central cone about 70 m (230 ft) high, and southern cone about 60 m (200 ft) high, representing relative thickness

Qgrb **Basalt flows**—Dark-gray, finely crystalline to glassy alkali olivine basalt. Groundmass composed of plagioclase, olivine, and augite laths. Include abundant olivine phenocrysts 0.25 to 5 mm in diameter, which form about 30% of flow in southern part. Unit overlies Harrisburg Member of the Kaibab Formation on Kanab Plateau and alluvium in upper Toroweap Valley of the Uinkaret Plateau. Basalt flow is offset about 26 m (85 ft) down-to-the-west by the Toroweap Fault north of Graham Ranch; offset about 34 m (110 ft) down-to-the-west south of Graham Ranch which is about half of total offset of Toroweap Fault, 76 m (220 ft). Thickness 3 to 18 m (10 to 60 ft)

Quaternary basalts, undivided (Pleistocene)—Informally named to include several pyroclastic cones and associated basalt flows of similar age north and south of Mount Trumbull. Basalts are assumed to have erupted penecontemporaneously because several flows have coalesced from several adjacent pyroclastic cones. Basaltic units north of Mount Trumbull are designated with Qb1 because the stratigraphic relationships in upper Toroweap Valley suggest that these flows may be older than flows (Qb) south of Mount Trumbull. Other Quaternary basalt flows and associated pyroclastic deposits that have mappable boundaries are informally designated with the elevation of the highest associated pyroclastic cone (hill) or informally named for a local nearby ranch designated on U.S. Geological Survey 7.5-minute quadrangles. These basalt units are randomly listed and are not assigned in order of increasing or decreasing age because all units may be similar in age. Divided into:

Qp1 **Pyroclastic deposits**—Reddish-gray, black, and red to gray tuff and welded tuff, ash, scoriaceous ejecta, cinder, and bomb deposits; partly consolidated in most cones. Include about 17 pyroclastic cones with one or more vents per cone that overlie coalescing basalt flows. Locally form thick, fine- to coarse-grained cinder deposits near cones. Map contacts are approximate and show thickest deposits. No K-Ar ages are available. Thickness 6 to 124 m (20 to 400 ft)

Qb1 **Basalt flows**—Dark-gray to black, finely crystalline, alkali-olivine basalt. Olivine and plagioclase phenocrysts common. Basalt flows originate from several pyroclastic vents or fissures north of Mount Trumbull and generally coalesce to flow eastward into upper Toroweap Valley. Basalt flows probably overlie Triassic strata of the Moenkopi Formation near pyroclastic cones and flowed over the Kaibab Formation and alluvial valleys before reaching Toroweap Valley. Basalt flows in Toroweap Valley south of Mount Trumbull are mostly covered with valley-fill and young alluvial deposits (Qv and Qa1) and basalt (Qb) flows. Thickness 6 to 15 m (20 to 50 ft)

Qp **Pyroclastic deposits**—Reddish-gray, black, red, and gray tuff, ash, scoriaceous ejecta, bombs, and cinder deposits; partly consolidated. Form Slide Mountain, about 183 m (600 ft) high, Petty Knoll, about 110 m (360 ft) high, and Mt. Emma about 150 m (500 ft) high, and several unnamed pyroclastic cones that average about 60 m (200 ft) high in the Uinkaret Mountains between Whitmore Canyon and Toroweap Valley. Include about 36 pyroclastic cones formed by one or more vent areas that overlie associated coalesced basalt flows. Consolidated as gray welded tuff and ash at Slide Mountain, Petty Knoll, and Mt. Emma. Include fine- to coarse-grained cinder sheet or ash deposits about 6 m (20 ft) thick near cones. K-Ar age determinations are not available. Map contacts are approximate and show thickest deposits

Qb **Basalt flows**—Dark-gray and light gray, finely crystalline, alkali-olivine basalt. Include scoriaceous material from pyroclastic deposits. Basalt cascaded from higher terrain of Uinkaret Mountains into Whitmore Canyon and Toroweap Valley. Lava cascades are steep where they flow over the Hurricane Fault scarp south of Hells Hollow and over upper cliffs of Toroweap Valley and Whitmore Canyon areas. Flows overlie the Moenkopi, Kaibab, and Toroweap Formations. Flows are partly buried by young-intermediate alluvial fan (Qa2) deposits in Hells Hollow drainage south of Hells Hole and various alluvial deposits in Whitmore Canyon and Toroweap Valley. Flows are partly eroded but surfaces are well preserved. There are no K-Ar ages available for (Qb) basalt flows south of Mount Trumbull, but some flows dated by cosmogenic methods indicate most of these flows are about 0.100 Ma (Fenton, 1998). The K-Ar age from middle part of Mount Logan may not represent age of the basalt of Mount Logan because Quaternary age basalts overlie Tertiary basalts in this area. Thickness 6 to 183 m (20 to 600 ft)

Qi **Basalt necks (Pleistocene)—**Greenish-black, finely crystalline, alkali olivine basalt necks. One neck is exposed in Harrisburg Member of Kaibab Formation 3 km (2 mi) southeast of Mount Trumbull and another is associated with a pyroclastic cone about 5 km (3 mi) north of Mount Trumbull. Necks are several meters in diameter and have been eroded to near bedrock surface. Approximate diameters shown on map

Basalt of Kenworthy Ranch (Pleistocene)—Informally named for the Kenworthy Ranch in Sink Valley, Uinkaret Plateau, northern Mohave County, Arizona (sec. 1, T. 35 N., R. 9 W.). Divided into:

Qkrp **Pyroclastic deposits**—Reddish-black and red tuff, ash, scoriaceous ejecta, and cinders; unconsolidated. Overlie associated basalt flows. Map contact is approximate. Include three unnamed cinder cones aligned in north-south orientation. The northern pyroclastic cone (hill 6430) is about 49 m (160 ft) high; just west of Kenworthy Ranch, the middle cone (hill 6348) is about 24 m (80 ft) high; and the southern cone (hill 6355) is about 24 m (80 ft) high, reflecting approximate thickness

Qkrb **Basalt flows**—Light- to dark-gray, finely crystalline alkali-olivine basalt. Include small phenocrysts of augite and olivine in glassy groundmass. Flows radiate out from all three pyroclastic cones and coalesce to form a large, elongated, north-south, oval-shaped basalt-flow mass. Overlie Harrisburg Member of the Kaibab Formation. Thickness 15 m (50 ft)

Basalt of Marshall Ranch (Pleistocene)—Informally named for Marshall Ranch about 2.5 km (1.5 mi) south of Kenworthy Ranch and west of Mount Trumbull, Uinkaret Plateau, northern Mohave County, Arizona (sec. 13, T. 35 N., R. 9 W.). Divided into:

Qmrp **Pyroclastic deposits**—Reddish-black and red tuff, ash, scoriaceous ejecta, welded tuff, and cinders; mostly unconsolidated. Overlie associated basalt flows. Include two unnamed pyroclastic cones and three smaller secondary spatter cones. Secondary cones appear to have originated from southern-most pyroclastic cone (hill 6633). Northern pyroclastic cone (hill 6538) is about 73 m (240 ft) high and southern cone (hill 6633) is about 85 m (280 ft) high, reflecting relative thickness

Qmrb **Basalt flows**—Gray-black, finely crystalline, alkali-olivine basalt. Majority of basalt came from southern pyroclastic cone (hill 6633) and flowed out in a radial pattern, mostly in a westerly direction about 3 km (2 mi). Partly overlie basalt of Potato Valley and Harrisburg Member of the Kaibab Formation. Thickness 12 to 36 m (40 ft to 120 ft)

Basalt of hill 6375 (Pleistocene)—Informally named for unnamed pyroclastic cone (hill 6375) at north end of Sink Valley, northwest of Mount Trumbull, Uinkaret Plateau, northern Mohave County, Arizona (sec. 31, T. 35 N., R. 8 W.). Divided into:

Qp6375 **Pyroclastic deposits**—Reddish-black cinder and scoriaceous ejecta overlying associated basalt flow. Include small deposit at north end of basalt flow that appears to be local splatter cone originating from the flow. Hill 6375 is about 64 m (210 ft) thick

Qb6375 **Basalt flow**—Dark-gray alkali-olivine basalt. Consists of one basalt flow that flowed west about 0.5 km (0.25 mi) and north about 1.5 km (1 mi). Overlies Harrisburg Member of the Kaibab Formation. Thickness 1 to 12 m (3 to 40 ft)

Basalt of hill 6646 (Pleistocene)—Informally named for unnamed pyroclastic cone (hill 6646), northwest end of Sink Valley, northwest of Mount Trumbull, Uinkaret Plateau, northern Mohave County, Arizona (sec. 35, T. 36 N., R. 9 W.). Divided into:

Qp6646 **Pyroclastic deposits**—Red and black cinder and scoriaceous deposits overly associated basalt flow. Include one large pyroclastic cone and two smaller adjacent cones. Three vents formed large cone (hill 6646). Cone has elongated north-south orientation that aligns with basaltic cones of Kenworthy Ranch. Main pyroclastic cone is about 76 m (250 ft) thick

Qb6646 **Basalt flow**—Dark-gray alkali-olivine basalt. Basalt flowed north about 3 km (2 mi). Overlies Harrisburg Member of the Kaibab Formation. Thickness 10 to 30 m (30 to 100 ft)

Basalt of hill 6457 (Pleistocene)—Informally named for unnamed cinder cone (hill 6457) just north of Mount Trumbull, Uinkaret Plateau, northern Mohave County, Arizona (sec. 16, T. 35 N., R. 8 W.). Divided into:

Qp6457 **Pyroclastic deposits**—Reddish-black cinder and scoriaceous deposits. Include two smaller cones that partly overlie basalt flow from cone 6457 and appear to have erupted from the flow. Pyroclastic cone (hill 6457) is 36 m (120 ft) high, northern cone (no number) is about 24 m (80 ft) high reflecting relative thickness

Qb6457 **Basalt flow**—Dark-gray alkali-olivine basalt. Consists of one flow from hill 6457 that flowed north about 0.8 km (0.50 mi) onto flat alluvial-filled valley. Thickness about 36 m (120 ft)

Basalt of Potato Valley (Pleistocene)—Informally named from Potato Valley west of Mount Trumbull, Uinkaret Plateau, northern Mohave County, Arizona (sec. 25, T. 35 N., R. 9 W.). Includes several pyroclastic cones and associated basalt flows along north and west edge of Potato Valley. Divided into:

Qpvp **Pyroclastic deposits**—Red and black cinder, tuff, ash, and scoriaceous ejecta. Include two main pyroclastic cones and five associated vent areas. Main pyroclastic cone on north side of Potato Valley is not named or numbered, but elevation is about 6680. A large pyroclastic cone on west side of Potato Valley is hill 6744. Both cones overlie associated flows and appear to be main source of basalt. Several smaller pyroclastic cones on associated flows appear to have erupted from the flows, such as hill 6370, 6484, 6482, and two other unlabeled hills. Western cone is about 106 m (350 ft) thick, northern cone is about 85 m (280 ft) thick

Qpvb **Basalt flows**—Dark-gray alkali-olivine basalt. Flows on north side of Potato Valley erupted mostly from unnamed cinder cone (elev about 6680) and flowed northwest about 3 km (2 mi). These flows appear to have merged with flows from pyroclastic cone (hill 6744) on western side of Potato Valley and together have formed a basaltic dam or valley blockage responsible for the accumulation of alluvium now filling Potato Valley. Basalt on west side of Potato Valley flowed mostly north about 5 km (3 mi). Thickness 2 to 25 m (6 to 50 ft)

Basalt of hill 6588 (Pleistocene)—Informally named for highest of 4 pyroclastic cones on east flank of Mount Trumbull, Uinkaret Volcanic Field, northern Mohave County, Arizona (sec. 36, T. 35 N., R. 8 W.). Includes pyroclastic deposits and associated basalt flows. Divided into:

Qp6588 **Pyroclastic deposits**—Reddish-black to mostly black and gray ash, cinder, scoriaceous fragments, and basaltic boulders; partly consolidated with interbedded basalt flows. Include four pyroclastic cones aligned in northwest-southeast orientation for about 2 km (1.25 mi). Deposits mostly overlie associated basalt flows and landslide debris but are often interbedded with basalt flows on steep eastern slopes of hill 6588. Variable thickness because of steep terrain, about 2 to 55 m (6 to 180 ft)

Qb6588 **Basalt flows**—Dark-gray and light-gray, finely crystalline, alkali-olivine basalt. Include interbedded scoriaceous pyroclastic deposits. Basalt cascades steeply over landslide debris and strata of the Moenkopi and Kaibab Formations into Toroweap Valley. Flows partly buried by undivided basalt flows (Qb) and alluvial fan (Qa1 and Qa2) deposits in Toroweap Valley. Thickness 2 to 10 m (6 to 30 ft)

Basalt of Craigs Knoll and Berry Knoll (Pleistocene)—Informally named for Craigs Knoll (sec. 4, T. 35 N., R. 8 W.), and Berry Knoll (sec. 24, T. 36 N., R. 9 W.), northwest of Mount Trumbull, Uinkaret Plateau, northern Mohave County, Arizona. Includes dikes, pyroclastic deposits and basalt flows that may have erupted simultaneously at Craigs Knoll, Berry Knoll, and unnamed pyroclastic cone (hill 6342) between Craigs and Berry Knoll. Divided into:

Qcbi **Intrusive dikes or necks**—Greenish-black olivine basalt. Widths of dikes shown are approximate

Qcbp **Pyroclastic deposits**—Gray and reddish-gray to black cinder, tuff, ash, and scoriaceous ejecta; mostly consolidated into welded tuff. Form cliff on east side of Craigs Knoll and steep slope on south and west side. Deposits mostly covered by dark-gray basalt on west and north flank of Craigs Knoll. Include smaller pyroclastic cone deposit on southern flank of Craigs Knoll. Overlie associated basalt flow on south flank of Craigs Knoll. Thickness 183 m (600 ft)

Qcbb **Basalt flows**—Light-gray and dark-gray alkali-olivine basalt. Unit includes lower and upper basalt. Lower basalt accumulated on Harrisburg Member of the Kaibab Formation and perhaps on lower members of the Moenkopi Formation. Estimated thickness of lower flow about 40 m (130 ft). Upper basalt erupted near top of Craigs Knoll, north flank, and flowed west, north, and east about 8 km (5 mi). Thickness 3 to 20 m (10 to 65 ft)

QTi **Basaltic dikes in Hells Hole (Pleistocene(?) or Pliocene(?))—**Gray-black alkali-olivine basalt. Near vertical dikes 1 to 2 m (3 to 6 ft) wide. Dikes are aligned N. 10° W. with local joint and fractures in Paleozoic and Mesozoic bedrock parallel to Quaternary pyroclastic cones north, east, and southeast of Hells Hole. Dikes near Hurricane Fault are aligned closer to northwesterly trend of the fault and may be associated with the basalt of Bundyville. Widths of dikes shown are approximate

Tertiary volcanic deposits

Basaltic rocks north of Mt. Emma (Pliocene)—Gray-black alkali-olivine basalt; includes several basalt flows, pyroclastic deposits, and intrusive necks and dikes. Pliocene rocks largely covered by Quaternary pyroclastic deposits of Mt. Emma and nearby north-south oriented pyroclastic cones and associated basalt flows. Unit offset about 200 m (650 ft) down-to-the-west by Hurricane Fault. No age determinations for these deposits, but are assumed to be Pliocene, based on similar flow direction, stratigraphic position, and elevation of other Pliocene basalts at Mount Logan and Mount Trumbull. 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. Diameter of neck unknown. Source for associated Tertiary basalt flows north and east of neck area is mostly covered by Quaternary volcanic rocks of Mt. Emma

Tp **Pyroclastic deposits**—Reddish-black cinder, scoria, ash, and scoriaceous ejecta; heavily eroded. Associated with intrusive neck (Ti) on downthrown side of local fault connected to the Hurricane Fault. Thickness 12 m (40 ft)

Tb **Basalt flows**—Gray-black alkali-olivine basalt; plagioclase laths common in glassy groundmass. Consist of several basalts that flowed east and south from intrusive neck area. The underlying strata are concealed, but because of similar stratigraphic position to basalt of Mount Logan and basalt of Mount Trumbull, it is assumed that this basalt overlies strata of either the Chinle Formation or upper Moenkopi Formation. Thickness 122 m (400 ft)

Basalt of Mount Logan (Pliocene)—Informally named for Mount Logan (Reynolds and others, 1986), elev 2,400 m (7,866 ft); Uinkaret Plateau, northern Mohave County, Arizona (sec. 12, T. 34 N., R. 9 W.). K-Ar age is 2.63±0.34 Ma obtained from an unspecified location on Mount Logan. This 2.63 age may reflect a younger flow rather than the oldest Mount Logan flow. New K-Ar age determinations are recommended to determine sequence of basaltic events at Mount Logan

Tmlb **Basalt flows**—Light-gray, finely crystalline, alkali-olivine basalt; contain red and green olivine phenocrysts 1 mm in diameter in glassy groundmass; include plagioclase laths in glassy groundmass. Plagioclase masses form white spotted blotches in some basalt flows. Basalt flows overlie Petrified Forest Member of the Chinle Formation at Hells Hole. Eastern extent of basalt may overlie upper red member and Shnabkaib Member of the Moenkopi Formation. Basalt dikes below summit of Mount Logan in Hells Hole may be source for the basalt of Mount Logan, but these dikes are aligned with Quaternary basalt cones and flow in the Sawmill Mountains just north of Hells Hole and may be the source for those deposits. The basalt of Mount Logan flowed east about 5.3 km (3.3 mi) from the summit of Mount Logan descending about 335 m (1,100 ft). Basalt of Mount Logan is recharge area for local springs such as Big Spring and Little Spring, which emerge in landslide debris below basalt-flow margins. Thickness 67 m (220 ft)

Basalt of Bundyville (Pliocene)—Informally named for abandoned settlement of Bundyville (town of 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.). Unit is present in northwest quarter of map area on downthrown side of Hurricane Fault. K-Ar age is 3.6±0.18 Ma (Reynolds and others, 1986). Divided into:

Tbi **Intrusive dikes**—Dark-gray alkali-olivine basalt. Dikes are near vertical and oriented N. 40° W. and nearly parallel the Hurricane Fault. Widths approximate on map and vary from 1 to 3 m (3 to 11 ft)

Tbb **Basalt flows**—Dark-gray, finely crystalline, olivine basalt. Groundmass contains olivine crystals. Consist of several flows that form a caprock overlying purple and white mudstone and sandstone beds of Petrified Forest Member of the Chinle Formation. Flow surfaces are locally distorted by soft-sediment deformation of underlying mudstone. Flows are assumed to have originated from local dikes (Tbi) that parallel the Hurricane Fault and are largely covered by basalt or landslide and talus debris. Thickness 30 to 55 m (100 to 180 ft)

Basalt of Mount Trumbull (Pliocene)—Informally named for Mount Trumbull by Hamblin and Best (1970) and Hamblin (1970); Uinkaret Plateau, northern Mohave County, Arizona, (sec. 27, T. 35 N., R. 8 W., central part of map area). K-Ar age is 3.6±0.18 Ma and 3.47±0.63 Ma (Reynolds and others, 1986). Divided into:

Tmi **Intrusive rocks—**Gray-black, finely crystalline, alkali-olivine basalt. Map contact approximate. Form highest point on Mount Trumbull (elev 8,029 ft), north side of Mountain. Source of Tertiary basalt flows on Mount Trumbull. Width of dike about 120 m (400 ft) or more

Tmb **Basalt flows—**gray-black, finely crystalline, alkali-olivine basalt. Groundmass contains olivine phenocrysts and plagioclase laths. Consist of one or more thin basalt flows that form caprock over purple and white mudstone and sandstone beds of Petrified Forest Member of the Chinle Formation, west side of mountain (exposed in landslide float material) and over red sandstone and siltstone of upper red member and possibly Shnabkaib Member of the Moenkopi Formation on east side of mountain. Partly covered by Quaternary pyroclastic cone southeast of Nixon Spring, south side of mountain. Western half of outcrop is recharge area for Nixon Spring, which emerges in landslide debris near base of basalt flow. Thickness 30 to 60 m (100 to 200 ft)

SEDIMENTARY ROCKS

Chinle Formation (Upper Triassic)—Includes the Shinarump and Petrified Forest Members, undivided. Both Members are mapped as the Petrified Forest Member for this report

Ꞧcp **Petrified Forest Member**—White, blue-gray, pale-red, and purple, slope-forming interbedded fluvial mudstone, siltstone, and coarse-grained sandstone. Contains small, well-rounded pebbles of yellow, brown, and red quartzite, and brown, yellow, white, and red petrified wood fragments in lower part within white, coarse-grained, ledge-forming sandstone that is likely the equivalent of the Shinarump Member of the Chinle Formation. Contains bentonitic clays derived from decomposition of volcanic ash. Unconformable contact with the overlying basalt of Bundyville just west of map area (Billingsley and others, 2000). Erosion removed an unknown thickness of upper part of Chinle Formation and younger Mesozoic strata prior to deposition of the basalt of Bundyville. Unit mostly covered by the basalt of Bundyville (Tbb) and landslide deposits (Ql) west of Hurricane Fault; mostly covered by basalt of Mount Logan east of Hurricane

Fault and Hells Hole. Unconformable contact with underlying slope-forming upper red member of the Moenkopi Formation; erosional relief less than 2 m (6 ft) at Hells Hole. Thickness 122 m (400 ft)

Moenkopi Formation (Middle? and 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:

Ћmu **Upper red member (Middle? and Lower Triassic)—**Red, thin-bedded, cliff- and slope-forming siltstone and sandstone. Unconformably overlain by the Chinle Formation at Hells Hole and Sawmill Mountain area; by the basalt of Mount Logan, east side of Mount Logan; and by the basalt of Mount Trumbull at Mount Trumbull. Gradational contact with underlying Shnabkaib Member of the Moenkopi Formation arbitrarily placed at uppermost thick, white or light-gray calcareous siltstone and dolomite beds. Regionally unit thins south and east, thickens north. Thickness 120 m (400 ft)

Ћms **Shnabkaib Member (Lower Triassic)—**White, laminated, slope-forming, aphanitic dolomite interbedded with light-gray, calcareous, silty gypsum and gypsiferous siltstone. Gradational lower contact with middle red member placed at lowest white or light-gray, calcareous, silty dolomite of the Shnabkaib Member. Unit thins south and west, thickens north. Thickness at Hells Hole about 135 m (445 ft)

Ћmm **Middle red member (Lower Triassic)—**Red-brown, thin-bedded to thinly laminated, slope-forming siltstone and sandstone. Includes interbedded 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 (30 ft) above gray, ledge-forming limestone bed of Virgin Limestone. Unit thins west, south, and east, thickens north. Thickness 120 m (400 ft)

Ћmv **Virgin Limestone Member (Lower Triassic)—**Consists of one light-gray, thin-bedded to thinly laminated, ledge-forming limestone 0.5 to 2 m thick. Includes overlying 10 m (30 ft) of pale-yellow, red, and bluish-gray, thin-bedded, slope-forming gypsiferous siltstone. Unit thins south and west, thickens north to include two limestone beds just north of map area (Billingsley, unpub. data b) and as many as four limestone beds near St. George, Utah (Billingsley and Workman, 1999). Unconformable contact with underlying lower red member of the Moenkopi Formation placed at base of limestone bed. Unit locally pinches out against or unconformably overlies paleohills of Harrisburg Member of the Kaibab Formation. Thickness 0 to 10 m (0 to 30 ft)

Ћml **Lower red member (Lower Triassic)—**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 the Kaibab Formation. Gradational contact with underlying Timpoweap Member of the Moenkopi Formation placed at lowermost red siltstone bed. Locally, unconformably overlies Harrisburg Member of the Kaibab Formation where Timpoweap Member is absent. Thickens in paleovalleys and pinches out against eroded paleohills of underlying Harrisburg Member. Thickness 0 to 20 m (0 to 65 ft)

Ћmt **Timpoweap Member (Lower Triassic)—**Light-gray, slope- and cliff-forming conglomerate in lower part and light-gray to light-red, slope-forming calcareous sandstone with interbedded conglomerate lenses in upper part. Conglomerate in lower part 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 cherty sandstone. Upper part includes beds of low-angle crossbedded, calcareous, yellow sandstone and conglomerate and minor red siltstone. Cemented by calcite and gypsum. All detritus in Timpoweap Member derived from erosion of the Kaibab Formation. Fills paleovalleys, about 1,500 m (4,900 ft) wide and as much as 70 m (230 ft) deep, eroded into Harrisburg Member of the Kaibab Formation. Imbrication of pebbles in conglomerate shows general northeastward flow of depositing streams. Thickness 0 to 70 m (0 to 230 ft)

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

Pkh **Harrisburg Member**—Includes upper, middle, and lower parts. Upper part consists mainly of slope-forming, red and gray, interbedded gypsiferous siltstone, sandstone, gypsum, and thin-bedded gray limestone capped by a resistant, pale-yellow or light-gray, fossiliferous (mollusks and algae) sandy limestone averaging about 1 m (3 ft) thick. Gradational contact with middle part. Middle part consists of two cliff-forming limestone beds as much as 2 m (6 ft) thick each. Upper bed is gray, thin-bedded, cherty limestone that weathers dark brown or black often forming bedrock surface east of Toroweap Fault on Kanab Plateau; lower bed is light-gray, thin-bedded, sandy limestone. Both beds thicken and thin locally and regionally thicken east and north, thin west. Minor erosional unconformity separates upper and lower bed. Lower part consists of slope-forming, light-gray and reddish-gray, gypsiferous siltstone and fine- to medium-grained calcareous sandstone. Includes interbedded gray, medium-grained, thin-bedded sandy limestone and gray, massive bedded gypsum. Dissolution of gypsum in lower part locally distorts limestone beds of middle part causing them to slump or bend into local surface drainages on Uinkaret and Kanab Plateaus. Unit is mostly covered by basalt flows west of Toroweap Valley on Uinkaret Plateau. Gradational contact with underlying Fossil Mountain Member of the Kaibab Formation arbitrarily placed at top of cherty limestone cliff of the Fossil Mountain. Thickness about 75 m (250 ft)

Pkf **Fossil Mountain Member**—Light-gray, fine- to medium-grained, thin-bedded, fossiliferous, cliff-forming, cherty limestone. Unit characterized by cliffs of chert-banded limestone. Erodes into conical pillars along cliffs on east side of Toroweap Valley and upper Cove Canyon. Unconformable contact with underlying Woods Ranch Member of the Toroweap Formation marked by channel erosion with relief as much as 2 m (6 ft) locally, but as much as 30 m (100 ft) in lower Whitmore Canyon and upper Toroweap Valley. Contact locally obscured by talus and minor landslide debris. Unit thickens west, thins east. Thickness 60 to 65 m (200 to 215 ft)

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

Ptw **Woods Ranch Member**—Gray, slope-forming gypsiferous siltstone and pale-red silty sandstone interbedded with white laminated gypsum. Beds locally distorted caused by gypsum dissolution. Gradational contact with underlying Grady Canyon Member of the Toroweap Formation placed at top of limestone cliff of Brady Canyon Member. Thickness 30 to 60 m (100 to 200 ft)

Ptb **Brady Canyon Member**—Gray, cliff-forming, medium-bedded, fine- to coarse-grained, fetid, fossiliferous limestone; weathers dark gray. Includes thin-bedded dolomite in upper and lower part. Limestone beds average about 0.5 m (2 ft) thick and contain chert lenses and nodules. Gradational contact with underlying Seligman Member of the Toroweap Formation placed at base of limestone cliff. Contact commonly covered by minor slump or talus debris. Unit thins east, thickens west. Thickness 60 m (200 ft)

Pts **Seligman Member**—Gray, thin-bedded, slope-forming dolomite and gypsiferous sandstone. Includes gray to red, thinly interbedded siltstone, sandstone, and gypsum. In lower part, includes brown, purple, and yellow, fine- to medium-grained, thin-bedded, low- to high-angle crossbedded and planar-bedded Coconino Sandstone that intertongues with basal part of Seligman Member of the Toroweap Formation in Whitmore Canyon and in Parashant Canyon about 13 km (8 mi) west of the map area (Fisher, 1961; Schleh, 1966; Rawson and Turner, 1974; Billingsley 1997b; Billingsley and others, 2000). Forms sharp, planar, unconformable contact with underlying Hermit Formation where Coconino Sandstone is absent. Unit often covered by talus (Qt) and alluvial fan (Qa1 and Qa2) deposits. Thickness 12 m (40 ft)

Pc **Coconino Sandstone (Lower Permian)—**White, tan, yellowish-brown, fine- to medium-grained, high-angle crossbedded, cliff-forming sandstone. Sharp planar, intertonguing contact between flat-lying sandstone beds of the Seligman Member of the Toroweap Formation. In some areas, crossbedded sandstone of the Coconino Sandstone forms a sharp planar contact with underlying Hermit Formation. Unit partly covered by talus (Qt) and alluvial fan (Qa1 and Qa2) deposits in Toroweap Valley. Thickness 35 to 45 m (115 to 150 ft)

Ph **Hermit Formation (Lower Permian)—**Light-red, yellowish-white, fine-grained, thin- to medium-bedded, slope- and ledge-forming sandstone and siltstone. Includes yellow silty sandstone beds 1 m (3 ft) thick interbedded with thick beds of dark-red, slope-forming siltstone and sandstone in upper part. Reddish sandstone beds commonly contain yellowish-white bleached spots in upper part near contact with Toroweap Formation or Coconino Sandstone. Sandstone beds are partly or completely bleached yellow-white near contact with overlying Coconino Sandstone or Seligman Member of the Toroweap Formation due to dissolution of ground water in the Seligman Member of the Toroweap Formation (Pts) or the Coconino Sandstone (Pc). Unit locally fills erosion channels cut into underlying cliff-slope unit of upper Esplanade Sandstone as much as 6 m (20 ft) deep; otherwise, contact is unconformable with erosional relief averaging about 1 to 2 m (3 to 6 ft) in Cove Canyon area. Unit mostly covered by alluvial fan (Qa1 and Qa2) and talus (Qt) deposits in Toroweap Valley and Whitmore Canyon. Best exposures are in Cove Canyon. Thickness 240 m (790 ft)

Supai Group—Includes, in descending order, Esplanade Sandstone (Lower Permian), Wescogame Formation (Upper Pennsylvanian), Manakacha Formation (Middle Pennsylvanian), and Watahomigi Formation (Lower Pennsylvanian and Upper Mississippian) as defined by McKee (1975 and 1982). Age of the Watahomigi Formation is redefined by Martin and Barrick (1999). Divided into Esplanade Sandstone and lower Supai Group undivided:

Pe **Esplanade Sandstone (Lower Permian)—**Light-red and light-pinkish gray, cliff-forming, fine- to medium-grained, medium-bedded (1 to 3 m [3 to 10 ft]), well-sorted, calcareous sandstone interbedded with dark-maroon-red, slope-forming siltstone. Forms an upper slope-cliff unit, a middle cliff unit, and a lower slope unit. Upper slope-cliff unit comprised of a red, thin-bedded siltstone and sandstone about 36 m (120 ft) thick capped by a cliff of light-red, medium-grained, thick-bedded, crossbedded sandstone about 25 to 30 m (80 to 100 ft) thick. Red sandstone slope is similar in appearance to the Hermit Formation and can be mistaken as part of the Hermit. Middle cliff unit is light-red, fine- to medium-grained, crossbedded sandstone. Contains small- to medium-scale, low-angle and high-angle planar crossbedded sandstone and calcareous sandstone in upper half and flat, massive, light-red to gray, low-angle crossbedded sandstone and calcareous sandstone in lower half. Gray calcareous sandstone in lower part undergoes facies change westward to become limestone cliff of Pakoon Limestone west of Hurricane Fault. Thickness of middle cliff unit averages about 60 m (200 ft). Lower slope unit consists of alternating layers of sandstone, siltstone, mudstone, locally thin-bedded limestone and basal limestone conglomerate. Thickness of lower slope unit averages about 25 m (80 ft). Unconformable contact with underlying Wescogame Formation in lower part of slope with local relief as much as 15 m (50 ft), but averaging about 11 m (35 ft). Thickness, about 153 m (500 ft)

MIPs **Lower Supai Group undivided (Pennsylvanian and Mississippian)--Wescogame Formation (Upper Pennsylvanian)—**Light-red, pale-yellow, and light-gray, fine- to coarse-grained sandstone, dolomitic sandstone, siltstone, mudstone, and conglomerate. Forms an upper slope unit and lower cliff unit. Upper slope unit is dark-red, fine-grained siltstone and mudstone and light-red sandstone. Lower cliff unit is light-red to gray sandstone with high-angle, large- and medium-scale, tabular crossbedded sets as thick as 12 m (40 ft). Includes interbedded, dark-red, thin-bedded siltstone in upper part. A limestone-chert conglomerate fills local erosion channels as much as 24 m (80 ft) deep at base eroded into underlying Manakacha Formation. Thickness 40 m (132 ft). **Manakacha Formation (Middle Pennsylvanian)—**Light-red, white, and gray sandstone, calcareous sandstone, dark-red siltstone, and gray limestone. Forms an upper slope unit and lower cliff unit. Upper slope is a shaley siltstone and mudstone interbedded with thin limestone and sandstone beds. Lower cliff unit is crossbedded calcareous sandstone and sandy limestone. Unconformable planer contact with underlying Watahomigi Formation; erosional relief generally less than 1 m (3 ft). Thickness, about 60 m (200 ft). **Watahomigi Formation (Upper Mississippian and Lower Pennsylvanian)—**Gray and purple-red, slope-forming limestone, siltstone, mudstone, and conglomerate. Includes cherty limestone conglomerate of Lower Pennsylvanian age in upper two-thirds of slope below sequence of alternating gray limestone and purplish-red shaley siltstone and mudstone. Limestone beds in upper part contain red chert nodules and chert veins. Lower third of slope unit is purplish-red mudstone, siltstone, and thin-bedded, aphanitic to granular limestone in upper part that contains fossil conodonts of Late Mississippian age (Martin and Barrick, 1999). Unconformable contact with underlying Redwall Limestone. The Surprise Canyon Formation (Upper Mississippian) is not present in map area but is present just south of map as valley-fill strata between the Watahomigi Formation and Redwall Limestone (Billingsley and Beus, 1999). Thickness about 40 m (130 ft)

Mr **Redwall Limestone (Upper and Lower Mississippian)—**Includes, in descending order, Horseshoe Mesa, Mooney Falls, Thunder Springs, and Whitmore Wash Members as defined by McKee (1963) and McKee and Gutschick (1969). **Horseshoe Mesa Member**—Light-olive-gray, thin-bedded, cliff-forming, fine-grained, locally fossiliferous limestone. Gradational contact with underlying massive-bedded limestone of the Mooney Falls Member. Includes ripple-laminated and oolitic limestone beds and some chert beds. Variable thickness 15 to 30 m (50 to 100 ft). **Mooney Falls Member**—Light-gray, fine- to coarse-grained, thick-bedded to very thick bedded (1 to 6 m [4 to 20 ft]), cliff-forming, fossiliferous limestone. Includes dark-gray dolomite beds in lower half; oolitic limestone and chert beds restricted to upper part. Includes large-scale, tabular and planar cross-stratification in upper third of unit. Disconformable contact with underlying Thunder Springs Member distinguished by sudden appearance of interbedded chert, a characteristic of Thunder Springs sediments. Thickness 122 m (400 ft). **Thunder Springs Member**—About 50% white, thin-bedded bands and lenses of fossiliferous chert and about 50% brownish-gray, finely crystalline, thin-bedded, dolomite and fine- to coarse-grained limestone. Weathers to distinctive prominent black and light-brown bands on cliff faces. Disconformable contact with underlying Whitmore Wash Member. Thickness 45 m (150 ft). **Whitmore Wash Member**—Yellowish-gray and brownish-gray, thick-bedded, fine-grained, fossiliferous, cliff-forming dolomite and limestone. Weathers dark gray. Unconformable contact with underlying Temple Butte Formation. Limestone beds fill low relief erosion channels as much as 2 to 3 m (5 to 10 ft) deep. Contact generally recognized where major cliff of Redwall Limestone overlies stair-step ledges of Temple Butte Formation. Thickness 25 m (80 ft)

Dtb **Temple Butte Formation (Upper and Middle Devonian)—**Purple, reddish-purple, dark-gray, and light-gray, ledge-forming dolomite, sandy dolomite, sandstone, mudstone, and limestone as defined by Beus (1990). Fine- to coarse-grained, thin- to medium-bedded, ripple-laminated ledges of mudstone, sandstone, dolomite, and conglomerate. Unconformable contact with underlying Cambrian undifferiented dolomite beds with erosional relief as much as 12 m (40 ft). Unconformity represents a major break in Paleozoic sequence involving the Late Cambrian, all of the Ordovician and Silurian, and Early and Middle Devonian Periods. Thickness 84 to 90 m (275 to 300 ft)

₵m **Muav Limestone (Upper and Middle Cambrian)—**Dark-gray, light-gray, brown, and orange-red, limestone, dolomite, and calcareous mudstone. The carbonate units consist of cliff-forming, fine- to medium-grained, thin- to thick-bedded, mottled, fossiliferous, silty limestone, limestone, and dolomite. About 63 m (210 ft) of upper part is exposed in Cove Canyon

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DIGITAL DATABASE DESCRIPTION FOR THE GEOLOGIC MAP OF PART OF THE UINKARET VOLCANIC FIELD, MOHAVE COUNTY, NORTHWESTERN ARIZONA

By Jessica L. Wellmeyer and Stephanie L. Dudash

INTRODUCTION

This is a digital geologic map database. This pamphlet describes what is in this database and gives instructions for obtaining the data. There is no paper map included in the Miscellaneous Field Studies report. The report does include however, 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 Uinkaret volcanic field. Together with the accompanying text file (uinkgeo.txt or uinkgeo.doc), 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 ZIP 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/mf2368

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-2368.

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 Uinkaret volcanic field. 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
uink_poly.e00	uink_poly/	FAULTS, CONTACTS, AND GEOLOGIC UNITS
uink_point.e00	uink_point/	Strike and dip information and annotation, point data and annotation
uink_anno.e00	uink_anno/	Unit labels, fault and fold names, and fault separations
uink_fold.e00	uink_fold/	Fold axes

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
parashant.lin.e00	Parashant.lin	Lineset
grndcyn.mrk.e00	grndcyn.mrk	Markerset
wpgcmyk.shd.e00	Wpgcmyk.shd	Shadeset
geoline.lut.e00	geoline.lut	Lookup table for line symbols
geomark.lut.e00	geomark.lut	Lookup table for marker symbols
polycolor.lut.e00	polycolor.lut	Lookup table for polygon symbols
pattern.shd.e00	pattern.shd	Patternset

uink_hyp.tif.gz Zipped background hypsography image

uink_hyp.tfw World file accompanying uink_hyp.tif

PostScript Plotfile Package

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

uinkmap.eps	Encapsulated PostScript plottable file containing complete map composition with geology, symbology, annotation and base map of the Uinkaret volcanic field
uinkgeo.doc	A Word file of this report and the report containing detailed unit descriptions and geological information, plus sources of data and references cited

PDF Plotfile Package

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

uinkmap.pdf A PDF file of the Uinkaret map sheet

uinkgeo.pdf A PDF file of this report, including the full geologic report.

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, and 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 PostScript 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 ArcScan. 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 a 2.5-minute grid of latitude and longitude 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.

RMS Report for transforming uinkpoly2rot grid from
pixel space to UTM zone 12 shifted (uinkticutm).
Nearest resampling method.
Polynomial order = 2.
Forward Transformation Coefficients

```
coef #      coef  x        coef  y
------ ---------------- ----------------
   0     -12698.740      26588.071
   1          1.049         -0.130
   2          0.060          1.034
   3          0.000          0.000
   4          0.000          0.000
   5          0.000          0.000
------ ---------------- ----------------
```

Forward Transformation Errors

```
gcp id      input  x        input  y
           output x       output y        x error        y error
------ ---------------- ---------------- ---------------- ----------------
   1     297536.803      41543.459
         298480.527      41560.539          0.393          0.557
   2     319332.885      42212.656
```

	320874.430	41066.279	-0.347	-0.240
3	298335.156	14586.603		
	297834.227	13824.430	0.676	0.328
4	320195.170	15246.760		
	320300.031	13331.512	-0.719	-0.642
5	301701.590	23677.944		
	301789.623	22983.425	-1.474	-0.389
6	316257.107	24117.632		
	316750.877	22654.512	1.605	1.330
7	301430.525	32664.581		
	302001.061	32228.716	-0.127	-0.937
8	312199.474	37496.078		
	313309.939	36601.959	-0.006	-0.008

Forward transformation RMS Error (X, Y) = (0.867, 0.679)
Forward transformation Chi-Square (X, Y) = (6.014, 3.686)

Backward Transformation Coefficients

coef #	coef x	coef y
0	13536.002	-24399.542
1	0.947	0.119
2	-0.056	0.959
3	0.000	0.000
4	0.000	0.000
5	0.000	0.000

Backward Transformation Errors

gcp id	input x output x	input y output y	x error	y error
1	297536.803	41543.459		
	298480.527	41560.539	-0.356	-0.555
2	319332.885	42212.656		
	320874.430	41066.279	0.329	0.251
3	298335.156	14586.603		
	297834.227	13824.430	-0.643	-0.350
4	320195.170	15246.760		
	320300.031	13331.512	0.670	0.654
5	301701.590	23677.944		
	301789.623	22983.425	1.417	0.447
6	316257.107	24117.632		
	316750.877	22654.512	-1.498	-1.359
7	301430.525	32664.581		

	302001.061	32228.716	0.080	0.909
8	312199.474	37496.078		
	313309.939	36601.959	0.001	0.003

------ ---------------- ---------------- ---------------- ----------------

Backward transformation RMS Error (X, Y) = (0.818, 0.689)
Backward transformation Chi-Square (X, Y) = (5.355, 3.794)

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

Following editing and annotation, the individual coverage's 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 UINK_POLY. These distinctions and the geologic identities of the boundaries are stored in the LINETYPE field according to their line type.

Arc Attribute Table Definition:

COLUMN	ITEM NAME	WIDTH	OUTPUT	TYPE	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	UINK_POLY#	4	5	B	-	-
29	UINK_POLY-ID	4	5	B	-	-
33	LINETYPE	50	50	C	-	-
83	NAME	50	50	C	-	-
133	POINTTYPE	50	50	C	-	-
183	UNIT	8	8	C		

The AAT defined above represents the AAT in UINK_POLY and UINK_FOLD is virtually identical.

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
UINK_POLY#	Unique internal number
UINK_POLY-ID	Unique identification number
LINETYPE	Line type
NAME	Name of line feature
POINTTYPE	Point type

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

Domain of Line Types recorded in LINETYPE field:

BASALT FLOW DIRECTION
BASALT FLOW DIRECTION TAIL
CONCEALED SYNCLINE
CONTACT
LANDSLIDE SCARP
NORMAL HIGH ANGLE CONCEALED FAULT
NORMAL HIGH ANGLE FAULT
SYNCLINE (uink_fold)
MONOCLINE (uink_fold)
CONCEALED MONOCLINE (uink_fold)

Domain of Point Types recorded in POINTTYPE field

bar and ball
syncline
monocline
none

POLYGONS

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

Definition of Polygon Attribute Table:

COLUMN	ITEM NAME	WIDTH	OUTPUT	TYPE	N. DEC	ALTERNATE NAME
1	AREA	8	18	F	5	-
9	PERIMETER	8	18	F	5	-
17	UINK_POLY#	4	5	B	-	-
21	UINK_POLY-ID	4	5	B	-	-
25	UNIT	8	8	C	-	-
33	PATTERN	4	4	I	-	-

Description of Item Names:

Item Name   Description

AREA	Area of polygon in square meters
PERIMETER	Perimeter of polygon in meters
UINK_POLY#	Unique internal number
UINK_POLY-ID	Unique identification number
UNIT	Unit label
PATTERN	Designated fill pattern for polygons

Domain of UNIT (map units):

Ꞓm	Qa3	Qg1	Qp6588	Ti
Dtb	Qaf	Qg2	Qp6646	Tmb
MⱣs	Qb	Qi	Qpvb	Tmi
Mr	Qb1	Qkrb	Qpvp	Tmlb
Pc	Qb6375	Qkrp	Qs	Tp
Pe	Qb6457	Ql	Qgrb	Ꞧcp
Ph	Qb6588	Qlsb	Qgrp	Ꞧml
Pkf	Qb6646	Qlsp	Qti	Ꞧmm
Pkh	Qc	Qmrb	Qb1	Ꞧms
Ptb	Qltb	Qmrp	Qv	Ꞧmt
Pts	Qcbb	Qp	Tb	Ꞧmu
Ptw	Qcbi	Qp1	Tbb	Ꞧmv
Qa1	Qcbp	Qp6375	Tbi	
Qa2	Qf	Qp6457		

Ꞓ represents Cambrian strata, D represents Devonian, M represents Mississippian, Ᵽ represents Pennsylvanian, P represents Permian strata, T represents Tertiary strata, Ꞧ 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 WPGCMYK.SHD and are related to the lookup table POLYCOLOR.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 UINK_POINT has only a point attribute table, and UINK_POLY has only a polygon attribute table.

Definition of Point Attribute Table:

COLUMN	ITEM NAME	WIDTH	OUTPUT	TYPE	N.DEC.	ALTERNATE NAME
1	AREA	8	18	F	5	-
9	PERIMETER	8	18	F	5	-
17	UINK_POINT#	4	5	B	-	-
21	UINK_POINT-ID	4	5	B	-	-
25	NAME	30	30	C	-	-
55	POINTTYPE	60	60	C	-	-
115	DIP	3	3	I	-	-
118	STRIKE	3	3	I	-	-

Description of Item Names:

Item Name	Description
AREA	
PERIMETER	
UINK_POINT#	Unique internal number
UINK_POINT-ID	Unique identification number
NAME	Feature name

POINTTYPE	Point type
DIP	Dip angle in azimuth degrees
STRIKE	Strike angle in degrees

The coverage UINK_POINT contains strike and dip data, and other pertinent structural data represented by point symbology, including collapses, sinkholes and domes. UINK_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 GEOMARK.LUT and are from the symbolset GRNDCYN.MRK.

Domain of POINTTYPE:

bedding
probable breccia pipe (c)
pyroclastic cone
sinkhole
vertical joint

ANNOTATION

The coverage UINK_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. UINK_ANNO contains annotation with unit labels, fault separation, and monocline names. Annotation pertaining to unit name is in subclass anno.unit, and all other annotation is contained in subclass anno.fault.

The textset used for all annotation was geofont.txt, specifically symbolset 38. 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 ^m.

BASE MAP PROCEDURE

The base map was prepared by piecing together 1:24,000-scale quadrangles of the Mount Trumbull NE, Mount Trumbull SE, Mount Trumbull NW, and Mount Logan and rescaling to 1:31,680. This new base was then scanned using the Optronics 5040 raster scanner at a resolution of 50 microns. This raster file was converted from RLE format to RLC format, and subsequently converted to an ARC/INFO Grid file. The grid file was converted into a registered TIFF in conjunction with a colormap file, producing an image file with all linework in gray. No editing of the actual linework or attribution 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 and 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.

OTHER FILES

The lineset used to display the appropriate line weight and symbology is PARASHANT.LIN. It is related to the database by a lookup table called GEOLINE.LUT. Similarly, the markerset for this database is GRNDMRK.MRK, and its lookup table is GEOMARK.LUT. Colors in the polygon coverage (UINK_POLY) are assigned based on the UNIT and were chosen from a shadeset called WPGCMYK.SHD and a lookup table POLYCOLOR.LUT. Annotation (unit labels, text labels and printed numerical values) were displayed using a font entitled GEOFONT.TXT which has capabilities for displaying proper notation of geologic text symbols.

Also enclosed in this database package is UINK.MET, the FGDC standard metadata for the database and UINK.REV, a revision list with current information on the status of all files described in this report and found in the database.