Geologic Map of Upper Clayhole Valley and Vicinity, Mohave County, Northwestern Arizona

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National Park Service and the
Bureau of Land Management

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Miscellaneous Field Studies Map MF-2418

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INTRODUCTION

Upper Clayhole Valley is on the Uinkaret Plateau of the Arizona Strip of northwestern Arizona and is part of the southern Colorado Plateau geologic province. This map is part of a U.S. Geological Survey project in cooperation of the Bureau of Land Management and National Park Service to provide a better understanding of the geologic framework of this unmapped part of northwest Arizona. Information gained will provide insights into the structural evolution of this region, which resulted from late Mesozoic-early Tertiary compression and Late Cenozoic extension and magmatism, and baseline information for future natural resource and environmental studies related to resource management of land use, range management, biological, archaeological, and flood control programs.

The map area is about 38 km (24 mi) south of the nearest settlement of Colorado City, Arizona (fig. 1). Elevations range from about 1,426 m (4,680 ft) west of the Hurricane Cliffs (northwest edge of map area) to 2,007 m (6,585 ft) at Berry Knoll, southwest quarter of the map area. Primary vehicle access is dirt roads locally known as the Clayhole Wash and Temple Trail Roads (fig. 1); unimproved dirt roads lead to various locations within the map area. Travel on these roads is possible with 2-wheel-drive vehicles except during wet conditions. Extra fuel, two spare tires, and extra food and especially water are highly recommended for travelers in this area.

The Bureau of Land Management, Arizona Strip Field Office, St. George, Utah, manages the area, including the newly established (January 11, 2000) Grand Canyon Parashant National Monument in the southeast corner of the map area. In addition, there are about 14 sections of land belonging to the State of Arizona and less than 1 section of private land at Langs Run drainage in the west-central part of map area (U.S. Department of the Interior, 1993). Lower elevations in the map area support a sparse growth of sagebrush, cactus, grass, and various high-desert shrubs. Salt cedar (tamarisk) trees are common along Clayhole Wash and its tributaries in Clayhole Valley. At higher elevations, sagebrush and grass thrive in alluvial valleys along with a few pinyon pine and juniper trees in the southwest part of the map area. Surface runoff within the map area drains north towards the Virgin River in southern Utah.

PREVIOUS WORK

Geologic mapping of this area was done by aerial photoreconnaissance in the 1960 s and compiled onto a 1:500,000-scale Arizona State geologic map by Wilson and others (1969) and later revised by Reynolds (1988). Billingsley mapped four 1:24,000-scale quadrangles (1994b, c, d, e; fig. 1). Geologic mapping of adjacent areas include: 1) the upper Hurricane Wash and vicinity, which bounds this map on the west (Billingsley and Dyer, 2003); 2) the lower Hurricane Wash and vicinity, which adjoins the northwest corner of this map (Billingsley and Graham, in press); 3) the Clayhole Wash and vicinity, which borders on the north (Billingsley and others, 2002); 4) the Heaton Knolls NW (Wild Band Pockets 7.5' quadrangle; Marshall, 1956), which adjoins the northeast corner of this map; 5) the Uinkaret Volcanic Field which borders on the south (Billingsley and others, 2001); and 6) the Parashant Canyon and vicinity (Billingsley and others, 2000), which adjoins the southwest corner of the map.

MAPPING METHODS

This map was produced using 1:24,000-scale 1976 infrared 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 pyroclastic cones and
flows. 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.

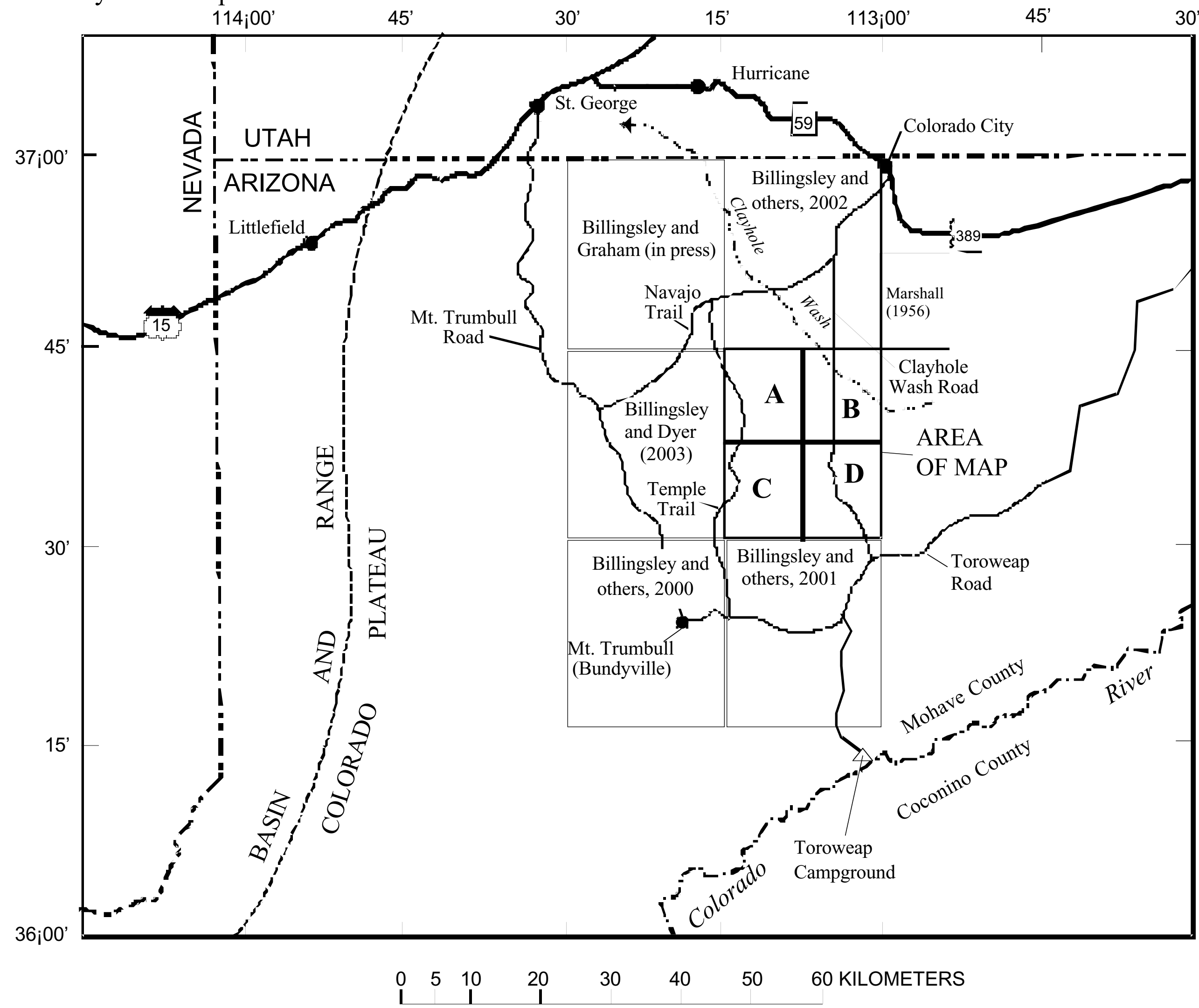

Figure 1. Map showing the Antelope Knoll (A), Little Clayhole Valley (B), Moriah Knoll (C), and Hat Knoll (D), U.S. Geological Survey 7.5-minute quadrangles and adjacent mapped areas, northern Mohave County, northwest Arizona.

GEOLOGIC SETTING

Most of the map area lies within the Uinkaret Plateau, a subplateau of the Colorado Plateaus physiographic province. A small area along the west edge of the map below the Hurricane Fault scarp lies within the Shivwits Plateau (Hamblin and Best, 1970).

The Shivwits and Uinkaret Plateaus are characterized by nearly flat-lying Paleozoic and Mesozoic sedimentary strata that are warped by minor folds and have an average regional dip of about 1… east except along the base of the Hurricane Cliffs, where dips are as steep as 24… east. The Hurricane Fault and Hurricane Monocline along the west edge of map area are the principal structures that offset the sedimentary rocks. Vertical displacement across the Hurricane Fault in this map area is estimated to be more than 300 m (1,000 ft) down-to-the-west. More than 400 m (1,315 ft) of Permian strata are exposed in the fault scarp and about 225 m (740 ft) of Triassic strata are exposed in the east half of the map area.

Quaternary volcanic rocks and alluvial deposits are widely distributed in the map area. The volcanic rocks are mostly alkali-olivine basalt dikes, flows, and pyroclastic deposits. Surficial map deposits include man-made artificial earth dams and diversion ditches, stream channel, floodplain, terrace-gravel, alluvial fan, talus debris, valley-fill, colluvial, and landslide deposits. Map contacts between surficial deposits are arbitrary because of intertonguing and (or) gradational lateral and vertical changes. The subdivision of Quaternary alluvium 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 and others, 2001).

PALEOZOIC AND MESOZOIC SEDIMENTARY ROCKS

The Paleozoic and Mesozoic rocks, in order of decreasing age, are the Hermit, Toroweap, and Kaibab Formations (Lower Permian), and the Moenkopi Formation (Lower Triassic). About 43 m (140 ft) of the upper Hermit Formation is exposed at the base of the Hurricane Cliffs. The Coconino Sandstone (Lower Permian), which crops out in the Grand Canyon between the Hermit and Toroweap Formations about 6 km (4 mi) south of this map, pinches out northward and is not exposed in the map area, although the Coconino Sandstone may be present in the subsurface in the south third of the map area. Gray siltstone, sandstone, gypsum, and limestone of the Toroweap Formation are well exposed only in the lower steep slopes and ledges of the Hurricane Cliffs. The Kaibab Formation forms the upper part of the Hurricane Cliffs and much of the exposed bedrock surface in the west half of the map area. The Kaibab Formation is composed of gray cherty limestone, gray, white, and pale-red siltstone and sandstone, and gray to white gypsum. Gray conglomerate and sandstone, light brown to red siltstone and sandstone, gray gypsum, and gray limestone of the Moenkopi Formation form the bedrock surface in the east half of the map area.

A major unconformity separates the Permian Kaibab Formation from the Triassic Moenkopi Formation. Two large Triassic paleovalleys (fig. 2) eroded into or through the Harrisburg Member and into the upper part of the Fossil Mountain Member of the Kaibab Formation. The paleovalleys are filled with conglomerate and sandstone of the Timpoweap Member of the Moenkopi Formation (Ꞧmt). Imbrication of pebbles in the basal conglomerate of the Timpoweap Member indicates deposition from streams that flowed toward the east and north.

The north paleovalley, Mustang Valley (Billingsley and Workman, 2000) is more than 44 km (27.5 mi) long and extends into the map area from the west (Billingsley, 1994a; Billingsley and Dyer, 2003); it averages about 1 km (1/2 mi) wide and about 60 m (200 ft) deep (fig. 2). The Antelope Knoll Basalt near Antelope Knoll covers the Mustang valley. Part of the paleovalley has been eroded away by the modern Langs Run and Little Clayhole Wash drainages. In the northeast part of the map area, younger strata of the Moenkopi Formation bury all paleovalleys. The paleovalley called Sullivan valley extends for more than 20 km (13 mi) west of the map area (Billingsley, 1994a; Billingsley and Workman, 2000). Sullivan valley also averages about 1 km (1.2 mi) wide and about 60 m (200 ft) deep. It is partly covered by the basalt of Craigs Knoll and Berry Knoll where a large unnamed paleovalley tributaries approach and join Sullivan valley from the southwest. Farther north, Sullivan valley is covered by lavas of the basalt of Moriah Knoll and the basalt of Seven Knolls. Exposures of the Kaibab Formation between Moriah and Antelope Knolls show no trace of Sullivan valley continuing north to join with Mustang valley; instead, Sullivan valley probably turns east from the Moriah Knoll area and extends beneath the basalt of Seven Knolls. An exposure of the Timpoweap Member of the Moenkopi Formation on the north side of Hat Knoll, about 10 km (6 mi) east of Moriah Knoll, may represent an eastward extension of Sullivan valley, but most of the paleovalley is obscured by alluvium or eroded away.

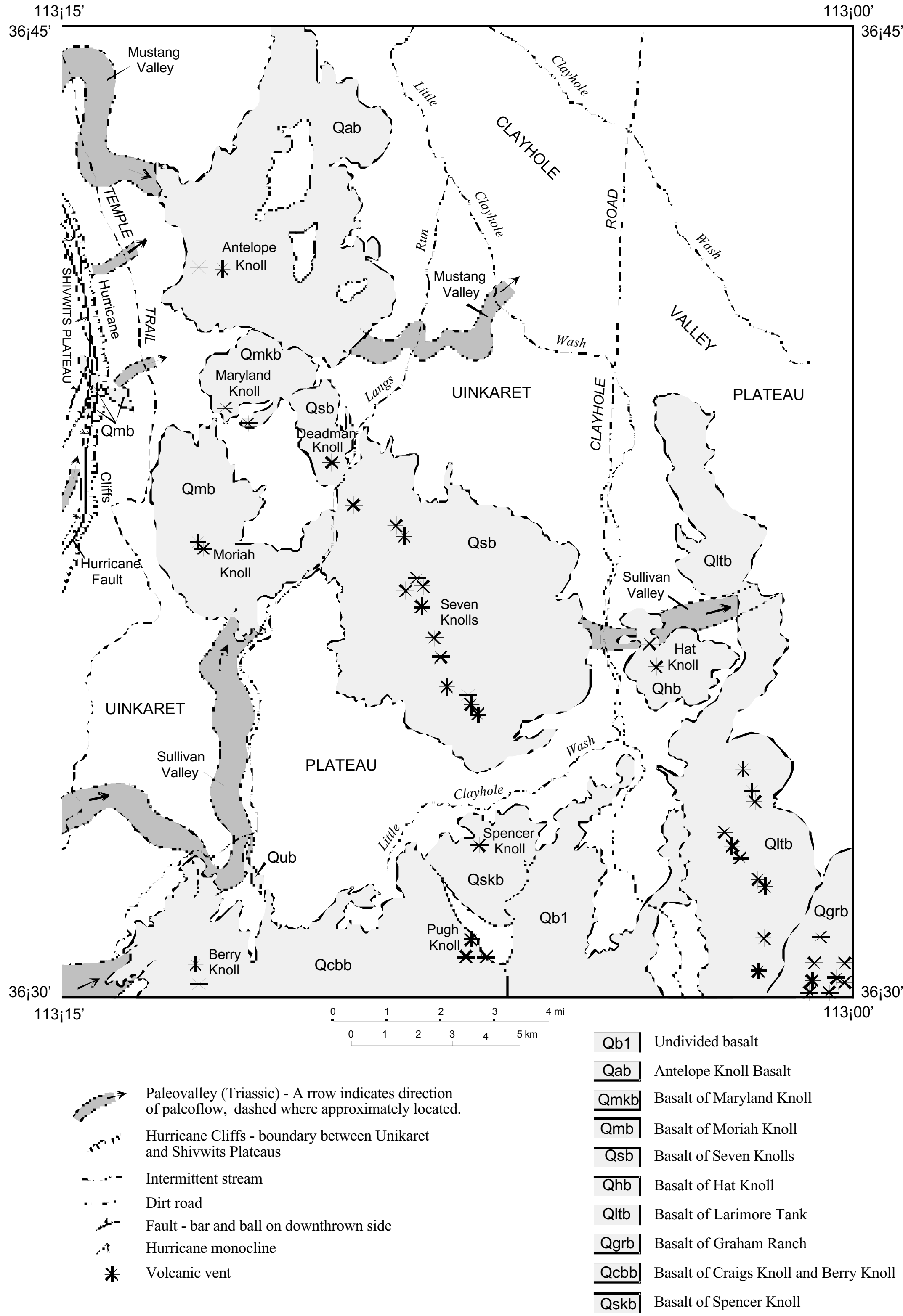

Figure 2. Map showing paleovalleys and selected geographic and geologic features of upper Clayhole

Valley and vicinity, northwestern Arizona.

VOLCANIC ROCKS

Volcanic rocks of the northern Uinkaret Volcanic Field (Koons, 1945; Hamblin and Best, 1970; Hamblin, 1970) cover a large part of the map area. These rocks are composed of alkali-olivine basalt flows and pyroclastic deposits that overlie the Kaibab and Moenkopi Formations. Four K-Ar ages were obtained from basalts in this part of the Uinkaret Volcanic Field. Just north of the map area, a K-Ar date of 0.580–0.30 Ma was obtained from basalt of Black Knolls at Black Knolls and a K-Ar date of 0.830–0.28 Ma from the northern extent of the Antelope Knoll Basalt (Billingsley and others, 2002). A K-Ar date of 0.635–0.24 Ma was obtained from the basalt of Graham Ranch just south of the southeast corner of this map area by Jackson (1990) and a K-Ar age of 0.284–0.48 Ma from the same basalt by Holmes and others (1978). Fenton and others (2001) obtained a cosmogenic ^{3}He age of 0.284–0.37 Ma for the basalt of Graham Ranch in the southeast corner of the map area.

The basalt flows originated primarily from dikes and pyroclastic vent areas. About 27 pyroclastic cones are present in the map area and several cones have two or more vents that form a single complex pyroclastic cone. Several of the largest pyroclastic cones form prominent, named landmarks on an otherwise relatively featureless plateau terrain. The volcanic eruptions may or may not have erupted simultaneously in the map area. Local stratigraphic relations suggest that some flows may be younger than others where one flow overlaps another. However, if several eruptions occurred simultaneously and were a few miles apart, the distance and topographic terrain between them may have caused one flow to overlap another making one appear younger than the other. Thus, an overlapping flow is not interpreted as younger unless there is other field evidence such as topographic elevation difference, the freshness of the flow surfaces, or type of surficial alluvial cover. Volcanic flows that are relatively isolated and easily traced to the source or multi-sourced area are mapped and described separately because each makes a unique contribution to the landscape development in this part of the Uinkaret Volcanic Field.

BASALT OF LARIMORE TANK

A young volcanic unit in the southeast corner of the map area was originally named the Cave Basalt in a report by Billingsley (1994d) and Billingsley and Workman (2000) for numerous sinkholes in the basalt flow but the name was incorrectly used on those two maps because the authors were unaware that the name Cave Basalt was recently established in Idaho. Thus, the name has been changed to basalt of Larimore Tank, a stock tank labeled Larimore Tank on the U.S. Geological Survey Hat Knoll 7.5-minute quadrangle in the southeast corner of the map area (Billingsley and others, 2001).

This informal unit consists of five pyroclastic cones, at least one intrusive dike, and a thin lava flow that coalesced into one flow derived from the five pyroclastic cones. Sinkholes in the basalt flows are the result of dissolution of gypsum in the underlying Harrisburg Member of the Kaibab Formation. The five pyroclastic cones are aligned along a north-south trend. The flows traveled north about 15 km (9.5 mi) into the upper reaches of Clayhole Valley. The flow wrapped around the south and east side of Hat Knoll lava pad about 30 m (100 ft) lower than the Hat Knoll lava pad, then advanced down and across a small northwest-facing fault scarp out onto the alluvial floor of Clayhole Valley. Offset of the Moenkopi Formation along the fault is a maximum of about 43 m (140 ft) down-to-the-northwest, but the lava flow is not offset. The lava flow was constricted to a width of less then 56 m (185 ft) on the upthrown side of the fault, a reflection of the headward erosion south and into the fault scarp prior to the flow. At the north end of the flow, the lava is about 7.5 m (25 ft) above the present drainage of Little Clayhole Wash. The basalt of Larimore Tank descended about 213 m (700 ft) over a distance of 15 km (9.5 mi) for a gradient of about 14.2 m/km (23 ft/mi).

Contact relations with other basalt flows in the map area indicate that the basalt of Larimore Tank postdates significant erosion of the basalt of Hat Knoll and other basalts. However, contact relations between the basalt of Larimore Tank and undivided basalt flows from the Pugh Knoll area are not definitive. But judged by the degree of weathering and preservation of relatively fragile surface features, the basalt of Larimore Tank is interpreted to be the youngest lava flow in the map area that probably erupted less than 100,000 years ago.

BASALT OF GRAHAM RANCH

The basalt of Graham Ranch is named for an abandoned ranch, Graham Ranch, in upper Toroweap Valley about 3 km (2 mi) south of the southeast corner of the map area. Billingsley and Workman (2000) 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 on the Grand Canyon quadrangle map (Billingsley and Hampton, 2000). The basalt of Graham Ranch in upper Toroweap Valley, just south of the map area, has a reported K-Ar age of 0.635–0.24 Ma by Jackson (1990) and 0.284–0.48 Ma by Holmes and others (1978). Fenton and others (2001) report a cosmogenic ^{3}He age of 0.284–0.37 Ma.

The basalt of Graham Ranch is an alkali-olivine basalt associated with a few pyroclastic cones; olivine phenocrysts make up about 30 percent of the rock. The pyroclastic cones are aligned north-south just east of the Toroweap Fault. Basalt from the cones coalesced into one flow that traveled north about 3 km (2 mi) towards the upper reaches of Clayhole Valley in the map area. South of the map area, the basalt of Graham Ranch flowed south into the upper reaches of Toroweap Valley where the Toroweap Fault offsets a pyroclastic cone and basalt flow (Billingsley and others, 2001). The pyroclastic cone is offset down-to-the-west as much as 26 m (85 ft), based on topographic expression. The basalt is also offset 36 m (120 ft) by movement on the Toroweap Fault just south of Graham Ranch. Just south of Graham Ranch, displacement of the underlying Kaibab Formation along the Toroweap Fault 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. Thus, about half of the 67 m (220 ft) of separation along this part of the Toroweap Fault occurred in the last 285 ka.

UNDIVIDED BASALTS

The undivided basalt in the Pugh Knoll area is part of a larger complex of basaltic rocks centered south of the map area (Billingsley and Workman, 2000; Billingsley and others, 2001). The undivided basalts are alkali-olivine basalts similar to other basaltic rocks of the Uinkaret Volcanic Field, have a similar stratigraphic position, and overlie similar bedrock strata of the Kaibab and Moenkopi Formations suggesting a Pleistocene age for the undivided basalts. The unit label is that used by Billingsley and others (2001).

BASALT OF SPENCER KNOLL

Spencer Knoll and associated lava flows form a mappable unit and is informally named the basalt of Spencer Knoll. The basalt of Spencer Knoll is another alkali-olivine basalt similar to other nearby alkali-olivine basalts in the map area and is likely of a similar age. Spencer Knoll is a 115-m-high (375-ft-high) pyroclastic cone on a basalt flow that came from the base of the cone in a radial fashion. The basalt overlies a relatively flat surface of the Harrisburg Member of the Kaibab Formation. The 60-m-high (200-ft-high) basalt pad under and around Spencer Knoll may have formed a diversion for basalt flows that came from the Pugh Knoll and Craigs Knoll area. Map contacts between the basalt of Spencer Knoll, the basalt of Craigs Knoll and Berry Knoll, and the undivided basalts are approximate and arbitrary and are determined partly on the basis of topographic differences and the surficial roughness of the Spencer Knoll lavas compared to the other basalt flows.

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, Berry Knoll, and an unnamed pyroclastic cone between them about 9 km (5 mi) south of the map area. Craigs Knoll is a 300-m-high (1,000-ft-high) pyroclastic cone about 5 km (3 mi) south of the map area and Berry Knoll is a 110-m-high (360-ft-high) pyroclastic cone in the southwest corner of the map area. These volcanoes appear to have erupted simultaneously and the resultant basalt flows of one or more flows coalesced and flowed north about 8 km (5 mi) into the south edge of the map area (Billingsley and others, 2001).

The basalts of Craigs Knoll and Berry Knoll are offset about 60 m (200 ft) along a north-south fault in the southwest corner of the map area. Displacement of the basalt and underlying Kaibab Formation strata along this fault is the same indicating that the fault is younger than the basalt flows (Billingsley 1994b). There have been no age determinations for the basalt of Craigs Knoll and Berry Knoll.

BASALT OF MARYLAND KNOLL

Just south of Antelope Knoll is the 92-m-high (300-ft-high) pyroclastic cone and associated basalt flow of Maryland Knoll (Billingsley, 1994d). The basalt of Maryland Knoll shares a common boundary with the Antelope Knoll Basalt and the relative ages are likely similar, but unknown. The basalt of Maryland Knoll is partly overlain by basalt flows from the basalt of Seven Knolls.

BASALT OF SEVEN KNOLLS

Basalt pyroclastic deposits of Seven Knolls form several northwest-elongated cones aligned parallel to the regional strike of vertical and subvertical joints in the underlying Paleozoic and Mesozoic rock strata (Billingsley, 1994c). Such parallelism is typical of the Uinkaret Volcanic Field (Hamblin and Best, 1970). Some of the pyroclastic cones exhibit two or more vents that form a single elongated cone that suggest elongated fissure eruptions.

Along its west side, the basalt of Seven Knolls overlies the Kaibab Formation; along the east side, it overlies either thin alluvium (not shown) or the lower part of the Moenkopi Formation. The basalt of Seven Knolls partly overlies the basalt of Moriah Knoll, but contact relations do not clearly define relative ages. Similarities of stratigraphic position and compositional characteristics suggest a Pleistocene age for all of these basalts.

Some of the lava flows from the Seven Knolls area traveled westward and down slope into the drainage of Langs Run. The flows appear to have temporarily blocked the drainage of Langs Run forcing the drainage to overflow a basalt flow from Moriah Knoll. It is probable that Moriah Knoll and Seven Knolls eruptions were simultaneous and the flow from Moriah Knoll arrived into the Langs Run drainage before lava from Seven Knolls.

Several flows from the Seven Knolls area advanced northeastward about 17 km (10.5 mi) down drainages and over an erosional scarp formed by the Harrisburg Member of the Kaibab Formation. The lava descended about 60 m (200 ft) onto a relatively gentle west slope of the ancestral Clayhole Valley floored by thin alluvium or gently east-dipping strata of the Moenkopi Formation. The present floor of Clayhole Valley is about 105 m (345 ft) lower than the basalt of Seven Knolls. Assuming the basalt to be about 830 Ka, similar to the Antelope Knoll Basalt, then Clayhole Valley has eroded an average of 0.13 m per thousand years in the last 830 ka in this area.

BASALT OF HAT KNOLL

The basalt of Hat Knoll consists primarily of a single pyroclastic cone, an intrusive dike, and a surrounding lava pad (Billingsley, 1994d). It is separated from the basalt of Seven Knolls by the erosion of Black Canyon, a 90-m-deep (300-ft-deep) tributary of Little Clayhole Wash. The basalt of Seven Knolls and the basalt of Hat Knoll occupy the same stratigraphic horizon, have nearly the same composition, and may have made contact with each other before the erosion of Black Canyon. Thus, the basalt of Hat Knoll is interpreted to be about 830 ka, a similar age to the Antelope Knoll Basalt in this part of the Uinkaret Volcanic Field.

Most of the basalt of Hat Knoll appears to have come from a fissure dike about 1 km (1/2 mi) south of the 100-m-high (330-ft-high) Hat Knoll pyroclastic cone. Much of the lava from the Hat Knoll area flowed eastward about 2.4 km (1.5 mi) onto a nearly flat alluvial terrain of the ancestral Clayhole Valley. The lava overlies a small northeast-trending fault that does not offset the lava.

BASALT OF MORIAH KNOLL

This unit is composed of alkali-olivine basalt that formed a 122-m-high (200-ft-high) pyroclastic cone on surrounding lava flows. Two samples of basalt from Moriah Knoll were obtained for K-Ar age determination. One sample yielded a 2.3–1.5 Ma age and the other a 1.5–1.5 Ma age (Harold Mehnert, U.S. Geological Survey, written commun., 1993 and 1994). According to Harold Mehnert, the samples were not well suited for K-Ar age determination purposes because of severe alteration of the basalt. As a result, both age determinations have an error range of 1.5 m.y. and are considered unreliable. The basalt of Moriah Knoll is interpreted to have erupted roughly contemporaneous or slightly before the Antelope Knoll Basalt because it occupies the same erosional surface, has nearly the same surficial elevation, and overlies similar Permian and Triassic bedrock terrain. A small part of the nearby Maryland Knoll pyroclastic cone overlies part of the basalt from Moriah Knoll suggesting that Maryland Knoll may be slightly younger than Moriah Knoll. An easterly lava flow from Moriah Knoll appears to be overlain by a lava flow from the Seven Knolls area in the Langs Run drainage again suggesting that the basalt of Moriah Knoll may be slightly older than the basalt of Seven Knolls. Surficial alluvial fan deposits largely cover a northerly lava flow from Moriah Knoll more so than other nearby lava flows suggesting that the basalt of Moriah Knoll may be slightly older than other nearby volcanic rocks. Field evidence of relative ages is equivocal, but suggest that the basalt of Moriah Knoll may be slightly older than the other volcanic rocks in the northern Uinkaret Volcanic Field, but close in age to the Antelope Knoll Basalt, which appears to be the oldest.

Basalt from Moriah Knoll flowed northwest down a minor drainage and spilled over the escarpment of the Hurricane Cliffs fault scarp onto tilted outcrops of the Harrisburg Member of the Kaibab Formation and alluvial slopes of the Shivwits Plateau below. Prior to the flow, the drainage had eroded headward only a few hundred meters into the Hurricane Cliffs. Remnants of the flow still cling to the cliff outcrops of the Fossil Mountain Member of the Kaibab Formation where the flow descended down and onto the east segment of the down-dropped, east-dipping block of Kaibab strata that was later offset down-to-the-west in three places. Displacement along the first or easternmost segment of the Hurricane Fault before the flow was about 168 m (550 ft). After the flow, the basalt was further offset down-to-the-west about 30 m (100 ft) for a total offset of about 198 m (650 ft). Below and west of the Hurricane Cliffs, a second segment of the Hurricane Fault offset the basalt of Moriah Knoll and underlying Paleozoic strata down-to-the-west about 26 m (85 ft). There was no offset of the underlying Paleozoic strata before the basalt flow. Farther west of the second fault segment, a third segment of the Hurricane Fault offset the basalt down-to-the-west about 40 m (130 ft). Along this third segment of the Hurricane Fault the Paleozoic strata was offset down-to-the-west about 46 m (150 ft) prior to the basalt flow making a total offset of about 85 m (280 ft) along the third segment of the Hurricane Fault.

The total fault offset of all three segments of the Hurricane Fault prior to the arrival of the basalt of Moriah Knoll was about 213 m (700 ft). Total down-to-the-west offset of the basalt of

Moriah Knoll is about 96 m (315 ft) making the total offset along this part of the Hurricane Fault about 310 m (1,015 ft). The Kaibab Formation strata beneath the basalt on the down dropped side of the Hurricane Fault dips east as much as 24…. The basalt of Moriah Knoll forms an angular unconformity over the Kaibab Formation, as it does not dip east.

Lava from Moriah Knoll divided into two flows after descending the Hurricane Cliffs and crossing the Hurricane Fault segments. One flow traveled a short distance south along the base of the fault scarp and a second more extensive flow continued northwest descending steeply down and over the lower segments of the Hurricane Fault. Both flows overlie either thin alluvial deposits or beveled east-dipping strata of the Harrisburg and Fossil Mountain Members of the Kaibab Formation.

ANTELOPE KNOLL BASALT

The Antelope Knoll Basalt, named by Billingsley and others (2002), is named for a pyroclastic cone called Antelope Knoll, the largest pyroclastic cone in the map area at 140 m (460 ft) high. K-Ar age of the Antelope Knoll Basalt is 0.83–0.28 Ma (secs.13, 18, 19, 24, T.38 N., Rs. 8, 9 W.): Billingsley, 1994c). Composition of this basalt is similar to all other alkali-olivine basalts in the area and is likely the oldest basalt flow in the north part of the Uinkaret Volcanic Field. The basalt contains olivine phenocrysts in a groundmass of plagioclase, augite, and glass (Wenrich and others, 1995). Flows from Antelope Knoll and other volcanic vents in the map area generally flowed north and east, presumably following drainages over gently east-dipping sedimentary strata on which the lava was emplaced.

The Antelope Knoll Basalt flowed north about 19 km (12 mi) descending about 122 m (400 ft) for a gradient of about 6.4 m per 1.5 km (21 ft per mi). A small part of the Antelope Knoll Basalt (sec. 16, T. 38 N., R. 8 W.) flowed down a narrow drainage onto what was probably the alluvial floor of Clayhole Valley at that time. This segment of basalt is 2 km (1 mi) west of the present alluvial floor of Clayhole Valley and is 45 m (150 ft) higher in elevation. This implies that Clayhole Wash has eroded Clayhole Valley at an average rate of about 0.06 m per 1,000 yr during the past 830,000 yr. This figure is similar to the 0.075 m per 1,000 yr obtained at the north end of the Antelope Knoll Basalt flow (Billingsley and others, 2002). The thin alluvium under the basalt flow was not mapped because it is limited in outcrop and too thin to show at map scale.

STRUCTURAL GEOLOGY

Major and minor structures of the map area show up particularly well on X-Band side-looking radar (SAR) images. These images give an overall perspective of the structural fabric of this part of Arizona (Western Atlas International, Inc., 1988).

The Hurricane Fault offsets Paleozoic rock units along the west edge of the map area, and a short, covered segment of the Toroweap Fault is present in the extreme southeast corner. In the western two-thirds of the map area, a zone of northwest-trending faults splays off the Hurricane Fault. Two northeast-striking faults in the southeast part of the map area parallel the strike of the nearby Toroweap Fault. The fault strike and fold axis trend are parallel to the nearly vertical joints in the bedrock, except for a few folds in the northeast quarter of the map area. Overall, the bedrock strata have a regional east to slightly northeast dip averaging about 1…. The regional dip increases to about 5… northeast in the southwest quarter of the map area along a northwest trending fault, and about 3… east in the western quarter of the map which probably reflect the eastern limits of the Hurricane Monocline.

Laramide compressional stresses resulted in the development of the Hurricane Monocline along favorably oriented, pre-existing faults in the Precambrian basement early in Laramide time (Huntoon, 1989; Elston and Young, 1991). The compressional stresses in this map area were generally from a westerly direction that produced the east-dipping Hurricane Monocline that elevated the terrain west of the fold axis. In Late Cenozoic time, east-west tensional stresses resulted in down-to-the-west normal faulting along the same pre-existing Precambrian basement faults, lowering the terrain west of the monoclinal axis and reversing the topography.

The Hurricane Fault and Monocline have a northerly strike near the west edge of the map area, but turns to a southwesterly strike direction southwest of this map (Billingsley, 1993a, 1993b; Billingsley and Dyer, 2003), and a northwesterly strike direction northwest of this map (Billingsley, 1992; Billingsley and Graham, in press). The axis of the Hurricane Monocline is just west of and approximately parallel to the Hurricane Fault (Huntoon and others, 1981; Wenrich and others, 1997). Strata of the Kaibab Formation dip as much as 24… east on the west side of the Hurricane Fault and generally less than 5… east on the east side. Some strata on the downthrown side of the Hurricane Fault dip west because of fault drag.

Unique to this map area is a basalt flow from Moriah Knoll that flowed over the Hurricane Cliffs fault scarp. Age of this basalt is thought to be about 850,000 years, as explained earlier. The basalt is displaced by movement along the Hurricane Fault, which provides a relative age of displacement along this segment of the fault. Total estimated offset of the basalt of Moriah Knoll, based on map contacts over the three segments of the Hurricane Fault, is about 96 m (315 ft). The combined vertical offset along the segments of the Hurricane Fault prior to the flow is estimated to be as much as 213 m (700 ft). Thus, total offset along all segments of the Hurricane Fault in the map area is estimated to be as much as 310 m (1,015 ft). Alluvial fans at the base of the Hurricane Cliffs have less than about 8 m (25 ft) of offset by the Hurricane Fault indicating that the fault is still active.

Near the town of Hurricane, Utah, about 60 km (37.5 mi) north of the map area, a basalt flow with a K-Ar age of 0.293–0.087 Ma is vertically offset about 87 m (285 ft) by the Hurricane Fault (Hamblin and others, 1981). The earliest movement or offset along the Hurricane Fault is less than 3.6–0.18 Ma, because the Bundyville basalt (Reynolds and others, 1986), about 10 km (16 mi) south of the map area, is offset the same amount as the underlying Permian and Triassic strata (Koons, 1945; Hamblin and Best, 1970; Hamblin, 1970). Thus, all vertical displacement along this segment of the Hurricane Fault must have occurred within the past 3.6 m.y. (Billingsley and Dyer, 2003) and at least 96 m (315 ft) of displacement has occurred within the past 1 m.y.

The Toroweap Fault in the southeast corner of the map is structurally similar to the Hurricane Fault and Hurricane Monocline. The Toroweap Monocline is not shown because the east-dipping bedrock strata are covered. The Toroweap Fault and Toroweap Monocline are exposed just south of the map area in Toroweap Valley (Billingsley and Huntoon, 1983). The Hurricane and Toroweap structures have a similar history, but the Toroweap is lesser in magnitude. Offset of Paleozoic strata along the Toroweap Fault in the southeast corner of the map area is estimated to be as much as 49 m (160 ft; Billingsley and others, 2001). The Toroweap Fault offsets the basalt of Graham Ranch as much as 26 and 34 m (85 and 112 ft) a few kilometers south of the map area. Thus, about half of the separation along this part of the Toroweap Fault occurred since the eruption of the basalt of Graham Ranch (Billingsley and others, 2001).

A small unnamed fault has offset the basalt flows of Berry Knoll as much as 30 m (100 ft) about 2 km (1 mi) east of Berry Knoll (southwest part of map area) indicating relatively young tectonic activity in this part of the map area as well.

Short, doubly plunging anticlines and synclines in the map area have a general northwest or northeast trend. These folds, like others elsewhere on the Colorado Plateaus, are probably related to early Laramide compressional stresses (Huntoon, 1989).

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. These bent strata are commonly associated with dissolution of gypsum along drainages or joints.

Shallow sinkholes and karst caves are associated with the dissolution of gypsum in the Harrisburg Member of the Kaibab Formation. The sinkholes are probably Holocene and Pleistocene in age. Hundreds of sinkhole depressions that are breached by drainages on the Uinkaret Plateau surface are not marked on the map. Only sinkholes that form enclosed basins or depressions are indicated on the map by a triangle symbol.

Some circular bowl-shaped areas that have inward-dipping strata may reflect underlying collapse-formed breccia pipes that originate in the deeply buried Mississippian Redwall Limestone (Wenrich and Huntoon, 1989; Wenrich and Sutphin, 1989). Such features are marked on the map by a dot and the letter C. However, breccia pipes cannot be distinguished with certainty from shallow collapse structures caused by the removal of gypsum. Moreover, some deep-seated breccia pipes are known to underlie gypsum collapse features (Wenrich and others, 1997). The deep-seated breccia pipes potentially contain economic deposits of copper and uranium minerals (Wenrich, 1985).

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DESCRIPTION OF MAP UNITS

SURFICIAL DEPOSITS

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

Qaf **Artificial fill 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, and pebble to boulder gravel; unconsolidated and poorly sorted. Locally overlaps young alluvial fan (Qa1), young terrace-gravel (Qg1), upper part of valley-fill (Qv), and floodplain (Qf) deposits. Inset against older alluvial fan (Qa2) and older terrace-gravel (Qg2 and Qg3) deposits. Stream channels subject to high-energy flows and flash floods. Little or no vegetation in stream channels except salt cedar (tamarisk) trees. Contacts with other alluvial deposits approximate. Thickness, 1 to 2 m (3 to 7 ft)

Qf **Floodplain deposits (Holocene)** Light-gray or tan silt, sand, and lenses of pebble to cobble gravel; unconsolidated. Locally contain cinder and basalt fragments. Intertongue with or overlap valley-fill (Qv) deposits. Form relatively flat surfaces having little or no vegetation. Subject to frequent flooding or ponding. Thickness, 1 to 4 m (3 to 12 ft)

Qg1 **Young terrace-gravel deposits (Holocene)** Light-brown, pale-red, and gray silt, sand, and pebble to boulder gravel composed about equally of well-rounded limestone and sandstone clasts and angular to subrounded chert clasts derived from the Kaibab Formation. Include well-rounded to subangular basalt clasts. Form benches about 1 to 3 m (3 to 10 ft) above active streambeds; locally inset into older terrace-gravel (Qg2 and Qg3) deposits. Thickness, 1 to 3 m (3 to 10 ft)

Qa1 **Young alluvial fan deposits (Holocene)** Gray and brown silt and sand. Include lenses of coarse gravel composed of subangular to rounded pebbles and cobbles of limestone, chert, and sandstone locally derived from the Hermit, Toroweap, Kaibab, and Moenkopi Formations, and locally well-rounded to sub-angular basalt clasts. Partly cemented by gypsum and calcite. Overlapped by or intertongue with stream-channel alluvium (Qs) and upper part of valley-fill (Qv) deposits. Intertongue with young terrace-gravel (Qg1), overlap intermediate and older terrace-gravel (Qg2 and Qg3) and older alluvial fan (Qa2) deposits. Alluvial fans subject to erosion by sheet wash and flash flood debris flows. Support sparse growth of sagebrush, cactus, and grass. Thickness, 4 m (12 ft) or more

Qv **Valley-fill deposits (Holocene and Pleistocene)** Gray and light-brown silt, sand, and lenses of pebble to small-boulder gravel; partly consolidated. Intertongue with or overlap talus (Qt), terrace-gravel (Qg1, Qg2, and Qg3), and alluvial fan (Qa1 and Qa2) deposits. Represent relatively less active, low-gradient alluvial stream-channel or drainage deposits. Subject to sheetwash flooding and temporary ponding; cut by arroyos as much as 2 m (6 ft) deep in larger valleys. Support moderate growths of sagebrush, grass, and cactus. As much as 5 m (17 ft) thick

Qt **Talus deposits (Holocene and Pleistocene)** Unsorted breccia debris composed of small and large angular blocks of local bedrock on steep to moderately steep slopes below outcrops. Include silt, sand, and gravel; partly cemented by calcite and gypsum. Intertongue with young and older alluvial fan (Qa1 and Qa2), valley-fill (Qv), young and intermediate terrace-gravel (Qg1 and Qg2), and landslide (Ql) deposits. Support sparse growth of sagebrush, cactus, and grass. Only extensive deposits shown. As much as 9 m (30 ft) thick

Ql **Landslide deposits (Holocene and Pleistocene)** Unconsolidated masses of unsorted rock debris. Include detached blocks that have rotated backward and slid downslope as loose incoherent masses of broken rock and deformed strata, often partly surrounded by talus (Qt). Found principally along upper part of Hurricane Cliffs. In Langs Run drainage, include large angular blocks of basalt as much as 2 m in diameter. Support sparse growth of sagebrush, cactus, grass, juniper and pinyon pine trees. Unstable when wet. Only large masses shown. Thickness, 35 to 45 m (115 to 150 ft)

Qc **Colluvial deposits (Holocene and Pleistocene)** Includes two types: (1) deposits associated with basalt flows and (2) deposits associated with extensive sheetwash alluvium over bedrock, northeast quarter of map. (1) In areas of basalt flows, consist of white to gray silt and fine-grained sand, black and reddish, fine-grained cinder, scoria, and basalt clasts; locally consolidated by gypsum and calcite cement. Located in enclosed basins or sinkhole depressions on or near basalt flows. Similar to floodplain (Qf) deposits, but limited to local accumulations generally not associated with stream drainages. Subject to temporary ponding. Support sparse growths of grass. (2) In northeast corner of map, consist of pale-red, tan, and brown, fine-grained sand and silt. Contain multicolored, well-rounded to rounded quartz and quartzite pebbles derived from Shinarump Member of Chinle Formation north and east of map area. Partly cemented with calcite, gypsum, and clay. Pebbles form thin desert pavement composed of black, brown, gray, white, red, and yellow pea-size quartzite gravel and rare fragments of petrified wood. Include integrated, poorly defined wind-blown sand sheet deposits. Thickness, 1 to 3 m (3 to 10 ft)

Qg2 **Intermediate terrace-gravel deposits (Holocene and Pleistocene)** Similar to young terrace-gravel deposits (Qg1) but partly consolidated. Composed mainly of light-red, fine-grained sand and silt together with gray silt and clay. Locally contain well-rounded basalt clasts as much as 12 cm (5 in) or more in diameter. Form flat benches about 2 to 4 m (6 to 12 ft) above active stream floors and about 1 to 3 m (3 to 10 ft) above young terrace-gravel (Qg1) deposits. Intertongue with or locally overlain by talus (Qt) and young alluvial fan (Qa1) deposits. Locally inset into older terrace-gravel (Qg3) deposits. Thickness, 2 to 4 m (6 to 13 ft)

Qa2 **Older alluvial fan deposits (Pleistocene)** Similar to young alluvial fan (Qa1) deposits, but partly cemented by calcite and gypsum. Commonly overlapped by young alluvial fan (Qa1) or young terrace-gravel (Qg1) deposits; intertongue with or overlap valley-fill (Qv) and talus (Qt) deposits. Include abundant subrounded to subangular basalt clasts in southwest part of map area. Support sparse growths of sagebrush, cactus, and grass. Thickness, 2 to 4 m (6 to 12 ft)

Qg3 **Older terrace-gravel deposits (Pleistocene)** Similar to young and intermediate terrace-gravel (Qg1 and Qg2) deposits, but 2 to 6 m (6 to 20 ft) higher than Qg2 and form benches about 4 to 8 m (14 to 27 ft) above local drainages. Composed of well rounded limestone, sandstone, chert, and basalt clasts in sandy gravel matrix. Partly consolidated by calcite, clay, and gypsum cement. Basalt clasts mainly derived from local basaltic outcrops. Terraces in south half of map contain basaltic clasts derived from volcanic areas south and southeast of map area. Locally include abundant well-rounded pebbles of quartzite and petrified wood derived from Shinarump Member of Chinle Formation, northeast corner of map area. As much as 6 m (20 ft) thick

VOLCANIC ROCKS

Basalt of Larimore Tank (Pleistocene) Originally named Cave Basalt by Billingsley and Workman (2000) for numerous sinkholes in the basalt flow before the name Cave Basalt was known to have been already in use in Idaho. Thus, the name was changed by Billingsley and others (2001) to basalt of Larimore Tank, a stock tank labeled Larimore Tank on the U.S. Geological Survey Hat Knoll 7.5 quadrangle, southeast corner of the map area. The surface of basalt flow is pockmarked with sinkholes. Basalt and associated pyroclastic deposits probably represent the youngest volcanic rocks in the map area (Billingsley, 1994b, 1994d). Divided into:

Qlti **Intrusive dike or neck** Dark-gray, finely crystalline alkali basalt forming dike or neck connected with basalt flows. Dikes are as much as 3 m (10 ft) wide and form ridge crest; necks are as much as 5 m (16 ft) in diameter

Qltp **Pyroclastic deposits** Red and reddish-black basaltic scoria and cinder deposits; partly consolidated. Consist of five 30 to 135-m-high (100 to 445-ft-high) pyroclastic cones that align along a north-south trend parallel to local nearly vertical joints in the underlying bedrock

Qltb **Basalt flows** Dark-gray, finely crystalline to glassy, alkali-olivine basalt. Contain abundant green and red olivine phenocrysts 0.25 to 1 mm in diameter. Consist of contemporaneous basalt flows that erupted from five pyroclastic cones, which appear to coalesce into a single flow. Basalt appears to overlap or abut undivided basalt flows from Pugh Knoll, southeast corner of map area. Sinkhole depressions in basalt are as much as 20 m (65 ft) deep and are the result of dissolution erosion of gypsum in underlying Harrisburg Member of the Kaibab Formation. Thickness, 1 to 25 m (3 to 80 ft)

Basalt of Graham Ranch (Pleistocene) Informally named for Graham Ranch in upper Toroweap Valley about 3 km (2 mi) south of the southeast corner of the map area, Uinkaret Plateau, Mohave County, Arizona (Billingsley and others, 2001). Incorrectly named the Sage Basalt by Billingsley and Workman (2000) and incorrectly used by Billingsley and Hampton (2000) before the name Sage Basalt was known to be already in use. Divided into:

Qgri **Intrusive plug or dike** Dark-gray alkali-olivine basalt and scoriaceous basalt. Forms plug in pyroclastic cone in southeast corner of map area, and dike in basalt flow. Widths of plug and dike are approximate on map

Qgrp **Pyroclastic deposits** Red-brown and reddish-black scoriaceous basalt, ash, and cinder deposits; partly consolidated. Consist of several pyroclastic cones aligned in a north-south trend, southeast corner of map area. Deposits overlie associated basalt flows. Toroweap Fault offsets the flow and a pyroclastic cone just south of the southeast corner of the map area about 26 m (85 ft) down-to-the west (Billingsley and others, 2001). Thickness, 24 m (80 ft)

Qgrb **Basalt flows** Dark-gray, finely crystalline to glassy alkali-olivine basalt. Groundmass composed of plagioclase, olivine, and augite laths. Include abundant olivine phenocrysts 9.25 to 5 mm in diameter that make up about 30% of flow in some areas. Overlie the lower red member of the Moenkopi Formation, southeast edge of map area. Thickness, 30 to 90 m (100 to 300 ft)

Undivided basalts (Pleistocene) Alkali-olivine basalt, southeast edge of map area. Include basalt flows that came from Pugh Knoll (this map area) and several unnamed volcanoes south of the map area as defined by Billingsley and others (2001). Deposits are assumed to be Pleistocene in age because they have similar composition and occupy similar stratigraphic position as other basalt flows in the central and north part of map area. Lavas flowed in northerly direction

Qi **Basalt dike** Dark-gray alkali basalt dike (NW_ of sec. 35, T. 37 N., R. 9 W., south-central edge of map area). Dike is 0.1 to 0.3 m (1 to 10 ft) wide, does not protrude above ground more than 0.1 m (1 ft), is near vertical and has a strike of N. 5… W. Does not appear to be associated with any local pyroclastic deposits or basalt flows

Qp1 **Pyroclastic deposits** Reddish-black to black and brown basaltic scoria and cinder deposits at Pugh Knoll. Thickness, 60 m (200 ft)

Qb1 **Basalt flows** Dark-gray, finely crystalline alkali basalt; fine-grained groundmass of plagioclase, olivine, augite, and glass. Flows originate from Pugh Knoll and several unnamed pyroclastic cones and probable buried dikes just south of the map area. Majority of the flows came from sources south of map area (Billingsley and others, 2001). Flows at Spencer Knoll, Pugh Knoll, and Berry Knoll are contemporaneous. Undivided basalt flows overlie the Harrisburg Member of the Kaibab Formation. Thickness, 1 to 80 m (3 to 260 ft)

Basalt of Spencer Knoll (Pleistocene) Informally named for Spencer Knoll in south-central part of map area (sec. 11, T. 36 N., R. 8 W.). Includes pyroclastic cone deposits and associated basalt flows at base of cone. Divided into:

Qskp **Pyroclastic deposits** Reddish-gray to black scoria, glass, cinder, and welded tuff deposits; partly consolidated. Thin pyroclastic deposits are interbedded with thin basalt flows near base of Spencer Knoll. Thickness, 143 m (470 ft)

Qskb **Basalt flows** Dark-gray to light-gray alkali-olivine basalt. Contain small phenocrysts of olivine and plagioclase laths in glassy groundmass. Include interbedded pyroclastic deposits near base of Spencer Knoll. Unit overlies Harrisburg Member of the Kaibab Formation (Pkh). Basalt flows from Spencer Knoll appear to have collided simultaneously with undivided basalt flows (Qb1) from the Pugh Knoll area southeast of Spencer Knoll forming common map contact. Map unit symbol Qb1 is from Billingsley and others (2001). Thickness, 54 m (175 ft)

Basalt of Craigs Knoll and Berry Knoll (Pleistocene) Informally named for Craigs Knoll south of this map area, Berry Knoll in the southwest corner of map area (sec. 24, T. 36 N., R. 9 W.), Uinkaret Plateau, 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) just south of the map area between Craigs Knoll and Berry Knoll. Divided into:

Qcbi **Intrusive dike or neck** Dark-gray alkali-olivine basalt. Unit is most likely a neck because of associated pyroclastic deposits. Unit is partly buried by basalt flows from Berry Knoll. Associated pyroclastic deposits may have formed a diversion for basalt flow from Berry Knoll

Qcbp **Pyroclastic deposits** Gray and reddish-gray to black cinder, tuff, ash, and scoriaceous ejecta; partly consolidated. Overlie associated basalt flows at Berry Knoll. Thickness, 122 to 153 m (400 to 500 ft)

Qcbb **Basalt flows** Light-gray and dark-gray alkali-olivine basalt. Basalt generally overlies Harrisburg Member of the Kaibab Formation and part of the Timpoweap Member of the Moenkopi Formation. Basalt flowed about 1.6 km (1 mi) in a northerly and westerly direction from Berry Knoll. Thickness, 40 m (140 ft)

Basalt of Maryland Knoll (Pleistocene) Informally named for Maryland Knoll in west central part of map area (sec. 31, T. 38 N., R. 8 W.). Divided into:

Qmkp **Pyroclastic deposits** Red-brown and black basaltic scoria, glass, and cinder deposits; unconsolidated. Form pyroclastic cone of Maryland Knoll and small unnamed cone 0.3 km southeast of Maryland Knoll. Deposits overlie basalt flows and Harrisburg Member of Kaibab Formation. Thickness, as much as 92 m (300 ft)

Qmkb **Basalt flows** Dark-gray, finely crystalline groundmass; includes phenocrysts of plagioclase, olivine, and augite. Include two flows from different sources that erupted simultaneously, one from Maryland Knoll and the other from a cone 0.3 km southeast of Maryland Knoll (see map); flows merge about 3 km (2 mi) east of Maryland Knoll. Overlie Harrisburg Member of the Kaibab Formation. Thickness, 2 to 20 m (6 to 65 ft)

Basalt of Seven Knolls (Pleistocene) Informally named for Seven Knolls in central part of map area (secs. 10, 15, 23, 26, T. 37 N., R. 8 W.). Includes basalt flows and pyroclastic deposits of Seven Knolls, Deadman Knoll, and unnamed knoll southeast of Deadman Knoll. Divided into:

Qsi **Intrusive dike or neck** Dark-gray alkali-olivine basalt. Includes pyroclastic scoria within dike or neck. Unit is part of pyroclastic vent area. Approximate width shown on map

Qsp **Pyroclastic deposits** Reddish-brown and black basaltic scoria and cinder deposits; partly consolidated. Form small range of pyroclastic cones aligned parallel to bedrock joint system oriented N. 10… W. Thickness, 30 to 76 m (100 to 250 ft)

Qsb **Basalt flows** Dark-gray, finely crystalline alkali-olivine basalt. Groundmass composed of glass, plagioclase, olivine, and augite. Contain small phenocrysts of green and red olivine. Include several flows from several vents that coalesced and spread out into one thick flow surrounding the Seven Knolls pyroclastic cones. Flow surfaces partly covered by pyroclastic deposits (Qsp) within 2 km (1 mi) of pyroclastic vent areas. Majority of basalt flowed east about 3 km (2 mi) and north about 4 km (2.5 mi) from Seven Knolls pyroclastic cone areas. Flows form protective caprock over gently east-dipping strata of middle and lower part of the Harrisburg Member of the Kaibab Formation and the lower red member and the Virgin Limestone Member of the Moenkopi Formation (Seven Knolls Bench). Thickness, 2 to 40 m (6 to130 ft)

Basalt of Hat Knoll (Pleistocene) Informally named for Hat Knoll in central part of map area (sec. 20, T. 37 N., R. 7 W.). Unit occupies same stratigraphic level as basalt of Seven Knolls and has similar composition to basalt of Seven Knolls;

interpreted to be Pleistocene age (Billingsley, 1994d). Divided into:

Qhi **Intrusive dike** Dark-gray, finely crystalline alkali-olivine basalt in nearly vertical fissure dike about 1.5 m (5 ft) thick. Dike orientation is N. 10… W., on alignment with Hat Knoll pyroclastic cone, which aligns parallel to northwest-striking, subvertical joints in underlying bedrock. Most of the surrounding basalt came from fissure dike south of Hat Knoll

Qhp **Pyroclastic deposits** Red to reddish-brown basaltic scoria and cinder deposits similar to pyroclastic deposits of Seven Knolls (Qsp); partly consolidated. Overlie basalt flows of Hat Knoll (Qhb), middle red member and Virgin Limestone Member of the Moenkopi Formation. Form prominent pyroclastic cone landmark in this part of map area. Thickness, 132 m (435 ft)

Qhb **Basalt flows** Dark-gray, finely crystalline alkali-olivine basalt. Contain olivine and plagioclase phenocrysts 1 to 5 mm in diameter. Include small basalt flow on north and west side of Hat Knoll. Majority of basalt flowed east about 2.4 km (1.5 mi). Basalt surface partly covered by pyroclastic deposits of Hat Knoll (Qhp). Basalt flows overlie gently east-dipping strata of middle red member, Virgin Limestone Member, and lower red member of the Moenkopi Formation. Thickness, 4 to 60 m (13 to 200 ft)

Basalt of Moriah Knoll (Pleistocene) Informally named for Moriah Knoll in west-central area of map (secs. 7, 12, 18, 13, T. 37 N., Rs. 8 and 9 W.). Divided into:

Qmp **Pyroclastic deposits** Red-brown and reddish-black scoria, glass, and cinder deposits; unconsolidated. Include thin vesicular basalt flows interbedded with pyroclastic deposits in most of cone structure. Thickness, 122 m (400 ft)

Qmb **Basalt flows** Dark-gray to black, fine-grained, vesicular alkali basalt. Include sparse, small phenocrysts of green olivine and dark-gray augite in glassy groundmass dominated by plagioclase and augite laths. Vesicles commonly filled with calcite. Thickness, 3 to 30 m (10 to 100 ft)

Antelope Knoll Basalt (Pleistocene) Antelope Knoll forms a prominent landmark on the Uinkaret Plateau in northwest quarter of map area (secs. 13, 18, 19, 24, T. 38 N., Rs. 8 and 9 W.). K-Ar age, 0.83–0.28 Ma (Billingsley, 1994c; Billingsley and others, 2002). Divided into:

Qap **Pyroclastic deposits** Reddish-black and brown basalt fragments, scoria, welded tuff, and cinder deposits. Glass fragments include dark-gray augite and green olivine phenocrysts. Partly consolidated as welded scoria. Forms rounded pyroclastic cone of Antelope Knoll. Thickness, 140 m (460 ft)

Qab **Basalt flows** Dark-gray, finely crystalline alkali basalt; glassy groundmass. X-ray fluorescence spectrography shows phenocrysts of olivine in groundmass dominated by plagioclase, augite, and glass (Wenrich and others, 1995). Flows originate from base of Antelope Knoll. Flow surfaces are partly covered by pyroclastic deposits (Qap) within 1 to 2 km (0.5 to 1 mi) of Antelope Knoll. Overlie some thin alluvium (too thin to show at map scale) and bedrock strata of the Harrisburg Member of the Kaibab Formation and Timpoweap Member and lower red member of the Moenkopi Formation. Thickness, 2 to 15 m (6 to 50 ft)

SEDIMENTARY ROCKS

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

₸ms **Shnabkaib Member** White, laminated, slope-forming, aphanitic dolomite interbedded with light-gray, calcareous silty gypsum. Upper part not exposed. Gradational lower contact placed at lowest thick white or light-gray calcareous siltstone and dolomite. About 30 m (100 ft) exposed

₸mm **Middle red member** Red-brown, thin-bedded to laminated, slope-forming siltstone and sandstone; red, white, and gray gypsum; and minor white platy dolomite, green siltstone, and gray-green to red gypsiferous mudstone. Gradational lower contact placed at top of highest gray limestone bed of Virgin Limestone Member. Thickness, 45 to 55 m (150 to 180 ft)

₸mv **Virgin Limestone Member** Consists of three light-gray, thin-bedded to laminated, ledge-forming limestone beds, 0.5 to 2 m (2 to 6 ft) thick, separated by white, pale-yellow, red, and bluish-gray, thin-bedded, slope-forming gypsiferous siltstone. Only two limestone beds are exposed in south part of map area. Lowest limestone bed contains star-shaped crinoid plates and poorly preserved *Composita* brachiopods in upper part; middle limestone bed contains fossil algae. Unconformable contact with lower red member of the Moenkopi Formation with erosional relief as much as 2 m (6 ft). Lower limestone bed thickens and thins as channel-fill deposit. Thickness, 20 to 30 m (65 to 100 ft)

₸ml **Lower red member** Red, fine-grained, thin-bedded, gypsiferous, slope-forming sandy siltstone; and gray, white, and pale-yellow, laminated gypsum and minor sandstone. Lower part contains redeposited gypsum and siltstone of Harrisburg Member of Kaibab Formation. Lower part includes marker bed of reddish-gray, coarse-grained, thin-bedded, cross-stratified, calcareous, ledge-forming sandstone 1 to 2 m (3 to 6 ft) thick. Gradational lower contact placed at lowermost red siltstone bed; unconformably overlies the Harrisburg Member of the Kaibab Formation where the Timpoweap Member is absent. Locally thickens in paleovalleys and thins onto eroded paleohills of underlying Kaibab Formation. Thickness, 3 to 40 m (10 to 130 ft)

₸mt **Timpoweap Member** Light-gray, slope and ledge-forming conglomerate in lower part and light-gray to light-red, slope-forming calcareous sandstone in upper part. Conglomerate composed of subangular to rounded pebbles and cobbles of gray and dark-gray limestone, white and brown chert, and gray sandstone in matrix of gray to brown, coarse-grained sandstone. Upper part includes beds of low-angle crossbedded, calcareous sandstone, conglomerate, and minor siltstone. All detritus in Timpoweap derived from members of the Kaibab Formation. Includes calcite and gypsum cement. Fills paleovalleys 1,500 m (5,000 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 a general eastward flow of depositing streams. Thickness, 3 to 50 m (10 to 165 ft)

₸mlt **Lower red member and Timpoweap Member, undivided** Red-brown, slope-forming conglomerate and brown sandy limestone lenses interbedded with red siltstone and gray gypsum. Fills paleovalley cut as much as 60 m (200 ft) into Harrisburg Member of the Kaibab Formation in south-central part of map area. Unconformable lower contact locally covered by surficial deposits. Thickness, 5 to 20 m (15 to 65 ft) exposed

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

Pkh **Harrisburg Member** Includes an upper, middle, and lower part. Upper part consists of slope-forming, red and gray, interbedded gypsiferous siltstone, sandstone, gypsum, and thin-bedded gray limestone. Includes caprock of resistant, pale-yellow or light-gray, fossiliferous (mollusks and algae) sandy limestone averaging about 1 m (3 ft) thick that weathers black or brown. Upper part is mostly eroded in the western quarter of map area, partly covered by basalt in central part of map area. Grades into underlying middle part. Middle part consists of two cliff-forming limestone beds as much as 4 m (14 ft) thick; upper bed consists of a gray, thin-bedded cherty limestone that weathers dark brown or black and often forms the bedrock surface of the map area; lower bed is light-gray, thin-bedded sandy limestone. Both beds thicken and thin laterally and form small cliffs. Minor erosional unconformity separates middle from lower part. Lower part consists of slope-forming, light-gray gypsiferous siltstone and fine- to medium-grained sandstone; gray, medium-grained, thin-bedded limestone; and gray, massive bedded gypsum. Dissolution of gypsum in lower part has locally distorted limestone beds of middle part causing them to slump or bend into local drainages. Lower contact with underlying Fossil Mountain Member is gradational and arbitrarily placed at top of cherty limestone cliff of the Fossil Mountain Member of the Kaibab Formation. Thickness, 92 m (300 ft)

Pkf **Fossil Mountain Member** Light-gray, fine- to medium-grained, thin-bedded, fossiliferous, cliff-forming, sandy, cherty limestone. Unit characterized by black-weathering chert bands. Lower contact marked by dissolution and channel erosion with relief as much as 2 m (6 ft); contact locally obscured by talus and minor landslides. Thickness, 80 m (265 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 are locally distorted because of the dissolution of gypsum. Lower contact gradational. Thickness varies from 55 to 80 m (180 to 265 ft) because of the dissolution of gypsum

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 parts. Limestone beds average about 0.5 m (1 to 2 ft) thick and include chert lenses and nodules. Lower gradational contact with underlying Seligman Member of the Toroweap Formation. Contact commonly covered by minor slump or talus debris. Thickness, 70 m (230 ft)

Pts **Seligman Member** Gray, thin-bedded, slope-forming dolomite and gypsiferous sandstone. Middle part includes gray to red, thinly interbedded siltstone, sandstone, and gypsum; lower part includes brown, purple, and yellow, fine- to medium-grained, thin-bedded, low- to high-angle crossbedded and planar-bedded sandstone that is mostly covered by talus debris. Lower contact with the Hermit Formation is unconformable with erosional relief as much as 1 m (3 ft); contact mostly covered by talus and alluvial deposits. Includes minor crossbedded sandstone tongues or lenses of the Coconino Sandstone in the middle part. Thickness, 51 m (170 ft)

Ph **Hermit Formation (Lower Permian)** Light-red, yellowish-white, fine-grained, thin- to medium-bedded, slope and ledge-forming sandstone and siltstone. Sandstone beds as much as 2.5 m (8 ft) thick are separated by beds of red, slope-forming siltstone and silty sandstone as much as 1 m (3 ft) thick. Reddish sandstone beds commonly contain yellowish-white bleached spots; locally all beds are partly or completely bleached yellowish-white. Sandstone beds gradually thicken and become more of a marine environment northward forming a massive white sandstone cliff; thins southward to form ledges of red interbedded sandstone and siltstone beds in Grand

Canyon. About 43 m (140 ft) exposed; middle and lower part of formation are not exposed

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APPENDIX

DIGITAL DATABASE DESCRIPTION FOR THE GEOLOGIC MAP OF UPPER CLAYHOLE VALLEY AND VICINITY, MOHAVE COUNTY, NORTHWESTERN ARIZONA

Database by Susan S. Priest

INTRODUCTION

This appendix serves to introduce and describe the digital files that are included in this publication, available for downloading at *http://geopubs.wr.usgs.gov*. These files include a set of ARC/INFO geospatial databases containing the geologic information as well as Adobe Portable Document Format (PDF) and Postscript plot files containing images of the geologic map sheet and the text of an accompanying pamphlet that describes the geology of the area.

The digital map publication, compiled from previously published and unpublished data and new mapping by the author, represents the general distribution of surficial and bedrock geology in Upper Clayhole Valley and vicinity. Together with the accompanying geologic description pamphlet, it presents current knowledge of the geologic structure and stratigraphy of the area covered. The database identifies map units that are classified by age and lithology following the stratigraphic nomenclature of the U.S. Geological Survey. The scale of the source maps limits 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 plot files containing images of much of the information in the database are available to those who do not use an ARC/INFO compatible Geographic Information System. The Postscript plotfile package contains an image of the geologic map sheet. The Adobe PDF plotfile package contains images of the map sheet, pamphlet, and this document. Those who have computer capability can access the plot file packages in either of the two ways described below (see the section Obtaining the digital database and plotfile packages); however, these packages do require gzip or WinZip utilities to access the plot files.

Those without computer capability can obtain plots of the map files through U.S. Geological Survey Information Services. Be sure to request Map MF-2418

U.S. Geological Survey Information Services
Box 25286
Denver, CO 80225

1-888-ASK-USGS

Email: ask@usgs.gov

DATABASE CONTENTS

The database consists of three digital packages. The first is the PostScript Plotfile Package which consists of PostScript plot files of the geologic map and map explanation. The second is the PDF Plotfile Package which contains the same plot files as the first package, as well as the database description, but in Portable Document Format (PDF). The third is the Digital Database Package which contains the geologic map database itself and the supporting data.

PostScript Plotfile Package

The package contains the PostScript image described below:

cvmap.eps	A PostScript plotfile containing the complete map composition with geology, correlation chart, and geologic description at a scale of 1:31,680

The PostScript image of the geologic map and map explanation is 42 inches high by 40 inches wide, so it requires a large plotter to produce paper copies at the intended scale. The PostScript plotfile of the geologic map was initially produced using the display command with the Adobe Illustrator option with compression set to zero in ARC/INFO version 8.0. The geologic description and correlation chart were created in Adobe Illustrator 8.0.

PDF Plotfile Package

The package contains the PDF images described below:

cvmap.pdf	A PDF file containing the complete map composition with geology, correlation chart, and geologic description at a scale of 1:31,680
cvgeo.pdf	A PDF file of the pamphlet, containing detailed geologic information and unit descriptions, and appendix
cvreadme.pdf	This appendix

Adobe Acrobat PDF (Portable Document Format) files are similar to PostScript plot files in that they contain all the information needed to produce a paper copy of a map or pamphlet and they are platform independent. Their principal advantage is that they require less memory to store and are therefore quicker to download from the Internet. In addition, PDF files allow for printing of portions of a map image on a printer smaller than that required to print the entire map without the purchase of expensive additional software. The PDF image of the geologic map and map explanation was created from a PostScript file using Adobe Acrobat Distiller. The PDF image of the pamphlet was produced in Microsoft Word 2000 using the Convert to Adobe PDF option from the Acrobat pulldown. In test plots we have found that paper maps created with PDF files contain almost all the detail of maps created with PostScript plot files. We would, however, recommend that those users with the capability to print the large PostScript plot files use them in preference to the PDF files.

To use PDF files, the user must get and install a copy of Adobe Acrobat Reader. This software is available **free** from the Adobe website (http://www.adobe.com/). Please follow the instructions given at the website to download and install this software. Once installed, the Acrobat Reader software contains an on-line manual and tutorial.

There are two ways to use Acrobat Reader in conjunction with the Internet. One is to use the PDF reader plug-in with your Internet browser. This allows for interactive viewing of PDF file images within your browser. This is an easy way to quickly look at PDF files without downloading them to your hard disk. The second way is to download the PDF file to your local hard disk, and then view the file with Acrobat Reader. **We strongly recommend that large map images be handled by downloading to your hard disk**, because viewing them within an Internet browser tends to be very slow.

To print a smaller portion of a PDF map image using Acrobat Reader, it is necessary to cut out the portion desired using Acrobat Reader and the standard cut and paste tools for your platform, and then to paste the portion of the image into a file generated by another software program that can handle images. Most word processors (such as Microsoft Word) will suffice. The new file can then be printed. Image conversion in the cut and paste process, as well as changes in the scale of the map image, may result in loss of image quality. However, test plots have proven adequate. Superior quality can be obtained by using image processing software that can open PDF files (like Adobe Photoshop Elements) to crop and print a portion of the map.

Digital Database Package

The database package includes geologic map database files for the map area. The digital maps, or coverages, and their associated INFO directories 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. Please refer to your GIS documentation.

ARC export files are converted to ARC/INFO format using the ARC command import . To ease conversion and preserve naming convention, an AML is enclosed that will convert all the export files in the database to coverages and will also create an associated INFO directory. From the ARC command line type *&r import.aml*. The export files included are listed below.

ARC/INFO export file	Resultant Coverage	Description
cv_poly.e00	cv_poly	Polygon and line coverage showing depositional contacts, rock units, and faults
cv_anno.e00	cv_anno	Line coverage showing annotation and annotation leaders
cv_dip.e00	cv_dip	Point coverage showing strike and dip information, collapse structures, sinkholes, and volcanic vents
cv_fold.e00	cv_fold	Line coverage showing fold axes and basalt flow lines
Geo.lin.e00	geo.lin	Lineset
Geo.mrk.e00	geo.mrk	Markerset
wpgcmyk.shd.e00	wpgcmyk.shd	Shadeset
geomrk.lut.e00	geomrk.lut	Lookup table for point symbols
geolin.lut.e00	geolin.lut	Lookup table for line types
geofont.txt.e00	geofont.txt	Text set used for all annotation

The database package also contains the following files:

import.aml	ASCII text file in ARC Macro Language to convert ARC export files to ARC coverages in ARC/INFO	
cvtopo.zip	cvtopoclean.tif & cvtopo.tfw	Background hypsography image and World file
Mf2418.txt	A text-only file containing an unformatted version of readme.pdf	
Mf2418met.txt	A parseable text-only file of publication level FGDC metadata for this report	
Rev_history_MF2418.doc	A Word file describing revisions, if any, to this publication	

The following supporting directory is not included in the database package, but is produced in the process of reconverting the export files into ARC coverages.

info/	INFO directory containing files supporting the database

OBTAINING THE DIGITAL DATA

The digital data may be obtained in either of two ways:

a.) From the Western Region Geologic Publication Web Page at:
http://geopubs.wr.usgs.gov/docs/wrgis/mf-map.html
Follow the directions to download the files.

b.) From the U.S. Geological Survey Western Region FTP server. The FTP address is:
geopubs.wr.usgs.gov
The user should log in with the user name anonymous and then input their e-mail address as the password. This will give the user access to all the publications available by FTP from this server. The files in this report are stored in the subdirectory: pub/map-mf/mf2418.

DATABASE SPECIFICS

Digital compilation

Scribecoat mylar sheets were scanned at the U.S. Geological Survey Flagstaff Science Center on an Optronics 5040 raster scanner at a resolution of 50 microns (508 dpi). The scans were output in TIFF format and converted to ARC/INFO grids. The grids were registered and rectified to four latitude/longitude registration points. Linework was vectorized using gridline . The lines were edited and attributed in ARC/INFO. Polygons were built and attributed in ARC/INFO. Point data were digitized on screen and then attributed in ARC/INFO.

Map Projection

Parameter	Description
Projection	UTM
Units	Meters on the ground
Zone	12
Datum	NAD27

Database Fields

The content of the geologic database can be described in terms of the lines, points, and areas that compose the map. Each line, point, or area in a map layer or index map database (coverage) is associated with a database entry stored in a feature attribute table. Each database entry contains both a number of items generated by ARC/INFO to describe the geometry of the feature and one or more items defined by the authors to describe the geologic information associated with that entry. Each item is defined as the amount and type of information that can be recorded. Descriptions of the database items use the terms explained below.

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 in cv_poly. These distinctions and the geologic identities of the boundaries are stored in the LTYPE field according to their line type.

Definition of cv_poly and cv_fold Arc Attribute Tables

Item Name	Width	Output	Type	N.Dec	Description
FNODE#	4	5	B		Starting node of the arc
TNODE#	4	5	B		Ending node of the arc
LPOLY#	4	5	B		Polygon to the left of the arc
RPOLY#	4	5	B		Polygon to the right of the arc
LENGTH	8	18	F	5	Length of the arc in meters
<COVERAGE>#	4	5	B		Unique internal number
<COVERAGE>-ID	4	5	B		Unique identification number
LTYPE	35	35	C		Line type
PTTYPE	35	35	C		Arcmarker symbol
PLUNGE	3	3	I		Coded integer indicating fold plunge (in cv_fold only)

Domain of Line Types recorded in LTYPE field

cv_poly

contact_certain
landslide_scarp
map_boundary
normal_flt_approx
normal_flt_certain
normal_flt_concealed
normal_flt_inferred

cv_fold
------

anticline_certain_red
anticline_concealed_red
basalt_flow_direction
monocline_certain_red
monocline_concealed_red
plunging_anticline_concealed_red
plunging_anticline_red
plunging_syncline_concealed_red
plunging_syncline_red
syncline_certain_red
syncline_concealed_red
syncline_inferred_red

Domain of arcmarkers recorded in PTTYPE field
cv_poly
------
fault_ball_fill
xx
cv_fold
------
anticline_red
monocline_red
syncline_red
xx

POLYGONS
Map units (polygons) are described in the polygon attribute table (PAT). This identifies the map units recorded in the PTYPE field by map label. The description of map units can be found on the geologic map sheet.

Definition of cv_poly Polygon Attribute Table

Item Name	Width	Output	Type	N.Dec	Description
AREA	8	18	F	5	Area of polygon in square meters
PERIMETER	8	18	F	5	Length of perimeter in meters
<COVERAGE>#	4	5	B		Unique internal number
<COVERAGE>-ID	4	5	B		Unique identification number
PTYPE	5	5	C		Map unit label

Domain of cv_poly PTYPE (map units)

Ph	Pkf	Pkh	Ptb	Pts	Ptw	Qa1
Qa2	Qab	Qaf	Qap	Qb1	Qc	Qcbb
Qcbi	Qcbp	Qf	Qg1	Qg2	Qg3	Qgrb
Qgri	Qgrp	Qhb	Qhi	Qhp	Qi	Ql
Qltb	Qlti	Qltp	Qmb	Qmkb	Qmkp	Qmp
Qp1	Qs	Qsb	Qsi	Qskb	Qskp	Qsp
Qt	Qv	TRml	TRmlt	TRmm	TRms	TRmt
TRmv						

Plain text is substituted for conventional geologic age symbols (TR for Triassic) shown on map.

POINTS
Points represent geographic features that have no area or length, or features that are too small for their boundaries to be apparent for the given input scale. Each point is described by a single x,y coordinate. A point attribute table (PAT) is used to hold the attribute data about points. ARC/INFO coverages cannot hold both point and polygon information.

Definition of cv_dip Point Attribute Table

Item Name	Width	Output	Type	N.Dec	Description
AREA	8	18	F	5	Area (degenerative)
PERIMETER	8	18	F	5	Perimeter (degenerative)
<COVERAGE>#	4	5	B		Unique internal number
<COVERAGE>-ID	4	5	B		Unique identification number
PTTYPE	35	35	C		Point type
DIP	3	3	I		Dip angle in degrees
STRIKE	3	3	I		Strike angle in degrees

Domain of cv_dip PTTYPE

bedding	approx_bedding
collapse_structure	sinkhole
vertical_joint	volcanic_vent

ANNOTATION

Annotation for geologic unit labels and fault offsets are contained in **cv_anno** in subclass anno.unit. **cv_dip** also contains annotation, such as that for strike and dip, collapse features, and geographic feature names.

The text set used for all annotation was geofont.txt. Use of this text set allows for proper symbol notation for unit symbols. The default ARC/INFO text set does not allow for a proper geologic symbol indicating Triassic. By using this alternate text set, the character pattern TRm prints instead as ^m. The only non-conventional text symbol used, was the ^ (carat) indicating Triassic.

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. The fact that this database was created and edited at a scale of 1:31,680 means that higher resolution data is generally not present. Plotting at scales larger than 1:31,680 will not yield greater real detail but may reveal fine-scale irregularities below the intended resolution.