Geologic Map of the Lower Hurricane Wash and Vicinity, Mohave County, Northwestern Arizona

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INTRODUCTION

Hurricane Wash is the principle drainage for Hurricane Valley just west of and parallel to the Hurricane Cliffs in northern Mohave County, Ariz. Hurricane Wash begins near the abandoned village of Mt. Trumbull, Ariz. in upper Hurricane Valley and flows north into Utah and the Virgin River (fig. 1). The nearest settlements are St. George, Utah, 16 km northwest of the map area, Hurricane, Utah, 17.5 km north of the map area, and Colorado City, Ariz., 32 km east of the map area. Elevations range from about 841 m (2,759 ft) at Dutchman Wash at the northwest corner of the map to 1,842 m (6,043 ft) at Seegmiller Mountain at the west-central edge of map area. Access to the map is by improved dirt roads locally referred to as the Sunshine Trail, from St. George, Utah, and the Navajo Trail, from Colorado City, Ariz. (fig. 1). Several unimproved dirt roads lead from the Sunshine and Navajo Trails to various locations within the map area.

The Bureau of Land Management, Arizona Strip Field Office, St. George, Utah, manages most of the area. In addition, there are about 8 sections managed by the State of Arizona and about 3 sections of private land in the vicinity of Clayhole Wash (U.S. Department of the Interior, 1993). Elevations below 1,372 m (4,500 ft) support a sparse growth of sagebrush, cactus, grass, greasewood brush, and various desert shrubs. At higher elevations, thick to moderate growths of sagebrush thrive in alluvial valleys and a moderate cover of pinyon pine and juniper trees are common on Seegmiller Mountain.

PREVIOUS WORK

The first geologic maps of the area are by Marshall (1957), Pomeroy (1959), and Petersen (1983). Data from the earliest maps were compiled onto a geologic map of the State of Arizona by Wilson and others (1969), and recompiled to a different scale by Reynolds (1988). Four preliminary geologic maps by Billingsley (1992a, b, c, d) cover the map area at a scale of 1:24,000. A geologic map of the Wolf Hole Mountain and vicinity borders the map area on the west (Billingsley, 1993a); a geologic map of the Sullivan Draw and vicinity adjoins the southwest corner of the map area (Billingsley, 1994); a geologic map of the Clayhole Wash and vicinity borders the east edge of the map area (Billingsley and others, 2002); a geologic map of the upper Hurricane Wash and vicinity borders the south edge of the map area (Billingsley and Dyer, 2003), and a geologic map of the Upper Clayhole Valley and vicinity adjoins the southeast corner of the map area (Billingsley and Priest, 2003).

MAPPING METHODS

Photogeologic mapping at the 1:24,000-scale began in 1992 and ended in late 1993. In particular, many of the Quaternary alluvial units having similar lithologies were mapped on the basis of geomorphic features observed on aerial photographs. Field investigations were conducted to assure accuracy and consistency of all map units and geologic structures.

GEOLOGIC SETTING

The map area lies within part of the St. George Basin, the Shivwits Plateau, and the Uinkaret Plateau, all of which are subprovinces of the southwestern part of the Colorado Plateau physiographic province (Billingsley and others, 1997). The boundary between the higher elevation Uinkaret Plateau and the lower elevation Shivwits Plateau and St. George Basin is the upper part of the Hurricane Fault scarp (fig. 2).

The arbitrary boundary between the Shivwits Plateau and the St. George Basin is drawn along the Dutchman Draw Fault to Joe Blake Hill, then southeast along the east rim of East Mesa to the Butte benchmark, then east to the highest point on the Hurricane Cliffs (fig. 2). Relatively flat-lying Paleozoic and Mesozoic strata having an average regional dip of about 1° northeast characterize this part of the

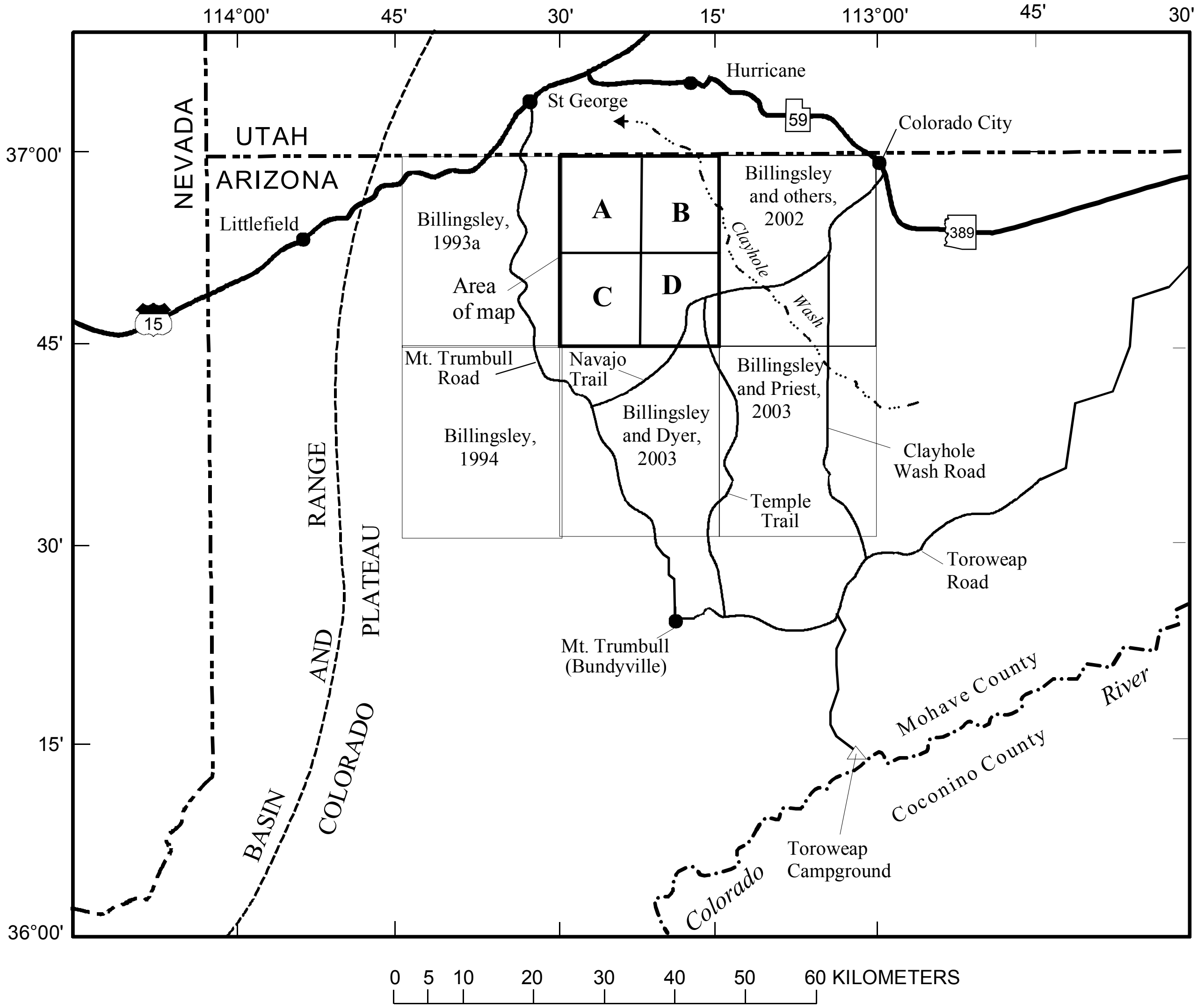

Figure 1. Map showing the Yellowhorse Flat (A), Rock Canyon (B), Hole-N-Wall Canyon (C), and Gyp Pocket (D) U.S. Geological Survey 7.5' quadrangles and adjacent mapped areas, northern Mohave County, northwestern Arizona.

Shivwits and Uinkaret Plateaus. In the St. George Basin, in the north third of the map area, strata are folded into north-south plunging anticlines and synclines with attitudes generally less than 10°.

The Hurricane Fault and Monocline are the major structural features of the map area. The Hurricane Fault has a northeast strike in the north part of the map area and a southeast strike in the south part. The resulting fault scarp, the Hurricane Cliffs, exposes more than 610 m of Permian strata. In the St. George Basin area west of the Hurricane Fault, about 396 m of Triassic strata are exposed in the folded terrain. Thickness of Triassic strata is estimated from nearly flat lying exposures 13 km east of the Hurricane Cliffs at Lost Spring Mountain (Billingsley, 1993b, c). Vertical displacement along the Hurricane Fault is about 610 m in the south part of the map area, increasing to nearly 1,830 m at the north edge of the map area. North of the map area and near the town of Hurricane, Utah, vertical displacement along the Hurricane Fault increases to a possible 3,000 m (Hamblin and Best, 1970).

Cenozoic deposits are widely distributed in the map area and consist of eolian and alluvial deposits and landslide debris. Volcanic rocks of Pleistocene and Pliocene age are present at scattered locations within the north half of the map area. The volcanic rocks consist of basaltic dikes, plugs, pyroclastic deposits, and flows. Man-made earthen dams, drainage ditches, and quarries are also mapped. Map contacts between most Quaternary deposits are arbitrary because of intertonguing and (or) gradational lateral and vertical changes. The surficial deposits are identified on the basis of geomorphic relations to structural features and erosional surfaces using photogeologic techniques. The subdivision of Quaternary deposits is intentionally detailed because these units strongly influence rangeland management, flood control, biological studies, soil erosion, and the planning of road construction by federal, state, and private organizations.

STRATIGRAPHY

The upper Paleozoic and lower Mesozoic stratigraphic units within the map area include, in order of decreasing age, the Esplanade Sandstone (Lower Permian), the Hermit, Toroweap, and Kaibab Formations (Lower Permian), the Moenkopi Formation (Lower and Middle(?) Triassic), and the Chinle Formation (Upper Triassic). The Esplanade Sandstone crops out along Hurricane Wash at the base of the Hurricane Cliffs where a nearly complete section is exposed in Black Rock Canyon (cross section *A-A′*). Complete sections of the Hermit Formation and Toroweap Formation are exposed in the steep slopes and cliffs of the Hurricane Cliffs. About two-thirds of the surface bedrock of the map area is composed of gray cherty limestone and reddish-gray siltstone and gypsum of the Harrisburg Member of the Kaibab Formation and the other one-third is red siltstone and sandstone and gray gypsum and dolomite of the Moenkopi Formation. The youngest strata are the Shinarump and Petrified Forest Members of the Chinle Formation that crop out in the northwest quarter of the map area.

The oldest volcanic rocks in the map area are the Tertiary Black Rock Canyon Basalt and the Seegmiller Mountain Basalt (Billingsley and Workman, 2000). The Black Rock Canyon Basalt was extruded onto an eroded surface of the Shinarump and Petrified Forest Members of the Chinle Formation and upper red member of the Moenkopi Formation (6 mi northeast of Seegmiller Mountain). A sample of the Black Rock Canyon Basalt (SW¼ sec. 34, T. 41 N., R. 10 W., Rock Canyon 7.5' quadrangle) yielded a K-Ar age of 3.5±0.6 Ma (Harold H. Mehnert, U.S. Geological Survey, Denver, Colorado, written commun., 1993). In this area, the Moenkopi and Chinle strata dip east about 12° along the Hurricane Monocline. The Black Rock Canyon Basalt flowed east and down the east-dipping Triassic strata toward the Hurricane Cliffs and then was diverted north down Hurricane Wash. After the basalt solidified, the basalt and tilted mudstone strata of the Petrified Forest Member of the Chinle Formation slid east as landslide debris flows into Hurricane Wash, probably during wetter conditions. Thus, Hurricane Wash was temporarily blocked by the Black Rock Canyon Basalt flow and later periodically blocked by subsequent landslide debris flows. The Pliocene age of the Black Rock Canyon Basalt is about 1 million years older than the Seegmiller Mountain Basalt, but both are nearly the same age as the basalt flows at Black Rock Mountain and Wolf Hole Mountain, 3.7 and 3.1 Ma respectively, about 9.5 km west of the map area (Billingsley, 1993a).

The basaltic rocks on Seegmiller Mountain form a resistant caprock over soft strata of the Moenkopi Formation. Reynolds and others (1986) informally used the name Seegmiller Mountain basalt from Damon (1968), and that name became formal by Billingsley and Workman (2000). The Seegmiller Mountain Basalt is comprised of several basalt flows that came from local intrusive dikes or vent areas that formed small pyroclastic cones deposits on top of the flows. Samples of the basalt collected by Damon (1968) just west of the map area (W ½ sec. 30, T. 40 N., R. 11 W.) yielded K-Ar ages of 2.35±0.31 and 2.44±0.51 Ma (Reynolds and others, 1986). The Seegmiller Mountain Basalt overlies a Tertiary erosion surface that slopes gently northwest and south from the vent areas of Seegmiller

Mountain. Most of the basalt flowed northwest down a nearly featureless bedrock surface of the Shnabkaib Member of the Moenkopi Formation. Presumably the basalt was flowing north toward an ancestral Virgin River in Utah. The Main Street Fault equally offsets the Seegmiller Mountain Basalt and the underlying Moenkopi strata on Seegmiller Mountain indicating that the Main Street Fault is younger than the basalt, whose average age is about 2.4 Ma. Assuming that most of the surrounding plateau surface was at or near the same general elevation as the Seegmiller Mountain Basalt at the time of its extrusion, the rate of denudation of the surrounding area was about 427 m, or 183 m/Ma, or roughly 2 m/10,000 yr.

Two basalt-capped mesas, West Mesa and east Mesa, lie northeast of Seegmiller Mountain. The basalt flows that cap these mesas were named West Mesa Basalt and East Mesa Basalt by Billingsley and Workman (2000). These basalts are about 2 km apart and are composed of an alkali-olivine basalt flows that overlie eroded surfaces of the Kaibab and Moenkopi Formations at about the same general elevation (fig. 2).

A sample of basalt collected from West Mesa, SW¼ sec. 12, T. 40 N., R. 11 W. (Hole-N-Wall Canyon 7.5' quadrangle), yielded a K-Ar age of 1.6±0.3 Ma (Harold H. Mehnert, U.S. Geological Survey, Denver, Colo., written commun., 1993). The West Mesa Basalt and associated volcanic deposits form the top of West Mesa and occupy part of a Quaternary paleodrainage having a northwesterly gradient of about 18 m/mi. The basalt originated from several sources marked by pyroclastic cones on the basalt surface and a few scattered dikes or pyroclastic vents south of West Mesa on the Harrisburg Member of the Kaibab Formation. The basalt flows at the south end of West Mesa flowed a short distance south (up) the ancestral paleodrainage of Dutchman Draw. At the north end of West Mesa, the basalt flowed over a thin alluvial deposit that may have been the ancestral Dutchman Draw drainage. The basalt also overlies bedrock surfaces of the Timpoweap Member, lower red member, and Virgin Limestone Member of the Moenkopi Formation, and the Harrisburg Member of the Kaibab Formation. Today, Dutchman Draw has eroded about 152 m deeper than the basalt flow at the north end of West Mesa, and about 20 m deeper at the south end of the mesa. West Mesa Basalt is now preserved as an inverted valley. The West Mesa Basalt is offset by faults at its south end.

About 2 km north of West Mesa and at about the same elevation, a slightly younger basalt erupted at what is now East Mesa. A sample of the East Mesa Basalt from East Mesa (NE¼NW¼ sec. 6, T. 40 N., R. 10 W.; Yellowhorse Flat 7.5' quadrangle), yielded a K-Ar age of 1.4±0.25 Ma (Harold H. Mehnert, U.S. Geological Survey, Denver, Colorado, written commun., 1993).

The East Mesa Basalt and associated volcanic deposits that form East Mesa also include Joe Blake Hill, a northwest extension of East Mesa. The East Mesa Basalt occupies a paleodrainage similar to and parallel to that of West Mesa. The gradient of the East Mesa paleodrainage is about 15 m/mi in a northwest direction toward the Virgin River in Utah. The basalt came from vents now exposed as dikes or necks along the eroded east flank of East Mesa and from vents marked by pyroclastic cones that formed on top of the basalt flows. The basalt flowed northwest down a bedrock surface of the Shnabkaib Member, middle red member, and Virgin Limestone Member of the Moenkopi Formation and over some thin alluvial deposits.

At Joe Blake Hill, north end of East Mesa, the Dutchman Draw Fault offsets the East Mesa Basalt and underlying sedimentary strata about 93 ft down-to-the-northwest indicating that the Dutchman Draw Fault became active after the basalt flow during the last 1.4±0.25 m.y. Erosion on both sides of East Mesa has removed an average of about 170 m of the Moenkopi and Kaibab strata since the basalt erupted. Assuming the surrounding surface was nearly level with the base of the East Mesa Basalt at the time of extrusion 1.4 m.y., the rate of drainage downcutting is estimated to be about 1.2 m/10,000 years.

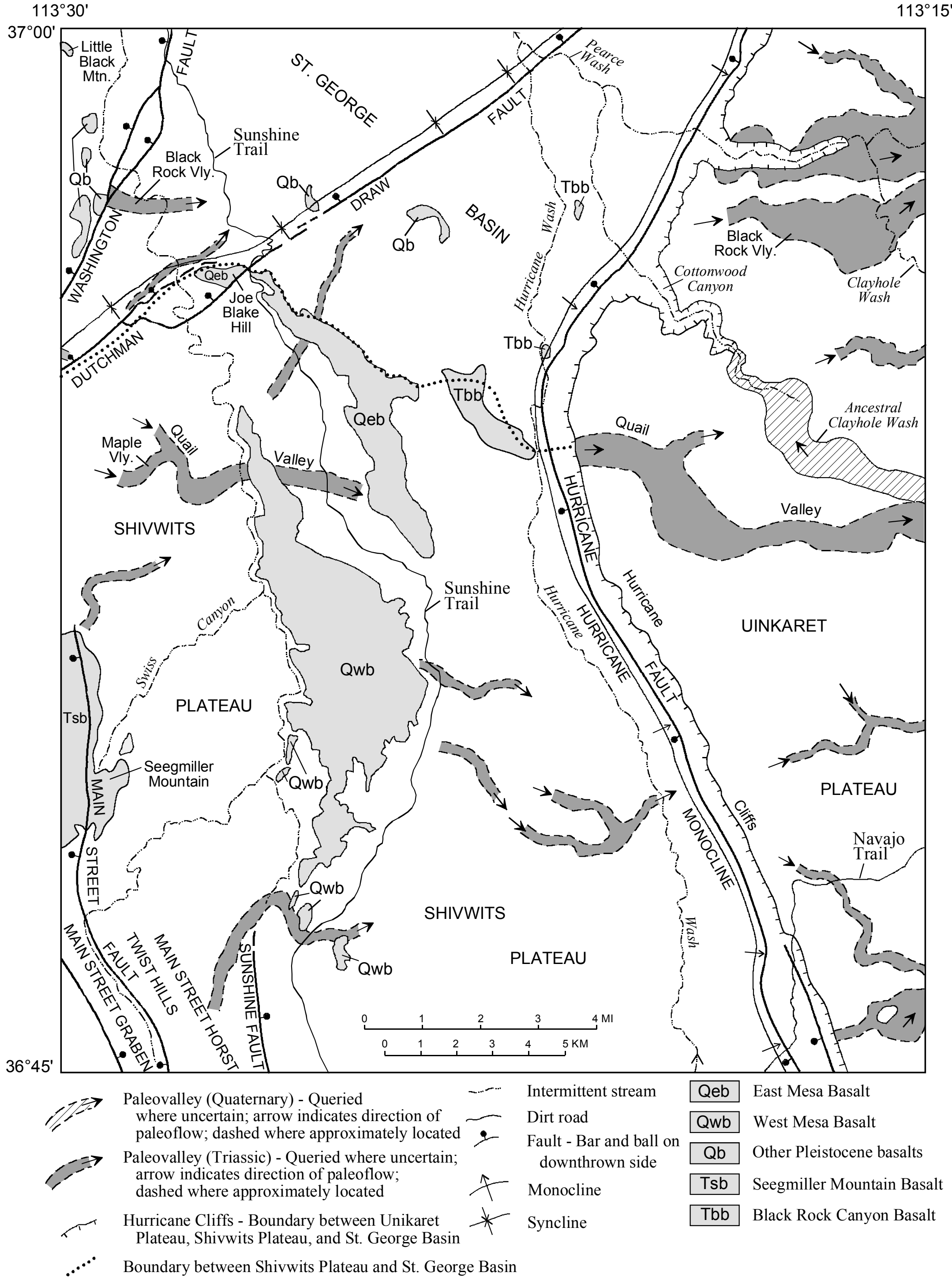

Figure 2. Selected geographic and geologic features of the lower Hurricane Wash area of northwestern Arizona.

About 5 km northwest of East Mesa are other outcrops of basalt at Little Black Mountain and Dutchman Wash (fig. 2). Those basalts are similar in lithology to the East Mesa Basalt and the West Mesa Basalt and are lower in elevation. A sample of basalt at Little Black Mountain (SW¼ sec. 33, T. 42 N., R. 11 W.; northwest part of map area) yielded a K-Ar age of 1.7±0.4 Ma (Harold H. Mehnert, U.S. Geological Survey, Denver, Colorado, written commun., 1993). The basalt flows that cap Little Black Mountain (Qb) and nearby areas in Dutchman Wash (northwest corner of map area) overlie strata of the Moenkopi and Chinle Formations on the downthrown side of the Washington Fault. The basalt at Little Black Mountain is likely correlative to either the West Mesa or East Mesa Basalt or both on the basis of age, hand specimen similarities, the close proximity of the West Mesa and East Mesa Basalts, and a northwest flow direction of the East Mesa and West Mesa Basalt toward Little Black Mountain. The 3º to 5° northerly regional dip and the 5 km distance also explain the basalt overlying the strata of Chinle Formation at Little Black Mountain.

The Washington, Dutchman Draw, and other lesser faults displaced the East Mesa Basalt and underlying strata down-to the-northwest about 680 m within the past 1.5 m.y. If the fault movements were regularly intermittent, then the average rate of displacement along the faults would be about 4.5 m per 10,000 years.

About 3 km north of East Mesa are two small, unnamed buttes capped by basalt flows. There are two basalt dikes or necks on the west slope of one of the unnamed buttes (elev. 1,302 m [4,271 ft]) and a dike at the top. Several basaltic dikes at East Mesa have a northerly strike towards one of the buttes suggesting that the basalt dikes and flow on the unnamed buttes are likely to be a similar Quaternary age. However, the dikes and flow at the unnamed buttes are also about 3 km northwest of the Tertiary Black Rock Canyon Basalt. Thus, the basalts at the unnamed buttes could be either Quaternary or Tertiary age, but because they have similar elevation as the basalt flows on East Mesa, they are mapped as Quaternary basalts undivided (Qb).

The predominantly Quaternary age assigned to alluvial deposits in the map area is based mainly on field relations with the Quaternary basalts of East and West Mesas and at Little Black Mountain and with the Pliocene basalts of Seegmiller Mountain and other areas of adjoining geologic maps (Billingsley, 1993a, 1994). Many of the alluvial deposits contain basalt clasts downslope from the Pliocene and Pleistocene basalt outcrops. Thus, most of the alluvial and surficial deposits of this map area are probably Pleistocene age and younger, except for an abandoned alluvial valley in the east-central part of the map.

STRUCTURAL GEOLOGY

The structural features in the map area show up particularly well on X-Band, side-looking radar images of the Grand Canyon quadrangle, Arizona (scale 1:250,000). These images give an overall perspective of the structural fabric of this part of Arizona, especially in flatland areas (Western Atlas International, Inc., 1988). The Hurricane Fault and Monocline are the main structural features of this geologic map. Both structures have a northeast trend in the north part of the map and a southeast trend in the south part. The Hurricane Fault scarp forms the Hurricane Cliffs, a prominent landmark of the Arizona Strip. The Hurricane Cliffs separate the higher Uinkaret Plateau (east of the scarp) from the lower Shivwits Plateau and St. George Basin (west of the scarp).

The Hurricane Monocline formed during the Laramide Orogeny as the result of east-directed compression in response to reverse movement along favorably oriented preexisting faults in the Precambrian basement (Huntoon, 1989, 2003; Elston and Young, 1991). The resulting compression produced easterly dips of as much as 20° east in strata along the Hurricane Monocline. Changes in strike of exposed monoclines of the eastern Grand Canyon area are linked to intersecting basement faults that were reactivated during the late Cenozoic (Huntoon, 2003).

By late Oligocene time, the western part of the Colorado Plateau was probably undergoing the first significant shallow east-west crustal extension to affect the region since late Precambrian time (Rowley and others, 1978). However, this extension does not appear to have affected the Hurricane Monocline until latest Pliocene and Pleistocene time. The Pliocene basalt of Bundyville (Billingsley and others, 2000), exposed 38 km south of the map area, has a K-Ar age of 3.6±0.18 Ma (Reynolds and others, 1986). Movement along this segment of the Hurricane Fault began no earlier than middle or possibly early Pliocene time (3.6 Ma) and has equally displaced the basalt of Bundyville and the underlying strata of the Moenkopi Formation. The Hurricane Fault and associated graben structures are thus the result of Pliocene-Pleistocene east-west extension that caused down-to-the-west normal faulting.

Significant but less regionally extensive structural features are the Washington, Dutchman Draw, and Main Street Faults. The Washington and Dutchman Draw Faults strike north-northeast and northeast, respectively, and the Main Street Fault strikes north. The Washington Fault displaces strata down-to-the-northwest a maximum of about 580 m, and the strata dips gently east or southeast on the east side of the fault. Because of extensive alluvial cover on the downthrown side of the Washington Fault, an east-southeast dipping monocline is suspected, but not shown. The Washington Fault is mostly covered by talus but appears to be a vertical normal fault as suggested by Hamblin and Best (1970) and Petersen (1983). However, an exposed fault plane just west of the map area suggests possible high-angle reverse movement along this segment of the fault (Billingsley, 1990).

On September 2, at 3:26 AM, 1992, Mountain Standard Time, a moderate earthquake shook the St. George and Hurricane areas of southwest Utah. The quake measured 5.7 to 5.9 on the Richter scale and was felt over most of southern Utah and northern Arizona. The epicenter was determined to be about 11 to 16 km southeast of St. George, Utah, near the Washington Fault. There were two very minor aftershocks, an unusual occurrence for an earthquake of this magnitude (Waverly Person, U.S. Geological Survey, Denver, Colo., written commun., 1992). The author visited the area within 24 hours after the quake to determine if any movement had occurred on faults in or near the epicenter area. The field investigation disclosed no observable displacement on any faults. As a result of the quake, however, several new minor rock fall scars were observed along the Hurricane Cliffs area. Most of the damage was caused to man-made dwellings and unstable road cuts. Damage occurred to some homes and to a highway at a locality known as Slide Hill or Balanced Rock landslide in nearby Springdale, Utah (Pearthree and Wallace, 1992).

The Dutchman Draw Fault branches from the Washington Fault about a half mile west of the map area (Billingsley, 1990). The Dutchman Draw Fault has an average vertical displacement of about 115 m at the west edge of the map, decreasing to about 76 m in the north-central part of the map area. The fault may be discontinuous for a short distance in the north-central part of the map area where the fault trace is covered by alluvium near Joe Blake Hill. A synclinal fold in the bedrock strata parallels the fault on its downthrown side.

The Main Street Fault, named by Hamblin and Best (1970), and Main Street Graben and Main Street Horst, named by Billingsley (1992c), are in the southwest corner of the map area. The Main Street Graben is about a half mile wide and extends south of the map area into Main Street Valley. The graben dies out at Seegmiller Mountain and the Main Street Fault dies out just north of Seegmiller Mountain. The Main Street Fault, which is the east-bounding fault of Main Street Graben, equally displaces the Seegmiller Mountain Basalt and the underlying bedrock strata down to the west about 48 m. These relations indicate that the Main Street Fault is younger than 2.4 Ma (Billingsley, 1993a).

Adjacent to the Main Street Graben is Main Street Horst. Main Street Horst is bounded on the west by the Main Street Fault and bounded on the east by the Sunshine Fault. Main Street Horst forms a local topographically high plateau called Twist Hills, which averages about 80 m higher than the surrounding landscape. Other minor structures include a few small normal faults south of the Dutchman Draw Fault that form several horst and graben structures in the south half of the map area. These structures are typical of the tectonic fabric of the Shivwits and Uinkaret Plateaus on the downthrown side of major structures such as the Hurricane Fault. They have a south-southeast strike in the south part of the map area and a northeast strike in the south-central part of the map. Several small plunging synclines and anticlines are randomly scattered in the north part of the map area and are a structural characteristic of the St. George Basin area. Strata east of the Hurricane Fault have a regional east dip of less than 2°. The minor folds are probably related to early Laramide compressional stresses (Huntoon, 1989, 2003). Warped and bent strata too small to show at map scale are the result of dissolution of gypsum in the Harrisburg Member of the Kaibab Formation and are commonly associated with drainage erosion or collapse structures.

Holocene movement has occurred along parts of many faults in the horst and grabens area between the Hurricane and Main Street Faults as evidenced by scarps in the alluvial deposits that are readily defined in the field and on aerial photographs. Erosion by mass wasting and the dissolution of gypsum within the Toroweap and Kaibab Formations shed soft, loose debris covering fault lines and scarps that often coincide with map contacts of bounding bedrock and alluvium and are shown as dotted faults. Faults that are sharply evident in Holocene alluvial material are shown as solid lines.

A few circular collapse structures, usually over 92 m in diameter are mostly due to dissolution of gypsum and gypsiferous siltstone in the Harrisburg Member of the Kaibab Formation. However, some circular, bowl-shaped areas that have inward-dipping strata may be collapse-formed breccia pipes that originated in the deeply buried Mississippian Redwall Limestone (Wenrich and Huntoon, 1989; Wenrich and Sutphin, 1989). Such features usually have inward dipping strata and are marked by a dot and the letter C to denote a possible deep-seated breccia pipe. However, breccia pipes cannot be distinguished with certainty from shallow collapse structures caused by the removal of gypsum in the Toroweap or Kaibab Formations. Moreover, some deep-seated breccia pipes are known to underlie gypsum collapse features (Wenrich and others, 1996). The deep-seated breccia pipes potentially contain economic deposits of copper and uranium minerals (Wenrich, 1985).

Dissolution of gypsum in the Harrisburg Member of the Kaibab Formation is probably the cause of several small, locally altered and bleached collapse structures in the lower red member, Virgin Limestone Member, and middle red member of the Moenkopi Formation in the northwest quarter of map area.

Small shallow sinkholes and karst caves are associated with the dissolution of gypsum in the Harrisburg Member of the Kaibab Formation. The sinkholes are relatively young features of Holocene and probable Pleistocene age as judged by their young appearance. Hundreds of sinkhole depressions are breached by drainages on the Shivwits and Uinkaret Plateau surfaces but are not marked on this map. Sinkholes that form an enclosed basin or depression are shown by a triangle symbol. Several drainages originate at or have breached sinkhole depressions in the south half of the map area.

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DESCRIPTION OF MAP UNITS

SURFICIAL DEPOSITS

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)**—Unconsolidated and poorly sorted, interlensing silt, sand, and pebble to boulder gravel. Intertongue or inset to young and intermediate alluvial fan (Qa_1, Qa_2) deposits, young and low terrace-gravel (Qg_1, Qg_2) deposits, upper part of valley-fill (Qv), floodplain (Qf), and talus (Qt) deposits. Stream channels subject to high-energy flows and flash floods and support little or no vegetation. Thickness, 1 to 4 m

Qd **Dune sand deposits (Holocene)**—Light-red and tan, fine-grained quartz sand. Aeolian sand originates from Jurassic sedimentary rocks north of map area but mostly derived from local stream-channel sediments of Fort Pearce Wash. Include gray, well-rounded chert grains. Form small climbing dunes and sand sheet deposits. Support grassy vegetation. Thickness, 3 m

Qf **Floodplain deposits (Holocene)**—Chiefly light-gray or brown silt, sand, and lenses of pebble to cobble gravel. Locally cemented by clay, calcite, and gypsum. Intertongue with valley-fill (Qv), young alluvial fan (Qa_1), and talus (Qt) deposits. Unit forms wide flat valley floors as opposed to small concave valley profiles of valley-fill (Qv) deposits. Subject to frequent flooding and local temporary ponding. Sparsely vegetated by cactus, sagebrush, and grass. Thickness, 30 m or more

Qc **Colluvial deposits (Holocene)**—Chiefly silt and fine-grained sand. Include lesser amounts of angular pebble to cobble gravel; locally consolidated. Accumulate in enclosed basins created by landslide debris. Subject to temporary ponding. Sparse or no vegetation. Thickness, 3 to 9 m

Qg_1 **Young terrace-gravel deposits (Holocene)**—Unconsolidated, light-brown to pale-red siltstone, sandstone, and lenses of gravel containing pebbles and boulders of well-rounded limestone, sandstone, and angular to subrounded chert. Locally contain well-rounded to rounded basalt clasts. Include reworked materials from young, intermediate, and old alluvial fan (Qa_1, Qa_2, Qa_3) deposits, young intermediate and intermediate terrace-gravel (Qg_2, Qg_3) deposits, and talus (Qt) deposits. Original floodplain (Qf) deposits along Hurricane Wash area are now terraces because arroyo erosion, as much as 3 m deep, eroded the floodplains where floodplain deposits no longer accumulate. Form bench about 1 to 3 m above modern streambeds. Thickness, 1 to 5 m

Qa_1 **Young alluvial fan deposits (Holocene)**—Unconsolidated silt and sand; contain lenses of coarse gravel composed of subangular to rounded pebbles and cobbles of limestone, chert, and sandstone. Include Tertiary and Quaternary basalt clasts in northwest quarter of map area. Partly cemented by gypsum and calcite. Intertongue with stream-channel alluvium (Qs), upper part of valley-fill (Qv) deposits, and young terrace-gravel (Qg_1) deposits. Include reworked materials from young and young intermediate terrace-gravel (Qg_1 and Qg_2) deposits and intermediate and old alluvial fan (Qa_2, Qa_3) deposits. Alluvial fans subject to sheetwash and flash flood erosion. Support sparse vegetation growths of sagebrush, greasewood shrubs, cactus, and grass. Thickness, 6 m

Qv **Valley-fill deposits (Holocene and Pleistocene)**—Partly consolidated silt, sand, and lenses of pebble to small-boulder gravel. Intertongue with talus (Qt), young terrace-gravel (Qg_1), and young and intermediate alluvial fan (Qa_1, Qa_2) deposits. Valleys subject to sheetwash flooding and temporary ponding; cut by arroyos in some larger valleys. Support thick vegetation growths of greasewood shrubs, sagebrush, grass, and cactus. Thickness, 9 m

Qt **Talus deposits (Holocene and Pleistocene)**—Unsorted debris consists of breccia and large angular blocks of local bedrock as much as 1 m in diameter. Includes silt, sand, and gravel; partly cemented by calcite and gypsum. Intertongue with young, intermediate, and old alluvial fan (Qa_1, Qa_2, Qa_3), valley-fill (Qv), and young and young intermediate terrace-gravel (Qg_1, Qg_2) deposits. Support sparse to moderate growths of greasewood shrubs, sagebrush, cactus, and grass. Only relatively extensive deposits are shown. Thickness, 9 m

Ql **Landslide deposits (Holocene and Pleistocene)**—Unconsolidated masses of unsorted rock debris, including detached blocks of strata that have rotated backward and slid downslope, often partly surrounded by talus (Qt). Occur principally below edges of basalt flows at East and West Mesa, Little Black Mountain, Seegmiller Mountain, and in Black Rock Canyon areas. Support sparse growths of greasewood shrubs, sagebrush, cactus, grass, and juniper trees. Likely to be unstable in wet climatic conditions. Only large masses are shown. Thickness, 45 m

Qg_2 **Young intermediate terrace-gravel deposits (Holocene and Pleistocene)**—Similar to young terrace-gravel deposits (Qg_1), partly consolidated. Form flat benches and abandoned stream channels about 4 to 9 m above modern streambeds. Intertongue with and locally overlain by talus (Qt) deposits. Inset against young terrace-gravel (Qg_1) deposits. Thickness, 2 to 5 m

Qa_2 **Young intermediate alluvial fan deposits (Holocene and Pleistocene)**—Similar to young alluvial fan (Qa_1) deposits; partly cemented by calcite and gypsum; generally lie topographically above but often overlapped by young alluvial fan (Qa_1) deposits. Intertongue with or inset against old alluvial fan (Qa_3), young and young intermediate terrace-gravel (Qg_1, Qg_2), valley-fill (Qv), and talus (Qt) deposits. Locally include basalt clasts. Support moderate growths of sagebrush, cactus, greasewood shrubs, and grass. Thickness, 3 to 12 m

Qg_3 **Intermediate terrace-gravel deposits (Pleistocene)**—Similar to young (Qg_1) and young intermediate (Qg_2) terrace-gravel deposits, but 6 to 11 m higher than Qg_2 and about 8 to 18 m above modern drainages. Consist of well-rounded limestone, sandstone, and chert clasts in sandy gravel matrix. Locally include abundant well-rounded clasts of basalt along Hurricane Wash. Partly consolidated by calcite and gypsum cement. Thickness, 5 m

Qa_3 **Old alluvial fan deposits (Pleistocene)**—Similar to young (Qa_1) and intermediate (Qa_2) alluvial fan deposits. Intertongue with talus (Qt) deposits. Often adjacent to or overlapped by young and intermediate alluvial fan (Qa_1, Qa_2), and talus (Qt) deposits. Include abundant basalt clasts in northeast quarter of map area. Thickness, 3 to 8 m

Qg_4 **Old intermediate terrace-gravel deposits (Pleistocene)**—Similar to young, young intermediate, and intermediate terrace-gravel (Qg_1, Qg_2, and Qg_3) deposits, but about 3 to 6 m higher than intermediate terrace-gravel (Qg_3) deposits and about 14 to 23 m above modern stream drainages. Consist of well-rounded basalt, limestone, sandstone, and chert clasts in fine-grained sandy matrix. Partly consolidated by calcite and clay cement. Thickness, 6 m

Qa_4 **Oldest alluvial fan deposits (Pleistocene)**—Partly consolidated, unsorted, silt and sand; contain subrounded to rounded pebbles and boulders of basalt, chert, and limestone. Partly cemented by gypsum and calcite. Consist of one outcrop at northwest edge of map area. Thickness, 2 m

Qg_5 **Older terrace-gravel deposits (Pleistocene)**—Similar to young, young intermediate, intermediate, old intermediate terrace-gravel (Qg_1, Qg_2, Qg_3, Qg_4) deposits, but 2 to 5 m higher than Qg_4 and about 26 m above modern drainages. Consist of well-rounded chert, basalt, and limestone clasts in sandy matrix. Partly consolidated by calcite and clay cement. Thickness, 5 m

QTa **Alluvial fan deposits (Pleistocene or Pliocene)**—Unconsolidated conglomerate, gravel, sandstone, and siltstone. Partly cemented with gypsum. Contain numerous black, brown, and yellow, well-rounded chert and quartzite pebbles averaging less than 2.5 cm in diameter and rare, rounded, petrified wood fragments, all derived from erosion of Shinarump Member of the Chinle Formation east of the map area. Unit is mostly a thin stream-lag gravel deposit overlying the Harrisburg Member of the Kaibab Formation in abandoned ancestral drainage of Clayhole Wash about 12 m above local drainages. The ancestral Clayhole Wash drainage was responsible for the erosion and cutting of Cottonwood Canyon, but headward erosion of Rock Canyon drainage from the north captured Clayhole Wash of Cottonwood Canyon near the east-central edge of the map area diverting Clayhole Wash from Cottonwood Canyon into Rock Canyon. Thickness, 1 to 3 m

VOLCANIC ROCKS

East Mesa Basalt (Pleistocene)—Named for East Mesa, the type area for the East Mesa Basalt (Tps. 40 and 41 N., R. 10 W.), northern Mohave County, Arizona, north-central part of map area. Unit consists of basalt flows, dikes, and pyroclastic deposits

Qei **Intrusive dike, plug, or vent area**—Dark-gray, finely crystalline, aphanitic. Weathers into crumbly small fragments owing to decomposition in abundant cooling joints. Sources for basalt flows of East Mesa

Qep **Pyroclastic deposits**—Red-brown and black clasts of angular alkali-olivine basalt deposits as dark-gray glassy fragments; unconsolidated. Associated with vent and dike extrusions forming pyroclastic cones on East Mesa Basalt flows. Form slope. Thickness, 50 m or more

Qeb **Basalt flows**—Dark-gray, massive alkali-olivine basalt; finely crystalline, aphanitic to glassy. Surface of basalt flows partly covered by fine-grained calcrete soil deposits or red-brown to red pyroclastic and scoria (Qep) deposits. K-Ar age is 1.4±0.25 Ma (Harold H. Mehnert, U.S. Geological Survey, Denver, Colo., written commun., 1993). Thickness, 9 to 55 m

West Mesa Basalt (Pleistocene)—Named for West Mesa, the type area for the West Mesa Basalt (T. 40 N., Rs. 10 and 11 W.), northern Mohave County, Arizona, west-central part of map area. Unit consists of basalt flows, dikes, and pyroclastic deposits

Qwi **Intrusive dike or plug**—Dark-gray, finely crystalline, aphanitic; weathers into crumbly small fragments owing to corrosion of abundant cooling joints. Sources for West Mesa Basalt flows

Qwp **Pyroclastic deposits**—Red-brown to black, slope-forming clasts of angular or glassy basalt fragments. Associated with vent and dike extrusions forming pyroclastic cones and thin cinder cover on top of West Mesa Basalt flows. Thickness, 30 m

Qwb **Basalt flows**—Dark-gray, finely crystalline, alkali-olivine, aphanitic groundmass; large columnar joints present at base of some flows, but not common. Surface of West Mesa Basalt partly covered by pyroclastic (Qwp) deposits of cinders and scoria. K-Ar age is 1.6±0.3 Ma (Harold H. Mehnert, U.S. Geological Survey, Denver, Colo., written commun., 1993). Thickness, 1 to 35 m

Other basalts (Pleistocene)—Include basalt flows and associated dikes and necks at two isolated unnamed buttes north of East Mesa that are assumed to be Pleistocene age because of similar lithology and elevation as East Mesa and West Mesa Basalts. Includes basalt flows at Little Black Mountain and in Dutchman Wash

Qi **Intrusive dike or neck**—Dark-gray, finely crystalline, aphanitic groundmass. Source vents for basalt flows on two unnamed buttes north of East and West Mesas

Qp **Pyroclastic deposits**—Red and black pyroclastic deposits associated with vent and dike on top of unnamed butte (4,271 ft elevation on map). Forms slope. Thickness, 1 to 3 m

Qb **Basalt flows**—Dark-gray, massive basalt; finely crystalline, aphanitic groundmass. K-Ar age of basalt at Little Black Mountain is 1.7±0.4 Ma (Harold H. Mehnert, U.S. Geological Survey, Denver, Colo., written commun., 1993). Flow is 9 m thick at Little Black Mountain and less than 15 m thick at unnamed buttes north of East and West Mesas

Seegmiller Mountain Basalt (Pliocene)—Named for Seegmiller Mountain as the type area (T. 40 N., R. 11 W.), northern Mohave County, Arizona, west-central edge of map area. Consists of several basalt flows and associated intrusive dikes and pyroclastic deposits

Tsi **Intrusive dike or plug**—Dark-gray alkali-olivine basalt. Contains olivine and pyroxene crystals in aphanitic groundmass. Weathers blue gray. Several source vents are just west of map area

Tsp **Pyroclastic deposits**—Red and black scoriaceous cinder and ash deposits associated with dikes or vents above and below basalt flows on Seegmiller Mountain. Thickness, 11 m

Tsb **Basalt flows**—Include dark-gray, finely crystalline, aphanitic groundmass and sparse olivine and unknown black (augite?) phenocrysts. K-Ar age is 2.35±0.31 to 2.44±0.51 Ma (Reynolds and others, 1986). Surfaces are blocky and partly covered with alluvial valley-fill (Qv) deposits in lowland areas. Consists of several flows. Thickness, 40 m

Black Rock Canyon Basalt (Pliocene)—Named for Black Rock Canyon, type area, along Hurricane Wash at base of Hurricane Cliffs (T. 41 N., R. 10 W.), northern Mohave County, Arizona

Tbb **Basalt flows**—Include dark-gray, finely crystalline, alkali-olivine basalt, aphanitic groundmass with sparse olivine phenocrysts. Source of flows not found but likely near summit at benchmark labeled "Butte" (elevation 5,104 ft) on map, west of Black Rock Canyon. K-Ar age 3.5±0.6 Ma (Harold H. Mehnert, U.S. Geological Survey, Denver, Colo., written commun., 1993). Consists of one or two flows. Thickness, 8 m

SEDIMENTARY ROCKS

Chinle Formation (Upper Triassic)—Includes, in descending order, Petrified Forest and Shinarump Members as used by Stewart and others (1972)

TRcp **Petrified Forest Member**—White, blue-gray, green-gray, pale-red, and purple-red mudstone, siltstone, and minor sandstone. Contains bentonitic clays derived from volcanic ash. Petrified wood fragments common. Unknown thickness of upper part is removed by erosion. Commonly covered by landslide (Ql), talus (Qt), and colluvial (Qc) deposits. Forms slopes. Gradational contact with underlying cliff-forming Shinarump Member of the Moenkopi Formation. Thickness, 60 m

TRcs **Shinarump Member**—Orange-brown to tan, coarse-grained, conglomeratic, thin-bedded to massive, cliff-forming conglomeratic sandstone. Weathers dark brown. Includes stream-channel deposits largely composed of well-rounded chert and quartzite pebbles in coarse-grained sandstone matrix; about 30 percent of clasts are black, well-rounded chert(?) or schist(?) too fine grained to determine. Contains silicified fossil wood fragments and petrified logs. Fills erosion channels cut into upper red member of the Moenkopi Formation as much as 100 ft deep forming an unconformable contact with the underlying Moenkopi Formation. Thickness, 25 to 55 m

Moenkopi Formation (Middle? and Lower Triassic)—Includes, in descending order, upper red member, Shnabkaib Member, middle red member, Virgin Limestone Member, lower red member, and Timpoweap Member as used by Stewart and others (1972). Middle-Lower Triassic boundary probably lies in upper red member (Morales, 1987)

TRmu **Upper red member (Middle? and Lower Triassic)**—Heterogeneous sequence of slope- and ledge-forming red sandstone, siltstone, mudstone, conglomerate, and minor gray gypsum. Includes thin-bedded cliff of sandstone in upper part. Erosional contact with underlying Shnabkaib Member at base of lowest red sandstone cliff, difficult to find at most localities. Map contact with Shnabkaib Member is arbitrarily placed at top of highest white, thick siltstone and dolomite bed of the Shnabkaib Member. Thickness, 62 m

TRms **Shnabkaib Member (Lower Triassic)**—Interbedded, white, slope-forming, laminated, aphanitic dolomite and silty gypsum; includes red, thin-bedded mudstone, siltstone, and sandstone in lower part. Gradational contact with underlying middle red member arbitrarily placed at base of lowest bed of light-gray dolomitic limestone or siltstone. Thickness, 183 m

TRmm **Middle red member (Lower Triassic)**—Interbedded, red-brown, slope-forming, thin-bedded, laminated siltstone and sandstone, white and gray gypsum, minor white platy dolomite, green siltstone, and gray-green gypsiferous mudstone. Gradational contact with underlying Virgin Limestone Member placed at top of highest gray limestone bed of Virgin Limestone. Thickness, 60 to 70 m

TRmv **Virgin Limestone Member (Lower Triassic)**—Consists of three, and in some areas four, light-gray, ledge-forming limestone beds 0.5 to 9 m thick, separated by white, yellowish-gray, and gray, slope-forming, thin-bedded, gypsiferous siltstone. Includes thin beds of brown, red, and green siltstone, gray limestone, and brown platy calcarenite. Lowest limestone bed is thickest and contains star-shaped crinoid plates and poorly preserved *Composita* brachiopods in upper part. Unconformable contact with underlying lower red member of the Moenkopi Formation with as much as 2 m of relief that truncates underlying siltstone of lower red member at base of lowest gray Virgin Limestone bed. Lowest limestone bed thickens and thins laterally as a channel-fill deposit. Thickness, 25 to 43 m

TRml **Lower red member (Lower Triassic)**—Interbedded, red, slope-forming, thin-bedded, sandy siltstone and sandstone, and gray, white, and pale-yellow laminated gypsum. Lower beds contain reworked gypsum and siltstone of Harrisburg Member of the Kaibab Formation. Includes marker bed of thin-bedded, calcareous, ledge-forming sandstone about 1 to 2 m thick in northeast quarter of map area. Marker bed contains raindrop impressions and rare carbonaceous plant fossils with malachite copper staining near Short Creek. Interbedded or gradational contact with underlying limestone, sandstone, or conglomerate of Timpoweap Member; contact arbitrarily placed at lowermost red siltstone bed. Locally thickens and thins laterally in shallow Triassic paleovalleys eroded into underlying Kaibab

Formation (fig. 2). Thickness, 9 to 30 m. Locally thickens to as much as 60 m in deepest Triassic paleovalleys

ŦRmt **Timpoweap Member (Lower Triassic)**—Light-gray, cliff- and slope-forming conglomerate and limestone, northeast quarter of map area. Upper part consists of interbedded light-gray, fine-grained, thick-bedded limestone and gray, coarse-grained, low-angle crossbedded sandstone. Gradational contact with conglomerate of lower part, which consists of subangular to rounded pebbles and cobbles of gray and dark-gray limestone, white and brown chert, and minor rounded quartzite. Chert and gray limestone clasts are derived from the Kaibab Formation. Mostly clast supported; includes matrix of gray to brown, coarse-grained sandstone, gravel, siltstone, and limestone. Upper and lower part fills valleys eroded into Harrisburg Member of the Kaibab Formation. The name Rock Canyon Conglomerate Member was proposed by Bassler and Reeside (1921), abandoned by Gregory (1948, 1952), used by Nielsen and Johnson (1979), and Nielsen (1986, 1991). The term Timpoweap Member of the Moenkopi Formation is used in this report. Unit fills Triassic paleovalleys estimated as much as 110 m deep and about 397 m wide eroded into the Kaibab Formation. Rocks of the Timpoweap Member occupy two major paleovalleys, Black Rock Valley, and Quail Valley (Billingsley, 1993a, b, c; Billingsley and Workman, 2000; fig. 2). Smaller and shallower tributary paleovalleys are scattered throughout map area. Imbrication of basal pebbles in conglomerate of the Timpoweap Member show an eastward paleoflow of depositing streams. Thickness, 6 to 110 m

ŦRmlt **Lower red member and Timpoweap Member, undivided (Lower Triassic)**—Same lithologies as ŦRml and ŦRmt but completely interbedded. Consists of conglomerate and limestone lenses within interbedded siltstone and gypsum. Occupies shallow paleovalleys with relief as much as 30 m cut into underlying Harrisburg Member of the Kaibab Formation. Unconformable contact with Harrisburg Member of the Kaibab Formation. Contact locally obscure where overlain by surficial deposits. Forms slopes with ledges. Thickness, 1 to 30 m

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

Pkh **Harrisburg Member**—Includes an upper, middle, and lower part not mapped separately. Upper part consists of slope-forming, red and gray, interbedded gypsiferous siltstone, sandstone, gypsum, and thin-bedded gray limestone. Includes an upper, resistant, pale-yellow or light-gray, fossiliferous, sandy limestone bed averaging about 1 m thick. Most of upper part is eroded from map area. Upper part locally pinches out in extreme north part of map area. Forms gradational contact with middle part. Middle part consists of two cliff-forming marker limestone beds; an upper, gray, thin-bedded cherty limestone that weathers dark brown or black, and a lower, light-gray, thin-bedded sandy limestone. Middle part commonly forms the bedrock surface map unit of the Uinkaret and Shivwits Plateaus where the upper part has eroded away. Forms minor unconformable contact with lower part at base of sandy limestone. Lower part consists slope-forming, light-gray, fine- to medium-grained gypsiferous siltstone, sandstone, thin-bedded gray limestone, and gray gypsum. Dissolution of gypsum in lower part has locally distorted limestone beds of middle part causing them to slump or bend into local drainages. Gradational and arbitrary contact between siltstone slope of Harrisburg Member and limestone cliff of Fossil Mountain Member of the Kaibab Formation. Harrisburg Member, in general, forms slope with middle limestone cliff. Thickness, 110 m

Pkf **Fossil Mountain Member**—Light-gray, cliff-forming, fine- to medium-grained, thin-bedded, fossiliferous, sandy, cherty limestone. Chert weathers black. Unconformable contact with underlying Woods Ranch Member of the Toroweap Formation marked by dissolution of gypsum and channel erosion with relief as much as 60 m; contact locally obscured by talus. Thickness, 110 m

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

Ptw **Woods Ranch Member**—Gray, slope-forming, gypsiferous siltstone and pale-red silty sandstone interbedded with medium-bedded white gypsum. Beds are locally distorted due to gypsum dissolution. Arbitrary contact with underlying Brady Canyon Member of the Toroweap Formation at top of limestone cliff of Brady Canyon Member. Thickness, 12 to 60 m

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 0.05 m thick. Contains chert lenses and nodules that are 50 percent less abundant than in the Fossil Mountain Member of the Kaibab Formation. Gradational contact with siltstone and gypsum of underlying Seligman Member of the Toroweap Formation; contact commonly covered by minor slump or talus debris. Thickness, 91 m

Pts **Seligman Member**—Consists of an upper, middle, and lower part. Upper part consists of gray, interbedded, thin-bedded dolomite and gypsiferous sandstone. Middle part consists of gray to red, thin-bedded, interbedded siltstone, sandstone, and gray gypsum. Lower part consists of brown, purple, and yellow, fine- to medium-grained, thin-bedded, low-angle and high-angle crossbedded and planar-bedded sandstone that may be equivalent to the Coconino Sandstone in Grand Canyon. Unconformable, sharp planar contact with underlying yellow or red sandstone of the Hermit Formation with local relief as much as 1 m. Slope-forming unit with ledges. Thickness, 30 to 60 m

Ph **Hermit Formation (Lower Permian)**—Light-red and white, slope- and ledge-forming, fine-grained, thin- to medium-bedded sandstone and siltstone. Red and white sandstone beds in upper part are separated from white sandstone beds in lower part by red, slope-forming siltstone and silty sandstone beds that contain horizontal burrows. Upper sandstone beds are commonly bleached yellow or white and thicken northward. Lower sandstone beds contain numerous burrows and plant? trace fossils. Unconformable contact with underlying Esplanade Sandstone marked by shallow, laterally discontinuous erosion channels with relief as much as 2 m. Arbitrary contact between lowest slope-forming, thin-bedded, red siltstone of Hermit Formation and cliff-forming, thick-bedded, tan or white, low-angle crossbedded sandstone of Esplanade Sandstone. Measured thickness, 138 m

Pe **Esplanade Sandstone (Lower Permian)**—Red, white, and tan, cliff-forming, fine- to medium-grained, medium- to thick-bedded, low- and high-angle crossbedded sandstone. Contains clusters of tube-like burrows that radiate out as much as 0.05 to 1 m from a central area within upper sandstone beds. Burrows within clusters average about 1 cm in diameter. Includes interbedded gray, fine-grained, thin-bedded, ledge- and slope-forming, calcareous silty sandstone in upper and lower part. Unit as a whole is white or tan sandstone cliff that includes small interbedded red siltstone recesses in upper part and pale-red, thin-bedded, slope-forming sandstone beds in lower part. Base not exposed, section incomplete. Correlative with Queantoweap Sandstone in Gorge of the Virgin River 43 km west of map area (Billingsley, 1993a). Measured thickness, 175 m

Pkl **Pakoon Limestone (Lower Permian)**—Light-gray, cliff-forming, fine- to coarse-grained, thin-bedded, fetid, fossiliferous limestone. Includes interbedded sandy dolomite and thinly laminated, gray to purple siltstone and sandstone. Shown only in cross section. The unit is not exposed within the map area but is assumed to be present in the subsurface on the basis of exposures in the Gorge of the Virgin River about 43 km west of map area

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APPENDIX

DIGITAL DATABASE DESCRIPTION FOR THE GEOLOGIC MAP OF LOWER HURRICANE WASH AND VICINITY, MOHAVE COUNTY, NORTHWESTERN ARIZONA

by

Scott E. Graham

INTRODUCTION

This appendix describes the digital geologic map database and gives instructions for obtaining the data. The report includes PostScript and PDF plot files containing images of the geologic map sheet and an explanation sheet as well as 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.

The 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 Lower Hurricane Wash. Together with the preceeding pamphlet, it provides current information on the geologic structure and stratigraphy of the area, as well as how to access the information in the digital map database. The database delineates map units that are identified 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. 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 plot file packages in either of the two ways described below (see the section “Obtaining the Digital Data”); 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-2396.

U.S. Geological Survey Information Services
Box 25286
Denver, CO 80225
1-888-ASK-USGS
e-mail:ask@usgs.gov

DATABASE CONTENTS

The digital database package consists of the geologic map database and supporting data including base maps, map explanation, geologic description, and references. The other two packages consist of PostScript or PDF plot files of the geologic map, explanation sheet and geologic description.

Digital Database Package

The digital database package is composed of geologic map database files for the Lower Hurricane Wash area. The 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. The export files included are:

ARC/INFO export file	Resultant Coverage	Description
lh-geol.e00	lh-geol/	Faults, contacts and geologic units
lh-strc.e00	lh-strc/	Strike and dip information and annotation, point data and annotation; fold axes
lh-anno.e00	lh-anno/	Unit labels, fault names, and fault separation values

The database package also contains the following files:

lhdrg.tif.gz	Zipped background topographic map image
lhdrg.tfw	World file accompanying lhdrg.tif
import.aml	ASCII text file in Arc Macro Language to convert Arc export files to Arc coverages in Arc/Info
mf2396.met	A parseable text-only file of publication level FGDC metadata for this report
mf2396.rev	ASCII text file describing revisions, if any, to this publication

PostScript Plot file Package

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

lhmap.ps	Encapsulated PostScript plottable file containing complete map composition with geology, geologic cross-sections, and correlation of units.
lhgeo.ps	Encapsulated PostScript plottable file containing detailed unit descriptions, geological information, sources of data, references cited and the database description.

The PostScript image of the geologic map and map explanation is 44 inches high by 36 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 'postscript' command with compression set to zero in ARC/INFO version 8.1. The geologic description and correlation chart were created in Adobe Illustrator 9.0.

PDF Plotfile Package

lhmap.pdf	A PDF file containing complete map composition with geology, geologic cross-sections, and correlation of units.
lhgeo.pdf	A PDF file containing detailed unit descriptions, geological information, sources of data, references cited and the database description.

The Acrobat files were created from corresponding .ps files and are compatible with Adobe Acrobat version 4.0 and higher. 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.

Tar files

The three data packages described above are stored in tar (UNIX tape archive) files. A tar utility is required to extract the database from the tar file. This utility is included in most UNIX systems, and can be obtained free of charge over the Internet from Internet Literacy's Common Internet File Formats Webpage (http://www.matisse.net/files/formats.html). Both tar files have been compressed, and may be uncompressed with gzip, which is available free of charge over the Internet via links from the USGS Public Domain Software page (http://edcwww.cr.usgs.gov/doc/edchome/ndcdb/public.html). In addition, several common proprietary freeware programs such as Stuffit Expander (http://www.aladdinsys.com/expander/index.html) and shareware programs such as WinZip (http://www.winzip.com) can handle both tar file extraction and gzip uncompression. When the tar file is uncompressed and the data is extracted from the tar file, a directory is produced that contains the data in the package as described above. The specifics of the tar files are listed below:

Name of compressed tar file (uncompressed)	Size of compressed tar file tar file	Directory produced when extracted from	Data package contained
mf2396c.tar.gz	MB (MB)	lhgeo	Digital Database Package
mf2396a.tar.gz	MB (MB)	lhps	PostScript Plotfile Package
mf2396b.tar.gz	MB (MB)	lhpdf	PDF Plotfile Package

Obtaining the Digital Data

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

a.) The Western Region Geologic Publication Web Page at:
http://geopubs.wr.usgs.gov/docs/wrgis/mf-2396
Follow the directions to download the files.

b.) 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/mf-map/mf2396.

ACCESSING DATABASE CONTENTS

ARC/INFO Export Files

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

ARC: &run import.aml

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

DATABASE SPECIFICS

Digital Compilation

Stable-base maps were scanned at the U.S. Geological Survey's Flagstaff Science Center using the Optronics 5040 raster scanner at a resolution of 50 microns (508 dpi). The resulting raster file was in RLE format and converted to the RLC format using the "rle2rlc" program written by Marilyn Flynn. The RLC file was subsequently converted to an ARC/INFO Grid in ARC/INFO. The linework was vectorized using gridline. A tic file was created in lat/long and projected into the base map projection (State Plane). Tics are defined in the four extreme corners of the map area in the geologic coverages corresponding with quadrangle corners both in base maps and digital maps. The tic file was used to transform the grid into STATEPLANE.

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

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

Map Projection:

Parameter	Description
Projection	STATEPLANE
Units	Meters on the ground
Zone	3201
Datum	NAD27
Spheroid	Clarke 1866

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 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 to 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, faults, and map boundaries in LH-GEOL, and fold axes in LH-STRC. These distinctions and the geologic identities of the boundaries are stored in the LTYPE field according to their line type.

Arc Attribute Table Definition

LH-GEOL.AAT

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	4	12	F	3	Length of the arc in meters
LH-GEOL#	4	5	B	-	Unique internal number
LH-GEOL-ID	4	5	B	-	Unique identification number
LTYPE	35	35	C	-	Line type
PTTYPE	35	35	C	-	Point type for arcmarkers

LH-STRC.AAT

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	4	12	F	3	Length of the arc in meters
LH-GEOL#	4	5	B	-	Unique internal number
LH-GEOL-ID	4	5	B	-	Unique identification number
LTYPE	35	35	C	-	Line type
PTTYPE	35	35	C	-	Point type for arcmarkers
PLUNGE	3	3	I	-	For plotting arrows on plunging fold axes and basalt flow direction

Line Types recorded in LTYPE field

LH-GEOL.AAT

contact_certain

fault_normal_approx
fault_normal_certain
fault_normal_concealed
landslide_scarp
map_boundary

LH-STRC.AAT
anticline_certain
anticline_concealed
basalt_flow_direction
monocline_certain
monocline_concealed
plunging_anticline
plunging_syncline
syncline_approx
syncline_certain
syncline_concealed
xsect

Arc marker types recorded in PTTYPE field

LH-GEOL.AAT
fault_ball_fill
xx

LH-STRC.AAT
anticline
monocline
syncline
xx

Arcs with PTTYPE value ‘xx’ indicate that there is no symbol attached to the arc.

Values recorded in PLUNGE field

LH-STRC.AAT
0
1
32

Arcs with PLUNGE value 0 indicate no arrowhead, arcs with PLUNGE value 1 indicate a black arrowhead, and arcs with PLUNGE value 32 indicate a red arrowhead.

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

accompanying text (lhgeo.txt, lhgeo.doc, or lhgeo.pdf)

Definition of Polygon Attribute Table

LH-GEOL.PAT

Item Name	Width	Output	Type	N. Dec	Description
AREA	4	12	F	3	Area of polygon in square meters
PERIMETER	4	12	F	3	Length of perimeter in meters
LH-GEOL#	4	5	B	-	Unique internal number
LH-GEOL-ID	4	5	B	-	Unique identification number
PTYPE	5	5	C	-	Unit label

Unit labels recorded in the ptype field

LH-GEOL.PAT

Pe	Qa1	Qeb	Qg5	Qwi	TRmt
Ph	Qa2	Qei	Qi	Qwp	TRmu
Pkf	Qa3	Qep	Ql	TRcp	TRmv
Pkh	Qa4	Qf	Qp	TRcs	Tbb
Ptb	Qaf	Qg1	Qs	TRml	Tsb
Pts	Qb	Qg2	Qt	TRmlt	Tsi
Ptw	Qc	Qg3	Qv	TRmm	Tsp
QTa	Qd	Qg4	Qwb	TRms	

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

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 LH-STRC has only a point attribute table, and LH-GEOL has only a polygon attribute table.

Definition of Point Attribute Table

LH-STRC.PAT

Item Name	Width	Output	Type	N. Dec	Description
AREA	4	12	F	3	Area of polygon in square meters

PERIMETER	4	12	F	3	Length of perimeter in meters
LH-STRC#	4	5	B	-	Unique internal number
LH-STRC-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 azimuth degrees

The coverage LH-STRC contains strike and dip data and other pertinent structural data represented by point symbology, including collapses, sinkholes and domes.

Point types recorded in the PTTYPE field

approx_bedding	sinkhole
bedding	vertical_joint
collapse_structure	
Dome	

ANNOTATION

The coverage LH-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. LH-ANNO contains annotation with unit labels, fault separation, and monocline names. Annotation directly related to unit labeling is contained in subclass "anno.unit" and annotation including fault separation values, fault names and place names is contained in "blank", or, not in a subclass.

BASE MAP PROCEDURE

The base map was prepared by mosaicing four 1:24,000 DRGs, and scanning the resultant image to generate a georeferenced TIFF (GeoTIFF) graphic. This graphic was subsequently projected into STATEPLANE, rotated and clipped into a secondary TIFF image to be used as the topographic base map for the cartographic layout.

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 which 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.