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Geologic map of the Antelope Knoll quadrangle northern Mohave County, Arizona

by
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INTRODUCTION

The Antelope Knoll 7.5′ quadrangle is located in northern Mohave County, northwestern Arizona. The quadrangle is about 26 km south of the Arizona/Utah State line and about 30 km southwest of Colorado City, Arizona, the nearest settlement (fig. 1). Elevations range from about 1,814 m (5,951 ft) at Antelope Knoll (central part of quadrangle) to 1,408 m (4,620 ft) on the southwestern edge of quadrangle. Access to the area is by improved dirt road locally referred to as the Temple Trail, a branch road from the Navajo Trail to Colorado City, Arizona (fig. 1). Several unimproved dirt roads lead from the Temple Trail to various locations within the quadrangle area. Travel on the Temple Trail can be done with 2 wheel drive vehicles; all other roads need high clearance vehicles or 4 wheel drive in muddy conditions.

The area is managed by the U.S. Bureau of Land Management, including about 5 sections belonging to the state of Arizona. The area supports a sparse growth of sagebrush, cactus, cliffrose bush, grass, and various high desert shrubs. A light cover of pinyon pine and juniper trees are east of the Hurricane Cliffs, southwest corner of the quadrangle.

PREVIOUS WORK

The area is included on two Arizona state geologic maps, one by Wilson and others (1969), and the other by Reynolds (1988). A geologic map is available for the upper Hurricane Wash and vicinity (Billingsley, in press, b), and The Grandstand 7.5′ quadrangle (Billingsley, 1993b), all bordering this quadrangle on the west. A geologic map of the lower Hurricane Wash and vicinity lies adjacent to the northwest corner of this quadrangle (Billingsley, in press, a). The White Pockets quadrangle (Billingsley, 1994), borders this area on the north. Preliminary geologic maps are also available for the Grand Canyon area about 45 km south of this quadrangle (Huntoon and others, 1981; Billingsley and others, 1983; Wenrich and others, 1986).

MAPPING METHODS

A preliminary geologic map was made from 1:24,000 scale aerial photographs. In particular, many of the Quaternary alluvial units having similar lithologies were mapped using photogeologic methods. Detailed field investigations were then conducted to check photo interpretations and to obtain descriptions for all map units.

GEOLOGIC SETTING

The map area lies within the Shivwits and Uinkaret Plateaus, subplateaus of the southwestern part of the Colorado Plateau physiographic province. The physiographic boundary between the higher elevations of the Uinkaret Plateau and the lower elevations of the Shivwits Plateau is demarcated along the upper part of the Hurricane Cliffs escarpment, a youthful fault scarp (fig. 2). The Shivwits and Uinkaret Plateaus are characterized by relatively flat-lying Paleozoic and Mesozoic strata that have an average regional dip of less than 2° east, except along the Hurricane Cliffs where dips of the Hurricane Monocline reach as much as 24° east.

The Hurricane Fault and Monocline is the major structural feature of the quadrangle. The resulting fault scarp, the Hurricane Cliffs, exposes more than 305 m of Permian strata. East of the Hurricane Cliffs, on the Uinkaret Plateau, about 67 m of Triassic strata are exposed under Quaternary basalt flows (southeast corner of map). Vertical displacement among various segments of the Hurricane Fault is estimated to be over 500 m.

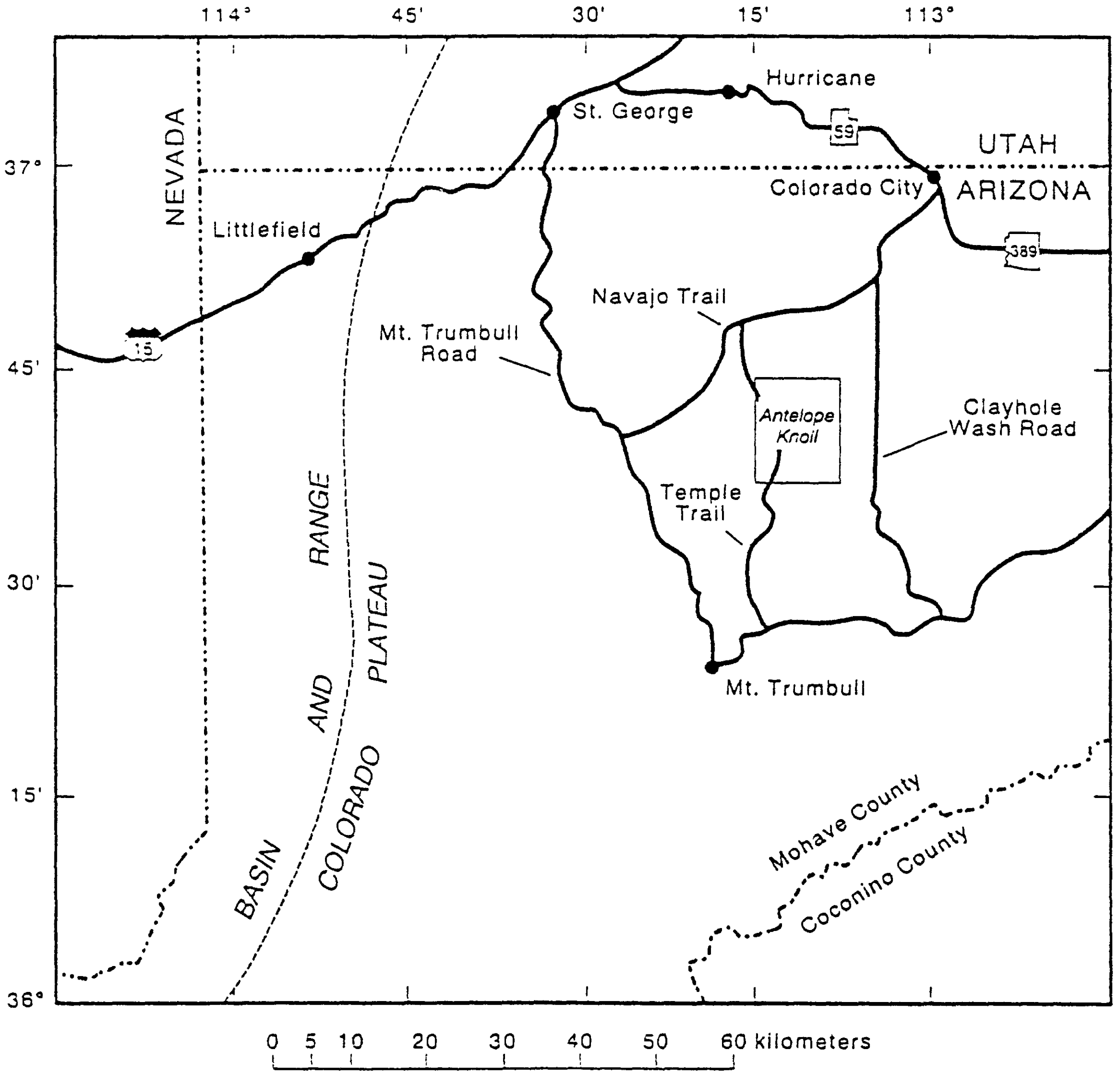

Figure 1. Index map of northern Mohave County, northwestern Arizona, showing the Antelope Knoll 7.5′ quadrangle.

Cenozoic deposits consists of igneous, surficial alluvium, and landslide deposits of Quaternary age. The igneous rocks are mapped as vent areas, pyroclastic deposits and basalt flows. The surficial deposits include artificial-fill and quarries, stream-terraces, alluvial-fans, talus, and landslide debris. These deposits form geomorphic features and erosional surface deposits having intertonguing or gradational contacts. The distribution of these Quaternary deposits are an important factor to consider in future environmental, land, and range management planning in this area by federal, state, and private organizations.

STRATIGRAPHY

The Paleozoic and Mesozoic stratigraphic units within the map area include, in order of decreasing age, the Toroweap, and Kaibab Formations (Lower Permian), and the Moenkopi Formation (Middle? and Lower Triassic). The base of the Seligman Member of the Toroweap Formation is not exposed along the bottom of the Hurricane Cliffs owing to a cover of alluvial fan deposits. The upper part of the underlying Hermit Formation (Lower Permian) would likely be exposed along the base of the Hurricane Fault scarp were it not for the alluvial cover. The Coconino Sandstone (Lower Permian), found in the Grand Canyon area south of this quadrangle, pinches out northward from the Grand Canyon and does not reach this area. Most of the Toroweap Formation is well exposed in the lower steep slopes and ledges of the Hurricane Cliffs as gray siltstone, sandstone, gypsum, and limestone. The Kaibab Formation forms the upper part of the Hurricane Cliffs and much of the bedrock surface of the Shivwits and Uinkaret Plateaus where not covered by Quaternary volcanic rocks or alluvial deposits. The Kaibab bedrock is composed of gray cherty limestone and gray to white siltstone and gypsum. The lower part of the Moenkopi Formation is composed of gray conglomerate and sandstone, light-brown to red siltstone and sandstone, gray gypsum, and gray limestone. Most of the Moenkopi Formation crops out along the base of Quaternary basalt flows, east edge of the quadrangle.

A large Triassic paleovalley is eroded into the Harrisburg Member of the Kaibab Formation and is filled with conglomerate, limestone, and sandstone strata of the Timpoweap Member of the Moenkopi Formation, northwest corner of the quadrangle area (fig. 2). This paleovalley is called Mustang valley and is mapped for more than 19 km west of this quadrangle (Billingsley, in press, a). Mustang valley is covered by igneous rocks for a few kilometers in the vicinity of Antelope Knoll, and crops out in the southeast part of the quadrangle where the paleovalley is mostly removed by erosion (fig. 2). Two smaller unnamed Triassic paleovallies in the western part of the quadrangle probably join Mustang valley in the vicinity of Antelope Knoll. Both small paleovallies are mapped for about 10 km west of this quadrangle (Billingsley, 1993c).

The outcrops of igneous rocks are basalt flows and pyroclastic deposits that overlie strata of the Kaibab and Moenkopi Formations. The basalt flows originate from vent areas associated with thick pyroclastic cinder and scoria deposits that form prominent cinder cones on the basalt flows. The igneous rocks represent the northern extent of the Uinkaret Volcanic Field (Hamblin and Best, 1970; Hamblin, 1970). Two whole-rock K-Ar ages have been obtained for the basalts in this part of the volcanic field and several more are pending.

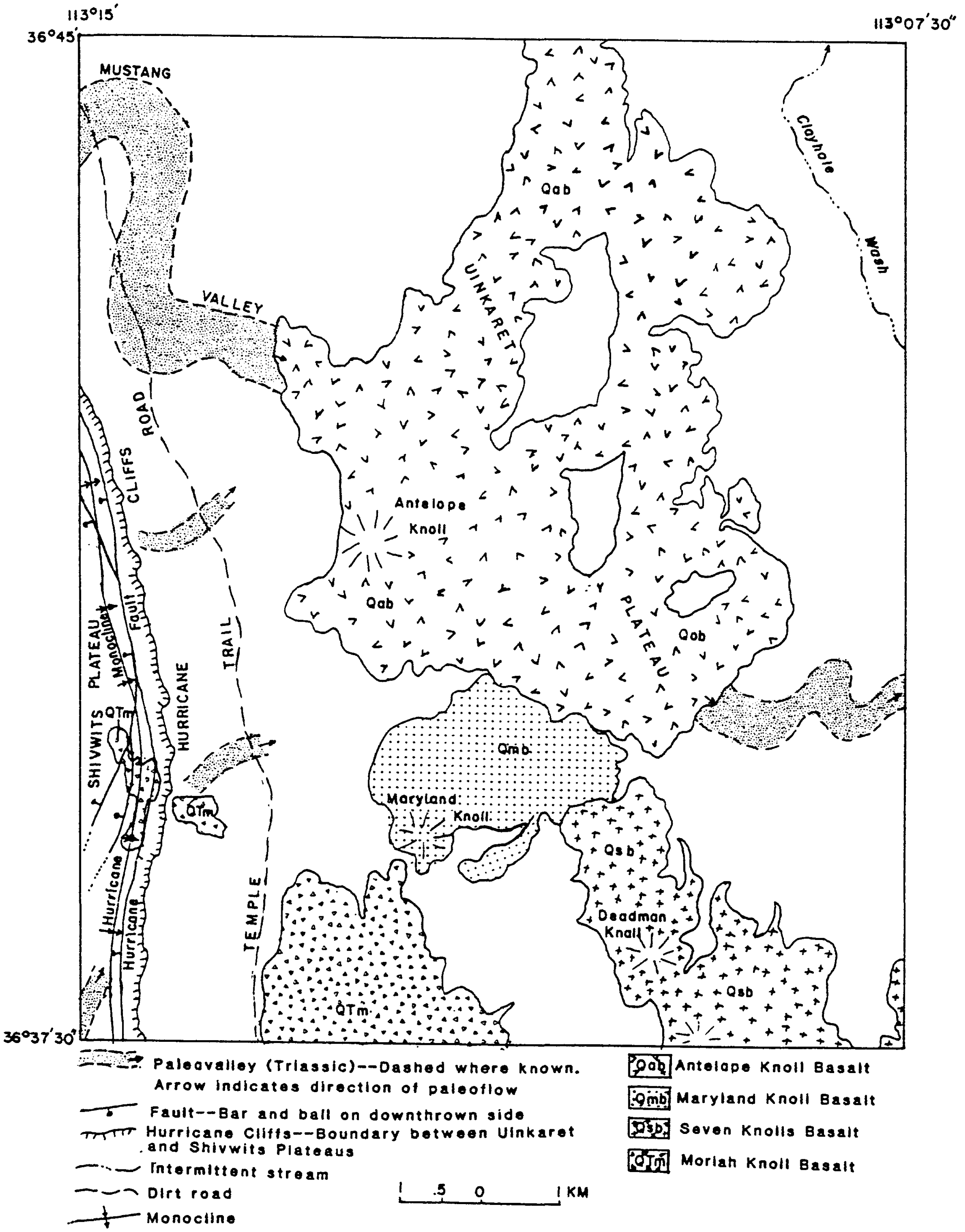

Figure 2. Selected geographic and geologic features of the Antelope Knoll quadrangle, northwestern Arizona.

Antelope Knoll is the largest of four cinder cones in the Quadrangle (fig. 2). The cinder and scoria deposits at Antelope Knoll are as much as 180 m thick and form a prominent cinder cone on the Uinkaret Plateau. The basalt flow from Antelope Knoll flowed in a northerly and easterly direction onto a gently east-dipping bedrock surface of the Harrisburg Member of the Kaibab Formation and the Timpoweap and lower red members of the Moenkopi Formation. The flow, or flows, are mapped as one map unit. The basalt flow, and associated cinder and scoria deposits, are named Antelope Knoll Basalt, for Antelope Knoll volcano, the type area, northern Mohave County, Arizona (Secs. 13, 18, 19, and 24, T. 38 N., Rs. 8 and 9 W.; fig. 2; Billingsley, 1994). The Antelope Knoll Basalt is comprised of reddish-black cinder and scoria deposits at Antelope Knoll and a dark gray, finely-crystalline groundmass of basalt having few or no phenocrysts. A sample of the Antelope Knoll Basalt obtained near the Navajo Trail north of this quadrangle (T. 39 N., R. 8 W., sw¼ of sec. 6, White Pockets quadrangle, Arizona; Billingsley, 1994) yielded a whole-rock K-Ar age of 0.83±0.28 Ma (Harold Mehnert, U.S. Geological Survey Isotope Laboratories, Denver, Colorado, written commun., 1993).

The Antelope Knoll Basalt flowed eastward over bedrock and alluvium for about 5 km, descending about 122 m for a gradient of about 40 m per kilometer. Thus, the landscape at the time of the flow, was much the same as it appears today. The eastern reaches of the Antelope Knoll Basalt flowed east and north within a shallow valley of mostly alluvium and bedrock eroded into the Moenkopi Formation. The bulk of the basalt flowed northward down a drainage that may have been a tributary to Clayhole Wash for nearly 19 km, descending about 122 m, for a gradient of about 33 m per kilometer

A small segment of the Antelope Knoll Basalt, east-central edge of the quadrangle (Sec. 16, T. 38 N., R. 8 W.), flowed down a narrow drainage and onto what may have been the drainage level of Clayhole Wash. This segment of basalt is about 45 m higher and 2 km west of the present Clayhole Wash drainage. Thus, Clayhole Wash has eroded its valley deeper at an average rate of about 0.6 m per 10,000 years, or 0.06 m per 1,000 years in the last 830,000 years. This figure is similar to the 0.075 m per 1,000 years at the northern end of the Antelope Knoll Basalt flow (Billingsley, 1994).

Other basalt flows and associated igneous deposits that are mapped separately from the Antelope Knoll Basalt, are basalt flows and pyroclastic deposits associated with Maryland Knoll volcano, here named the Maryland Knoll Basalt. The Maryland Knoll Basalt appears to merge with, or share a common boundary with part of the Antelope Knoll Basalt. This common boundary suggests a similar Pleistocene age for both basalts. The Maryland Knoll Basalt was not sampled for age dating.

A basalt flow and associated pyroclastic deposit of Deadman Knoll volcano, and a nearby unnamed cinder cone (southeast edge of quadrangle), are mapped as part of extensive basalt flow and associated cinder cones that are aligned in a northwest strike. Southeast of this quadrangle (Moriah Knoll and Hat Knoll 7.5′ quadrangles), are several cinder cones, called Seven Knolls, that align in a northwest strike. Deadman Knoll appears to be the northern extent of the Seven Knolls volcano alignment, all occupying about the same elevation, and all overlie similar bedrock strata of the Kaibab and Moenkopi Formations. The northwest alignment of the Seven Knolls volcanoes matches the northwest strike of near vertical joints in the underlying bedrock strata.

Antelope Knoll, Maryland Knoll, and Deadman Knoll cinder cones and basalt flows, all occupy similar elevations on the Uinkaret Plateau and have similar compositional characteristics. The basalts in this quadrangle appear to merge or share common boundaries and are thus considered to be a similar Pleistocene age as the Antelope Knoll Basalt. Olivine is a common phenocrysts in all of the basalts. Future K-Ar ages will probably show that most, if not all of the basalts in an around this quadrangle, are Pleistocene in age.

A basalt flow in the southwest corner of the quadrangle came from a cinder cone about 1 km south of this quadrangle called Moriah Knoll (Moriah Knoll quadrangle, Arizona, 1971) and is called the Moriah Knoll Basalt (Billingsley, 1993c; in press, b). A whole-rock K-Ar age of the Moriah Knoll Basalt is 2.3±1.5 Ma (Harold Mehnert, U.S. Geological Survey, Denver, Colo. written commun., 1993). According to Harold Mehnert, the sample was not the best for K-Ar dating purposes because of alteration, as a result, the date has an error range of 1.5 m.y. Thus, the 2.3 Ma age is not considered a reliable age for the Moriah Knoll Basalt. The Moriah Knoll Basalt is likely to be a Pleistocene age because it occupy's the same erosional surface as the Antelope Knoll Basalt, and are only 8 km apart.

A unique feature of the Moriah Knoll Basalt is that it flowed north for about 6.4 km down a small drainage cut into soft gypsum and siltstone of the Harrisburg Member of the Kaibab Formation. The basalt continued down the drainage and over the Hurricane Cliffs onto outcrops of the Harrisburg Member of the Kaibab Formation and alluvial slopes of the Shivwits Plateau below. Prior to the flow, the drainage had deepened by headward erosion into the Hurricane Cliffs fault scarp for a distance of only a few hundred meters. The Moriah Knoll Basalt still clings to steep canyon walls of the Fossil Mountain Member of the Kaibab where the flow had descended to the down-dropped, east-dipping block of Kaibab strata on the west side of the first segment of the Hurricane Fault (southwest corner of quadrangle). Displacement along this first segment of the Hurricane Fault was about 110 m before the basalt flow. Offset of the Moriah Knoll Basalt along this first segment is about 73 m for a total offset of about 183 m along this segment of the Hurricane Fault. Strata of the Kaibab on the west side of the Hurricane Fault dip as much as 24° east towards the fault scarp.

After crossing the first segment of the Hurricane Fault, the Moriah Basalt divided into two flows: one flow traveled a short distance south along the base of the first segment of the Hurricane Fault scarp, and a second, larger flow continued northwest and steeply down and across the second and third segments of the Hurricane Fault. The basalt flow overlies thin alluvial deposits and beveled east-dipping strata of the Harrisburg and Fossil Mountain Members of the Kaibab Formation in a steep drainage onto the Shivwits Plateau.

The Moriah Knoll Basalt was offset down to the west about 26 m along a second segment of the Hurricane Fault, and about 30 m along a third (western-most) segment of the fault. Offset of underlying strata in the second and third segments of the Hurricane Fault are unknown, but add up to several hundred meters. Total estimated offset of the Moriah Knoll Basalt on all segments of the Hurricane Fault is about 130 m in the last 2.3 m.y. Minimum vertical offset along the various segments of the Hurricane Fault, before the Moriah Knoll Basalt, is estimated to be as much as 380 m. Thus, total offset along all segments of the Hurricane Fault is estimated to be as much as 510 m in this area.

If the Moriah Knoll Basalt is close in age to the Antelope Knoll Basalt as suspected, then most of the offset along the Hurricane Fault occurred before 830,000 years ago, and about 130 m of offset has occurred within the last 830,000 years. Just north of the Arizona-Utah State line near the town of Hurricane, Utah, a basalt flow 0.293±0.087 Ma is vertically displaced about 87 m by the Hurricane Fault (Hamblin and others, 1981), indicating continued Pleistocene activity along the Hurricane Fault.

The earliest offset along the Hurricane Fault is less than 3.6±0.18 Ma because the Bundyville basalt (dated at 3.6±0.18 Ma), about 36 km south of this quadrangle (Koons, 1945; Hamblin and Best, 1970; Hamblin, 1970; Reynolds and others, 1986), is offset as much as the underlying strata, indicating that most, if not all displacement along that section of the Hurricane Fault, occurred within the last 3.6 Ma (Billingsley, in press, b).

The Quaternary age assigned to the alluvial deposits in this quadrangle is based mainly on field relationships of these deposits to Pleistocene basalts in this quadrangle and nearby areas (Billingsley, 1993a, 1994, in press, a and b). Many of the alluvial deposits contain basalt clasts that are downslope from basaltic outcrops of Pleistocene age. Therefore, all alluvial and surficial deposits of this quadrangle are Pleistocene age and younger. The oldest alluvial unit of this map area, terrace-gravel (Qg_3), contains basalt clasts derived from the Antelope Knoll and Seven Knolls Basalts. Details of the stratigraphic sequence of alluvial deposits are given in the description of map units.

STRUCTURAL GEOLOGY

The Hurricane Fault and Monocline have a northerly strike in the southwest corner of this quadrangle. Both structures turn to a southwesterly direction southwest of this quadrangle (Billingsley, 1993c; in press, b) and a northwesterly direction northwest of the this quadrangle (Billingsley, 1993b, in press, a). The axis of the Hurricane Monocline is located approximately just west of and parallel to the Hurricane Fault because the greatest bend of strata is found on the downthrown block. Strata of the Kaibab Formation dip as much as 24° west of the main segment of the fault, and generally less than 5° east on the east side of the fault. The greater dip of strata on the downthrown block is accentuated by reverse fault drag (Hamblin, 1970).

The axis of the Hurricane Monocline is approximately located on the quadrangle based on deep exposures in the Grand Canyon about 86 km south of this quadrangle (fig. 3; Huntoon, 1989; Huntoon and others, 1981; Wenrich and others, 1986). Changes in strike of exposed monoclines of the eastern Grand Canyon area are linked to intersecting basement faults that have been reactivated during the Late Cenozoic (Huntoon, 1989).

The graben structures shown on the downthrown side of the Hurricane Monocline in figure 3 are likely buried under thick alluvial deposits just west of the quadrangle area. Tertiary compressional stresses resulted in the development of the Hurricane Monocline along favorably oriented, pre-existing faults in the Precambrian basement in Laramide time (Huntoon, 1989; Elston and Young, 1991).

The Hurricane Fault scarp forms the Hurricane Cliffs, a prominent landmark in northwestern Arizona. The Hurricane Fault line is mostly covered by talus and alluvial deposits, but appears to be a normal vertical fault with a fault plane dipping west as suggested by Hamblin and Best (1970). The Hurricane Fault cuts alluvial deposits vertically as much as 25 m or more along the main segment. Even though the fault line is visible in alluvial

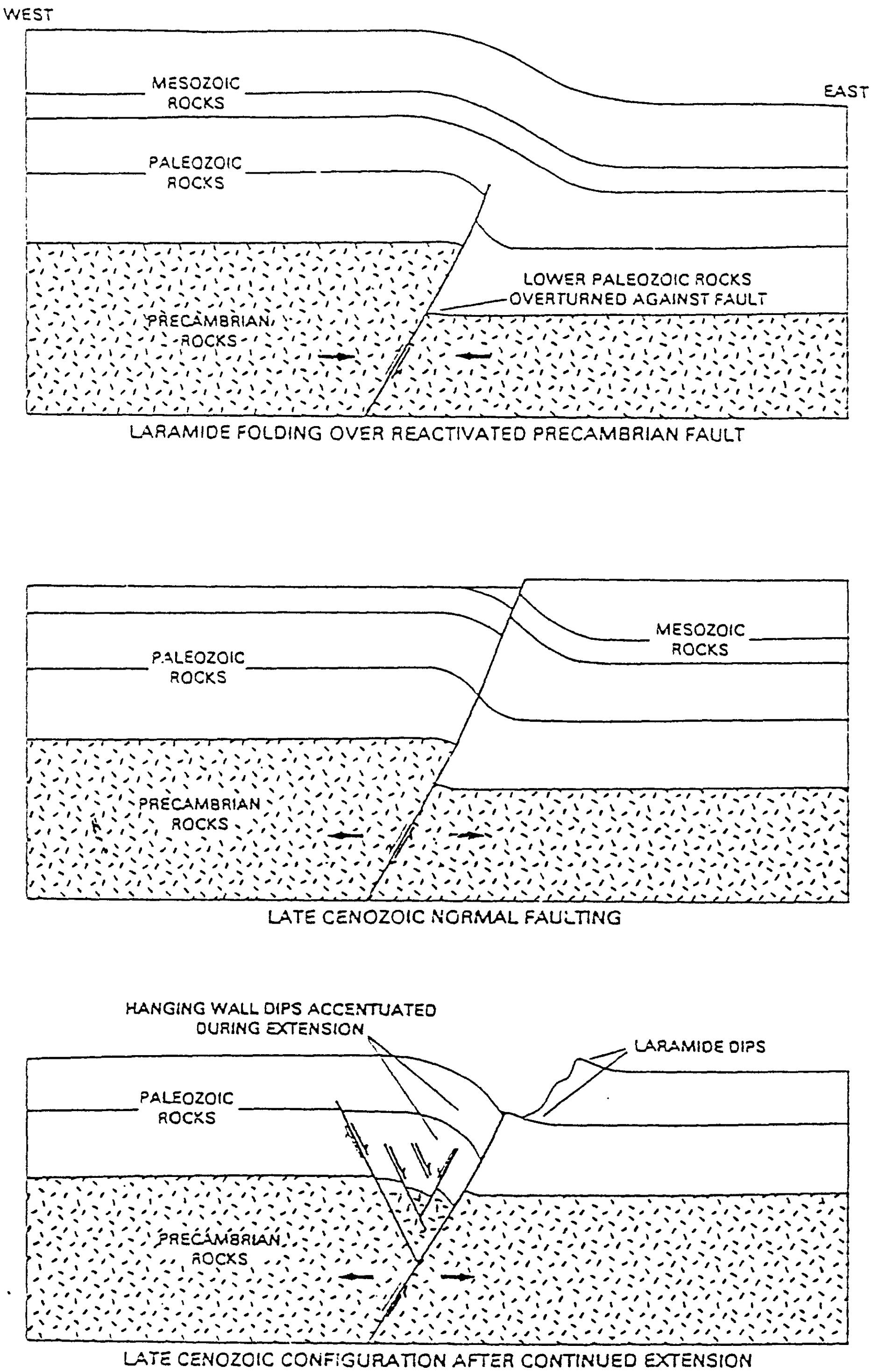

Figure 3. Stages in the development of a typical north-trending monocline-fault zone, Grand Canyon region, Arizona (Huntoon, 1989, p. 80).

deposits, the fault is dotted on the map because of extensive talus and younger alluvial cover, except along one small segment where the alluvium appears recently faulted.

Small folds present in the quadrangle are probably related, in part, to early Laramide compressional stresses (Huntoon, 1989), and to later extensional stresses allowing strata to bend or fold into graben structures. Locally, warped and bent strata too small to show at map scale are the result of solution of gypsum in the Harrisburg Member of the Kaibab Formation. These deformed strata are commonly associated with solution of gypsum along drainages.

Circular collapse structures with a surface expression as a bowl-shaped area having 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 are marked by a dot and the letter C on the map. However, they cannot be distinguished with certainty from shallow collapse structures caused by the removal of gypsum by solution. Moreover, some deep-seated breccia pipes are known to be overlain by gypsum collapse features (Wenrich and others, 1986). The deep-seated breccia pipes potentially contain economic deposits of copper and uranium minerals (Wenrich, 1985).

Shallow sinkholes and karst caves are associated with the solution of gypsum in the Harrisburg Member of the Kaibab Formation. The sinkholes are Holocene and probable Pleistocene age because of their young appearance. Hundreds of sinkhole depressions that are breached by drainages on the Uinkaret Plateau surface are not marked on this map. Only sinkholes that form an enclosed basin or depression are shown by a triangle symbol. Several minor drainages originate at sinkhole depressions in the quadrangle.

DESCRIPTION OF MAP UNITS

Surficial deposits

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)**--Unconsolidated and poorly sorted, interlensing silt, sand, and pebble to boulder gravel. Active wash or large arroyo. Intertongues, inset to, or locally overlies valley-fill (Qv), alluvial-fan (Qa_1 and Qa_2), and terrace-gravel (Qg_1, Qg_2, and Qg_3) deposits. Stream channels subject to high-energy flows and flash floods and support little or no vegetation. Contacts approximate. Estimated thickness 1 to 3 m

Qg_1 **Young terrace-gravel deposit (Holocene)**--Unconsolidated, light-brown to pale-red siltstone, sandstone, and lenses of gravel containing pebbles and boulders of well-rounded limestone and sandstone and angular and subrounded chert derived from the Kaibab and Toroweap Formations. Includes lenses of gray silt and sand and locally well-rounded to subangular basalt clasts. Includes reworked materials from alluvial-fans (Qa_1 and Qa_2), terrace-gravel (Qg_2 and Qg_3), talus (Qt), and landslide (Ql) deposits. Locally cut by arroyos. Forms alluvial benches about 1 to 3 m above local stream beds. Averages about 1 to 3 m thick

Qa_1 **Young alluvial fan deposit (Holocene)**--Unconsolidated gray silt and sand. Contains 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. Locally includes well-rounded to sub-angular basalt clasts. Partly cemented by gypsum and calcite. Overlaps, intertongues, or partly includes reworked materials from stream-channel (Qs), valley-fill (Qv), terrace-gravel (Qg_1, Qg_2, and Qg_3), and older alluvial-fan (Qa_2) deposits. Alluvial fans subject to erosion by sheet wash and flash floods. Supports sparse growths of sagebrush, cactus, and grass. As much as 4 m or more thick

Qv **Valley-fill deposit (Holocene and Pleistocene)**--Partly consolidated gray and light-brown silt, sand, and lenses of pebble to small-boulder gravel. Intertongues or overlaps talus (Qt), terrace-gravel (Qg_1, Qg_2 and Qg_3) deposits, and alluvial fan (Qa_1 and Qa_2) deposits. Subject to sheetwash flooding and temporary ponding; cut by arroyos as much as 2 m deep in larger valleys. Supports sparse growths of sagebrush, grass, and cactus. As much as 5 m thick

Qt **Talus deposit (Holocene and Pleistocene)**--Unsorted debris consisting of breccia composed of small and large angular blocks of local basalt bedrock as much as 2 m in diameter. Includes silt, sand, and gravel; partly cemented by calcite and gypsum. Intertongues with alluvial-fan (Qa_1 and Qa_2), valley-fill (Qv), and terrace-gravel (Qg_1 and Qg_2) deposits. Supports sparse growths of sagebrush, cactus, and grass. Only relatively extensive deposits shown. As much as 3 m thick

Ql **Landslide deposit (Holocene and Pleistocene)**--Unconsolidated and unsorted masses of rock debris, including detached blocks of bedrock strata that have rotated backward and slid downslope as loose, incoherent masses of broken rock and deformed strata, often surrounded by talus. Includes blocks of strata of the Fossil Mountain Member of Kaibab Formation along the upper ledges of the Hurricane Cliffs. Supports sparse growth of sagebrush, cactus, grass, juniper and pinyon pine trees. Unstable when wet. Only large masses are shown. As much as 35 to 45 m thick

Qg_2 **Intermediate terrace-gravel deposit (Holocene and Pleistocene)**--Similar to young terrace-gravel deposits (Qg_1) but partly consolidated. Contains well-rounded basalt clasts as much as 12 cm or more in diameter. Forms benches as abandoned stream channels about 2 to 4 m above local stream beds and about 1 to 3 m above young-terrace gravel (Qg_1) deposits. Intertongues with and locally overlain by talus (Qt) and young alluvial-fan (Qa_1) deposits. Locally inset against higher terrace-gravel (Qg_3) deposits. Approximately 2 to 4 m thick

Qa_2 **Intermediate alluvial fan deposit (Holocene and Pleistocene)**--Similar to young alluvial-fan (Qa_1) deposits and partly cemented by calcite and gypsum. Locally overlapped by young alluvial-fan (Qa_1), young terrace-gravel (Qg_1), valley-fill (Qv), and talus (Qt) deposits. Locally includes abundant subrounded to subangular basalt clasts. Supports sparse growths of sagebrush, cactus, and grass. Ranges from 2 to 4 m thick

Qg_3 **Older terrace-gravel deposit (Pleistocene)**--Similar to young and intermediate terrace-gravel (Qg_1 and Qg_2) deposits, but 2 to 6 m higher than intermediate (Qg_2) deposits and about 4 to 8 m above local drainages. Composed of well-rounded limestone, sandstone, chert, and basalt clasts in sandy gravely matrix. Basalt clasts mainly derived from local basalt flows, but contain clasts from areas father south and southeast of this quadrangle. Partly consolidated by calcite, clay, and gypsum cement. As much as 6 m thick

IGNEOUS ROCKS

Antelope Knoll Basalt (Pleistocene)--Named for Antelope Knoll volcano, type area for Antelope Knoll Basalt. Antelope Knoll is located in central part of quadrangle, Secs. 13, 18, 19, and 24, T. 38 N., Rs. 8 and 9 W., northern Mohave County, Arizona. Includes basalt flows and associated pyroclastic deposits. Divided into:

Qai **Antelope Knoll intrusive vent area (Pleistocene)**--Includes two vent areas for basaltic flows north and east from Antelope Knoll. Vent areas are approximately marked on map owing to thick cover of reddish-black cinder and scoria (Qac) deposits

Qac **Antelope Knoll cinder and pyroclastic deposit (Pleistocene)**--Reddish-black and brown fragments of angular basaltic cinder and scoria deposits. Includes dark-gray augite(?) and olivine(?) glass fragments; partly consolidated as welded scoria. Forms cinder cone as much as 150 m thick

Qab **Antelope Knoll Basalt flow(s) (Pleistocene)**--Dark-gray, finely crystalline, aphanitic groundmass. Surfaces of flows are partly covered by cinder and pyroclastic (Qac) deposits within 1 to 2 km of Antelope Knoll. K-Ar whole rock age is 0.83±0.3 Ma (Harold Mehnert, U.S. Geological Survey Isotope Laboratories, Denver, Colorado, written commun., 1993). Overlies alluvium, Harrisburg Member of Kaibab Formation, and lower red member and Timpoweap Member of Moenkopi Formation. Ranges from 2 to 15 m thick

Seven Knolls Basalt (Pleistocene)--Named for Seven Knolls volcanoes, type area for Seven Knolls Basalt. Seven Knolls volcanoes are in Secs. 10, 15, 23 and 26, T. 37 N., R. 8 W., northern Mohave County, Arizona (U.S. Geological Survey Moriah Knoll and Hat Knoll 7.5' quadrangles, 1971). Includes basalt flows and associated pyroclastic deposits of Deadman Knoll and unnamed knoll, southeast corner of quadrangle. Divided into:

Qsi **Seven Knolls vent area (Pleistocene)**--Vent areas are covered by reddish-brown to black cinder and scoria deposits that form cinder cones; source vent areas for local basalt flows of Seven Knolls Basalt. Basalt flowed in a northerly direction from vent areas

Qsc **Seven Knolls cinder and pyroclastic deposit (Pleistocene)**--Reddish-brown and black fragments of angular basaltic scoria and cinder deposits. Includes Deadman Knoll and unnamed cinder cone in southeast corner of quadrangle; unconsolidated. Associated with Seven Knolls Basalt flows. Forms cinder cones 30 to 60 m thick

Qsb **Seven Knolls Basalt flow(s) (Pleistocene)**--Dark-gray, finely crystalline groundmass composed of plagioclase, olivine, and augite; contains small phenocrysts of green olivine. Includes one or more flows that merge into one thick flow from Deadman Knoll and unnamed knoll which merges with basalt flows from Seven Knolls volcanoes 1 to 6 km southeast of this quadrangle. Flow surfaces partly covered by cinder and pyroclastic (Qsc) deposits. Overlies middle and lower part of Harrisburg Member of Kaibab Formation, and lower red member and Virgin Limestone Member of Moenkopi Formation. Ranges from 2 to 15 m thick

Maryland Knoll Basalt (Pleistocene)--Named for Maryland Knoll volcano, type area for Maryland Knoll Basalt. Maryland Knoll is in the south central part of quadrangle, Sec. 31, T. 38 N., R. 8 W., northern Mohave County, Arizona. Includes basalt flows and pyroclastic deposits. Divided into:

Qmi **Maryland Knoll intrusive vent area (Pleistocene)**--Includes two vent areas approximately marked on map for source of Maryland Knoll Basalt and pyroclastic (Qmc) deposits

Qmc **Maryland Knoll cinder and pyroclastic deposit (Pleistocene)**--Red-brown and black fragments of angular basaltic scoria, glass, and cinder deposit; unconsolidated. Forms two cinder cones as much as 90 m thick

Qmb **Maryland Knoll Basalt (Pleistocene)**--Dark-gray, finely crystalline, aphanitic groundmass composed of plagioclase, olivine, and augite. Includes two flows that merge into one flow. Basalt flow shares common boundary or abuts against Antelope Knoll Basalt; partly overlain by Seven Knolls Basalt. Surface is partly covered by cinder and pyroclastic (Qmc) deposits. Overlies Harrisburg Member of the Kaibab Formation. Flow extends for about 3 km east from Maryland Knoll. Ranges from 2 to 20 m thick

QTm **Moriah Knoll Basalt (Pleistocene-Pliocene?)**--Named for Moriah Knoll volcano in Secs. 7, 12, 18, and 13, T. 37 N., Rs. 8 and 9 W., (Moriah Knoll 7.5′ quadrangle, 1971), about 1 km south of quadrangle edge, northern Mohave County, Arizona (Billingsley, 1993c; in press, b). Moriah Knoll is type area for Moriah Knoll Basalt. Black, aphanitic, vesicular basalt. Includes minor olivine phenocrysts and vesicles commonly filled with calcite. K-Ar whole rock age is 2.3±1.5 Ma (Harold Mehnert, U.S. Geological Survey Isotope Laboratories, Denver, Colorado, written commun., 1993). One flow, about 3 m thick

SEDIMENTARY ROCKS

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

Ҧmv **Virgin Limestone Member**--Consists of one light-gray, ledge-forming limestone bed containing star-shaped crinoid plates and poorly preserved Composita brachiopods in top part. Upper part of Virgin Limestone has been eroded away. Overlain by Seven Knolls Basalt. Basal unconformity with as much as 1 m of relief truncates underlying red siltstone of lower red member. As much as 4 m thick

TRml **Lower red member**--Interbedded red, fine-grained, thin-bedded, gypsiferous sandy siltstone, gray, white, and pale-yellow laminated gypsum and minor sandstone. Lower beds contain reworked gypsum and siltstone of Harrisburg Member of Kaibab Formation. Interbedded or gradational contact with sandstone or conglomerate of Timpoweap Member arbitrarily placed at lowermost red siltstone bed. Unconformable contact with Kaibab Formation. Forms slope. Locally thickens and fills Triassic paleovalleys eroded into underlying Kaibab Formation. Forms slope. Ranges from 3 to 25 m thick

TRmt **Timpoweap Member**--Light gray conglomerate and sandstone. Conglomerate composed of subangular to rounded pebbles and cobbles of gray and dark gray limestone, white and brown chert, and rounded quartzite in matrix of gray to brown, coarse-grained, low-angle cross-bedded calcareous sandstone, gravel, and minor siltstone derived from Kaibab Formation. Source for dark-gray limestone and quartzite may be Paleozoic rocks west of map area. Forms slope. Fills Triassic paleovalleys eroded into Kaibab Formation estimated as much as 70 m deep and about 800 m wide. Rocks of Timpoweap occupy one major paleovalley considered an eastern extension of Mustang valley (fig. 2; Billingsley, 1994; in press a) and two minor paleovalley's in southwest quarter of quadrangle. Imbrication of pebbles in conglomerate show a southeastward paleoflow of depositing streams. As much as 6 to 43 m thick

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

Pkh **Harrisburg Member**--Includes an upper, middle and lower part. Upper part consists mainly of slope-forming, red and gray, interbedded gypsiferous siltstone, sandstone, gypsum, and thin-bedded gray limestone. Includes an upper resistant, pale-yellow or light-gray, fossiliferous (mollusks and algae), sandy limestone bed averaging about 1 m thick that weathers black or brown. Most of upper part is eroded from this quadrangle except in northeast quarter. Forms gradational contact with middle part. Middle part consists mainly of two cliff-forming marker limestone beds. Top marker bed consists of gray, thin-bedded, cherty limestone; weathers dark brown or black and often forms bedrock surface of exposed Harrisburg Member. Bottom marker bed consists of light-gray, thin-bedded, sandy limestone; both beds are only a few meters thick. Erosional unconformably separates middle part from lower part. Lower part consists of slope-forming, light-gray, fine- to medium-grained, gypsiferous siltstone, sandstone, medium-grained, thin-bedded gray limestone, and gray massive bedded gypsum. Solution of gypsum in lower part has locally distorted limestone beds of middle part causing them to slump or bend into local drainages. Gradational and arbitrary contact between siltstone slope of Harrisburg Member and limestone cliff of Fossil Mountain Member. Harrisburg, in general, forms slope with limestone cliff in middle. As much as 92 m thick

Pkf **Fossil Mountain Member**--Light-gray, fine- to medium-grained, thin-bedded, fossiliferous, sandy, cherty limestone. Chert weathers black. Contact with Woods Ranch Member of Toroweap Formation marked by solution and channel erosion with relief as much as 3 m; contact locally obscured by talus and minor landslides. Forms cliff. About 80 m thick

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 gypsiferous siltstone and pale-red silty sandstone interbedded with medium-bedded white laminated gypsum. Beds are locally distorted due to gypsum solution. Gradational and arbitrary contact between slope-forming Woods Ranch Member and cliff-forming Brady Canyon Member of Toroweap. Variable thickness from 55 to 80 m due to solution of gypsum

Ptb **Brady Canyon Member**--Gray, fetid, medium-bedded, fine- to coarse-grained, fossiliferous limestone; weathers dark dray. Includes thin-bedded dolomite in upper and lower part. Limestone beds average about 0.5 m thick. Includes chert lenses and nodules but these are 50% less than in Fossil Mountain Member of Kaibab. Gradational and arbitrary contact between cliff-forming limestone of Brady Canyon Member and slope-forming siltstone and gypsum of Seligman Member of Toroweap; commonly covered because of minor slump or talus debris. Forms cliff. Approximately 70 m thick

Pts **Seligman Member**--Consists of an upper gray, interbedded, thin-bedded dolomite and gypsiferous sandstone; a middle gray to red, thin-bedded, interbedded siltstone, sandstone, and gray gypsum; and a lower brown, purple, and yellow, fine- to medium-grained, thin-bedded, low- to high-angle cross-bedded and planar-bedded sandstone, mostly covered. Contact with underlying Hermit Formation is covered by talus and alluvial deposits. Forms slope with ledges. About 45 m exposed

Contact--Dashed where approximately located

8+ **Fault**--Dashed where inferred or approximately located; dotted where concealed; bar and ball on downthrown side. Number is estimated displacement in meters. Number with plus denotes minimum estimated displacement

Landslide detachment--Headward scarp of landslide, hachures point in direction of slide

Folds--Showing trace of axial plane and direction of plunge; dashed where approximately located; dotted where concealed

Anticline

Syncline

Monocline

Dome

Doubly plunging anticline

Strike and dip of beds--Showing dip where known

Inclined

Approximate--Estimated from aerial photographs

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

Strike of vertical and near-vertical joints--Interpreted from aerial photographs

Collapse structure--Circular collapses, strata dipping inward toward central point. May reflect collapse of deep-seated breccia pipe that originated in Redwall Limestone

Sinkholes--Steep-walled or enclosed depression or cave

Flow direction of basalt

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CORRELATION OF MAP UNITS

SURFICIAL DEPOSITS AND IGNEOUS ROCKS