U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

Geologic map of The Grandstand quadrangle, northern Mohave County, Arizona

by
George H. Billingsley[1]

Open-File Report 93-588

1993

---

[1]U.S. Geological Survey, Flagstaff, Arizona

INTRODUCTION

The Grandstand 7.5′ quadrangle (96 sq km) is located in northern Mohave County, Arizona, about 35 km southwest of Colorado City, Arizona, the nearest settlement (fig. 1). Altitudes range from about 1,280 m in a drainage north of Toquer Tank (north central edge of quadrangle) to 1,680 m, at a benchmark on the Hurricane Cliffs (northeast corner of quadrangle). Access to the quadrangle is by two improved dirt roads, locally referred to as the Sunshine Trail, from St George, Utah and the Navajo Trail from Colorado City, Arizona (fig. 1). Several unimproved dirt roads lead from the Sunshine and Navajo Trails to various locations within the quadrangle area.

The area is managed entirely by the U.S. Bureau of Land Management including about one and a half sections belonging to the state of Arizona. At lower elevations, the area supports sparse growths of sagebrush, cactus, grass, and various desert shrubs. At higher elevations, moderate growths of sagebrush thrive in alluvial valleys including a few scattered pinyon pine and juniper trees.

PREVIOUS WORK

The area was mapped photogeologically and included on two Arizona state geologic maps, one by Wilson and others (1969) and the other by Reynolds (1988). A geologic map of the Gyp Pocket 7.5′ quadrangle (Billingsley, 1992a) is available bordering the north edge of this quadrangle, and a geologic map of the Sullivan Draw and vicinity, Arizona is located about 11 km west of this quadrangle (Billingsley, 1994).

MAPPING METHODS

A preliminary geologic map was made from aerial photographs, scale 1:24,000. In particular, many of the Quaternary alluvial units having similar lithologies were mapped using photogeologic methods based on regional geomorphic characteristics. Detailed field investigations were then conducted to insure accuracy and consistency of all map units for descriptive purposes.

GEOLOGIC SETTING

The quadrangle area lies within the Shivwits and Uinkaret Plateaus, subplateaus of the southwestern part of the Colorado Plateaus physiographic province. The physiographic boundary between the higher elevation Uinkaret Plateau and the lower elevation Shivwits Plateau is demarcated by the upper part of the Hurricane Fault scarp, the Hurricane Cliffs (fig. 2). The Shivwits and Uinkaret Plateaus in this quadrangle are characterized by relatively flat lying bedrock strata having an average regional dip of about 1° northeast.

The Hurricane Fault is the major structural feature of the quadrangle that occurs as two subparallel segments, both having a northwest strike with both displacing strata down on the southwest side. The resulting fault scarp is called the Hurricane Cliffs, a physiographic feature exposing more than 275 m of Permian strata. Overall displacement among various segments of the Hurricane Fault are estimated to be at least 460 m.

About 10 km southwest of the Hurricane Fault lies the Sunshine Fault that offsets strata down to the east about 110 m (fig 2). The 10 km-wide region between the Hurricane and Sunshine Faults includes several minor horsts and grabens that closely parallel the Sunshine and Hurricane Faults.

Cenozoic deposits are widely distributed in the quadrangle area consisting of igneous, surficial alluvial, and landslide deposits of Quaternary age. The surficial deposits are identified by photogeologic

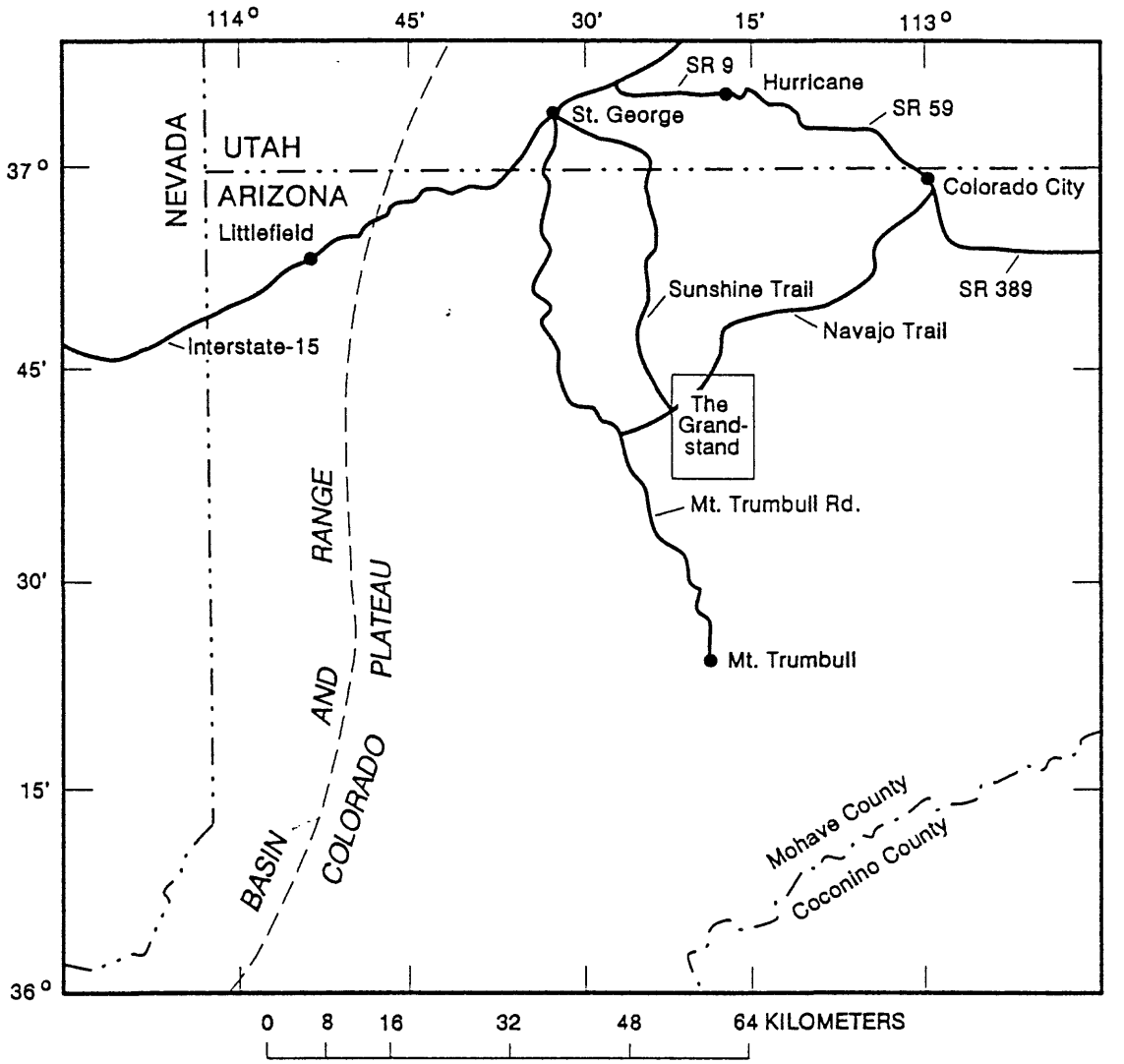


Figure 1. Index map of northern Mohave County, northwestern Arizona, showing The Grandstand 7.5′ quadrangle mapped in this report. SR = State route.

techniques based on their geomorphic relations to structural features and erosional surfaces. The distribution of Quaternary alluvial deposits are an important factor in future environmental, land, and range management planning in this area by federal, state, and private organizations. The surficial units are useful in the study of local geomorphology and have intertonguing and gradational contacts.

STRATIGRAPHY

The sedimentary bedrock strata of this quadrangle include, in ascending order, the Toroweap and Kaibab Formations (Lower Permian), and the Moenkopi Formation (Middle? and Lower Triassic). About 7/8 of the surface bedrock of the map area is composed of gray cherty limestone and gray to white siltstone and gypsum of the Kaibab Formation. The other 1/8 of the surface bedrock is gray siltstone, sandstone, gypsum, and limestone of the Toroweap Formation, gray conglomerate and limestone of the Timpoweap Member of the Moenkopi Formation, and red siltstone of the lower red member of the Moenkopi Formation. Outcrops of the Moenkopi Formation are mainly restricted to paleovalleys in the north and southwest part of the quadrangle (fig. 2). The Timpoweap Member and the lower red member of the Moenkopi Formation is suspected beneath extensive alluvial deposits on the downthrown side of the Sunshine Fault, but are not exposed.

The basalt at the east-central edge of the quadrangle came from a pyroclastic volcano named Moriah Knoll about 3 km southeast of this outcrop (Antelope Knoll 7.5′ quadrangle). The basalt is herein referred to as the Moriah Knoll Basalt and is considered to be Pleistocene in age because of its relationship to other Pleistocene basalts near Clayhole Wash about 6 km east of this quadrangle (Harold Mehnert, U.S. Geological Survey, Denver Colorado, written commun., 1993). The Moriah Knoll Basalt flowed down a drainage from Moriah Knoll and over the Hurricane Cliffs fault scarp flowing less then a half kilometer on bedrock of the Kaibab Formation. The Moriah Knoll Basalt was later faulted just east of this outcrop by various segments of the Hurricane Fault probably in late Pleistocene and Holocene time.

The predominantly Quaternary age assigned to the alluvial deposits in the quadrangle area is based mainly on field relationships to the Quaternary and Pliocene basalts west and north of this quadrangle (Billingsley, 1992a,b,c, 1993, 1994). Many alluvial deposits contain Pliocene and Pleistocene basalt clasts downslope from basaltic outcrops of known Pliocene and Pleistocene age (3.5 Ma to less than 800,000 years). With time for erosion and deposition, it is likely that all alluvial and surficial deposits of this quadrangle are probably Pleistocene age and younger. The oldest alluvial unit in this quadrangle, a terrace-gravel deposit (Qg_3), contains basalt clasts derived from the Diamond and Twin Buttes area about 5.5 km south of this quadrangle. The basalt at Diamond Butte yields a K-Ar age of 4.3±0.6 Ma (Harold Mehnert, U.S. Geological Survey, Denver, Colorado, written commun., 1993). Details of the stratigraphic sequence of alluvial deposits are given in the description of map units.

STRUCTURAL GEOLOGY

The structural features in the quadrangle area show up particularly well on X-Band, side-looking radar imagery 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 (S.A.R. System, 1988).

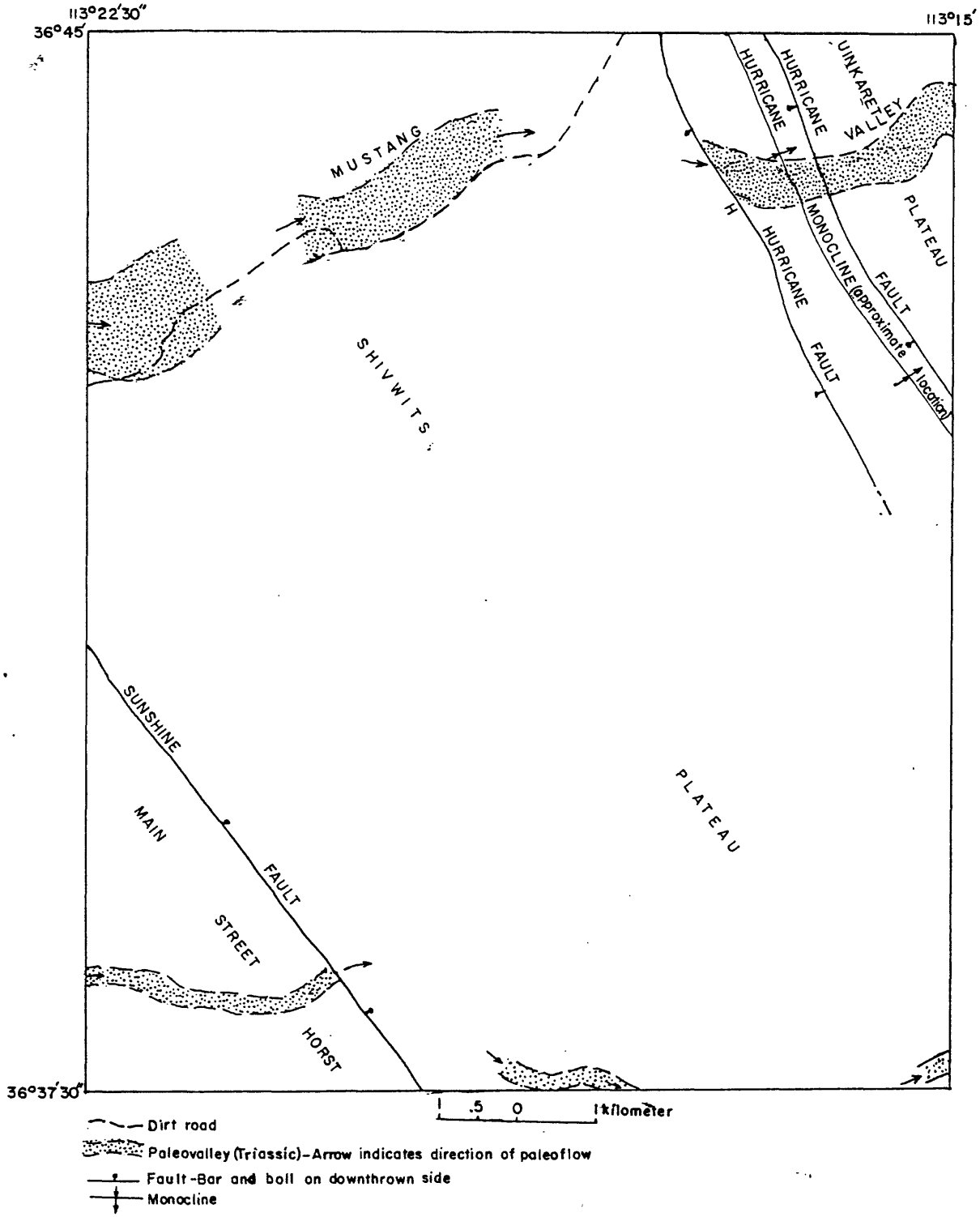


Figure 2. Selected geographic and geologic features of The Grandstand 7.5′ quadrangle, northwestern Arizona.

The Hurricane Monocline and Fault have a northwest strike in the northeast corner of the quadrangle. The axis of the Hurricane Monocline is parallel to the Hurricane Fault on the downthrown side, with strata dipping east from 12 to 33 degrees. The monocline axis is approximately located based on deep exposures in the Grand Canyon about 64 kilometers south of this quadrangle (fig. 3). Strata east of the approximate axis of the Hurricane Monocline has a regional dip of less than 2° east-northeast.

The graben structures shown on the downthrown side of the monocline in figure 3 are likely buried under thick alluvial deposits in this quadrangle. Tertiary compressional stresses resulted in the development of the Hurricane Monocline in Laramide time (Huntoon, 1989). Later, Quaternary tensional stresses reactivated the deep seated fault plane allowing the normal fault to cut all Paleozoic and Mesozoic strata, but reversing the displacement of strata down to the west (Huntoon, 1989). The estimated displacement of strata along the Hurricane Fault segments in this quadrangle is about 700 m down to the west with east dipping strata on both sides of the fault (fig. 3).

The Hurricane Fault and associated faults were probably initiated in late Pliocene time with most of the activity occurring in Pleistocene time based on faulted 3.6 Ma basalts 16 km south of this quadrangle (Reynolds and others, 1986). Equal displacement of the basalt and underlying strata south of this quadrangle indicate that total offset along the Hurricane Fault occurred within the last 3.6 Million years.

The next largest structure is the Sunshine Fault inferred to be Pleistocene age with probable Holocene activity based on the young-looking character of the fault scarp located in the southwest corner of the quadrangle. The Sunshine Fault (Billingsley, 1992b) has a northwest strike and displaces strata down to the northeast about 116 m. West of the Sunshine Fault is an uplifted block named the Main Street Horst (Billingsley, 1992b). The Main Street Horst is bounded on the west by the Main Street Fault (Dutchman Draw AZ 7.5′ quadrangle) and on the east by the Sunshine Fault. Main Street Horst forms a highland averaging about 90 m higher then the surrounding landscape.

Elsewhere, several normal dip-slip faults form a series northwest striking graben-and-horst blocks between the Hurricane and Sunshine Faults. The horst-and-graben structures are typically common on the downthrown side of the Hurricane Fault, and usually parallel the Hurricane Fault strike. Fault scarps in talus and alluvial deposits are common along parts of many small faults but they are not always easily recognized in the field as they are on aerial photos. Because erosion and mass wasting has shed soft and loose debris over unconsolidated alluvial fault scarps, the faults are shown dotted on the map often forming alluvial contacts. A solid fault line is shown where faulting appears most recent in alluvial material. The fault structures in this quadrangle are probably Pleistocene age because Pleistocene basalts and underlying strata are equally offset by faults north of this quadrangle (Billingsley, 1992a,b,c, 1993, 1994).

Small folds present in the south half of the quadrangle are probably related to early Laramide compressional stresses (Huntoon, 1989). Locally, warped and bent strata are too small to show at map scale and are the result of solution of gypsum in the Harrisburg Member of the Kaibab Formation. These bent strata are commonly associated with solution of gypsum along drainages.

A few circular bowl-shaped collapse structures, usually over 100 m in diameter, are found on the surface of the quadrangle area and are mostly due

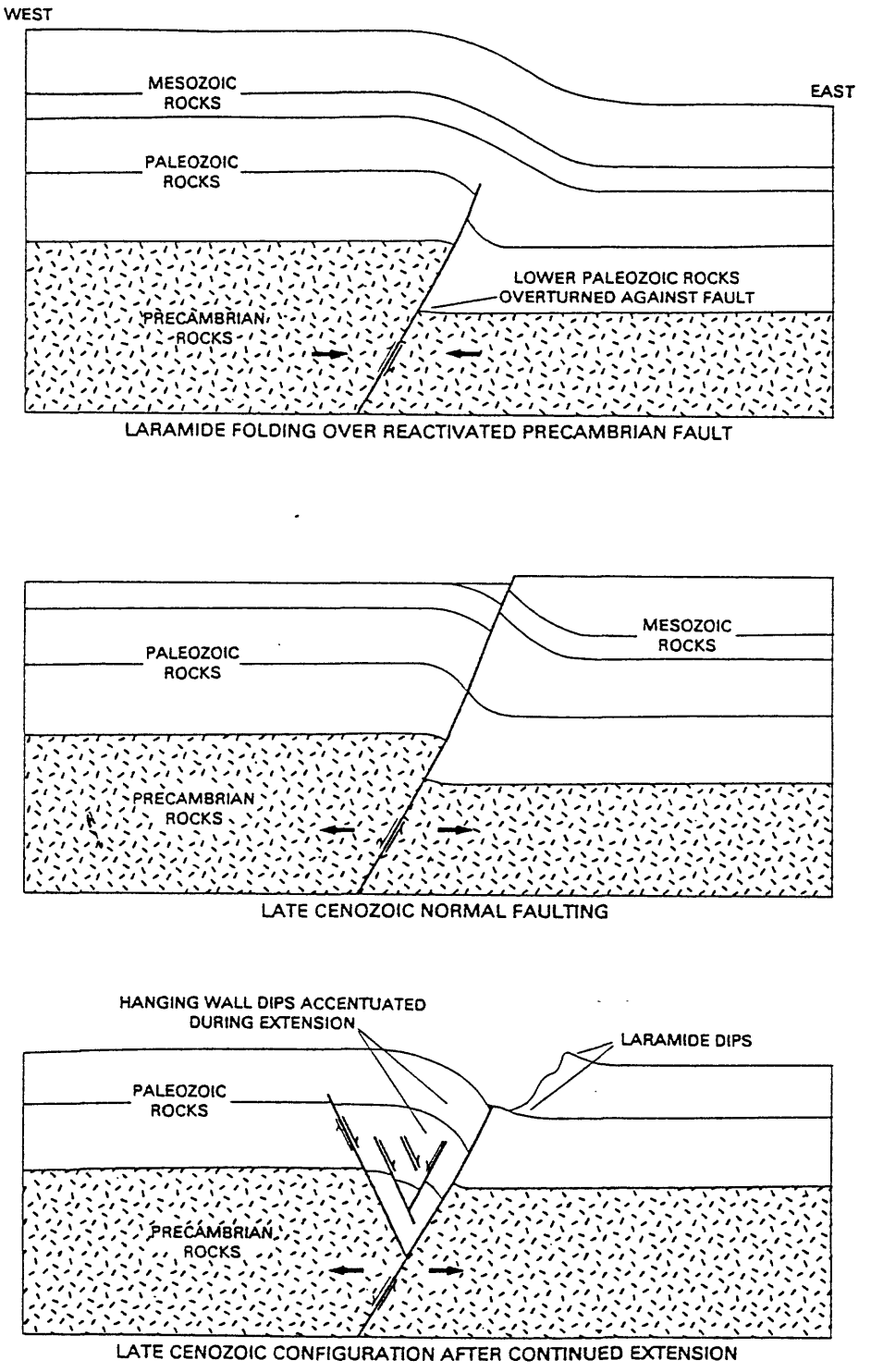


Figure 3. Stages in the development of a typical north-trending monocline-fault zone, Grand Canyon region, Arizona (Huntoon, 1989, p. 80).

to solution of gypsum and gypsifereous siltstone in the Harrisburg Member of the Kaibab Formation. However, some circular bowl-shaped areas that have strongly inward-dipping strata may be collapse-formed breccia pipes that originate in the deeply buried Mississippian Redwall Limestone (Wenrich and Huntoon, 1989; Wenrich and Sutphin, 1989). Such features on this quadrangle usually have inward dipping strata and are marked by a dot and the letter C to denote possible deep-seated breccia pipes. However, they cannot be distinguished with certainty from shallow collapse structures caused by the removal of gypsum in the Kaibab or Toroweap Formations. Moreover, some deep-seated breccia pipes are known to be overlain by gypsum collapse features (Wenrich and others, 1986). The deep-seated collapse breccia pipes potentially contain economic deposits of copper and uranium minerals (Wenrich, 1985).

Small shallow sinkholes and karst caves are associated with the solution of gypsum in the Harrisburg Member of the Kaibab Formation. The sinkholes are relatively young features of Holocene and probable Pleistocene age because of their young appearance. At the west central edge of the quadrangle, one sinkhole appears fairly young about 1.6 km south of the Navajo Trail and has diverted an entire drainage into the sink. The hole is about 12 m in diameter and of unknown depth. 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 sinkhole depressions in the Harrisburg Member of the Kaibab Formation.

DESCRIPTION OF MAP UNITS

Surficial deposits

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

Qs **Stream-channel alluvium (Holocene)**--Active wash or large arroyo. Contains unconsolidated and poorly sorted, interlensing silt, sand, and pebble gravel. Intertongues with or inset against alluvial-fan (Qa_1 and Qa_2), terrace-gravel (Qg_1), and valley-fill (Qv), deposits. Stream channels subject to high-energy flows and flash floods and support little or no vegetation. Contacts approximate. Estimated thickness 1 m

Qf **Flood-plain deposits (Holocene)**--Flat-valley area. Contains unconsolidated light-gray or brown silt, sand, and lenses of pebble to cobble gravel. Deposits intertongue, merge with, inset against, or locally overlies valley-fill (Qv), alluvial-fan (Qa_1 and Qa_2), and young to older-terrace gravel (Qg_1, Qg_2 and Qg_3) deposits. Forms wide flat valley floors as opposed to narrow concave valley profiles of valley-fill (Qv) deposits. Deposits are sparsely vegetated by grass. Locally cut by arroyos. Floodplain subject to flooding and local temporary ponding. Thickness about 20 m or more

Qg_1 **Young terrace-gravel deposits (Holocene)**--Unconsolidated, light-brown, pebble to boulder gravel composed about equally of well-rounded limestone and sandstone and angular and subrounded chert derived locally from the Kaibab and Toroweap Formations. Includes lenses of silt and sand and locally well-rounded to rounded basalt clasts from Diamond and Twin Buttes area 5 km south of quadrangle reworked from low and older terrace-gravels (Qg_2 and Qg_3) deposits. Includes reworked materials from alluvial-fans (Qa_1, and Qa_2), and talus (Qt) deposits. Cut by arroyos as much as 3 m deep. Forms alluvial benches about 1 to 3 m above local stream beds. Averages about 1 to 4 m thick

Qa_1 **Young alluvial-fan deposits (Holocene)**--Unconsolidated gray silt and sand. Includes lenses of coarse gravel composed of subangular to rounded pebbles and cobbles of limestone, chert, and sandstone locally derived from the Kaibab and Toroweap Formations. Partly cemented by gypsum and calcite. Overlaps or intertongues with stream-channel alluvium (Qs), valley-fill (Qv), and young terrace-gravel (Qg_1) deposits. Overlaps and partly includes reworked materials from young, low, and older terrace-gravels (Qg_1, Qg_2, and Qg_3) and older alluvial-fan (Qa_2) deposits near their downslope ends. Alluvial-fans subject to erosion by sheet wash and flash floods. Supports sparse growths of sagebrush, greasewood shrubs, cactus, and grass. As much as 6 m thick

Qv **Valley-fill deposits (Holocene and Pleistocene?)**--Partly consolidated silt, sand, and interbedded lenses of pebble to small-boulder gravel. Intertongues or overlaps talus (Qt), floodplain (Qf), young terrace-gravel (Qg_1), and alluvial-fan (Qa_1 and Qa_2) deposits. Subject to sheetwash flooding and temporary ponding; cut by arroyos in larger valleys. Supports moderate growths of sagebrush, grass, and cactus. As much as 9 m thick

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. Intertongues with alluvial-fan (Qa_1, and Qa_2), and valley-fill (Qv), deposits. Supports sparse to moderate growths of sagebrush, cactus, and grass. Only relatively extensive deposits shown. As much as 9 m thick

Ql **Landslide deposits (Holocene? and Pleistocene)**--Unconsolidated and unsorted rock debris, including blocks of detached segments of bedrock strata that have rotated backward and slid downslope. Unstable when wet. Only large masses are shown. Thickness probably as much as 20 m

Qg_2 **Low terrace-gravel deposits (Holocene? and Pleistocene?)**--Similar to young terrace-gravel deposits (Qg_1) but partly consolidated. Contains well-rounded basalt clasts as much as 5 cm in diameter. Forms benches as abandoned stream channels about 2 to 6 m above local stream beds and about 1 to 2 m above young terrace-gravel (Qg_1) and floodplain (Qf) deposits. Approximately 2 to 7 m thick

Qa_2 **Older alluvial-fan deposits (Holocene? and Pleistocene)**--Similar to young alluvial-fan (Qa_1) deposits and partly cemented by calcite and gypsum. Locally overlapped by or merges into floodplain (Qf), valley-fill (Qv), young alluvial-fan (Qa_1), and terrace-gravel (Qg_1 and Qg_2) deposits. Intertongues with or inset against talus (Qt) deposits. Supports moderate growth of sagebrush, cactus, and some grass. Ranges from 1 to 10 m thick

Qg_3 **Older terrace-gravel deposits (Pleistocene)**--Similar to young and low terrace-gravel (Qg_1 and Qg_2) deposits but 2 to 4 m higher than Qg_2 and about 4 to 8 m above local drainages. Composed of well-rounded limestone, sandstone, chert, and basalt clasts in sandy gravely matrix. Locally includes abundant, well-rounded clasts of basalt derived from Diamond and Twin Buttes about 5 km south of this quadrangle. Partly consolidated by calcite and gypsum cement. As much as 6 m thick

Igneous rocks

Qb **Moriah Knoll Basalt (Pleistocene)**--Dark-gray massive basalt; finely crystalline to aphanitic groundmass; blocky. Contains abundant calcite and olivine. Approximately 3 to 5 m thick

Sedimentary Rocks

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

Rmv **Virgin Limestone Member--Consists of two light-gray, thin-bedded to thinly laminated, ledge-forming limestone beds, separated by white, pale-yellow, and gray slope-forming, thin-bedded, gypsiferous siltstone. Includes thin beds of brown, red, and green siltstone, gray limestone, and brown platy calcarenite. Upper part is eroded away or covered by alluvial deposits. Erosional unconformity at base of lowest gray limestone bed truncates underlying red siltstone of lower red member as much as 1 m in relief. Lower limestone bed thickens and thins as channel fill deposit. Mostly covered by alluvial deposits along Hurricane Cliffs, northeast corner of quadrangle. Forms ledges in slope. About 5 m exposed**

Rml **Lower red member**--Red, fine-grained, thin-bedded, gypsifereous sandy siltstone interbedded with 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 limestone, sandstone, or conglomerate of Timpoweap Member. Unconformable contact with Kaibab Formation. Locally fills paleovalleys eroded into underlying Kaibab Formation. Forms slope. Ranges from about 9 to 15 m thick. Locally thickens to as much as 30 m in paleovalleys (fig. 2)

Trmt **Timpoweap Member**--Light gray conglomerate and coarse-grained calcareous sandstone, and gray limestone. Includes an upper and lower part. Upper part consists of interbedded light-gray, fine-grained, thick-bedded limestone and gray, coarse-grained, low-angle cross-bedded sandstone forming gradational contact with lower part or unconformabable contact with Harrisburg Member of Kaibab Formation. Lower part consists of conglomerate composed of subangular to rounded pebbles and cobbles of gray and dark gray limestone, white and brown chert, and rounded quartzite in gray limestone matrix derived from Kaibab Formation. Source for dark-gray limestone and quartzite may be Paleozoic rocks west of quadrangle. Conglomerate mostly clast supported; includes matrix of gray to brown, coarse-grained, sandstone, gravel, and minor siltstone. Forms cliff. Fills Triassic paleovalleys eroded into Kaibab Formation estimated as much as 80 m deep and about 760 m wide (fig. 2). Rocks of Timpoweap occupy major paleovalley considered an eastern extension of Mustang Valley (fig. 2; Billingsley, 1991, 1993). A significant smaller tributary paleovalley is located in southwest corner of quadrangle (fig. 2). Imbrication of pebbles in lower conglomerate shows an eastward paleoflow in depositing streams for both paleovalleys. As much as 15 to 80 m thick

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. Upper part consists mainly of slope-forming, red and gray, interbedded gypsifereous siltstone, sandstone, gypsum, and thin-bedded gray limestone; mostly removed by erosion. Topmost unit is resistant, pale-yellow or light-gray, fossiliferous, sandy limestone bed averaging about 1 m thick. 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 this quadrangle. Bottom marker bed consists of light-gray, thin-bedded, sandy limestone. Middle part unconformably truncates 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 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 middle limestone cliff. As much as 100 m thick

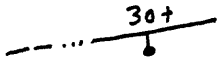
Pkf **Fossil Mountain Member**--Light-gray, fine- to medium-grained, thin-bedded, fossiliferous, sandy, cherty limestone. Chert weathers black. Contact with Woods Ranch member of Toroweap Formation marked by solution and channel erosion with relief as much as 5 m; contact generalized on quadrangle because of extensive talus cover and gypsum solution. Forms cliff. About 110 m thick

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 gypsiferous siltstone and pale-red silty sandstone interbedded with medium-bedded white gypsum. Beds are locally distorted due to gypsum solution. Variable thickness about 12 to 60 m

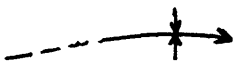
Ptb **Brady Canyon Member**--Gray, fetid, medium-bedded, fine- to coarse-grained, fossiliferous limestone; weathers dark dray. Includes thin-bedded dolomite in upper and lower part. Limestone beds average about 0.5 m thick. Includes chert lenses and nodules but these are 50% less than in Fossil Mountain Member of Kaibab. Gradational contact with siltstone and gypsum of underlying Seligman Member; often covered because of minor slump or talus debris. Forms cliffs. Approximately 90 m thick

Contact--Dashed where approximately located

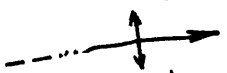


Fault--Dashed where inferred or approximately located; dotted where concealed; bar and ball on downthrown side. Number is estimated displacement in meters. Number with plus denotes minimum estimated displacement

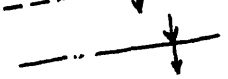
Folds--Showing trace of axial plane and direction of plunge; dashed where approximately located; dotted where concealed



Syncline

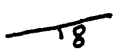


Anticline

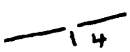


Monocline

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--Interpretated 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

REFERENCES CITED

Billingsley, G.H., 1991, Geologic map of the Sullivan Draw North quadrangle, northern Mohave County, Arizona: U.S. Geological Survey Open-File Report 91-558, scale 1:24,000.

_____ 1992a, Geologic map of the Gyp Pocket quadrangle, Mohave County, northwestern Arizona: U.S. Geological Survey Open-File Report 92-412, scale 1:24,000.

_____ 1992b, Geologic map of the Hole-N-Wall Canyon quadrangle, Mohave County, northwestern Arizona: U.S. Geological Survey Open-File Report 92-432, scale 1:24,000.

_____ 1992c, Geologic map of the Yellowhorse Flat quadrangle, Mohave County, northwestern Arizona: U.S. Geological Survey Open-File Report 92-442, scale 1:24,000.

_____ 1993, Geologic map of the Wolf Hole Mountain and vicinity, Mohave County, northwestern Arizona: U.S. Geological Survey Miscellaneous Investigation Series Map I-2296, scale 1:31,680.

_____ 1994, Geologic map of the Sullivan Draw and vicinity, Mohave County, northwestern Arizona: U.S. Geological Survey Miscellaneous Investigations Map Series I-2396, scale 1:31,680.

Huntoon, P.W., 1989, Phanerozoic tectonism, Grand Canyon, Arizona, in Elston, D.P., Billingsley, G.H., and Young, R.A., eds., Geology of Grand Canyon, northern Arizona (with Colorado River guides): 28th International Geological Congress Field Trip Guidebook T115/315, American Geophysical Union, Washington D.C., p. 76-89.

Reynolds, S.J., Florence, F.P., Welty, J.W., Roddy, M.S., Currier, D.A., Anderson, A.V., and Keith, S.B., 1986, Compilation of radiometric age determinations in Arizona: Arizona Bureau of Geology and Mineral Technology, Geological Survey Branch, Tucson, Arizona, Bulletin 197, 252 p.

Reynolds, S.J., 1988, Geologic map of Arizona: Arizona Geological Survey, Tucson, Arizona, Map 26, scale 1:1,000,000.

S.A.R. System, 1988, Grand Canyon, Arizona, Synthetic Aperture Radar Imagery X-band, near-range, east-look: Produced for the U.S. Geological Survey by Aero Service Division, Western Atlas International, Inc., Radar Image Mosaic, scale 1:250,000.

Sorauf, J.E., and Billingsley, G.H., 1991, Members of the Toroweap and Kaibab Formations, Lower Permian, northern Arizona and southwestern Utah: Rocky Mountain Geologists, v. 28, no. 1, p. 9-24.

Stewart, J.H., Poole, F.G., and Wilson, R.F., 1972, Stratigraphy of the Triassic Moenkopi Formation and related strata in the Colorado Plateau region, with a section on sedimentary petrology: in Cadigan, R.A., U.S. Geological Survey Professional Paper 691, 195 p.

Wenrich, K.J., 1985, Mineralization of breccia pipes in northern Arizona: Economic Geology, v. 80, no. 6, p. 1722-1735.

Wenrich, K.J., Billingsley, G.H., and Huntoon, P.W., 1986, Breccia pipe and geologic map of the northeastern Hualapai Indian Reservation and vicinity, Arizona: U.S. Geological Survey Open-File Report 86-458-A, scale 1:48,000, includes pamphlet, 26 p.

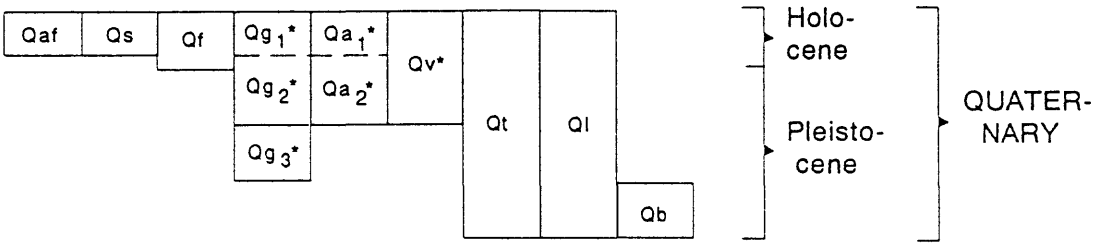
Wenrich, K.J., and Huntoon, P.W., 1989, Breccia pipes and associated mineralization in the Grand Canyon region, northern Arizona: in Elston, D.P., Billingsley, G.H., and Young, R.A., eds., Geology of Grand Canyon, Northern Arizona (with Colorado River Guides), 28th International Geological Congress Field Trip Guidebook T115/315, American Geophysical Union, Washington, D.C., p. 212-218.

Wenrich, K.J., and Sutphin, H.B., 1989, Lithotectonic setting necessary for formation of a uranium-rich, solution-collapse breccia-pipe province, Grand Canyon region, Arizona: U.S. Geological Survey Open-File Report 89-0173, 33 p.

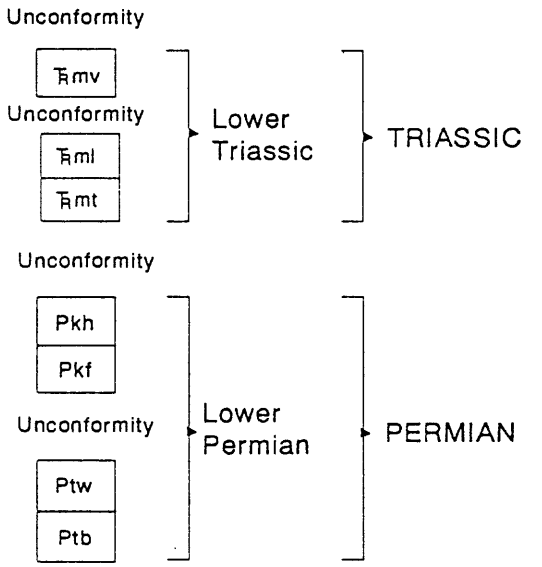
Wilson, E.D., Moore, R.T., and Cooper, J.R., 1969, Geologic map of the State of Arizona: Arizona Bureau of Mines, University of Arizona, Tucson, Arizona, scale 1:500,000.

CORRELATION OF MAP UNITS

SURFICIAL DEPOSITS AND IGNEOUS ROCKS



SEDIMENTARY ROCKS



* See description of map units for exact unit age assignment