

## GEOLOGIC MAP OF THE LITTLEFIELD 30' × 60' QUADRANGLE, MOHAVE COUNTY, NORTHWESTERN ARIZONA

By George H. Billingsley and Jeremiah B. Workman

### INTRODUCTION

This map is one result of the U.S. Geological Survey's intent to provide geologic map coverage and a better understanding of the transition in regional geology between the Basin and Range and Colorado Plateaus in southeastern Nevada, southwestern Utah, and northwestern Arizona. Information gained from this regional study provides a better understanding of the tectonic and magmatic evolution of an area of extreme contrasts in late Mesozoic-early Tertiary compression, Cenozoic magmatism, and Cenozoic extension. This map is a synthesis of 32 new geologic maps encompassing the Littlefield 30' x 60' quadrangle, Arizona. Geologic information presented in this map and report may aid future land management decisions about land use, flood control, and environmental and range management programs for federal, state, and private agencies.

The Littlefield 30' x 60' quadrangle encompasses approximately 3,100 km<sup>2</sup> (1,937 mi<sup>2</sup>) of northwestern Arizona. The map area is bordered on the north by the Utah-Arizona state line and is approximately 5 km east of the Nevada-Arizona state line (see map). The quadrangle is bounded by long 113° to 114° and lat 36°30' to 37°. The east three-quarters of the map area is within the southwestern part of the Colorado Plateaus province (herein referred to as the Colorado Plateau), and the west quarter is within the Basin and Range province. The Basin and Range is locally subdivided into three physiographic areas; the Mesquite Basin, the Virgin Mountains, and the Grand Wash Trough (fig. 1, on map sheet). The Colorado Plateau is subdivided into three physiographic areas; the St. George Basin, the Shivwits Plateau, and the Uinkaret Plateau (fig. 1, on map sheet). The St. George Basin is part of the transition zone between the Colorado Plateau and the Basin and Range that extends northward into Utah. The arbitrary boundary between the Basin and Range, the transition zone, and the Colorado Plateau is based on physiographic, geologic, and topographic relations (Stokes, 1977; Billingsley, 1993g).

Settlements within the map area include small communities of less than 250 people at Littlefield and Beaver Dam, Arizona, in the northwest corner of the map; Mt. Trumbull (locally known as Bundyville), in the south-central part of map; and Colorado City, Arizona, a community of over 5,000 people, in the northeast corner of the map. Hilldale, Utah, lies adjacent to Colorado City on the north side of the Utah-Arizona state line. St. George and Hurricane, Utah, are about

10 km north of the north-central part of the map and are the largest settlements near the map area.

Interstate Highway 15 and U.S. Highway 91 provide access to the northwest corner of the map area, and Arizona State Highway 389 provides access to the northeast corner. Access to the rest of the map area is by dirt roads maintained by the U.S. Bureau of Land Management, Arizona Strip District, St. George, Utah. The area is largely managed by the U.S. Bureau of Land Management, the Arizona Strip District, which includes sections of land controlled by the State of Arizona. There are several isolated sections of privately owned lands, mainly near the communities of Littlefield, Beaver Dam, and Colorado City. If traveling in this area, always take plenty of extra water and food; and two spare tires are recommended.

Elevations range from 2,442 m (8,012 ft) at Hancock Peak of Mount Bangs, Virgin Mountains, in the northwest corner of the map, to 506 m (1,660 ft) at the Virgin River, at the northwest edge of the map. The Colorado Plateau region averages about 1,525 m (5,000 ft) in elevation.

Most of the drainages on the Colorado Plateau and those on the west and north slopes of the Virgin Mountains flow northward into the Virgin River. Drainages on the east and south slopes of the Virgin Mountains, the Grand Wash Trough area, and the west edge of the Colorado Plateau drain southward to the Colorado River.

Compilation of this map is from new geologic mapping by Bohannon (1991, 1992), Bohannon and others (1991), Bohannon and Lucchitta (1991), Lucchitta and others (1995a, b), Billingsley (1990a, b, c, d; 1991a, b, c, d; 1992a, b, c, d; 1993a, b, c, d, e, f; 1994a, b, c, d, e, f, g; 1995), and Billingsley and Bohannon (1995). Geologic maps of the Grand Canyon, about 30 km south of this quadrangle, are available (Huntoon and others, 1981; Billingsley and Huntoon, 1983; Wenrich and others, 1997; and Billingsley 1997a, b, c).

### GEOLOGIC SETTING

The map area is characterized by gently dipping Paleozoic and Mesozoic strata for much of the Colorado Plateau, and structurally deformed Paleozoic, Mesozoic, and Cenozoic strata in the Basin and Range. Proterozoic crystalline and metamorphic rocks overlain by Paleozoic, Mesozoic, and Cenozoic strata are exposed only in the Virgin Mountain area. The map area is in a transitional setting between the miogeosynclinal section of rocks to the west, in the south-

eastern Great Basin, and the platform sequence of rocks in the Colorado Plateau to the east; overall, the area displays an east-to-west facies change and westward thickening of strata. The stratigraphic nomenclature established for rocks of the Colorado Plateau, chiefly in southern Utah and the Grand Canyon region of Arizona, differs from that used in the southern Great Basin. For this quadrangle, nomenclature from both provinces is used, but most nomenclature reflects that of the Grand Canyon region because of stratigraphic similarities and closer proximity to Grand Canyon type localities.

The Virgin River and its tributaries have dissected the northern part of the map area exposing about 2,555 m of Paleozoic strata, about 2,300 m of Mesozoic strata, and about 300 m of Cenozoic strata. The Triassic, Jurassic, and parts of the Cretaceous sections once covered the entire map area, but have been largely eroded, except where preserved under late Tertiary and Quaternary basalt flows. The highland areas of the Colorado Plateau are capped by Tertiary basalts that form tabletop mountains such as Black Rock, Wolf Hole, and Seegmiller Mountains. Tertiary basalt flows that flowed southward make up widespread deposits in the Grand Wash Trough area. Quaternary basalt flows on the Uinkaret Plateau in the southeast quarter of the map area, are a remnant of the Pleistocene landform in this area.

The oldest basalts are in the Grand Wash Trough and generally range from 6 to 4 million years in age. The youngest basalts are in the Uinkaret Volcanic Field on the Uinkaret Plateau and are generally less than 850,000 years in age (fig. 1, on map sheet). In general, the basalts young from west to east across the map area. None of the basalt flows are tilted, but many have been faulted. Most of the Tertiary and Quaternary basalt deposits overlie slightly tilted strata, forming an angular unconformity.

Quaternary stream deposits, wind deposits, and colluvial surficial deposits cover much of the landscape. Thick deposits of gypsum and gypsiferous siltstone and mudstone within the landslide deposits are easily removed by solution. The landslide masses containing these rocks on steep slopes beneath the basalt-capped mountains are unstable in wet conditions. Fractures and small land-failure faults, too small to show at this map scale, have developed in the basalt rims above landslides, especially on the east slopes where slippage is facilitated along east-dipping strata. Landslides date from drainage incision, probably from the early Pleistocene, and continue intermittently to the present. Gypsum, a common mineral in the bedrock of the Colorado Plateau area, is largely responsible for the failure of several earthen dams on the plateau through dissolution.

## STRUCTURAL GEOLOGY

High-angle to nearly-vertical normal faults in gently tilted strata are the characteristic structures found on the Shivwits and Uinkaret Plateaus (Billingsley, 1994g, unpub. data a, b, c, d, e). Folds are common in the St. George Basin

(Billingsley, 1993g, unpub. data a). Compressional folding and regional uplift began in Late Cretaceous and early Tertiary time (Huntoon, 1990), causing erosion from the Paleocene(?) through early Pliocene time. Basaltic deposition began during the late Pliocene(?) and continued through Pleistocene time. During the late Pliocene(?) and Pleistocene, east-west extension produced several normal faults that form west-facing fault scarps, such as the Hurricane Cliffs. In addition, several horst-and-graben structures have offset Paleozoic and Mesozoic strata, forming north-south structurally controlled valleys (Billingsley, unpub. data a, b, c, d, e).

Small monoclines and relatively short, doubly-plunging anticlines and synclines on the Colorado Plateau have generally northerly strikes.

The Hurricane Fault, whose fault scarp forms the Hurricane Cliffs, separates the lower Shivwits Plateau from the higher Uinkaret Plateau. The maximum displacement along the Hurricane Fault is about 850 m at the north edge of the map, decreasing southward to about 510 m near the middle of the map, then increasing to more than 670 m at the south edge of the map (Billingsley, unpub. data a, b). Strata on the downthrown side of the Hurricane Fault dip toward the fault plane as much as 20 degrees at some locations. The increase in dip toward the Hurricane Fault is considered by Hamblin (1965) to be reverse drag flexures associated with movement along the fault. Huntoon (1990) believes the Hurricane Fault overlies deep-seated reverse faults that folded the strata up-to-the-west during Late Cretaceous and Early Tertiary time producing a monoclinial flexure along the fault. The reverse drag scenario is adopted for this map.

Equal offset of the  $3.6 \pm 0.18$  Ma Bundyville basalt (Billingsley, 1997a) and underlying Mesozoic strata along the Hurricane Fault, 13 km south of this map area, indicate that extension along the Hurricane Fault began after deposition of the basalt. Approximately 380 m of the offset occurred before the basalt flow from Moriah Knoll cascaded over the Hurricane Cliffs. The basalt flow has since been offset 130 m during the last 850,000 years (Billingsley, 1994f, unpub. data d).

On the Colorado Plateau area of this map, several major and minor faults offset Tertiary and Quaternary basalt flows, as young as 1.6 Ma (Dutchman Draw Fault, northeast part of map), equally as much as underlying strata. Several younger Quaternary basalts are cut by faults, but are not offset as much as the underlying strata, which suggests that most, if not all of the faults on the Shivwits and Uinkaret Plateaus probably became active about 3.5 to 2 million years ago. All major and several minor faults on the Colorado Plateau show minor displacement of Quaternary alluvial deposits (Billingsley, 1993g, 1994g, unpub. data a, b, c, d, e). A recent magnitude 5.6 earthquake southeast of St. George, Utah, September 1993 (Billingsley, unpub. data a; Pearthree, P.A., and Wallace, T.C., 1992), indicates that tectonic activity continues today.

In the Basin and Range, Late Cretaceous and early Tertiary compression resulted in major folding, reverse faulting, and thrust faulting that produced the Virgin Mountains. This tectonism initiated a period of erosion and deposition in Paleocene(?), Oligocene, and early Miocene time. East-west extension during the late Miocene began to form the Mesquite Basin, the Grand Wash Trough, and the Grand Wash Cliffs (Hintze, 1986; Bohannon and others, 1993).

The Grand Wash Fault, whose fault scarp forms the Grand Wash Cliffs, separates the Basin and Range province from the Colorado Plateau province. Movement along the Grand Wash Fault began in the early or middle Miocene (Bohannon and others, 1993). Hobble Graben, a 240-m-deep structure near the Grand Wash Cliffs, formed as part of the associated extension of the Grand Wash Trough. Hobble Graben deepens and widens near its junction with the Grand Wash Fault, and its northwest strike aligns with the West Branch segment of the Grand Wash Fault system.

Offset along the Grand Wash Fault is very small in the vicinity of Black Rock Mountain but increases both northward and southward. Total offset is as much as 3,000 m near the Colorado River, south of this map area (Lucchitta, 1979), and about 1,100 m at the north edge of the map area. At Black Rock Mountain, the displacement along the structure has been transferred to the West Branch Fault that splays westward from the Grand Wash Fault and the Sullivans Canyon Fault. Strata between the West Branch and Sullivans Canyon Faults and the Grand Wash Fault are nearly flat-lying.

The Piedmont Fault (Moore, 1972) separates the Virgin Mountains from the Mesquite Basin and is mostly buried by alluvial deposits. The fault trace can be observed as small fault scarps in the alluvial fans along the lower slopes of the Virgin Mountains. The total offset along the Piedmont Fault is as much as 6 km (Bohannon and others, 1993).

Circular collapse structures, minor folds, and other surface irregularities on the Colorado Plateau are due to dissolution of gypsum and gypsiferous siltstone not only in the Kaibab, but also in the Toroweap and the lower part of the Moenkopi Formations. Some bowl-shaped depressions in the Kaibab Formation, characterized by inward-dipping strata, may be the surface expressions of collapse-formed breccia pipes originating from dissolution of the deeply buried Mississippian Redwall Limestone (Wenrich and Huntoon, 1989). Such features were not observed in the Basin and Range part of the map.

Suspected breccia pipes have inward dipping strata and are marked on the map by a dot and the letter C. Some deep-seated breccia pipes are known to be overlain by gypsum collapse features related to thinning by dissolution of gypsum within the Woods Ranch Member of the Toroweap Formation (Wenrich and others, 1997). However, breccia pipes cannot be distinguished with certainty from shallow collapse structures on the plateaus caused by the dissolution of gypsum. The deep-seated collapse structures are potential hosts

for economic deposits of copper and uranium oxide minerals; whereas, the shallow structures are unlikely to be mineralized (Wenrich, 1985).

The Hidden Mines are located on a breccia pipe in the Hermit Formation in Hidden Canyon (sec. 16, T. 36 N., R. 13 W.). The mine tailings contain copper minerals, but no production records are available. Minor amounts of uranium were reported in samples from cores drilled in 1982 by Pathfinder Mines (oral commun., 1991). There are two small copper prospects on the Colorado Plateau within the map area. The prospect on the Shivwits Plateau (sec. 13, T. 38 N., R. 8 and 9 W.; Billingsley, 1994b) is associated with a breccia pipe. The prospect on the Uinkaret Plateau (sec. 31, T. 38 N., R. 10 W.; Billingsley, 1993c) is not associated with a breccia pipe. Copper may have been hauled from the prospects, but no production records are available.

Thick-bedded gypsum occurs in the Toroweap and Kaibab Formations. Gypsum is being mined from the Harrisburg Member of the Kaibab Formation about 5 km south of Interstate Highway 15, north-central edge of the map area (sec. 25, T. 41 N., R. 13 W.). Also a thick pocket of gypsum occurs within the upper Callville Formation and Queantoweap Sandstone north of the Virgin River (northwest corner of the map). A few quarries for sandstone are operated intermittently on Lost Spring Mountain (northeast quarter of the map).

Gypsum dissolution in the Harrisburg Member of the Kaibab Formation has resulted in small sinkholes and caves where the unit is exposed on the Colorado Plateau. The sinkholes are most common in the northern part of the Shivwits Plateau. The karst is Holocene and perhaps Pleistocene in age, because young alluvium partly fills many of the depressions and several depressions occur within alluviated valleys (Billingsley, 1993g, 1994g, unpub. data a, b, c, d, e).

## ACKNOWLEDGMENTS

This map is a product of several geologists that have worked in the area and contributed their expertise and hard work as indicated on the map as sources of geologic data. We are especially grateful to the following individuals for their advice, revisions, and information: Brian Atwater, L. Sue Beard, Bruce H. Bryant, Clay M. Conway, Gary L. Dixon, Wendell Duffield, Donald P. Elston, Dave S. Harwood, James G. Honey, King N. Huber, Angela Jayko, Jonathan C. Matti, David M. Miller, Paul Stone, Victoria Todd, Wesley A. Ward, Gordon Weir, Van S. Williams, Peter W. Huntoon, and Charles W. Barnes. Special thanks for technical support go to Tony Bryant, Kelly Burke, Thomas W. Judkins, Marjorie MacLachlan, Carol Ostergren, Susan Priest, Dale Russell, Kathryn Thompson, Charles L. Powell, II, Kathy Nimz, and Jan L. Zigler.

## DESCRIPTION OF MAP UNITS

### SURFICIAL DEPOSITS

- Qs Stream-channel alluvium (Holocene)**—Unconsolidated, unsorted, interlensing clay, silt, sand, and pebble to boulder gravel. Intertongues or overlaps flood-plain (Qf), upper part of valley-fill (Qv), young alluvial fan (Qay), and talus (Qt) deposits. Inset to young and old terrace-gravel (Qgy and Qgo) deposits and old alluvial fan (Qao) deposits. Stream channels subject to high-energy debris flows and flash floods. Little or no vegetation in stream channels, except a few salt cedar (tamarisk) trees. Estimated thickness 3 to 6 m
- Qf Floodplain deposits (Holocene)**—In Basin and Range area, gray to brown, interbedded, silt, sand, and pebble to boulder gravel along Beaver Dam Wash and Virgin River; unconsolidated, subject to frequent channel erosion; deposits shown are from 1976 aerial photo interpretation along Beaver Dam Wash and Virgin River. On Colorado Plateau, mostly gray, interbedded silt and sand; locally contains cinder and basalt fragments near basaltic areas, partly consolidated or cemented by gypsum and calcite. Intertongues or overlapped by stream-channel (Qs), dune sand (Qd), young alluvial fan (Qay), and talus (Qt) deposits. Forms flat surface, as opposed to gently sloping valley-fill areas, because subject to frequent low-energy flooding or ponding. No vegetation in local dry lake basins; sparsely vegetated by growths of sagebrush, cactus, and rabbitbrush. Thickest deposits are on Colorado Plateau, central area of map along Sullivan and Main Street Grabens and base of Hurricane Cliffs. Thickness ranges from 1 to 10 m
- Qd Dune sand and sand sheet deposits (Holocene)**—In Basin and Range, light-reddish-orange, very fine grained to fine-grained, well-sorted sand sheets and small complex dunes on pediment calcrete (Qpc) surfaces west of Virgin River; forms falling dunes along west bank of Beaver Dam Wash and Virgin River; sand locally derived from outcrops of the Muddy Creek Formation (Tmc). Forms white, very fine grained to fine-grained, well-sorted sand sheets and small dunes in Virgin River floodplain areas in dry season (not shown on map). Includes light-red, very fine grained to fine-grained, well-sorted sand sheets and small dunes on bedrock surfaces in upper Grand Wash Trough area; sand locally derived from outcrops of the rocks of the Grand Wash Trough (Tgw) and the Navajo Sandstone (Jñn). On Colorado Plateau, consists of white and light-red, fine-grained, well-sorted quartz sand derived locally from stream-channel (Qs) deposits that form small climbing dunes, sand sheets, or levee dunes along banks of Short Creek, northeast corner of map area; commonly stabilized by grass. Only active sand sheets and dunes shown; thin sand deposits stabilized by vegetation not mapped. Sand sheets and dunes formed by regional southwesterly winds. Thickness ranges from 1 to 5 m
- Qtt Travertine deposits (Holocene and Pleistocene?)**—Gray, porous, thin-bedded, freshwater, calcium carbonate deposit. Weathers to rough pitted surface. Derived from warm spring outlets along east bank of Virgin River at and near Interstate Highway 15 bridge, northwest corner of map area. Locally includes silt, sand, pebbles, and cobbles derived from sheetwash erosion of pediment calcrete (Qpc) and young alluvial fan (Qay) sediments. Includes encrustation of local roots and leaves preserved as modern fossils. Forms cliff or resistant bench. Thickness is 1 to 4 m
- Qc Colluvial deposits (Holocene and Pleistocene?)**—Colorado Plateau area, northeast quarter of map, consists of two types: (1) ponded deposits associated with enclosed depressions on basalt flow surfaces, sinkhole depressions on the Harrisburg Member (Pkh) of the Kaibab Formation, or enclosed depressions caused by landslide blocks and (2) deposits associated with extensive sheetwash alluvium over bedrock. In basalt flow, sinkhole, and landslide areas, contain white to gray silt, fine-grained sand, and black to reddish, fine-grained cinder, scoria, and basalt clasts; locally consolidated by gypsum and calcite cement. Similar to floodplain (Qf) deposits but generally not associated with drainages. Subject to frequent ponding. Supports sparse growths of grass. Sheetwash deposits near Colorado City, Arizona (at northeast corner of map area) consist of pale-red, tan, and brown, fine-grained sand,

silt, and gravel; partly cemented by gypsum and clay; locally contains boulders of the Shinarump Member (Fcs) of the Chinle Formation as much as 2 m in diameter. Clay content greatest near outcrops of the Petrified Forest Member (Fcp) of the Chinle Formation near Colorado City area. Lag gravel forms thin desert pavement on colluvial surface south and west of the Shinarump Member outcrop. Lag gravel consists of numerous black, brown, yellow, red, and gray, very well rounded quartzite and chert pebbles, 1 to 5 cm in diameter, and occasional rounded, gray-white petrified wood fragments, all derived from the Shinarump Member (Fcs) of the Chinle Formation. Locally includes integrated, poorly defined, windblown, sand-sheet deposits (not mapped). Overlapped by young alluvial fan (Qay) and upper part of valley-fill (Qv) deposits. Approximately 1 to 12 m thick

**Qgy Young alluvial terrace deposits (Holocene and Pleistocene?)**—On Colorado Plateau, unconsolidated to partly consolidated, light-brown, pale-red, and gray silt, sand, and pebble to boulder gravel composed equally of well-rounded, limestone, sandstone, and basalt clasts. Similar lithology in Basin and Range except clasts dominated by metamorphic and igneous rock types west of Virgin Mountains. Commonly intertongues or overlapped by stream-channel (Qs), floodplain (Qf), valley-fill (Qv), young alluvial fan (Qay), and talus (Qt) deposits. Subject to high-energy flooding or erosion. Forms bench about 1 to 3 m above modern stream beds in Basin and Range area and about 1 to 9 m above modern stream beds on Colorado Plateau area. Moderately vegetated by grass, cactus, and creosote bush below 5,000 ft elevation and by sagebrush, cactus, grass, and pinion pine or juniper trees at higher elevations. Thickness, 1 to 10 m

**Qay Young alluvial fan deposits (Holocene and Pleistocene?)**—On Colorado Plateau, unconsolidated and unsorted clay, silt, and sand; contains gravel lenses of subangular to rounded pebbles and boulders of basalt, chert, limestone, and sandstone. In Basin and Range, similar lithologies to Colorado Plateau but include abundant clasts of metamorphic and igneous rocks that are partly cemented by gypsum and calcite. In both

regions, intertongues with stream-channel (Qs), young alluvial terrace (Qgy), floodplain (Qf), talus (Qt), upper part of valley-fill (Qv), and older alluvial fan (Qao) deposits near their downslope ends. Subject to erosion by flash floods, debris flows, and sheetwash. Sparsely vegetated by creosote bush, cactus, grass, and sagebrush below the 5,000-ft elevation; moderately vegetated by sagebrush, pinion pine, and juniper trees above 5,000 ft. Estimated range of thickness about 3 to 24 m

**Qv Valley-fill alluvial deposits (Holocene and Pleistocene)**—Gray and light-brown clay, silt, sand, and lenses of pebble to small boulder gravel; partly consolidated. Intertongues or overlapped by young alluvial fan (Qay), talus (Qt), and stream-channel (Qs) deposits. Subject to low-energy sheetwash flooding; larger valleys on Colorado Plateau often cut by arroyos, some as deep as 11 m. Where major valley-fill deposits are cut by deep arroyos, alluvium no longer accumulates and valley-fill alluvium is classified as young alluvial terrace (Qgy) deposit. On Colorado Plateau, thickly vegetated by sagebrush, cactus, and grass; no trees. In Basin and Range, sparsely vegetated by cactus, creosote bush, grass, and some mesquite and catclaw trees. Thickest deposits are on Colorado Plateau; estimated overall thickness, 3 to 18 m

**Qt Talus deposits (Holocene and Pleistocene)**—Unsorted breccia debris composed of sand, gravel, and small to large angular blocks of local bedrock on steep to moderately steep slopes. Locally includes boulders as large as 3 m in diameter. Includes silt, sand, and gravel partly cemented with gypsum and calcite. Intertongues with younger (Qay) and older alluvial fan (Qao), valley-fill (Qv), young (Qgy) and old alluvial terrace (Qgo), and landslide (Ql) deposits. Supports sparse growth of sagebrush, cactus, grass, and creosote bush below 5,000 ft; includes some juniper and pinion trees at higher elevations. Only extensive deposits shown. As much as 9 m thick

**Ql Landslide deposits (Holocene and Pleistocene)**—Unconsolidated masses of unsorted rock debris. On Colorado Plateau, includes detached blocks of strata that have rotated backward and slid downslope as loose incoherent masses of broken rock and deformed strata, often partly surrounded by

talus. Found principally below basalt flows of several basalt-capped mountains and buttes and often includes strata of the Moenkopi Formation. In Basin and Range area, locally found along Beaver Dam Wash and Virgin River and isolated areas of Virgin Mountains. Supports growth of sagebrush, cactus, grass, and creosote bush below 5,000 ft; some pinion and juniper trees at higher elevations. Unstable when wet, especially below basalt-capped mountains on Colorado Plateau. Minor rockfalls or landslides not shown; mapped areas are potential rockfall or landslide hazard areas. Thickness ranges from 3 to 22 m

**Qao Older alluvial fan deposits (Holocene(?) and Pleistocene)**—On Colorado Plateau, similar to younger alluvial fan deposits (Qay), but basalt clasts are dominant lithology and often coated with desert varnish. Forms conspicuous bench or tableland about 20 to 50 m above younger alluvial fan deposits and forms protective caprock over nonresistant beds of the Kaibab and Moenkopi Formations. Partly cemented with gypsum and calcite. Merges with talus (Qt), younger alluvial fan (Qay), or landslide (Ql) deposits. Deposits at base of Hurricane Cliffs are locally faulted as much as 12 m along Hurricane Fault. In Basin and Range, similar lithologies as young alluvial fan (Qay) deposits; has yellowish, smooth, lighter-tone surface texture on aerial photos because of thick soil development; partly consolidated by calcite cement. Clasts are dominated by metamorphic and granitic rocks west of Virgin Mountains; basalt clasts common east of Virgin Mountains. Locally, deposits are faulted as much as 18 m along Piedmont Fault, west side of Virgin Mountains. Regionally, surface clasts have well developed desert varnish; clasts within deposit have coating of caliche. Partly overlapped by younger alluvial fan (Qay) and active stream (Qs) deposits on upper slopes. Strongly incised and eroded by arroyos that contribute material to younger alluvial fans at downslope ends. Sparsely vegetated by creosote bush, sagebrush, cactus, and grass in all regions. Thickness ranges from 9 to 50 m

**Qpc Pediment calcrete (Holocene(?) and Pleistocene)**—Mesquite Basin area of Basin and Range, northwest corner of map area. Pale-

yellowish-brown to light-gray, moderately sorted, massive to thin-bedded, cliff-forming siltstone and sandstone. Includes thick beds or nodules of white caliche and caliche-cemented siltstone that produces lighter-tone surface on aerial photographs. Unit locally covered by dune sand (Qd). Exposed caliche nodules at surface are deeply pitted or etched by solution weathering. Generally forms flat to gently sloping surfaces, locally tilted as much as 4° east; dissection is variable; surfaces are locally faulted. Surfaces are subject to modern sheetwash flow and local flooding. Base of unit generally forms low, angular, unconformable contact with the underlying Muddy Creek Formation (Tmc). Generally less than 5 m thick

**Qgo Older alluvial terrace deposits (Holocene(?) and Pleistocene)**—Similar to younger alluvial terrace deposits (Qgy), but forms terraces 6 to 12 m above stream-channel (Qs) or valley-fill (Qv) deposits along tributary drainages on Colorado Plateau, and about 25 to 90 m above stream-channel (Qs) deposits along Virgin River and Beaver Dam Wash in Basin and Range area. Composed of well-rounded clasts of chert, limestone, sandstone, quartzite, basalt, and metamorphic clasts; quartzite and basalt clasts are common in uppermost terraces of Colorado Plateau and igneous and metamorphic clasts common in Basin and Range area; unit commonly cemented by calcite and gypsum. Merges with and often covered by local talus (Qt) or young alluvial fan (Qay) deposits. Alluvial terraces 67 to 73 m above alluvial fan deposits, south of Interstate Highway 15 Black Rock Interchange, contain quartzite clasts from Utah that show that an ancestral Virgin River flowed west along a course marked approximately by Interstate Highway 15. Thickest deposits are along Virgin River and Beaver Dam Wash area, northwest quarter of map. Thickness, 2 to 14 m

**Ta Old alluvium (Pleistocene and Pliocene)**—In Basin and Range, Grand Wash Trough area, southwest corner of map area; consists of silt, sand, pebbles, cobbles, and boulders in widespread, sheetlike deposits that formed on pediment surfaces; strongly dissected by modern erosion. Poorly sorted to moderately sorted, angular to subrounded constituents as large as several meters in

diameter; unconsolidated (Bohannon, 1991). Includes isolated deposits on gently sloping surfaces of basalt flows (Tb) as much as 140 m above modern stream beds. Supports moderate growth of desert vegetation, mainly grass. Includes light-brown to medium-orange-brown, medium- to fine-grained, poorly sorted sandstone and siltstone intrabasaltic sediments that may be, in part, equivalent to but indistinguishable from upper part of the Muddy Creek Formation (Tmc); contains scattered pebbles of basalt, as much as 30 cm in diameter, and pebbles of black and white chert, metavolcanic rocks, and sandstone. Thickness of intrabasaltic sediments as much as 90 m (Lucchitta and others, 1995a, b), but averages about 50 m. On Colorado Plateau, includes two separate deposits: (1) Shivwits Plateau between Hobbie Graben and Sullivan Draw, central part of map area (Billingsley, 1994g) and (2) Uinkaret Plateau between Cottonwood Canyon and Clayhole Wash, northeast-central part of map area (Billingsley, unpub. data c). Shivwits Plateau deposits are light-brown, unconsolidated silt, sand, and gravel. Contains white chert and limestone locally derived from the Kaibab Formation and sparse, well-rounded basalt and quartzite pebbles as much as 4.8 cm in diameter and rare petrified wood clasts from the Shinarump Member of the Chinle Formation. Basalt source may be Diamond Butte (K-Ar age  $4.3 \pm 0.6$  Ma; Billingsley, unpub. data b) or Poverty Mountain just south of this map area (K-Ar age  $4.7 \pm 0.26$  Ma; Best and others, 1980). Thickness ranges from 1.5 to 15 m. Uinkaret Plateau deposits are light-gray, unconsolidated silt, sand, gravel, and numerous pebbles. Contains black, brown, and yellow, well-rounded chert and quartzite pebbles and rare petrified wood pebbles, all averaging less than 2.4 cm in diameter; derived from the Shinarump Member (Tcs) of the Chinle Formation. Deposits occupy ancestral Clayhole Wash drainage that is now abandoned due to headward erosion from Rock Canyon area and stream capture of Clayhole Wash from Cottonwood Canyon (Billingsley, 1992d). Thickness about 1 to 3 m

## VOLCANIC ROCKS

**Young basalts, undivided (Pleistocene)**—On Colorado Plateau, includes basalt flows and dikes at Black Knolls (Uinkaret Plateau), flows and numerous dikes just north of East Mesa (St. George Basin), and flows in the Little Black Mountain area (St. George Basin). Whole rock K-Ar age ranges from  $0.58 \pm 0.30$  Ma at Black Knolls to  $1.7 \pm 0.4$  Ma at Little Black Mountain (Billingsley, unpub. data a)

**Qi Intrusive dikes (Pleistocene)**—Dark-gray, finely crystalline, olivine alkali basaltic dikes in most areas; black andesitic basalt with augite, olivine, and plagioclase phenocrysts in others. X-ray fluorescence spectrography shows phenocrysts of augite and olivine; groundmass composed mainly of plagioclase, augite, glass, and olivine (Wenrich and others, 1995). Dikes are not found at Little Black Mountain. Dikes commonly vertical; widths range from 0.3 to 1 m and protrude 0.2 to 2 m above local surfaces. All dikes are generally aligned parallel to vertical and subvertical bedrock joints. This unit includes dikes at Black Knolls and 6.5 km southeast of Black Knolls, a dike southwest of Moriah Knoll, dikes associated with the Sage Basalt (Qsp and Qsb), the basalt of Hat Knoll (Qhp and Qhb), and the basalt of Seven Knolls (Qskp and Qskb) of the Uinkaret Plateau, east and southeast quarter of the map area. Includes numerous dikes and necks near unnamed buttes north of and at East Mesa in St. George Basin, north-central part of map, that are generally not physically connected to, but locally associated with, nearby basalt flows and pyroclastic deposits. Includes dikes on and near West Mesa (north-central part of map) and dikes associated with the Little Tanks Basalt (Qlp and Qlb), Shivwits Plateau, south-central edge of map area

**Qb Basalt flows (Pleistocene)**—Dark-gray, finely crystalline to glassy groundmass of alkali olivine basalt. Contains olivine, augite, and plagioclase phenocrysts. Typically consists of one flow on top of two unnamed buttes north of East Mesa and west of the Hurricane Cliffs, St. George Basin, north-central part of map; one flow at and south of Little Black Mountain west of Washington Fault, St. George Basin, north-central edge of

map; and one flow at Black Knolls, Uinkaret Plateau, northeast quarter of map area. Flows vary from 1 m thick at Black Knolls to about 10 m thick at Little Black Mountain and less than 15 m thick at unnamed buttes north of East Mesa

**Cave Basalt (Pleistocene)**—Informally introduced by Billingsley (1994e, unpub. data d), and formally named here for numerous sinkhole depressions in the basalt flow north of Toroweap Valley, the type area, Uinkaret Plateau, northern Mohave County, Arizona. One of the sinkholes is labeled “cave” on the USGS Hat Knoll quadrangle, southeast corner of this map (sec. 33, T. 37 N., R. 7 W.). Unit consists of five unnamed pyroclastic cones and thin lava flows that coalesced and flowed north towards Clayhole Wash and partly south to Toroweap Valley just south of the southeast corner of this map area. Sinkholes in the Cave Basalt are as much as 20 m deep. A whole-rock K-Ar age of  $0.63 \pm 0.24$  Ma was obtained by Jackson (1990a, b) from the Sage Basalt (Qsb) about 3 km south of the southeast corner of the map. Divided into:

Qcp **Pyroclastic deposits**—Red and reddish-black basaltic scoria and cinder deposits; partly consolidated. Forms five pyroclastic cones 30 to 135 m tall that align in a north-south trend

Qcb **Basalt flows**—Dark-gray, finely crystalline to glassy alkali olivine basalt. Contains abundant olivine phenocrysts 0.25 to 1 mm in diameter. Most of the flows advanced northward down unnamed drainages and wrapped around the south and east sides of the basalt pad of Hat Knoll, extending about 15 km into Cabin Valley and Clayhole Valley. Numerous sinkhole depressions in the Cave Basalt are the result of solution of gypsum in the underlying Harrisburg Member (Pkh) of the Kaibab Formation. Ranges from 1 to 25 m thick

**Sage Basalt (Pleistocene)**—Named for a triangulation point labeled “Sage” on top of a 134-m-high pyroclastic cone 1 km south of the southeast corner of this map near the upper reaches of Toroweap Valley (just south of the map), the type area, Kanab Plateau, northern Mohave County, Arizona (USGS Mount Trumbull NE 7.5' quadrangle, sec. 26, T. 36 N., R. 7 W). Divided into:

Qsp **Pyroclastic deposits**—Reddish-black and red glassy fragments and scoriaceous ejecta, cinders, and bombs; partly consolidated. Includes two 24-m-high pyroclastic cones, at the southeast corner of this map, and two cones 134 and 97 m high, 0.3 and 3 km respectively, south of the southeast corner of this map; the highest cone has the Sage triangulation station on top. The four cones of the Sage Basalt are aligned in a north-south trend and are offset by the Toroweap Fault as much as 26 m down to the west (southeast corner of this map). Offset of the underlying Kaibab Formation by the Toroweap Fault is about 67 m down to the west

Qsb **Basalt flows**—Dark-gray to black alkali olivine basalt, vuggy with calcite fillings; altered olivine in glassy groundmass. The lava flowed out in a radial pattern from each cone, but most of the basalts flowed north and west about 0.5 to 2.4 km into the upper reaches of Toroweap Valley. Overlies the Harrisburg Member (Pkh) of the Kaibab Formation

**Undivided basalt (Pleistocene)**—Dark-gray olivine basalt, southeast edge of map. Includes basalt flows and associated pyroclastic cones of Pugh Knoll and Spencer Knoll, southeast corner of map area (Billingsley, 1994e). Deposits are assumed to be Pleistocene age because of similar composition and stratigraphic position to other volcanic rocks in the Uinkaret Volcanic Field. Lava flowed in northerly directions similar to other nearby basalt flows in this part of map area. Divided into:

Qup **Pyroclastic deposits**—Reddish-black to black and brown, basaltic, scoriaceous cinder deposits. Forms Spencer Knoll, a 113-m-high pyroclastic cone, and Pugh Knoll, a 60-m-high cone at the southeast edge of map area

Qub **Basalt flows**—Dark-gray, finely crystalline, alkali olivine basalt; fine-grained groundmass of plagioclase, olivine, augite, and glass. Olivine is the most common constituent in flows. Basalt overlies strata of the Harrisburg Member (Pkh) of the Kaibab Formation and the lower red member (Tml) of the Moenkopi Formation. Numerous lava flows, which flowed mostly in a northerly direction, originate from Pugh Knoll and other unnamed volcanoes south of this map area. At Spencer Knoll, lava flowed in a



radial pattern about 1.5 km from Spencer Knoll. About 1 to 50 m thick

**Antelope Knoll Basalt (Pleistocene)**—Named for Antelope Knoll, a pyroclastic cone 140 m high that forms a prominent landmark east of the Hurricane Cliffs on the Uinkaret Plateau; type area for the Antelope Knoll Basalt, secs. 13, 18, 19, and 24, T. 38 N., Rs. 8 and 9 W., northern Mohave county, Arizona. K-Ar age is  $0.83 \pm 0.28$  Ma (Billingsley, 1994c, unpub. data c, d). Divided into:

**Qap Pyroclastic deposits**—Reddish-black and brown cinder and scoria deposits similar in composition to Antelope Knoll Basalt. Includes glass fragments, augite, and olivine phenocrysts. Partly consolidated as welded tuff and scoria. Forms rounded cinder cone of Antelope Knoll about 140 m thick

**Qab Basalt flows**—Dark-gray, finely crystalline, alkali basalt; glassy groundmass. X-ray fluorescence spectrography shows sparse phenocrysts of olivine in groundmass dominated by plagioclase, augite, and glass (Wenrich and others, 1995). Flow surfaces are partly covered by pyroclastic deposits (Qap) within 1 to 2 km of Antelope Knoll. Overlies thin alluvium of tributaries to Clayhole Wash (outcrops too small to show at this map scale), the Harrisburg Member (Pkh) of the Kaibab Formation, and the Timpoweap Member ( $\bar{\text{T}}\text{mt}$ ) and lower red member ( $\bar{\text{T}}\text{ml}$ ) of the Moenkopi Formation. Basalts flowed east, then north as far as 17 km down ancestral tributary to Clayhole Wash drainage. Ranges from 2 to 15 m thick

**Basalt of Seven Knolls (Pleistocene)**—Informally named for Seven Knolls, an alignment of seven pyroclastic cones, including three more unnamed cones and Deadman Knoll (secs. 10, 15, 23, and 26, T. 37 N., R. 8 W.; Billingsley, 1994c, unpub. data d). Divided into:

**Qskp Pyroclastic deposits**—Reddish-brown and black, basaltic scoria and cinder deposits. Includes about 14 cinder cones or vent areas that form a small range of pyroclastic cones aligned parallel to subvertical bedrock joint system oriented N.  $10^\circ$  W. Ranges from 30 to 76 m thick

**Qskb Basalt flows**—Dark-gray, finely crystalline basalt. Groundmass composed of plagioclase, olivine, and augite; contains small phenocrysts of olivine. Includes several flows

from different pyroclastic cones that have coalesced into one thick flow that spread out in a radial pattern from Seven Knolls cones; most of the basalt flowed east and north into an ancestral Clayhole Valley drainage area. Flow surfaces partly covered by pyroclastic deposits (Qskp) within 2 km of cones. Forms protective caprock called Seven Knolls Bench that overlies gently east-dipping strata of middle and lower part of the Harrisburg Member (Pkh) of the Kaibab Formation, and the lower red member ( $\bar{\text{T}}\text{ml}$ ) and Virgin Limestone Member ( $\bar{\text{T}}\text{mv}$ ) of the Moenkopi Formation. Flows range from 2 to 40 m thick

**Basalt of Hat Knoll (Pleistocene)**—Informally named for Hat Knoll, a 132-m-high pyroclastic cone near Clayhole Valley (sec. 20, T. 37 N., R. 7 W.), Uinkaret Volcanic Field, northern Mohave County, Arizona (Billingsley, 1994e, unpub. data d). Divided into:

**Qhp Pyroclastic deposits**—Red to reddish-brown, basaltic scoria and cinder deposits; partly consolidated. Overlies basalt flows of Hat Knoll, the middle red member ( $\bar{\text{T}}\text{mm}$ ) and the Virgin Limestone Member ( $\bar{\text{T}}\text{mv}$ ) of the Moenkopi Formation. Forms the prominent 132 m high cinder cone of Hat Knoll

**Qhb Basalt flows**—Dark-gray, finely crystalline, alkali olivine basalt. Contains abundant olivine and plagioclase phenocrysts 1 to 5 mm in diameter. Includes a small basalt flow on the north and west sides of Hat Knoll. Majority of the basalt flowed east about 2.4 km. Basalt surface partly covered by pyroclastic deposits (Qhp) near Hat Knoll. Basalt overlies gently east-dipping strata of the middle red member ( $\bar{\text{T}}\text{mm}$ ), the Virgin Limestone Member ( $\bar{\text{T}}\text{mv}$ ), and the lower red member ( $\bar{\text{T}}\text{ml}$ ) of the Moenkopi Formation. Thickness, 4 to 60 m

**Basalt of Maryland Knoll (Pleistocene)**—Informally named for Maryland Knoll, a 92-m-high pyroclastic cone about 4 km south of Antelope Knoll, the type area in the Uinkaret Volcanic Field, northern Mohave County, Arizona (sec. 31, T. 38 N., R. 8 W.). Includes two vent areas and associated basalt flows (Billingsley, 1994f, unpub. data d). Divided into:

**Qmkp Pyroclastic deposits**—Red-brown and black basaltic scoria, glass, and cinders; unconsolidated. Forms pyroclastic cone of Maryland Knoll and small unnamed cone 0.3

	km southeast of Maryland Knoll. About 92 m thick		
Qmkb	<b>Basalt flows</b> —Dark-gray, finely crystalline basalt composed of plagioclase, olivine, and augite groundmass with olivine phenocrysts. Includes two pyroclastic vents that are 0.3 km apart and two basalt flows that flowed eastward to coalesce into one flow. Flow shares common boundary with or abuts against Antelope Knoll Basalt (Qab); appears to be partly overlain by the basalt of Seven Knolls (Qskb). Surface is partly covered by pyroclastic deposits (Qmkp) near Maryland Knoll. Overlies the Harrisburg Member (Pkh) of the Kaibab Formation. Flows extend about 3 km east of Maryland Knoll. Thickness, 2 to 20 m	Qcbp	<b>Pyroclastic deposits</b> —Gray and reddish-gray to black cinder, tuff, ash, and scoriaceous ejecta; partly consolidated. Overlies associated basalt flow. Thickness is about 115 m at Berry Knoll and 183 m at Craigs Knoll
	<b>Basalt of Moriah Knoll (Pleistocene)</b> —Informally named for Moriah Knoll, a 122-m-high pyroclastic and basaltic cone in Uinkaret Volcanic Field (secs. 7, 12, 18, and 13, T. 37 N., Rs. 8 and 9 W.), northern Mohave county, Arizona, about 3.5 km east of Hurricane Cliffs (Billingsley, 1994f, unpub. data d). Divided into:	Qcbb	<b>Basalt flows</b> —Light-gray and dark-gray, alkali-olivine basalt and andesite(?). Basalt flows that radiate out from Berry Knoll and Craigs Knoll appear to have erupted simultaneously because the flows coalesced into one general flow mass between both vent areas. Basalt from Berry Knoll flowed north about 2 km joining with basalt flows from Craigs Knoll. South of this map area, lavas from Craigs Knoll flowed about 8 km north and northeast down drainages eroded into the Harrisburg Member (Pkh) of the Kaibab Formation; may overlie the lower red member (Tml) of the Moenkopi Formation in some areas south of this map. Variable thickness, 3 to 20 m
Qmp	<b>Pyroclastic deposits</b> —Red-brown and reddish-black scoria, glass, and cinder deposits; unconsolidated. Includes thin, vesicular basalt flows in lower part (thickness unknown); forms Moriah Knoll pyroclastic cone. As much as 92 m thick		<b>Little Tanks Basalt (Pleistocene)</b> —Named for Little Tanks Reservoir, sec. 5, T. 36 N., R. 10 W., the type area, northern Mohave County, Arizona, south-central part of map area (Billingsley, 1993e). K-Ar whole-rock age is $1.0 \pm 0.4$ Ma (Billingsley, unpub. data b). Divided into:
Qmb	<b>Basalt flow</b> —Dark-gray to black, fine-grained, vesicular alkali basalt. Includes sparse, small phenocrysts of olivine and augite in groundmass dominated by plagioclase, augite, and glass. Vesicles commonly filled with calcite. Basalt is only flow in northern Uinkaret Volcanic Field that flowed over the Hurricane Cliffs and Hurricane Fault. Offset of basalt by the Hurricane Fault is 130 m; offset of underlying Paleozoic strata prior to the flow is 380 m. Ranges from about 3 to 30 m thick	Qlp	<b>Pyroclastic deposits</b> —Red-brown and black fragments of angular basaltic scoria deposits. Includes augite and olivine phenocrysts; unconsolidated. Forms unnamed pyroclastic cone. As much as 40 m thick
	<b>Craigs Knoll/Berry Knoll basalt (Pleistocene)</b> —Informally named from Craigs Knoll just south of this map about 5 km (sec. 4, T. 35 N., R. 8 W.), and Berry Knoll, southeast edge of this map (sec. 24, T. 36 N., R. 9 W.), the type area, Uinkaret Plateau, northern Mohave County, Arizona (Billingsley, 1994f, 1997b). Includes dikes, pyroclastic deposits, and basalt flows that appear to have erupted simultaneously at Craigs Knoll, Berry Knoll, and another unnamed cinder cone between Berry and	Qlb	<b>Basalt flow</b> —Dark-gray, finely crystalline, olivine basalt. Groundmass composed of plagioclase, olivine, and augite. Includes two areas of basalt flows that radiate out from dikes or vent areas. Flow surfaces partly covered by pyroclastic (Qlp) deposits. Overlies the Harrisburg Member (Pkh) of the Kaibab Formation, the lower red member (Tml) and the Virgin Limestone Member (Tmv) of the Moenkopi Formation, and older alluvial fan (Qao) deposits. Averages about 6 m thick
			<b>East Mesa Basalt (Pleistocene)</b> —Named for East Mesa, a narrow north-south-trending mesa on Shivwits Plateau near St. George Basin, north-central part of map area, sec. 31, T. 41 N., R. 10 W., the type area, northern Mohave County, Arizona. K-Ar age is $1.4 \pm 0.25$ Ma (Billingsley, 1992c, unpub. data a). Divided into:

Qep	<b>Pyroclastic deposits</b> —Red-brown cinder and scoria and dark-gray to black, angular, glassy basalt fragments; unconsolidated. Forms pyroclastic cones as much as 50 m thick	
Qeb	<b>Basalt flows</b> —Dark-gray, finely crystalline to glassy basalt; massive. Surface of basalt partly covered with fine-grained calcareous silt deposits and red-brown pyroclastic (Qep) deposits near vent areas. Overlies thin alluvium (not shown on map), and the Shnabkaib Member (Tms), middle red member (Tmm), and Virgin Limestone Member (Tmv) of the Moenkopi Formation. Basalt flowed mostly in northwesterly direction. Basalt and underlying strata offset 97 m by the Dutchman Draw Fault at north end of flow. Variable thickness, 9 to 55 m	
	<b>West Mesa Basalt (Pleistocene)</b> —Named for West Mesa, a narrow north-trending mesa on the Shivwits Plateau south of St. George Basin, north-central part of map area, sec. 19, T. 40 N., R. 10 W., the type area, northern Mohave County, Arizona. K-Ar age is $1.6\pm0.3$ Ma (Billingsley, 1992c, unpub. data a). Divided into:	
Qwp	<b>Pyroclastic deposits</b> —Red-brown to black, angular, glassy fragments of basalt and scoria. Includes two small basaltic deposits about 1.7 km south of the main basalt flows and pyroclastic deposits on West Mesa. Forms pyroclastic cones as much as 60 m thick	
Qwb	<b>Basalt flows</b> —Dark-gray basalt; finely crystalline groundmass. Consists of one or two flows with large columnar joints at base in some areas. Overlies the Virgin Limestone Member (Tmv), the lower red member (Tml), and the Timpoweap Member (Tmt) of the Moenkopi Formation, the Harrisburg Member (Pkh) of the Kaibab Formation, and young alluvial fan (Qay) deposits. Main flows radiate out from two large and one small pyroclastic vent areas; most of the basalt flowed northwest. Includes two small isolated basalt flows, dikes, and pyroclastic deposits 1.7 km south of south end of West Mesa. Base of flow is about 36 m lower than base of the East Mesa Basalt, which is about 1 km north. Thickness ranges from 1 to 35 m	
	<b>Older basalts, undivided (Pliocene)</b> —On Colorado Plateau, includes basalt capping Mustang Knoll and nearby unnamed knoll, Shivwits Plateau, south of Black Rock Mountain (Billingsley, 1994g). In Basin and Range, includes basalt flows defined by Bohannon and others (1991), Bohannon and Lucchitta (1991), Bohannon (1992), and Lucchitta and others (1995a, b), mainly in Grand Wash Trough area. K-Ar whole-rock ages of basalt flows in Grand Wash Trough area are $4.7\pm0.18$ Ma, $5.45\pm1.11$ Ma, and $6.87\pm0.20$ Ma (Reynolds and others, 1986). K-Ar ages of 6.85 Ma on flows 10 km south of map area in Grand Wash Trough and 3.8 to 3.79 Ma on flows 50 km south of map area at Sandy Point, Lake Mead, and Grand Wash Bay area reported by Damon and others (1978)	
	<b>Intrusive dikes</b> —Dark-gray, finely crystalline, olivine or andesitic basalt; plagioclase laths and glassy groundmass; vesicular. Weathers blue-gray, crumbly. Often eroded to present erosion surface. On Colorado Plateau, dikes are on Black Rock Mountain, south of Black Rock Mountain, and southwest of Mustang Knoll (central part of map area). In Basin and Range, includes numerous dikes between Black Rock and Mud Mountain in the upper Grand Wash Trough area	Ti
	<b>Basalt flows</b> —On Colorado Plateau, dark-gray, finely crystalline olivine basalt or andesitic basalt; plagioclase laths in glassy groundmass; columnar joints at base. Approximately 48 m thick at Mustang Knoll and 36 m thick at nearby unnamed knoll. Source of flows may be from Black Rock Mountain, but intrusive dikes located 1 to 2 km southwest of Mustang Knoll and unnamed knoll may be source area. In Basin and Range, medium- to dark-gray, finely crystalline olivine basalt; plagioclase laths in glassy groundmass; olivine crystals as much as 4 mm in diameter; vesicular. Includes upper and lower basalt flows of Mud Mountain (Lucchitta and others, 1995a, b). Forms single flow or, in places, as many as 10 flows locally as thick as 10 m each. Thickness ranges from 1.5 m to as much as 150 m	Tb
	<b>Pyroclastic deposits</b> —Red-brown, angular, olivine basalt fragments; unconsolidated. Associated with volcanic vent areas, overlies basalt flows south of Mud Mountain in Grand Wash Trough area. Thickness ranges from 15 to 24 m	Tbp
	<b>Seegmiller Mountain Basalt (Pliocene)</b> —Named for Seegmiller Mountain, northern Mohave County, Arizona, sec. 31, T. 40 N., R. 11 W., the type area, northern	

	<p>Mohave County, Arizona (Billingsley, 1990c; unpub. data a). K-Ar age is <math>2.35 \pm 0.31</math> and <math>2.44 \pm 0.51</math> Ma (Reynolds and others, 1986). Divided into:</p>		flows form resistant caprock over less resistant beds of the Chinle, Moenkopi, and Kaibab Formations. Basalt flows in northern part of Wolf Hole Mountain flowed in northerly direction. Ranges from 15 to 114 m thick
Tsp	<p><b>Pyroclastic deposits</b>—Red and black, scoriaceous cinder and ash deposits. Forms one pyroclastic cone capped by basalt in central part of Seegmiller Mountain, a small pyroclastic cone on east edge of mountain along Main Street Fault, and a small area near vent along Washington Fault north of Seegmiller Mountain. Includes interbedded pyroclastic deposits between basalt flows near vent areas. Variable thickness as much as 30 m</p>		<p><b>Black Rock Canyon Basalt (Pliocene)</b>—Formally named for Black Rock Canyon of Hurricane Wash, Shivwits Plateau, northern Mohave County, Arizona (sec. 33, T. 41 N., R. 10 W.). K-Ar age is <math>3.5 \pm 0.6</math> Ma (Billingsley, 1994b, unpub. data a)</p>
Tsb	<p><b>Basalt flow</b>—Dark-gray, finely crystalline olivine and augite basalt. Surfaces are blocky and partly covered with caliche, valley-fill (Qv), alluvial fan (Qay), and pyroclastic (Tsp) deposits. Overlies lower part of the Shnabkaib Member (<math>\bar{\text{T}}\text{ms}</math>) of the Moenkopi Formation at south end of Seegmiller Mountain, upper part of the Shnabkaib at north end. Basalt offset same amount as underlying strata as much as 50 to 70 m by the Main Street Fault and as much as 60 to 70 m by the Washington Fault. Consists of several flows from 30 m to as much as 60 m thick</p>	Tbrb	<p><b>Basalt flow(s)</b>—Dark-gray, finely crystalline, alkali olivine basalt; glassy groundmass. Contains sparse olivine phenocrysts. Source of flow(s) not certain, but probably near summit of bench mark labeled “Butte” on USGS Lizard Point 7.5' quadrangle, Mohave County, Arizona (elevation 5,104 ft), west of Black Rock Canyon (north-east quarter of map area). Basalt overlies east-dipping strata of the Shinarump (<math>\bar{\text{T}}\text{cs}</math>) and Petrified Forest Members (<math>\bar{\text{T}}\text{cp}</math>) of the Chinle Formation along the Hurricane Monocline. Basalt flowed east and appears to have stopped against Hurricane Cliffs fault scarp, then flowed north down Hurricane Wash. Most of basalt flow is severely distorted by landslides. Average thickness, about 8 m</p>
	<p><b>Wolf Hole Mountain Basalt (Pliocene)</b>—Named for Wolf Hole Mountain, the type area, northern Mohave County, Arizona, sec. 8, T. 39 N., R. 12 W. K-Ar age is <math>3.1 \pm 0.4</math> Ma (Billingsley, 1993g). Divided into:</p>		<p><b>Hobble basalt (Pliocene)</b>—Informally named from Hobble Canyon, the type area, Shivwits Plateau, northern Mohave County, Arizona, sec. 8, T. 37 N., R. 13 W. K-Ar age is <math>3.6 \pm 0.54</math> Ma (Billingsley, 1991d, 1994g)</p>
Twp	<p><b>Pyroclastic deposits</b>—Red-brown, glassy, cinders, scoria, and basaltic ribbon fragments; unconsolidated. Forms 60-m-high cone</p>	Thb	<p><b>Basalt flow</b>—Dark-Gray, finely crystalline, olivine basalt. Source of flow is large dike just west of Hobble Canyon drainage in Hobble Graben, sec. 4, T. 37 N., R. 13 W. (southwest quarter of map area). Flow erupted through the Shnabkaib Member (<math>\bar{\text{T}}\text{ms}</math>), and probably part of the upper red member (<math>\bar{\text{T}}\text{mu}</math>) of the Moenkopi Formation in Hobble Graben, then flowed southwest from and out of Hobble Graben onto the lower red member (<math>\bar{\text{T}}\text{ml}</math>) of the Moenkopi Formation and the Harrisburg Member (Pkh) of the Kaibab Formation. Basalt flowed down ancestral Jump Canyon drainage towards Grand Wash Cliffs (Billingsley, 1994g). About 9 m thick</p>
Twb	<p><b>Basalt flows</b>—Dark-gray, finely crystalline olivine basalt. Surfaces are blocky. Includes basalt flows of Mokaac Mountain, a northerly extension of Wolf Hole Mountain. Basalt sources probably erupted simultaneously from 12 vent areas that encompass Wolf Hole and Mokaac Mountains. Basalt flows overlain by thin alluvial valley-fill (Qv) deposits that accumulated in relatively flat drainage areas; valley-fill alluvium, containing calcrete-cemented silt, sand, and angular fragments of basalt, as much as 3 m thick at some locations; also overlain by pyroclastic deposits on Wolf Hole Mountain. Alluvial material may have a wind-transported origin, while stream erosion accumulated materials into shallow drainage valleys. Basalt</p>		<p><b>Black Rock Mountain Basalt (Pliocene)</b>—Named for Black Rock Mountain, the type area, Shivwits Plateau, northern Mohave County, Arizona, sec. 12, T. 39 N., R. 14</p>

W. (northwest quarter of map area). K-Ar age is  $3.7 \pm 0.6$  Ma (Billingsley, 1990a, 1993g)

Tbb

**Basalt flows**—Dark-gray, finely crystalline, olivine basalt flows. Matrix is andesine-labradorite laths, clinopyroxene, oxides, and olivine. Includes associated thinly scattered red pyroclastic deposits near vent areas (not mapped) and intrusive dikes near top of Black Rock Mountain. On Colorado plateau, east half of Black Rock Mountain, basalt flowed northward towards Low Mountain and the Virgin River canyon descending 550 m in 13 km, a gradient of 42 m/km; at south end of Black Rock Mountain, flows descended eastward 457 m in 7 km, a gradient of 65 m/km. Basalt forms north sloping unconformable caprock over the Shinarump Member (Tcs) of the Chinle Formation at southern part of Black Rock Mountain, transcending all members of the Moenkopi Formation to the Fossil Mountain Member (Pkf) of the Kaibab Formation. In Basin and Range, west half of Black Rock Mountain, basalt flowed southwestward down a valley along east side of Virgin Mountains over various rock strata from the Miocene rocks of the Grand Wash Trough to the Permian Kaibab Formation. Basalt descended 915 m in 32 km, a gradient of 46 m/km. Basalt flows are offset by faulting on Colorado Plateau, but not in Basin and Range. Numerous basalt flows range from 3 to 100 m thick

**Basalt of Diamond Butte (Pliocene)**—Informally named for Diamond Butte, the type area, Shivwits Plateau, northern Mohave County, Arizona, south-central part of map area (sec. 33, T. 37 N., R. 10 W.). Includes basalt flow on Twin Butte about 4 km east of Diamond Butte. K-Ar whole-rock age is  $4.3 \pm 0.6$  Ma (Billingsley, 1993f, unpub. data b). Divided into:

Tdb

**Basalt flow**—Dark-gray, massive, finely crystalline, olivine basalt. Groundmass contains sparse olivine phenocrysts. Consists of one, possibly two flows, that forms caprock for Diamond and Twin Buttes; flow at Diamond Butte overlies beveled beds of the lower part of the upper red member (Tmu) of the Moenkopi Formation and beveled beds of upper part of the upper red member at Twin Butte. Basalt flowed east over east-dipping strata; no basalt or

upper Moenkopi rocks preserved east of Hurricane Cliffs. Source of flow unknown, assumed to have originated from local feeder dikes at Diamond Butte now covered by landslide and talus debris. About 30 m thick

## SEDIMENTARY ROCKS

**Sedimentary rocks of the Grand Wash Trough and Mesquite Basin (Pleistocene and Miocene)**—Commonly referred to as the Muddy Creek Formation (Tmc) in the Mesquite Basin part of map area. Commonly referred to as rocks of the Grand Wash Trough in the grand Wash Trough area (Tgw). In the Mesquite Basin, northwest corner of map, Muddy Creek Formation (Tmc) includes all sedimentary rocks below pediment calcrete (Qpc) deposits (Billingsley, 1995; Billingsley and Bohannon, 1995). In Grand Wash Trough, rocks of the Grand Wash Trough (Tgw) include sediments deposited in closed basins not connected to the Muddy Creek Formation type section and all sedimentary rocks beneath lowest basalt flows (Tb and Tbb) and above the Rainbow Gardens Member (Thrl, Thrt, and Thrc) of the Horse Spring Formation (Bohannon, 1991; Beard, 1996)

Tmc

**Muddy Creek Formation**—In Mesquite Basin, Muddy Creek consists of pinkish-red, gray, and white, fine-grained, thinly laminated, thick- to thin-bedded, calcareous, gypsiferous, slope-forming sandstone and siltstone interbedded with localized calcrete soil zones and locally includes channel lenses of thin-bedded, medium- to coarse-grained, low-angle cross-stratified sandstone. Calcrete beds, 1 to 2 m thick contain carbonate nodules as large as 20 cm in diameter. Locally includes unsorted, thick beds of cross-stratified quartzite conglomerate and coarse-grained sandstone of multicolored, very well rounded chert, quartzite, limestone, and dolomite cobbles and pebbles. Along Virgin River and Beaver Dam Wash, includes dark-gray to brown, cliff-forming conglomerate, gravel, and sandstone; poorly sorted, moderately well bedded. Clasts composed of reddish-brown, brown, red, grayish-green, and light-green, well-rounded rhyolite, black schist, gneiss, gabbro, diorite,

	red pegmatite, granite, white quartz, gray limestone and dolomite, red sandstone, and dark-gray basalt. Boulders as large as 43 cm in diameter; contains calcite cement. Unconformably overlies or intertongues with fine-grained sediments of the Muddy Creek		
Tgw	<b>Rocks of the Grand Wash Trough (informal name)</b> —Composed of a lower conglomerate facies and an upper sandstone and siltstone facies, undivided. Lower conglomerate facies consists of a light-gray and brown, ledge and slope-forming conglomerate; poorly sorted, poorly bedded. Clasts locally derived from Virgin Mountain area of Proterozoic gneiss and Paleozoic carbonate rocks. Intercalated with sandstone and siltstone facies. Variable thickness, conglomerate may be locally as thick as 600 m in subsurface. Upper sandstone and siltstone facies consists of pinkish-red to orange-red, slope-forming sandstone, siltstone, and minor amounts of conglomerate. Sandstone is medium- to fine-grained, gypsiferous, silty and clayey carbonate matrix. Conglomerate beds contain small subrounded to angular clasts of Proterozoic crystalline rocks; clasts are well sorted, matrix supported, and commonly found on crossbed surfaces. Upper sandstone and siltstone facies thickness ranges from 0 to 450 m, thickening southeastward. Rocks of the Grand Wash Trough unconformably overlie members of the Horse Spring Formation as an angular unconformity (Beard, 1996). About 62 m exposed along Virgin River		
	<b>Rainbow Gardens Member of the Horse Spring Formation (Miocene)</b> —Named the Cottonwood Wash Formation by Moore (1972), but because these rocks have close lithologic and stratigraphic similarity to the Rainbow Gardens Member of the Horse Spring Formation, this usage is followed herein as used by Bohannon (1984). Divided into:		
Thrl	<b>Limestone unit</b> —Pale-brown, pinkish-white, and light-gray, medium- to coarse-grained, thin- to medium-bedded, crystalline, cliff-forming limestone and intraformational limestone breccia; nonmarine, lacustrine. Wavy, parallel, and continuous beds about 0.1 to 1 m thick. Gradational contact with underlying Tuffaceous limestone unit. About 75 to 100 m thick	Thrt	<b>Tuffaceous limestone and sandstone unit</b> —Green to white tuffaceous, cliff-forming limestone and crystalline limestone interbedded with green to light-brown, ledge-forming calcareous sandstone and tuffaceous sandstone and slope-forming white claystone. Unit is nonmarine and airfall-tuff beds are rare. Tuffaceous limestone beds are 2- to 50-cm thick; calcareous sandstone and tuffaceous sandstone beds are 0.5 to 1 m thick; laminated claystone beds are 1 to 5 m thick; claystone beds more common in upper part. Sandstone is conglomeratic in places with small, rounded clasts of chert, quartzite, and carbonate fragments (probably Paleozoic) in carbonate matrix. Unconformable contact with underlying conglomerate unit. 50 to 100 m thick
		Thrc	<b>Conglomerate unit</b> —Brown and red-brown, nonmarine, cliff-forming, well-sorted conglomerate. Bedding is poorly defined and discontinuous. Clasts are subrounded to subangular cobbles and pebbles from 1 to 70 cm in diameter. Conglomerate is clast supported in sandy, calcareous matrix. Unconformable contact with the Willow Tank Formation (Kwt). 3 to 50 m thick
		Kwt	<b>Willow Tank Formation (Lower Cretaceous)</b> —Outcrops in Grand Wash Trough, east flank of Virgin Mountains, Basin and Range. Red, gray, brown, and tan, nonmarine claystone, siltstone, sandstone, and conglomerate. Conglomerate occurs mostly at base as discontinuous unit, but also occurs throughout formation in small amounts. Named the Jacobs Ranch Formation by Moore (1972), but called the Willow Tank Formation by Bohannon (1991) because of its close lithologic similarity to the Willow Tank Formation in North Muddy Mountains, 60 km west of this map area in southern Nevada (Longwell, 1949). Unconformable contact with the underlying Navajo Sandstone. About 60 m thick
		JĴrn	<b>Navajo Sandstone (Jurassic and Triassic?)</b> —Outcrops in Grand Wash Trough, east flank of Virgin Mountains, Basin and Range. Red and less commonly pale-yellow to white, cliff-forming, fine-grained, well-sorted, quartz arenite sandstone; eolian. Discontinuous, nonparallel beds with large-scale (as much as 10 m thick) planar cross-stratification. Sand grains are frosted, very well rounded quartz. Correlative with, and

lithologically identical to, the Aztec Sandstone of southeastern Nevada. Gradational and intertonguing contact with the underlying Kayenta and Moenave Formations, arbitrary map boundary. About 850 to 1,100 m thick

**TKm Kayenta and Moenave Formations, undivided (Upper Triassic?)**—Outcrops in upper Grand Wash Trough of Basin and Range, and north of this map in St. George Basin area. Upper part is the Kayenta Formation; red, fine-grained, thick-bedded, very well sorted, ledge- and slope-forming sandstone and siltstone. Includes large-scale cross-stratification sets similar to that of the Navajo Sandstone; interbedded with thin-bedded, fine-grained sandstone and red siltstone. Gradational and arbitrary contact between the Kayenta and Moenave Formations. Lower part is the Moenave Formation; brick red and dark-red, fine-grained, well-sorted, slope-forming sandstone and siltstone. Low-angle cross-stratification common in sandstone beds. Gradational contact with the underlying Chinle Formation, arbitrary map boundary placed at top of first white carbonate beds or purple siltstone beds of the Chinle. Combined thickness about 170 m

**Chinle Formation (Upper Triassic)**—Includes, in descending order, the Petrified Forest and Shinarump Members as used by Stewart and others (1972). Outcrops mapped in Black Rock and Virgin Mountain area of Basin and Range and north edge of map in St. George Basin and Uinkaret Plateau of Colorado Plateau. Divided into:

**TKcp Petrified Forest Member**—White, blue-gray, green-gray, pale-red, and purple-red, slope-forming mudstone, siltstone, and coarse-grained sandstone. Contains bentonitic clays derived from decomposition of volcanic ash. Only lower part of unit is exposed in map area (northeast corner). Mostly covered by stream-channel alluvium (Qs), dune sand (Qd), floodplain (Qf), young alluvial terrace (Qgy), and colluvial (Qc) deposits. Unconformable contact with the underlying cliff-forming Shinarump Member; locally fills channels eroded into the Shinarump Member. About 60 m thick

**TKcs Shinarump Member**—Orange-brown, black, tan, cliff-forming, cross-stratified to massive-bedded, coarse-grained, pebble conglomerate and conglomeratic sandstone. Weathers brown or black. Includes lenses

or channel-fill troughs of pebbles and cobbles composed of well-rounded quartzite, black metamorphic clasts, and chert in coarse-grained sandstone matrix. About 30 percent of clasts are black, well-rounded quartzite or chert. Includes flat-bedded and medium-trough cross-bedding sets of medium-grained sandstone and conglomerate. Includes petrified wood fragments and logs. Unconformable contact with the underlying upper red member (TKmu) of the Moenkopi Formation, fills erosional channels as much as 5 m deep. Unit mined for natural stone in quarries, for “picture stone” in upper part. Picture stone is light-red to brown, coarse-grained, cross-bedded, sandstone that contains prominent red and black iron-stained Liesegang banding. Variable thickness as channel fill, thickest at Lost Spring Mountain, where it forms resistant caprock of Lost Spring Mountain (northeast corner of map). Thickness ranges from 0 to 55 m

**Moenkopi Formation (Middle? and Lower Triassic)**—Divided into, in descending order, the upper red, Shnabkaib, middle red, Virgin Limestone, lower red, and Timpoweap Members as used by Stewart and others (1972). Boundary between Middle? and Lower Triassic lies within the upper red member (Morales, 1987). Formation as a whole gradually thickens northwesterly across map area. Divided into:

**TKmu Upper red member (Middle? and Lower Triassic)**—Heterogeneous sequence of cliff- and slope-forming red conglomerate, sandstone, siltstone, mudstone, and minor gray gypsum. Erosional unconformity at bottom of lowest red sandstone cliff (middle part of unit) at Lost Spring Mountain has relief as much as 2 m and may represent boundary between Middle and Lower Triassic (not shown on map). Most complete and thickest exposure is at Lost Spring Mountain (northeast corner of map), limited exposure elsewhere due to erosion and landslide-debris cover such as at Black Rock, Wolf Hole, Seegmiller, and Little Black Mountains (north-central part of map). Arbitrary contact with the underlying Shnabkaib Member placed in slope at top of highest thick white siltstone and dolomite bed of the Shnabkaib. Top of unit beveled by erosion. Unit thickens from about 30 m, southwestern part of map, to about 73 m

	at Lost Spring Mountain area		
Ƨms	<b>Shnabkaib Member (Lower Triassic)</b> —Interbedded and intertonguing, white, light-gray, laminated, slope-forming, aphanitic dolomite, silty gypsum, and red siltstone. Includes red, thin-bedded mudstone, siltstone, and sandstone beds in lower and upper part. Exposed locally below late Pliocene basalt-capped mountains in north-central part of map and at Lost Spring Mountain. Gradational contact with the middle red member placed at base of lowest bed of white or light-gray dolomitic limestone or gypsiferous siltstone of the Shnabkaib Member. Thickness variable because of arbitrary contacts; regionally thickens northwesterly across map area from 115 to 210 m		stone, gray limestone, green mudstone, and brown platy calcarenite. Basal limestone bed contains abundant small echinoderm columnals with star shaped interiors and small, poorly preserved brachiopods in top part of bed, and fossil algae in next two upper limestone beds. Limestone beds thickest at north edge of map, thinning to two limestone beds at south edge of map. Lowest limestone bed is thickest and most extensive in map area. Unconformable contact with the lower red member. Lowest limestone bed thickens and thins as part of channel fill cut into the lower red member as much as 3 m deep in northeast quarter of map area. Unit as a whole thickens northward across map area from about 25 to 60 m
Ƨmm	<b>Middle red member (Lower Triassic)</b> —Red-brown, thin-bedded, slope-forming, laminated siltstone and sandstone, white and gray gypsum, minor white platy dolomite, green siltstone, and gray-green to red gypsiferous mudstone. Includes abundant veinlets of gypsum in siltstone. Gradational contact with the Virgin Limestone Member placed at top of highest gray limestone bed of the Virgin Limestone Member. Unit gradually thickens northeasterly across map area from 45 to 55 m	Ƨml	<b>Lower red member (Lower Triassic)</b> —Red, thin-bedded, slope-forming, sandy siltstone, interbedded with gray, white, and pale-yellow laminated gypsum and sandstone. Lower beds contain reworked gypsum and siltstone of the Harrisburg Member (Pkh) of the Kaibab Formation. Lower part includes a marker bed of reddish-gray, coarse-grained to conglomeratic, thin-bedded, calcareous, low-angle cross-stratified, ledge-forming sandstone 2 to 4 m thick from Hurricane Cliffs eastward. Marker bed includes raindrop impressions and rare carbonaceous plant fossils stained green by malachite copper minerals near Short Creek (northeast quarter of map). Interbedded or gradational contact with underlying limestone, sandstone, or conglomerate of the Timpoweap Member (Ƨmt); otherwise unconformable contact with the Harrisburg Member (Pkh) of the Kaibab Formation. Locally fills paleovalleys eroded into the underlying Kaibab Formation or pinches out onto paleohills of the Kaibab. Thickness ranges from 0 to 85 m with thickest deposits in northeast quarter of map area
Ƨsu	<b>Upper red member, Shnabkaib Member, and middle red member, undivided (Middle? and Lower Triassic)</b> —In Grand Wash Trough area, used where the upper red, Shnabkaib, and middle red cannot be easily differentiated from one another, or where one or more of those members are absent or covered. Lithologic descriptions are same as above. Units are generally slope-forming; have conformable contact with the underlying Virgin Limestone Member (Ƨmv) or undifferentiated lower part of the Moenkopi Formation (Ƨmb). Units dip southeast along east flank of Virgin Mountains and are mostly covered by alluvial deposits. Unit as a whole thickens northward to about 235 m		
Ƨmv	<b>Virgin Limestone Member (Lower Triassic)</b> —Consists of three and sometimes four, light-gray, thin-bedded to thinly-laminated, ledge-forming limestone beds, 1 to 22 m thick, separated by slopes of white to pale-yellow, red, and blue-gray, thin-bedded, gypsum and gypsiferous siltstone. Includes thin beds of brown, red, and green silt-	Ƨmt	<b>Timpoweap Member (Lower Triassic)</b> —On Colorado Plateau area, includes an upper and lower part. Upper part consists of gray, cliff-forming, light-gray, fine-grained, thick-bedded sandy limestone as much as 3 m thick overlying conglomerate in eastern-most outcrops; includes gray, interbedded, coarse-grained, low-angle cross-bedded sandstone locally containing small chert pebbles. Lower part consists



mainly of cliff- and slope-forming, gray, dark-gray, white and red-brown conglomerate consisting of subangular to rounded pebbles and cobbles of limestone, chert, and quartzite derived from the Kaibab Formation. Includes yellow, red-brown, interbedded, calcareous, thin-bedded, cross-stratified, sandstone, siltstone, gray gypsiferous siltstone, and yellow to gray, thin-bedded sandy limestone. Conglomerate is pebble-supported in most areas with pebbles compressed into one another; where matrix-supported, matrix is gray limestone and coarse-grained sandstone. Conglomerate clasts are as much as 30 cm in diameter throughout map area. Unconformable contact with the underlying Harrisburg (Pkh) and Fossil Mountain (Pkt) Members of the Kaibab Formation as Triassic paleovalleys (fig. 1, on map sheet). Imbrication of pebbles in conglomerate indicates easterly flow of depositing streams. Average paleovalley width is about 305 m at bottom with sloping paleovalley walls that widen upward to about 490 m or more. Paleovalley depths range from about 45 to 110 m. Paleovalley names (fig. 1, on map sheet) are from Billingsley (1990a, b, c, d; 1991a, b). Rock Canyon Conglomerate was proposed and abandoned by Gregory (1948, 1952), used by Nielsen and Johnson (1979), and Nielsen (1986, 1991). Timpoweap Member of the Moenkopi Formation is used in this report as used by Stewart and others (1972). Unit as a whole thickens from west to east across map area and is largely confined to narrow deeper paleovalleys in western part of map, more widespread and confined to shallower paleovalleys in eastern part of map. Thickness ranges from 0 to as much as 110 m

Ṛmb

**Basal members, Virgin Limestone Member and lower red member, undivided (Lower Triassic)**—In Grand Wash Trough area, used where the Virgin Limestone Member and lower red member cannot be easily differentiated from one another or where one or more of those members are absent. Virgin Limestone Member; light olive-gray to light-gray, ledge- and slope-forming, aphanitic to very finely crystalline, thinly laminated limestone beds that range from about 10 cm to 1 m thick, separated by brownish-gray, greenish-gray, and light olive-gray siltstone. Limestone beds contain

marine fossils of crinoids, pelecypods, gastropods, cephalopods, worm trails, and crustaceans (Poborski, 1954). Lower red member; grayish-red and light-brown, gypsiferous, ripple-laminated, slope-forming siltstone and cross-stratified sandstone. In places, includes conglomerate at base that may be the Timpoweap Member of the Moenkopi Formation, but not differentiated. Unconformable contact with the Kaibab Formation difficult to locate because of similar lithologies between the Harrisburg Member (Pkh) of the Kaibab and the lower red member (Ṛml) of the Moenkopi Formation. Average thickness, about 70 m

Ṛmlt

**Lower red member and Timpoweap Member undivided (Lower Triassic)**—On Colorado Plateau, same lithologies as the lower red member (Ṛml) and the Timpoweap Member (Ṛmt) of the Moenkopi Formation as interbedded mixed lithologies. Fills shallow paleovalleys eroded into the Harrisburg Member (Pkh) of the Kaibab Formation that form tributary paleovalleys to major paleovalleys. Unconformable contact with the Harrisburg Member (Pkh) of the Kaibab Formation; unit locally eroded away or obscured where overlain by alluvial deposits. Variable thickness 5 to 20 m

**Kaibab Formation (Lower Permian)**—Divided into, in descending order, the Harrisburg and Fossil Mountain Members as defined by Sorauf and Billingsley (1991). Formation as a whole thickens northwestward across map area. Divided into:

Pkh

**Harrisburg Member**—Includes an upper, middle, and lower part. Upper part consists mainly of slope-forming, red and gray, gypsiferous siltstone, sandstone, gray gypsum, and thin-bedded gray limestone. Includes caprock of resistant, pale-yellow or light-gray, fossiliferous (mollusks and algae) sandy limestone averaging about 1 m thick that weathers black or brown (Billingsley, 1970). Upper part is mostly eroded from west two-thirds of map area and locally covered by basalt. Thickest deposits are as much as 50 m in St. George Basin area; unit gradually thins southward across map area. Gradational contact with middle part. Middle part consists of two cliff-forming limestone beds that together gradually thicken from 6 m to as much as 14 m southeastward across map area. Top

bed is gray, thin-bedded, cherty limestone that weathers dark brown or black, often forming bedrock surface of the exposed Harrisburg Member (Pkh) on Colorado Plateau. Bottom bed is light-gray to white, thick-bedded, sandy limestone separated from top bed by thin-bedded gypsiferous sandstone. Both beds thicken and thin at expense of each other; bottom bed fills erosional channels as much as 4 m deep. Erosional unconformity separates middle part from lower part. Lower part consists of slope-forming, light-red, fine- to medium-grained gypsiferous siltstone and sandstone; interbedded with gray, medium-grained, thin-bedded limestone and gray to white, massive-bedded gypsum. Lower part maintains uniform thickness across map area of about 40 m, gradually thinning south-eastward. Solution of gypsum in lower part has locally distorted limestone beds of middle part causing them to slump or bend into local drainages. Gypsum is mined from lower part about 5 km south of Interstate Highway 15, northwestern part of map area. Gradational contact between the slope-forming Harrisburg Member and the cliff-forming Fossil Mountain Member. Harrisburg Member locally removed by erosion of paleovalleys and subsequently filled by the Timpoweap and the lower red members (Tmt and Tml) of the Moenkopi Formation (fig. 1, on map sheet). Harrisburg deposits occupy wide northwest-trending trough-like embayment across map area; thickest deposits as much as 107 m in northwest quarter of map; as much as 80 m thick in central Grand Canyon area (Billingsley, 1970)

Pkf

**Fossil Mountain Member**—Yellow-gray to light-gray, fine- to medium-grained, thin-bedded, cliff-forming, fossiliferous, sandy, cherty limestone. Unit characterized by black-weathering chert bands in cliff outcrops. Intergrades with the overlying Harrisburg Member; arbitrary contact placed at uppermost cherty limestone cliff, which is difficult to locate in flatland exposures. Locally cut into by paleovalley erosion and subsequently filled with deposits of the Timpoweap Member (Tmt) and the lower red member (Tml) of the Moenkopi Formation. Unconformable contact with the underlying Woods Ranch Member (Ptw) of the Toroweap Formation.

Unconformity has local relief of as much as 4.6 m; contact mostly covered by talus and landslide debris. Unit as a whole maintains uniform thickness throughout map area averaging about 92 m, gradually thinning east and south of map area and thickening southwestward (86 m thick in central Grand Canyon [Billingsley, 1970])

**Toroweap Formation (Lower Permian)**—On Colorado Plateau, divided into, in descending order, the Woods Ranch, Brady Canyon, and Seligman Members as defined by Sorauf and Billingsley (1991). In Basin and Range, divided into, in descending order, the Woods Ranch Member and lower part which includes the Brady Canyon and Seligman Members undivided (Bohannon and others, 1991):

Ptw

**Woods Ranch Member**—Gray gypsiferous siltstone and pale-red silty sandstone interbedded with white to gray, laminated to massive-bedded gypsum. Commonly covered by talus and landslide debris. Gradational contact with the underlying Brady Canyon Member is placed at lithologic break between limestone cliff of the Brady Canyon Member (Ptb) and siltstone-gypsum slope of the Woods Ranch Member (Ptw). Much local subsidence and distortion of beds from solution of gypsum within unit. Thickest deposits (110 m) are along Hurricane Cliffs, east-central part of map area, gradually thinning east, west, and south from this area. Locally thins and thickens from 30 to 110 m owing to solution of gypsum

Ptb

**Brady Canyon Member**—Gray, fossiliferous, medium-bedded, medium- to coarse-grained, cliff-forming limestone, weathers dark-gray. Includes thin beds of dolomite in upper and lower parts. Gradational contact with the underlying Seligman Member; contact placed at lithologic and topographic break between cliff-forming limestone and slope-forming sandstone. Thickest deposits are along the Grand Wash Cliffs, southwest quarter of map area (about 90 m), gradually thinning eastward to about 65 m, central Grand Canyon area (Billingsley, 1970)

Pts

**Seligman Member**—Gray, thin-bedded, ledge-forming sandy limestone in upper part; gray to red, slope-forming, thin-bedded, interbedded calcareous and gypsiferous sandstone, siltstone, silty limestone,

dolomite, and gypsum in middle part; and brown, purple, and yellow, slope-forming, fine- to medium-grained, thin-bedded, low- to high-angle crossbedded and planar-bedded sandstone in lower part. Includes gray-brown, cliff-forming, high-angle crossbedded sandstone bed in lower part that thickens and thins along Grand Wash Cliffs northward to Virgin River Canyon, and thickens westward to form large cliff as much as 50 m high in Virgin Mountains area; often called the Coconino Sandstone (Bohannon, 1991; Bohannon and others, 1991; Billingsley, 1997b). Recent mapping by Billingsley (unpub. data d) suggests that the Coconino Sandstone may intertongue with the Seligman Member (Pts) of the Toroweap Formation. Overall, unit forms steep slope. Erosional contact with the underlying Hermit Formation placed between gray-brown, high-angle, cross-bedded sandstone, or slope-forming, gypsiferous, flat-bedded sandstone of the Seligman Member (Pts) and red or pale-yellow, thick-bedded, ledge-forming sandstone of the Hermit Formation (Ph). Thickness ranges from 8 to 50 m

**Ptl Toroweap Formation, lower part undivided—**  
Includes the Brady Canyon and Seligman Members (Ptb and Pts) as defined above, but combined in Basin and Range area of map because the Seligman Member is too thin to show at this map scale (Bohannon and others, 1991). Combined thickness about 70 m

**Ph Hermit Formation (Lower Permian)—**Consists of an upper steep-slope-forming, pale-yellow to light-red, massive, calcareous, fine-grained sandstone, grading downward into a middle sequence of ledge-forming, interbedded white and light-red, medium-bedded, fine-grained sandstone and thin-bedded red siltstone, grading downward into lower cliff-forming, white, cross-bedded, medium- to fine-grained sandstone; lower part includes interbedded dark-red, thin-bedded, lenticular siltstone beds between cross-bedded sets. Most, if not all sandstone was originally a light-red color, later bleached to white or pale-yellow. Unit as whole is slope forming, coarse grained, and stratigraphically equivalent to Hermit Formation (Shale) in Grand Canyon. Unit changes south and west into a mostly red, medium- to fine-grained sand-

stone and siltstone, and changes northwestward to an all white sandstone in the Virgin River canyon area (Billingsley, 1997b). Informally includes an upper sandstone unit, a middle sandstone and siltstone unit, and a lower sandstone unit. Upper unit is about 60 m thick in the Virgin River canyon, thickens northwestward and thins south and southeastward; middle unit is a sandstone and siltstone sequence, about 213 m in Virgin River canyon area, thickens northwestward and thins southeastward. Lower unit is 60 m thick and equivalent to upper slope units of the Esplanade Sandstone of McKee (1982) in western and central Grand Canyon, but is included as part of the Hermit Formation in this map area; lower 60 m thins southeastward and thickens northwestward. Arbitrary contact between the Hermit Formation and the Queantoweap Sandstone placed at lowest red siltstone bed in cliff of white sandstone in Virgin River canyon area, erosional contact at base of red slope-forming sandstone-siltstone sequence and top of white sandstone cliff of the Esplanade Sandstone along the Grand Wash and Hurricane Cliffs. Unit as a whole thickens west and northwestward (thickness unknown), thins southeastward to about 200 m in central Grand Canyon (Billingsley, 1970), and thins northeastward to about 137 m along upper Hurricane Cliffs area (Billingsley, 1997b). Maximum thickness, Virgin River canyon, about 333 m

**Pep Esplanade Sandstone and Pakoon Limestone (Lower Permian)—**On Colorado Plateau, light-brown to light-red, white, fine- to medium-grained, thick cross-bedded (sets 3 to 12 m thick), cliff-forming sandstone. The name Esplanade Sandstone is restricted to the Grand Wash Cliffs, Grand Canyon, and the Hurricane Cliffs of the Colorado Plateau; includes the Pakoon Limestone of McNair (1951) that intertongues into the basal part of the Esplanade Sandstone of McKee (1982). Pakoon Limestone is gray, medium- to coarse-grained, thin-bedded, cliff-forming limestone and sandy dolomite; weathers brown-gray with sugary texture. Limestone and dolomite beds separated by gray-purple, thin-bedded siltstone and sandstone beds; limestone is fossiliferous in upper part; includes lenses and pods of brown chert. Locally trough cross-

stratified. The Pakoon Limestone is included in the upper part of the Callville Limestone (or the Bird Spring Formation) in the Virgin River canyon area and Virgin Mountain area (Bohannon and others, 1991). The Pakoon Limestone intertongues with lower part of the Esplanade Sandstone along Hurricane Cliffs and in western Grand Canyon areas. Forms a disconformable contact with the underlying Callville Limestone that is difficult to locate; contact can be narrowed down by fossil faunas between Lower Permian and Upper Pennsylvanian types. Thickness about 137 m along Grand Wash Cliffs. Equivalent to the Queantoweap Sandstone at Virgin River canyon and Virgin Mountain area (Billingsley, 1997b). Unit is 175 m thick along Hurricane Cliffs, north-eastern part of map area, thinning southward to about 115 m thick in central Grand Canyon (Billingsley, 1970); about 160 m thick along Grand Wash Cliffs

**Pq Queantoweap Sandstone (Lower Permian)—**In Virgin Mountains and Virgin River canyon (northwest quarter of map area): tan and white, fine-grained to very fine grained, medium- to thick-bedded (2 to 3 m), cross-stratified cliff- or ledge-forming sandstone. Includes pale-red, thin-bedded silty sandstone beds between cross-bedded sets in upper part. Cross-stratification includes mixed high-angle and low-angle cross-stratified sets representing both eolian coastal or marine offshore dune environment. Locally includes gypsiferous facies of Bohannon and others (1991). Locally confined to small area north of Virgin River canyon, northwest corner of map area: red-brown, red, gray-brown, and yellow-brown, silty, sandy, slope-forming gypsum. Gypsum comprises about 20 to 30 percent of unit. Bedding irregular and poorly defined. This is only place where gypsum is present in the Queantoweap Sandstone, Pakoon Limestone, and Callville Limestone regionally. May have once been more widespread, but, if so, has been removed from most areas by dissolution (Bohannon and others, 1991). Gradational contact with underlying gypsiferous unit (PPcg) and the upper Callville Limestone (PIPc), 0 to 100 m thick. The name Queantoweap Sandstone applies to the Virgin River canyon, Virgin Mountains, and Beaver Dam Mountains of southeastern Nevada and southwestern Utah

(Billingsley, 1997b). Unit thickens north-westward from the Virgin River becoming indistinguishable from, and including, overlying sandstone beds of the Hermit Formation. The Queantoweap Sandstone may need to be renamed in future studies north of Virgin River canyon because the term "Queantoweap" is an obsolete Grand Canyon term (replaced by the term Esplanade Sandstone). About 124 m thick at Virgin River canyon

**Callville Limestone (Lower Permian; Upper, Middle, and Lower Pennsylvanian)—**In Basin and Range, Virgin Mountains, and Virgin River canyon areas, upper part includes rocks mapped as the Pakoon Limestone, and lower part includes rocks mapped as the Callville Limestone by Hintze (1986); also includes rocks mapped as the Bird Spring Formation by Bohannon and others (1991). Divided into:

**PIPc Limestone, cherty limestone, arenaceous limestone, and calcareous sandstone—**Gray, light-gray, and white, thin- to medium-bedded (0.5 to 1 m thick), ledge-forming arenaceous limestone; weathers brown and yellow-brown; chert pods and lenses are brown. Cross-bedding common in sandstone and sandy limestone beds. Cherty limestone is about 10 to 30 percent of formation; arenaceous limestone and calcareous sandstone interbedded with limestone form about 10 to 20 percent of formation. Basal 10 m of formation is slope-forming silty limestone and reddish-weathered siltstone. Unit highly fossiliferous in west half of map and gradually thickens westward across map area. Average thickness about 360 m

**PIPcg Gypsiferous facies—**Gray, thin-bedded (1 m to 20 cm thick), slope-forming, gypsiferous dolomite alternating with white gypsum beds. Unit is present in upper part of the Callville Limestone (Pakoon Limestone equivalent) and restricted geographically to same area as gypsiferous facies of lower part of the Queantoweap Sandstone. Facies is an uncommon local occurrence of evaporite deposition of the Callville Limestone. Grades laterally into gray limestone of the Callville Limestone. Lower part of the Callville may, in part, be Early Mississippian age based on Mississippian conodonts in the Watahomigi Formation of the Supai Group in Grand

		Canyon (Martin and Barrick, 1999). Erosional and topographical contact between slope-forming siltstone-limestone beds of the Callville Limestone and the cliff-forming Redwall Limestone. 0 to 100 m thick	
Mr		<b>Redwall Limestone (Upper and Lower Mississippian)</b> —Equivalent to the Monte Cristo Limestone of Basin and Range (Hewett, 1931). Consists of four members in Grand Canyon as described by McKee (1963). Undivided members include, in descending order, the Horseshoe Mesa Member (lithologic equivalent to the Yellowpine Member of the Monte Cristo Limestone; basal part lithologic equivalent to the Arrowhead Member of the Monte Cristo Limestone); the Mooney Falls Member (lithologic equivalent to the Bullion Member of the Monte Cristo Limestone); the Thunder Springs Member (lithologic equivalent to the Anchor Member of the Monte Cristo Limestone); and the Whitmore Wash Member (lithologic equivalent to the Dawn Member of the Monte Cristo Limestone). Horseshoe Mesa Member: brownish-gray, medium-grained, thin-bedded (0.5 to 1 m thick), ledge and cliff-forming limestone; includes minor amounts of brownish chert nodules and lenses. Basal part is dark-gray, very thin bedded (10 to 20 cm thick), aphanitic, recessive, 10-m-thick limestone; weathers yellowish-brown. Mooney Falls Member: medium-gray, medium- to coarse-grained, massive to thick-bedded, cliff-forming, bioclastic limestone. Thunder Springs Member: medium-gray, medium- to coarse-grained, thin-bedded, cliff-forming, bioclastic limestone interbedded with white to gray chert lenses and beds that weather brown or black. Chert lenses and beds 5 to 20 cm thick; amount of chert varies from 20 to 50 percent of member. Whitmore Wash Member: medium to dark-gray, very coarse grained to coarse-grained, massive, cliff-forming, crystalline and bioclastic limestone and dolomite; weathers light-gray. The Redwall Limestone forms single uniform cliff that generally appears unbedded from distance except where chert bands of the Thunder Springs Member are present. Unconformable contact with the underlying Temple Butte Formation. Averages about 213 m thick	
	Dtb	<b>Temple Butte Formation (Upper and Middle Devonian)</b> —As defined by Beus (1980). Mapped as unnamed limestone and dolomite (Bohannon, 1991; Bohannon and others, 1991). Exposed in Virgin and Beaver Dam Mountains, northwest quarter of map area. Dark-gray and medium-gray, medium- to fine-grained, sugary textured, medium-bedded (0.4 to 2 m thick), ledge-forming dolomite. Includes thin purple-gray siltstone and calcareous sandstone beds between larger dolomite beds. Probably equivalent to the Valentine Member and part of the Crystal Pass Member of the Sultan Limestone of Hewett (1931). The unconformity at the base of the Temple Butte represents a major break in the Paleozoic rock sequence during the Late Cambrian, most or all of the Ordovician, all of the Silurian, and most of the Early and Middle Devonian time. Thickness ranges from about 60 to 120 m thick	
	En	<b>Nopah Formation (Upper Cambrian)</b> —As mapped by Bohannon (1991), and Bohannon and others (1991). Light-gray, medium-grained, thin-bedded, ledge-forming dolomite. Base of unit contains yellowish to brownish-gray, thin-bedded, discontinuous, slope-forming sandy dolomite that weathers dark or medium brown. This basal unit may be the Dunderberg Shale Member, but is not differentiated on map. Distinguished from underlying dolomite by yellow color and slope-forming beds at base. About 115 m thick	
		<b>Tonto Group (Upper, Middle, and Lower Cambrian)</b> —Includes in descending order, the Muav Limestone, Bright Angel Shale, and Tapeats Sandstone as defined by Noble (1922) and modified by McKee and Resser (1945); units recognized on the basis of their distinct lithologies. All the limestone and dolomite lithology in the Cambrian sequence belongs to the Muav Limestone, the shale and siltstone belong to the Bright Angel Shale, and the sandstone and conglomerates belong to the Tapeats Sandstone	
	Em	<b>Muav Limestone (Upper and Middle Cambrian)</b> —Includes in descending order, unnamed light-gray dolomite, 130 m thick; informal striped unit, about 75 m thick (Bohannon and others, 1991), including subdivisions described by McKee and Resser (1945) and mapped by Bohannon	

(1991) and Bohannon and others (1991); the Havasu Member, about 20 m thick; the Gateway Canyon Member, about 50 m thick; the Kanab Canyon and the Peach Springs Members, about 75 m thick; the Spencer Canyon, Sanup Plateau, and Rampart Cave Members, about 60 m thick. Unit mostly comprised of cliff-forming, dark-gray and brown-gray, medium-grained to crystalline, thin- to medium-bedded (20 cm to 1 m thick), silty limestone, sandy limestone, and dolomite and calcareous mudstone; weathers yellow brown, rust brown, or brown gray often with sugary or pitted surface texture. Includes greenish micaceous shale bed partings between limestone beds in upper and lower part. Contact with the underlying Bright Angel Shale is arbitrarily placed at the bottom of the Rampart Cave Member, which in Grand Canyon generally represents a topographic and lithologic break between limestone cliffs of the Muav Limestone and shale slopes of the Bright Angel Shale. The lower half of the Muav contains unnamed interbedded shale beds that are lithologically equivalent to the Bright Angel Shale. Unit as a whole is about 410 m thick in northwest quarter of map area, thickens northwestward into Nevada and thins southeastward to about 200 m in central Grand Canyon area

Cba

**Bright Angel Shale (Middle Cambrian)—**

Described by McKee and Resser (1945), mapped by Bohannon (1991) and Bohannon and others (1991). Upper third of unit consists of black to dark-gray shale that probably correlates to the Chisholm Shale of the Basin and Range; overlies dark-gray to reddish-gray, thin-bedded, iron-stained, ledge-forming limestone that is discontinuous on regional basis; weathers rusty brown; is about 10 m thick; may correlate to the Lyndon Limestone of the Basin and Range. Lower two-thirds of unit consists of black to dark-gray, slope-forming shale; weathers gray and light brown; contains interbedded yellow-brown, thin-bedded sandstone lithologically equivalent to the Tapeats Sandstone. Beds range from less than 1 cm to about 5 cm thick. Lower unit commonly covered by talus or alluvium. Lower unit may correlate in part to the Pioche Shale of Basin and Range. Arbitrary lithologic and topographic contact between slopes

Ct

of the Bright Angel Shale and cliffs of the Tapeats Sandstone. Unit overall thickens northwestward and thins southeastward, depending on arbitrary boundaries between the Muav Limestone and the Tapeats Sandstone. Thickness about 60 to 100 m

**Tapeats Sandstone (Lower Cambrian)—**

Pale-red and light-brown, fine- to medium-grained, thin-bedded (5 to 50 cm thick), well-sorted, cliff-forming sandstone and quartzite; weathers dark red and yellow brown. Upper part is yellow brown and lower part is reddish. Most beds have low- to moderate-angle cross-stratification. Upper part includes thin beds of greenish shale between sandstone beds that are equivalent to the Bright Angel Shale lithology. Variable unconformable contact with underlying crystalline rocks. Thickness ranges from about 65 to 80 m

Xc

**Crystalline rocks, undivided (Early Proterozoic)—**

Gneiss, schist, and granitic rocks. Not studied in detail; description follows Moore (1972). Garnet-biotite gneiss, garnet-sillimanite-biotite schist, gneissic hornblendite, granitic gneiss, amphibolite, and granitic and gabbroic intrusives. Locally dikes and sills of coarsely crystalline pink granite are abundant in gneiss and these masses closely follow grain of gneissic foliation and compositional layering. More or less concordant dike swarms of light-colored pegmatite containing quartz, feldspar, and muscovite are locally abundant. Exposed in Virgin Mountains of Basin and Range, northwest quarter of map area

## REFERENCES CITED

- Beard, L. Sue, 1996, Paleogeography of the Horse Spring Formation in relation to the Lake Mead Fault system, Virgin Mountains, Nevada and Arizona: Geological Society of America Special Paper 303, p. 27-60.
- Best, M.G., McKee, E.H., and Damon, P.E., 1980, Space-time composition patterns of late Cenozoic mafic volcanism, southwestern Utah and adjoining areas: *American Journal of Science*, v. 280, p. 1035-1050.
- Beus, S.S., 1980, Late Devonian (Fresnian) paleogeography and paleoenvironments in northern Arizona, in Fouch, T.D., ed., *Paleozoic paleogeography of the west-central United States; Rocky Mountain Paleogeography Symposium I: Society of Economic Paleontologists and Mineralogists, Rocky Mountain Section, Denver, Colorado*, p. 59-69.
- Billingsley, G.H., 1970, General geology of Tuckup Canyon, cen-

- tral Grand Canyon, Mohave County, Arizona: Flagstaff, Northern Arizona University, unpublished MS thesis, 115 p.
- 1990a, Geologic map of the Purgatory quadrangle, northern Mohave County, Arizona: U.S. Geological Survey Open-File Report 90-540, scale 1:24,000.
- 1990b, Geologic map of the Wolf Hole Mountain West quadrangle, northern Mohave County, Arizona: U.S. Geological Survey Open-File Report 90-541, scale 1:24,000.
- 1990c, Geologic map of the Lizard Point quadrangle, northern Mohave County, Arizona: U.S. Geological Survey Open-File Report 90-643, scale 1:24,000.
- 1990d, Geologic map of the Wolf Hole Mountain East quadrangle, northern Mohave County, Arizona: U.S. Geological Survey Open-File Report 90-644, scale 1:24,000.
- 1991a, 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, 10 p.
- 1991b, Geologic map of the Sullivan Draw South quadrangle, northern Mohave County, Arizona: U.S. Geological Survey Open-File Report 91-559, scale 1:24,000, 9 p.
- 1991c, Geologic map of the Mustang Knoll quadrangle, northern Mohave County, Arizona: U.S. Geological Survey Open-File Report 91-560, scale 1:24,000, 12 p.
- 1991d, Geologic map of the St. George quadrangle, northern Mohave County, Arizona: U.S. Geological Survey Open-File Report 91-561, scale 1:24,000, 11 p.
- 1992a, Geologic map of the Gyp Pocket quadrangle, northern Mohave County, Arizona: U.S. Geological Survey Open-File Report 92-412, scale 1:24,000, 17 p.
- 1992b, Geologic map of the Hole-N-Wall Canyon quadrangle, northern Mohave County, Arizona: U.S. Geological Survey Open-File Report 92-432, scale 1:24,000, 15 p.
- 1992c, Geologic map of the Yellowhorse Flat quadrangle, northern Mohave County, Arizona: U.S. Geological Survey Open-File Report 92-442, scale 1:24,000, 17 p.
- 1992d, Geologic map of the Rock Canyon quadrangle, northern Mohave County, Arizona: U.S. Geological Survey Open-File Report 92-449, scale 1:24,000, 17 p.
- 1993a, Geologic map of the Lost Spring Mountain East quadrangle, northern Mohave County, Arizona: U.S. Geological Survey Open-File Report 93-565, 9 p.
- 1993b, Geologic map of the Lost Spring Mountain West quadrangle, northern Mohave County, Arizona: U.S. Geological Survey Open-File Report 93-566, scale 1:24,000, 11 p.
- 1993c, Geologic map of the Dutchman Draw quadrangle, northern Mohave County, Arizona: U.S. Geological Survey Open-File Report 93-587, scale 1:24,000, 12 p.
- 1993d, Geologic map of The Grandstand quadrangle, northern Mohave County, Arizona: U.S. Geological Survey Open-File Report 93-588, scale 1:24,000, 15 p.
- 1993e, Geologic map of the Little Tanks quadrangle, northern Mohave County, Arizona: U.S. Geological Survey Open-File Report 93-682, scale 1:24,000, 13 p.
- 1993f, Geologic map of the Russell Spring quadrangle, northern Mohave County, Arizona: U.S. Geological Survey Open-File Report 93-717, scale 1:24,000, 17 p.
- 1993g, Geologic map of the Wolf Hole Mountain and vicinity, Mohave County, northwestern Arizona: U.S. Geological Survey Miscellaneous Investigations Series Map I-2296, scale 1:31,680, includes text and cross sections.
- 1994a, Geologic map of the Formaster Well quadrangle, northern Mohave County, Arizona: U.S. Geological Survey Open-File Report 94-243, scale 1:24,000, 10 p.
- 1994b, Geologic map of the White Pockets quadrangle, northern Mohave County, Arizona: U.S. Geological Survey Open-File Report 94-244, scale 1:24,000, 11 p.
- 1994c, Geologic map of the Antelope Knoll quadrangle, northern Mohave County, Arizona: U.S. Geological Survey Open-File Report 94-449, scale 1:24,000, 18 p.
- 1994d, Geologic map of the Little Clayhole Valley quadrangle, northern Mohave County, Arizona: U.S. Geological Survey Open-File Report 94-290, scale 1:24,000, 11 p.
- 1994e, Geologic map of the Hat Knoll quadrangle, northern Mohave County, Arizona: U.S. Geological Survey Open-File Report 94-554, scale 1:24,000, 14 p.
- 1994f, Geologic map of the Moriah Knoll quadrangle, northern Mohave County, Arizona: U.S. Geological Survey Open-File Report 94-634, scale 1:24,000, 14 p.
- 1994g, Geologic map of Sullivan Draw and vicinity, Mohave County, northwestern Arizona: U.S. Geological Survey Miscellaneous Investigations Series Map I-2396, scale 1:31,680, includes text and cross sections.
- 1995, Geologic map of the Littlefield quadrangle, northern Mohave County, Arizona: U.S. Geological Survey Open-File Report 95-559, scale 1:24,000, 15 p.
- 1997a, Geologic map of the Mount Logan quadrangle, northern Mohave county, Arizona: U.S. Geological Survey Open-File Report 97-426, scale 1:24,000, 21 p.
- 1997b, Permian clastic sedimentary rocks of northwestern Arizona, *in* Maldonado, Florian, and Nealey, L.D., eds., *Geologic studies in the Basin and Range-Colorado Plateau Transition in southeastern Nevada, southwestern Utah, and northwestern Arizona*, 1995: U.S. Geological Survey Bulletin 2153-F, p. 108-124.
- 1997c, Geologic map of the Mount Trumbull NW quadrangle, northern Mohave County, Arizona: U.S. Geological Survey Open-File report 97-488, scale 1:24,000, 19 p.
- Billingsley, G.H., and Huntton, P.W., 1983, Geologic map of Vulcan's Throne and vicinity, western Grand Canyon, Arizona: Grand Canyon Natural History Association, Grand Canyon, Arizona, scale 1:48,000.
- Billingsley, G.H., and Bohannon, R.G., 1995, Geologic map of the Elbow Canyon quadrangle, northern Mohave County, Arizona: U.S. Geological Survey, Open-File Report 95-560, scale 1:24,000, 16 p.
- Bohannon, R.G., 1984, Nonmarine sedimentary rocks of Tertiary age in the Lake Mead region, south-eastern Nevada and northwestern Arizona: U.S. Geological Survey Professional Paper 1259, 72 p.
- 1991, Geologic map of the Jacobs Well and southern part of the Elbow Canyon quadrangles, Mohave County, Arizona: U.S. Geological Survey Miscellaneous Investigations Series Map I-2167, scale 1:24,000.
- 1992, Geologic map of the Red Pockets quadrangle, Mohave County, Arizona: U.S. Geological Survey Miscellaneous Investigations Series Map I-2288, scale 1:24,000.
- Bohannon, R.G., Lucchitta, Ivo, and Anderson, R.E., 1991, Geologic map of the Mountain Sheep Spring quadrangle, Mohave County, Arizona: U.S. Geological Survey Miscellaneous Investigations Series Map I-2265, scale 1:24,000.

- Bohannon, R.G., and Lucchitta, Ivo, 1991, Geologic map of the Mount Bangs quadrangle, Mohave County, Arizona: U.S. Geological Survey Miscellaneous Investigations Series Map I-2166, scale 1:24,000.
- Bohannon, R.G., Grow, J.A., Miller, J.J., and Blank, R.H., Jr., 1993, Seismic stratigraphy and tectonic development of Virgin River depression and associated basins, southeastern Nevada and northwestern Arizona: *Geological Society of America Bulletin*, v. 105, no. 4, p. 501-520.
- Damon, P.E., Shafiqullah, Mehmet, and Scarborough, R.B., 1978, Revised chronology for critical stages in the evolution of the lower Colorado River [abs.]: *Geological Society of America Abstracts with Programs, Cordilleran Section*, v. 10, n. 3, p. 101-102.
- Gregory, H.E., 1948, Geology and geography of central Kane County, Utah: *Geological Society of America Bulletin* 59, p. 211-248.
- , 1952, Geology and geography of the Zion Park region, Utah and Arizona: U.S. Geological Survey Professional Paper 220, 200 p.
- Hamblin, K.W., 1965, Origin of "reverse drag" on the downthrown side of normal faults: *Geological Society of America Bulletin*, v. 76, p. 1145-1164.
- Hewett, D.F., 1931, Geology and ore deposits of the Goodspring quadrangle, Nevada: U.S. Geological Survey Professional Paper 162, 172 p.
- Hintze, L.F., 1986, Geology of the Mountain Sheep Spring quadrangle, Mohave County, Arizona, in Griffen, D.T., and Phillips, W.R., eds., Thrusting and extensional structures and mineralization in the Beaver Dam Mountains, southwestern Utah: Utah Geological Association Publication 15, Annual Field Conference, St. George, Utah, 217 p., plate 1, scale, 1:24,000.
- Huntoon, P.W., 1990, Phanerozoic structural geology of the Grand Canyon, in Beus, S.S., and Morales, Michael, eds., *Grand Canyon Geology*: New York, Oxford University Press, Museum of Northern Arizona, p. 261-310.
- Huntoon, P.W., Billingsley, G.H., and Clark, M.D., 1981, Geologic map of the Hurricane Fault zone and vicinity, western Grand Canyon, Arizona: Grand Canyon, Arizona, Grand Canyon Natural History Association, scale 1:48,000.
- Jackson, G.W., 1990a, Tectonic geomorphology of the Toroweap Fault, western Grand Canyon, Arizona; Implications for transgression of faulting on the Colorado Plateau: *Arizona Geological Survey Open-File Report 90-4*, 67 p.
- , 1990b, The Toroweap Fault; One of the most active faults in Arizona: *Arizona Geological Survey, Arizona Geology*, v. 20., no. 3, p. 7-10.
- Longwell, C.R., 1949, Structure of the northern Muddy Mountain area, Nevada: *Geological Society of America Bulletin*, v. 60, p. 923-967.
- Lucchitta, Ivo, 1979, Late Cenozoic uplift of the southwestern Colorado Plateau and adjacent lower Colorado River region: *Tectonophysics*, v. 61, p. 63-95.
- Lucchitta, Ivo, Dehler, C.M., and Basdekas, P.G., 1995a, Geologic map of the Cane Springs Southeast quadrangle, northern Mohave County, Arizona: U.S. Geological Survey Open-File Report 95-48, scale 1:24,000.
- Lucchitta, Ivo, Basdekas, P.G., Bohannon, R.G., Reick, H.J., and Dehler, C.M., 1995b, Geologic map of the Cane Springs quadrangle, northern Mohave County, Arizona: U.S. Geological Survey Open-File Report 95-86, scale 1:24,000.
- Martin, Harriet, and Barrick, J.E., 1999, Conodont Biostratigraphy; Chapter F, in Billingsley, G.H., and Beus, S.S., eds., *Geology of the Suprise Canyon Formation of the Grand Canyon, Arizona*: Museum of Northern Arizona Bulletin 61, p. 97-116.
- McKee, E.D., 1963, Nomenclature for lithologic subdivisions of the Mississippian Redwall Limestone, Arizona: U.S. Geological Survey Professional Paper 475-C, p. 21-22.
- , 1982, The Supai Group of Grand Canyon: U.S. Geological Survey Professional Paper 1173, 504 p.
- McKee, E.D., and Resser, C.E., 1945, Cambrian history of the Grand Canyon region: *Carnegie Institution of Washington Publication* 563, 232 p.
- McNair, A.H., 1951, Paleozoic stratigraphy of part of northwestern Arizona: *American Association of Petroleum Geologists Bulletin*, v. 35, no. 3, p. 503-541.
- Moore, R.T., 1972, Geologic map of the Virgin and Beaver Dam Mountains, Arizona, in Moore, R.T., ed., *Geology of the Virgin and Beaver Dam Mountains, Arizona*: The Arizona Bureau of Mines Bulletin 186, University of Arizona, Tucson, Arizona, 66 p., plates 1 and 2.
- Morales, Mike, 1987, Terrestrial fauna and flora from the Triassic Moenkopi Formation of the southwest United States: *Journal of the Arizona-Nevada Academy of Science*, v. 22, p. 1-19.
- Nielsen, R.L., 1986, The Toroweap and Kaibab Formations, southwestern Utah, in Griffen, D.T., and Phillips, W.R., eds., Thrusting and extensional structures and mineralization in the Beaver Dam Mountains, southwestern Utah: Utah Geological Society Annual Field Conference, Utah Geological Association Publication 15, Salt Lake City, Utah, p. 37-53.
- , 1991, Petrology, sedimentology and stratigraphic implication of the Rock Canyon conglomerate, southwestern Utah: *Miscellaneous Publication 91-7*, Utah Geological Survey, Utah Department of Natural Resources, p. 29-33.
- Nielsen, R.L., and Johnson, J.L., 1979, The Timpoweap Member of the Moenkopi Formation and associated strata, Timpoweap Canyon, Utah: *Utah Geology*, v. 6, no. 1, p. 17-28.
- Noble, L.F., 1922, A section of the Paleozoic formations of the Grand Canyon at the Bass Trail: U.S. Geological Survey Professional Paper, 131-B, p. 23-73.
- Pearthree, P.A., and Wallace, T.C., 1992, The St. George earthquake of September 2, 1992: *Arizona Geological Survey, Arizona Geology*, v. 22, no. 4, p. 7-8.
- Poborski, S.J., 1954, Virgin Formation (Triassic) of the St. George, Utah, area: *Geological Society of America Bulletin*, v. 65, no. 10, p. 971-1006.
- 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, Bulletin* 197, 258 p.
- Sorauf, J.E., and Billingsley, G.H., 1991, Members of the Toroweap and Kaibab Formations, Lower Permian, northern Arizona and southwestern Utah: *The Mountain Geologist*, v. 28, no. 1, p. 9-24.
- Stewart, J.H., Poole, F.G., and Wilson, R.F., 1972, Stratigraphy and origin of the Triassic Moenkopi Formation and related strata in the Colorado Plateau region with a section on sedimentary petrology by R.A. Cadigan: U.S. Geological Survey



- Professional Paper 691, 195 p.
- Stokes, W.L., 1977, Physiographic subdivisions of Utah: Utah Geological and Mineral Survey Map 43, scale 1:2,400,000.
- 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., 1997, Breccia pipe and geologic map of the northeastern part of the Hualapai Indian Reservation and vicinity, Arizona: U.S. Geological Survey Miscellaneous Investigations Series Map I-2440, scale 1:48,000, 19 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., Billingsley, G.H., Blackerby, B.A., 1995, Spatial migration and compositional changes of Miocene-Quaternary magmatism in the western Grand Canyon: *Journal of Geophysical Research*, v. 100, no. B7, p. 10,417-10,440.

#### UNPUBLISHED DATA

- Billingsley, unpub. data a, Lower Hurricane Wash and vicinity, Mohave County, northwestern Arizona
- unpub. data b, Upper Hurricane Wash and vicinity, Mohave County, northwestern Arizona
- unpub. data c, Clayhole Wash and vicinity, Mohave County, northwestern Arizona
- unpub data d, Clayhole Valley and vicinity, Mohave County, northwestern Arizona
- unpub data e, Upper Parashant Canyon and vicinity, Mohave County, northwestern Arizona





