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

By George H. Billingsley, L. Sue Beard, Susan S. Priest, Jessica L. Wellmeyer, and Debra L. Block

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INTRODUCTION

This geologic map is a product of a cooperative project between the U.S. Geological Survey, the National Park Service, and the Bureau of Land Management designed to provide geologic information for part of Grand Canyon National Park, Lake Mead National Recreation Area, and Grand Canyon Parashant National Monument, Arizona. The map area is mostly in the Grand Wash trough of the Basin and Range Province and partly in the Grand Wash Cliffs and the Grand Gulch Bench (Sanup Plateau on large-scale maps) of the Colorado Plateaus Province (herein the Colorado Plateau), all in northwestern Arizona. Grand Wash is the principal drainage for the Grand Wash trough, which is bounded by the Grand Wash Cliffs on the east, the Virgin Mountains on the north (not in map area), the South Virgin Mountains on the west (not in map area), and Lake Mead on the south (southwest edge of map). Grand Wash drains southward toward the Colorado River that is now covered by Lake Mead.

The map area is one of the few remaining areas where uniform scale geologic mapping was needed to complete the Mount Trumbull 30' x 60' quadrangle of Arizona (Billingsley and Wellmeyer, 2003). The geologic information in this report may be useful for federal, state, and private land resource managers who develop land management programs such as range management, biological studies, and flood control. The geologic data will also contribute to future geologic investigations and related scientific studies of this unique area.

The map area is in a remote region known as the Arizona Strip in northwestern Arizona about 20 mi north of Meadview, Arizona, the nearest settlement. Elevations range from about 6,748 ft on the Grand Gulch Bench (east-central edge of map area) to about 1,200 ft at Grand Wash (southwest corner of map area). Primary vehicle access is by dirt road and unimproved jeep trails that traverse various parts of the map area, except within the Grand Wash Wilderness Area of the Grand Gulch Bench (northeast corner of map area). Maps, extra fuel, two spare tires, and extra food and water are highly recommended when traveling in this remote region along with local U.S. Geological Survey 7.5′ topographic quadrangle maps (Grand Gulch Bench, Gyp Hills, Olaf Knolls, and Pakoon Springs) to accompany this map.

Most of the map area is in the Grand Canyon Parashant National Monument, which is managed by the Bureau of Land Management through the Arizona Strip District Office in St. George, Utah. The southern part of the map area includes part of the Lake Mead National Recreation Area managed by the National Park Service at Boulder City, Nevada. Other land within the map area includes about 2º sections belonging to the State of Arizona and about æ of a section of private land along the Grand Wash drainage (U.S. Department of the Interior, 1993). The Grand Wash Cliffs Wilderness Area (northeast edge of map area) was designated in 1984 (written commun., Becky Hammond, Bureau of Land Management, summer, 1998) and is administrated by the Bureau of Land Management in St. George, Utah. Grand Canyon National Park lands are about 4 mi southeast of the map area.

The Grand Gulch Bench area supports a sparse growth of sagebrush, cactus, grass, cliffrose bush, and Joshua, pinyon, and juniper trees. At lower elevations in the Grand Wash trough, a variety of sparse desert shrubs, grass, cactus, and Joshua trees are present.

PREVIOUS WORK

An early reconnaissance photogeologic map of this area was compiled by Wilson and others (1969) and later used by Reynolds (1988) as part of a geologic map of the State of Arizona. Billingsley and others (1986) produced a preliminary geologic map of the Grand Wash Wilderness Area, and Lucchitta and Beard (1981a, b) produced two preliminary geologic maps in the northeast area of the map. This map area is summarized on a regional geologic map of the Mount Trumbull 30′ x 60′ quadrangle by Billingsley and Wellmeyer (2003). Geologic mapping of adjacent areas (fig. 1) includes (1) the Red Pockets quadrangle (Bohannon, 1992) that borders the northwest quarter of the map area, (2) the Cane Springs SE quadrangle (Lucchitta and others, 1995) that borders the northeast quarter of the map, (3) Sullivan Draw and vicinity (Billingsley, 1994) that is adjacent to the northeast corner of the map area, (4) Hidden Hills and vicinity (Billingsley and others, 2002) along the east edge of the map area, (5) lower Granite Gorge and vicinity (Huntoon and others, 1982) bordering the southeast edge of the map area, (6) the northwest part of the

Hualapai Indian Reservation (Wenrich and others, 1996), an upgraded version of Huntoon and others (1981) that borders the southeast edge of the map area, (7) the Littlefield 30′ x 60′ quadrangle (Billingsley and Workman, 2000) that borders the north edge of the map area, and (8) the Lake Mead 30′ x 60′ quadrangle (Beard and others, unpub. data) that borders the west edge of the map area.

MAPPING METHODS

The geology was mapped using 1976 infrared 1:24,000-scale aerial photographs flown by the Bureau of Land Management and followed by extensive field checking. Many of the Quaternary alluvial deposits have similar lithologic and geomorphic characteristics and were mapped almost entirely by photogeologic methods. In some areas, lithology is an important factor in establishing age and correlation of some alluvial units. The stratigraphic position and the amount of erosional degradation were used to determine relative ages of alluvial deposits having similar lithologies. Each map unit and structure was investigated in the field to insure accuracy of description. Many alluvial units are distinctly different in lithology east and west of the Grand Wash drainage because of different geologic source areas.

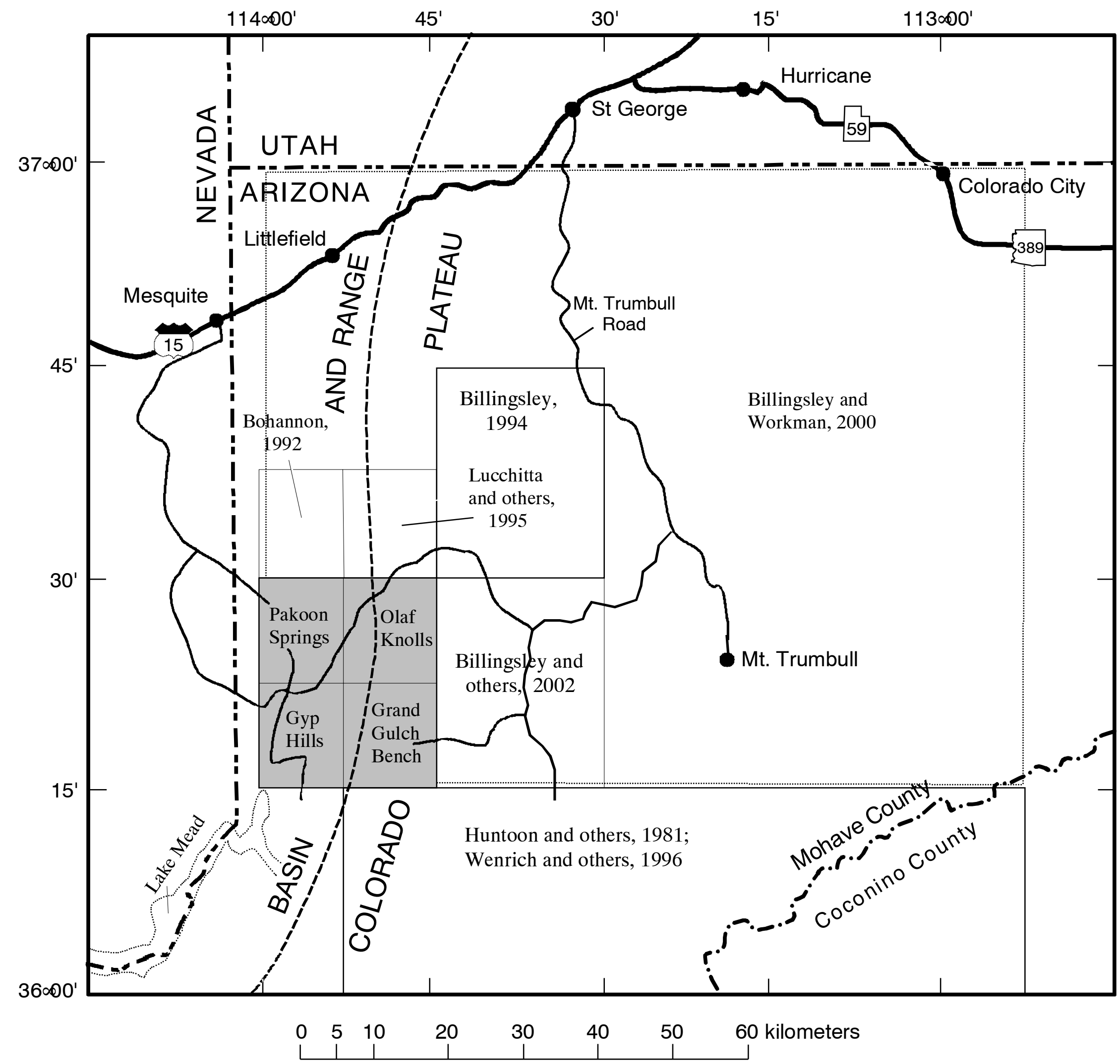

Figure 1. Map showing the Pakoon Springs, Olaf Knolls, Gyp Hills, and Grand Gulch Bench 7.5' quadrangles and adjacent mapped areas, northern Mohave County, northwest Arizona.

GEOLOGIC SETTING

Part of the map area lies within the Grand Gulch Bench (Sanup Plateau), a subprovince of the Colorado Plateau (Billingsley and others, 1997), but most of the map area is within the Grand Wash trough of the Basin and Range Province. The boundary between the Colorado Plateau and Basin and Range Provinces follows the base of the lower Grand Wash Cliffs along the approximate position of the Grand Wash Fault. The Grand Gulch Bench is a relatively flat benchland just east of the lower Grand Wash Cliffs. The Grand Gulch Bench is characterized by nearly flat lying Paleozoic sedimentary strata having an average regional dip of about 1ʃ to 2ʃ E., except along the lower Grand Wash Cliffs where Paleozoic strata dip as much as 30∞W. into the Grand Wash trough.

The Paleozoic rocks along the west margin of the Colorado Plateau have been downfaulted and tilted west toward the Grand Wash trough where they are buried by Tertiary and Quaternary sedimentary and volcanic deposits. Major faults include the Grand Wash Fault, along which Paleozoic strata of Wheeler Ridge were downdropped to the west and tilted eastward, and the Wheeler Fault that truncates Wheeler Ridge and drops Paleozoic strata down to the west in the subsurface. The Cockscomb along the northwest side of the map area is another east-dipping fault block that exposes Paleozoic strata.

PALEOZOIC AND MESOZOIC SEDIMENTARY ROCKS

About 5,200 ft of Paleozoic strata ranging in age from Cambrian to Permian are exposed in Pigeon Canyon and the lower Grand Wash Cliffs. An additional 1,550 ft of Permian strata and about 400 ft of Triassic strata are exposed at The Cockscomb in the northwest quarter of the map area. The Paleozoic and Mesozoic rocks are, in order of increasing age, the Moenkopi Formation (Triassic); the Kaibab, Toroweap, and Hermit Formations (Permian); the Esplanade Sandstone and Pakoon Limestone (Permian); the Supai Group (Mississippian and Pennsylvanian); the Surprise Canyon Formation (Mississippian); the Redwall Limestone (Mississippian); the Temple Butte Formation (Devonian); and the Muav Limestone (Cambrian). The Coconino Sandstone (Permian) is too thin and discontinuous to be shown at map scale between the Toroweap and Hermit Formations but is present as a crossbedded sandstone in The Cockscomb area. Measured sections by Fisher (1961) and Schleh (1966) and mapping by Billingsley and others (2000) document that the Coconino Sandstone intertongues with the lower part of the Seligman Member of the Toroweap Formation in Parashant Canyon about 30 mi east of the map area.

The Moenkopi Formation is partly exposed on the east side of The Cockscomb west and northwest of Pakoon Springs. The Moenkopi consists of red and white siltstone together with silty yellowish-gray dolomite and limestone. Early Tertiary erosion removed an unknown thickness of the upper part of the Triassic Moenkopi Formation and overlying younger Triassic and Jurassic strata that were likely present before deposition of the Horse Spring Formation and rocks of the Grand Wash trough. These Triassic rocks are likely to be present at depth within the Grand Wash trough, because they crop out at the north end of the Grand Wash trough and in similar basins just northwest of the map area.

CENOZOIC ROCKS

Four Tertiary rock assemblages occupy the Grand Wash trough and mostly bury the downdropped east-tilted fault blocks of Paleozoic and Mesozoic strata. (1) Earliest Cenozoic sedimentary rocks (24 to 18 Ma) consist of a lower red-brown conglomerate, a middle red siltstone and sandstone interbedded with gray silty limestone, and an upper limestone sequence, all part of the Horse Spring Formation (Ths; Bohannon, 1984), formally called the Tassi Ranch Formation (Moore, 1972). The only outcrop of the Horse Spring Formation in the map area is just east of Tassi Spring and the Wheeler Fault in The Box of Pigeon Wash (southwest edge of map area).

(2) The Horse Spring Formation is unconformably overlain by rocks of the Grand Wash trough comprised of fluvial and alluvial sediments, freshwater shallow lake deposits, and shallow basin evaporite deposits (Tgc, Tgrc, Tgl, Tgg, and Tgx). These Tertiary deposits were included as part of the Muddy Creek Formation by Lucchitta (1979) and, informally, the rocks of the Grand Wash trough by Bohannon (1984). Recent studies by Bohannon (1984, 1991, 1992), Bohannon and others (1993), and Beard (1996)

emphasized that these sedimentary rocks are not connected to the Muddy Creek Formation at its type area near the Muddy River in southeastern Nevada. Instead, they formed in basins separate from and about the same time as the red sandstone unit of Bohannon (1984) exposed in the western Lake Mead area. A tuff interbedded within limestone deposits yielded a tephrochronology correlation age of 11.72 Ma (table 1).

Tertiary alluvial fan deposits (Tgc) at the top of the rocks of the Grand Wash trough sequence filled an ancestral Pigeon Canyon and covered the west wall of Pigeon Canyon near its mouth along the lower Grand Wash Cliffs. The alluvial fan drained northwest across the buried west wall and into the Grand Wash trough. Subsequent headward erosion of the northwest Pigeon Canyon drainage allowed this part of the drainage to became superimposed onto the buried west wall of the original canyon resulting in a deeply incised new Pigeon Canyon 2 mi north of the original canyon mouth.

(3) The rocks of the Grand Wash trough are overlapped by younger rocks of Grand Wash that crop out mostly west of the trace of the Wheeler Fault. The deposits consist of a basal conglomerate exposed along Grand Wash (Tgwc) overlain by red siltstone and sandstone (Tgr) of mostly fluvial and eolian origin. These rocks were originally included in the rocks of the Grand Wash trough by Bohannon (1984), but map relations and tentative tephrochronology correlation ages bracketed between 3.33 Ma and 4.1 Ma on two tuffs exposed north of the map area in Cottonwood Wash (table 1) suggest that these rocks correlate with the Muddy Creek Formation or younger rocks.

(4) Both the rocks of the Grand Wash trough and the younger rocks of Grand Wash are partly covered by extensive Pliocene basalt flows (Tb) and interbedded fluvial gravel deposits between some of the flows (Tbs). Young and old alluvium (Tay, Tao) and calcrete soil (Tk) deposits overlie the basalt flows.

Headward erosion by Grand Wash drainage and its tributaries northward from the Colorado River cut into the rocks of the Grand Wash trough and Quaternary or Late Tertiary fluvial and alluvial deposits. Quaternary surficial deposits include terrace gravels, alluvial fans, calcrete soil deposits, talus, and landslide debris masses throughout the map area. Artificial fill and quarries developed by human activity are also mapped. Most Quaternary deposits are intertonguing and have gradational map contacts both laterally and vertically and the map contacts between these units are approximate. The Quaternary surficial units are subdivided in detail, because they can strongly influence the planning of road construction, range management conditions, flood control, and soil erosion resource programs. In addition, the Quaternary deposits temporally constrain Quaternary landscape development of this region.

VOLCANIC ROCKS

Tertiary basalt flows in the Grand Wash trough are associated with fissure eruptions and pyroclastic vents in the upper reaches of Grand Wash trough north of the map area and with some dikes along Cottonwood Wash southeast of Pakoon Springs. Most of the basalt along Grand Wash originated from sources north of the map area and flowed south down ancestral Grand Wash and Cottonwood Wash toward the Colorado River in late Pliocene time. Three large dikes or necks along the east side of Cottonwood Wash south of Pakoon Springs contributed some basalt to the flows. The basalt flowed at least 4 mi south of the map area to the Colorado River and then about 9 mi down the Colorado River gorge to Sandy Point, Lake Mead. Cole (1989) reported a K-Ar age of 3.99±0.06 Ma for the uppermost flow exposed along Tassi Road in an eastern tributary of lower Grand Wash. South of the map area, K-Ar ages of 3.8±0.11 Ma on the lowest flow at Grand Wash Bay and 3.79±0.46 Ma farther south at Sandy Point (Reynolds and others, 1986) suggested a correlation between these flows. However, Faulds and others (2004) report a $^{40}Ar/^{39}Ar$ age of 4.41±0.03 Ma for the Sandy Point basalt, which overlies Colorado River gravels. This age corresponds well with $^{40}Ar/^{39}Ar$ correlation ages of 4.64, 4.8, and 4.6 Ma and 4.71±0.03 Ma (Mick Kunk, written commun., 2002) on basalts just west of the map area, which are continuous with flows exposed on the west side of Cottonwood Wash that directly overlie red siltstone and sandstone rocks of Grand Wash (Tgr). In addition, Damon and others (1996; first reported in Cole, 1989) reports a K-Ar age of 4.7±0.07 Ma for the basalt flow east of Pakoon Springs in the present map area. The bulk of the flows in Cottonwood Wash, therefore, are in the range of 4.41 to 4.8 Ma. Further dating is needed to establish whether there really are younger flows at Grand Wash Bay on Lake Mead.

Olaf Knolls volcano (north-central part of map) is an isolated eruptive center bounded on the north and west by Tertiary basalt flows erupted from sources north of the map area either during or just after the eruption of Olaf Knolls. A large dike at the highest point of Olaf Knolls is the source for most of the local 250-ft-thick section of basalt flows at Olaf Knolls. The dike intrudes the Late Miocene(?) to Pliocene reddish interbedded siltstone and sandstone rocks of Grand Wash (Tgr). A large circular depression on the north flank of Olaf Knolls is marked with hachures on the map and appears to be either a maar or a collapse depression. However, most of the basalt appears to have erupted from the central dike onto eroded slopes and into drainage tributaries of an ancestral Grand Wash valley. Olaf Knolls may be the youngest basalt in the map area but remains undated at this time. The drainage of Grand Wash has since re-established itself along the west margin of the basalt flows in the Olaf Knolls area. Young alluvial fan deposits derived from the Grand Wash Cliffs and in situ calcrete soils (Tk, QTk) cover most of the basalt flows of Olaf Knolls along Grand Wash and Cottonwood Wash drainages. Quaternary alluvial deposits mostly bury a basalt flow near the Grand Wash Cliffs in the northeast quarter of the map area. This basalt does not appear to be related to the Olaf Knolls volcano and its source and age remain unknown.

The Moenkopi Formation and rocks of the Grand Wash trough that underlie the basalt flows are readily subjected to erosion around the edges of the flows along Cottonwood Wash and Grand Wash. Undercutting of the resistant basalt flows has destabilized steep hillsides in the underlying soft sediments promoting numerous slope failures marked by landslide blocks and debris (Ql). Landslide erosion by headward sapping into the basalt flows is a major mass wasting process along Cottonwood Wash and Grand Wash that significantly contributes to valley widening.

On the Grand Gulch Bench in the eastern part of the map (Sanup Plateau), a few alkali-olivine basalt dikes are present in Pigeon Canyon (Tsi). They are included here as part of the Snap Point Basalt event because they align with north-striking dikes and basalt flows at Snap Point about 7 mi south of the map area (Wenrich and others, 1995; Wenrich and others, 1996). There are no basalt flows associated with the dikes in the Pigeon Canyon area, and, if any were present, they were either eroded or aerially restricted to the Pigeon Canyon area. The K-Ar age of the Snap Point Basalt is 9.07±0.8 Ma and 9.20±0.13 Ma (Wenrich and others, 1995) and the ^{40}Ar/^{39}Ar age is 8.80±0.04 Ma (J.E. Faulds, Nevada Bureau of Mines, written commun., June 2000).

An isolated remnant of the Snap Point Basalt (Tsb) forms a protective caprock on Tertiary gravels at Nevershine Mesa (elev 3,800 ft) at the extreme south-central edge of the map area. The K-Ar date on the Snap Point Basalt on Nevershine Mesa is 8.84±0.08 Ma. (J.E. Faulds, written commun., 2000). This basalt was derived from Snap Point on the Shivwits Plateau just southeast of the map area. Most of the Snap Point Basalt flowed east onto the Shivwits Plateau for about 2 mi, but one flow cascaded west down a steep erosional paleoslope from Snap Point into Snap Canyon and continued west down Snap Canyon into the Grand Wash trough. At the time of the flow, Snap Canyon was mostly filled with the gray alluvial-fan deposits similar to those in Pigeon Canyon north of Snap Canyon (Tgc). The basalt flow terminated its westerly and northerly progress on what was then the valley floor of the Grand Wash trough. Subsequent erosion has left a remnant of the Snap Point Basalt as a topographically inverted ridge called Nevershine Mesa, which is barely visible at the south-central edge of the map.

STRUCTURAL GEOLOGY

Gently tilted Paleozoic and Mesozoic strata are offset by near-vertical normal faults along the Grand Gulch Bench and lower Grand Wash Cliffs area. The regional dip of Paleozoic and Mesozoic strata on the Colorado Plateau is about 1∫ to 3∫ ENE. along the east edge of the map area. Locally, the Paleozoic strata dip steeply west as much as 30∫ into the Grand Wash trough along the lower Grand Wash Cliffs east of the Grand Wash Fault. The west-dipping strata may represent large blocks that slowly tilted into an opening void provided by the west-side-down motion along the Grand Wash Fault as footwall drag. The Grand Wash Fault is a major middle to late(?) Miocene structure that separates the Colorado Plateau Province from the Basin and Range Province (Bohannon, 1984; Bohannon and others, 1993). The fault trace on the map is approximate because of Tertiary and Quaternary alluvial sediment cover. A few small normal faults offset the Quaternary alluvium along the base of the Grand Wash Cliffs but do not necessarily mark the location of the buried Grand Wash Fault. Maximum vertical separation of strata across the Grand Wash Fault was estimated to be (listric) about 10,000 ft down to the west (Lucchitta, 1979, 1984). The Grand Wash Fault is inferred to shallow at depth because of the eastward tilt of strata in the hanging wall of the fault, as exposed at Wheeler Ridge. Several small normal and reverse faults associated with the Grand Wash Fault are within a 2-mi-wide zone along the lower Grand Wash Cliffs and Grand Gulch Bench.

A second major fault in the map area is the north-northeast-striking Wheeler Fault. The Wheeler Fault appears to be a large normal fault that offsets Paleozoic and Mesozoic strata down to the west a minimum of about 4,200 ft. North of Tassi Spring, Quaternary and Tertiary sediments mostly conceal the fault. Along the projected northeast strike of the Wheeler Fault, limestone and gypsum sediments (Tgl, Tgg) are sharply folded and dip as much as 76∫ WNW. These folded sediments suggest that the fault gradually dies out north of Tassi Spring, and the steep fold marks the structural trend of the fault as displacement decreases northeastward. Between Grand Gulch Wash and Tank Canyon, Quaternary alluvial deposits obscure the fold. The Wheeler Fault probably became active in late Miocene or early Pliocene time after the Grand Wash Fault became active. Rocks of the Grand Wash trough east of Wheeler Fault and north of Tassi Spring dip 3∫ to 7∫ E. toward the Grand Wash Cliffs, forming the east limb of an anticline that plunges north into the structural trend of the Wheeler Fault. An erosional scarp in the old Tertiary alluvium (Tao) marks the approximate trace of the Wheeler Fault or folded sediments along the covered fault trace north of Tassi Spring. Slight folding of the Tertiary and Quaternary alluvial fan sub-units along the structural trend of the fault may have been responsible for the erosional scarp in these deposits.

West of the Wheeler Fault, a few minor normal faults offset the thick young alluvial fan deposits (Tay) and strike north parallel to the plunging anticline east of the fault. It is possible that the northern extent of the Wheeler Fault and anticline curves northwest and dies out into the Grand Wash trough area in the central part of the map. However, the erosional scarp in the alluvial fan and folded limestone and gypsum sediments (Tgl, Tgg) north of the anticline suggest that the Wheeler Fault may extend northeast in the subsurface toward the Grand Wash Fault.

The Pigeon Canyon Fault on the Grand Gulch Bench is assumed to connect to the Grand Wash Fault zone. Offset of Paleozoic strata along the Pigeon Canyon Fault is down to the northwest about 265 ft. The fault has probably controlled the headward erosion of Pigeon Canyon drainage into the Grand Gulch Bench for about 6 mi. The upper reach of Pigeon Canyon extends several miles east of the map area into the Shivwits Plateau and is not fault controlled.

Grand Gulch Graben on the Grand Gulch Bench, in the northeast quarter of the map area, is about a quarter to a half mile wide and forms a structural and topographic trough as much as 550 ft deep. The graben parallels the Grand Wash Fault for about 4 mi before veering southeast at Squaw Canyon. Based on the proximity to the Grand Wash Fault, the Pigeon Canyon Fault and Grand Gulch Graben are likely middle to late(?) Miocene structures similar in age to the Grand Wash Fault.

Locally warped and folded strata between the Wheeler Fault and the Grand Wash Cliffs (Tgg, Tgl, Tgrc, Tgc) are partly exposed in drainages west of the Grand Wash Cliffs. These folds may represent local shortening within the Grand Wash trough or may have formed above normal faults at depth.

Circular bowl-shaped depressions on the Grand Gulch Bench, characterized by inward-dipping strata, are probably the surface expression of breccia-pipe structures that originated from dissolution of the deeply buried Mississippian Redwall Limestone (Wenrich and Huntoon, 1989; Wenrich and Sutphin, 1989). Some breccia pipes host copper and many other mineral commodities on the Colorado Plateau, but not all breccia pipes are mineralized. On the Grand Gulch Bench within the map area, mineralized breccia pipes are more common than elsewhere on the Colorado Plateau. Copper mines, such as the Grand Gulch, Cunningham, and Savanic, represent some of the oldest and richest copper mines on the Colorado Plateau that were active during the late 1890s and early 1900s. They were abandoned in the late 1950s, but the discovery of uranium minerals in some breccia pipes sparked a minor flurry of uranium exploration in these and other breccia pipes on the plateau during the 1980s (Billingsley and others, 1997). The recent declaration of this entire map area as part of the Grand Canyon Parashant National Monument has nullified all mining claims and precluded future mining of this area.

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DESCRIPTION OF MAP UNITS

SURFICIAL DEPOSITS

Holocene, Pleistocene, and Pliocene surficial deposits are differentiated from one another chiefly by photogeologic techniques on the basis of differences in morphology and physiographic position. Older alluvial fan and terrace-gravel deposits generally exhibit extensive erosion and have greater topographic relief, whereas younger deposits either are actively accumulating material or are lightly eroded as observed on 1976 aerial photographs. Map contacts between Pleistocene and Holocene surficial map units are approximate.

Qaf **Artificial fill and quarries (Holocene)**ó Excavated alluvium and bedrock material quarried to build livestock tanks, drainage diversion dams, roads, and mine operations

Qs **Stream-channel alluvium (Holocene)**ó Interbedded silt, sand, and pebble to boulder gravel; unconsolidated and poorly sorted. Locally overlaps youngest (Qa1) and young alluvial fan (Qa2), youngest terrace-gravel (Qg1), and upper part of valley-fill (Qv) deposits. Inset against young alluvial fan (Qa2) and young terrace-gravel (Qg2) deposits. Stream channels subject to intermittent high-energy flows and flash floods. Little or no vegetation in stream channels except sagebrush, mesquite, cat claw, and desert willow trees along Grand Wash. Thickness, 2 to 10 ft

Qd **Dune sand and sand sheet deposits (Holocene)**ó Reddish to white, fine-grained, wind-blown sand. Commonly forms sand-sheet deposits on stream-channel alluvium (Qs) and youngest terrace-gravel deposits (Qg1) and as climbing dunes on older terrace-gravel (Qg2, Qg3) deposits along Cottonwood Wash and Grand Wash. Sand is locally derived from stream channels where channels are wide. Thickness, 3 to 30 ft

Qg1 **Youngest terrace-gravel deposits (Holocene)**ó Light-brown, pale-red, and gray silt, sand, and pebble to boulder gravel, east of Grand Wash, composed of rounded limestone and sandstone and angular to subrounded chert clasts that are locally derived from Paleozoic rocks of the Grand Wash Cliffs; include rounded to subrounded basalt clasts derived from local basalt flows. Also include mixed assemblages of limestone, chert, basalt, and Proterozoic clasts derived north and west of map area. Form terraces about 3 to 10 ft above modern streambeds. Locally inset into young terrace-gravel (Qg2) deposits. Subject to flash flooding or debris flows. Thickness, 3 to 12 ft

Qa1 **Youngest alluvial fan deposits (Holocene)**ó Gray-brown silt, sand, gravel, and boulders. East of Grand Wash, composed of coarse gravel containing subangular to rounded pebbles and cobbles of limestone, chert, and sandstone derived from Paleozoic, Tertiary, and Quaternary rocks along Grand Wash Cliffs. West of Grand Wash, composed of abundant Proterozoic rock types such as silt, sand, gravel, pebbles, and cobbles derived from mountains west of map area and Permian limestone clasts derived from Pakoon Ridge, northwest quarter of map area. Locally include well-rounded to sub-angular basalt clasts and Triassic chert and quartzite clasts. Partly consolidated by silty gypsum and calcite. Overlapped by or intertongue with upper part of valley-fill (Qv), stream-channel (Qs), and sand dune (Qd) deposits. Intertongue with or overlaps young and intermediate alluvial fan (Qa2, Qa3) deposits and youngest and young terrace-gravel (Qg1, Qg2) deposits. Subject to extensive sheet-wash erosion and flash-flood debris flows. Support moderate growths of sagebrush, cactus, creosote bush, and some grass. Thickness, 3 to 30 ft

Qv **Valley-fill deposits (Holocene and Pleistocene)**ó Gray and light-brown silt, sand, and lenses of pebble to small-boulder gravel; partly consolidated by gypsum and calcite cement. Include rounded clasts of limestone, subrounded to angular chert, and subrounded to angular basalt clasts east of Grand Wash. Intertongue with or overlap youngest and young alluvial fan (Qa1, Qa2) deposits and youngest and young terrace-gravel (Qg1, Qg2) deposits. Represent relatively less-active, low-gradient, alluvial stream-channel or shallow-drainage accumulations. Subject to sheetwash flooding and temporary ponding. Support moderate growth of sagebrush, grass, cactus, and some juniper trees. Thickness, 3 to 12 ft

Qt **Talus deposits (Holocene and Pleistocene)**ó Unsorted breccia debris composed of small to large angular blocks of local bedrock on steep to moderately steep slopes below outcrops. Include silt, sand, and gravel partly cemented by calcite and gypsum. Intertongue with or overlap youngest, young, and intermediate alluvial fan (Qa1, Qa2, Qa3) deposits, youngest and young terrace-gravel (Qg1, Qg2) deposits, and landslide (Ql) deposits. Support sparse growth of sagebrush, cactus, grass, and various desert shrubs. Only thick or extensive deposits shown. Thickness, 6 to 20 ft

Ql **Landslide deposits (Holocene and Pleistocene)**ó Unconsolidated masses of unsorted rock debris. Include detached blocks that have rotated and slid downslope as loose incoherent masses of broken rock and deformed strata. Found principally downhill from exposures of Tertiary basalt flows along Grand and Cottonwood Washes and local tributaries; also minor deposits in Grand Wash Cliffs and near mouth of Pigeon Canyon. Support sparse to moderate growth of sagebrush, cactus, grass, creosote bush, and various desert shrubs. May become unstable in very wet conditions. Thickness, 10 to 60 ft

Qg2 **Young terrace-gravel deposits (Holocene and Pleistocene)**ó Lithologically similar to youngest terrace-gravel deposits (Qg1); unconsolidated. Composed mainly of gray to brown siltstone and sandstone mixed with subangular to rounded pebbles and boulders of various rock types supported by fine-grained sand and silt matrix. Include well-rounded basalt and limestone clasts as much as 3 ft in diameter along Grand Wash and its tributaries. Form terrace benches about 6 to 30 ft above modern streambeds and about 3 to 20 ft above youngest terrace-gravel (Qg1) deposits. Locally intertongue with or inset into youngest and intermediate alluvial fan (Qa2, Qa3) deposits. Intertongue with or locally overlain by talus (Qt), youngest alluvial fan (Qa1), valley-fill (Qv), and landslide (Ql) deposits. Subject to flash flood erosion. Thickness, 6 to 20 ft

Qa2 **Young alluvial fan deposits (Holocene and Pleistocene)**ó Lithologically similar to youngest alluvial fan (Qa1) deposits; partly cemented by calcite and gypsum. Surfaces are rocky and cut by arroyos as much as 10 ft deep. Commonly overlapped by youngest alluvial fan (Qa1) deposits; intertongue with or overlap valley-fill (Qv), young terrace-gravel (Qg2), and talus (Qt) deposits. Include abundant subrounded to subangular basalt clasts and Proterozoic clasts west of Grand Wash. Support moderate growth of creosote bush, sagebrush, cactus, and grass. Thickness, 6 to 50 ft

Qg3 **Intermediate terrace-gravel deposits (Pleistocene)**ó Lithologically similar to youngest and young terrace-gravel (Qg1, Qg2) deposits, partly cemented by calcite and gypsum. Include well-rounded basalt clasts up to 3 ft in diameter along Grand Wash; smaller basalt cobbles form desert pavement in some areas. Form terrace benches about 12 to 40 ft above modern streambed of Grand Wash and in Pigeon Canyon. Inset into old terrace-gravel (Qg4) deposits along Grand Wash. Thickness, 2 to 40 ft

Qa3 **Intermediate alluvial fan deposits (Pleistocene)**ó Lithologically similar to youngest and young alluvial fan (Qa1, Qa2) deposits; partly cemented by calcite and gypsum. Surface has thin overlying calcrete soil that forms a flat surface except near Grand Wash Cliffs where surface is very rocky. Include basalt clasts from Tertiary basalt flows north of map area. Arroyos common near Grand Wash and are as much as 20 ft deep or more due to headward erosion from Grand Wash and its tributaries. Commonly overlapped by or intertongue with talus (Qt), landslide (Ql), and youngest and young alluvial fan (Qa1, Qa2) deposits. Include abundant limestone clasts that form thin desert pavement surface near Grand Wash Cliffs. Locally, include abundant clasts of basalt, schist, and gneiss that form desert pavement surfaces west of Grand Wash, southwest corner of map area. Support moderate growth of creosote bush, grass, and cactus. Thickness, 5 to 25 ft

Qg4 **Old terrace-gravel deposits (Pleistocene)**ó Lithologically similar as youngest, young, and intermediate terrace-gravel (Qg1, Qg2, Qg3) deposits, but form thicker deposits. Form terrace benches about 30 to 120 ft above modern drainage along Grand Wash and Cottonwood Wash. Inset into terrace-gravel (QTg) deposits. Grade laterally into old alluvial fan (Qa4) deposits. Deposits were thicker and more widespread along Cottonwood Wash and Grand Wash, now removed by modern erosion. Unit correlates to old alluvial fan (Qa4) deposits that once formed extensive valley-fill alluvium, extending east along Grand Wash in north half of map area to the Grand Wash Cliffs. Thickness, 120 ft

Qa4 **Old alluvial fan deposits (Pleistocene)**ó Similar to youngest, young, and intermediate alluvial fan (Qa1, Qa2, Qa3) deposits. Surface limestone boulders 3 ft or more in diameter are strongly weathered and deeply pitted near base of Grand Wash Cliffs. Unit is unsorted mix of silt, sand, gravel, pebbles, cobbles, and boulders, partly consolidated by calcite and gypsum cement that forms a calcrete-capped soil surface on higher hills along lower slopes of Grand Wash Cliffs and on isolated hills on Grand Gulch Bench. Include some deeply weathered angular carbonate boulders and pebbles. Composed mostly of Paleozoic clasts derived from the Grand Wash Cliffs. Include some basalt clasts near Olaf Knolls area. Overlapped by young and intermediate alluvial fan (Qa2, Qa3) deposits in some areas; intertongue with or overlap old terrace-gravel (Qg4) deposits. West of Grand Wash, contain almost 90 percent clastic material derived from Proterozoic rocks north and west of map area and about 10 percent basalt clasts derived from local Tertiary basalt flows just west of map. Thickness, 60 ft

QTg **Terrace-gravel deposits (Pleistocene or Pliocene)**ó Lithologically similar to young, intermediate, and old terrace-gravel (Qg2, Qg3, Qg4) deposits, but form poorly sorted, consolidated, terrace benches 12 to 160 ft above modern streambed of Cottonwood and Grand Washes. Unit grades laterally into Quaternary or Tertiary alluvial fan (QTk) deposits east of Grand Wash. Include silt, sand, gravel, cobble, and boulders that are well rounded to subrounded but strongly pitted by weathering on clast surfaces. Clasts are dominantly limestone, chert, basalt, and minor sandstone. Basalt clasts most common along Cottonwood Wash. Unit capped by calcrete soil about 5 to 12 ft thick along Grand Wash; includes abundant basalt clasts. Thickness, 160 ft

QTa1 **Young alluvial fan deposits (Pleistocene or Pliocene)**ó Lithologically similar to intermediate and old alluvial fan (Qa3, Qa4) deposits; partly consolidated by calcite and gypsum cement. East of Grand Wash, composed mostly of gravelly mixture of limestone and chert clasts derived from Paleozoic rocks of the Grand Wash Cliffs. Include abundant basalt clasts near Grand Wash. Contain limestone and basalt boulders as much as 2 ft in diameter near Grand Wash; boulders are heavily weathered with pitted surfaces. Form protective boulder caprock on isolated hills on Grand Gulch Bench. Thickness, 20 to 45 ft

QTk **Calcrete soil deposits (Pleistocene or Pliocene)**ó White, light gray, and tan, ledge-forming, silt, sand, and pebble gravel cemented by calcium carbonate. Deposit covers young, intermediate, and old alluvial fan (QTa1, QTa2, QTa3) deposits east of Grand Wash to Grand Wash Cliffs. Composed mostly of silty and sandy calcium carbonate calcrete soil averaging about 6 ft thick. Form caprock bench as much as 200 to 460 ft above modern streambeds. Calcrete surface is flat and rocky. Unit supports sparse growth of desert vegetation, mainly cactus and creosote bush. Unconformable contact of low relief with underlying young, intermediate, and old alluvium (QTa1, QTa2, QTa3) and sedimentary rocks of the Grand Wash trough (Tgl, Tgg). Unit may have formed an extensive deposit over all sedimentary rocks of the Grand Wash trough and old alluvium (Tao) deposits east of Wheeler Fault, now mostly removed by erosion. Thickness, 3 to 12 ft

QTa2 **Intermediate alluvial fan deposits (Pleistocene or Pliocene)**ó Gray, poorly sorted debris flow and stream-channel alluvial fan deposits, partly consolidated by calcite and gypsiferous silt. Composed of silt, sand, gravel, cobbles, and boulders composed of limestone, chert, and sandstone 3 ft in diameter. Boulders and smaller clasts are subrounded to subangular and strongly pitted, etched, and weathered. Outcrops near Grand Wash Cliffs composed primarily of Paleozoic rocks from drainages eroded into Paleozoic strata of the Grand Wash Cliffs. Locally include conglomerate and fine-grained limestone, siltstone, and gypsum derived from sedimentary rocks of the Grand Wash trough. Form caprock or ridge-crest deposits 40 to 60 ft higher than old alluvial fan (Qa4) and young alluvial fan (QTa1) deposits that overlie sedimentary rocks of the Grand Wash trough (Tgc, Tgrc, Tgl, Tgg). Inset against intermediate alluvial fan (QTa2) deposits. Thickness, 10 to 20 ft

QTa3 **Old alluvial fan deposits (Pleistocene or Pliocene)**ó Lithologically similar to young and intermediate alluvial fan (QTa1, QTa2) deposits, but surface about 14 ft topographically higher than QTa2. Unconformable contact with underlying red Paleozoic-clast conglomerate facies (Tgrc) and limestone and siltstone facies (Tgl) of rocks of the Grand Wash trough near base of Grand Wash Cliffs, south-central part of map area. Unit is highly dissected by modern erosion. Thickness, 15 ft

Tay **Young alluvium (Pliocene)**ó Gray and light-brown, poorly sorted, consolidated, silt, sand, gravel, cobbles, and boulders derived from Paleozoic rocks of the Grand Wash Cliffs. Clastic material consists of about 90 percent limestone and dolomite clasts and 10 percent chert clasts in gray gypsiferous siltstone and sandstone gravelly matrix. Unit is capped by thin calcrete soil, 3 to 6 ft thick that weathers light brown. Surface clasts of rounded and subrounded limestone and chert often coated by calcite. Does not contain basalt clasts. Occurs as isolated outcrops near Grand Wash Cliffs and inset 40 to 50 ft topographically below surface of old alluvium (Tao) deposits. Unconformably overlies red Paleozoic-clast conglomerate facies (Tgrc) and limestone and siltstone facies (Tgl) of sedimentary rocks of the Grand Wash trough. Unit is highly eroded. Supports sparse growth of creosote bush, cactus, and some grass. Thickness, 60 ft

Tk **Calcrete soil deposits (Pliocene)**ó White, light-gray, and tan, ledge-forming, calcium carbonate-cemented silt, sand, and pebble gravel. Deposit covers uppermost basalt flow (Tb) surfaces in northwest half of map area. Composed almost entirely of silty, sandy calcrete soil averaging about 4 ft thick. Unit is about 200 to 460 ft above modern streambeds and drapes over basalt flows and associated alluvial deposits. Calcrete surface forms widespread, lumpy, thick bed of calcrete and gravel soil that is partly eroded from basalt (Tb) surface in many areas north of Grand Wash. Contain scattered pebbles and fragments of basalt as much as 12 in. in diameter. Supports sparse growth of desert vegetation, mainly cactus of various types, and creosote bush. Unconformable contact with underlying basalt flows (Tb), Grand Wash conglomerate (Tgwc), and red siltstone and sandstone (Tgr) deposits. Unit may have formed an extensive deposit over all Tertiary sedimentary and volcanic rocks in west and north half of map area, now partly removed by modern erosion. Unit gradually thickens north toward Virgin Mountains and upper Grand Wash trough northwest and north of map area. Thickness, 3 to 12 ft

Tao **Old alluvium (Pliocene)**ó Regionally widespread alluvium, lithologically similar to young alluvium (Tay) deposits, but 40 to 50 ft topographically higher than young alluvium (Tay) below and near Grand Wash Cliffs about 4 mi west of Grand Gulch Mine. Fan debris material is about 90 percent limestone and dolomite clasts that are strongly pitted and etched on weathered surfaces and 10 percent chert clasts derived from Paleozoic rocks of the Grand Wash Cliffs near Wheeler Fault and Grand Wash Cliffs area. Forms highly eroded consolidated deposits on high isolated hills and ridges between Wheeler Fault and Grand Wash Cliffs and consolidated deposits west of Wheeler Fault to Grand Wash. In northwest corner of map area, unit overlies uppermost basalt flows of the Grand Wash trough (Tb) and is composed of poorly sorted to moderately sorted, coarse-grained, rounded, limestone and dolomite fluvial gravel, pebble, and cobble deposits mixed with subangular to rounded gneiss, granite, and limestone constituents as large as 3 ft in diameter; all clasts derived from the Virgin Mountains northwest of map area. Unit is strongly dissected by modern erosion. Thickness, 60 to 65 ft near Wheeler Fault, more than 200 ft in northwest corner of map area

YOUNG VOLCANIC ROCKS AND ASSOCIATED SEDIMENTARY ROCKS

Include intrusive dikes, necks, and basalt flows (Ti, Tb) along Cottonwood and Grand Washes and Olaf Knolls area. K-Ar ages on these rocks in and near the map area include 3.80±0.11 Ma, 3.24±0.05 Ma, 3.79±0.46 Ma, and 4.80±0.07 Ma (Reynolds and others, 1986; Cole, 1989; Damon and others, 1996; Faulds and others, 2004). Flows just west of map that are continuous with those exposed on the west side of Cottonwood Wash yielded $^{40}Ar/^{39}Ar$ date of 4.71±0.07 Ma (Mick Kunk, written commun., 2002). In addition, the basalt at Sandy Point in Lake Mead south of the map area yielded $^{40}Ar/^{39}Ar$ age of 4.41±0.03 Ma, suggesting it may be the southernmost extent of this volcanic sequence (Faulds and others, 2004).

Ti **Dikes and necks (Pliocene)**ó At Olaf Knolls (sec. 1, T. 35 N., R. 15 W.), consist of light-gray, alkali-olivine basalt dike that intrudes red siltstone and sandstone (Tgr) alluvial deposits in Grand Wash trough. Form highest part of Olaf Knolls (elev 3,232 ft). Hachures on the map indicate a small maar or collapse depression on the north flank of Olaf Knolls volcano, which is assumed to be about 4 Ma based on relations to other nearby basalt flows (Tb). Unit includes intrusive dikes or necks of dark-gray alkali-olivine basalt along east side of Cottonwood Wash south of Pakoon Springs (west-central quarter of map area). Dikes intrude red siltstone and sandstone (Tgr) alluvial deposits in Grand Wash trough. Pyroclastic deposits are not present with dikes. Age is assumed to be Pliocene based on stratigraphic position and relation to nearby basalt flows. May be source for some local basalt flows in Cottonwood Wash area. As much as 100 ft in width

Tb **Basalt flows (Pliocene)**ó Light-gray to medium-gray alkali-olivine basalt. Include several basalt flows and alluvial sediments interbedded between upper and lower basalt flows along Cottonwood Wash and Grand Wash; many flows originate from vents and dikes in Grand Wash trough north of map area and occupy ancestral Grand Wash and Cottonwood Wash. Majority of basalt at Olaf Knolls flowed approximately 1.5 mi southwest from a dike source (Ti) that forms the highest point of Olaf Knolls and occupies part of ancestral drainage of Grand Wash. Basalt flows 1 mi southeast of Olaf Knolls near the Grand Wash Cliffs may have originated from sources north of map area or from Olaf Knolls. Basalt flows along lower reaches of Grand Wash may have originated from dikes along east side of Cottonwood Wash, east-central part of map area, and may correlate with youngest flows at Grand Wash Bay of Lake Mead, south of map area. Unit includes several interbedded alluvial fan and stream-gravel deposits of variable thickness (Tbs). Only thickest sediments between flows are shown; thinner sediments are too small to show at map scale. Basalt contains calcite-filled veins and vugs. Lowest basalt flow unconformably overlies red siltstone and sandstone (Tgr) and conglomerate (Tgwc) in Grand Wash trough. Basalt flows in the Cottonwood Wash area are offset by several minor faults. Unit as a whole appears to be tilted about 1∫ or 2∫ E. towards Grand Wash along east side of The Cockscomb east of Pakoon Spring. Basalt is folded in a short-length monocline that dips as much as 7∫ S. between Cottonwood Wash and

Grand Wash in central part of map area. Based on gradient at base of basalt, it flowed in southerly direction down ancestral Cottonwood and Grand Washes toward Colorado River just south of map area. Thickness of basalt (Tb) and interbedded sediments (Tbs), 7 to 450 ft

Tbs **Conglomerate (Pliocene)**ó Light-brown to medium-orange-brown, coarse- to fine-grained, poorly sorted conglomeratic sandstone and siltstone of variable thickness as fluvial and (or) alluvial deposits that fill erosional surfaces between basalt flows. Many deposits are too thin to show at map scale. Clasts consist predominantly of schist, granite, gneiss, and amphibolite derived from Proterozoic outcrops in Virgin Mountains about 6 to 7 mi northwest of map area. Proterozoic clasts are mixed with clasts of angular, white and gray chert and subrounded to rounded, gray and dark-gray, limestone and dolomite that average about 2 in. in diameter derived from Paleozoic units exposed in Virgin Mountains. Thickness, 10 to 80 ft

ALLUVIAL DEPOSITS

Alluvial deposits are ivided into, in descending order, conglomerate of Grand Wash and red siltstone and sandstone.

Tgwc **Conglomerate of Grand Wash (Pliocene)**ó Gray and brown sand, gravel, and conglomerate. Consists of dark-gray and light-gray, well-rounded to subangular chert, sandstone, limestone, and dolomite clasts in lithologically similar sandstone and siltstone matrix; consolidated by calcite and gypsum cement. Includes subrounded basalt clasts derived from basalt flows north of map area as common constituent along Cottonwood, Grand, and Pakoon Washes; some basalt clasts may be locally derived. Forms cliff where protected by overlying basalt flows (Tb). Unconformably overlies red siltstone and sandstone (Tgr). Unit fills drainage valleys of ancestral Cottonwood Wash, Grand Wash, and Pakoon Wash that eroded into underlying red siltstone and sandstone (Tgr). Pinches out westward onto The Cockscomb and eastward toward Grand Wash Cliffs. Overlain by alluvial fan (Qa1, Qa2, Qa3) deposits in northeast part of map area near Grand Wash Cliffs. Thickness, 0 to 300 ft

Tgr **Red siltstone and sandstone (Pliocene and late Miocene(?))**ó Red to orange-red, slope-forming, gypsiferous siltstone; medium- to fine-grained sandstone; and coarse-grained gravel. Includes unconsolidated gray to white silty gypsum deposits near Pakoon Springs and along Pakoon Wash, Cottonwood Wash, and Grand Wash. Locally includes channel lenses of thin-bedded, medium- to coarse-grained, low-angle, cross-stratified red sandstone and conglomerate. Conglomerate contains subrounded to angular pebbles of Proterozoic crystalline rock along Pakoon Wash and Grand Wash; clasts are well sorted and matrix supported. Locally includes large-scale crossbedded sets of red sandstone of probable eolian origin. Two tuff samples taken near top of unit where exposed about 8 mi north of map area yielded a tephrochronology correlation age ranging between 3.3 Ma and 4.1 Ma (table 1). Thickness, 1,475 to 1,550 ft or more north of map area (Billingsley and Workman, 2000). Thickness may range from 985 ft to possibly 1,475 ft in subsurface north and west of Wheeler Fault. Thickness along Grand Wash, 425 ft

OLD VOLCANIC ROCKS

Snap Point Basalt (Miocene)ó Includes basalt flow at Nevershine Mesa (extreme south edge of map area just east of 113∫52'30") and several dikes in Pigeon Canyon on Grand Gulch Bench. Informally named Snap Point basalt in Reynolds and others (1986) and Wenrich and others (1995); formally named Snap Point Basalt for Snap Point, the type area, Shivwits Plateau, upper Grand Wash Cliffs, about 9 miles southeast of map area, northern Mohave County, Arizona (Billingsley and Workman, 2000). K-Ar ages are 9.07±0.80 Ma at Snap Point (Reynolds and others, 1986) and 9.2±0.13 Ma for correlative Garret Dikes below and south of Snap Point on the Grand Gulch Bench (Wenrich and others, 1995). $^{40}Ar/^{39}Ar$ ages of basalt include 8.80±0.04 Ma at Snap Point and 8.84±0.08 Ma at Nevershine Mesa (J.E. Faulds, Nevada Bureau of Mines, written commun. June, 2000). Snap Point Basalt probably originated from a dike buried beneath flows on Snap Point. The basalt flowed northwest into Snap Canyon and out onto ancestral valley floor of Grand Wash trough. North-south dikes in Pigeon Canyon area are assumed to be associated with Snap Point Basalt because they parallel dikes at Snap Point and Garret Dikes south of Snap Point on Grand Gulch Bench (Wenrich and others, 1995)

Tsi **Dikes**ó Dark-gray, greenish, finely crystalline, alkali-olivine basalt. Contain phenocrysts of augite and olivine less than 1 mm in diameter. Crumbly. Dikes average about 2 ft in width and have near-vertical dips. Dikes strike north-south parallel to joints and fractures in Pennsylvanian and Permian bedrock in the Pigeon Canyon area. Several dikes in upper Pigeon Canyon are just east of map and mostly covered by alluvium

Tsb **Basalt flow**ó Dark-gray, alkali-olivine basalt. Forms small black cliff at south-central edge of map area (just east of 113∫52í30î). Basalt flow (8.84±0.08 Ma, J.E. Faulds, written commun., 2000) preserves an inverted valley called Nevershine Mesa, just south of map edge in Grand Wash trough. Overlies gray Paleozoic-clast conglomerate facies (Tgc) derived from Snap (south of map area) and Pigeon Canyons along base of lower Grand Wash Cliffs. South of map area, unit intertongues with gray Paleozoic-clast conglomerate (Tgc) deposits. Thickness, 30 ft

SEDIMENTARY ROCKS OF THE GRAND WASH TROUGH

Rocks of the Grand Wash trough, informally named by Bohannon (1984), were deposited in a closed basin just west of the Grand Wash Cliffs. Alluvial deposits (Tgwc, Tgr) beneath young volcanic rocks and associated sedimentary rocks (Ti, Tb, Tbs) west of Wheeler Fault and along Grand Wash are herein interpreted as younger than sedimentary rocks of the Grand Wash trough (Tgc, Tgrc, Tgl, Tgg, and Tgx) and Snap Point Basalt (Tsb) east of Wheeler Fault. Rocks of the Grand Wash trough unconformably overlie the Horse Spring, Moenkopi, Kaibab, Toroweap, and Hermit Formations and Esplanade Sandstone, forming an angular unconformity at local basin margins.

Tgc **Gray Paleozoic-clast conglomerate facies (Miocene)**ó Light-gray, brown, ledge- and slope-forming, poorly sorted, poorly bedded alluvial fan debris flows derived from Paleozoic strata in the Grand Wash Cliffs; clasts dominantly limestone and dolomite. Intertonguing or gradational contact with underlying red Paleozoic-clast conglomerate facies (Tgrc) along base of Grand Wash Cliffs and intertonguing or gradational contact with underlying limestone and siltstone facies (Tgl) between Grand Wash Cliffs and Wheeler Fault. Snap Point Basalt (Tsb) is interbedded within upper part of unit. Unit thins west and southwest of Grand Wash Cliffs; locally absent in Grand Wash area. Thickness, 2,220 ft

Tgrc **Red Paleozoic-clast conglomerate facies (Miocene)**ó Red and reddish-brown, poorly sorted, consolidated, alluvial fan conglomerate, gravel, sand, and silt near base of Grand Wash Cliffs. Clasts are limestone, dolomite, chert, and sandstone in reddish matrix of sandstone and gravel derived from canyons eroded into Paleozoic strata of upper and lower Grand Wash Cliffs, southeast quarter of map area. Reddish matrix is probably derived from Hermit Formation and Esplanade Sandstone of Grand Gulch Bench and upper Grand Wash Cliffs. Gradational and intertonguing contact with underlying limestone and siltstone facies (Tgl). Unit thins northward along Grand Wash Cliffs. Maximum exposed thickness, 340 ft at Pigeon Canyon, base of Grand Wash Cliffs

Tgl **Limestone and siltstone facies (Miocene)**ó Gray, fine-grained limestone and silty limestone interbedded with gray and light-red gypsiferous siltstone, gypsum, and siltstone. Forms 1- to 3-ft-thick ledges and slopes. Includes two tephra beds in upper part of unit south of Tank Canyon and north of Grand Gulch Wash about 2 mi east of Grand Wash (too small to show at map scale). Limestone is freshwater deposit containing fossil algae and plant root casts; beds are vuggy and marly. Limestone beds about 2 to 20 ft thick are separated by sequences of siltstone beds 15 to 70 ft thick. Limestone beds thickest near Grand Wash Cliffs and extend in north-south orientation between Grand Wash Cliffs and Wheeler Fault. A tuff in gypsiferous limestone near base of section yielded a tephrochronology correlation to tuff of Rainier Mesa, dated at 11.72 Ma (table 1). Limestone beds are likely equivalent to, although not continuous with, Hualapai Limestone south of Colorado River, south of map area. Limestone beds thin west and may be folded or faulted down to the west near Wheeler Fault where they are buried by alluvial sediments (Twgc and Tgr) near Grand Wash. Unit locally folded and deformed by northwest-trending folds east of Grand Wash. Gradational and intertonguing vertical and lateral contact with underlying gypsum and gypsiferous siltstone facies (Tgg). Unit mostly removed by modern erosion of Colorado River along south edge of map area. Maximum thickness, 800 ft in central part of map, thinning to less than 200 ft at expense of thickening gypsum and gypsiferous siltstone facies (Tgg) in southern part

Tgg **Gypsum and gypsiferous siltstone facies (Miocene)**ó Gray and red, slope-forming, interbedded gypsum, gypsiferous siltstone, and siltstone. Includes thin beds of gray limestone in upper part. Lower part is mostly gray and white, thick-bedded, silty gypsum and gypsiferous siltstone. Includes interbedded white to purplish-white, 2- to 3-ft-thick, partly reworked air-fall tuff beds within lower part of unit along jeep trail north of Pigeon Wash about 2.5 mi east of Wheeler Fault, south-central edge of map area. Forms soft hummocky badlands called Gyp Hills. Locally folded by north-plunging anticline just east of Wheeler Fault. Unconformably overlies, abuts against, or intertongues with Proterozoic-clast conglomerate facies (Tgx) near Wheeler Fault. Teprochronology analysis on a tuff within section (table 1) collected along jeep trail about one-half mile east of Wheeler Fault, suggests tuff is slightly older than a tuff dated at 11.93±0.03 Ma (tuff of Ibex Hollow, Perkins and others, 1998). This correlation suggests that this unit intertongues laterally as well as vertically within limestone and siltstone facies (Tgl), which contains a tuff correlated directly with the Rainier Mesa Tuff. Only top part of unit exposed, about 400 ft thick; may be as thick as 800 ft or more in subsurface

Tgx **Proterozoic-clast conglomerate facies (Miocene)**ó Red-brown, poorly sorted, consolidated, moderately well bedded, silt, sand, and gravel of cobbles and boulders. Comprised mostly of reddish-brown, brown, red, grayish-green, and light-green clasts of rounded, subrounded, and subangular black schist, gneiss, gabbro, diorite, red pegmatite, granite, and white quartz derived from Proterozoic rocks exposed at Jumbo Peak about 12 mi west of map area. Locally includes gray limestone, dolomite, and red sandstone clasts probably derived from east-dipping Paleozoic rocks just east of Jumbo Peak. Boulders of granite and gneiss can be as much as 5 ft in diameter. Tgx is interpreted as an alluvial fan deposit derived by stream, sheet wash, and debris flows from south and southwest of map area (Lucchitta, 1966). Unconformable contact with underlying Horse Spring and Kaibab Formations east of Wheeler Fault. Thickness, 460 ft exposed, may reach 600 ft in subsurface

OLDER TERTIARY SEDIMENTARY ROCKS

Ths **Horse Spring Formation, Rainbow Gardens Member (Miocene and Oligocene)**ó Originally named the Tassi Wash Group by Longwell (1928, 1936) and Lucchitta (1966) and included as the Cottonwood Wash Formation by Moore (1972) north of the map area. However, because these rocks have close lithologic and stratigraphic similarities to the Rainbow Gardens Member of the Horse Spring Formation, the usage herein follows Bohannon (1984) and Beard (1996). Rainbow Gardens Member includes, in descending order, an upper limestone, a middle sandstone and sandy carbonate, and a basal conglomerate. Thumb Member of the Horse Spring Formation may be present in the subsurface. Age of Rainbow Gardens Member of the Horse Spring Formation is bracketed between older than 26 Ma and 18.8 Ma (Beard, 1996). Only one outcrop is exposed in map area just east of Tassi Spring (southwest-central edge of map area) on upthrown side of Wheeler Fault at The Box. Unconformably overlies the Harrisburg Member of the Kaibab Formation (too thin to show at map scale) and the Fossil Mountain Member of the Kaibab Formation (Pkf). Unit is unconformably overlain by red Proterozoic-clast conglomerate facies (Tgx) of rocks of the Grand Wash trough. Horse Spring Formation dips 24∫ to 34∫ ESE., as much as the underlying Kaibab Formation. Thickness of the Horse Spring Formation, 435 to 450 ft

Upper limestone includes about 100-ft-thick, gray-orange, pink, and white, cliff-forming, vuggy, thin- to medium-bedded, marly crystalline limestone overlain by about 30 ft of red, slope-forming siltstone. Limestone is lacustrine and forms wavy, parallel, and continuous beds about 1 to 3 ft thick in upper part. Limestone is unconformably overlain by Proterozoic-clast conglomerate facies (Tgx) of rocks of the Grand Wash trough. Locally, thin deposits of Paleozoic-clast conglomerate facies (Tgc) are preserved beneath Tgx. Thickness, 130 ft

Middle sandstone and sandy carbonate includes pinkish-white to light-gray, slope- and ledge-forming, fine- to coarse-grained sandstone, calcareous sandstone, sandy limestone, calcareous siltstone, and white, altered thin-bedded tuff beds. Lower part is red, crumbly, slope-forming, thin-bedded siltstone and sandstone about 130 ft thick, conformably overlain by reddish-gray and gray, cliff-forming, thin-bedded sandy limestone sequence 30 to 35 ft thick. Conformably overlain by reddish-brown, slope-forming siltstone and calcareous sandstone, altered tuffaceous sandstone, and conglomeratic sandstone interbedded with pinkish-white, light-gray, medium- to coarse-grained, thin- to medium-bedded, crystalline limestone 140 ft thick in lower part, in turn conformably overlain by upper limestone unit. Thickness of middle unit, 300 ft

Basal conglomerate contains brown to red-brown, slope- and ledge-forming, well-sorted nonmarine conglomerate and gravel. Clasts are gray, subrounded to subangular cobbles and pebbles of limestone and chert (0.5 to 28 in. diam) derived from the Kaibab Formation, supported in reddish, coarse-grained, calcareous sand and gravel matrix also primarily derived from the Kaibab Formation; consolidated by calcite and gypsum cement. Unconformable contact with underlying Kaibab Formation (Pkf). Gradational contact with overlying middle sandstone and sandy carbonate unit. Thickness of basal unit, 25 to 35 ft

MESOZOIC AND PALEOZOIC ROCKS

Moenkopi Formation (Middle(?) and Lower Triassic)ó Includes, in descending order, the upper red member, Shnabkaib Member and Virgin Limestone Member, undivided, and lower red member (Stewart and others, 1972). Only part of upper red member (Middle(?) Triassic) is exposed in the map area (northwest corner). The Timpoweap Member (Lower Triassic) is not present or exposed in the map area; the middle red member occurs on the Colorado Plateau east of the map area, but is not present between the Shnabkaib and Virgin Limestone Members in the map area near The Cockscomb

Ŧmu **Upper red member (Middle(?) and Lower Triassic)**ó Red slope-forming siltstone and sandstone. Gradational contact with underlying silty dolomite of the Shnabkaib Member and Virgin Limestone Member, undivided. Incomplete exposure in upper reaches of Pakoon Wash north and east of Pakoon Springs. Thickness, 300 ft

Ŧmvs **Shnabkaib Member and Virgin Limestone Member, undivided (Lower Triassic)**ó Yellowish-white, thinly laminated to thin-bedded, slope-forming, aphanitic dolomite, limestone, and silty dolomite interbedded with light-gray or reddish-gray, calcareous silty gypsum. Limestone beds form thin ledges (1 to 3 ft thick), interbedded with pale-yellow and red, thin-bedded, slope-forming gypsiferous and calcareous siltstone. Unconformable contact with underlying lower red member of the Moenkopi Formation (Ŧml) at base of lowest limestone bed, mostly obscure. Unit locally onlaps against and unconformably overlies paleohills of the Harrisburg Member of the Kaibab Formation (Pkh). Thickness, 400 ft

Ꞇml **Lower red member (Lower Triassic)**ó Red, fine-grained, thin-bedded, gypsiferous, slope-forming, sandy siltstone and gray, white, and pale-yellow laminated gypsum and minor sandstone. Lower part contains reworked gypsum and siltstone of Harrisburg Member (Pkh) of the Kaibab Formation. Unconformably overlies Harrisburg Member east side of Pakoon Ridge; locally thickens in small paleovalleys and pinches out onto eroded paleohills of underlying Harrisburg Member. Thickness, 30 to 65 ft

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

Pkh **Harrisburg Member**ó Red and yellowish-gray, slope-forming, interbedded gypsiferous siltstone, sandstone, gypsum, and thin-bedded gray limestone. Exposed along east flank of Pakoon Ridge, northwest quarter of map area. Gradational and arbitrary contact with underlying cliff-forming Fossil Mountain Member. Thickness, 200 ft

Pkf **Fossil Mountain Member**ó Light-gray, fine- to medium-grained, thin-bedded, fossiliferous, cliff-forming, cherty limestone. Chert beds weather as dark-gray or black bands at various locations. Unit characterized by cliff of cherty limestone. Unconformable contact with underlying slope-forming Woods Ranch Member of the Toroweap Formation. Contact locally obscured by talus due to thinness of Woods Ranch Member. Thickness, 200 to 250 ft

Toroweap Formation (Lower Permian)ó Includes, in descending order, Woods Ranch, Brady Canyon, and Seligman Members defined by Sorauf and Billingsley (1991). Exposed along east flank of Pakoon Ridge

Ptw **Woods Ranch Member**ó Yellow-gray to reddish-gray, slope-forming gypsiferous siltstone and pale-red silty sandstone interbedded with white thin laminated gypsum. Forms recess in cliff sections. Beds are locally distorted due to gypsum dissolution. Lower contact gradational and marked at top of limestone cliff of Brady Canyon Member. Thickness about 60 ft but can be as little as 10 ft due to dissolution of gypsum

Ptb **Brady Canyon Member**ó Gray, cliff-forming, medium-bedded, fine- to coarse-grained, fetid, fossiliferous limestone; weathers dark dray. Limestone beds average about 2 ft thick and include chert lenses and nodules. Contact with underlying Seligman Member is gradational and arbitrarily marked at base of limestone cliff. Contact commonly covered by minor slump or talus. Thickness, 300 ft

Pts **Seligman Member**ó Gray, yellowish-red, and purple, slope-forming, thin-bedded dolomite and gypsiferous siltstone and sandstone. Thin-bedded siltstone, sandstone, and gypsum in lower part include lenses of brown, purple, and yellow, fine- to medium-grained, thin-bedded, low- to high-angle crossbedded and planar-bedded Coconino Sandstone. Coconino Sandstone not mapped separately because it is too thin to show at map scale. Coconino Sandstone forms a sandstone tongue within the lower part of Seligman Member of the Toroweap Formation (Fisher, 1961; Schleh, 1966; Rawson and Turner, 1974; Billingsley and Workman, 2000; Billingsley and others, 2000). Unit mostly covered by Quaternary talus and alluvial fan deposits. Thickness, 20 to 80 ft

Ph **Hermit Formation (Lower Permian)**ó Light-red, yellowish-white, fine-grained, thin- to medium-bedded, slope- and ledge-forming sandstone and siltstone. Sandstone beds as much as 10 ft thick separated by dark-red, slope-forming, thin-bedded siltstone and yellowish silty sandstone as much as 7 ft thick. Reddish sandstone beds commonly contain yellowish-white bleached spots; some thin sandstone is partly or completely bleached yellowish-white near contact with overlying Toroweap Formation on Grand Gulch Bench due to reducing effect of ground water percolating down from the Toroweap Formation. Unconformable contact with underlying Esplanade Sandstone (Pe) shows erosional relief averaging about 3 to 6 ft. Unit mostly covered by alluvial fan (Qa1, Qa2, Qa3) and talus (Qt) deposits on Grand Gulch Bench, on west side of Pakoon Ridge, and near mouth of Squaw Canyon at base of Grand Wash Cliffs. Thickness, 800 to 860 ft

Supai Group (Lower Permian, Pennsylvanian, and Upper Mississippian)ó The Supai Group defined east of Grand Wash Fault (Colorado Plateau) by McKee (1982), includes the Esplanade Sandstone and Pakoon Limestone (Colorado Plateau). The Supai Group nomenclature does not extend west of the Grand Wash Fault into the Basin and Range Province but we mapped the Lower Permian Esplanade Sandstone, which is present in The Cockscomb area in the northwest corner of the map, to be consistent

Pe **Esplanade Sandstone (Lower Permian)**ó Red and light-red to white, ledge- and slope-forming, fine- to medium-grained, medium-bedded (3 to 10 ft), well-sorted, calcareous sandstone and interbedded, dark-maroon-red, slope-forming siltstone. Includes small to medium-scale, planar-type low-angle and high-angle crossbeds of sandstone and calcareous sandstone in upper half and flat, massive, light-red to gray, low-angle crossbedded sandstone and calcareous sandstone in lower half. Gray limestone beds of Pakoon Limestone (Pkl) intertongue in lower part of Esplanade Sandstone along the Grand Wash Cliffs and are mapped separately on the Grand Gulch Bench. Arbitrary contact placed at base of reddish massive sandstone of the Esplanade Sandstone (Pe) and top of light-gray limestone of Pakoon Limestone (Pkl). Contact is laterally variable because of facies changes in Pakoon Limestone. Thickness, 300 ft

Pkl **Pakoon Limestone (Lower Permian)**ó Named by McNair (1951). Gray, medium- to coarse-grained, thin-bedded, cliff-forming limestone and sandy dolomite; weathers brown gray with sugary surface texture. Unit intertongues with the lower part of the Esplanade Sandstone (Pe). Limestone and dolomite beds are commonly separated by gray-purple, thin-bedded siltstone and sandstone beds; limestone is fossiliferous in upper part; limestone contains lenses and pods of brown chert throughout. Locally cross-stratified, crossbedded laminations are etched out in relief on weathered surfaces. Unconformable contact with underlying limestone beds of the Wescogame Formation of the Supai Group east of Grand Wash Fault and unconformable to mostly disconformable west of the fault. Unconformity represented by lenticular erosional channels as much as 60 ft deep and occupied by ledge-forming, well-sorted, pebbly limestone conglomerate beds. Pakoon Limestone is generally a lighter gray than underlying Pennsylvanian limestone of the Supai Group. Thickness, 200 ft

MIPs **Lower part of Supai Group, undivided (Upper, Middle, and Lower Pennsylvanian and Upper Mississippian)**ó The equivalent Pennsylvanian rocks of the lower part of the Supai Group west of Grand Wash Fault (Basin and Range) is the Callville Formation (not exposed in map area) and farther west, the Bird Spring Formation. The lower part of Supai Group, undivided, includes, in descending order, the Wescogame, Manakacha, and Watahomigi Formations

The Wescogame Formation (Upper Pennsylvanian) is light-red, pale-yellow, and light-gray, fine- to coarse-grained sandstone, dolomitic sandstone, siltstone, mudstone, and conglomerate. Includes an upper slope unit and a lower cliff unit. Upper slope unit is a dark-red, fine-grained siltstone and mudstone and a light-red sandstone. Lower cliff unit is a light-red to gray, high-angle, large- and medium-scale, tabular-planar, crossbedded sandstone with sets as much as 40 ft thick. Unconformable contact with underlying Manakacha Formation characterized by several deep erosion channels filled with chert and limestone-pebble conglomerate in sandy matrix. Thickness, 160 ft

The Manakacha Formation (Middle Pennsylvanian) consists of two informal units, a lower cliff unit and an upper slope unit. Upper slope unit is composed largely of gray shaley mudstone and interbedded thin beds of limestone and sandstone. Gradational contact with underlying lower cliff unit. Lower cliff unit is dominated by crossbedded, calcareous sandstone and sandy limestone or dolomite. Flat, unconformable or disconformable contact with underlying Watahomigi Formation generally marked at base of lower cliff unit. Thickness, 180 ft

The Watahomigi Formation (Upper Mississippian and Lower Pennsylvanian) is composed of three informal units, a lower slope unit (Upper Mississippian), a middle cliff unit (Lower Pennsylvanian), and an upper slope unit (Lower Pennsylvanian). Upper slope unit consists of alternating beds of gray limestone and shaley siltstone or mudstone. Unconformable contact at base with middle cliff unit commonly marked by lenticular bed of chert and limestone pebble conglomerate containing Atokan age fossils. Middle cliff unit consists mostly of thin-bedded (2 to 4 ft), cliff-forming, gray limestone and interbedded, thin, purple siltstone beds. Flat gradational contact with lower slope unit. Lower slope unit dominated by red and purple argillaceous mudstone and siltstone interbedded with thin-bedded limestone. Limestone beds contain red nodules and lenses of red chert containing Late Mississippian conodonts (Martin and Barrick, 1999). Includes local beds of conglomerate at base and within unit composed mainly of angular, gray and brown chert pebbles within matrix of dark-red-brown silt or coarse-grained cherty sand and gravel. Unconformable contact with underlying Redwall Limestone (Mr) or Surprise Canyon Formation (Ms). Thickness, 300 ft

Ms **Surprise Canyon Formation (Upper Mississippian)**ó Includes an upper slope-forming unit, a middle cliff-forming unit, and a lower slope-forming unit defined by Billingsley and Beus (1999). Only lower slope-forming unit is present in map area near mouth of Pigeon Canyon. Equivalent, in part, to the Bird Spring Formation farther west of map area. Composed of gray to white chert and gray limestone-cobble-conglomerate lenses in dark-red-brown gravel and sandstone matrix. Chert clasts are subangular to subrounded and derived from the Redwall Limestone. Unit occupies channels eroded into underlying Redwall Limestone. Unit is absent along most of the Grand Wash Cliffs area. Thickness, 0 to 40 ft

Mr **Redwall Limestone, undivided (Upper, Middle, and Lower Mississippian)**ó Includes, in descending order, the Horseshoe Mesa, Mooney Falls, Thunder Springs, and Whitmore Wash Members defined by McKee (1963) and McKee and Gutschick (1969)

The Horseshoe Mesa Member is light-olive-gray, ledge- and cliff-forming, thin-bedded, fine-grained limestone. Weathers to form receding ledges. Gradational and disconformable contact with underlying massive-bedded limestone of Mooney Falls Member marked by thin-bedded, platy limestone beds that form a recess about 3 to 9 ft high at base of member near top of Redwall Limestone cliff. Fossils are not common, except locally. Includes distinctive ripple-laminated limestone, oolitic limestone beds, and some chert. Locally absent where partly removed by Late Mississippian paleovalley erosion. Disconformable and gradational contact with underlying Mooney Falls Member. Thickness, 50 to 100 ft

The Mooney Falls Member is a light-gray, cliff-forming, fine- to coarse-grained, thick bedded to very thick bedded (4 to 20 ft) fossiliferous limestone. Contains dark-gray dolomite beds in lower part; oolitic limestone and chert beds are restricted to upper part. Contains large-scale, tabular and planar, low-angle cross-stratified limestone beds in upper third of unit. Limestone weathers dark gray and chert beds weather black. Unconformable contact with underlying Thunder Springs Member distinguished by lithology; Thunder Springs Member is thin-bedded dark-gray to brown dolomite and chert beds and Mooney Falls Member is massive-bedded, gray limestone. Thickness, 400 ft

The Thunder Springs Member is about 50 percent gray, cliff-forming, fossiliferous limestone, dolomite, and thin-bedded bands of white chert and about 50 percent brownish-gray, thin-bedded (1 to 5 in), finely crystalline dolomite and fine- to coarse-grained limestone. Limestone most common in north half of map area; dolomite is most common in south half. Weathers into distinctive prominent section of black and light-brown bands on cliff face where dolomite is most common. Locally, includes large-scale crossbedding and irregularly folded beds. Disconformable planar contact with underlying Whitmore Wash Member distinguished by distinct lack of chert in Whitmore Wash Member. Thickness, 100 ft

The Whitmore Wash Member is yellowish-gray and brownish-gray, cliff-forming, thick-bedded, fine-grained limestone and dolomite. Weathers dark gray. Fossils present, but uncommon. Unconformable contact with underlying Temple Butte Formation marked by erosional channels of low relief (5 to 10 ft depth). Contact generally recognized where major cliff of Redwall Limestone overlies stair-step ledges of Temple Butte Formation. Thickness, 80 ft

Dtb **Temple Butte Formation (Upper and Middle Devonian)**ó Purple, reddish-purple, dark-gray, and light-gray, ledge-forming dolomite, sandy dolomite, sandstone, mudstone, and limestone defined by Beus (2003). Includes purple, reddish-purple, and light-gray, fine- to coarse-grained, thin- to medium-bedded, ripple-laminated ledges of mudstone, sandstone, dolomite, and conglomerate fill channels eroded into the underlying Cambrian strata as much as 20 ft. Contact is mostly disconformable flat surface. Contact often recognized by color contrast between light-gray Cambrian dolomites and overlying dark- to olive-gray, medium- and thick-bedded dolomite, sandy dolomite, limestone, and sandstone that forms a sequence of dark-gray ledges. Unconformity at base represents major stratigraphic break in Paleozoic rock record in Grand Wash Cliffs area that includes part of Late Cambrian, all of Ordovician and Silurian, and most of Early and Middle Devonian time, representing about 100 m.y. Exposed only in Grand Wash Cliffs area. Rocks of Ordovician age may be present pending future investigations. Thickness, 475 ft

€m **Muav Limestone (Middle Cambrian)**ó Light-gray, brown, and orange-red, cliff-forming, limestone, dolomite, and calcareous mudstone. Includes unclassified dolomites and possibly Havasu Member as defined by McKee and Resser (1945). Only upper 360 ft is exposed in Pigeon Canyon and Grand Wash Cliffs

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UNPUBLISHED DATA

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Table 1. Tephrochronology Correlations for Grand Wash trough and vicinity, Mohave County, northwestern Arizona. [Correlations by Sarna-Wojcicki, A.M., Walker J.P., and Wan, Elmira, U.S. Geological Survey Tephrochronology Laboratory, Menlo Park, Calif.]

Sample No.	Latitude Longitude	Description	Correlation
GGB-93-1	36ʃ22'20" 113ʃ51'48"	Near base of limestone and siltstone facies (Tgl), rocks of Grand Wash trough	*About 12 Ma*. Correlated age control is 2-8-16 J, a tephra layer from Stewart Valley, Nev., that underlies, with small stratigraphic separation, a biotite vitric tuff dated 11.8 Ma by K-Ar (Evernden and others, 1964)
GGB-93-2	36ʃ22'15" 113ʃ52'06"	Lowest of three closely spaced tuffs, limestone and siltstone facies (Tgl), rocks of Grand Wash trough	*11.72 Ma.* Good match for the tuff of Rainier Mesa, 11.72 Ma, White Basin, Nev. (Perkins and others, 1998). Written confirmation from M.E. Perkins, 2002
GH-93-1	36ʃ17'57" 113ʃ55'24"	Prominent tuff along jeep road east of Pigeon Wash, near base of gypsum and gypsiferous facies (Tgg), that inter-tongues with and overlies Proterozoic-clast conglomerate facies, rocks of Grand Wash	*Older than 11.93 Ma.* Matches a tuff in the Dos Pueblos Beach section, a well-known stratigraphic section west of Santa Barbara and Goleta on the coast of Calif., in the marine Monterey Fm. This layer, DPB-10, underlies DPB-12, which matches tuff of Ibex Hollow (Perkins and others, 1998). GH-93-1 is probably older than 11.93 +/- 0.03 Ma
93-1a Cottonwood Wash	36ʃ55'58" 113ʃ55'33"	Lower of two tuffs in red siltstone and sand-stone unit (Tgr) in northern end of Grand Wash trough (outside of map area)	*Between 4.1 and 3.33 Ma.* Matches best with an Upper Pliocene tuff in the San Joaquin Formation in the Kettleman Hills, Calif., within a section bracketed by the Lawlor Tuff below (4.1 Ma; Sarna-Wojcicki, 1976, modified for new ^{40}K decay constants published by Steiger and Jager, 1977) and the Nomlaki Tuff (3.33 Ma) above
93-1b Cottonwood Wash	36ʃ55'58" 113ʃ55'33"	Upper of two tuffs in red siltstone and sandstone unit (Tgr) in northern end of Grand Wash trough (outside of map area)	*Between 4.1 and 3.33 Ma.* Matches best with an Upper Pliocene tuff in the San Joaquin Formation in the Kettleman Hills, Calif., within a section bracketed by the Lawlor Tuff below (4.1 Ma; Sarna-Wojcicki, 1976, modified for new ^{40}K decay constants published by Steiger and Jager, 1977) and the Nomlaki Tuff (3.33 Ma) above