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Geologic map of the Elbow Canyon quadrangle, northern Mohave County, Arizona

by
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INTRODUCTION

The Elbow Canyon 7.5′ quadrangle lies in the northwestern corner of Mohave County, Arizona (fig. 1). Elevations range from about 500 m (1,640 ft) at the Virgin River (west-central edge of quadrangle) to 2,263 m (7,425 ft) in the Virgin Mountains (southeast edge of quadrangle). Interstate Arizona Highway 15 provides a general access to the northwest quarter of the quadrangle while several unimproved dirt roads lead to remote areas of the quadrangle. The communities of Littlefield and Beaver Dam, Arizona are 2 km north of this quadrangle (via Interstate 15), and Mesquite, Nevada is 3 km west of the west-central edge of the quadrangle along the north bank of the Virgin River. These communities represent the only settlements in the northwestern corner of Arizona and nearby Nevada. The environment, topography, and geography is typical of the Mohave Desert of Nevada and California.

There are about 10 sections of private land in the quadrangle and about 4.5 sections belonging to the state of Arizona. The balance is public land administered by the U.S. Bureau of Land Management Arizona Strip District Office in St. George, Utah. The area supports a sparse growth of desert shrubs, mainly creosote bush and cactus. Dense growths of tamerisk (salt cedar), cottonwood, and willow trees thrive along the alluvial terraces and banks of the Virgin River. A variety of pinion pine, juniper, and oak trees form a moderate forest on the higher slopes of the Virgin Mountains.

PREVIOUS WORK

The quadrangle area is included on two Arizona state geologic maps, one by Wilson and others (1969), and the other by Reynolds (1988), but these maps show only regional geology at a scale of 1:500,000 and 1:1,000,000. A regional geologic map showing a little more geologic detail of the area at 1:62,500 scale was published by Moore (1972). A geologic map of part of the Elbow Canyon quadrangle and all of the Jacobs Well quadrangle was made by Bohannon, 1991. A geologic map of the Mount Bangs quadrangle borders the east edge of this quadrangle (Bohannon and Lucchitta, 1991), a preliminary geologic map of the Mesquite quadrangle by Williams (in progress) borders the west edge of this quadrangle, and a geologic map of the Littlefield quadrangle by Billingsley (in progress) borders the north edge of this quadrangle.

MAPPING METHODS

A preliminary geologic map of this quadrangle was made from 1:24,000 scale 1976 aerial photographs. In particular, many of the Quaternary alluvial units having similar lithologies and intertonguing boundaries were mapped using photogeologic methods. These units were differentiated from one another by topographic expression, differences in albedo, morphologic character, physiographic position, amount of dissection, and amounts and types of vegetation cover. Field investigations were then conducted to check photo interpretations and to obtain descriptions of map units. Paleozoic and Proterozoic rocks in the Virgin Mountains are those mapped by Bohannon (1991). The Proterozoic rocks were not studied in detail and are mapped as one unit.

GEOLOGIC SETTING

The Elbow Canyon quadrangle lies along the southeastern edge of the Virgin River depression (Bohannon and others, 1993), one of several basins in the eastern part of the Basin and Range physiographic province of northwestern Arizona. The Virgin River depression abuts the Virgin Mountains (southeast half of the quadrangle), and they are separated by the Piedmont Fault (Moore,

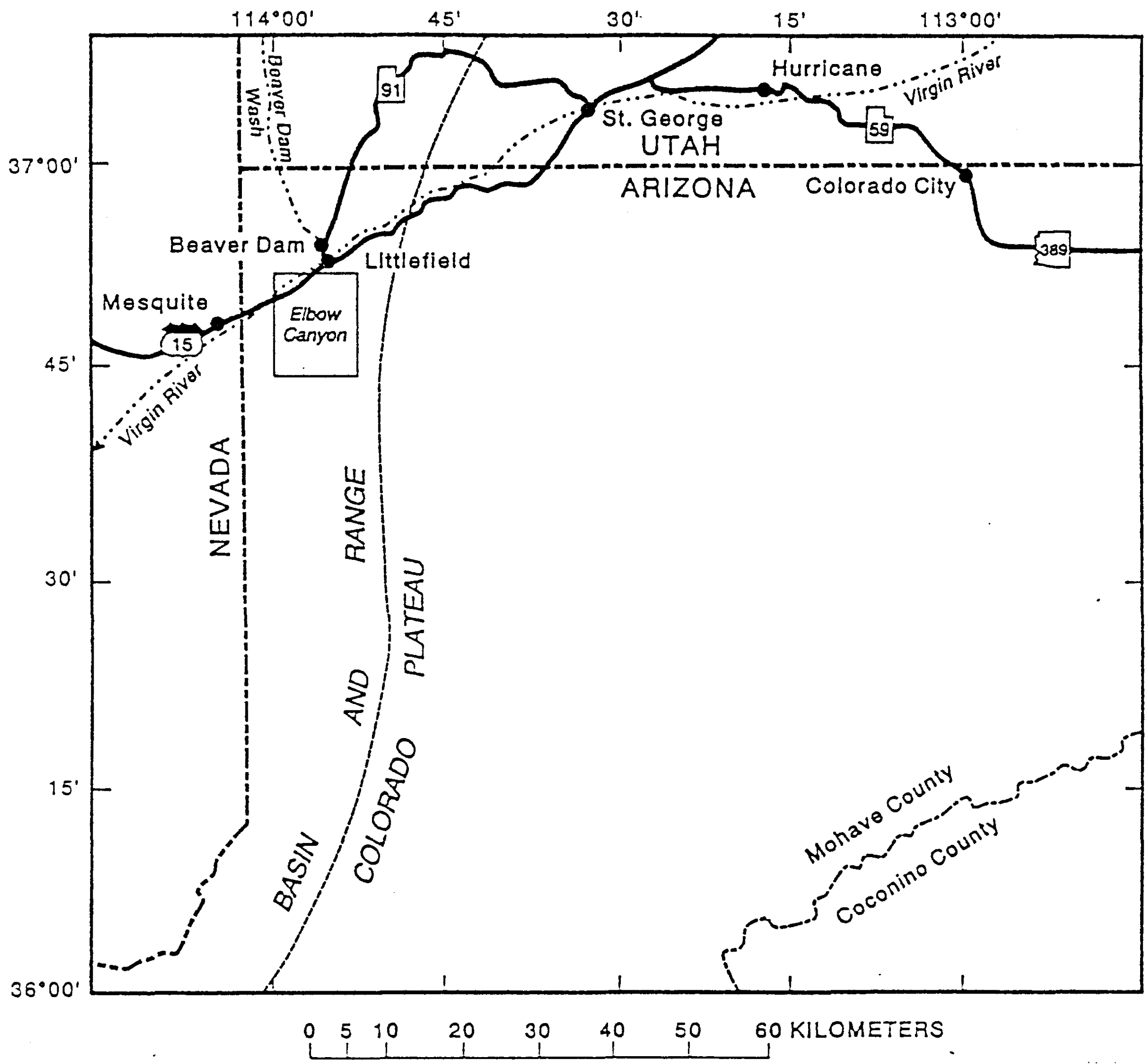

Figure 1. Index map of northern Mohave County, northwestern Arizona, showing the Elbow Canyon 7.5′ quadrangle.

1972). The Virgin Mountains are the easternmost mountains in this part of the Basin and Range, and they are separated from the Colorado Plateau province by the Grand Wash Fault about 13 km (8 mi) east of this quadrangle.

The Virgin River depression is approximately 4,875 m (16,000 ft) deep and filled with intra-basin alluvial sediments (Bohannon and others, 1993). Only the top 60 m (200 ft) of these sediments, the Muddy Creek Formation (Miocene and Pliocene?), which includes ancestral Virgin River conglomerate, are exposed in this quadrangle. The Virgin Mountains were subjected to middle Miocene extension and strike-slip faulting resulting in the exposure of Proterozoic crystalline metamorphic and igneous rocks that are overlain by extensively faulted and folded Paleozoic and Mesozoic strata.

The stratigraphic nomenclature of Paleozoic and Proterozoic rocks in the Virgin Mountains used in this report are those used by Hintze (1986), Bohannon and others (1991), and Bohannon and Lucchitta (1991). The Tertiary strata of the Muddy Creek Formation include siltstone, sandstone, calcrete, and conglomerate. There are two types of conglomerate beds within the Muddy Creek Formation. One type consists of multicolored, well-rounded quartzite clasts about 30 to 35 m (100 to 115 ft) below the top exposed beds of the Muddy Creek, and the other type consists of a mixture of rhyolite, basalt, metamorphic and sedimentary rock clasts near the top of the Muddy Creek.

The lower quartzite conglomerate and gravel form a channel lense within the Muddy Creek exposed in a tributary drainage to the Virgin River (NW 1/4 of sec. 26, T. 40 N., R. 16 W.), about where interstste 15 crosses the tributary. A larger deposite of quartzite gravel and conglomenrate is exposed in a drainage west of this quadrangle (Mesquite 7.5′ quadrangle, sec. 15, T. 40 N., R. 16 W.). The conglomerate and gravel in the upper part of the Muddy Creek represents a deposite of an ancestral Virgin River, informally called the Virgin River conglomerate for mapping purposes. The Virgin River conglomerate pinches out within the fine-grained sediments of the upper Muddy Creek Foramtion in this quadrangle (see correlation chart). The conglomerate is overly by fine-grained siltstone and sandstone sediments that appear to be deposits of the Muddy Creek, but may be reworked Muddy Creek deposits by the Virgin River. The basaltic clasts within the Virgin River conglomerate are probably Pliocene age or younger based on mapping and K-Ar ages of basalt flows upstream of the Virgin River in Utah and Arizona where they are late Pliocene and Pleistocene (Billingsley, 1993; in press).

The Tertiary Muddy Creek Formation is overlain by a relatively thin Cenozoic deposite of pediment calcrete, except east of the Virgin River where the Muddy Creek is overlain by alluvial deposits such as stream-channel deposits, sand sheets and dunes, terrace-gravels, alluvial fans, talus and colluvium. These alluvial deposits form distinctive geomorphic features and have intertonguing or gradational contacts. The distribution of the Tertiary and Quaternary deposits are important for future considerations of human resource development and environmental and range management planning of this area by federal, state, and private organizations. Resource considerations include flood-control, roads, buildings, erosion control, farming, and endangered plant or animal habitats. The composition of materials in the surficial units may have significant impact for urban and range management development.

The Quaternary age assigned to the surficial alluvial deposits in this quadrangle are based on similarity of desert-varnish development observed for Quaternary deposits at the Nevada Test Site, (Hoover and others, 1981), to similarity of established Quaternary deposits of the Colorado Plateau area (Billingsley, 1993, 1994, in press), and to geomorphic field relationships to the Muddy Creek Formation.

GEOLOGIC STRUCTURE

The Virgin River depression is a large tectonic basin extensionally deformed during Miocene time and filled with a thick sequence of basin-fill deposits. Reddish-brown and light-gray siltstone, sandstone, calcrete, and conglomerate of the upper Muddy Creek Formation (Miocene and Pliocene) is exposed in cliffed banks along the Virgin River and its tributaries. Thickness of the Muddy Creek Formation averages about 884 m (2,900 ft) in this area (Bohannon and others, 1993), but only the upper 60 m (200 ft) is exposed in this quadrangle.

Sometime during the Pliocene, specific time unknown, the finer-grained and quartzite conglomerate deposits within the upper Muddy Creek deposits was subsequently eroded by an ancestral Virgin River and its tributaries. This erosion was incised about 200 m (650 ft) into the Muddy Creek Formation below the town of Mesquite, Nevada (Van Williams, U.S. Geological Survey, written commun., 1995) and resulted in a local erosional unconformity filled with an ancestral Virgin River conglomerate inset into the finer-grained Muddy Creek sediments, and later overlain by fine-grained sediments of the Virgin River.

In this quadrangle, the ancestral erosion of the Virgin River is less then that below the town of Mesquite and more than that further upstream near the town of Littlefield, Arizona. Average depth in this quadrangle is about 43 m (140 ft), increasing in depth southwestward (northwest quarter of quadrangle). However, the Virgin River conglomerate does not appear to be inset into the fine-grained Muddy Creek Formation, but instead, pinches out into the Muddy Creek (see correlation chart). The fine-grained sediments that overly the Virgin River conglomerate are not readily separated from the fine-grained sediments that underly the conglomerate beyond the pinch out area. For this reason, and because of the lack of an unconformity or mappable boundary beyond the conglomerate pinchout, all fine-grained sediments below and above the conglomerate are mapped as part of the upper Muddy Creek Foramtion in this quadrangle.

Subsequent minor uplift, tilting, and erosion of the Muddy Creek deposits, including the Virgin River conglomerate, allowed for development of a thick calcrete soil over the Muddy Creek during the late Pliocene and early Pleistocene. A low-angular unconformity seperates the calcrete from the underlying Muddy Creek. The calcrete and Muddy Creek sediments were later subjected to faulting and further tilting, probably during the early Pleistocene.

Sometime in the early Pleistocene, a modern Virgin River had eroded into the calcrete and upper Muddy Creek Formation as much as 100 m (300 ft) deep. The modern Virgin River and its tributaries were subsequently filled with fluvial conglomerate, gravel, and sand that form terraces that are inset against upper Muddy Creek sediments. The modern Virgin River drainage appears to alternate between periods of aggradational accumulation of sediments and degradational downcutting. The Quaternary terraces and adjacent alluvial fans along the Virgin River are the result of cyclical aggradation and degradation caused mostly by climatic fluctuations. The Quaternary deposits are partly modified later by Quaternary tectonic deformation associated with uplift of the Virgin Mountains and, to a lesser degree, subsidence in the Virgin River depression.

Pliocene? and Pleistocene faulting and folding is common in the northwestern part of the Elbow Canyon quadrangle, and along the Piedmont Fault. Sediments of the Muddy Creek Formation and the pediment calcrete deposits, have been gently tilted east and northeast as much as 3° in the northwestern quarter of the quadrangle. A brief reconnaissance of Muddy Creek and calcrete deposits west of this quadrangle indicate a gentle east-dipping limb of a broad anticlinal crest, the axis of which lies about 6 km west of this quadrangle. The east-dipping Muddy Creek Formation and calcrete sediments are offset by several normal high-angle normal faults that have general displacements down to the southwest. Maximum offset on a single fault is 30 m (100 ft) near the Virgin River.

Faulting of older alluvial fans along the Piedmont Fault at the base of the Virgin Mountains was probably associated with the faulting in the northwest quarter of the quadrangle. Young stream deposits (Qas), sand (Qd), young terrace-gravels (Qg_1, Qg_2, Qg_3, and Qg_4), and young alluvial fan (Qa_1) deposits are not faulted or folded in this quadrangle. Thus, faulted strata of the upper Muddy Creek Formation, the Virgin River conglomerate, pediment calcrete, and older alluvial fans (Qa_2 and Qa_3), suggest that the latest pulse of tectonic activity in this quadrangle (and adjacent Littlefield quadrangle to the north) began during the late Pliocene and probably continued into the middle Pleistocene. It is probable that tectonic activity is still potentially active in this quadrangle.

The Virgin River depression is separated from the Virgin Mountains by the Piedmont Fault (Moore, 1972; Bohannon and others, 1991). The Piedmont Fault is mostly covered by several sequences of alluvial fan deposits, three of which are identified in this quadrangle. The Piedmont Fault offsets older and intermediate alluvial fan (Qa_3 and Qa_2) deposits along the west side of the Virgin Mountains, but does not offset some intermediate alluvial fan (Qa_2), and none of the younger (Qa_1) alluvial fans, talus and colluvium, (Qt), or stream (Qas) deposits in this quadrangle. Faulting of older and intermediate alluvial fan (Qa_2 and Qa_3) indicate the location of the Piedmont Fault trace along the base of the Virgin Mountains. The Piedmont Fault has a northeast strike and is a normal high-angle fault in the Quaternary alluvial deposits with displacement of Quaternary deposits down to the west-northwest. Accumulations of alluvial fan deposits may reach at least 400 m ((1,300 ft) and perhaps as much as 458 m (1,500 ft) thick along the down-thrown side of the Piedmont Fault based on present elevations of alluvial fan slopes from the fault to the Virgin River. The Virgin River conglomerate (Tmv) may thicken eastward from the Virgin River area toward the Piedmont Fault beneath the alluvial fan deposits. It is possible that the upper Muddy Creek Formation may have eroded deeper along or near the Piedmont Fault area than as exposed today along the modern Virgin River. After Muddy Creek deposition, alluvial fan accumulation along the Piedmont Fault may have shifted the Virgin River west to its present position along the distal ends of alluvial fans.

DESCRIPTION OF MAP UNITS

Surficial deposits (Holocene and Pleistocene)--Surficial deposits are differentiated from one another chiefly by photogeologic techniques on the basis of difference in albedo, morphologic character, physiographic position and, to some extent, amount and types of vegetation cover

Qaf **Artificial fill and quarries (Holocene)**--Alluvial and bedrock material removed from pits and trenches to build stock tanks, roads, and drainage diversion dams. Includes quarries for sand and gravel

Qas **Alluvium of active stream channels (Holocene)**--Interlensing silt, sand, and pebble to boulder gravel; unconsolidated and poorly sorted. Locally overlies or inset to younger and intermediate alluvial fan (Qa_1 and Qa_2) and floodplain (Qf) deposits; inset to intermediate and older terrace gravel (Qg_2 and Qg_3) deposits. Stream channels subject to high-energy debris flows and flash floods. Supports little to no vegetation. Contacts with other alluvial deposits approximate. Only most active channel deposits shown as seen on 1976 aerial photos. Exposed thickness 1 to 2 m

Qd **Dune sand and sand sheet deposits (Holocene)**--Light-reddish-orange sand on pediment calcrete (QTpc) deposits; light-gray sand along Virgin River. Sand is very fine- to fine-grained, well-sorted, unconsolidated. Forms scattered sand sheets and small complex dunes on pediment calcret surfaces, in tributary drainages, and on floodplain (Qf) or young terrace-gravel (Qg_1) deposits along Virgin River. Sand locally derived from eroded and weathered outcrops of Muddy Creek Formation (Tmc), Virgin River conglomerate (Tmv), pediment calcrete (QTpc), and talus and colluvial (Qt) deposits; distributed by southwesterly and northwesterly winds. Forms falling dunes along western bank of Virgin River and its tributaries. Sand dunes along Virgin River are locally derived from active stream channel and floodplain areas in dry season. Supports sparse to moderate growth of desert vegetation and grass. Only active sand sheets and dunes mapped, thin stabilized sand sheets not mapped. Thickness ranges from 1 to 5 m

Qf **Floodplain deposits (Holocene)**--Light-red or brown silt, sand, and gravel; mostly well-sorted, poorly bedded, unconsolidated. Contains reworked material from ancestral Virgin River conglomerate (Tmv), alluvial fans (Qa_1 through Qa_3), and terrace gravels (Qg_1 through Qg_5). Contacts with other alluvial deposits approximate. Intertongues with active stream (Qas) deposits of Virgin River, and inset to terrace-gravel (Qg_1 and Qg_2) deposits. Forms bench 1 to 1.5 m (3 to 5 ft) above active stream channel of Virgin River. Subject to frequent flooding and local erosion or accumulation of sediment several times per year. Supports moderate growth of grass and shrubs. Exposed thickness 0.5 to 1.5 m

Qg_1 **Young terrace-gravel deposits (Holocene)**--Pale-reddish-brown, gray, and light-brown silt, sand, and gravel; moderate to well-sorted, thin to massive bedded. Contains reworked material from floodplain (Qf), alluvial fans (Qa_1, Qa_2, and Qa_3), talus and colluium (Qt), Muddy Creek (Tmc), and Virgin River conglomerate (Tmv) deposits. Forms bench about 3 m (10 ft) above active stream channels; inset against low intermediate terrace-gravel (Qg_2), alluvial fan (Qa_1 and Qa_2) deposits, and Muddy Creek (Tmv) deposits. Supports moderate to heavy growth of vegetation, mainly tamerisk, willow, cottonwood, and ash trees along Virgin River. Exposed thickness, about 3 m

Qa_1 **Young alluvial fan deposits (Holocene)**--Light-gray and brown silt, sand, pebbles, and boulders, poorly sorted, unconsolidated. Includes lenses of poorly sorted, thin-bedded gravelly sand and pebbles. Includes boulders as much as 0.5 m diameter. Pebble and boulder clasts are angular to rounded gneiss, schist, granite, pegmatite, quartzite, sandstone, limestone, dolomite, and chert derived from Virgin Mountains east of Virgin River. Locally includes reworked deposits of Muddy Creek Formation (Tmc), Virgin River conglomerate (Tmv), terrace-gravel (Qg_3 through Qg_6), and older alluvial fan (Qa_2 and Qa_3) deposits. Overlaps intermediate and older alluvial fans (Qa_2 and Qa_3) on lower fan slopes; inset against intermediate and older alluvial fan deposits on upper fan slopes. Intertongues with younger terrace-gravel (Qg_1) deposits, and overlaps low intermediate terrace-gravel (Qg_2) deposits along Virgin River. Subject to sheet wash erosion and high-energy flash floods and debris flows. Supports sparse growth of desert shrubs, creosote bush, and cactus. About 4 m exposed, estimated as much as 12 m thick

Qt **Talus and colluvial deposits (Holocene and Pleistocene?)**--Light-reddish-brown to yellowish-gray silt, sand, pebbles, boulders, and breccia debris as loose incoherent mass of weathered or broken rock; unsorted and partly consolidated along base of Virgin Mountains. Locally includes reworked decomposed weathered material from Proterozoic rocks in Virgin Mountains. Intertongues with active stream (Qas) and alluvial fan (Qa_2 and Qa_3) deposits in Elbow Canyon and other western drainages of Virgin Mountains. Supports sparse growth of desert shrubs and creosote bush. As much as 4 m thick

Ql **Landslide deposits (Holocene and Pleistocene?)**--Unconsolidated and unsorted debris that have detached and slid downslope as loose incoherent masses of broken rock and deformed strata. Landslide masses are mostly composed of Paleozoic rocks in Elbow Canyon area. One small landslide involves Muddy Creek strata along west bank of Virgin River. Supports mountain shrubs and juniper trees in Elbow Canyon area, no vegetation at Virgin River. Unstable when wet in Elbow Canyon, or further undercut along Virgin River. Minor rockfall or landslides not shown; distinct potential of future rockfall or landslide hazard is prevalent along cliffed banks of Virgin River. Thickness as much as 6 m

Qg_2 **Low intermediate terrace-gravel deposits (Holocene)**--Similar lithology to young terrace-gravel (Qg_1) and floodplain (Qf) deposits. Consists mostly of sand and silt. Locally inset to middle intermediate terrace-gravel (Qg_3) and older terrace-gravel deposits. Forms benches about 1 to 2 m (3 to 7 ft) above young terrace-gravel (Qg_1) deposits, and as high as 4 m (12 ft) above active stream (Qas) and floodplain (Qf) deposits along Virgin River. Supports growth of mixed vegetation, mainly shrubs and tamerisk trees and some willow, ash, and cottonwood trees. As much as 4 m thick

Qa_2 **Intermediate alluvial fan deposits (Holocene and Pleistocene?)**--Same lithologies to younger alluvial fan (Qa_1) deposits but with lesser silt and sand, partly consolidated by calcite cement; stony surface. Includes boulders as large as 2 m (6 ft) in diameter. Rocky surface has minor to well developed desert varnish. Commonly overlapped by young alluvial fan (Qa_1) deposits, incised into older alluvial fan (Qa_3) deposits in upper fan slopes; overlaps older alluvial fans (Qa_3) just east of Virgin River. Intermediate fan surfaces are heavily dissected in upper part as much as 2 m deep. Subject to sheet wash and gully erosion. Supports sparse growth of desert shrubs, creosote bush, cactus and grass. As much as 6 m exposed, estimated maximum thickness, 90 m or more

Qgu **Undifferentiated gravels (Holocene and Pleistocene)**--Gray, light-brown, light-red sand, silt, and conglomeratic gravel, poorly sorted. Partly consolidated, contains calcite and gypsum cement. Fluvial deposits of alluvium in tributary drainage channels west side of Virgin River. Sediments derived from Muddy Creek Formation (Tmc) and Virgin River conglomerate (Tmv), and pediment calcrete (QTpc) deposits. Tributary drainages are being re-excavated by present day erosion. Thickness as much as 30 m

Qg_3 **Middle intermediate terrace-gravel deposits (Holocene and Pleistocene?)**--Similar color and lithology to young and low intermediate terrace-gravels (Qg_1 and Qg_2), consists mostly of gray silt and sand; partly consolidated. Inset against upper and older terrace-gravel (Qg_4, Qg_5, and Qg_6) deposits or unconformably overlies sediments of Muddy Creek Formation (Tmc) and Virgin River conglomerate (Tmv). Forms benches about 5 to 10 m (15 to 30 ft) above modern stream beds. Incised by local arroyo erosion. Supports sparse desert vegetation, mainly creosote bush, cactus, and grass. Averages about 6 m thick

Qg_4 **High intermediate terrace-gravel deposits (Pleistocene)**--Similar color and lithology to younger terrace-gravels (Qg_1, Qa_2, and Qg_3). Inset against older terrace-gravel (Qg_5 and Qg_6) deposits, sediments of the Muddy Creek Formation (Tmc) and Virgin River conglomerate (Tmv). Exposed surface pebbles and boulders have desert varnish coating, limestone clasts are partially pitted or weathered; partly consolidated. Locally incised and supplies material for local young alluvial fan (Qa_1) deposits. Intertongues with or overlapped by young and intermediate alluvial fan (Qa_1 and Qa_2) deposits. Unconformably overlies sediments of

Muddy Creek Formation (Tmc) and Virgin River conglomerate (Tmv). Forms benches 1 to 2 m (3 to 6 ft) above middle terrace-gravel (Qg_3) deposits, and 12 m (36 ft) or more above modern stream bed of Virgin River. Supports sparse vegetation of desert shrubs, cactus, and grass. Averages 4 m thick

Qg_5 **Old terrace-gravel deposits (Pleistocene)**--Similar color and lithologies to younger terrace-gravel (Qg_1, Qg_2, Qg_3, and Qg_4) deposits. Some exposed surface pebbles and boulders have desert varnish coating with caliche deposited on underside. Limestone, dolomite, and sandstone clasts are pitted and weathered on exposed surface. Inset into or unconformably overlying sediments of Muddy creek Formation (Tmc) and Virgin River conglomerate (Tmv). Forms benches about 10 to 12 m (30 to 36 ft) above active stream bed of Virgin River. Locally overlapped by intermediate alluvial fan (Qa_2) deposits. Supports sparse growth of desert shrubs, cactus, and grass. As much as 12 m thick

Qg_6 **Oldest terrace-gravel deposits (Pleistocene)**--Similar color and lithology to younger terrace-gravels (Qa_1 through Qa_5). Inset against or unconformably overlying Muddy Creek Formation and pediment calcrete (QTpc) deposits. Forms benches 18 to 24 m (60 to 80 ft) above active stream bed of Virgin River. Some surface clasts have desert varnish coating, limestone and dolomite clasts are pitted or deeply weathered. Supports sparse growth of desert shrub, creosote bush, cactus, and grass. As much as 6 m thick

Qa_3 **Old alluvial fan deposits (Pleistocene)**--Similar lithologies to younger alluvial fans (Qa_1 and Qa_2). Has yellowish, smooth, lighter tone surface texture than younger alluvial fans (Qa_1 and Qa_2) on aerial photos owing to thin soil development and grassey surface; partly consolidated by calcite cement. Surface clasts have well developed desert varnish, and clasts within deposit have coating of caliche. Partly overlapped by younger alluvial fans (Qa_1 and Qa_2) and active stream (Qas) deposits on upper slopes. Strongly incised and eroded by arroyos that contribute material to younger alluvial fans downslope from Qa_3. Exposed deposits are mostly at base of Virgin Mountains and are offset by faults as much as 18 m (60 ft) along Piedmont Fault. Supports sparse growth of grass, cactus, and creosote brush. Exposed thickness is as much as 20 m

Sedimentary rocks (Tertiary to Cambrian)--Stratigraphic nomenclature established for rocks of the Colorado Plateau and Basin and Range Province are adopted from Hintze (1986), Bohannon and Lucchitta (1991), and Billingsley (1993). Because of limited outcrop and erosion in Virgin Mountains, sections of Paleozoic and Mesozoic stratigraphic sequence are missing. Includes strata of upper Muddy Creek Formation

QTpc **Pediment calcrete (Holocene, Pleistocene, and Miocene)**--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 which produces lighter tone surface on aerial photographs. Little or no soil development on surface of unit but covered locally 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 3° east and northeast in northwest quarter of quadrangle; dissection is variable. Subject to modern sheet flow and local flooding. Base of unit generally forms low angular unconformable contact with underlying Muddy Creek Formation (Tmc) and Virgin River conglomerate (Tmv). Generally less than 6 m thick

Muddy Creek Formation (Miocene and Pliocene?)--Includes a lower quartzite conglomerate and gravel and an upper conglomerate of mixed lithologies of rhyolite, basalt, metamorphic rocks, and sedimentary rocks of ancestral Virgin River, informally called Virgin River conglomerate. Virgin River conglomerate pinches out within fine-grained Muddy Creek deposits. Only upper 60 m (200 ft) exposed

Tmc **Fine-grained sediments of Muddy Creek Formation**--Light reddish-brown, gray, and white, slope-forming, fine-grained, thin- to thick-bedded, calcareous, gypsiferous, siltstone, sandstone, and calcrete. Calcrete beds, 1 to 2 m (3 to 6 ft) thick, contain carbonate nodules as large as 20 cm (8 in) in diameter. Most siltstone and sandstone beds are weakly cemented with calcite and gypsum. Locally includes channel lenses of thin-bedded, medium- to coarse-grained sandstone. Locally, about 35 m (115 ft) below top of unit in small western tributary to Virgin River, NW 1/4 sec. 26, T. 40 N., R. 16 W., includes channel lens of light-gray, slope-forming, unsorted, thick bed of trough cross-stratified quartzite conglomerate and coarse-grained sandstone (not shown on map). Conglomerate consists of multicolored (mostly black), very well-rounded chert and quartzite cobbles and pebbles averaging about 4 cm (2 in) in diameter. Also includes gray limestone and dolomite clasts; pebble imbrication indicates a southward flowing paleocurrent of depositing stream. About 62 m exposed

Tmv **Virgin River conglomerate**--Consolidated dark-gray to brown, cliff-forming conglomerate, gravel, and sandstone; poorly sorted, moderately well-bedded. Conglomeratic clasts and gravel characterized and composed of reddish-brown, brown, red, grayish-green, and light-green rhyolite pebbles and boulders; includes lesser amounts of well-rounded, black schist and gneiss, black gabbro and diorite, red pegmatite and granite, white quartz, light-gray and dark-gray limestone and dolomite, and minor white, red, and multicolored chert and quartzite clasts. Clasta are subrounded to well-rounded pebbles, cobbles, and boulders as large as 43 cm (18 in) in diameter, deposited in gray, coarse- to fine-grained gravel or gravely sandstone composed of same material as conglomerate. Includes lenses of interbedded pale-red, fine-grained, thin-bedded siltstone and sandstone. Calcite cement common. Schist, gneiss, gabbro, diorite, granite, limestone, dolomite, and minor sandstone clasts increase in dominance eastward towards Virgin Mountains. Includes abundant basalt clasts derived from Utah and Arizona and rhyolite clasts from Beaver Dam Wash north of this quadrangle. Unconformably overlies or intertongues with pale-red, fine-grained sediments of Muddy

Creek Formation (Tmc) with as much as 60 m of relief near Virgin River, decreasing to nearly flat surface of relief 1 to 2 km west of Virgin River and pinching out; conformably overlain by fine-grained sediments of upper Muddy Creek that may be deposited by Virgin River. Upper fine-grained sediments were either not deposited over Virgin River conglomerate or were eroded away along lower part of Virgin River area. Muddy Creek Formation (Tmc) and Virgin River conglomerate (Tmv) locally tilted before deposition of overlying pediment calcrete (QTpc) west of Virgin River forming low-angular unconformity. Units of Muddy Creek Formation, Virgin River conglomerate, and pediment calcrete (QTpc) were later faulted and tilted further and unconformably overlain by young, intermediate, and old alluvial fan (Qa_1, Qa_2, and Qa_3) deposits, or intermediate and older terrace-gravels (Qg_3, Qg_4, Qg_5, and Qg_6) east side of Virgin River. Presumably grades laterally eastward into base of old alluvial fan (Qa_3) deposits near Virgin Mountains because of increasing metamorphic clasts east of Virgin River. Unit pinches out about 1 km northwest of Virgin River. Active stream (Qas), floodplain (Qf), terrace-gravels (Qg_1 through Qg_6), and undifferentiated gravels (Qgu) are inset into Virgin River conglomerate (Tmv) deposits. Ranges from 1 to 25 m thick

PPb **Bird Spring Formation (Lower Permian and Pennsylvanian)**--Gray, light-gray, and white limestone, cherty limestone, arenaceous limestone, and light-yellow calcareous sandstone. Limestone weathers gray, calcareous sandstone weathers yellowish-brown; cherty limestone weathers brown. Crossbedding common in sandstone; beds 0.5 to 1 m (1 to 3 ft) thick. Cherty limestone is about 10 to 30 percent of unit; arenaceous limestone and calcareous sandstone interbedded with limestone and forms about 10 to 20 percent of unit. Basal 10 m of unit is slope-forming silty limestone and reddish-weathering siltstone. Marine and highly fossiliferous. As mapped, upper part probably includes rocks that are mapped elsewhere in region as Pakoon Limestone, and lower part includes rocks called the Callville Limestone (Hintze, 1986; Billingsley, 1993). Pakoon Limestone is commonly dolomite and weathers white, in contrast with gray underlying Callville Limestone, but not at all localities. About 360 to 400 m thick

Mm **Monte Cristo Limestone (Upper and Lower Mississippian)**--Medium gray, aphanitic, thick-bedded limestone, cherty limestone and dolomite. Lithologically equivalent to Redwall Limestone of Colorado Plateau Province (Mckee, 1963). Upper part includes Yellowpine, Arrowhead, and upper part of Bullion Members of Monte Cristo Limestone (Hewett, 1931). Upper part is equivalent to Horseshoe Mesa Member and upper part of Mooney Falls Member of Redwall Limestone (McKee, 1963). Medium- to coarse-grained bioclastic limestone and dolomite within Bullion Member is equivalent to Mooney Falls Member. Lower part includes Anchor Member of Monte Cristo Limestone which is equivalent to Thunder Springs Member of Redwall Limestone. Anchor Member is medium-gray, medium- to coarse-grained bioclastic limestone and cherty limestone, chert beds generally white and as much as 0.5 m thick. Lower part includes Dawn Member of Monte Cristo Limestone which is equivalent to (Whitmore Wash Member of Redwall Limestone. Dawn Member is medium-gray, coarse-grained, massive-bedded, crystalline and bioclastic dolomite and limestone. All members form cliff that generally appears unbedded except where chert beds of Anchor Member are present. About 350 m thick

Dls **Limestone (Devonian)**--Light-gray to dark-gray, medium- to coarse-grained, medium-bedded (0.4 to 2 m thick), dolomite, dolomitic sandstone, and limestone. Weathers dark-gray. Unit is primarily equivalent to Valentine Member of Sultan Limestone of Hewett (1931), upper part may be equivalent to Crystal Pass Member of same formation. Equivalent to Temple Butte Formation of Colorado Plateaus Province (Beus, 1980). Unconformable contact with overlying Monte Cristo Limestone. Conformable or gradational contact with underlying Nopah Formation. About 60 to 100 m thick

Ꞓn **Nopah Formation (Upper Cambrian)**--Light-gray, cliff-forming dolomite and sandy dolomite; crystalline texture. Weathers to uniform pale yellowish-gray; forms slope. Beds are centimeters to several meters thick. Base of unit marked by thin sandy dolomite that erodes to recessive slope and is yellow to brownish-gray, weathing to dark to medium-brown. Includes dark-gray limestone and interbedded green shale. About 60 m thick

Ꞓd **Dolomite (Upper Cambrian)**--Light-gray, medium- to fine-grained thin-bedded (5 cm and 0.5 m thick), cliff-forming dolomite. Weathers brownish-gray. About 100 to 130 m thick

Muav Limestone (Middle Cambrian)--Subdivision of Muav follows McKee and Resser (1945). The Muav Limestone is probably lithologically equivalent to upper part of Bonanza King Formation west of mapped area, but is younger than Bonanza King, which is Late and Middle Cambrian

Ꞓmst **Striped unit**--Light-gray to white, thin- to medium-bedded (1 to 3 m [3 to 10 ft] thick), cliff-forming limestone and dolomite. Light-colored beds are composed of uniform fine- to medium-grained crystalline carbonate minerals with distinct fine laminations. Darker beds are composed of fine-grained crystalline carbonate minerals and about 10 percent silt that weathers yellow-brown. Small-scale trough cross-lamination present in darker beds. About 75 to 100 m thick

Ꞓmh **Havasu Member**--Medium to dark-gray, fine-grained to crystalline, thin-bedded, cliff-forming dolomite and limestone; silty. Weathers yellow-brown. Bedding is distinct, parallel, even, and continuous. 40 to 50 m thick

Ꞓmg **Gateway Canyon Member**--Light-gray to white dolomite, limestone, sandy dolomite, and sandy limestone. Composed of three subunits. Top subunit is recessive, light-gray to white, finely laminated dolomite with parallel, continuous, and even beds 20 cm to 1 m (12 in to 3 ft) thick. Middle subunit is cliff-forming, light-gray to brown-gray silty dolomite and limestone containing internal cross-lamination. Bottom subunit is light-gray to brown-gray moderately resistant sandy limestone and sandy dolomite that weather orange-brown; has parallel to low-angle cross-limitations. About 50 m thick

€mkp **Kanab Canyon and Peach Springs Members, undivided**--Brown-gray and dark-gray, fine- to medium-grained, crystalline, cliff-forming silty limestone and dolomite. Weathers to yellow-brown, rust-brown, and brown-gray. Bedding is distinct and parallel, wavy, and continuous, 5 cm to 1 m (2 in to 3 ft) thick. About 75 to 90 m thick

€msr **Spencer Canyon, Sanup Plateau, and Rampart Cave Members, undivided**--Medium to dark-gray, fine- to medium-grained, cliff-forming silty limestone and dolomite. Weathers to medium-gray, yellow-gray, and brown-gray. Bedding is parallel, even, continuous, 5 cm to 1 m (2 in to 3 ft) thick, and well defined by interbeds of yellow-brown silty carbonate rocks with medium-gray carbonate rocks. 60 to 110 m thick

€b **Bright Angel Shale (Middle Cambrian)**--Upper part is black to dark-gray, slope-forming shale that probably correlates to the Chisholm Shale of Great Basin. Includes resistant limestone and dolomite unit about 10 m thick that is discontinuous on regional basis; commonly iron stained and weathers rust colors; may correlate to Lyndon Limestone of Great Basin. Lower part consists of black to dark-gray, slope-forming shale that weathers gray and light-brown; includes interbedded yellow-brown, thin, quartzite beds; may correspond in part to Pioche Shale of Great Basin. About 60 to 100 m thick

€t **Tapeats Sandstone (Middle and Lower Cambrian)**--Pale red and light-brown, fine- to medium-grained, thin-bedded, 5 to 50 cm (2 to 20 in), cliff-forming sandstone and quartzite. Weathers dark-red and yellow-brown. Upper part is yellowish-brown and lower half is reddish. Most beds have low- to moderate-angle cross-stratification. About 65 to 80 m thick

€u **Undifferentiated limestone and dolomite (Middle and Lower Cambrian)**--Light-gray dolomite; weathers yellow, forms slope. Includes dark-gray limestone and interbedded green shale. Limestone beds as thick as 5 m (16 ft). Forms alternating cliffs and slopes. Euaivalent to unclassified dolomite and part of Muav Limestone of Colorado Plateaus Province (McKee and Resser, 1945). About 300 m exposed

Xc **Crystalline rocks (Early Proterozoic)**--Gneiss, schist, and granitic rocks. Not studied in detail, description follows Moore (1972). Garnet-biotite gneiss, garnet-sillimanite-biotite schist, gneissic hornblendite, granite gneiss, amphibolite, and granitic and gabbroic intrusives. Locally dikes and sills of coarsely crystalline pink granite are abundant in gneisses 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

Contact--Dashed where approximately located

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

Strike and dip of beds--Showing dip where known

Vertical and near vertical

Direction of prevailing winds for sand deposits

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