Geologic map of Clayhole Wash and vicinity, Mohave County, northwestern Arizona

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Prepared in cooperation with the
National Park Service and the
Bureau of Land Management

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INTRODUCTION

This geologic map is part of a cooperative project between the U.S. Geological Survey, the Bureau of Land Management, and the National Park Service. The map completes one of several remaining areas where uniform quality geologic mapping is needed to provide geologic information for this part of the Uinkaret Plateau of the Arizona Strip north of Grand Canyon National Park and west of Pipe Springs National Monument. Geologic information in this report will be useful toward future geologic, biologic, and hydrologic resource studies conducted by the Bureau of Land Management and other federal and state agencies and private concerns.

Clayhole Wash, an intermittent stream, is the principal drainage outlet for the northern part of the Uinkaret Plateau area and drains northwest toward the Virgin River in southwest Utah. Lost Spring Mountain is the principle landmark of the map area about 13 km (8 mi) west of Colorado City, Arizona, the nearest settlement. The map area borders the Utah/Arizona state line along its north boundary (fig. 1). Elevations range from about 1,295 m (4,248 ft) at Short Creek to about 1,737 m (5,698 ft) at Lost Spring Mountain. Access to the map area is by improved dirt roads, locally referred to as the Navajo Trail and Clayhole Wash road (fig. 1). Several unimproved dirt roads lead from these roads to various locations within the map area. Travel on these roads can be done with 2-wheel-drive vehicles, except on unimproved roads during muddy conditions. Extra food and water are highly recommended for travelers to this remote area.

The Bureau of Land Management, Arizona Strip Field Office, St. George, Utah, manages most of the area. In addition, there are 15 sections that belong to the State of Arizona and about 17 sections that are private land near Colorado City, Arizona (U.S. Department of the Interior, 1993). Lower elevations in the map area support a sparse growth of sagebrush, cactus, grass, and various high-desert shrubs. At higher elevations, generally above 1,525 m (5,000 ft), sagebrush and grass thrive in alluvial valleys and pinion pine and juniper trees are common on Lost Spring Mountain. Salt cedar (tamarisk) and Russian olive trees grow along the banks of Clayhole Wash and some of its tributaries.

PREVIOUS WORK

Marshall (1956b, c, d) made the earliest geologic map of the northeast half of the map area for the U.S. Atomic Energy Commission that was later compiled onto a geologic map of the State of Arizona by Wilson and others (1969) and modified by Reynolds (1988). Four preliminary 1:24,000-scale geologic maps by Billingsley (1993a, b; 1994a, b) are compiled into this map. Geologic mapping of adjacent areas (fig. 1) include the lower Hurricane Wash and vicinity that borders the map area on the west (Billingsley and Graham, unpub. data a); the upper Hurricane Wash and vicinity that adjoins the southwest corner of the map area (Billingsley and Dyer, unpub. data b); the Clayhole Valley and vicinity that adjoins the south edge of the map area (Billingsley and others, unpub, data c), and the Antelope Knoll and Little Clayhole Valley 7.5' quadrangles that border the south edge of this map area (Billingsley, 1994c, d). The Short Creek NW 7.5' quadrangle by Marshall and Pillmore (1956) and the Short Creek SW 7.5' quadrangle by Marshall (1956a) borders this map on the east.

MAPPING METHODS

This map was produced using Bureau of Land Management 1:24,000-scale 1976 aerial photographs followed by extensive field checking. Many of the Quaternary alluvial deposits that have similar lithologies but different geomorphic characteristics were mapped almost entirely by aerial photography. Stratigraphic position and amount of erosional degradation were used to determine relative ages of alluvial deposits having similar lithologies. Each map unit and structure was investigated in detail in the field to insure accuracy and consistency of description (Billingsley, 1993a, b; 1994a, b).

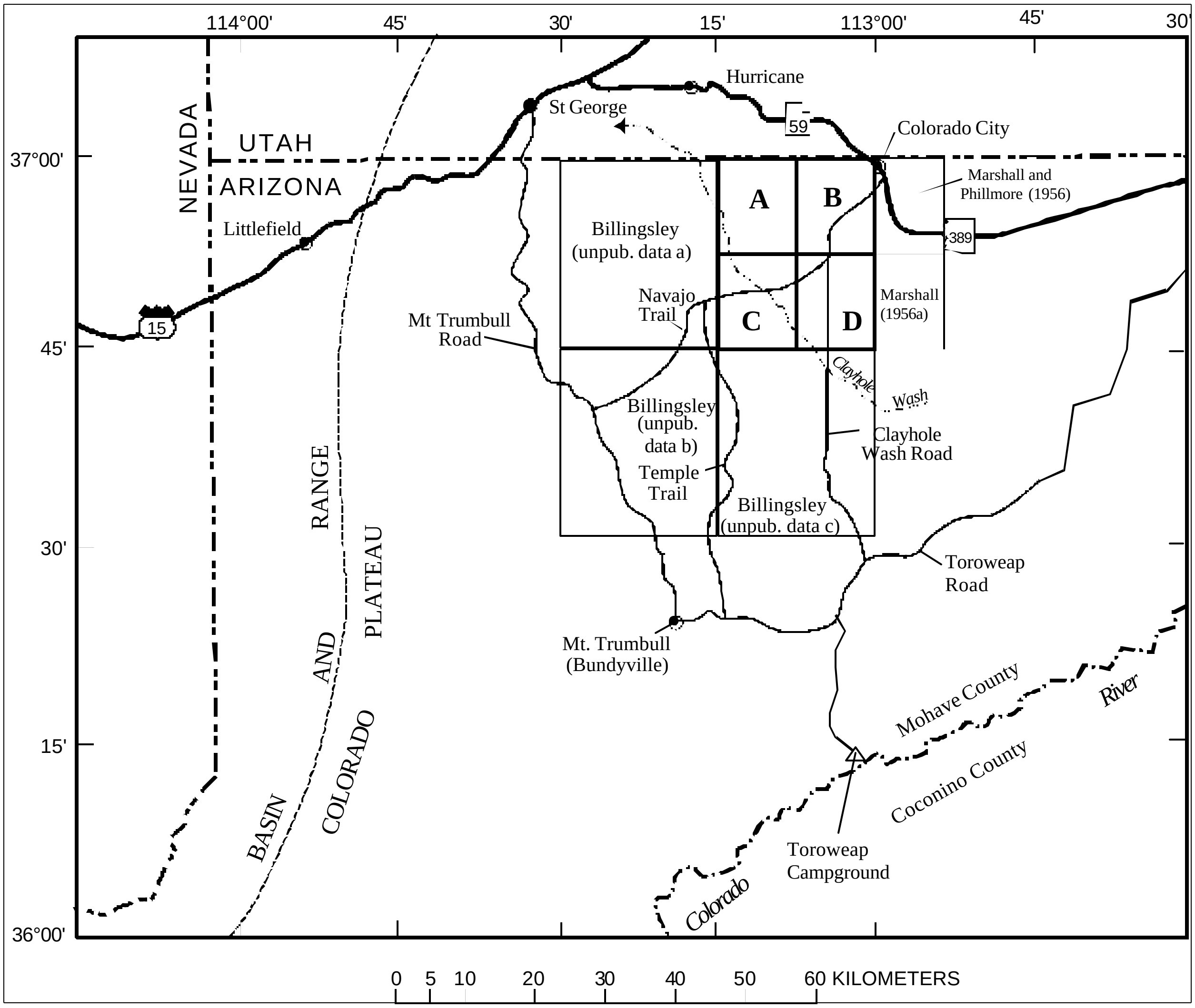

Figure 1. Map showing the U.S. Geological Survey Lost Spring Mountain West (A), Lost Spring Mountain East (B), White Pockets (C), and Formaster Well (D) 7.5' quadrangles of this map area and adjacent mapped areas, northern Mohave County, northwest Arizona.

GEOLOGIC SETTING

The map area lies within the northern part of the Uinkaret Plateau, a subplateau of the southwest part of the Colorado Plateaus physiographic province. Nearly flat-lying Paleozoic and Mesozoic sedimentary strata have an average regional dip of about 1° to 2° east and are gently warped by minor north-south-trending folds that characterize this part of the Uinkaret Plateau. About 400 m (1,315 ft) of Triassic strata and about 60 m (200 ft) of Permian strata form the sedimentary rocks in the map area. These rocks are offset by minor normal faults along a northwest-southeast strike in the west half of the map area.

Quaternary deposits are widely distributed in the map area and consist of fluvial alluvium, sand dunes, talus, and minor landslide deposits. Artificial fill and quarry deposits are also mapped. Map contacts between Quaternary deposits are arbitrary because of intertonguing and (or) gradational lateral and vertical changes. The subdivision of Quaternary surficial units on the map is intentionally detailed because these units strongly influence the resource management of rangeland, flood control, biological studies, soil erosion, and the planning of local construction projects. All surficial deposits in the map area are Pleistocene or younger because they contain materials derived from Quaternary volcanic deposits similar to related deposits in adjacent mapped areas (Billingsley and Graham, unpub. data a; Billingsley and Dyer, unpub. data b).

STRATIGRAPHY

The Paleozoic and Mesozoic stratigraphic units exposed within the map area include, in order of decreasing age, the Kaibab Formation (Lower Permian), the Moenkopi Formation (Lower and Middle? Triassic), and the Chinle Formation (Upper Triassic). Gray cherty limestone and gray, red, and white siltstone and gypsum of the Kaibab Formation crop out mainly west and southwest of Clayhole Wash. About three-fourths of the surface bedrock in the east part of the map area is red siltstone, sandstone, gray gypsum, and dolomite of the Moenkopi Formation. A light-brown and black, thick conglomeratic sandstone of the Shinarump Member of the Chinle Formation crops out in the north-central part of the map area and forms the resistant surface caprock of Lost Spring Mountain. Erosional unconformities separate the Kaibab Formation from the Moenkopi Formation and the Moenkopi Formation from the Shinarump Member of the Chinle Formation. A small part of the Petrified Forest Member of the Chinle Formation crops out in the Short Creek area and is the youngest Triassic unit on the map. A complete section of the Kaibab and Toroweap Formations are exposed just west of the map area (Billingsley, 1992; Billingsley and Graham, unpub. data a).

Outcrops of igneous rocks are uncommon in the map area. The Antelope Knoll Basalt flow (Billingsley, 1994c; Billingsley and Workman, 2000) is west of Clayhole Wash and two intrusive alkali-olivine basalt dikes and associated minor flows are in the southeast quarter of the map area. These basalts help to establish a Quaternary age for the local alluvial deposits.

The Antelope Knoll Basalt consists of one fine-grained alkali-olivine basalt flow containing sparse olivine phenocrysts in a groundmass of plagioclase, augite, and glass. The K-Ar age is 0.83±0.28 Ma (Wenrich and others, 1995). The outcrop distribution and geomorphic position of the Antelope Knoll Basalt suggest that the basalt flowed north following a drainage that was probably the ancestral drainage of Clayhole Wash. Clayhole Wash has since migrated east and downdip of strata about 3 km (2 mi) and has eroded 60 m (200 ft) deeper in the past 830 thousand years, an average rate of downcutting at 0.075 m/1,000 yrs.

At Black Knolls, a basalt dike intruded along a northwest-trending joint system and produced a local basalt flow. Another small basalt dike and flow occur 6.5 km (4 mi) southeast of Black Knolls along a northwest-trending joint system. The minor flows associated with both dikes flowed onto a thin colluvial surface. Erosion lowered the surrounding colluvial surface about 18 m (60 ft) since the basaltic eruptions, and fragments and pebbles of basalt have been transported about 1.5 kilometers (1 mi) from their source areas. The K-Ar age for the basalt at Black Knolls is 0.580±0.30 ka (Harold Mehnert, U.S. Geological Survey, written commun., 1993). The small dike 6.5 km (4 mi) southeast of Black Knolls is probably a similar age to the basalts at Black Knolls because they have a similar northwest strike, are about the same elevation on a colluvial plain, and are separated by only a few kilometers.

More than half of the bedrock outcrops in the map area are covered by pale-red, gray, and brown alluvial sediment that forms a uniform colluvial deposit that is locally derived from outcrops of the Chinle and Moenkopi Formations. It is likely that some of the colluvium is derived from younger Triassic and Jurassic strata of the Vermilion Cliffs northeast of the map area. The colluvium ranges from less than 1 m (3 ft) to 12 m (40 ft) thick. A veneer of lag gravel forms a desert pavement on the colluvial deposit. Clasts in the desert pavement consist of small, multicolored, mostly black, well-rounded chert and quartz pebbles all derived from the Shinarump Member of the Chinle Formation. Along a ridge in the southeast-central part of the map, scattered boulders of the Shinarump remain on the colluvial surface as further evidence for the origin for most of the colluvium and the lag gravel cover. The desert pavement typically can be used to distinguish the colluvial deposits from the younger alluvial fan and terrace-gravel deposits, except in the extreme northeast corner of the map area where a desert pavement does not exist. Near

Short Creek and Colorado City, the colluvial deposits are stratigraphically above the Shinarump Member of the Chinle and are composed mostly of sand and silt derived from younger Triassic and Jurassic sedimentary rocks east of Colorado City, Arizona.

The alluvial deposits in the map area are assigned to the Quaternary based mainly on field relations between these deposits and Pleistocene volcanic rocks in the region, including the Antelope Knoll Basalt, basaltic rocks at Black Knolls, and Quaternary volcanic deposits southwest and west of this map (Billingsley and Graham, unpub. data a; Billingsley and Dyer, unpub. data b). Vertical and lateral stratigraphic relations among the various alluvial deposits are provided in the Description of Map Units.

STRUCTURAL GEOLOGY

Structural features of the map area show up particularly well on side-looking radar images of the U.S. Geological Survey 1:250,000-scale Grand Canyon quadrangle, Arizona. These images provide an overall perspective of the structural fabric of this part of Arizona (Western Atlas International Inc., 1988).

The map area, as a whole, displays few geologic structures. A belt of small normal faults and parallel folds lie west and southwest of Lost Spring Mountain. These structures have a north to slightly northwest strike. Displacements along the faults are less than 15 m (50 ft), and most offsets are down-to-the-east. Some of the faults may be as old as late Pliocene, but most of the faulting probably occurred during the Pleistocene and Holocene as observed west and southwest of this map area (Billingsley and Workman, 2000). The Hurricane Fault, a major structural feature in this part of Arizona, lies about 8 km (5 mi) west of the map area, has a north to northwest strike, and displaces strata down-to-the-west. The faults and folds are parallel to the nearly vertical joints in the bedrock, except for a few folds in the southwest quarter of the map area. Overall, the bedrock strata have a regional east to slightly northeast dip averaging less than 2°. The regional dip increases to about 4° in the southwest corner of the map area.

CLAYHOLE DOME

A structural dome in the southwest corner of the map forms a low mound-like feature on a relatively flat landscape. The dome, herein called "Clayhole Dome," is roughly 1.6 km (1 mi) in diameter, rises about 30 m (100 ft) above the surrounding landscape and has stratal dips as much as 20° on its flanks. The surface bedrock of Clayhole Dome is composed of limestone strata of the middle part of the Harrisburg Member of the Kaibab Formation. A synclinal fold nearly encircles the dome, which probably helped establish the circular drainage around the dome. Clayhole Dome may be a laccolith at depth that developed in conjunction with the Pleistocene volcanic eruptions of the north part of the Uinkaret Volcanic Field (Billingsley, 1994c); however, volcanic rocks are not exposed in the breached drainages of the dome.

LARAMIDE FOLDS

Short, doubly plunging synclines and plunging anticlines in the map area have a general north-south strike. These folds, like others found elsewhere on the Colorado Plateau, are probably related to early Laramide compressional stresses (Huntoon, 1989). Locally warped and bent strata along the west and southwest part of the map area, too small to show at map scale, are the result of Pleistocene and Holocene dissolution of gypsum in the Harrisburg Member of the Kaibab Formation. These bent strata are commonly associated with solution erosion of gypsum along drainages.

COLLAPSE STRUCTURES

The shallow sinkholes and karst caves in the map area are associated with the dissolution of gypsum in the Harrisburg Member of the Kaibab Formation. The sinkholes are relatively young features of Holocene and probable Pleistocene age. Sinkholes that form an enclosed basin or depression are marked on the map by a triangle symbol.

Some circular bowl-shaped areas that have inward-dipping strata may be collapse-formed breccia pipes that originated in the deeply buried Mississippian Redwall Limestone (Wenrich and Huntoon, 1989; Wenrich and Sutphin, 1989). Such features on this map (southwest quarter) have inward dipping strata and are marked on the map by a dot and the letter C. However, these collapse features cannot be distinguished with certainty from shallow, collapse structures caused by the dissolution of gypsum. The deep-seated breccia pipes potentially contain economic deposits of copper and uranium minerals (Wenrich, 1985).

An abandoned copper mine is near one collapse structure in the southwest corner of the map area (sec. 26, T. 39 N., R. 9 W.). The copper minerals in the middle part of the Harrisburg Member of the Kaibab Formation at the mine are mainly malachite and azurite. This copper deposit is similar to other copper deposits in the Harrisburg Member of the Kaibab Formation at other locations on the Colorado Plateau north and south of Grand Canyon.

The copper mine (no name) is little more than a prospect with two small mine shafts. A small pile of copper minerals lie on the ground near one of the shafts suggesting a small production of copper ore from this mine in its early days. It is not known when the mine was operational, but copper was being discovered and mined in similar deposits elsewhere on the plateau in the early and middle 1900's (Billingsley and others, 1997). Energy Fuels Nuclear Inc. of Fredonia, Arizona claimed the mine during the early or middle 1980's when breccia-pipe uranium prospecting was at its peak.

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DESCRIPTION OF MAP UNITS

SURFICIAL DEPOSITS

[Surficial units on this on this map have slightly different names and descriptions than units with the same map symbol on adjoining maps.]

Qaf **Artificial fill and quarries (Holocene)**—Alluvium and bedrock material removed from pits and trenches to build stock tanks and drainage diversion dams. Includes rock quarries on Lost Spring Mountain

Qd **Sand dune deposits (Holocene)**—White and light-red, fine-grained, well-sorted quartz sand. Sand derived from Short Creek drainage, northeast corner of map area. Form small climbing dunes or thin sand sheets deposited by southwesterly winds. Support grassy vegetation. Minor dune or sand sheet deposits are not shown but commonly overlie colluvial (Qc) deposits. Thickness, 1 to 3 m (3 to 10 ft)

Qf **Floodplain deposits (Holocene and Pleistocene)**—Light-gray or brown silt, sand, and gravel. Partly cemented by clay, calcite, and gypsum. Deposits intertongue with or overlap stream-channel (Qs), valley-fill (Qv), young and intermediate alluvial fan (Qa1 and Qa2) deposits and upper part of colluvium (Qc). Form flat valley floors as opposed to narrow concave valleys of valley-fill (Qv) deposits. Locally cut by arroyos. Subject to frequent flooding and local temporary ponding. Sparsely vegetated by grass. Thickness, 20 m (65 ft) or more

Qs **Stream-channel alluvium (Holocene and Pleistocene)**—Poorly sorted, interlensing silt, sand, and pebble gravel. Intertongues with or abuts intermediate alluvial fan (Qa2), young and intermediate terrace-gravel (Qg1 and Qg2), and upper part of valley-fill (Qv) deposits. Overlaps floodplain (Qf) and young alluvial fan (Qa1) deposits. Stream channels subject to high-energy flows and flash floods. Little or no vegetation in stream channels, except a few salt cedar (tamarisk) trees and Russian olive trees. Contact with other alluvial deposits are approximate. Thickness, 1 to 2 m (3 to 6 ft)

Qg1 **Young terrace-gravel deposits (Holocene)**—Gray silt and light-brown or red, pebble to boulder gravel composed about equally of well-rounded limestone, sandstone, and chert. Include lenses containing pale-red silt and sand with well-rounded quartzite and petrified wood clasts derived from Shinarump Member of the Chinle Formation along Clayhole Wash and its eastern tributaries. Include reworked material from intermediate and older alluvial fan (Qa2 and Qa3) deposits, intermediate and older terrace-gravel (Qg2 and Qg3) deposits, talus (Qt) deposits, and colluvial (Qc) deposits. Form terrace about 1 to 3 m (3 to 10 ft) above local streambeds. Thickness, 1 to 3 m (3 to 10 ft)

Qa1 **Young alluvial fan deposits (Holocene)**—Pale-red, gray, and brown silt and sand. Include lenses of coarse gravel composed of subangular to well-rounded pebbles and cobbles of limestone, chert, and sandstone locally derived from Kaibab and Moenkopi Formations. Include well-rounded quartzite and petrified wood clasts derived from Shinarump Member of the Chinle Formation east of Clayhole Wash; partly cemented by gypsum and calcite. Overlapped by or intertongue with stream-channel alluvium (Qs) and upper part of valley-fill (Qv) deposits. Intertongue or overlap young and intermediate terrace-gravel (Qg1 and Qg2) deposits and intermediate alluvial fan (Qa2) deposits near their downslope ends. Overlap colluvial (Qc) deposits. Alluvial fan deposits subject to sheet wash and arroyo erosion by flash flood debris flows. Support sparse growth of sagebrush, cactus, and grass. Thickness, 6 m (20 ft)

Qv **Valley-fill deposits (Holocene and Pleistocene)**—Partly consolidated silt, sand, and interbedded lenses of quartzite and chert pebble gravel derived from the Kaibab Formation west of Clayhole Wash. Include rounded quartzite pebbles and sand derived from the Shinarump Member of the Chinle Formation east of Clayhole Wash. Intertongue with young terrace-gravel (Qg1) deposits; intertongue with or overlapped by young alluvial fan (Qa1) deposits; overlap colluvial (Qc) deposits. Subject to sheetwash flooding, temporary ponding, and arroyo erosion. Support moderate growth of sagebrush, grass, and cactus. Thickness, 7 m (23 ft)

Qt **Talus deposits (Holocene and Pleistocene)**—Unsorted breccia debris composed of small and large angular blocks of local bedrock. Include boulders of Shinarump Member of the Chinle Formation as much as 2 m (6 ft) in diameter on lower slopes of Lost Spring Mountain and boulders of Antelope Knoll Basalt as much as 0.5 m (2 ft) in diameter near Clayhole Wash, southwest corner of map. Include silt, sand, and gravel derived from local bedrock and partly cemented by calcite and gypsum. Intertongue with young and intermediate alluvial fan (Qa1 and Qa2) and landslide (Ql) deposits. Support sparse growth of sagebrush, cactus, grass, and juniper trees. Only large or extensive deposits shown. Thickness, 2 to 9 m (6 to 30 ft)

Ql **Landslide deposits (Holocene and Pleistocene)**—Unconsolidated masses of unsorted rock debris. Include detached blocks of local bedrock strata that rotated backward and slid downslope as loose incoherent masses of broken rock and deformed strata, often partly surrounded by talus (Qt) deposits. Commonly found on slopes of Lost Spring Mountain below cliffs of Shinarump Member of the Chinle Formation. Include strata of the Chinle and Moenkopi Formations that slid down over sandstone, siltstone, and gypsum beds of the Moenkopi Formation. Support growth of sagebrush, cactus, grass, pinion trees, and juniper trees. May become unstable in very wet conditions. Thickness, as much as 20 m (65 ft)

Qc **Colluvial deposits (Holocene and Pleistocene)**—Pale-red, gray, and brown silt, sand, and gravel; partly cemented by gypsum, calcite, and clay. Locally include boulders of Shinarump Member of the Chinle Formation as much as 2 m (6 ft) in diameter. Clay content greatest near outcrops of Petrified Forest Member of the Chinle Formation in the Short Creek area, northeast corner of map area. Contain numerous black, brown, yellow, red, and gray, very well rounded quartzite and chert pebbles, 1 to 5 cm (0.5 to 2 in) in diameter and rare, rounded, gray-white petrified wood fragments derived from the Shinarump Member of the Chinle Formation. Pebbles form thin desert pavement as lag gravel on colluvial surface below outcrops of the Shinarump Member of the Chinle Formation in central and southeast part of map area. Lag gravel and desert pavement absent near Short Creek area, northeast corner of map area. Locally include basalt fragments near Black Knolls as a desert pavement and poorly defined sand dune and sand sheet deposits near Short Creek. All material is locally derived from Triassic and Jurassic sedimentary strata east of Clayhole Wash. Overlapped by young alluvial fan (Qa1), old terrace-gravel (Qg3), and valley-fill (Qv) deposits. Thickness, 3 to 12 m (10 to 40 ft)

Qg2 **Intermediate terrace-gravel deposits (Pleistocene)**—Similar to young terrace-gravel deposit (Qg1) but partly consolidated. Composed mainly of light-red, fine-grained sand and silt with gray silt and clay. Form flat terraces about 3 to 4 m (10 to 14 ft) above local streambeds. Locally eroded into old terrace (Qg3) deposits. Locally eroded by arroyos as deep as 3 m (10 ft). Thickness, 2 to 6 m (6 to 18 ft)

Qa2 **Intermediate alluvial fan deposits (Pleistocene)**—Similar to young alluvial fan (Qa1) deposits, but partly cemented by calcite, clay, and gypsum. Commonly overlapped by young alluvial fan (Qa1) deposits and intertongue with or eroded into talus (Qt) and valley-fill (Qv) deposits. Locally heavily dissected by erosion in upper part. Support moderate growth of sagebrush, cactus, and grass. Thickness, 2 to 10 m (6 to 32 ft)

Qg3 **Old terrace-gravel deposits (Pleistocene)**—Similar to young and intermediate terrace-gravel (Qg1, Qg2) deposits, but 1 to 3 m (3 to 10 ft) higher than intermediate terrace-gravel (Qg2) deposits that form terraces about 4 to 9 m (12 to 30 ft) above local drainages. Composed of well-rounded limestone, sandstone, and chert clasts in sandy gravel matrix. Locally include abundant, well-rounded clasts of yellow and white quartzite pebbles and petrified wood clasts derived from Shinarump Member of the Chinle Formation. Partly consolidated by calcite, clay, and gypsum cement. Thickness, 3 m (10 ft)

Qa3 **Old alluvial fan deposits (Pleistocene)**—Similar to young and intermediate alluvial fan (Qa1, Qa2) deposits; stony surface; contributes material to younger alluvial fan deposits. Composed mainly of silt, sand, gravel, and cobbles of chert and limestone locally derived from the Kaibab Formation and basalt clasts from the Antelope Knoll Basalt. Intertongue with talus (Qt) and old terrace-gravel (Qg3) deposits. Adjacent to or overlapped by young and intermediate alluvial fan (Qa1, Qa2) and valley-fill (Qv) deposits. Thickness, 3 to 4 m (10 to 14 ft)

IGNEOUS ROCKS

Qi **Intrusive dikes (Pleistocene)**—Dark-gray, finely crystalline alkali basalt; x-ray fluorescence spectrography shows sparse phenocrysts of augite; groundmass composed mainly of plagioclase, augite, glass, and olivine (Wenrich and others, 1995). Form Black Knolls and small black ridge 6.5 km (4 mi) southeast of Black Knolls. Outcrops are surrounded by colluvial (Qc) deposits. Outcrops in both areas are aligned north 45° west along nearly vertical bedrock joints and fractures

Qb **Basalt flow (Pleistocene)**—Dark-gray, finely crystalline alkali basalt as in Qi above. Flow is associated with intrusive dikes (Qi) and flowed less than 150 m (500 ft) from dike source over colluvial (Qc) deposits. K-Ar age at Black Knolls is 0.580±0.30 ka (Harold Mehnert, U.S. Geological Survey, written commun., 1993). Thickness, 1 to 2 m (3 to 6 ft)

Qab **Antelope Knoll Basalt (Pleistocene)**—Consists of one dark-gray, fine-grained alkali-olivine basalt flow. X-ray fluorescence spectrography shows sparse phenocrysts of olivine in groundmass dominated by plagioclase, augite, and glass (Wenrich and others, 1995). Flow originated from Antelope Knoll, a 137 m (450 ft) high pyroclastic cone about 6.5 km (4 mi) south of map area (Antelope Knoll 7.5' quadrangle, secs. 13 and 24, T. 38 N., R. 8 and 9 W.). K-Ar age is 0.83±0.28 ka (Harold Mehnert, U.S. Geological Survey, written commun., 1993). Occupies ancestral Clayhole Wash drainage. Thickness, 1 to 4 m (3 to 12 ft)

SEDIMENTARY ROCKS

Chinle Formation (Upper Triassic)—Includes the Petrified Forest and Shinarump Members as used by Stewart and others (1972)

^cp **Petrified Forest Member**—White, blue-gray, green-gray, pale-red, and purple-red, slope-forming mudstone, siltstone, and coarse-grained sandstone. Contains bentonitic clays derived from decomposition of volcanic ash. Only lower part of unit is exposed in map area (northeast corner). Mostly covered by stream-channel (Qs), dune sand (Qd), and colluvial (Qc) deposits. Erosional contact with underlying cliff-forming Shinarump Member; locally fills channels cut into Shinarump. Estimated incomplete thickness, 60 m (200 ft)

^cs **Shinarump Member**—Orange-brown, black, tan, crossbedded to massive-bedded, pebbly, coarse-grained, cliff-forming sandstone, conglomeratic sandstone, and conglomerate. Weathers brown or black. Includes pebbles and cobbles largely composed of well-rounded quartzite, chert, and dark metamorphic clasts in coarse-grained, brown sandstone matrix. About 30 percent of clasts are black, well-rounded quartzite or chert. Includes petrified wood fragments and petrified logs. Unconformable contact with upper red member of the Moenkopi Formation. Fills erosion channels as much as 5 m (15 ft) deep eroded into upper red member of the Moenkopi Formation. Scattered quarries for natural picture art sandstone are in top part of unit. Picture art sandstone is light red to brown, coarse grained, and crossbedded; contains prominent red or black, iron-stained Liesegang banding. Unit forms resistant caprock surface of Lost Spring Mountain. Thickness, 55 m (180 ft)

Moenkopi Formation (Middle? and Lower Triassic)—Includes, in descending order, upper red member, Shnabkaib Member, middle red member, Virgin Limestone Member, lower red member, and Timpoweap Member as used by Stewart and others (1972). Boundary between Middle and Lower Triassic probably lies in upper red member (Morales, 1987)

^mu **Upper red member (Middle? and Lower Triassic)**—Heterogeneous sequence of red, slope- and ledge-forming sandstone, siltstone, mudstone, and minor gray gypsum. Includes cliffs of thin-bedded sandstone in upper and lower part. Erosional unconformity at bottom of lowest red sandstone cliff in lower part is difficult to locate but has as much as 2 m (6 ft) of relief and may represent boundary between Middle and Lower Triassic (not shown on map). Contact with underlying Shnabkaib Member placed arbitrarily at top of highest thick white siltstone and dolomite bed of Shnabkaib Member. Thickness, 70 m (230 ft)

^ms **Shnabkaib Member (Lower Triassic)**—Interbedded and intertonguing, white, light-gray, laminated, slope-forming, aphanitic dolomite, silty gypsum, and red siltstone. Includes red, thin-bedded mudstone, siltstone, and sandstone beds in lower and upper part. Gradational contact with middle red member placed at base of lowest bed of white or light-gray dolomitic limestone or siltstone of Shnabkaib Member. Thickness, 115 m (380 ft)

^mm **Middle red member (Lower Triassic)**—Red-brown, thin-bedded, slope-forming, laminated siltstone and sandstone, white and gray gypsum, minor white platy dolomite, green siltstone, and gray-green to red, gypsiferous mudstone. Gradational contact with underlying Virgin Limestone Member placed at top of highest gray limestone bed of Virgin Limestone Member. Thickness, 45 to 55 m (150 to 180 ft)

^mv **Virgin Limestone Member (Lower Triassic)—**Includes three light-gray, thin-bedded to thinly laminated, ledge-forming limestone beds, 1 to 4 m (3 to 12 ft) thick, separated by slopes of white, pale-yellow, red, and blue-gray, thin-bedded, gypsiferous siltstone. Includes thin beds of brown, red, and green siltstone, gray limestone, and brown platy calcarenite. Contains star-shaped crinoids and poorly preserved brachiopod fossils in top part of lowest limestone bed and fossil algae in upper two limestone beds. Erosional unconformity separates lowest gray limestone bed from underlying red siltstone of lower red member with relief as much as 3 m (10 ft). Lowest limestone bed thickens in channels. Limestone beds form small cliffs in general slope of unit. Thickness, 25 to 30 m (80 to 100 ft)

^ml **Lower red member (Lower Triassic)**—Red, thin-bedded, slope-forming, sandy siltstone interbedded with gray, white, and pale-yellow, laminated gypsum and minor sandstone beds. Lower sandstone and siltstone beds contain reworked gypsum and siltstone derived from Harrisburg Member of the Kaibab Formation. Lower part of unit includes a marker bed of reddish-gray, coarse-grained, thin-bedded, calcareous, ledge-forming sandstone about 1 to 2 m (3 to 6 ft) thick. Marker bed includes raindrop impressions and rare carbonaceous plant fossils stained green by malachite copper minerals near Short Creek (northeast corner of map area). Interbedded or gradational contact with underlying limestone, sandstone, and conglomerate beds of the Timpoweap Member of the Moenkopi Formation. Base of unit placed at lowermost red siltstone bed of lower red member. Fills local paleovalleys eroded into underlying Kaibab Formation as major unconformity between the Triassic Moenkopi Formation and the Permian Kaibab Formation. Forms gradational contact with underlying Timpoweap Member of the Moenkopi Formation where the Timpoweap is present. Variable thickness, 9 to 60 m (30 to 200 ft)

^mt **Timpoweap Member (Lower Triassic)**—Light-gray conglomerate and limestone. Lower part is conglomerate composed of subangular to rounded pebbles and cobbles of gray and dark-gray limestone, white and brown chert, and white quartzite in gray limestone matrix derived from the Kaibab Formation. Clasts are as much as 30 cm (12 in) in diameter. Conglomerate is largely clast supported but includes matrix of gray to brown, coarse sand, gravel, and minor silt. Upper part is a cliff-forming, interbedded light-gray, fine-grained, thick-bedded, sandy limestone and gray, coarse-grained, low-angle crossbedded sandstone; sandstone beds locally contain small chert pebbles. The name Rock Canyon Conglomerate was proposed and abandoned by Gregory (1948, 1952) and used by Nielsen and Johnson (1979) and Nielsen (1986, 1991). The name Timpoweap Member of Moenkopi Formation is used in this report as used by Stewart and others (1972) for the Moenkopi Formation. Unit fills Triassic paleovalleys eroded into the Kaibab Formation that forms a major unconformity between the Kaibab Formation and the Moenkopi Formation. Imbrication of pebbles in lower conglomerate show an eastward paleoflow of depositing streams. Thickness, 0 to 45 m (150 ft)

^mlt **Lower red member and Timpoweap Member, undivided (Lower Triassic)**—Same rock types as in the lower red member (^ml) and Timpoweap Member (^mt) of the Moenkopi Formation, but is an interbedded mixture of both units. Composed of slope-forming, thin-bedded, interbedded conglomerate, limestone, siltstone, sandstone, and gypsum. Fills small shallow paleovalleys eroded into Harrisburg Member of the Kaibab Formation as much as 20 m (65 ft) deep. Unconformable contact with Harrisburg Member of the Kaibab Formation; locally obscure where overlain by alluvial deposits. Thickness, 5 to 20 m (15 to 65 ft)

Kaibab Formation (Lower Permian)—Includes, in descending order, the Harrisburg and Fossil Mountain Members as defined by Sorauf and Billingsley (1991). Only the Harrisburg Member is exposed. The Fossil Mountain Member is shown in cross section only

Pkh **Harrisburg Member**—Includes upper, middle, and lower part, not mapped separately. Upper part composed of slope-forming, red and gray, interbedded gypsiferous siltstone, sandstone, gypsum, and thin-bedded gray limestone; upper part of unit mostly removed by erosion. Includes pale-yellow or light-gray, thin-bedded, fossiliferous (mollusks and algae), sandy limestone caprock averaging about 1 m (3 ft) thick. Gradational contact with middle part.

Middle part is composed of two prominent limestone beds; an upper gray, thin-bedded, cherty limestone, and a lower light-gray, thin-bedded, sandy limestone. Cherty limestone bed weathers dark brown or black and commonly forms bedrock surface of the map area where upper part is eroded away in southwest quarter of map area. Erosional unconformity separates middle part from lower part. Lower part is composed of slope-forming, light-gray, fine- to medium-grained gypsiferous siltstone and sandstone; medium-grained, thin-bedded gray limestone; and gray massive-bedded gypsum. Dissolution of gypsum locally distorts limestone beds of middle part causing them to slump or bend into local drainages. Base of lower part not exposed. Harrisburg, in general, forms slope with a middle limestone cliff. Thickness, 60 m (200 ft)

Pkf **Fossil Mountain Member**—Light-gray, fine- to medium-grained, thin-bedded, fossiliferous, cliff-forming, sandy, cherty limestone. Contact with underlying Woods Ranch Member of the Toroweap Formation is marked by dissolution and channel erosion with relief as much as 5 m (15 ft). Forms cliff. Thickness, 110 m (360 ft)

Toroweap Formation (Lower Permian)—Includes the Woods Ranch Member as defined by Sorauf and Billingsley (1991). The Woods Ranch Member is shown in cross section only

Ptw **Woods Ranch Member**—Gray, slope-forming, gypsiferous siltstone and pale-red silty sandstone interbedded with medium-bedded, white, laminated gypsum. Beds are locally distorted due to gypsum dissolution. Variable thickness, 12 to 75 m (40 to 300 ft)

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APPENDIX

DIGITAL DATABASE DESCRIPTION FOR THE GEOLOGIC MAP OF CLAYHOLE WASH AND VICINITY, MOHAVE COUNTY, NORTHWESTERN ARIZONA

INTRODUCTION

This publication includes, in addition to cartographic and text products, geospatial databases and other digital files. The database files are particularly useful because they can be combined with any other type of geospatial data for purposes of display and analysis. The other files include digital files that support the databases, and digital plot files that can be used to display and print the cartographic and text products in this publication.

The digital map database, compiled from previously published and unpublished data and new mapping by the author, represents the general distribution of surficial and bedrock geology in the mapped area. The database delineates map units that are identified by age and lithology following the stratigraphic nomenclature of the U.S. Geological Survey. The scale of the source maps limits the spatial resolution (scale) of the database to 1:31,680 or smaller. The content and character of the database, as well as two methods of obtaining the database, are described below.

FOR THOSE WHO DON'T USE DIGITAL GEOLOGIC MAP DATABASES

Two sets of plot files containing images of much of the information in the database are available to those who do not use an ARC/INFO compatible Geographic Information System (GIS). Each set contains an image of the geologic map sheet and explanation and the database description. There is a set available in PostScript format and another in Acrobat PDF format (see sections below). Those who have computer capability can access the plot file packages in either of the two ways described below (see the section "Obtaining the Digital Data"); however, these packages do require gzip or WinZip utilities to access the plot files.

Those without computer capability can obtain plots of the map files through U.S. Geological Survey Information Services. Be sure to request Map MF-2394.

USGS Information Services
Box 25286
Denver, CO 80225

1-888-ASK-USGS
e-mail: ask@usgs.gov

DATABASE CONTENTS

This report consists of three digital packages. The first is the PostScript Plotfile Package, which consists of PostScript plot files of the geologic map and map explanation. The second is the PDF Plotfile Package, and contains the same plot files as the first package, as well as the database description, but in Portable Document Format (PDF). The third is the Digital Database Package that contains the geologic map database itself and the supporting data.

PostScript Plotfile Package

This package contains the PostScript image described below:

cwmap.eps	A PostScript plot file containing the complete map composition with geology, correlation chart, and geologic description at a scale of 1:31,680

The PostScript image of the geologic map and map explanation is 46 inches high by 40 inches wide, so it requires a large plotter to produce paper copies at the intended scale. The PostScript plot file of the geologic map was initially produced by the 'postscript' command with compression set to zero in ARC/INFO version 8.0. The geologic description and correlation chart were created in Adobe Illustrator 8.0.

PDF Plotfile Package

This package contains the PDF images described below:

cwmap.pdf	A PDF file containing the complete map composition with geology, correlation chart, and geologic description at a scale of 1:31,680
cwgeo.pdf	A PDF file containing an image of the accompanying pamphlet containing detailed geologic information and unit descriptions, sources of data, references cited, and digital database description

The PDF image of the geologic map and map explanation was created from a PostScript file using Adobe Acrobat Distiller. The PDF image of the pamphlet was produced in Microsoft Word 2000 using the "Convert to Adobe PDF' option from the Acrobat pulldown. In test plots we have found that paper maps created from PDF files contain almost all the detail of maps created with PostScript plot files. We would, however, recommend that those users with the capability to print large PostScript plot files use them in preference to the PDF files.

To use PDF files, the user must get and install a copy of Adobe Acrobat Reader. This software is available **free** from the Adobe website (http://www.adobe.com/). Please follow the instructions given at the website to download and install this software. Once installed, the Acrobat Reader software contains an on-line manual and tutorial.

Digital Database Package

The database package includes geologic map database files for the map area. The digital maps, or coverages, and their associated INFO directories have been converted into ARC/INFO export files. These export files are uncompressed and are easily handled and compatible with some Geographic Information Systems other than ARC/INFO. Please refer to your GIS documentation.

ARC export files are converted to ARC/INFO format using the ARC command 'import'. To ease conversion and preserve naming convention, an AML is enclosed that will convert all the export files in the database to coverages and will also create an associated INFO directory. From the ARC command line type *&r import.aml*. The export files included are:

ARC/INFO export file	Resultant Coverage	Description
cwpoly.e00	cwpoly	Polygon and line coverage showing depositional contacts, rock units, and faults
cwanno.e00	cwanno	Line coverage showing annotation and annotation leaders
cwdip.e00	cwdip	Point coverage showing strike and dip information, collapse structures, and sinkholes
cwfold.e00	cwfold	Line coverage showing fold axes and basalt flow lines
geo.lin.e00	geo.lin	Lineset
geo.mrk.e00	geo.mrk	Markerset
color524.shd.e00	color524.shd	Shadeset
pattern.shd.e00	pattern.shd	Pattern shadeset
cwpoly.lut.e00	cwpoly.lut	cwpoly lookup table
geomrk.lut.e00	geomrk.lut	Lookup table for point symbols

geolin.lut.e00	geolin.lut	Lookup table for line types
geofont.txt.e00	geofont.txt	Text set used for all annotation

The database package also contains the following files:

import.aml	ARC macro language macro for importing ARC export files
cwtopo.tif	Background hypsography image
cwtopo.tfw	World file accompanying cwtopoclean.tif
cwgeo.txt	A text-only file containing an unformatted version of readme.pdf
cwmet.met	A parseable text-only file of publication level FGDC metadata for this report
mf2394.rev	A text-only file describing revisions, if any, to this publication

OBTAINING THE DIGITAL DATA

The digital data may be obtained from:

a.) The Western Region Geologic Publication Web Page at:
http://geopubs.wr.usgs.gov/docs/wrgis/mf-map.html
Follow the directions to download the files.

b.) The U.S. Geological Survey Western Region FTP server.
The FTP address is: geopubs.wr.usgs.gov
The user should log in with the user name 'anonymous" and then input their e-mail address as the password. This will give the user access to all the publications available via FTP from this server. The files in this report are stored in the subdirectory: pub/mf-map/mf2394.

DATABASE SPECIFICS

Digital compilation

Stable-base maps were scanned at the U.S. Geological Survey Flagstaff field office on an Optronics 5040 raster scanner at a resolution of 50 microns (508 dpi). The resulting raster file was in RLE format and converted to RLC format using the "rle2rlc" program written by Marilyn Flynn. The RLC file was subsequently converted to an ARC/INFO Grid in ARC/INFO. The linework was vectorized using gridline. A tic file was created in latitude and longitude and projected into the base map projection (Transverse Mercator). Tics are defined in the four extreme corners of the map area and in the geologic coverages corresponding with quadrangle corners. The tic file was used to transform the grid to Universal Transverse Mercator (UTM). ARC/INFO generated a root mean square (RMS) report after transforming the original Grid into UTM. ARC/INFO generated the following RMS report:

```
Forward Transformation Coefficients

coef #           coef   x           coef   y
------ ---------------- ----------------
     0       -30705.768       14950.041
     1            1.080          -0.110
     2            0.053           1.115
     3            0.000           0.000
     4            0.000           0.000
     5            0.000           0.000
------ ---------------- ----------------

Forward Transformation Errors

gcp id          input   x          input   y
                output  x          output  y          x error          y error
------ ---------------- ---------------- ---------------- ----------------
     1       299777.380       95772.086
             299784.654       97035.756            0.067            0.573
     2       320108.246       96157.540
```

	322033.473	96538.926	-0.086	-0.743
3	300250.808	70426.839		
	299130.674	69297.647	0.126	1.085
4	320640.528	70816.876		
	321452.247	68802.083	-0.027	-0.231
5	303407.369	83146.536		
	303171.465	83079.816	-0.273	-2.347
6	313587.843	83335.755		
	314314.131	82829.280	0.373	3.202
7	310363.334	74838.343		
	310394.272	73665.406	-0.179	-1.539

Forward transformation RMS Error (X, Y) = (0.198, 1.700)
Forward transformation Chi-Square (X, Y) = (0.274, 20.240)

Backward Transformation Coefficients

coef #	coef x	coef y
0	28897.797	-10719.861
1	0.920	0.086
2	-0.043	0.892
3	0.000	0.000
4	0.000	0.000
5	0.000	0.000

Backward Transformation Errors

gcp id	input x output x	input y output y	x error	y error
1	299777.380	95772.086		
	299784.654	97035.756	-0.039	-0.526
2	320108.246	96157.540		
	322033.473	96538.926	0.051	0.682
3	300250.808	70426.839		
	299130.674	69297.647	-0.074	-0.995
4	320640.528	70816.876		
	321452.247	68802.083	0.016	0.211
5	303407.369	83146.536		
	303171.465	83079.816	0.160	2.153
6	313587.843	83335.755		
	314314.131	82829.280	-0.218	-2.936
7	310363.334	74838.343		
	310394.272	73665.406	0.105	1.411

Backward transformation RMS Error (X, Y) = (0.116, 1.559)
Backward transformation Chi-Square (X, Y) = (0.094, 17.018)

Lines, points, polygons, and annotation were edited using the ARCEDIT modules. Following editing and annotation, the individual coverages were projected into UTM projection.

Map Projection:

Parameter	Description
Projection	UTM
Units	Meters on the ground

Zone	12
Datum	NAD27

Database Fields:

The content of the geologic database can be described in terms of the lines, points, and areas that compose the map. Each line, point, or area in a map layer or index map database (coverage) is associated with a database entry stored in a feature attribute table. Each database entry contains both a number of items generated by ARC/INFO to describe the geometry of the feature, and one or more items defined by the authors to describe the geologic information associated with that entry. Each item is defined as to the amount and type of information that can be recorded. Descriptions of the database items use the terms explained below.

Parameter	Description
Item Name	Name of database field
Width	Maximum number of characters or digits stored
Output	Output width
Type	B - binary integer; F- binary floating point number, I - ASCII integer, C - ASCII character string
N.Dec	Number of decimal places maintained for floating point numbers

LINES

The arcs are recorded as strings of vectors and described in the arc attribute table (AAT). They define the boundaries of the map units, faults, and map boundaries in cwpoly. These distinctions and the geologic identities of the boundaries are stored in the LTYPE field according to their line type.

Definition of cwpoly and cwfold Arc Attribute Tables:

Item Name	Width	Output	Type	N.Dec	Description
FNODE#	4	5	B		Starting node of the arc
TNODE#	4	5	B		Ending node of the arc
LPOLY#	4	5	B		Polygon to the left of the arc
RPOLY#	4	5	B		Polygon to the right of the arc
LENGTH	8	18	F	5	Length of the arc in meters
<COVERAGE>#	4	5	B		Unique internal number
<COVERAGE>-ID	4	5	B		Unique identification number
LTYPE	35	35	C		Line type
PTTYPE	35	35	C		Point type for arc markers
PLUNGE	3	3	I		Coded integer indicating fold plunge (in cv_fold only)

Domain of Line Types recorded in LTYPE field:

cwpoly

------

contact_certain
landslide_scarp
map_boundary
normal_flt_certain
normal_flt_concealed
normal_flt_inferred

basalt_flow_direction

cwfold
------

anticline_certain_red
anticline_concealed_red
anticline_inferred_red
monocline_certain_red
monocline_concealed_red
plunging_anticline_red
plunging_syncline_red
syncline_certain_red
syncline_concealed_red
map_boundary

Domain of arcmarkers recorded in PTTYPE field:

cwpoly
------

fault_ball_fill
xx

cwfold
------

anticline_red
monocline_red
syncline_red
xx

POLYGONS

Map units (polygons) are described in the polygon attribute table (PAT). This identifies the map units recorded in the PTYPE field by map label. The description of map units can be found on the geologic map sheet.

Definition of cwpoly Polygon Attribute Table:

Item Name	Width	Output	Type	N.Dec	Description
AREA	8	18	F	5	Area of polygons
PERIMETER	8	18	F	5	Length of perimeter
<COVERAGE>#	4	5	B		Unique internal number
<COVERAGE>-ID	4	5	B		Unique identification number
PTYPE	5	5	C		Map unit label

Domain of cwpoly PTYPE (map units):

Pkh	Qa1	Qa2	Qa3	Qab	Qaf	Qb
Qc	Qd	Qf	Qg1	Qg2	Qg3	Qi
Ql	Qs	Qt	Qv	TRcp	TRcs	TRml
TRmlt	TRmm	TRms	TRmt	TRmu	TRmv	

Plain text is substituted for conventional geologic age symbols (TR for Triassic) shown on map.

POINTS

Points represent geographic features that have no area or length, or features that are too small for their boundaries to be apparent for the given input scale. Each point is described by a single x,y coordinate. A point attribute table

(PAT) is used to hold the attribute data about points. ARC/INFO coverages cannot hold both point and polygon information.

Definition of cwdip Point Attribute Table:

Item Name	Width	Output	Type	N.Dec	Description
AREA	8	18	F	5	Area (degenerative)
PERIMETER	8	18	F	5	Perimeter (degenerative)
<COVERAGE>#	4	5	B		Unique internal number
<COVERAGE>-ID	4	5	B		Unique identification number
PTTYPE	35	35	C		Point type
DIP	3	3	I		Dip angle in degrees
STRIKE	3	3	I		Strike angle in degrees

Domain of cwdip PTTYPE:

bedding	approx_bedding	prospect
collapse_structure	sinkhole	
vertical_joint	dome_red	

ANNOTATION

Annotation for geologic unit labels is contained in **cwanno** in subclass anno.unit. **cwdi**p also contains annotation, such as that for fault offsets, fault names, strike and dip, collapse features, and geographic feature names.

The text set used for all annotation was geofont.txt. Use of this text set allows for proper symbol notation for unit symbols. The default ARC/INFO text set does not allow a proper geologic symbol indicating 'Triassic.' By using this alternate text set, the character pattern '^m' prints instead as ^m.

SPATIAL RESOLUTION

Use of this digital geologic map database should not violate the spatial resolution of the data. Although the digital form of the data removes the constraint imposed by the scale of a paper map, the detail and accuracy inherent in map scale are also present in the digital data. This database was created and edited at a scale of 1:31,680 means that higher resolution data is generally not present. Plotting at scales larger than 1:31,680 will not yield greater real detail, but may reveal fine-scale irregularities below the intended resolution.