# GEOLOGIC MAP OF THE SMITHSONIAN BUTTE QUADRANGLE, WASHINGTON COUNTY, UTAH AND MOHAVE COUNTY, ARIZONA

*by*

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# GEOLOGIC MAP OF THE SMITHSONIAN BUTTE QUADRANGLE, WASHINGTON COUNTY, UTAH AND MOHAVE COUNTY, ARIZONA

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## ABSTRACT

The quadrangle lies at the north end of the Uinkaret Plateau and shares its south border with the Utah-Arizona state line. The region was uplifted and tilted slightly northeast in the late Tertiary and Quaternary Periods. Thousands of feet of bedrock strata were eroded, sculpting bench, alluvial-plain, and cliff landforms on the uplifted plateau. About 3,300 feet (1,000 m) of Triassic and Jurassic continental sedimentary rocks, mostly fluvial redbeds and eolian sandstone, are exposed. A bajada (Big Plain) covered by thin (<100 feet, < 30 m) fan alluvium west of the Vermilion Cliffs indicates an approximate balance between stream erosion and deposition since middle Pleistocene time.

A normal fault in the northwest corner of the quadrangle at Grafton Wash has the largest stratigraphic throw of any fault in the quadrangle. It offsets the Chinle Formation about 250 feet (76 m) and at depth it has potential to trap oil in Paleozoic reservoir rocks. The fault appears to be a southward extension of an en echelon fault zone, mapped by Gregory (1950) and Hamilton (1978) as the West Cougar Mountain fault in Zion National Park.

Several unpatented mining claims exist in the quadrangle and one was being prospected for platinum and silver in 1990. To date, no significant metallic ore or oil and gas have been produced in the quadrangle. Recent exploration drilling in southern Utah has led some geologists to speculate that Cambrian rock units, which probably are about 7,300 to 9,300 feet (2,225-2,835 m) beneath the Shinarump Member of the Chinle, are potential oil reservoir rock units.

Of the 18 Quaternary deposits mapped, fan alluvium is the most widespread. In the center of the quadrangle (mostly section 10 and 15, T. 43 S., R. 11 W.) is the largest (0.71 square mile or 1.85 $km^2$) mass-wasting deposit consisting of old debris-flow, rockfall-avalanche, and landslide deposits. This complex deposit rests on an alluvial fan of estimated late middle Pleistocene age.

Significant geologic hazards are flash flooding in ephemeral stream channels and the rapid emplacement of water-saturated debris (mudflows) on low parts of alluvial fans during cloudburst storms. Rockfall is a potential hazard near steep, rubble-mantled hillslopes. Landsliding is active locally on moderate to steep slopes, and swelling soils exist, especially on the Petrified Forest Member of the Chinle Formation.

## INTRODUCTION

This report describes rock units and surficial deposits, their economic and engineering potential, and geologic hazards that can impact use of the land. The Smithsonian Butte quadrangle, with its south border on the Utah-Arizona state line, is in southwest Utah 24 miles (39 km) east of St. George. The nearest communities - Hildale, Utah and Colorado City, Arizona - are about 2 miles (3 km) southeast (figure 1). Zion National Park is a few miles north of the map area. The quadrangle takes its name from the butte named by geologist Clarence Dutton as a tribute to the Smithsonian Institution in Washington, D.C., which supported his scientific expeditions in the region (Dutton, 1882, p. 57).

The map area spans two sets of escarpments (cliffs) separated by a plain of coalesced alluvial fans called Big Plain (figures 1 and 2). Big Plain slopes southwest, opposite the dip of underlying mudstone, which it bevels. John Wesley Powell named one escarpment, in the southwest quarter of the area, the Shinarump Cliffs. The other escarpment, northeast of the first and cut in massive reddish sandstone, is the most imposing line of cliffs in southwest Utah. Powell (1873) named these the Vermilion Cliffs.

Geologic structure in the quadrangle is simple. Strata dip northeast in a slightly tilted block. The tilting resulted from differences in vertical movement on the Hurricane and Sevier faults, two major north-trending faults that bound the block west and east of the quadrangle, respectively (figure 1). The late Cenozoic tilting and uplift of the Colorado Plateaus initiated erosion that sculpted the Shinarump and Vermilion Cliffs. Eroded Mesozoic and younger bedrock strata may exceed 7,000 feet (about 2,100 m) (Gregory, 1950, p. 169). Strata presently exposed in the Smithsonian Butte quadrangle are about 3,300 feet (1,000 m) thick. Subsurface sedimentary rocks are 9,000 to 10,000 feet (2,740-3,050 m) thick. This assumes no major change from an area 20 miles (32 km) east where the McDermott No. 1 State well penetrated 10,440 feet (3,182 m) of strata before hitting Precambrian basement rock (Tapp, 1963). In the quadrangle, no deep wells are recorded (Thomas Chidsey, Utah Geological Survey, written communication, 1990).

The highest rock formation is the Navajo Sandstone, made of thick, spectacularly cross-bedded quartz sand that accumulated in dunes on a vast Jurassic desert. The rock forms precipitous cliffs around Smithsonian Butte and

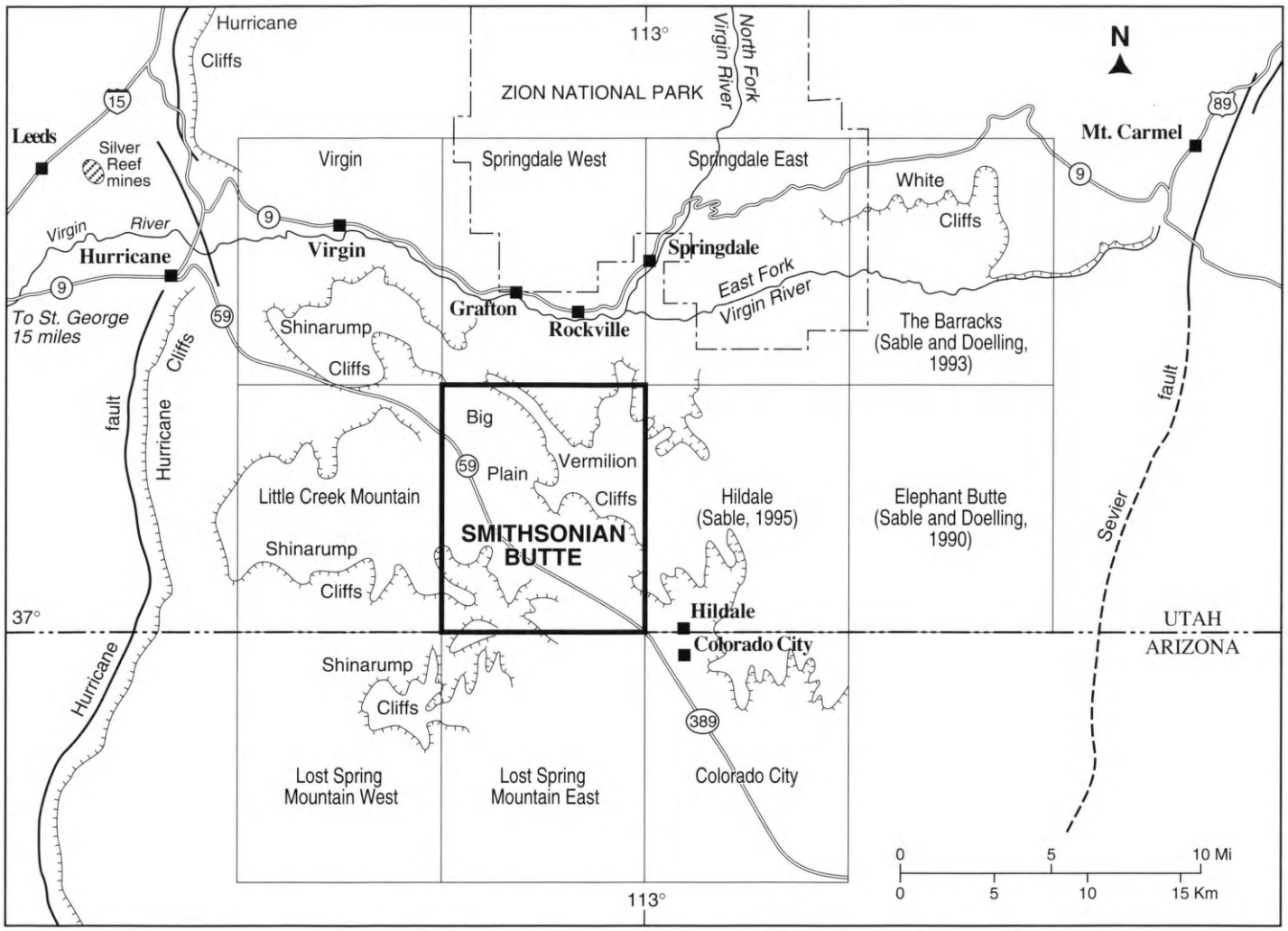


***Figure 1.*** *Location of the Smithsonian Butte quadrangle and adjoining quadrangles, including geologic maps published by the Utah Geological Survey.*

Canaan Mountain (figure 2). A few miles north, where the Virgin River cuts a winding gorge 2,000 feet (610 m) into the formation, towering cliffs and monoliths of the Navajo are the scenic marvel of Zion National Park.

Some formations have produced valuable mineral and energy resources elsewhere in Utah. For example, the Springdale Sandstone Member of the Moenave Formation near Leeds, Utah (16 miles or 26 km northwest) yielded silver at the Silver Reef mines (Cook, 1960, p. 24). About 8 miles (13 km) northwest of the quadrangle, the now-abandoned Virgin oil field produced approximately 183,000 barrels of oil from the Moenkopi Formation between 1909 and 1942 (Hauptman, 1952). The formations in the Smithsonian Butte quadrangle thus have varied economic potential (Van Loenen and others, 1988).

Vertical-walled dry channels (arroyos) of the ephemeral streams are typical of semiarid regions. Torrential flow may follow intense precipitation. Frequency and amount of flow are unpredictable. Horse Valley Wash was the only channel observed in June 1990 that had continuous, small, spring-fed flow. The perennial master stream is the Virgin River, 2 miles (3 km) north of the quadrangle. Its tributaries cut the soft mudstone north of Smithsonian Butte into colorful badlands. South of Smithsonian Butte is a bajada (Big Plain on the map) of coalesced alluvial fans that slope from the Vermilion Cliffs (figure 2).

State Highway 59 crosses Big Plain in a northwest-southeast direction. A gravel road intersects Highway 59 at Big Plain Junction and heads north to cross the Virgin River. This road goes to Rockville and to a paved road to Springdale, Utah and Zion National Park.

Land in the central and western parts of the quadrangle is privately owned semiarid rangeland. In 1990, fewer than 10 residential dwellings existed in the quadrangle. The eastern third is public land characterized by high mesas rimmed by rugged sandstone cliffs and steep rocky slopes sparsely vegetated by juniper, pinyon pine, and sagebrush. Here Canaan Mountain rises 1,500 to 2,200 feet (about 500-600 m) above Big Plain.

We used conventional field methods except that dips and strikes of near-horizontal beds were measured by computer-assisted photogrammetry (Dueholm and Pillmore, 1989). Bedrock map units were defined using the criteria of previous workers. We mapped Quaternary surficial deposits

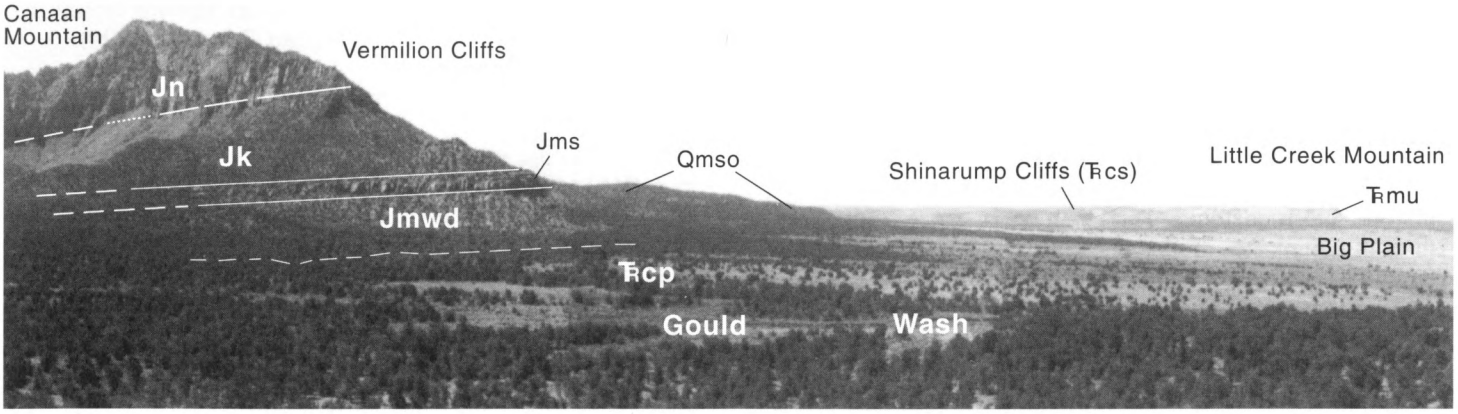


***Figure 2.*** *View south from Smithsonian Butte toward Arizona state line on right skyline. On left, 1,200 feet (366 m) of eroded Jurassic Navajo Sandstone (Jn) caps Canaan Mountain, which is about 2,000 feet (610 m) higher than the plain in middle ground. Units under the Navajo are: Kayenta Formation (Jk), Moenave Formation consisting of the Springdale Sandstone Member (Jms), Whitmore Point and Dinosaur Canyon Members (Jmwd), Triassic Chinle Formation consisting of the easily eroded Petrified Forest Member (Ꞧcp) and resistant Shinarump Member (Ꞧcs), and the upper red member of the Moenkopi Formation (Ꞧmu). The latter forms slopes under the distant Shinarump Cliffs. Some unconsolidated surficial deposits include an old megaslide complex (Qmso), merged alluvial fans (Big Plain), and colluvium and talus (not labeled) on steep slopes.*

thicker than 2 feet (0.6 m) after classifying them genetically and by relative age. For convenience we use "young," "intermediate-age," and "old." Rock colors were compared to the Munsell system in the Rock-Color Chart (distributed by Geological Society of America). Geologic terminology follows Bates and Jackson (1980).

Previous geologic studies of regions that included the Smithsonian Butte quadrangle were conducted by Dutton (1882), Gregory (1950), Cook (1960), and Hintze (1963). The geology a few miles west is described in Thune (1952). Potential for undiscovered oil and gas and mineral resources in the region has been assessed (Molenaar and Sandberg, 1983; Ryder, 1983; Van Loenen and others, 1988; Eppinger and others, 1990). Pillmore (1956) mapped the quadrangle previously. Moore and Sable (1994) produced a preliminary version of this publication.

## STRATIGRAPHY

Lithostratigraphic formations, from oldest to youngest, exposed in the quadrangle are: the Moenkopi (upper part) and Chinle Formations of Triassic age, and the Moenave and Kayenta Formations and the Navajo Sandstone of Jurassic age. Sediment of the Moenkopi Formation was deposited on a stable cratonic shelf that sloped very gently northwest and west in terms of modern compass directions (Pipiringos and O'Sullivan, 1978; Blakey and Gubitosa, 1983). During this time, remnant uplands of the ancestral Rocky Mountains stood in southwest Colorado, northeast Arizona, and northwest New Mexico (Mallory, 1972), and a complex volcanic arc terrain was present south-southwest of the region in southern Arizona and southeastern California (Dickinson, 1981; Blakey, 1990). The remaining formations formed in the Western Interior Basin on the west margin of the North American craton (Peterson, 1994).

Previous workers assigned geologic ages of the formations using paleontological data. While a Triassic age for the Moenkopi and Chinle Formations is long established, age of the overlying Glen Canyon Group (in ascending order includes the Moenave and Kayenta Formations and Navajo Sandstone) has been less certain. A Triassic/Jurassic age was favored before the late 1970s. A Triassic age became less credible after fossil pollen in the Moenave Formation was assigned by Bruce Cornet (Gulf Research and Development Company) to the Early Jurassic (Peterson and others, 1977). The overlying Kayenta Formation contained taxa then considered typical of both the Late Triassic and Early Jurassic. In the late 1980s Padian (1989) proposed an Early Jurassic age for the Kayenta when he identified dermal scutes (external bony plates or scales) from that unit as belonging to the ornithischian (birdlike pelvis) dinosaur *Scelidosaurus* from Lower Jurassic marine rocks in England. By extension, an Early Jurassic or younger age was also favored for the overlying Navajo Sandstone. In this report, we follow later workers and assign an Early Jurassic age to the Glen Canyon Group.

### Triassic System

#### Moenkopi Formation (Lower and Middle? Triassic)

Red beds of the upper one-fifth of the Moenkopi Formation (Ward, 1901) crop out on side slopes of mesas in the southwest part of the Smithsonian Butte quadrangle. Distinctive reddish-brown to pinkish, even, persistent beds form the slopes around Little Creek Mountain (figure 2). Elsewhere in the map area, the formation is concealed except on a small butte in the northwest corner and in Horse Creek Wash. It is fully exposed in the Virgin River valley (McKee, 1954) north of the quadrangle where it is 1,500 to 1,760 feet (457-536 m) of interbedded reddish claystone, siltstone, and sandstone of continental and marginal marine origin (Gregory, 1950, p. 52; Stewart and others, 1972b, plate 4, p. 71). The formation is wedge-shaped, about 2,000 feet (610 m) thick in southwest Utah near the Triassic seaway, thinning to tens of feet near the Colorado-Utah border. Source material was terrigenous mud, silt, and fine sand carried west and northwest (Stewart and others, 1972b, p. 77) by streams

flowing on a vast coastal plain from the Uncompahgre highland of Colorado and the Mogollon highland of Arizona and New Mexico. A few east-thinning limestones, like the Virgin Limestone Member, record the eastward spreading of a shallow, epicontinental Triassic sea from Nevada and western Utah (Stewart and others, 1972b, p. 71).

**Shnabkaib Member:** Only the uppermost 20 to 60 feet (6-18 m) of the Shnabkaib is exposed. This part is interbedded siltstone and mudstone. The siltstone is gypsiferous, grayish-orange-pink to moderate-grayish-red, and moderately cemented. Siltstone laminae and very thin, planar beds cemented by gypsum commonly form an aggregate thickness of about 3 feet (1 m) and crop out as ledges. The ledges are separated by 3 to 6 feet (1-2 m) of light-brown and yellowish-gray, soft, crumbly mudstone, which weathers to earthy slopes. Weathering of laminae of silty gypsum breaks them into pinkish-gray, large, flat pieces 0.2 to 0.5 inches (5-13 mm) thick. These litter the outcrop. Small selenite crystals, wavy laminations about 0.1 inch (1.3 mm) thick, and small-scale oscillation ripples are common. About 7 miles (11.3 km) northwest of our Little Creek Mountain measured section MS-3 (appendix), Lambert (1984, p. 52) measured 425 feet (130 m) of Shnabkaib strata, a likely thickness for the entire unit concealed beneath the Smithsonian Butte quadrangle. The Shnabkaib consists of clay, silt, and evaporites deposited on sabkhas (supratidal flats in hot dry climates), on intertidal flats, and in lagoons at the edge of a shallow, hypersaline Triassic sea (Stewart and others, 1972b, p. 71; Lambert, 1984, p. 62). Pinkish colors of the Shnabkaib distinguish it from overlying red beds of the upper red member.

**Upper red member:** The upper red member crops out in the southwest part of the quadrangle and is 292 feet (89 m) thick in measured section MS-3 (appendix). Alternating beds of gypsiferous siltstone, very fine-grained quartzose sandstone, clayey siltstone, and mudstone make up the unit. Predominant colors are pale red to dark reddish brown, although earthy slopes in the lower part are light and moderate brown. Beds of gypsiferous siltstone are very thin, unfossiliferous and commonly ripple-marked. Intimately associated with siltstone are parallel laminae, both planar and wavy forms, of finely crystalline gypsum. Medium to thick beds (Ingram, 1954) of sandstone occur in stratal intervals 7 to 18 feet (2-6 m) thick. Sedimentary structures in the sandstone include rib and furrow (plan view of small-scale trough cross-strata on bedding surfaces), current lineations on bedding planes, and low-angle trough cross-bedding. The sandstone beds are probably stream-channel deposits. Mudstone is calcareous, silty, contains shrinkage cracks and weathers to a crumbly, earthy slope. Mudstones probably record overbank deposits on floodplains. The upper red member was deposited on a fluvial plain that prograded westward over Shnabkaib deposits as the marine shoreline withdrew (Poole, 1961).

The top of the upper red member is beveled by the major TR-3 unconformity of Pipiringos and O'Sullivan (1978, p. A17). On this regional surface streams deposited gravel in Late Triassic time. The gravel, now a cliff-forming pale-grayish-orange conglomerate (Shinarump Member of the Chinle Formation), unconformably overlies dark-reddish-brown ("chocolate"-colored) mudstone of the upper red member. This unconformable contact at the base of the conglomerate is conspicuous, abrupt, and rather flat in the quadrangle. Elsewhere it includes channels that cut tens of feet into Moenkopi beds (Gregory, 1914; Witkind, 1956; Wilson, 1965, p. 36), recording incision by rivers flowing northwest across the Triassic continental margin (Marzolf, 1990).

## Chinle Formation (Upper Triassic)

The Chinle Formation originally was defined by Gregory (1916) as thick, variegated shale overlying the Shinarump Conglomerate (Powell, 1873; Gilbert, 1875) in Chinle Valley, northeastern Arizona. Gregory and Williams (1947) redefined the variegated shale as the Petrified Forest Member and the basal conglomerate as the Shinarump Member. Stewart and others (1972c) thoroughly chronicle a century of Chinle studies. In the Smithsonian Butte quadrangle, the Chinle is about 490 feet (149 m) of fluvial and lacustrine beds, mostly mudstone, bound below and above by major unconformities.

**Shinarump Member:** This remarkably continuous fluvial conglomerate extends into southern Nevada, southern to northeastern Utah, and northwestern New Mexico. Locally the unit caps a broad bench called Little Creek Mountain and forms cliffs (Shinarump Cliffs of Powell, 1873) west of Highway 59 (figure 1). The Shinarump Cliffs extend southeast to Fredonia, Arizona. West of Highway 59 some outcrops are truck-sized, rounded hoodoos and pale grayish orange in color. More characteristically, the Shinarump forms a low-relief (6-9 feet [2-3 m] vertical in 600 feet [200 m] horizontal distance) surface discontinuously mantled with less than 2 feet (< 1 m) of brown silty, pebbly quartz-sand residuum, reworked by surface wash. This is best seen along the west edge of the quadrangle (section 8, T. 43 S., R. 11 W.). The rock is sandy, chert- and quartz-pebble conglomerate or pebbly, very-pale-orange and grayish-orange, medium- to coarse-grained quartz and chert litharenite (table 1) well cemented by interstitial iron oxide-calcite-(silica?)-clay. Pebbles are abundant and well rounded. In the St. George, Utah area, average composition of pebbles is 40 percent quartz, 31 percent quartzite, and 29 percent chert (Stewart and others, 1972a, p. 69).

Bedding includes large-scale trough cross-beds with planar low-angle foresets 1 to 6 feet (0.3-2 m) thick, pebble lenses in sandstone, horizontal planar sandstone beds, and massive 10 to 50 foot-thick (3 to 15-m) gravel beds (figure 3). Silicified logs are sparse to common. Locally, thin lenses of varicolored mudstone display flowage folds and pull-apart structures. The unit is 111 feet (34 m) thick in the southwest and 119 feet (36 m) thick in Horse Valley Wash, 1 mile (1.6 km) north of the quadrangle. The contact between the Shinarump and the overlying member is sharp in measured section MS-2A, but elsewhere is gradational (Wilson and Stewart, 1967). The Shinarump records aggradation and lateral accretion of gravel and sand in channels and on point bars in Late Triassic streams. The streams, perhaps mostly braided (Blakey and Gubitosa, 1983, p. 66), flowed west and northwest across a broad coastal alluvial plain (Poole, 1961) from the Mogollon highlands in southern Arizona and the ancestral Rocky Mountains in western Colorado (Stewart and others, 1972a, p. 87) toward a seaway (a back-arc basin) in western Nevada.

**Petrified Forest Member:** This unit is chiefly brightly varicolored, bentonitic (Schultz, 1963) claystone. The unit crops out in badlands north and northeast of Smithsonian Butte

***Table 1.*** *Petrography of selected sandstone and siltstone samples.*

| Sample | Rock Name[1] | Components (percent): FRAMEWORK GRAINS[2] Q | F | RF | VOIDS[3] V | Remarks |
|---|---|---|---|---|---|---|
| | **KAYENTA FORMATION[4]** | | | | | |
| 10 | very fine grained subarkose | 91 | 6 | 3 | 20 | second 25-ft-thick sandstone bed above base of formation. 119 ft above base of formation |
| 9 | very fine grained sublitharenite | 79 | 8 | 13 | 7 | 102 ft above base of formation |
| 8 | very fine grained calcitic sublitharenite | 85 | 7 | 8 | 10 | 63 ft above base of formation |
| 7 | very fine grained sublitharenite to subarkose | 88 | 6 | 6 | 16 | 53 ft above base; top of first 40-ft-thick sandstone |
| Z1 | very fine to medium-grained (bimodal) calcitic sublitharenite | 87 | 6 | 7 | 19 | Lamb Point Tongue of Navajo Sandstone; from base: 0.3 mi south of Zion Lodge[5] |
| 14 | very fine to fine-grained subarkose | 92 | 6 | 2 | 20 | second thick sandstone above Springdale Sandstone Member of Moenave Formation; 10 ft above base[6] |
| 13a | fine-grained subarkose to sublitharenite | 93 | 3 | 4 | 23 | crossbedded fluvial sandstone[7] |
| 13b | fine-grained subarkose to sublitharenite | 94 | 3 | 3 | 15 | crossbedded fluvial sandstone[7] |
| | **MOENAVE FORMATION[4]** | | | | | |
| | **Springdale Sandstone Member** | | | | | |
| 6 | medium-grained sublitharenite | 87 | 5 | 8 | 22 | 65 ft above base of member |
| 5 | fine- to medium-grained feldspathic litharenite | 74 | 10 | 16 | 8 | 25 ft above base of member |
| | **Whitmore Point Member** | | | | | |
| 4 | coarse siltstone: calcitic subarkose | 80 | 11 | 9 | 5 | 45 ft above base (2 ft-thick bed) of member |
| 3 | silty very fine grained calcitic feldspathic litharenite | 72 | 14 | 14 | 3 | 4 ft above base (0.5 ft-thick bed) of member |
| | **Dinosaur Canyon Member** | | | | | |
| 2 | coarse siltstone: calcitic subarkose | 83 | 9 | 8 | 11 | 5 ft below top of member |
| 1 | coarse siltstone: calcitic subarkose | 83 | 10 | 7 | 9 | 7 ft below top of member |
| | **CHINLE FORMATION** | | | | | |
| | **Petrified Forest Member** | | | | | |
| C-1 | very fine grained feldspathic litharenite | 59 | 13 | 28 | 5 | 97 ft below top of member |
| | **Shinarump Member** | | | | | |
| 11 | fine- to medium-grained litharenite | 72 | 1 | 27 | 10 | 15 ft below top of member; SW1/4, SE1/4, SW1/4, sec.16,T.43S.,R.11W. |
| 12 | pebbly coarse-grained litharenite | 69 | 0 | 31 | 9 | 22 ft. above base of member; SW1/4, SE1/4, SW1/4, sec.16,T.43S.,R.11W. |

**Notes:**
1 - after Folk, 1968
2 - percentage in point count of framework grains only: Q - quartz, F - feldspar, RF - rock fragments
3 - percentage of voids in point count of framework grains, matrix, and voids
4 - samples of Kayenta and Moenave Formations (samples 1-10) collected at accessible exposure, SW1/4, NE1/4, sec.33, T.43S., R.10W. (southwest Hildale quadrangle)
5 - sample Z1 collected in Springdale East quadrangle, UTM grid 4123600m N, 32655m E (Zion Canyon)
6 - sample 14 from SW1/4, SE1/4, NE1/4, sec.27, T.43S., R.10W. in Maxwell Canyon (southwest Hildale quadrangle)
7 - sample 13a and 13b from NW1/4, NW1/4, SW1/4, sec.26, T.43S., R.10W. in Maxwell Canyon (southwest Hildale quadrangle)

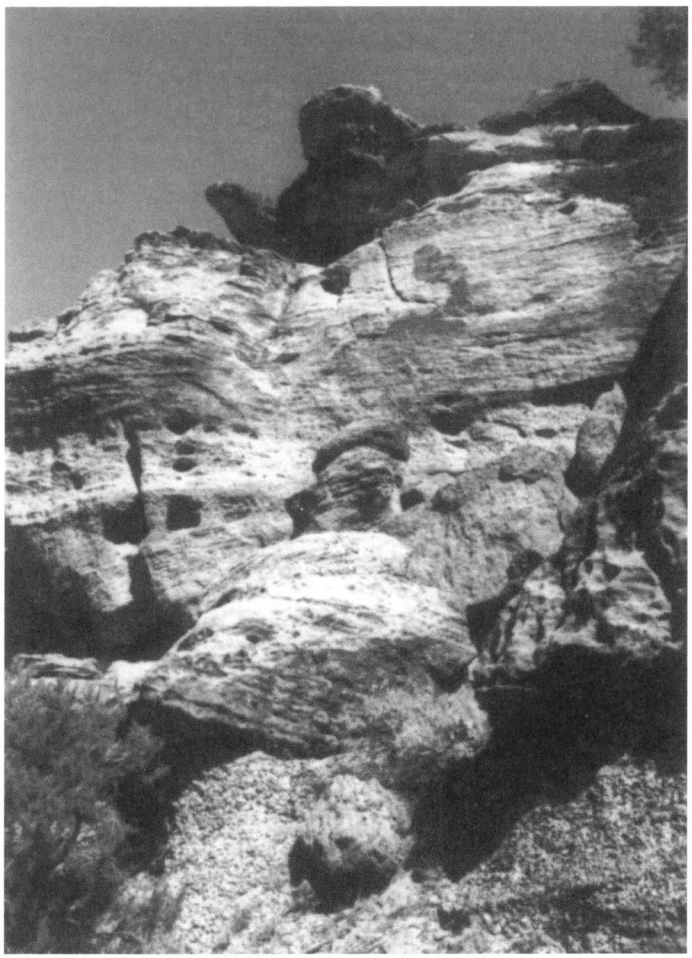

*Figure 3. The Shinarump Member of the Chinle Formation is a commonly cross-bedded sandy conglomerate and pebbly sandstone that forms a cliff.*

where slopes are prone to landsliding (figure 4). Elsewhere in the quadrangle a west-sloping plain bevels the member. The rocks closely resemble those of the Petrified Forest Member in Arizona as described by Gregory (1950). In Arizona, fossil pollen and spores indicate a late Carnian age, which is early Late Triassic (Fisher and Dunay, 1984, p. 262). Planar beds of silty claystone that weather to an earthy, expanded "popcorn" surface contain abundant expansive clay minerals. Beds interpreted as altered volcanic ash are light gray, pale red, pale red purple, pale olive, light greenish gray, and light bluish gray. Stewart and others (1972a, p. 36) found that grayish red and pale red predominate; next most common was light greenish gray. Red and purple hues probably are oxidized iron and manganese minerals in clay-enriched B-horizons of paleosols that formed on floodplain and lacustrine sediment under a moist climate in Late Triassic time (Kraus and Bown, 1986). The thick bentonitic claystone represents stream, lake, and swamp mud deposited in a subsiding basin that received a voluminous influx of volcanic ash (Blakey and Gubitosa, 1983, p. 70). Sparse sandstone beds of fluvial origin pinch out laterally and are very fine-grained, feldspathic litharenite (table 1, sample C-1). The thickest is a 25-foot-thick (7.6 m), light-gray, cross-bedded sandstone in the NE 1/4 section 15, T. 43 S., R. 11 W. In the northwest corner (appendix, measured section MS-2A), 286 feet (87 m) of the Petrified Forest Member is exposed. However, actual thickness may be about 390 feet (119 m); a landslide deposit there precluded precise measurement. Regionally, a thickness of 350 to 450 feet (107-137 m) is fairly constant (Wilson and Stewart, 1967, p. D11).

The top of the Petrified Forest Member was placed at the highest set of thick, variegated claystone beds. The beds above are thin-laminated, moderate-reddish-orange and moderate-reddish-brown coarse siltstone and grayish-red silty mudstone of the Dinosaur Canyon Member of the Moenave Formation. This contact is the extensive J-0 unconformity at the base of the Glen Canyon Group that bevels successively older parts of the Chinle Formation from southeast to southwest Utah (Wilson, 1965, p. 35; Pipiringos and O'Sullivan, 1978, p. A19).

*Figure 4. View south of Smithsonian Butte and, in foreground, even bedding of variegated shale of the Petrified Forest Member of the Chinle Formation. This north slope has many shallow landslides on it.*

## Jurassic System

### Moenave Formation (Lower Jurassic)

The Moenave Formation was named by Harshbarger and others (1957) for outcrops near Moenave, Arizona. Strata of this formation previously were included in the upper part of the Chinle Formation (Gregory, 1950, p. 67). At measured section MS-2B, the Moenave Formation is about 470 feet (143 m) thick and is subdivided into three members, from oldest to youngest: Dinosaur Canyon, Whitmore Point, and Springdale Sandstone Members. The Dinosaur Canyon and Whitmore Point Members were mapped as one unit.

**Dinosaur Canyon Member and Whitmore Point Member:** The Dinosaur Canyon Member is 226 feet (69 m) thick and crops out as pale-red, reddish-brown, moderate-reddish-brown, and reddish-orange, interbedded sandstone, siltstone, and silty mudstone strata on the lowest hillslopes of Smithsonian Butte. Southeast of Canaan Ranch, the member is partly exposed, revealing 145 vertical feet (44 m) of alternating mudstone slopes, sandstone, and siltstone ledges. Ledges are mostly 3 to 6 feet (1-2 m) thick. A few are as much as 40 feet (12 m) thick. Sandstone and siltstone are moderate reddish brown and composed of very fine-grained quartz and feldspar framework grains (table 1, samples 1 and 2). Veinlets and laminae of gypsum are abundant locally in the lower 10 to 20 feet (3-6 m) of the Dinosaur Canyon. The rocks have very thin planar laminae and small-scale trough cross-laminations, are calcareous, and are friable to strongly indurated. Parting (current) lineations (figure 5) and rib-and-furrow structures are common. Ephemeral streams flowing north to northwest from the Mogollon slope in south-central Arizona deposited the member (Blakey, 1994, p. 279).

The Whitmore Point Member (Wilson, 1967) ranges in thickness from 68 feet (21 m) at the north edge of the area to 44 feet (13 m) in the southeast corner. The unit closely resembles the type section at Whitmore Point, Arizona (20 miles southeast), where it is 70 feet (21 m) of alternating gray, greenish-gray, grayish-red, and pale-brown siltstone and claystone beds (Wilson, 1967, p. 34). In the Smithsonian Butte quadrangle, the unit forms a light-gray and pinkish-gray earthy slope with thin ledges immediately under the prominent cliff of the Springdale Sandstone Member and immediately above a steep, ledgy slope of reddish-orange Dinosaur Canyon Member (appendix, measured sections MS-1 and MS-2B). Rocks of the Whitmore Point Member are very fine-grained, calcareous, feldspathic litharenite; calcareous, subarkosic, coarse-grained siltstone; subordinate mudstone; and sparse, thin limestone beds. Sandstone is very fine grained, white, very light gray and pinkish gray, and contains lenses of coarse sand and subfissile mudstone, which has fossil shrinkage cracks. Bedding includes planar, 1 to 10-inch-thick (2.5 - 25 cm) beds, common wavy laminations, and small-scale trough cross-laminae. The limestone is light greenish gray and contains sparse fish scales, abundant intraclasts (granules and small pebbles of reworked, penecontemporaneous lime mud) and tiny ovoids (ostracodes? pellets?) in a discontinuous sparry calcite matrix (poorly washed intramicrudite of Folk, 1968, p. 157). The scales are 0.5 inch (13 mm) across and, on weathered rock surfaces, have a very dusky red, nearly black, glossy enameloid covering. They were identified as Holostean fish scales by Kenneth Carpenter (Denver Museum of Natural History, oral communication, 1993). Scales and bone fragments referable to *Semionotus*, a fish closely related to the garpike family, are known from the Moenave Formation (Wilson, 1967, p. 36). A fresh-water, well-oxygenated lacustrine and stream depositional environment is indicated.

**Springdale Sandstone Member:** The uppermost member of the Moenave Formation is 128 to 176 feet (39-54 m) thick. Near the base of the Vermilion Cliffs, the member makes a prominent blocky and ledgy cliff 107.5 to 168 feet (33-51 m) high. The cliff weathers light to reddish brown, grayish orange at the top. Unweathered rock is pale-red, white, and very light gray, fine- to medium-grained sandstone, silty and finely micaceous in places, thin beds and lenses of claystone pebble conglomerate in places. Compositionally it is a sublitharenite to feldspathic litharenite (table 1, samples 5,6). Abundant white kaolin- and silica(?)-cemented spherical nodules with diameters of 0.08 to 0.16 inches (0.20 - 0.41 cm) make bumps on weathered surfaces. Bedding is uniform, parallel, planar laminations and very thin beds, some wavy, 0.5 to 3 inches (1-7 cm) thick. Common thin

***Figure 5.*** *Parting lineations on bedding surfaces of laminated, very fine-grained sandstone in the Dinosaur Canyon Member of the Moenave Formation. These structures appear wherever these sediments are exposed along the Vermilion Cliffs, illustrating the widespread uniformity of conditions during deposition.*

interbeds of claystone granules and pebbles, wavy laminations, horizontal fossil logs, penecontemporaneous deformation structures, and massive beds interbedded with large-scale low-angle trough cross-bedding suggest a fluvial origin. The unit was probably deposited by energetic streams flowing west-northwest across a broad alluvial plain away from source areas of the ancestral Rocky Mountains and Mogollon slope (Poole, 1961; Wilson, 1967; Peterson, 1994).

## Kayenta Formation (Lower Jurassic)

The Kayenta Formation (Baker, 1933) is 680 feet (207 m) thick in the southeast corner of the quadrangle (appendix, measured section MS-1) and 615 feet (190 m) at Smithsonian Butte (appendix, measured section MS-2C). It is chiefly mudstone containing many interbeds of siltstone and very fine-grained sandstone and scarce, very thin microcrystalline limestone beds (measured section MS-1, unit 23). Viewed from afar, the unit is a moderate-reddish-orange ledgy slope in the lower half of the Vermilion Cliffs below the cross-bedded Navajo Sandstone (figure 6). In places, the upper 50 to 70 feet (15-21 m) of the Kayenta is cliff-forming sandstone that weathers moderate reddish brown. Freshly broken sandstone is pinkish-gray, very fine to fine-grained subarkose to sublitharenite (table 1). Sedimentary structures include wavy laminations in sets 1 to 2 inches (25-50 mm) thick and cross-bed sets, which are 3 to 6 feet (1-2 m) thick. Such structures formed when rivers flowed over loose, sandy channel bottoms and silty floodplains.

More evidence for a fluvial origin is in section 20, T. 43 S., R. 10 W. where two or three prominent 40-foot-thick (12-m) channel sandstone beds crop out as continuous cliffs in the lower half of the formation. The lowest sandstone, 110 feet (33 m) above the base, contains high-angle, large-scale trough cross-beds in sets 3 to 6 feet (1-2 m) thick. Cross-bedding in tabular sandstone beds probably formed in aqueous sand dunes on point bars of stream channels. Dinosaur tracks are relatively common on bedding surfaces of mudstone in the formation in Zion National Park (Hamilton, 1984, p. 81). Kayenta strata are accumulations of terrigenous sediment moved westward by a large system of streams flowing from the ancestral Rocky Mountains (Luttrell, 1993).

The basal contact with the Springdale Sandstone Member of the Moenave Formation in places is gradational through an interval of interbedded mudstone, siltstone, and sandstone about 15 to 25 feet (5-8 m) thick (appendix, measured section MS-2C). Near the top of the Kayenta, mudstone grades up to cliff-forming, planar-bedded sandstone that grades up into the cross-bedding of the Navajo Sandstone.

## Navajo Sandstone (Lower Jurassic)

The youngest bedrock unit is the massive eolian Navajo Sandstone (Gregory, 1916). Remarkably uniform composition (framework grains are more than 90 percent quartz) and large-scale, sweeping, high-angle cross-beds characterize this formation. Erosion has carved the massive light-brown and grayish-orange-pink west-facing cliffs of Canaan Mountain (figure 2), where the unit is as much as 1,350 feet (about 410 m) thick. In Zion National Park, it is generally 1,500 to 1,800 feet (457-550 m) thick, and is as thick as 2,280 feet (695 m) at the towering Temple of Sinawava (Gregory 1950, p. 83). The sandstone occurs widely in northern Arizona, throughout Utah, and in extreme western Colorado. It is correlative in part with the Nugget Sandstone of Wyoming and northern Utah (Gregory, 1950, p. 83) and the Aztec Sandstone of southern Nevada (Peterson and Pipiringos, 1979, p. B34).

For mapping purposes the base of the formation is the bottom of the first (ascending) large-scale, steeply inclined cross-beds. According to Averitt and others (1955), in Zion National Park the base of the Navajo intertongues with the Kayenta Formation as the Lamb Point Tongue of the Navajo. A reference sample of the latter was collected and examined (table 1, sample Z1). We did not recognize, beyond all doubt, the Lamb Point Tongue in the Smithsonian Butte quadrangle.

The Navajo Sandstone is generally inaccessible. Only

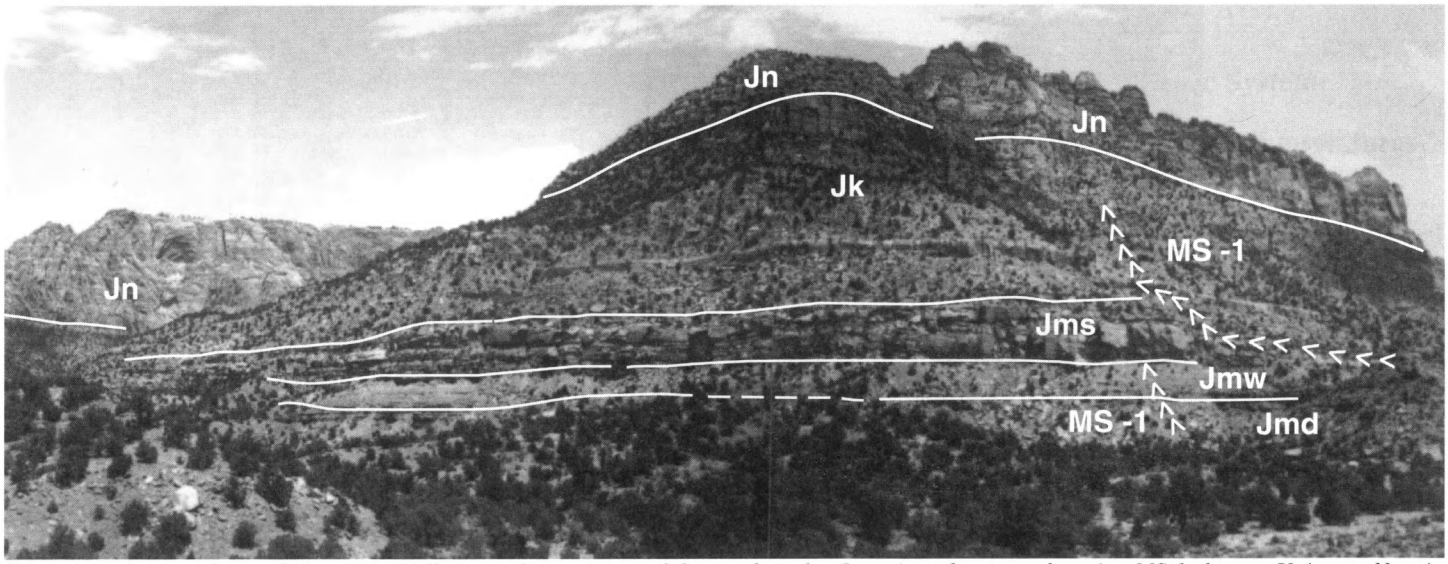


*Figure 6. View northeast of Vermilion Cliffs in southeast corner of the quadrangle. Location of measured section MS-1 shown. Units are Navajo Sandstone (Jn), Kayenta Formation (Jk), and Moenave Formation members: Springdale Sandstone Member (Jms), Whitmore Point Member (Jmw), and Dinosaur Canyon Member (Jmd).*

the lower 175 feet (53 m) of the unit at the west end of Smithsonian Butte was examined in detail (measured section MS-2C, appendix). There, rounded ledges and mounds are weathered grayish orange pink; freshly broken rock is light brown. Exposures display sweeping, large-scale, inclined (15-30°) tangential and planar cross-beds, which are tabular or wedgelike. The sandstone is firmly to weakly cemented by iron-oxide-stained secondary calcium carbonate and silica and is predominantly very fine to fine-grained, well-sorted, calcareous quartz arenite. Framework quartz grains are subrounded to subangular; 2 to 5 percent are frosted well-rounded medium sand. About 2 percent of grains, perhaps altered feldspar or a diagenetic mineral, are white, opaque, and rectangular with Mohs hardness of 3. A trace of accessory minerals is present.

The Navajo probably formed marginal coastal dunes inland (east) of an Early Jurassic sea in western Nevada (Kocurek and Dott, 1983). Cross-bedding, uniform quartz composition, and paucity of fossils over huge areas indicate that the Navajo and correlative sandstone units accumulated in eolian dunes on a vast sandy desert. The coastal dunes in southwestern Utah prograded southward. Depositional environments of the sandstone were interpreted by Stokes (1991, p. 17). Some features suggest refinements to the classic hot, dry desert interpretation. Thin interbeds of lenticular, mud-cracked, unfossiliferous limestone suggested to Gregory (1916) ephemeral interdune ponds. Stokes (1991, p. 17) reported lenticular beds of dolomite or limestone, 1 to 4 feet (0.3-1 m) thick and 100 to 300 feet (30-91 m) in diameter. Some contained remains of algae, invertebrate trace fossils, trails, burrows, fern pieces, *Equisetum* (horsetail rush), ostracodes, branchiopods (diminutive aquatic crustaceans), and dinosaur bones. Stokes also noted fossil tree stumps, probably conifers, in growth position, in the Navajo Sandstone near Moab, Utah. These features suggest evaporative lakes, interdune ponds, playas, and a high water table capable of supporting tree growth. Desborough and Poole (1992, p. 7) interpreted the carbonate-rich interbeds to indicate a hot, dry environment having a sporadically high water table.

## Quaternary Deposits

### Recognition of Deposits and Estimation of Age

Surficial deposits of unconsolidated detritus occur in alluvial fans, arroyo channels, and alluvial terraces, and on hillslopes in the Smithsonian Butte quadrangle. We divided the deposits into 18 map units based on depositional process and relative age. An example of a depositional process follows in this simple explanation of how fan alluvium accumulates. Where a sediment-laden stream flows swiftly from a hilly watershed onto a plain, the sediment accumulates in a fan-shaped deposit (in map view). The sediment is deposited when its concentration increases as the water is absorbed by permeable ground or as streamflow spreads and thins. Cloudburst-triggered mudflows add mud and debris to the fan alluvium. Over time, shifting streams start new (young) fans and abandon others (intermediate-age and old fans). Thus, in Quaternary time, alluvial-fan deposits (Qaf symbol on map) accumulated west of Smithsonian Butte and the Vermilion Cliffs. Similarly, other depositional processes like landsliding, make deposits (Qms - m for mass movement) that also vary in age (Qmso - o for old).

Relative age (young, intermediate-age, and old) was used to divide deposits that were formed by the same depositional process but in different time periods. Relative ages served mapping purposes in place of absolute ages, which are unknown because no datable materials were found. Relative ages are useful on the geologic map for assessing hazards. Young deposits (for example, landslide deposits) that are active may damage property, whereas old deposits are more likely to be stable.

Age determination relies on principles of geomorphology and soil development (Morrison, 1967; Birkeland, 1974). We saw in the deposits from place to place, especially alluvium, consistent patterns in heights above modern streams (geomorphic position), preservation of original depositional surfaces, and development of relict soils. These age-dependent criteria result from post-depositional patterns of weathering and erosion. Older deposits are higher and more eroded than younger deposits. On their best-preserved, stable surfaces, old deposits have relict soils of thick, clay-enriched (argillic) horizons (B) underlain by strongly developed calcium carbonate-cemented (calcic) horizons (C), properties that reflect weathering for many tens of thousands of years. Soils on the young deposits lack argillic horizons because weathering has not gone on long enough to make a clay-rich horizon.

Unfortunately, relative ages have little meaning in terms of geologic time delimited by absolute dates. To better constrain the age of the Quaternary deposits in the quadrangle, albeit generally and indirectly, we looked again at the age-related criteria, comparing them to the age-related criteria of deposits having absolute ages. Deposits in nearby areas have been dated using radioactive decay of elements and the rates of soil-carbonate accumulation, which allows estimation of the time of origin of the deposits in terms of informal time divisions of the Quaternary Period.

Age control is available from the Beaver Basin and the Paragonah, Utah area. In Beaver Basin, 80 miles (129 km) to the north, chronology of late Cenozoic alluvial deposits indirectly supports an estimated maximum age of about 250,000 years for the alluvial deposits in the Smithsonian Butte quadrangle. By dating igneous rocks, buried volcanic ashes, and calcic soils in deposits in Beaver Basin, Machette (1985) established age control for some of the deposits. Like the streams in the Beaver Basin in the latter part of the Quaternary Period, streams in the Smithsonian Butte quadrangle have cut downward and deposited alluvium, leaving a sequence of alluvial deposits at several geomorphic levels. In the Beaver Basin, differences in average long-term discharge and rate of downcutting among the large streams and tributary streams probably account for some variation in heights of alluvial deposits of a given age above the streams. Given this natural variability, if the main streams eroded and deposited in Beaver Basin and in Smithsonian Butte quadrangle at comparable rates, alluvial deposits at about the same height above streams should be about the same age (table 2).

Age control also exists near Paragonah, Utah, about 65 miles (105 km) to the north. West of town, Parowan Valley is formed on upper Tertiary and lower Quaternary sediments that fill a down-faulted basin. In the valley and on the low

flanks of nearby hills, relatively thin fan alluvium widely buries the basin fill. To the highest part of this sequence of fan alluviums, Williams and Maldonado (1995) assigned a middle Pleistocene geologic age based on relative age criteria and on a radioisotopically dated basalt. The Parowan Valley fan alluvium generally resembles that in the Smithsonian Butte quadrangle regarding height above modern streams, carbonate enrichment in soil, and preservation of original depositional surface. Therefore, fan alluvium in the Smithsonian Butte quadrangle is interpreted to be about the same age.

The relatively thin alluvial-fan deposits (<100 feet, <30 m) in the Smithsonian Butte quadrangle suggest approximately equal depositional and erosional rates during approximately the last 250,000 years. If deposition had exceeded erosion, on average, thick deposits of fan alluvium would exist in the quadrangle. This is not the case. An explanation is fairly obvious in the physiographic setting. On the edge of the Colorado Plateau (includes Uinkaret Plateau and Smithsonian Butte quadrangle) where erosion is great, alluvium cannot thicken greatly. Indirectly supporting the interpretation of high rates of erosion in Quaternary time is the finding that the modern average rate of erosion on the Colorado Plateau is high compared to the rest of the United States (Judson and Ritter, 1964).

In summary, alluvium is eroded from the quadrangle, mainly by streams, about as fast as it accumulates. The oldest Quaternary deposits appear to be about 0.25 million years old.

## Types of Deposits

Mapped surficial deposits are of four genetic types: alluvial, mass wasting, eolian, and lacustrine.

**Alluvial deposits:** Channel and terrace alluvium (map units Qal, Qat) is confined to narrow deposits in and adjacent to the main stream channels. More widely distributed are fan alluvium (Qaf) and alluvium mixed with colluvium (Qac). Exposures in arroyos indicate that most alluvium in the map area is less than 50 feet (15 m) thick, but well data suggest that some is as thick as 100 feet (30 m). Joe Jessop, driller, stated (oral communication, 1995) that alluvium at Canaan Gap is 50 to 60 feet (15-18 m) thick, and that water wells at Hildale and Colorado City, 6 miles (10 km) east southeast of Canaan Gap, show that alluvium at the mouth of Short Creek does not exceed 115 feet (35 m).

The channel and terrace alluvium (Qal, Qat) varies in grain size. In general it is silty, very fine to coarse quartz sand, and is gravelly in places. Sand grains are subangular to subrounded; few are rounded. Typically, alluvium is mostly reddish brown and reddish yellow and is derived from the Vermilion Cliffs. The exception is alluvium of Little Creek, which is pale-brown silty sand that contains rounded quartzite pebbles and cobbles derived from the Shinarump Member of the Chinle Formation.

Fan alluvium is highly variable in grain size and is crudely bedded. In gross shape the deposits are wedge-like, thick at the fan apex and thinning rapidly down-dip to a few feet of pebbly sand and silt, which may grade to playa clay (Qp). Near the cliffs, deposits are cobbly, bouldery sand and poorly sorted sandy gravel tens of feet thick and crudely layered in channel-and-fill bedding. The geometry, variable grain size, and rapid thinning are produced by torrential flooding and debris flows that rush from steep watersheds on the flanks of Canaan Mountain and Smithsonian Butte. Fan alluvium is young ($Qaf_1$), intermediate-age ($Qaf_2$), and old ($Qaf_3$). As young fan alluvium accumulates, intermediate-age and old alluvium is "recycled"— eroded, conveyed out of the quadrangle, or redeposited in young fans ($Qaf_1$). The cycle is illustrated clearly by a series of fans at Canaan Wash (center of southeast quarter of quadrangle). On young fans, sheetwash actively deposits yellowish-red sandy and pebbly alluvium on the graded surfaces. Young fan deposits commonly pinch out on a pediment cut on the Petrified Forest Member or grade imperceptibly to alluvium of adjacent fans. Remnants of old fan alluvium ($Qaf_3$) and lag gravel cover isolated hillocks 15 to 25 feet (4.5-7.5 m) higher than the surface of adjacent fans of intermediate age ($Qaf_2$). The antiquity of the old fan alluvium is evident in a well-developed relict soil profile that generally includes a reddish brown (5 YR 6/4), very fine, sandy clay B horizon, and a pink (5 YR 7/4), calcareous, sandy C horizon that is 2 to 3 feet (0.6 - 1 m) thick. This soil is exposed in a cut of Highway 59 in SW$^1/_4$ SE$^1/_4$, section 9, T. 43 W., R. 11 W.

Alluvium and colluvium (Qac) cover some broad, gentle slopes in the quadrangle, especially in the southwest quarter. The deposits are laminated and consist of clay, silt, very fine sand particles, and sparse pebbles deposited chiefly by sheets of rainfall runoff. The surfaces of these deposits resemble graded surfaces that geomorphologists attribute to a state of balance among erosion, transportation, and deposition of detritus. The source of the fine-grained detritus is nearby outcrops of Moenkopi and Chinle Formations and from higher parts of the graded slope itself.

**Mass-wasting deposits:** Unsorted debris, ranging from clay particles to huge blocks of bedrock emplaced by gravity, covers most hillslopes and areas below cliffs. Only the thickest deposits were mapped. These deposits include landslide debris (Qms, Qmso), talus (Qmt), coarse-grained colluvium

*Table 2. Comparison of heights and ages of some dated alluvial deposits in Beaver Basin, Utah (Machette, 1985) with heights of alluvial deposits in the Smithsonian Butte quadrangle.*

| Height of deposit above Beaver River in Beaver Basin | Geologic age (approx. years from Machette, 1985) | Map symbol of coeval(?) unit in this report | Height of deposit above streams in Smithsonian Butte quadrangle |
|---|---|---|---|
| At drainage level | Holocene (0-10,000) | Qal | 0 to 6 feet (0-2 m) |
| 9 to 18 feet (3-6 m) | Latest Pleistocene (12,000-15,000) | $Qaf_1$ | 0 to 30 feet (0-10 m) |
| 40 to 43 feet (12-13 m) | Late Pleistocene (140,000) | $Qaf_2$ | 35 to 65 feet (11-19 m) |
| 53 to 60 feet (16-18 m) | Late middle Pleistocene (about 250,000) | $Qaf_3$ | 55 to 90 feet (17-27 m) |

(Qcc), fine-grained colluvium (Qcf), debris-flow deposits (Qmf, Qmfo), and rock-avalanche deposits (Qma, Qmao). With time, gravity deposits break down to grains that wind or running water move and redeposit as eolian (Qes, Qed) and alluvial deposits (Qal, Qaf, Qat).

Widespread landslide deposits (Qms, Qmso) form by slumping and block rotation. Slump deposits are chaotic soil and rock debris having hummocky surfaces that bulge downslope and are delimited upslope by pull-away scarps. Slump deposits tend to develop on north-facing slopes of mudstone where soil moisture is high. Rotational or Toreva blocks are relatively coherent blocks of strata, usually the lowest 100 feet (30 m) of the Dinosaur Canyon Member, that dip about 30° to 50° or more back toward the cliffs from which they broke away. Diagrams of rotational blocks sketched by Doelling and others (1989, p. 152) nicely illustrate the Toreva blocks that we saw at the base of the Vermilion Cliffs, especially in the SW$^1/_4$ section 21, T. 42 S., R. 11 W. Varying degrees of tilting suggest that block rotation is active. Rotation probably occurs as relatively small displacements on saturated beds of expansive clay near the top of the Petrified Forest Member of the Chinle Formation.

Other common gravity deposits are talus and colluvium. Talus (Qmt) is jumbled, angular pieces of sandstone ranging from sand to large boulder size, mostly large pebbles to small boulders. Talus accumulates in cone-like deposits having a uniform, steeply sloping, unvegetated surface. Colluvium contains more fine-grained debris than talus, collects on gentle to moderate hillslopes, and may have a weakly developed soil on relatively stable slopes. Most colluvium is coarse grained (Qcc), consisting of a heterogeneous mix of rock pieces, sand, silt, and clay, and may include minor alluvium. It results from downslope movement involving creep, heave, and rotation of clasts caused by expansion of clay and freezing, debris slides, and minor rock fall. A fine colluvium (Qcf) was also mapped where weathering and disintegration of large sandstone fragments has formed slope deposits consisting primarily of quartz sand.

Two comparatively scarce deposits, both sedimentary breccia, were emplaced by debris flows and rock avalanches. These dynamic origins are suggested by chaotic internal structure, long narrow form, and coarse, hummocky topographic surface that slopes away from the Vermilion Cliffs. The oldest of these deposits (Qmfo, Qmao) in part rest on an alluvial fan of late middle Pleistocene age ($Qaf_3$)and bedrock near the center of the quadrangle (sections 14, 15, T. 43 S., R. 11 W.). The debris-flow deposits (Qmf, Qmfo) are massive to crudely bedded, sheetlike, and composed of weathered variegated claystone clasts of the Chinle Formation supported in a matrix of clay mixed with small angular pieces of soft shale. The rock-avalanche deposits are sandstone breccia (small boulder to car-sized clasts), clast-supported, and mostly Navajo Sandstone and some red-brown sandstone (Kayenta?). At least two rapid mass-wasting events separated by time are indicated by the differences in topographic surfaces. Avalanche deposits were emplaced when huge parts of the cliffs fell, disintegrated, and the shattered rock fragments dispersed rapidly over the upper part of an alluvial fan. A maximum age of late middle Pleistocene is indicated by the high geomorphic position and advanced cementation of these deposits by secondary silicate and carbonate minerals (figure 7).

One map unit, old megaslide complex (Qmso), encompasses a deposit consisting of many parts too small to map individually. The parts include Toreva blocks, landslides, rock falls, and debris-flow deposits. The largest complex forms a hill of debris near the center of the quadrangle and near the Vermilion Cliffs (section 10, T. 43 S., R. 11 W.). Several large, high-angle, apparently listric slip surfaces cut the complex, forming arcuate scarps. In places, bedrock blocks are rotated and rock formations are in normal stratigraphic order. In other places, strata are mixed into a chao-

***Figure 7.*** *Rubble of Navajo Sandstone in a rock-avalanche deposit of Pleistocene age (unit Qmao in center of quadrangle). Rubble is cemented by calcium carbonate and some silica. Hammer is 1 foot (0.3 m) long.*

tic megabreccia. Smaller complexes occur in the northwest corner of the map area and in Horse Valley (section 24, T. 42 S., R. 11 W.).

**Eolian deposits:** Eolian sand (Qes), derived from granular disintegration of sandstone, has been deposited by wind in discontinuous sheets generally 1 to 4 feet (0.3-1 m) thick. The prevailing west wind also sweeps sand onto talus on sandstone benches and near the bases of cliffs, forming "ramps" and coppice dunes (small dunes around yucca and sage) of light-brown, very fine to fine quartz sand 2 to 6 feet (0.7-2 m) thick (Qed). Scattered sand dunes on alluvial fans, too small to map, were included in unit Qed.

**Playa deposits:** Laminated playa clay (Qp) underlies two ephemeral lakes (playas) on Big Plain bajada. Discontinuous gravel deposits (not mapped), including small boulders, on the playa 0.3 mile (0.5 km) west of Big Plain Junction, indicate that flash floods or debris flows have recently reached the playa, traversing the 2 miles (3 km) from the nearest cliffs.

## VOLCANIC ROCKS

Although volcanic rocks are not exposed in the quadrangle, a cinder cone only 1 mile (1.6 km) to the west suggests that a feeder basaltic dike(s) may underlie the northwest part of the quadrangle. If so, the dike could divert ground-water flow in unexpected ways or could be a potential source of aggregate. Just west of the point where Highway 59 crosses the west edge of the quadrangle stands a 300-foot-high (91 m) cinder cone, Gray Knoll. This cone marks the southeast end of a 5-mile-long (8-km) line of 28 cinder cones and a small basaltic lava field in the adjacent Little Creek Mountain quadrangle. Eruption from these aligned Quaternary volcanic vents was controlled by a vertical joint that is partly occupied by a dike and that trends N. 40° W. (Anderson and Christenson, 1989, p. 25). According to Anderson (1988) and Anderson and Christenson (1989, p. 25), geochemical data and aligned basaltic vents such as this one west of Smithsonian Butte suggest that deeply penetrating joints serve as conduits for magma rising from the lithospheric crust. Another feature that supports this inference is Divide Dike (Gregory, 1950, p. 136), an exposed basaltic dike 7 miles (11 km) west of the quadrangle trending about N. 40° W. parallel to the joints in the Smithsonian Butte quadrangle. This dike appears to have formed by the intrusion of basaltic lava along a joint that parallels the line of cinder cones west of the Smithsonian Butte quadrangle and the joints mapped in the eastern half of the quadrangle.

## STRUCTURE

Strata dip generally northeast 1° to 3°. Aside from local Toreva blocks and landsliding, strata are not significantly deformed. No folds were seen and the few local faults have moderate to small normal displacements. A fault zone extends 1 or 2 miles (1.6-3.2 km) into the mapped area from the north.

Regionally, two major normal faults record uplift and slight eastward tilting. The north-trending Hurricane and Sevier faults lie west and east of the quadrangle (figure 1). Eleven miles (18 km) to the west, the Hurricane fault is the boundary between the Colorado Plateau and the extended Basin and Range Province. Maximum down-to-the-west displacement on the fault has been estimated variously as follows: 10,000 feet (about 3,000 m) (Gardner, 1941, p. 248), 8,000 feet (about 2,400 m) (Threet, 1963, p. 104; Averitt, 1964), 4,000 to 6,000 feet (1,200-1,800 m) (Kurie, 1966, p. 869), and less than 6,560 feet (2,000 m) (Anderson and Christenson, 1989, p. 8). Sixteen miles to the east, the Sevier fault has downdropped rocks west of it about 1,000 to 2,000 feet (300-600 m) (Doelling and others, 1989, p. 93). Thus, the Smithsonian Butte quadrangle is part of an uplifted and slightly tilted fault block 32 miles (51 km) wide at the Utah-Arizona state line.

In the Smithsonian Butte quadrangle, the fault of largest displacement is in the northwest corner of the map area. The fault lies in a disturbed zone that trends north of the quadrangle, making two eastward en echelon steps as short segments 1 mile (1.6 km) or less in length as it strikes north. These fault segments are spatially related to the Cougar Mountain fault in Zion National Park as mapped by Gregory (1950). At Grafton Wash, the Petrified Forest Member in the downthrown block abuts the Shinarump Member in the upthrown block. Displacement is about 250 feet (76 m). Beds on either side of the fault dip about 10° east and the fault dips west 70° at the surface. South of Grafton Wash, the fault was not found. It may continue south a mile or two with diminished net slip under fan alluvium. North of the quadrangle, the fault forms a west-facing fault scarp on Grafton Mesa and trends north 2.7 miles (4.3 km) almost to the Virgin River, where displacement is a few feet. The fault at Grafton Wash has apparent dip-slip normal offset, and like the Hurricane, Sevier, and West Cougar Mountain faults, it probably formed during east-west extension of the region in Miocene to late Quaternary time (Averitt, 1964; Hamilton, 1984; Anderson and Christenson, 1989).

In the south part of the Smithsonian Butte quadrangle, three short faults displace Triassic strata less than 50 feet (15 m). Mid-quadrangle, another fault displaces strata about 50 to 75 feet (15-23 m). All are minor faults.

Northwest-trending, vertical joints transect the Navajo Sandstone. On aerial photographs the joints in sandstone are obvious, but are not evident in the softer rocks such as those in the Chinle Formation. However, evidence that such rocks may also be jointed is found in the trend of the aligned basaltic volcanic vents (presumably joint-controlled) just west of the quadrangle (discussed in Volcanic Rocks section). This trend parallels that of vertical joints that we mapped in the Navajo Sandstone on Canaan Mountain, suggesting a continuous joint system across the quadrangle. Proposed origins for the joints include local stress fields between faults, local domal uplift (Van Loenen and others, 1988; Sable, 1995) and east-west compression of crustal rocks (Hamilton, 1984).

Linear features on the surface of some Quaternary deposits were seen on aerial photographs and were mapped. Their origin is unknown; they may result from erosion by runoff, nonuniform settling of sediments or bedrock, or incipient faulting.

## GENERALIZED HYDROLOGY

No flow data are available for the ephemeral streams in the mapped area. Stream flow usually occurs as unpredictable flash floods generated by sporadic summer thunderstorms (Thomas and Lindskov, 1983, p. 16). For adjacent Kane County, 28 major spring or summer storm-generated floods from 1881 to 1983 have been recorded (Doelling and others, 1989, p. 163). The records are useful because they characterize flood behavior in a region that includes the Smithsonian Butte quadrangle. In contrast to the floods, some large rainfall events generate no flow or only localized flow because most surface runoff is absorbed by permeable alluvium in the dry stream channels. Two miles (3 km) north of the quadrangle is the perennial Virgin River, the largest stream in the region. It flows west with an average monthly discharge of about 650 cubic feet per second (18.4 $m^3/s$) at Virgin, Utah where its drainage area is 934 square miles (2,428 $km^2$).

The Navajo Sandstone is an aquifer in much of the Colorado Plateau (Gates, 1965, p. 154), but its exposures in the Smithsonian Butte quadrangle serve chiefly to take in water rather than to provide ground water. A coefficient of transmissibility of 8,000 gallons per day per foot (99.2 $m^2/d$) was calculated using a well that penetrates the aquifer 15 miles (24 km) northeast of Smithsonian Butte (Gates, 1965). Transmissibility (transmissivity) in the quadrangle probably is less because the aquifer is thinner there.

Other units in the quadrangle are aquifers. Wells produce water from units below the base of the Navajo and from local perched water tables. Yields of about 15 to 20 gallons per minute (gal/min) or 57 to 76 liters per minute (L/min) from the Shinarump Member of the Chinle are obtained from scattered wells in the lowlands west of Canaan Mountain according to Joe Jessop, well driller, Hildale, Utah (oral communication, May 18, 1993). The aquifer that supplies a well at Canaan Gap is unidentified, but is about 400 feet (122 m) stratigraphically below the Shinarump (Joe Jessop, oral communication, November 2, 1995). Sustained yields of wells in the larger region are 50 to 500 gal/min (190-1,900 L/min), with exceptional yields as much as 500 to 2,000 gal/min (1,900-7,600 L/min) (Price, 1982).

Springs in the quadrangle that convey ground water useable by man, livestock and wildlife are shown by Price (1982). At least nine springs on the southwest side of the Vermilion Cliffs flow from the Springdale Sandstone Member of the Moenave Formation, the Kayenta Formation, and basal Navajo Sandstone. A spring on Canaan Mountain flows from the Navajo more than 1,000 feet (300 m) above its base. At least two other small springs about 1 mile (1.6 km) south of Smithsonian Butte flow sufficiently to water a few livestock.

## ECONOMIC GEOLOGY

### Oil and Gas

Potential for oil and gas in the quadrangle appears to be low. Structural traps are not likely above the Ꞧ-3 unconformity because no folds exist and faults are few with little offset (see structural contours on geologic map). The uniform lithology of the rock units suggests stratigraphic traps are unlikely. However, the potential for such traps in buried units cannot be ruled out entirely, as evident in the shallow Timpoweap Member of the Moenkopi Formation, a known reservoir rock in the nearby abandoned Virgin oil field. Lack of deep drill holes in the quadrangle and lack of seismic data impede assessment of subsurface structure. We speculate that the fault at Grafton Wash could extend downward to form a structural trap in Paleozoic reservoir rock units.

Previous workers, looking at large areas that include the quadrangle, inferred a medium potential for undiscovered oil and gas resources (Molenaar and Sandberg, 1983; Ryder, 1983; Van Loenen and others, 1988). They considered (1) the proximity of the now-abandoned shallow Virgin oil field about 8 miles (13 km) to the northwest, (2) data from deeper Paleozoic strata, including oil shows in nearby drill holes in Arizona, and (3) the likelihood of anticlines and stratigraphic traps, particularly in limestone of Mississippian and Permian age.

In 1984, oil and gas leases covered about one-third of the quadrangle. By 1985, however, no drilling or other exploration activity had been done, and by 1987 most leases were canceled (Van Loenen and others, 1988, p. A7). Four dry holes are located about 1.5 miles (2.4 km) south of Grafton, Utah, and about 2 miles (3 km) north of the Smithsonian Butte quadrangle (Van Loenen and others, 1988). Wells having no known record are evident where steel casing pipe protrudes from the ground. Casing was observed at three locations: a 10.25-inch-diameter (32 cm) pipe in the Shnabkaib Member in Canaan Gap, section 33, and two 6-inch-diameter (15 cm) pipes in the Petrified Forest Member in section 15, all in T. 43 S., R. 11 W. (see plate 1). These wells may have been drilled in search of water, oil and gas, or mineralization.

Recent studies suggest that organic mudstone and siltstone of the late Proterozoic Chuar Group exposed in the Grand Canyon, Arizona are potential petroleum source rocks (Chidsey and others, 1990; Rauzi, 1990; Reynolds and others, 1988). Geochemical analyses indicate that these rocks contain up to 10 percent organic carbon and are within the oil-generating window. The Chuar Group rocks dip north from the Grand Canyon under much of southern Utah. Located about 40 miles (65 km) east of the Smithsonian Butte quadrangle, the Tidewater No. 1 Kaibab Gulch well was drilled to a depth of 6,253 feet (1,906 m) on the Kaibab Uplift and, although dry, penetrated organic-rich rocks of the Chuar Group. Other wells in central and southern Utah have penetrated Chuar-equivalent rocks. Although other data indicate that the Chuar Group rocks terminate east of the quadrangle, the Cambrian Muav Limestone and Tapeats Sandstone, which could be oil reservoirs for the Chuar source rocks, are probably present (Robert Blackett, Utah Geological Survey, written communication, April, 1994)

### Precious Metals and Uranium

There are no known past or current producing mines or identified mineral resources in the Smithsonian Butte quadrangle. The nearest mining district is the Silver Reef district about 15 miles (24 km) west (figure 1) which was mined mainly for silver between 1875 and 1910 (Proctor, 1953). Later, minor amounts of copper, uranium, and vanadium

were produced from the Springdale Sandstone Member of the Moenave Formation (Cook, 1960, p. 24; Wilson and Stewart, 1967, p. D5). An assessment of mineral resource potential of the Springdale Sandstone Member that included geochemical analysis of modern stream sediment, heavy mineral concentrate, and bedrock samples in the area around Canaan Mountain revealed no indications of commercial-grade metal ore in the sandstone or other rock units (Van Loenen and others, 1988).

Small amounts of gold and other precious metals have long been known in claystone of the Petrified Forest Member of the Chinle Formation in the region (Gregory, 1950), but attempts at economic recovery have not been successful. Two banks of unpatented mining claims have been filed on the Petrified Forest Member and surficial deposits on it. The claims were valid as of May 1993 (Walter Phelps, Bureau of Land Management, Salt Lake City, oral communication, 1993). One bank extends east-west along the north edge of the quadrangle in sections 21, 22, and the west part of section 23, T. 42 S., R. 11 W. Assessing the mineral potential of the claims by sampling and laboratory analyses, Kreidler reported in Van Loenen and others (1988, p. A7) that economic recovery of metals was not feasible.

The second bank of claims extends north-south along the line between sections14 and 15, T. 43 S., R. 1 W. on a hummocky, brecciated, light-reddish-brown (2.5YR 6/4), calcareous, poorly cemented, silty clay and firm clayey, very fine-grained sand. We interpret the deposit to be a mudflow of Pleistocene age (unit Qmfo) derived from the Petrified Forest Member of the Chinle Formation. An open prospect pit was roughly 30 by 25 feet (9 by 8 m) in area and 5 to 10 feet (1.5-3 m) deep. The claim holder showed one of us (DWM) a small ingot of heavy, silver-colored metal that he claimed was silver and platinum obtained from the mudstone using a process that separated and concentrated submicroscopic-sized particles of the metals from the mudstone. The author collected three 4-pound (1.8-kg) samples of the light-reddish-brown diamicton from walls of the pit and submitted them to the U.S. Geological Survey, Denver, Colorado for geochemical analysis. Separate splits of samples were analyzed by three techniques. Concentrations of 40 standard chemical elements were obtained using inductively coupled plasma-atomic emission spectroscopy (ICP-AES). No unusual concentrations were found; silver was reported at less than 2 ppm (parts per million) and gold was less than 8 ppm. Concentrations of the platinum group elements (platinum, palladium, rhodium, ruthenium, and iridium) were determined using ICP-MS (mass spectrometer). All were less than 1 ppb (part per billion). Uranium and thorium concentrations were determined using delayed neutron radiochemistry techniques; uranium was 3-4 ppm and thorium was 9-13 ppm.

Potential sources of uranium are suggested by uranium ore in channels in the Shinarump Member of the Chinle Formation at White Canyon, Utah (Chenoweth, 1993) and by minor ore in the Moenkopi Formation at the contact with the overlying Chinle in the Circle Cliffs district (Doelling, 1975, p. 105). However, assuming these units and contacts in the Smithsonian Butte quadrangle have been examined by prospectors, the general absence of diggings suggests that commercial mineralization is not likely. Kreidler and Zelten report (Van Loenen and others, 1988, p. A7) that near Smithsonian Butte and Canaan Mountain, examination by scintillometer for high radioactivity on outcrops of the Moenave Formation and the Shinarump and Petrified Forest Members of the Chinle yielded negative results. Along the west valley wall of Horse Valley Wash, trails were apparently bulldozed in the Petrified Forest Member. They are believed to have been uranium prospects or access trails to prospects. A small, probable uranium prospect pit in the Shinarump Member ($SW^1/_4SW^1/_4$ section 24, T. 42 S., R. 11 W.) was also noted during mapping. A short discussion on uranium prospecting activity in the region is given in Van Loenen and others (1988, p. A7).

### Sand and Gravel

Two pits exist near the west edge of the quadrangle along Little Creek (units Qat and $Qaf_1$). Borrow pits along Highway 59 possibly could be exploited for this resource with a minimum of environmental disturbance.

### Cinders

About 1 mile (0.6 km) west of the quadrangle, cinders were being mined in 1990 on the east side of a basaltic cinder cone (Gray Knoll). The vesicular, lightweight cinders are black, gray and reddish brown and chiefly about 0.2 to 3 inches (0.5-8 cm) in diameter. Use of the cinders was not determined, but presumably they are used as road aggregate and perhaps in manufacture of cinder block or other construction materials.

## GEOPHYSICS

Aeromagnetic and gravity data for the Canaan Mountain Wilderness Study Area were reported by Van Loenen and others (1988, p. A13-A14 and figures 5 and 6). Gravity readings in the Smithsonian Butte quadrangle indicate a fairly uniform decrease in values from –160 mGal in the southwest corner to about -178 mGal in the northeast corner. A low anomaly of about –186 mGal at the central east border apparently is of shallow origin and is caused by the thick Navajo Sandstone of Canaan Mountain. The area lies on the east flank of a circular magnetic high of more than +50 nT (nanoTeslas) 3 miles east of the northwest corner of the quadrangle; values decrease from about –90 nT along the west border to –240 nT along the east border. These magnetic variations appear to be due to magnetic sources in the underlying basement rocks.

## GEOLOGIC HAZARDS

Flash floods, landslides, rock falls, debris flows, expansive clays, and earthquakes are the chief geologic hazards in the quadrangle. Foundation instability related to collapsible soil is possible, but we know of no local occurrences. This section offers information to help the map user avoid localities where the geologic map indicates a high risk for the listed hazards.

Spring and summer cloudburst storms may cause torrential flooding in channels and on alluvial fans and can cause rapid sloughing of debris from hillslopes that triggers debris

flows. Floods and debris flows in this region are dangerous because they occur with little, if any, warning, and swiftly convey huge amounts of sediment and debris with sufficient force to move or destroy massive objects. On December 5-6, 1966, this kind of flooding occurred (Butler and Mundorff, 1970) and triggered destructive flows of mud and debris from steep slopes. On September 26, 1983, debris flows caused $1.2 million in damage after 3 inches (76 mm) of rain fell on Springdale, Utah, in 1 hour (Kaliser, 1989, p. 23). Currently in the Smithsonian Butte quadrangle, flood risk to property and public safety is small owing to sparse habitation. Risk will increase as more homes are built, especially if building is on young alluvial fans (map unit $Qaf_1$), immediately downslope from landslide deposits (Qms), or near potential rock falls. Risk is high to occupants of vehicles and pedestrians attempting to cross flooding drainageways and to hikers in confined canyons when storms are active.

In 1990, flood debris was piled high on some culverts of Highway 59 and on banks of dry stream channels, indicating recent flooding. Also, recent flood deposits of sand and gravel and (or) mudflow deposits were seen at the downslope ends of several channels that cut young fans ($Qaf_1$). As a general guide, avoid building structures on parts of unit $Qaf_1$ where unweathered, unvegetated deposits of sand and gravel cover the surface. Building on playa lake clay (Qp) should be avoided.

Prediction of stormwater and debris-flow paths on alluvial fans is prone to error because of stream avulsion, a key process in fan deposition. Nevertheless, a few guidelines are useful. Risk of floods and debris flows on old fan deposits ($Qaf_3$) is practically nil because they are high, well drained, and drainageways are incised around them. Risk on the higher parts of fans of intermediate age ($Qaf_2$) probably is small where entrenched drainageways bypass the areas. Areas at risk are mid-fan and lower where much land upslope can collect runoff and where shallow channels may overflow or shift course. Other risky areas lie downslope from unstable mass-wasting deposits (Qms, Qmso), which can be remobilized by cloudburst storms. Field inspection may reveal small mass-wasting deposits not shown on the map. Building sites high on fans and slopes should be examined for proximity to unstable deposits. Examples of possibly hazardous areas, but not all of them, are in sections 23 and 36, T. 42 S., R. 11 W., and sections 14, 13, and the southern part of section 12, T. 43 S., R. 11 W.

Swelling clay in the Petrified Forest Member of the Chinle Formation, and to a lesser extent in the Kayenta Formation, contributes to slumping or landsliding. This is evident in chaotic debris, bedding deformation, and scarps where masses of material have pulled away from hillslopes. Blocks of the Dinosaur Canyon Member of the Moenave Formation are rotated 30° to 50° toward the cliffs from which they broke away (Qms, Qmso). The bases of the blocks have slid away from the cliff on moist clay beds at the top of the underlying Petrified Forest Member of the Chinle Formation. Large mass movement complexes and smaller landslides (Qms) occur on north slopes of Smithsonian Butte and in the north-central part of the quadrangle.

A somewhat obvious hazard of rock falls exists in areas below cliffs and slopes with large boulder-sized sandstone fragments. Thick deposits of coarse sandstone rubble are interpreted to have been emplaced by one or more rock avalanches. Such deposits, although scarce, in sections 14 and 15, T. 43 S., R. 11 W. extend about 1.1 miles (1.8 km) from the Vermilion Cliffs, indicating that the rock fall hazard is not limited to just the foot of cliffs.

Foundation instability could be a problem if construction is not carefully placed. Where expansive clay or potentially collapsible soil structure is suspected, sampling and laboratory testing to determine strength of the subsoil is advisable. The Petrified Forest Member of the Chinle Formation contains clay that expands when it adsorbs water. This expansion and subsequent shrinkage upon loss of the water can damage foundations and buildings. Another hazard is collapsible soil. The grain structure of some alluvium or wind-laid material, especially those derived from the Moenkopi Formation, may collapse after prolonged watering combined with vertical loading by a heavy building, causing foundations to subside (Rollins and others, 1992).

Earthquakes could damage man-made structures. The Smithsonian Butte quadrangle is within a seismically active zone called the Intermountain seismic belt (Smith and Sbar, 1974) that extends northward to northwest Montana and is in Uniform Building Code zone 2B (International Conference of Building Officials, 1997). Although no earthquake has been recorded in the quadrangle, epicenters in the 2-4.9 magnitude range are mapped a few miles to the west and east (Goter, 1990). We saw no certain recent fault scarps during field mapping, and the Grafton Wash fault shows no signs of Quaternary movement. Lineaments on alluvial deposits were identified on aerial photographs and may record small, incipient fault scarps or scarps produced by differential subsidence of sediments. Earthquakes are known in this region and risk of damage cannot be discounted (Christenson and others, 1987).

On September 2, 1992, a Richter magnitude ($M_L$) 5.9 earthquake occurred about 5 miles (8 km) southeast of St. George, Utah. The earthquake caused no serious injuries nor did it form fault scarps. It triggered landsliding at Springdale, Utah (figure 1) that destroyed three homes and blocked the highway (Black and others, 1995). From 1850 through 1986, 33 seismic events of $M_L$ 2.0 and greater (greatest was 5.5) occurred in the Long Valley region near Kanab, east of the quadrangle (Arabasz and others, 1979; University of Utah Seismology Catalog, 1986). An earthquake of estimated pre-instrumental magnitude 6 occurred in 1902 near Pine Valley 30 miles (48 km) northwest of Smithsonian Butte. Anderson and Christenson (1989) documented fault scarps that offset Quaternary basalt flows and alluvial deposits in the Hurricane fault zone, indicating Quaternary seismicity in that area. The proximity of the Hurricane fault about 10 miles (16 km) west and the historic record of small to moderate earthquakes in this region suggests a low to moderate potential for damaging earthquakes in the quadrangle. According to Anderson and Christenson (1989, p. 4), who discussed seismicity in the surrounding region, even the largest historic earthquakes in the region were not large enough to cause faulting of the earth's surface; however, large faults such as the Hurricane fault do have the potential to cause surface rupture.

Radon gas, associated with the Chinle Formation and material eroded from the Chinle, has a moderate hazard potential in parts of the quadrangle (Black, 1993). It should be considered in existing and new construction.

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# APPENDIX

## MEASURED SECTIONS

### SOUTHEAST SMITHSONIAN BUTTE QUADRANGLE, SECTION MS-1

Top of section in south-central part of section 20, T. 43 S., R. 10 W., Washington County, Utah; 2900 ft east and 200 ft north of southwest corner of section 20 [measured by Moore and Charles Tabor, June 1990].

| Top of measured section at base of inaccessible cliff; not top of exposure | *Thickness* (ft) |
|---|---|
| **Navajo Sandstone** (not measured) | |
| **Kayenta Formation** | |
| 27. Sandstone, moderate-reddish-brown (10R 4/6), weathers same color; very fine grained, subangular quartz, 10-20 percent silty clay matrix; brittle to hard; mostly very thin, parallel horizontal laminations, dark heavy minerals abundant in some laminae; some low-angle planar cross-bedding; forms cliff; lower 3 ft is interbedded sandstone and thinly laminated micaceous siltstone which forms closely spaced parting and weathers as reentrant | 62 |
| 26. Mudstone, siltstone, and sandstone interbedded. Mudstone, light-olive-gray (5Y 6/1), silty, calcareous; subfissile to hackly fracture. Siltstone, pale-red (5R 6/2), laminated, weathers to ledges 2-6 ft thick. Sandstone, moderate-reddish-orange (10R 6/6), clayey, silty, beds 4-8 ft thick, laminated, blocky weathering. Upper part of unit contains many interbeds of thinly laminated, clayey, micaceous siltstone that weather as recessive beds; top of unit grades into unit 27 | 188 |
| 25. Sandstone, moderate-reddish-orange (10R 6/6) to moderate-reddish-brown (10R 4/6), very fine to fine-grained, feldspathic; subrounded quartz grains, moderately well sorted; low-angle planar cross-bedding in sets 1.5-2 ft thick and lesser horizontal parallel laminations; base gradational | 35 |
| 24. Sandstone, pale-reddish-brown (10R 5/4), mottled pinkish-gray (5YR 8/1); very fine grained; calcareous cement; subangular quartz grains; slightly feldspathic; small-scale cross-bedding and wavy laminations; beds 1-1.5 ft thick; sharp base; forms ledge | 5 |
| 23. Similar to unit 26. Beds are 0.5-3 ft thick; 29 ft and 62 ft above base of unit are two microcrystalline limestone beds, 2-4 in. thick, yellowish-gray (5Y 8/1); upper parts of limestone beds are very thin laminated and slightly burrowed; 13 ft below top of unit is the coarsest-grained sandstone bed, a predominantly fine-grained quartz arenite, about 20 percent rounded and medium quartz grains; grayish-pink (5R 8/2), 1 ft thick, slightly calcareous, 10-15 percent siliceous cement; very hard, forms thin ledge; unit forms a slope interrupted by thin ledges; sharp base | 130 |
| 22. Sandstone, moderate-reddish-orange (10R 6/6), upper 6 in. moderate-orange-pink (5YR 8/4); very fine grained quartzose, slightly feldspathic, slightly silty, predominantly low-angle, planar cross-bedding, sets 2-6 in. thick, trough crossbedded in upper 2 ft; forms prominent ledge; gradational base | 6 |
| 21. Mudstone, siltstone, and sandstone interbedded. Mudstone, mostly light-olive-gray (5Y 6/1), weathers same color on a frothy surface; some silty mudstone, moderate-reddish-brown (10R 4/6). Siltstone, pale-red (5R 6/2), thinly laminated, beds 2-6 ft thick. Sandstone, yellowish-gray (5Y 8/1) to moderate-reddish-orange (10R 6/6), very fine grained, clayey, silty, 1 percent biotite, calcareous; weathers into blocks 0.4 - 1.6 in across; planar and wavy laminations; trough cross-laminated in places. In middle of unit 21 scarce scour-and-fill structure occur and sandstone beds are as thick as 3 ft; in lower part of unit, sandstone interbeds are 1-6 in. thick; in upper one-fourth of unit sandstones become thicker and more numerous; unit has sharp basal contact | 104 |
| 20. Sandstone and pebbly sandstone, pinkish-gray (5YR 3/4), mostly fine, subrounded to subangular quartz grains; about 20 percent very fine quartz grains; 2-4 percent medium, well-rounded, frosted grains; chiefly planar, horizontal thin beds | |

| | |
|---|---|
| and thick laminae, few low-angle, curving cross-beds; abundant light-greenish-gray (5GY 8/1), flat to discoid fine pebbles of mudstone on many bedding surfaces; many dispersed, white nodules, 0.1-0.2 in. diameter; thick laminae of siltstone, silty mudstone, and conglomeratic (light-greenish-gray mudstone pebbles) sandstone in lower 2 ft of unit and as lenses of pebbles in lower 6-8 ft of unit; forms smooth, vertical, pale-reddish-brown (10R 5/4) massive cliff with no parting except in upper 6-8 ft where several ledges form | 43 |
| 19. Mudstone, siltstone, and sandstone, interbedded similar to unit 17; forms distinct minor ledges and recessive beds on a talus-covered slope | 37 |
| 18. Sandstone, pinkish-gray (5YR 8/1), mottled grayish-red (10R 4/2), very fine grained, quartzose, wavy to parallel planar beds, some low-angle cross-beds; beds 1-4 in. thick; parting 0.5-10 in. thick; wavy laminations; cross-bed sets 1-2 in. thick; upper 1 ft contains calcareous, brown-weathering nodules 1 in. diameter; unit thins northward within 1/4 mi to 1 ft and thickens southward within 400 ft to 18 ft thick | 9 |
| 17. Sandstone, siltstone, and mudstone, interbedded. Sandstone and siltstone, moderate-reddish orange (10R 6/6), pinkish-gray (5YR 8/1) at tops of beds; calcareous, very thin indistinct planar bedding, locally cross-bedded, lenticular beds 0.5 - 2 ft thick; soft. Mudstone dark-reddish-brown (10R 3/4), silty, subfissile to hackly fracture; unit forms slope and weak ledges | 58 |
| 16. Sandstone and basal conglomerate, moderate-reddish-brown (10R 4/6) mottled pinkish-gray (5YR 8/1), upper foot of unit is quartz-rich, very fine grained sandstone; medium-bedded, slabby, gradational base with conglomerate below. Conglomerate, sandstone pebbles in a sandy, calcareous matrix; low-angle cross-bedding, cut-and-fill bedding, wavy sharp base; 0-40 in. thick, pinches out laterally | 2.3 - 3.3 |
| Total of Kayenta Formation | 680 |

## Moenave Formation

### Springdale Sandstone Member

| | |
|---|---|
| 15. Sandstone and mudstone, interbedded. Sandstone, pinkish-gray (5YR 8/1), subangular fine quartz grains, slightly feldspathic, calcareous, very slightly micaceous; wavy laminations; most beds 4-18 in. thick, thickest beds 3 ft; beds pinch and swell. Mudstone, grayish-red (5R 4/2), silty, includes lenses of clayey very fine-grained sandstone; forms thick ledge | 6 |
| 14. Dolomite, brownish-gray (5YR 4/1), nodules are light-olive-gray (5Y 6/1) to pale-red (5R 6/2), light-greenish-gray (5G 8/1) mottles; few, very thin shale interbeds, shale is silty containing 10 percent very fine quartz sand; common very fine plant root casts, 0.02 in. diameter | 1.5 |
| 13. Sandstone, very-pale-orange (10YR 8/2), very fine grained quartzose; abundant round calcium-carbonate nodules 0.2 in. diameter; wavy and parallel beds 0.2-2 in. thick | 11.5 |
| 12. Clayey sandstone, grayish-red (5R 4/2), very fine grained quartzose, 15-20 percent clay matrix; hackly to brittle fracture; forms reentrant; sharp basal contact | 1.3 |
| 11. Sandstone, white (N9) and very light gray (N8), weathers light-brown (5YR 6/4), upper few feet bleached to pale-yellowish-orange (10YR 8/6); uniform very fine to fine-grained angular quartz grains; massive, planar cross-bedding; liesegang banding is dark-yellowish-orange (10YR 6/6); some remarkably even, parallel laminae 0.08 in. thick and abundant lenses of small-scale cross-laminated siltstone; slump structures; scattered lenticular beds (0.5-1.5 ft thick) and lenses of mudstone pellets and intraformational conglomerate of small mudstone and siltstone pebbles. Two notable conglomerate beds 20 ft and 10 ft above base of unit; unit is main body of Springdale Sandstone Member and is prominent cliff along Vermilion Cliffs; sharp basal contact, gently undulating | 107.5 |
| Total of Springdale Sandstone Member | 128 |

## Whitmore Point Member

| | |
|---|---|
| 10. Mudstone, sandstone, and limestone, interbedded, similar to unit 8 | 11.5 |
| 9. Sandstone, white (N9), very fine, angular, quartz sand; well-sorted, noncalcareous, brittle; burrowed; trace fossils on bedding planes, closely spaced, regular, meandering tunnel trails (resembles *Helminthoida*?), trails are nonmarine; fossil mudcracks; planar, thin bedding to wavy laminations; forms minor ledge | 2 |
| 8. Mudstone, sandstone, and limestone, interbedded. Mudstone, moderate-brown (5YR 4/4), grayish-red (10R 4/2), pale-red (5R 6/2), calcareous; breaks into angular blocks, 2-6 in. across; weathers to earthy slope. Sandstone, pale-olive (10 Y 6/2), pale-red (5R 6/2) staining; very fine to medium grained, beds 1-1.5 in. thick; hard. Limestone, light-greenish-gray (5GY 8/1); dense; thin beds; abundant granule- and small pebble-size blebs of lime mud, ovoid bodies 0.02-0.06 in. diameter (ostracodes?), and Holostean fish scales replaced by apatite(?) and calcite (very dusky red 10R 2/2 and dusky-red 5R 3/4) in a discontinuous sparry calcite matrix (poorly washed intramicrudite of Folk, 1968). Paleosols(?) in mudstone, moderate-yellowish-brown (10YR 5/4), beds 10 in. thick (0.5 and 2.5 ft above base of unit); contains much very fine quartz sand and silt; breaks into small (0.3 in. across) blocks; firm, dark-yellowish-brown (10 YR 4/2) clay skins (0.01 in. thick) on some ped faces; white (N9) calcium carbonate and dolomite(?) irregular nodules 1.5-4 in. diameter in upper brown zone; slope-forming unit | 13 |
| 7. Sandstone and siltstone interbedded. Sandstone, very light gray (N8) and pinkish-gray (5YR 8/1), large grayish-red (10R 4/2) mottles; beds 3-10 in. thick. Siltstone, grayish-red (10R 4/2), minor interbeds 1-8 in. thick, hackly fracture; very fine mica flakes abundant | 6 |
| 6. Siltstone, reddish-brown (10R 5/4), slightly clayey, calcareous, erodes to alternating firm and crumbly beds 4-12 in. thick on a slope | 11.5 |
| Total of Whitmore Point Member | 44 |

## Dinosaur Canyon Member (part)

| | |
|---|---|
| 5. Sandstone, moderate-reddish-brown (10R 4/6), very fine grained, slightly silty, hard, massive beds and low-angle cross-bedding, few thin beds; noncalcareous, thin deposits of calcite along fractures; joint sets oriented N. 15°W. and N. 68°E.; forms vertical cliff, rounded at top | 43 |
| 4. Sandstone, moderate-reddish-brown (10R 4/6), very fine grained, silty, calcareous, friable to soft; planar, horizontal beds and low-angle trough cross-beds; common parting lineations on bedding planes; few soft, beds are grayish-orange-pink (10R 8/2); silty, finely micaceous shale bed, 1 ft thick, at top of unit; forms alternating slopes and ledges 3-6 ft thick | 58 |
| 3. Similar to unit 1, except 0.5-1 ft-thick shale interbeds are common | 23 |
| 2. Shale, moderate-reddish-brown (10R 4/4) and dark-reddish-brown (10R 3/4), slightly silty, calcareous, hackly fracture; base sharp color break but gradational textural contact with unit 1 below | 0.8 |
| 1. Sandstone, moderate-reddish-brown (10R 4/6), very fine, angular grains, quartzose, calcareous, silty, friable; horizontal planar laminated; interbeds 0.5-8 in. thick of grayish-orange-pink (5Y 7/2) silty, very fine grained, sandstone; laminated, very thin laminae of dark grains; soft, weathers to small tabular pieces; unit forms low hillocks, weak ledges, and gullies at base of Vermilion Cliffs | 20.3 |
| Total of incomplete Dinosaur Canyon Member | 145 |
| Total of incomplete Moenave Formation | 317 |
| Total section measured | 997 |

Base of section MS-1, base of exposure, elevation 5100 ft in small wash 900 ft east and 900 ft south of northwest corner of section 29, about 300 ft northwest of 100 ft-high conical hill connected by narrow ridge to Vermilion Cliffs.

## NORTHWEST SMITHSONIAN BUTTE QUADRANGLE, SECTION MS-2, IN THREE PARTS FROM TOP TO BOTTOM 2C, 2B, 2A, SECTION MS-2C NEAR GRAFTON WASH

Top of section is at western extremity of Smithsonian Butte, SW1/4,NE1/4,SE1/4 section 21, T. 42 S., R. 11 W., 1450 ft north and 900 ft west of southeast corner of section 21; about 6350 ft elevation [measured by Moore, Brenda Buck, and Charles Tabor, June 1990].

| Top of section, not top of exposure | *Thickness* (ft) |
|---|---|
| **Navajo Sandstone (part)** | |
| 15. Sandstone, light-brown (5YR 6/4) weathers grayish-orange-pink (5YR 7/2), very fine- to fine-grained, moderately well-sorted quartz arenite, subrounded to subangular grains; 2-5 percent well-rounded, frosted medium-grained quartz; very large-scale planar and tangential cross-bedding; sets 6-30 ft thick; basal contact gradational | 175 |
| Total of incomplete Navajo Sandstone | 175 |
| **Kayenta Formation** | |
| 14. Sandstone, siltstone, and mudstone. Sandstone, moderate-red (5R 4/4), weathers moderate-reddish-brown (10YR 4/6), very fine grained, silty, much sandy coarse-grained siltstone; laminae 0.02-0.04 in. thick, parting 2-4 ft thick; low-angle cross-bedding; cylindrical curved burrows with bumpy walls that resemble marine trace fossil *Scalarituba*; asymmetric, folded laminae (penecontemporaneously deformed). Siltstone, moderate-red (5R 4/4), laminated; hard; contains interbeds of sandstone 0.5-2 in. thick. Mudstone, grayish-red (5R 4/2), thin and medium beds 4-12 in. thick; fissile in places, micaceous, silty; fine blocky fracture; contains lenses of starved sand ripples (lenticular bedding). In lower 2 ft of unit is sandstone having trough cross-beds; weathers as a recessive bed and forms silty and clayey sand; basal contact sharp and noticeably undulatory (4-7 ft of relief in 300 ft horizontally) | 98 |
| 13. covered interval | 45 |
| 12. Sandstone and siltstone. Sandstone, pinkish-gray (5YR 8/1) and moderate-reddish-brown (10R 5/6), very fine- to fine-grained, angular to subangular quartz grains; contains 5-10 percent rounded, frosted medium quartz grains; planar parallel, thick laminae, local medium-scale low-angle cross-beds; flaser bedding (very thin clay drapes on sand ripples); greenish-gray (5GY 6/1) mudstone granules common in places; firm to soft strength. Siltstone, moderate-reddish-brown (10R 5/6), very fine sand quartz grains, planar parallel laminated; forms weak ledges 1.5-2 ft thick; unit forms a slope | 95 |
| 11. Sandstone, moderate-reddish-brown (10R 4/6), weathers pale-reddish-brown (10R 4/6), very fine grained, silty, chiefly parallel laminated, scarce medium-scale low-angle cross-beds; scarce mudstone interbeds, moderate-reddish-brown, micaceous and fissile, 2-8 in. thick; sharp basal undulating contact, about 5 ft relief in 300 ft horizontal distance | 17.7 |
| 10. Sandstone, siltstone, and mudstone, interbedded. Sandstone, light-greenish-gray (5GY 8/1), pale-reddish-brown (10R 5/6), and variegated similar colors; very fine grained, silty, clayey in places; quartz grains well cemented by calcareous cement; planar bedding 8-24 in. thick, scarce low-angle cross-beds; forms thin flagstone pieces and ledges. An unusually thick channel sandstone bed, 10 ft thick, is 49 ft below top of unit, is fine grained, contains 5 percent medium quartz grains, accessory muscovite and chlorite, altered feldspar, and 10 percent dark lithic and heavy mineral grains; very thin planar laminations. Siltstone, same colors as sandstone, calcareous, slightly micaceous, firm, forms slope and weak ledges 4-15 in, thick. Mudstone, moderate-reddish-brown (10R 4/6), silty in places, beds 4-30 in. thick, angular blocky fracture; forms slope | 203 |
| 9. Mudstone, grayish-red (10R 4/2), weathers moderate-reddish-orange (10R 6/6) and yellowish-gray (5Y 8/1), very thinly laminated; very calcareous, weak, breaks into angular granules and chips; unit contains few interbeds 1-2 ft thick of very | |

| | |
|---|---|
| fine-grained sandstone, with mudcracks and unidentified trace fossils on bedding planes; some small-scale cross-laminae; mottled colors moderate-red (5R 4/6) and yellowish-gray (5Y 8/1) parallel the bedding | 40.7 |
| 8. Sandstone, pale-red (5R 6/2), bluish-white (5B 9/1) in top and basal 2 ft; very fine grained, well sorted; iron-oxide stains quartz grains pinkish-gray (5YR 8/1); channel sand pinches out within 150 ft horizontally; firm; even, thin laminae and medium-scale crossbedding dipping east 10°; scarce plant impressions; forms prominent, rounded ledge | 8.5 |
| 7. Sandstone, moderate-reddish-brown (10R 4/4), weathers same color; very fine grained, silty, slightly clayey, poorly sorted; abundant rib and furrow on bedding surfaces; small-scale trough cross-laminae, very thin planar laminae; weathers to siltstone-chip-covered slope and 2 to 3 minor ledges about 16 in. thick | 28 |
| 6. Sandstone, pale-red (10R 6/2), weathers same color; very fine grained, silty, calcareous, firm, very small-scale ripples and cross-laminae, beds 1.5-2 ft thick; scarce silty shale interbeds, 4 in. thick; forms ledge; sharp undulatory base | 5 |
| 5. Shale, grayish-red (10R 4/2), weathers same color | 2 |
| 4. Sandstone and mudstone, interbedded. Sandstone, pale-red (10R 6/2), dark reddish-brown (10R 3/4), moderate-reddish-brown (10R 4/6), weathers light-brown (5YR 6/4); very fine grained, silty, slightly clayey, weakly calcareous, planar bedding 8-16 in. thick and very thin, planar laminae. Mudstone, dark reddish-brown (10R 3/4) to greenish-gray (5GY 6/1), silty, contains some very fine sand, micaceous, subfissile to hackly fracture; beds 6-12 in. thick | 25.5 |
| 3. covered | 10 |
| 2. Mudstone, siltstone, and sandstone, interbedded. Mudstone, very dark reddish brown (10R 2/4), weathers pale-reddish-brown (10R 5/4), breaks into angular granule-size blocks; basal contact gradational with siltstone. Siltstone, moderate-reddish-brown (10R 4/6), slightly clayey. Sandstone, same color as siltstone, very fine grained, quartzose; wavy, discontinuous laminations; medium bedded; unit forms slope | 11 |
| 1. Sandstone and siltstone, interbedded. Sandstone, moderate-reddish-brown (10R 4/6), weathers moderate-red (5R 5/4) and mottled locally to white (N9); very fine grained quartz, slightly calcareous; forms small ledges in gradational zone between Kayenta Formation and Springdale Sandstone Member. Siltstone, dark reddish-brown (10R 3/4), weathers same color, contains very fine quartz sand grains; very thin laminations. Sandstone beds form minor ledges on a moderate slope | 26 |
| Total Kayenta Formation | 615 |
| Total measured section 2C | 790 |

Base of section MS-2C is on Vermilion Cliffs 1750 ft north of and 3150 ft east of southwest corner of section 21, T. 42 S., R. 11 W., about 5560 ft elevation.

## NORTHWEST SMITHSONIAN BUTTE QUADRANGLE, SECTION MS-2B, GRAFTON WASH

Top of section elevation 5540 ft, 1500 ft north of and 3000 ft east of southwest corner of sec. 21, T. 42 S., R. 11 W. [measured by Moore and Charles Tabor, June 1990].

| | *Thickness* (ft) |
|---|---|
| **Moenave Formation:** | |
| Springdale Sandstone Member | |
| 24. Sandstone, pale-red (5R 6/2); in upper 15 ft grayish-orange (10YR 6/2); chiefly fine quartz grains, calcareous, micaceous, 2 percent lithic and heavy mineral dark grains, 5-10 percent white, very fine sand sized clay (altered feldspar?); | |

massive bedded, planar and wavy laminations; fossil logs 8 in. diameter; abundant lenses 0.5-2 ft thick of mudstone and dolomitic mudstone fine pebble conglomerate, moderate-yellowish-brown (10YR 5/4); channel-fill consisting of wavy laminated fine quartzose sand; sharp contact at base, undulating 2 ft relief; well-cemented; forms high vertical cliff with huge arch-like fractures 168

23. Conglomerate, yellowish-gray (5Y8/1), weathers moderate-brown (5YR 4/4); clasts of subrounded granules and fine pebbles of siltstone, very fine grained sandstone, and finely crystalline dolostone in a calcareous, silty matrix of very fine-grained quartz sand; channel-fill deposit having undulatory base contact; 1-5 ft thick along outcrop and grades laterally into mudstone, medium-greenish-gray (5G 5/1) 2.5

22. Sandstone, pale-red (10R 6/2) weathers reddish-brown (2.5YR 5/4); bleached to grayish-orange (10YR 7/4) in upper 2 ft; very fine grained, silty and micaceous, grades upward to coarse siltstone; uppermost 0.5 ft is fissile, pale-brown (5YR 5/2) clayey siltstone containing discoid iron-oxide concretions; 0.04-0.08 in.-diameter spheres weather out on surface of outcrop; planar, parallel beds 0.5-4 in. thick, some are wavy; forms flaggy to blocky rubble; sharp, rolling basal contact, 10 ft vertical relief in 600 ft horizontally 5

Total Springdale Sandstone Member of Moenave Formation 176

**Whitmore Point Member**

21. Mudstone, dusky-red (5R 3/4), weathers grayish-red (5R 4/2); contains very thin planar laminae of silt and very fine quartz sand; micaceous; breaks into blocky pieces 0.2-0.7 in. across; earthy slope 5.5

20. Sandstone, forms three subunits: upper subunit is 2.5 ft thick, very fine grained, thin, planar laminae, upper 0.5 ft is silty, very finely crystalline dolostone, mottled moderate-yellowish-brown (10YR 5/6) and grayish-red (10R 4/2). Middle subunit is 3.5 ft thick pale-reddish-brown (10R 5/4), wavy laminated, very coarse quartz sand in basal foot; forms massive bed. Lower subunit is 4.5 ft thick grayish-red (10R 4/2) mottled very light gray (N8) containing lenses of small mudstone pebbles; planar laminae 10.5

19. Mudstone, similar to unit 13. Has 0.5 ft-thick very fine-grained sandstone bed yellowish-gray (5Y 8/1) 2 ft below top of unit; forms slope 4

18. Sandstone, pinkish-gray (5YR 8/1) weathers grayish-orange-pink (5YR 7/2), very fine grained quartzose, calcareous, slightly silty; thin planar laminae, inclined 15-20° to upper and lower contact. Sigmoidal, inclined cross-bedding; sets are 1 ft thick, sharp top of lower 3-ft bed; forms ledge 4.1

17. Mudstone, same as unit 13 11

16. Sandstone, yellowish-gray (5Y 8/1) to light-greenish-gray (5GY 8/1); very fine grained, calcareous, medium to thick bedded; channel fill in places; forms slightly rounded ledge 2.3

15. Siltstone and sandstone, interbedded. Siltstone and sandstone, pale red (5R 6/2) and (10R 6/2), variegated with yellowish-gray (5Y 8/1) to light-greenish-gray (5GY 8/1); chiefly planar, thin beds. Sandstone forms shallow channel fill; scarce lenses of coarse quartz sand; sharp uneven base; forms weak, crumbly ledge 2

14. Sandstone, greenish-gray (10GY 5/2) to light-greenish-gray (5GY 8/1), bimodal coarse- and very coarse-grained quartz and chert sand, some frosted and pitted grains; contains sparse, greenish-gray mudstone lenses; wavy, thin, uneven, very thick laminae; sparse inclusions of flat-chalcedony or chert nodules, very dusky red (10R 2/2), 0.8-2.5 in. long enameloid Holostean fish scales; Kenneth Carpenter, Denver Museum of Natural History, oral communication, 1993; unit pinches out 0.7

13. Mudstone, grayish-red (5R 4/2), silty; breaks into angular granules 2.5

12. Sandstone, pale-red (5R 6/2); weathers moderate-reddish-brown (10R 4/4); very fine grained, silty, thinly laminated; forms weak ledge 2

| | |
|---|---|
| 11. Siltstone, grayish-red (5R 4/2) weathers pale-red (5R 6/2), weakly calcareous; contains very fine grained quartz sand; forms angular blocks 0.25 in. across | 4.7 |
| 10. Sandstone, pale-red (5R 6/2), slightly silty and micaceous; wavy laminae 0.1-1 in. thick; firm; forms ledge | 1 |
| 9. Sandstone, pale-red (5R 6/2), very fine grained, quartzose; silty, subfissile; forms slope | 11 |
| 8. Sandstone, similar to unit 6; forms ledge | 0.8 |
| 7. Sandstone, similar to unit 5 | 1.5 |
| 6. Sandstone, very light gray (N8) to yellowish-gray (5Y 8/1), variegated to pale-red (5R 6/2); wavy beds 0.4-1.5 in. thick; firm; forms minor ledge | 0.8 |
| 5. Sandstone, pale-red (5R 6/2) and (10R 6/2); weathers same colors; very fine-grained quartz, silty, moderately well sorted; wavy laminated, symmetrical wave ripples in phase; slightly fissile; weathers as slabby pieces (0.5 in thick) on slope | 3.5 |
| Total of Whitmore Point Member | 68 |

**Dinosaur Canyon Member**

| | |
|---|---|
| 4. Sandstone, pale-reddish-brown (10R 5/4) weathers same color, mainly very fine quartz grains, slightly silty, micaceous in places; firm, planar to wavy parallel laminated, scarce small-scale trough cross-laminae (sets of laminae are 0.4 - 0.6 in. thick); rib and furrow structures; contains lenses of weakly fissile mudstone, silty and dark-reddish-brown (10R 3/4); at base and at top are very thin beds of very pale orange (10YR 8/2) sandstone; blocky to massive parting; parting lineations; forms persistent set of thick ledges to cliff; basal contact sharp and even | 60 |
| 3. Sandstone, moderate-reddish-brown (10R 4/6), chiefly very fine-grained quartz, silty, moderately sorted; calcareous, scarce stringers of gypsum 0.1-0.2 in. thick; horizontal, planar parallel, and hummocky to wavy, very thin laminae break out as individual sheets 1-1.5 ft across; abundant rib and furrow structures on bedding surfaces; some small-scale trough cross-laminae; forms slope with scattered weak ledges | 85 |
| 2. Mudstone, reddish-brown (2.5 YR 4/4) with less light-greenish-gray (5GY 8/1) zones, spots, and mottles; calcareous; weathers to angular granules and very fine pebble-sized blocks; forms earthy "popcorn" slope; base is gradational | 21 |
| 1. Sandstone and siltstone, interbedded. Sandstone and siltstone, moderate-reddish-brown (10R 4/6), very fine-grained quartz, silty, some clayey beds; thinly laminated, planar to wavy laminae; parting lineations; cemented by and finely interlaminated with white gypsum laminae in lower 20 ft; rock variegated to light-greenish-gray (5GY 8/1), weathers to same color, forms debris-covered slope with few hard rounded ledges 2-4.5 ft thick; contact with underlying Chinle Formation is gradational in texture, but sharp in color; very firmly cemented by gypsum. Siltstone beds 3-4.5 in. thick | 60 |
| Total of Dinosaur Canyon Member | 226 |
| Total of Moenave Formation and of measured section 2B | 470 |

**Chinle Formation** (part)

**Petrified Forest Member** (part)

| | |
|---|---|
| Mudstone, pale red (10R 6/4), clayey, contains silty very pale orange (10YR 8/2) planar beds, 0.2-0.5 in. thick; unit weathers to frothy (popcorn) earthy slope | unmeasured |

Base of section MS-2B, in Grafton Wash, 2,020 ft east of west border of section 21, 1,900 ft north of south border, SE$^1/_4$,NE$^1/_4$,SW$^1/_4$ section 21, T. 42 S., R. 11 W. Section trends generally east-northeast.

## NORTHWEST SMITHSONIAN BUTTE QUADRANGLE, SECTION MS-2A

Top of section is 3,300 ft north of and 2,400 ft east of southwest corner of section 21, T. 42 S., R. 11 W. [measured by Brenda Buck and Charles Tabor, June 1990].

| Top of section; not top of exposure | *Thickness* (ft) |
|---|---|
| landslide (unit Qms) | |
| 18. Covered. slumped material, moderate-reddish-brown (10R 4/6); mixed soil material, debris, and pieces of sandstone, very fine grained and thinly laminated | 107 |
| **Chinle Formation** (part) | |
| **Petrified Forest Member** (part) | |
| 17. Mudstone, light-brownish-gray (5YR 6/1) | 15 |
| 16. Siltstone and silty mudstone. Siltstone, pinkish-gray (5YR 8/1), yellow mottled at base. Mudstone, dark-gray (N3), weathers medium-dark-gray (N4) mottled by various yellow hues near base; silty; noncalcareous | 22 |
| 15. Mudstone, siltstone, and sandstone, interbedded. Alternating very thin beds about 0.5 in. thick that grade into one another; mudstone and clayey siltstone predominate; sandstone is fine grained; unit forms slope with thin, weak ledges | 11 |
| 14. Sandstone, light-brownish-gray (5YR 6/1); fine grained, slightly calcareous; beds 0.1-0.4 in thick; forms a ledge; pinches out laterally | 13 |
| 13. Claystone, grayish-red-purple (5RP 4/2), weathers pale-red-purple (5RP 6/2); lacks appreciable sand or silt | 32 |
| 12. Sandstone, light-brownish-gray (5YR 6/1), fine grained, feldspathic, calcareous, silty, poorly cemented in middle of unit; at base and at top is very hard and forms small ledge | 8 |
| 11. Claystone and clayey siltstone, light-greenish-gray (5GY 8/1), weathers light-brownish-gray (5YR 6/1), silty, thinly laminated, clayey siltstone interbeds throughout; variegated colors in various intervals in unit include moderate-reddish-brown (10R 4/4), pale-red purple (5RP 6/2), very light gray (N8), and shades of yellow mottled with light gray (N7); forms porous, earthy slope | 95 |
| 10. Sandstone, yellowish-gray (5Y 8/1), medium grained, subrounded grains of volcanic lithic and feldspar grains; top part weathers light-brownish-gray (5YR 6/1); porous slope | 2 |
| 9. Mudstone, yellowish-gray (5Y 8/1) to dark gray (N3), silty, not calcareous, isolated piece of vertebrate bone, 3 in. diameter, not identified | 4 |
| 8. Sandstone, grayish-red (5R 4/2), weathers same, fine-grained volcanic and feldspar grains, micaceous; bimodal fine quartz sand grains and medium-grained feldspar; gradational basal contact | 2 |
| 7. Sandstone, pale-yellowish-brown (10YR 6/2) weathers pale-purple (5P 6/2), fine grained, some medium sand grains; 20 percent of grains are dark minerals and lithic grains; silty, very slightly clayey, poorly cemented by calcite; weak, crumbly; basal 2 ft is silty mudstone; sharp basal contact | 15 |
| 6. Claystone, pinkish-gray (5YR 8/1), yellow mottling, clasts of silty clay-iron oxide(?) concretions; sparse calcium-carbonate-cemented concretions; very hard; contains less than 20 percent very fine-grained quartz sand; slightly dolomitic; dusky-red (5R 3/4) to dusky-brown (5YR 2/2) iron-manganese oxide concretions; goethite-limonite-enriched concretions | 2 |
| 5. Claystone, pale-red-purple (5RP 6/2); scarce thin selenite bladed crystals; weathers to earthy slope with frothy surface, probably contains swelling clay | 5 |

| | |
|---|---|
| 4. Claystone, grayish-red-purple (5RP 4/2) weathers same color, weathers to earthy, slope with frothy surface, probably contains swelling clay | 20 |
| 3. Claystone, medium-gray (N5), weathers light-brownish-gray (5YR 6/1); forms earthy slope with frothy surface, probably contains swelling clay | 5 |
| 2. Covered section | 30 |
| 1. Claystone, light-brownish-gray (5YR 6/1), slightly silty, forms slope; sharp basal contact on conglomeratic sandstone of Shinarump Member | 5 |
| Total incomplete Petrified Forest Member | 286 |
| Total measured section 2A | 393 |
| Total measured strata in sections 2A, 2B, and 2C | 1653 |

Shinarump Member of Chinle Formation (not measured, not described)
Base of measured section, not base of exposure
Base of section MS-2A is in NE1/4,SW1/4,NW1/4 section 21, T. 42 S., R. 11 W., 650 ft along road north-northeast of Grafton Wash culvert. Section trends east through unit 3, then east-southeast to top.

## SOUTHWEST SMITHSONIAN BUTTE QUADRANGLE, SECTION MS-3

Measured on steeply sloping side of an eastern part of Little Creek Mountain in SE1/4,SE1/4,NE1/4, section 32, T. 43 S., R. 11 W. Bottom of section elevation 4660 ft, 1400 ft north of Arizona state line, 400 ft west of section 33-32 section line [measured by Moore, Brenda Buck, and Charles Tabor, June 1990].

| Top of section; top of exposure | *Thickness* (ft) |
|---|---|
| **Chinle Formation** (part) | |
| **Shinarump Member** (eroded) | |
| 14. Conglomerate and sandstone. Conglomerate, pale-grayish-orange (10 YR 8/4), grayish-orange (10YR 7/4), weathers light-brown (5YR 6/4), pale-yellowish-orange (10YR 8/6), dark-yellowish-orange (10YR 4/6), rounded quartzite, quartz, and chert pebbles and scarce small cobbles in fine to very coarse sand matrix; limonite-silica-clay cement is 15 percent of rock volume; pebbles as large as 2.5 in. diameter, most are 0.3-1.3 in. diameter; planar to trough low-angle and high-angle foresets in cross-bedding, sets 1-4.5 ft thick; planar bedding. Sandstone, pale-grayish-orange (10YR 8/4), weathers light-brown (5YR 6/4), fine to medium grained, parts are medium to very coarse grained, stained moderate-reddish-brown (10R 4/6) by iron oxides locally; common small manganese and iron carbonate concretions and nodules throughout; fossil wood debris; on surface of mesa forms car- to cabin-sized erosional knobs and rounded outcrops, much sandy alluvium on surface; stained zone 2 ft thick and 10 ft below top is dusky red (5R 3/4); unit forms caprock and cliff | 51 |
| 13. Mudstone, yellowish-gray (5Y 8/1), calcareous, slope covered with manganese(?) and iron-carbonate (siderite) concretions (1 in. diameter) probably derived from unit 14; forms earthy slope | 10-12 |
| 12. Sandstone, grayish-orange (10YR 7/4), mainly medium-grained quartz, few lenses of pebble conglomerate; quartzite, quartz, and chert pebbles 0.5 in. diameter; trough cross-beds, foreset beds 1 ft thick, troughs 3 ft across | 40 |
| 11. Conglomerate and mudstone. Conglomerate like unit 14; predominantly siliceous and some claystone rounded pebbles 0.2-1.2 in. diameter; in places clayey sand matrix and kaolinized feldspar grains, 0.04-0.15 in. diameter; very thick beds of channel-fill gravel and common lenses of pebbly sandstone. Mudstone, medium gray (N5), weathers light-gray (N7), slightly silty and fissile, wood fragment imprints; thin interbeds of mudstone in lower 1.5 ft of unit, beds of mudstone | |

deformed as flowage folds, pull-apart layers; slightly undulatory, sharp basal contact is Ꞧ-3 unconformity 9.5

Total of eroded Shinarump Member 112

Ꞧ-3 unconformity of Pipiringos and O'Sullivan (1978)

**Moenkopi Formation**

**Upper red member**

10. Shale, medium-light-gray (N6), fissile, pinches and swells from 0 to 4 in. thick; sharp wavy contact at base 0.3

9. Mudstone, light-greenish-gray (5GY 8/1), wavy laminations; calcareous; planar laminae of gypsum, 0.25 in. thick 1-1.5

8. Siltstone, moderate-brown (5YR 4/4), weathers dusky red (5R 3/4); upper 4 ft is grayish-red (10R 4/2) fresh and weathered color; planar bedding 0.5-2 ft thick and wavy laminations 33

7. Siltstone, moderate-brown (5YR 4/4) weathers same color, micaceous, very calcareous, cliff and ledge forming, extremely thin (about 0.02 in.) wavy, laminations; firm, basal contact covered; base and top of ledges are gradational with slopes between ledges 42.9

6. Similar to unit 2. Siltstone has abundant small-scale trough cross-bedding and rib and furrow structures; shrinkage cracks in mudstone; forms earthy slope 86

5. Sandstone, moderate-brown (5YR 4/4), weathers pale-red (10R 6/2); mostly very fine subangular quartz grains, well-sorted; gypsiferous; thin, planar parallel laminations, medium-scale low-angle crossbeds in lower 3 ft; unit contains scarce very thin beds of light-greenish-gray (5GY 8/1), well-sorted coarse-grained siltstone having asymmetric ripples on bedding planes; unit forms weak, rounded ledge 7

4. Mudstone and siltstone, interbedded. Like unit 2 except forms mostly a silty, earthy slope; subordinate amounts of very light greenish-gray (5GY 9/1), sandy siltstone is present; siltstone contains 1 percent light green, translucent, very fine sand grains 38

3. Sandstone, grayish-orange-pink (5 YR 7/2) and very light brown (5YR 7/4), weathers light-brown (5YR 6/4), silty, very fine quartz sand, 5 percent dark-mineral coarse silt grains, planar parallel thin laminae, some very low-angle, parallel large-scale cross-laminae; abundant gypsum laminae; parting lineations on bedding planes; low-angle trough cross-beds in upper 3 ft 18

2. Siltstone and mudstone, interbedded. Siltstone, light-brown (5YR 6/4), weathers same color; clayey and gypsiferous; laminated and beds 0.12 in. thick; common very thin laminae of gypsum, grayish-orange-pink (10R 8/2); fissile in places; small-scale rib and furrow structures on bedding planes. Mudstone, moderate-brown (5YR 4/4) and light-olive-gray (5Y 6/1), contains silt and very fine-grained quartz sand and mica; common gypsum laminae, wavy in places; siltstone and mudstone form alternating intervals 2-6 ft thick 65

Total of upper red member 292

**Shnabkaib Member (part)**

1. Siltstone, moderate-grayish-red (10R 5/2); coarse-grained silt; gypsiferous, abundant gypsum laminae are finely crystalline and 0.04-0.08 in. thick, grayish-orange-pink (5 YR 7/2) and pinkish gray (5YR 8/1), gypsum weathers to light-brown (5YR 6/4) large chips and flat pieces on earthy slopes; unit forms ledges 2-3 ft thick separated by earthy slopes 8-12 ft thick; abundant small selenite crystals 0.04-0.08 in. diameter occur in siltstone; even, very thin bedding and

| | |
|---|---|
| very small-scale, wavy laminations (0.01-0.03 in. thick); small-scale oscillation ripples on bedding surfaces | 24 |
| Total of Shnabkaib Member (part) | 24 |
| Total of Moenkopi Formation (part) | 316 |
| Total measured section | 428 |

Base of section, base of exposure

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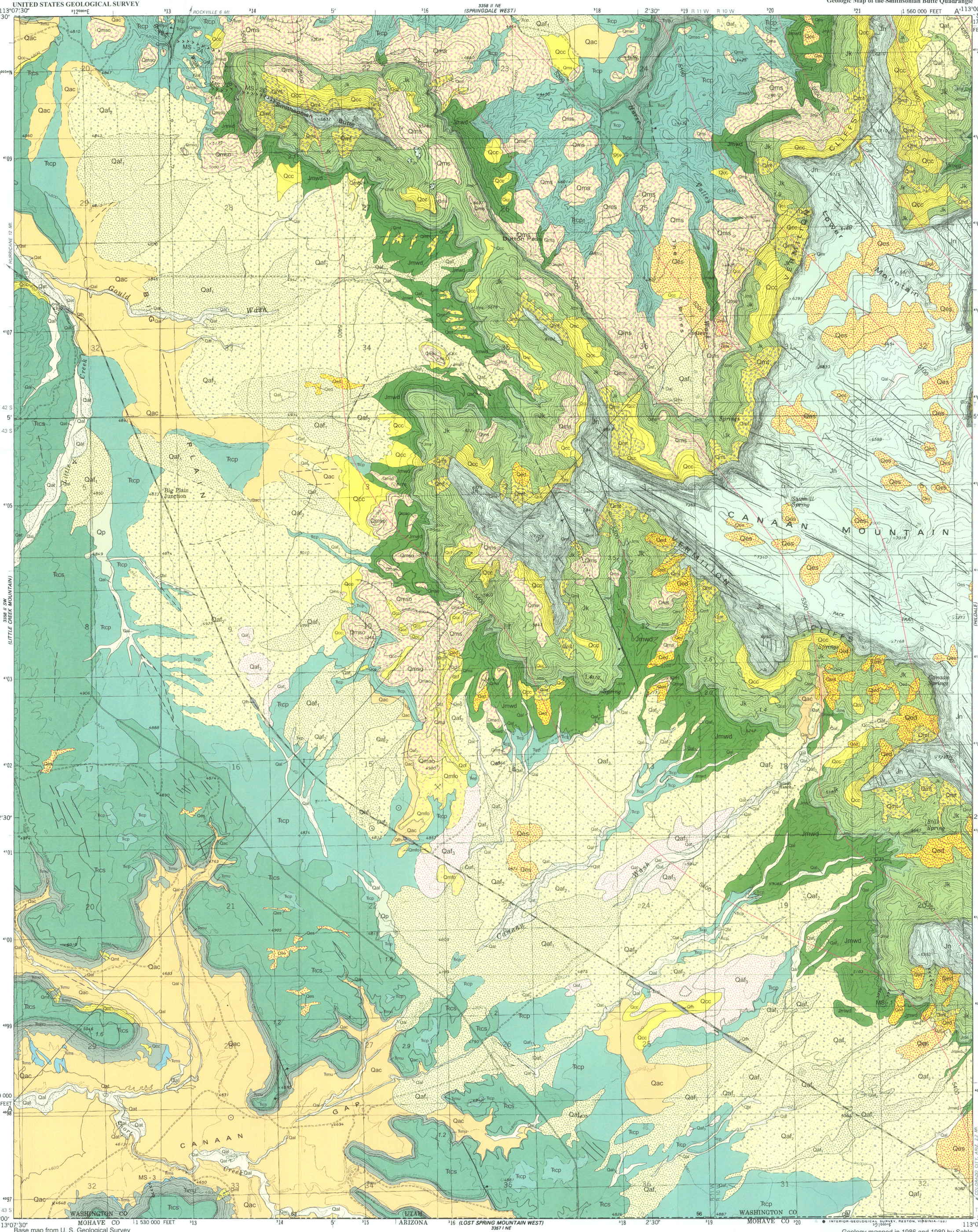



Base map from U. S. Geological Survey
Smithsonian Butte 7.5' Quadrangle, 1980

SCALE 1 : 24,000

1 — 1/2 — 0 — 1 MILE

1000 — 0 — 1000 — 2000 — 3000 — 4000 — 5000 — 6000 — 7000 FEET

1 — .5 — 0 — 1 KILOMETER

CONTOUR INTERVAL 40 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

Geology mapped in 1986 and 1989 by Sable and in 1990 by Moore assisted by Charles Tabor and Brenda Buck
Photogrammetric assistance by James Messerich
Digitized by Art Straub



13°4'
232

2001 MAGNETIC DECLINATION
AT CENTER OF SHEET

# GEOLOGIC MAP OF THE SMITHSONIAN BUTTE QUADRANGLE, WASHINGTON COUNTY, UTAH

by

David W. Moore
and
Edward G. Sable

2001

UTAH

QUADRANGLE LOCATION

UTAH GEOLOGICAL SURVEY
*a division of the*
UTAH DEPARTMENT OF NATURAL RESOURCES
*in cooperation with the*
UNITED STATES GEOLOGICAL SURVEY



## DESCRIPTION OF MAP UNITS

**Qfh** Highway fill (Holocene)—*Rock and soil emplaced by earth-moving equipment*

**Qal** Channel alluvium (Holocene)—*Reddish-brown and reddish-yellow silty, very fine to coarse quartz sand containing granules, pebbles, cobbles, and scarce boulders of sandstone; alluvium in Little Creek is pale brown with quartzite gravel; grains within individual strata moderately well sorted; highly variable grain size among strata; underlies floodplains and adjacent low terraces; unit grades into Qac and $Qaf_1$ deposits; estimated thickness 4 to 12 feet (1.2-4 m)*

**Qac** Alluvium and colluvium (Holocene)—*Reddish-brown, silty and clayey fine to very fine quartz sand, locally coarse sand, scarce sandstone and quartzite pebbles, mostly alluvium on gently sloping land; colluvium derived from nearby hillslopes; interfingers with Qal; one to 3 feet (0.3-1 m) thick at distal edge of alluvial fans;10 to 35 feet (3-11 m) thick in Canaan Gap area; water wells west of quadrangle indicate thickness may exceed 50 feet (15 m)*

**Qcc** Coarse colluvium (Holocene)—*Red, yellowish-red, and pale-red sandy gravel to gravelly sand slope deposit; abundant angular sandstone gravel fragments; includes minor talus and alluvium; 2 to 40 feet (0.7-12 m) thick*

**Qcf** Fine colluvium (Holocene)—*Moderate-brown fine quartz sand, silt, and minor sandstone pebble-size pieces; silt reworked by wind locally; about 2 feet (< 1 m) thick*

**Qp** Playa deposit (Holocene)—*Light-brown silty clay including very thin beds of sandstone pebbles, cobbles, and scarce small boulders washed in by sporadic flash floods; thinly laminated, friable; interfingers laterally with sandy distal fan alluvium ($Qaf_1$); estimated thickness 2 to 8 feet (0.7-2 m)*

**Qes** Eolian sand, sheet-wash, and residuum, undivided (Holocene)—*Sand, fine- to medium-grained quartz; light brown, orange, pink, and yellowish gray; veneer of mostly stabilized sheet sand and small dunes on alluvial fans; on mesas and buttes is irregular fillings in bedrock hollows and deposits of intermittent streams; locally includes small outcrops of bedrock; generally 1 to 4 feet (0.3-1 m) thick; 2 to 6 feet (0.7-2 m) thick at head of Horse Valley Wash*

**Qed** Eolian-sand dunes and ramps (Holocene)—*Wind-blown sand, like unit Qes except no appreciable alluvium or residuum; sand accumulates in ramp-like mantles and small dunes on talus; may grade downslope into unit Qes; 2 to 6 feet (0.7-2 m) thick*

**Qmt** Talus (Holocene)—*Blocky debris, brown, pink, and reddish-brown sandstone; steep (25° to 30°) aprons and cone-like deposits at foot of cliffs; (talus in adjoining Hildale quadrangle of Sable,1995, p. 8, is included in unit Qc); talus is 2 to 20 feet (0.7-6 m) thick*

**$Qaf_1$** Young fan alluvium (Holocene to upper Pleistocene)—*Reddish-brown to reddish-yellow silt, sand, and sandstone gravel on broad, sloping surfaces, parts of which presently are aggrading; crudely bedded; bedding dips 1° to 4° mainly southwest; mid- and down-fan segments are chiefly pebbly sand; weak to no soil development in uppermost part; fan surfaces are not deeply eroded and are at a geomorphic level of a few feet to as much as 30 feet (10 m) above modern streams; 2 to 20 feet (7-6 m) thick*

**Qat** Terrace alluvium (Holocene to upper Pleistocene)—*Silt, sand, and gravel similar to Qal; occurs as nearly flat, tabular deposits of former channels and floodplains 6 to 15 feet (2-4.5 m) above modern stream channels; 2 to 6 feet (0.7-2 m) thick*

**Qms** Landslide debris (Holocene to upper Pleistocene)—*Heterogeneous debris; matrix is clay- to sand-size; clasts of sandstone range from granules to blocks as long as 500 feet (150 m); strata in blocks are brecciated or coherent; some colluvium (Qcc) included; some Toreva blocks are active; estimated thickness 10 to 150 feet (3-46 m)*

**$Qaf_2$** Intermediate-age fan alluvium (upper Pleistocene)—*Silt, sand, and gravel; reddish-orange and reddish-brown very fine to fine quartz sand, subordinate medium to coarse quartz sand; lenses of clay; in upper part of fan, sandy subangular to subrounded sandstone pebbles, cobbles, and boulders and interbeds of clayey gravel (mudflow deposits); crudely stratified; unit is higher and more eroded than $Qaf_1$, and in upper 3 feet (1 m) is an A/C horizon soil profile, and locally, reddish-brown Bt horizon 6 to 10 inches (15-25 cm) thick, moderately well developed; surface of deposit 30 to 60 feet (9-18 m) higher than modern stream level; thickness <2 feet (<1 m) at edges to 50 feet (15 m) at fan apex*

**Qmf** Debris-flow deposit (upper Pleistocene)—*Unsorted, nonbedded clay, silt, sand, and blocky sandstone rubble derived from Mesozoic bedrock; matrix supported; common as interbeds (not mapped as such) near apex of alluvial fans; a distinctive mapped deposit occurs in section 27, T. 42 S., R. 11 W.; 4 to 20 feet (1-6 m) thick*

**Qma** Rock-avalanche deposit (upper Pleistocene)—*Coarse angular sandstone fragments; forms a south-sloping, low, linear, rounded ridge that rests on an intermediate-age alluvial fan in NW¼ section 14, T. 43 S., R. 11 W. and two deposits in section 11; partly disintegrated to sand; 5 to 20 feet (1.5-6 m) thick*

**$Qaf_3$** Old fan alluvium (upper middle Pleistocene)—*Deeply weathered and degraded remnants of moderate-reddish-brown sand and sandy gravel, subangular to rounded sandstone pebbles, cobbles, and small boulders; sparse boulders as large as 5 feet (1.6 m) across; gravel-filled channels cut thick beds of yellowish-red, well-sorted, cross-laminated quartz sand, fine to medium grained; deposits form low hills 40 to 90 feet (12-27 m) higher than level of modern streams; surface soil at or near maximum development; unit is 10 to 25 feet (3-8 m) thick*

**Qmfo** Old debris-flow deposit (upper middle Pleistocene)—*Weathered lobate deposit; chaotic; contains reddish-brown sandstone blocks of Kayenta Formation and variegated mudstone debris of the Petrified Forest Member; thins downslope; estimated maximum thickness 25 feet (7.5 m); 1 to 2 feet (<1 m) thick at edges*

**Qmao** Old rock-avalanche deposit (upper middle Pleistocene)—*Weathered sandstone rubble, about 90 percent Navajo Sandstone, 10 percent Kayenta Formation; clasts are 1 inch (2.5 cm) across to car size; chiefly bouldery, chaotic, blocky rubble; upper 2 to 3 feet (0.6-1 m) cemented by secondary calcium carbonate and silica; lobate deposit with hummocky and south-sloping surface; 60 feet (18m) exposed in gully; base covered; estimated thickness 6 to 80 feet (2-24 m) or more*

**Qmso** Old megaslide complex (upper middle Pleistocene)—*Complex of debris emplaced by landslides and Toreva rotational slumps, subordinate debris flows and rock falls; poorly consolidated mudstone and sandstone breccia derived from Petrified Forest Member and younger bedrock units; grain size is clay to huge blocks; hummocky, steeply to moderately sloping; estimated thickness 25 to 300 feet (8-91 m)*

**Jn** Navajo Sandstone (Lower Jurassic)—*Light-brown, very fine- to fine-grained, with minor medium-grained quartzose sandstone, weathers grayish orange pink; some frosted subangular to subrounded equant grains; firmly to weakly cemented by iron-oxide-stained calcium carbonate and silica; massive, with sweeping high-angle cross-beds in sets 10 to 30 feet (3-9 m) thick; imposing cliffs, rounded hills, ledges, sloping rock faces and knolls; incomplete exposed thickness about 1,350 feet (about 410 m)*

**Jk** Kayenta Formation (Lower Jurassic)—*Mudstone, siltstone, and sandstone; moderate reddish orange and pale red; very fine to fine-grained pinkish-gray sandstone is silty sublitharenite to subarkose, calcitic in places; sandstone beds are continuous to lenticular and exhibit small-scale trough cross-beds with medium-scale sets 3 to 6 feet (1-2 m) thick; also large-scale cross-beds; variegated mudstone forms earthy slopes; sparse, very thin micritic limestone beds near middle of unit; measured thickness 615 to 680 feet (190-207 m)*

Moenave Formation (Lower Jurassic)—*Consists of three members (descending): Springdale Sandstone, Whitmore Point Member and Dinosaur Canyon Member, the last two mapped as one unit*

**Jms** Springdale Sandstone Member --*Pale-red, very light-gray, light-brown, very fine to fine-grained sublitharenite to feldspathic litharenite; weathers light to reddish brown, grayish orange and grayish orange pink; locally also white to very light gray; makes persistent cliff about 110 feet (33 m) high; forms flaggy to blocky rubble; intraformational sandy mudstone and dolomite pebble conglomerate to pebbly, medium-grained sandstone; contains sparse silicified fossil logs; load casts in purple mudstone near base; thickness 128 to 176 feet (39-54 m)*

**Jmwd** Whitmore Point and Dinosaur Canyon Members--*Whitmore Point Member is variously light-colored, interbedded sandstone, siltstone, minor mudstone, and sparse thin limestone; viewed from afar, unit is a light-grayish and pinkish-gray slope; sparse Holostean fish scales, very dusky red; the member is 44 to 68 feet (13-21 m) thick. The "brick-red" (pale red and various reddish colors) Dinosaur Canyon Member is siltstone, mudstone, and silty, very fine-grained calcitic subarkose sandstone; trough cross-laminae; sparse thin interbed of micaceous soft shale; Dinosaur Canyon Member is 226 feet (69 m) thick*

Chinle Formation (Upper Triassic)—*Consists of two members, the Petrified Forest Member and the underlying Shinarump Member*

**Ŧcp** Petrified Forest Member--*Variegated claystone and few beds of very fine-grained gray sandstone; contains volcanic ash beds altered to bentonitic clay and multicolored chalcedony pieces 0.5 to 2 inches (1.2-5 cm) across; few thick, lenticular, cross-bedded channel-fill sandstone beds; chiefly floodplain deposits; common paleosols; forms badlands; landslide prone; 286 feet (87 m) exposed, but upper part covered; total thickness probably 390 feet (119 m)*

**Ŧcs** Shinarump Member--*Gray and grayish-orange, fine- to very coarse-grained sandstone, and granule to cobble conglomerate and conglomeratic sandstone; weathers pale grayish orange; well cemented; contains well-rounded clasts of sandstone, quartzite, chert and petrified wood pieces and logs; forms cliffs and cuestas; 111 to 119 feet (34-36 m) thick*

Moenkopi Formation (Middle? and Lower Triassic)--*Two members exposed in quadrangle, the entire upper red member and the upper part of Shnabkaib Member*

**Ŧmu** Upper red member (Middle? and Lower Triassic)--*Light-brown, dusky-red, pale-red, grayish-orange-pink and moderate-brown alternating gypsiferous siltstone, very fine-grained quartzose sandstone, clayey siltstone, and dark-reddish-brown ("chocolate"-colored) silty mudstone; thin-bedded to laminated; thin veins and veinlets of small selenite crystals common; 292 feet (89 m) thick*

**Ŧms** Shnabkaib Member (Lower Triassic)--*Grayish-orange-pink, gypsiferous siltstone alternating with light-brown and yellowish-gray crumbly mudstone which weathers to earthy slopes; exposed strata are about 20-60 feet (6-18 m) thick; the entire member is probably about 425 feet (130 m) thick in subsurface*

## MAP SYMBOLS

CONTACT--*dashed where approximate or inferred*

FAULT--*bar and ball on downthrown block; dotted where concealed, dashed where approximate or inferred, queried where uncertain. Arrow and number show dip of fault plane in degrees* (70)

LARGE TOREVA BLOCK OF NAVAJO SANDSTONE

SCARP --*head of landslide or slump; hachures point in direction of movement*

JOINT

LINEAR FEATURE OBSERVED ON AERIAL PHOTOGRAPHS--*may be fault or joint trace*

TOPS OF PROMINENT SANDSTONE BEDS--*in Kayenta Formation*

5500 STRUCTURE CONTOUR--*datum, top of Springdale Sandstone Member of Moenave Formation; extrapolated where land surface is below datum; contour interval 100 feet*

2.5 STRIKE AND DIP OF BEDS--*number is dip in degrees; calculated by computer-assisted photogrammetric methods on stereographic plotter*

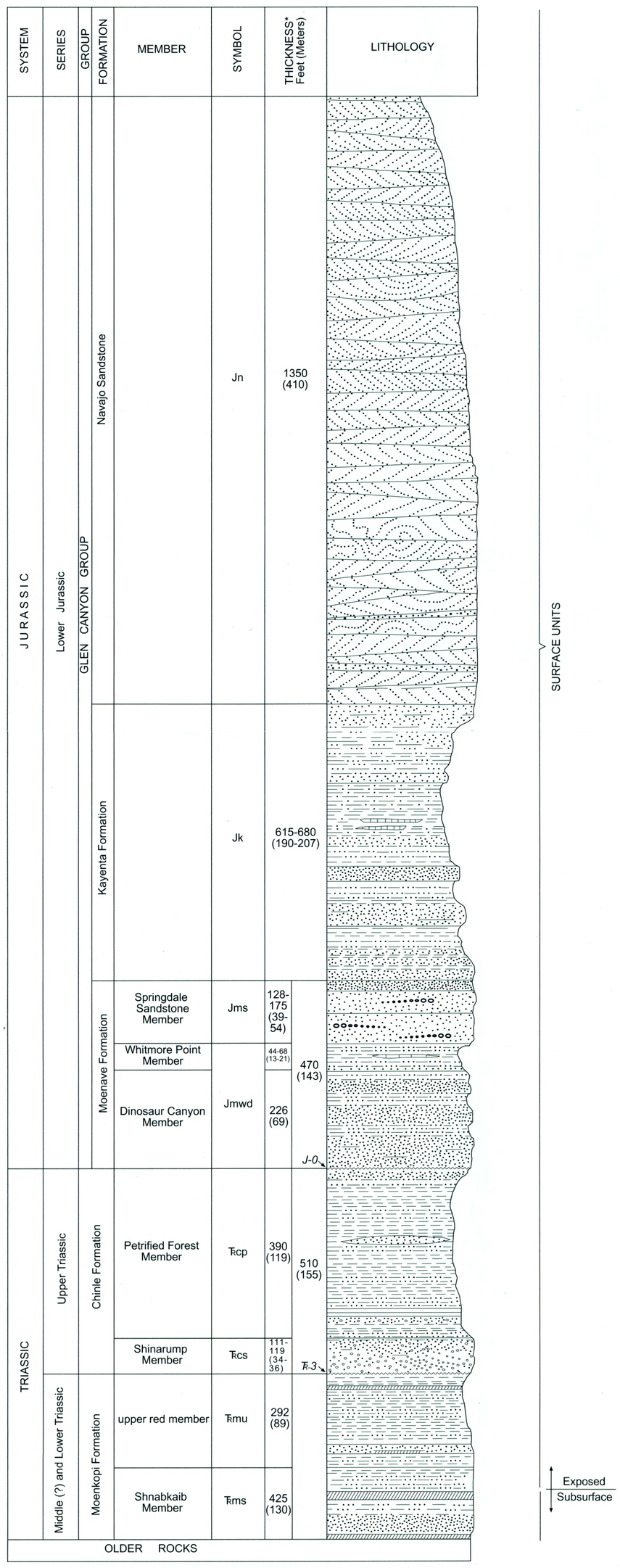
BORROW PIT

PROSPECT PIT

SAND AND GRAVEL PIT

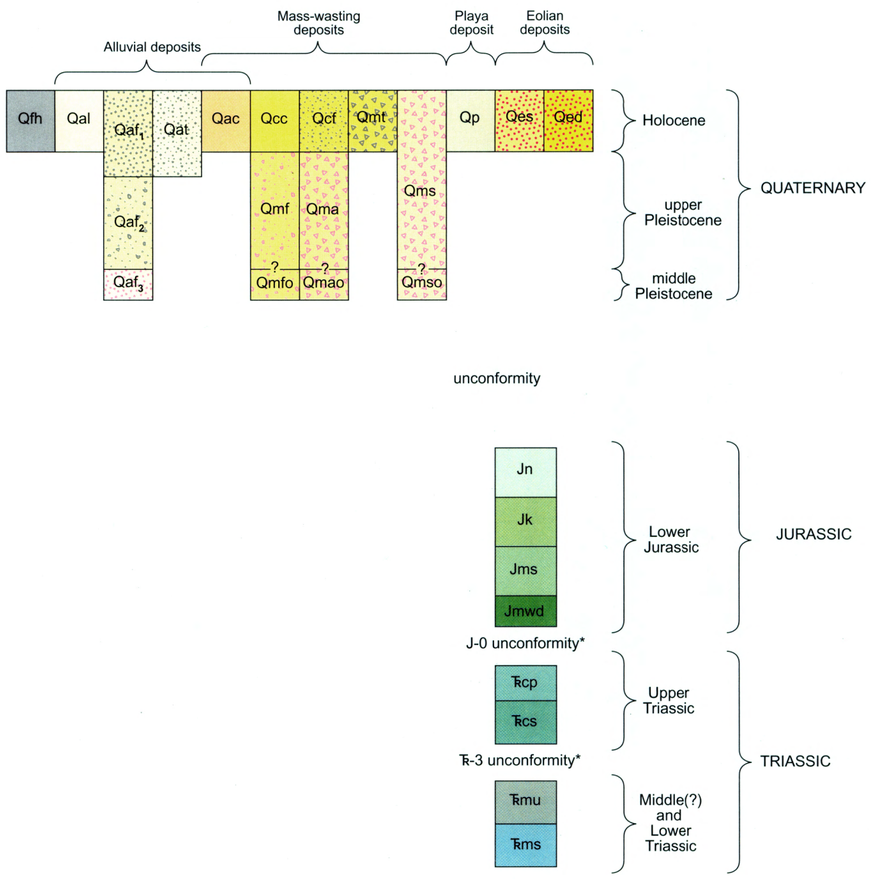
DRILL--PIPE CASING

MS-2A MEASURED SECTION




*Thickness not to scale

## CORRELATION OF MAP UNITS




*unconformity of Pipiringos and O'Sullivan (1978)