DEPARTMENT OF INTERIOR

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PRELIMINARY REPORT AND MAP OF THE GEOLOGY OF SMITHSONIAN BUTTE QUADRANGLE, WASHINGTON COUNTY, UTAH

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INTRODUCTION

Smithsonian Butte quadrangle is located in southwestern Utah at the north edge of the Uinkaret Plateau, 24 mi east of St. George in southeastern Washington County. Hildale, Utah, and Colorado City, Arizona, are located about 2 mi east and southeast of the southeast corner of the quadrangle. The south border of the quadrangle lies on the Utah-Arizona State line. The northeast corner of the quadrangle is about 6 mi south-southwest of the headquarters of Zion National Park.

Sedimentary rock strata in the quadrangle dip gently east and northeast. Subsurface strata in this region are more than 5,000 ft thick, according to Van Loenen and others (1988). The strata may be closer to 10,000 ft thick, assuming the local geology is like that 20 to 90 mi east where drill holes reveal subsurface information. We also assume that drill hole depth approximates true thickness of strata. Unfortunately, no wells are known in the Smithsonian Butte quadrangle (Thomas Chidsey, Utah Geological Survey, written commun., 1990). However, 20 mi east, the McDermott no. 1 State well penetrated 10,440 ft of Phanerozoic strata before hitting Precambrian rock (Tapp, 1963). Eighty-five miles east-northeast, two other wells penetrated about 10,000 ft of Paleozoic and Mesozoic strata (Doelling and others, 1989, p. 116).

This report describes only exposed bedrock strata and unconsolidated surficial deposits of Quaternary age in the quadrangle. The exposed strata are 2,600 ft thick and of Mesozoic age. From bottom to top, the sequence of exposed strata changes color and landform. However, similarities exist at certain levels in the sequence. These similarities, together with fossil assemblages, allow strata to be grouped into formations that are consistent from place to place in the quadrangle and surrounding region, which includes the Colorado Plateau and southern Basin and Range. In this region, some formations have yielded valuable mineral and energy resources. In the quadrangle, the same formations thus have economic potential of varying degrees (Van Loenen and others, 1988).

The most distinctive and youngest bedrock formation is the Navajo Sandstone. The Navajo is a thick sequence of conspicuously crossbedded quartz sand, which most workers believe was deposited in large dunes on a vast Jurassic desert. This lithified sand appears as stark tan and white sandstone cliffs high on the skyline, sculpted by recent erosion. The sandstone, much eroded, forms Smithsonian Butte itself. A few miles north, cliffs of the sandstone are the scenic marvel of Zion National Park.

Other stratigraphic formations in the quadrangle have different characteristics, age, and origin. These aspects will be described as a basis for understanding the rocks, their economic potential, and how they may affect engineering and other uses.

Streams in the quadrangle flow infrequently following intense precipitation. Horse Valley Wash near the north boundary of the map area was the only drainage observed to have a continuous, small flow sustained by springs. A few other small springs issue from the base of the Vermilion Cliffs. The nearest perennial stream is the Virgin River, two miles north of the quadrangle. Its tributaries cut numerous ravines in soft mudstone of the Chinle Formation low on the north slope of Smithsonian Butte, forming colorful "badlands". Extensive landsliding has occurred on this slope in recent geologic time and continues on a small scale in historic time. South of Smithsonian Butte and west of Canaan Mountain, sloping southwest from the base of the Vermilion Cliffs, is a broad plain, a bajada. This sloping plain formed by sporadic erosion and aggradation of ephemeral streams. Unlike the "badlands" north of Smithsonian Butte, the plain south of the butte receives much alluvium. It has been, and is presently, planed by streams shifting and cutting laterally across soft mudstone of the Chinle Formation. The streams deposit alluvial fans downslope, which build up and overlap, forming the bajada.

State Highway 59 crosses the bajada, in a northwest-southeast direction. The north part of the sloping bajada is labeled Big Plain on the map. A gravel road goes north from Highway 59 at Big Plain Junction and leaves the map area to cross the Virgin River about 6 mi north. The same road joins the town of Rockville to Highway 9, which is access to Springdale, Utah, and Zion National Park.

Land in the central and west parts of the quadrangle is privately owned, arid, and marginally suitable for grazing few livestock. About 6 to 10 residential dwellings are in the mapped area. The eastern third is public land. This part is bare or sparsely vegetated buttes and mesas. Here Smithsonian Butte and Canaan Mountain rise 1,500-2,200 ft above Big Plain.

METHODS AND ACKNOWLEDGMENTS

Conventional methods of geologic mapping were used in the field. Aerial photographs and topographic map (both having scale 1:24,000) were used as a base for locating and marking geologic contacts. Bedding attitude measurements made in the field were prone to error because beds are nearly horizontal. More reliable measurements were made and plotted on the geologic map using computer-assisted photogrammetric methods and stereographic plotter.

Charles Tabor and Brenda Buck, National Association of Geology Teachers Field Assistant appointees, helped with field work. Mr. Brooks Pace kindly allowed us on his land in Horse Valley. James Messerich set stereographic models and gave helpful instruction on photogrammetric methods. Van Williams reviewed the manuscript.

STRATIGRAPHY

MESOZOIC ROCKS

Strata of the following formations (ascending) are exposed: Moenkopi, Chinle, Moenave, Kayenta, and Navajo Sandstone.

TRIASSIC SYSTEM

MOENKOPI FORMATION (Lower and Middle (?) Triassic)

The Moenkopi Formation was named by Ward (1901) for rocks exposed at Moenkopi Wash, Grand Canyon, Arizona. Although the type section is in Arizona, the sections that are most nearly complete and serve as standards are in the Virgin River Valley (McKee, 1954), only 5 to 10 mi northwest of Smithsonian Butte. Reeside and Bassler (1922, p. 58) first named subdivisions of the formation; development of nomenclature is discussed by McKee (1954). The Moenkopi is chiefly red claystone and siltstone of continental origin. The formation is wedge-shaped across southern Utah, becoming 1,500-2,000 ft thick and including marine beds in western Utah nearest the axis of the early Triassic seaway. In the Zion Park region, the formation is 1,500-1,760 ft thick and six distinct subdivisions are present (Gregory, 1950, p. 52). Eastward it thins to tens or hundreds of feet near the Colorado-Utah boundary and the Arizona-New Mexico boundary farther south. Continental redbeds predominate along the east margin of the basin, an area that includes Smithsonian Butte quadrangle and southwest Utah.

About 310-330 ft of the uppermost Moenkopi Formation are exposed in the southwest corner of the quadrangle. Exposures are very steep sideslopes of a cuesta at the east end of Little Creek Mountain. The oldest exposed beds in the quadrangle are the uppermost beds of the Shnabkaib Member, which is the second youngest member of the Moenkopi Formation. The beds are 24 ft thick and are laminated and very thin bedded grayish orange pink (5YR 7/2) to moderate grayish red (10R 5/2) gypsiferous siltstone. The siltstone alternates with light-brown (5YR 6/4) and yellowish-gray soft crumbly mudstone, 9-12 ft thick, that weathers to earthy slopes. About 7 mi northwest of our section, Lambert (1984, p. 52) measured 425 ft for the Shnabkaib, a reasonable approximation for thickness of the member beneath the quadrangle.

The siltstone may contain numerous laminae of silty gypsum, pinkish gray (5YR 8/1), which break into large chips and flat pieces 0.2-0.5 in. thick. In places, siltstone ledges are as much as 3 ft thick. Small selenite crystals, wavy lamination 0.1-0.05 in thick, and small-scale oscillation ripples are common.

The youngest member of the Moenkopi Formation, informally called the upper red member, overlies the Shnabkaib and is 290 ft thick at a measured section 0.2 mi north of the Arizona state line in NE1/4 sec. 32, T. 43 S., R. 11 W. The upper red member is chiefly alternating gypsiferous siltstone, very fine grained sandstone, clayey siltstone and silty mudstone. As the name suggests, rocks are pale red (10R 6/2), although earthy slopes in the lower part are light brown (5YR 6/4). Other weathering colors are grayish orange pink (10R 8/2), moderate brown (5R 4/4), grayish red (10R 4/2), and dusky red (5R 3/4).

CHINLE FORMATION (Upper Triassic)

The Chinle Formation rests unconformably on the Moencopi. The Chinle Formation was defined by Gregory (1916) to include 400 to 1,000 ft of variegated shales with limestone conglomerate beds that overlie the Shinarump Conglomerate in Chinle Valley, northeastern Arizona. However, present definition of the formation, following Gregory and Williams (1947) includes a basal conglomerate, the Shinarump Member (formerly the Shinarump Conglomerate of Gilbert, 1875), together with the overlying variegated shales of the Petrified Forest Member.

The Shinarump Member is a remarkably continuous, resistant conglomeratic sandstone caprock which forms an east-sloping bench west of Highway 59. In the southwest corner of the quadrangle, it is part of Little Creek Mountain; in the northwest corner, it is part of Gooseberry Mesa; both mesas are largely west of the Smithsonian Butte quadrangle. The sandstone is very pale orange (10YR 8/2) and fine- to very coarse grained. It is well cemented by limonite-silica-clay and contains abundant rounded chert and quartzite pebbles. Bedding is locally large-scale trough crossbeds, but more commonly massive, 10- to 50-ft-thick beds composed of well-rounded chert pebbles, which were deposited in channels and on point bars of Late Triassic streams. Silicified logs are sparse to common. The Shinarump is 111 ft thick in the southwest corner of the quadrangle and 119 ft thick 1 mi north of the quadrangle at Horse Valley Wash.

The overlying Petrified Forest Member is a variegated claystone and mudstone. It is predominantly light gray (N7), pale red (10R 6/4), pale red purple (5RP 6/2), pale olive (10YR 6/2), light greenish gray (5G 8/1), and light bluish gray (5B 7/1). Sandstone beds are scarce and pinch out within hundreds of feet laterally. A 25-ft-thick, crossbedded fluvial sandstone bed crops out in the NE1/4 sec. 15, T. 43 S., R. 11 W. and another 15-ft-thick one crops out in Horse Valley Wash. At a measured section in the northwest corner of the quadrangle, NW1/4SW1/4NW1/4 sec. 21, T. 42 S., R. 11 W., the exposed Petrified Forest Member is 286 ft thick. However, the upper beds are covered by landslides and the member could be as thick as about 380 ft.

JURASSIC SYSTEM

MOENAVE FORMATION (Lower Jurassic ?)

The Moenave Formation was named by Harshbarger and others (1957) for outcrops on the Navajo Indian Reservation near Moenave, Arizona. In the Zion Park region, the Moenave Formation was previously included in the upper part of the Chinle Formation (Gregory, 1950, p. 67). In the Smithsonian Butte quadrangle three members were recognized, from lowest to highest: Dinosaur Canyon, Whitmore Point, and Springdale Sandstone. The Moenave is about 470 ft thick in the quadrangle.

The Dinosaur Canyon Member is 226 ft thick in the northwest corner of the quadrangle where it forms the lowest red beds on steep slopes below Smithsonian Butte. Farther southeast near Canaan Ranch and low on the Vermilion Cliffs, the unit erodes as ledges and slopes and small pediments between alluvial fans (unit Qaf2). The pediments are discontinuously covered by thin, scattered deposits of red-brown (5YR 5/4) to red (2.5YR 4/6) alluvial and eolian sand. The upper part of the member generally is interbedded moderate-reddish-brown (10R 4/6) very fine grained, soft sandstone, moderate-brown (5YR 4/4) siltstone, and mudstone. However, in the southeast corner of the quadrangle, the upper part is a massively bedded sandstone that forms a cliff 30 ft high.

The Whitmore Point Member is 68 ft thick at the north edge of the area; it thins to 44 ft in the southeast corner. It forms a gray earthy, sloping narrow bench above the Dinosaur Canyon Member. The Whitmore Point is interbedded very light gray (N8), pale-red (5R 6/2) and (10R 6/2), and yellowish-gray (5Y 8/1) very fine grained quartzose sandstone, siltstone, and subordinate mudstone. Sparse, brownish-black phosphatic scutes (about 0.5 in. across) of Mesozoic reptiles were collected from a fine sandstone.

The Springdale Sandstone Member makes a prominent cliff, 110-175 ft-high, which is light brown to reddish brown and low on the Vermilion Cliffs. The cliff is marked by huge subconchoidal fractures. The sandstone is tough, laterally continuous, pale red (10R 6/2) to very light gray (N8) fine-grained, quartzose, and is silty and finely micaceous in places. Sand of this unit was probably deposited by rivers on a broad alluvial plain. A fluvial origin is suggested by sparse thin interbeds of claystone granules and small pebbles, wavy laminations, fossil logs, and large-scale low-angle tabular cross-bedding.

KAYENTA FORMATION (Lower Jurassic?)

The Kayenta Formation is 616 ft thick at a measured section in the southeast corner of the quadrangle. It consists of a sequence of alternating very fine grained quartzose sandstone, siltstone, mudstone, and sparse, thin limestone. It forms a moderate-reddish-orange (10R 6/6) steep slope below vertical sandstone cliffs of the overlying Navajo Sandstone. The slope is interrupted in places by sandstone ledges. A cliff may form in the upper 50-70 ft of the Kayenta where hard sandstone beds occur. This cliff is continuous with the light brown cliff above, made of Navajo Sandstone. Pinkish-gray (5YR 8/1) (weathers brown) sandstone of the Kayenta is composed of very fine grained quartz sand, silty in places. It contains wavy laminations and sets of small-scale crossbeds 1-2 in. thick, probably formed in river floodplains or channels. One to two pinkish-gray (5YR 8/1) sandstone beds about 40 ft thick form vertical cliffs in the lower half of the Kayenta. Locally, sets of crossbeds are as much as 2 or 3 ft thick and may record alternating or simultaneous eolian and fluvial deposition of sand.

NAVAJO SANDSTONE (Lower Jurassic)

The youngest bedrock unit in the quadrangle is the crossbedded Navajo Sandstone which forms the striking, massive light-brown to pink, west-facing cliffs of Canaan Mountain, where the sandstone attains a maximum thickness of approximately 1,350 ft. Smithsonian Butte is an isolated erosional remnant of Navajo Sandstone, which is about 800 ft thick on the butte. Ten miles north in Zion Park, the Navajo is 1,500-1,800 ft thick in most places. The thickness of 2,280 ft at the Temple of Sinawava (Gregory 1950, p. 83) is the maximum reported thickness for southwestern Utah (Wilson and Stewart, 1976, p. 18).

Most cliffs of Navajo Sandstone are inaccessible. However, outcrops at the west end of Smithsonian Butte were climbed and the lower 175 ft of the unit was examined. This part is light brown (5YR 6/4) on a fresh surface, very fine to fine-grained quartzose sandstone that is moderately well sorted. It weathers to grayish orange pink (5YR 7/2) and is calcareous. Framework quartz grains are subrounded to subangular with 2-5 percent being well rounded, frosted, and medium sand size. About 2 percent of grains are white, opaque, blocky in shape and soft. These are probably weathered feldspar. It displays large-scale, tangential and tabular crossbeds, accentuated by spheroidal weathering on huge rounded ledges, knolls and moundlike outcrops. Large-scale sets of steeply inclined, sweeping crossbedding is characteristic here and elsewhere in southwest Utah. The crossbedding seen on cliff faces is the tangential and planar types. Visualized in three dimensions, the planar types are tabular or wedgelike.

Ten miles east, the Navajo has been subdivided vertically into three informal mapping units based on differences in color and bedding (Sable and Doelling, 1990). In the Smithsonian Butte quadrangle, no such systematic differences were apparent.

CENOZOIC ROCKS

QUATERNARY SYSTEM

Nineteen types of surficial deposits were recognized for mapping purposes. The deposits were distinguished according to characteristics that reflect kinds of deposition and differences in age. For example, fan alluvium is sediment that is deposited sporadically in stream channels on a fan-shaped aggradational slope. The fan shape is formed over geologic time by the shifting of channels (avulsion) across the slope.

Age recognition was the second part of classifying the deposits. This also was based on field criteria. For example, the land surfaces of two alluvial fan deposits may differ in height above modern streams, in soil development, and in erosion. They were inferred to have formed in relatively young or old Quaternary time accordingly. Greater height, erosion, and soil development indicate older age. This established method of classifying Quaternary deposits is based on principles of pedology, stratigraphy, and geomorphology (Morrison, 1967; Birkeland, 1974).

The surficial deposits are of four broad genetic types: alluvial, mass-wasting, eolian, and lacustrine. Alluvium is gravel, sand, and silt eroded from Mesozoic bedrock and carried westward or northwestward by streams. Sporadic cloudburst storms produce torrential runoff that transports detritus downslope in ephemeral channels like Gould Wash. A small portion of alluvium that was deposited on fans during the latest Tertiary Period or middle(?) Quaternary Period (units QTaf and Qaf2) subsequently has been eroded by streamflow. The sediment has been carried west by storm runoff and deposited as young fan alluvium (unit Qaf1) on the distal part of old fans (unit Qaf2). All fan alluvium thins westward from many tens of feet to less than 2 ft thick near its edge where it veneers variegated claystone of the Chinle Formation (unit TRcp), but was not mapped. In places, fine detritus is deposited by water that flows as sheets and in small rills rather than in channels. This type of alluvium, slopewash (unit Qac), is finer grained, more laminar, and has nearer source rock than fan alluvium.

Mass-wasting (gravity) deposits are soil and rock debris emplaced directly by the force of gravity. These nonsorted, nonstratified deposits remain on steep slopes until further disintegration reduces the debris to grain sizes that wind or running water can transport. Generally, gravity deposits are smaller areally but more massive than the sheetlike alluvium. Mass-wasting deposits include landslide debris (units Qms, QTms), talus (unit Qmt), fine-grained colluvium (unit Qcf) and gravelly colluvium (unit Qcg), debris flow deposits (units Qmf, QTmf), and rock avalanches (units Qma, QTma). Landslide deposits are bulky masses of unsorted debris ranging from clay to huge blocks. They develop on steep slopes, especially on north-facing ones underlain by mudstone where soil moisture levels are presumed high. Two types of landslide debris exist: slumps and rotational (toreva) blocks of strata. Slumps are mixed and deformed soil and rock debris having hummocky, profiles that bulge downslope. Upslope, pull-away scarps may develop. Toreva blocks are relatively coherent blocks of strata, usually the lowest 100 ft of the Dinosaur Canyon Member, that dip about 30-50° back toward the Vermilion cliffs from which they broke away. Talus is piles of angular blocky rock debris fallen from ledges and cliffs. Colluvium is finer than talus and it may include water-transported sand, silt, and fine gravel.

Two comparatively scarce types of gravity deposits, both sedimentary breccia, were emplaced by debris flow and rock avalanche events. Times of emplacement are only roughly known to be younger than the relatively old alluvial fan (QTaf) on which they rest near the center of the quadrangle (secs. 14, 15, T. 43 S., R. 11 W.). The age of the fan itself is conjectural. Our interpretation of origin the breccia is based on their chaotic internal structure, lobate landform, and south-sloping surface that approximately matches that of the underlying alluvial fan and erosional surface (pediment?) cut on claystone of the Chinle Formation. The debris flow deposits are unsorted, massive to crudely bedded, and sheetlike. The debris is chiefly variegated claystone clasts of the Chinle Formation supported in a mixed clay and fine mudstone debris matrix. The rock avalanche deposits are tabular sandstone breccia (small boulder to car-sized clasts), clast-supported, and composed chiefly of Navajo Sandstone and some red-brown sandstone (Kayenta?) pieces cemented by a silica-calcium carbonate(?) compound. Avalanche deposits seem to have been emplaced more than once when voluminous masses of sandstone fell from cliffs, disintegrated, and the debris spread very rapidly over the upper part of an alluvial fan.

Windblown sand (unit Qes) forms discontinuous, thin (less than 4 ft) sheets in places. Granular disintegration of Navajo Sandstone blocks in landslides and talus probably provides the source of the sand. The eolian sand commonly forms "ramps" consisting of a veneer 1-3 feet thick on steeply sloping talus. Ramps were mapped as unit Qed as was sand on fans where small dunes are present.

Lacustrine deposits are minor in the area. Laminated clay that accumulated in small, ephemeral lakes (playas) was mapped as playa clay (unit Qlc).

STRUCTURE

Strata dip east and northeast 1-3°. Aside from a fault at Grafton Wash, the rocks have been little disrupted; no folding was apparent. About 2 mi north of the quadrangle near Grafton, Gregory (1950, p. 148) noted a low anticlinal fold. Two major regional faults lie west and east of the quadrangle. Eleven miles west is the north-trending Hurricane Fault, which is the boundary between the structurally high Colorado Plateaus and the structurally low Basin and Range province. Tectonic uplift of the crustal block east of the fault, which includes the Smithsonian Butte quadrangle in the High Plateaus region, is thousands of feet (about 8,000 ft according to Threet, 1963 p. 104) relative to rocks west of the fault. Sixteen miles east of Smithsonian Butte, is the second major fault. The Sevier Fault, like the Hurricane Fault, is north-trending and downdropped on the west side, but offset is less. These faults are discussed by others (Gardner, 1941; Gregory, 1950, p. 143; Threet, 1963). Thus the Smithsonian Butte quadrangle is part of a huge uplifted block, 27 mi across east-to-west, bounded on the west and east by major normal faults.

In the northwest corner of the quadrangle at Grafton Wash, a fault that displaces bedding about 250 ft is notable. The trace of this fault lies about 1 mi west of the southward extension of the trace of the West Cougar Mountain Fault mapped by Hamilton (1984) north of the Virgin River. Like the Hurricane, Sevier, and Cougar Mountain Faults, it strikes approximately north and is apparently a dip-slip normal fault. The fault plane strikes N 10-15° E and dips 70° W. West of the fault, beds of the Petrified Forest Member of the Chinle Formation dip 10° E and are faulted down against the Shinarump Member, which caps a west-facing fault scarp. The fault extends 2.7 mi north along Grafton Mesa to the Virgin River, where the offset is less than 50 ft. About 2.5 mi NNE of the Smithsonian Butte quadrangle in Zion National Park, a north-to-northwest-striking fault and small anticline (Grafton anticline) was mapped in Scoggins and Coalpits Wash and near Cougar Mountain by Gregory (1950) and Hamilton (1984). The West Cougar Mountain Fault continues NNW at least another 8 mi. The unnamed fault at Grafton Wash in the Smithsonian Butte quadrangle bears an en echelon spatial relation to the West Cougar Mountain Fault within a single north-trending fault zone. South of Grafton Wash and farther into the quadrangle, the fault was not seen. However, we believe that the fault may offset bedrock under the alluvial cover for a mile or two south of Grafton Wash.

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DESCRIPTION OF MAP UNITS

All colors use the Munsell system based on matches to color chips appearing in the Rock-Color Chart (distributed by Geological Society of America) and loose-leaf notebook (distributed by the Munsell Color Company, Inc., Baltimore, MD). Where the base of a deposit was covered, thickness is approximate. Unconsolidated surficial deposits less than about 2 ft thick were not mapped.

UNCONSOLIDATED SURFICIAL DEPOSITS

Qal **Alluvium (Holocene)**--Reddish-brown, to reddish-yellow, very fine sand and pale-brown, coarse quartz sand containing common pebbles, few cobbles, and scarce boulders of sandstone and quartzite. In Little Creek, clasts and pale-brown sand derived from the Shinarump Sandstone. In Gould Wash and west-flowing ephemeral stream channels, chiefly reddish-brown, pebbly very fine to fine sand. Distinctly stratified and individual beds moderately well sorted. Grades downslope into Qac and Qaf1 deposits. 9-12 ft thick

Qaf1 **Young fan alluvium (Holocene)**--Silt, sand, and gravel; reddish-brown to reddish-yellow. Similar to Qal except distributed on broad, west-sloping, fan-like surfaces. Crudely bedded; bedding dips mainly west, south, and between at 1 to 4 degrees. Clasts chiefly pebbles and cobbles of sandstone. Becomes finer grained downslope. 2-15 ft thick

Qac **Alluvium and colluvium (Holocene)**--Chiefly reddish-brown, silty and clayey fine to very fine quartz sand; locally coarse sand; scarce lenses of sandstone pebbles. Deposited chiefly by sheetwash on surfaces that slope gently toward ephemeral stream channels. Deposit interfingers with channel and floodplain alluvium. Thin (1-3 ft) near the distal edge of alluvial fans where it tapers to a few inches on weathered claystone of Chinle Formation. Greatest accumulation downslope from erosive siltstones and mudstones of the Moenkopi Formation west of Canaan Gap where it is 10-35 ft thick. Water wells west of quadrangle indicate thickness may exceed 50 ft there

Qcg **Coarse colluvium (Holocene)**--Coarse rubble, chiefly sandstone, mixed with subordinate sand and finer debris. Red to yellowish red where debris is derived from Dinosaur Canyon Member of Moenave Formation and pale red where debris is Springdale Sandstone. Contains significant sand, silt, and clay resulting from in situ disintegration of sandstone debris at base of cliffs and on steep hillslopes. Includes some talus that does not form distinct talus cones. 2-40 ft thick

Qcf **Fine colluvium (Holocene)**--Quartz sand and pebble-sized sandstone gravel resulting from granular disintegration of Navajo Sandstone rubble that was emplaced by rockfall avalanche (unit Qma) on a west-sloping alluvial fan on the border of secs. 14 and 15, T. 43 S., R. 11 W. Appears to have been transported a few tens of feet downslope by creep, slopewash, and minimally by wind. estimated thickness 0.5-2 ft

Qlc **Playa clay (Holocene)**--Light-brown, silty clay with very thin beds of sandstone pebbles, cobbles, and scarce small boulders washed in from adjoining channels by torrential runoff. Very thinly laminated, soft. Interfingers laterally with sandy distal fan alluvium. Estimated thickness 3-8 ft

Qes **Eolian sand, sheet flow deposits, and residuum, undivided (Holocene)**--Sand, fine- to medium-grained quartz; light brown, orange, pink, and yellowish-gray; loose veneer of mostly stabilized sheet sand and irregular fillings of bedrock hollows and intermittent drainages in lowland areas and on mesas and buttes. Grades downslope to alluvium. Locally includes small outcrops of bedrock. Generally 1-4 ft thick; about 2-6 ft thick at head of Horse Valley Wash

Qed **Eolian sand in dunes and ramps (Holocene)**--Sand as above chiefly as ramps and aprons flanking cliffs and steep slopes and grading downslope to unit Qes. 2-6 ft thick

Qea **Eolian sand, reworked by slopewash (Holocene)**--Sand as above chiefly on surfaces of alluvial deposits. 1-3 ft thick

Qat **Terrace alluvium (Holocene to Late Pleistocene)**--Silt, sand, and gravel similar to Qal except occurs as sheets in former channels and on floodplains of streams, at levels 6 or more ft higher than modern channels. 2-4 ft thick

Qmt **Talus (Holocene to Late Pleistocene)**--Blocky debris, chiefly brown, pink, and reddish-brown sandstone, that forms steep cone-like deposits on steep slopes below cliffs. 2-12 ft thick

Qms **Landslide debris (Holocene to Middle Pleistocene?)**--Heterogeneous mix of fine matrix and clasts; matrix is clay- to sand-size and clasts of sandstone range from granule size to blocks of strata as large as 500 ft long; strata in blocks are breccia in places, relatively coherent elsewhere; debris contains coarse colluvium (Qcg), uniformly admixed or local masses too small and numerous to map separately. Debris is prevalent along northern border of the quadrangle, where headward erosion by drainages of the nearby Virgin River has oversteepened hillslopes; some rotated bedrock blocks (toreva blocks) break older pediment surfaces. Toreva blocks of Dinosaur Canyon Member beds appear active, that is, are sporadically slipping by small increments on claystone beds in upper 50-100 ft of the Petrified Forest Member of the Chinle Formation. Estimated maximum thickness of unit more than 100 ft

Qaf2 **Old fan alluvium (Late to Middle Pleistocene?)**--Silt, sand, and gravel, mostly reddish-orange to reddish-brown very fine to fine quartz sand, less medium quartz sand; subangular to subround sandstone pebbles, cobbles, and small boulders in abandoned channels form erosional hillocks on surface; surface veneered chiefly by very fine quartz sand reworked by wind and sheetflow; deposits are gently convex-up and slope toward lowlands, fanlike. Well-developed A/C horizon soil profile, and locally, reddish-brown Bt horizon 6-10 in thick, weakly developed in upper 3 ft. Alluvium is being eroded by modern stream channels. Holocene fan alluvium (Qaf1) accumulates in places on distal parts of the old fans. About 1-2 ft thick at the distal edge; estimated as thick as 50 ft at upslope end

Qmf **Debris flow deposits (Late to Middle Pleistocene?)**--Unsorted, non-bedded clay, silt, sand, and blocky rubble of sandstone derived from formations of Mesozoic age. Thickest on apex of alluvial fans at base of cliffs. Estimated 4-20 ft thick

Qma **Rockfall avalanche deposit (Late to Middle Pleistocene?)**--Coarse angular sandstone fragments that have decomposed to varying degrees to sand. Forms a linear, half-mile-long, south-sloping low rounded ridge on the surface of an old fan in NW 1/4 of sec. 14, T. 43 S., R. 11 W. Rock debris appears to have fallen from cliff of Navajo Sandstone and Kayenta Formation when cliff was perhaps 1/2 mi farther south than its present location. Thickness about 5-15 ft

QTaf **Older fan alluvium (Early Pleistocene to Late Tertiary?)**--Silt, sand, and gravel. Same as Qaf1 and Qaf2 except forms rounded, eroded low hills that stand about 15 to 25 ft above the general level of Qaf2. At its surface is a well developed soil profile having a reddish-brown (5 YR 6/4), very fine sandy B horizon, and a pink (5 YR 7/4), 2 to 3 ft-thick calcareous sandy C horizon. Sand and gravel beds lenticular with cut-and-fill geometry. Mostly mid-fan and lower fan facies preserved, but in SW 1/4 sec. 11, T. 42 S., R. 11 W., a bouldery, proximal facies is preserved. Estimated 10-25 ft thick

QTmf **Old debris flow (Early Pleistocene to Late Tertiary?)**--Weathered mudstone and sandstone blocky debris, chaotic; parts contain Kayenta reddish-brown sandstone and other parts are chiefly a mix of angular debris composed of variegated mudstone of the Petrified Forest Member of the Chinle Formation. Thins downslope and has lobate morphology. Estimated maximum thickness 25 ft, thinning at edges to 1 to 2 ft

QTma **Old rockfall avalanche deposit (Early Pleistocene to Late Tertiary?)**--Weathered rubble of Navajo Sandstone and sandstone of the Kayenta Formation. Clasts range in size from a 0.5 in. to car size; most clasts are boulder-sized; chaotic blocky rubble that is cemented by calcium carbonate in the upper 3 to 4 ft, forming a resistant caprock. Surface has large-scale hummocky form and slopes south; deposit has a lobate shape on map. Estimated 6-50 ft thick

QTms **Megaslide complex (Early Pleistocene to Late Tertiary?)**--Large complex jumble of old deposits emplaced by landslides, rockfalls, debris flows, and toreva rotational slumps composed of debris derived from the Petrified Forest Member of Chinle Formation, Moenave and Kayenta Formations, and the Navajo Sandstone. Area of combined QTms, QTma, and QTmf materials is 0.71 mi^2 (measured by planimeter). Hummocky, steeply to moderately sloping. In places, beds of formations are in stratigraphic order, but are rotated to dips of 50 to 70° and broken up in varying degrees. Elsewhere, a chaotic mix of rubble derived from different formations is seen. A few steeply dipping normal faults cut the complex in places. Debris ranges from clay to huge blocks hundreds of feet long. The slide appears to rest on an old alluvial fan in places and on claystone of the Petrified Forest Member of the Chinle Formation. Deep ravines and small canyons are eroded between the megaslide complex and the bedrock source rocks. The erosion of the complex, its location far from modern cliffs of bedrock, and its height above modern streams suggest that the megaslide is relatively old. Thickness estimated 25-400 ft

CONSOLIDATED ROCK UNITS

Jn **Navajo Sandstone (Lower Jurassic)**--Sandstone, quartzose, mostly fine- to medium-grained; light-brown on fresh surface, weathers grayish orange pink; frosted subangular to subrounded equant grains with calcareous, siliceous, or iron-oxide cement; massive, with sweeping high-angle crossbeds in sets 10 to 30 feet thick; steep-sided cliffs to rounded hills, ledges, sloping rock faces and knolls. Incomplete exposed thickness about 1,350 feet

Jk **Kayenta Formation (Lower Jurassic?)**--Siltstone, mudstone, sandstone, and shale; reddish-orange to pale-red; sandstone is quartzose in composition and is silty and very fine grained. Bedding is generally lenticular, some thick sandstone units contain sets of trough crossbeds. Variegated mudstones form earthy slopes. Two to three sandstones 20-40 ft thick occur in lower half of formation; they persist a few miles, but not across entire quadrangle; a gray, quartzose sandstone, about in middle of formation is highly crossbedded, may be of mixed eolian-fluvial origin, and may represent the Lamb Point Tongue of the Navajo Sandstone. Formation measured 616 ft thick at Smithsonian Butte, 696 ft thick at southeast corner of quadrangle

Moenave Formation (Lower Jurassic?)--Consists of three members (descending): Springdale Sandstone, Whitmore Point, and Dinosaur Canyon, the latter two combined as one map unit

Jms **Springdale Sandstone**--Pale-red, light-brown very fine grained quartzose sandstone; weathers grayish orange and grayish-orange pink; locally also white to very light gray, weathers light-brown. White kaolin and silica(?)-cemented spherical nodules 0.08-0.16 in diameter form abundant bumps on weathered surface; notably uniform parallel, planar laminations and very thin beds, some wavy, 0.5-3 in. thick; locally crossbedded and penecontemporaneous deformation structures; flaggy to blocky rubble. Intraformational sandy mudstone fine pebble conglomerate to pebbly, medium-grained sandstone. Contains sparse silicified fossil logs. Dolomite pebble conglomerate in fine quartz sand matrix 85 ft above base; load casts in purple mudstone near base. Forms persistent cliff throughout mapped area. Measured 175.5 ft thick at west end of Smithsonian Butte and 126 ft in southeast corner of quadrangle

Jmwd **Whitmore Point and Dinosaur Canyon Members**--Whitmore Point Member is interbedded gray to brownish-red siltstone, pale-red quartzose sandstone, minor pale-red sandstone claystone, and mudstone; sandstone is thin-bedded, contains scarce lenses of coarse sand and subfissile mudstone; Whitmore Point Member is 68-44 ft thick. Forms sloping bench at foot of Springdale Sandstone cliff. Dinosaur Canyon Member is reddish-brown to reddish-orange siltstone and mudstone and silty, very fine grained quartzose sandstone. Small, thin patches of eolian and alluvial sand, too small to show on map, discontinuously cover the outcrop at foot of cliffs. Dinosaur Canyon Member measured 226 ft thick at west end of Smithsonian Butte and 145 ft (partly eroded) in southeast corner of quadrangle

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

TRcp **Petrified Forest Member**--Variegated claystone and clay and subordinate sandstone. Contains volcanic ash beds altered to clay; in a few places contains scarce varicolored chalcedony (?) that accumulates as a surficial lag of small angular pieces; few lenticular, crossbedded channel-fill gray sandstone beds. In Virgin River drainage basin, forms badlands, rilled earthy slopes that are prone to landsliding; many landslides (Qms) in north part of quadrangle, an alluvium-mantled bajada in central and southeast part. Exposed beds measured 286 ft thick at west end of Smithsonian Butte, but upper part covered; member estimated to be about 380 ft thick

TRcs **Shinarump Member**--Gray to pale grayish-orange, fine- to very coarse grained sandstone and granule to cobble conglomerate and conglomeratic sandstone; contains well-rounded clasts of resistant silicic rocks, especially hard sandstone and quartzite. Contains petrified wood. Forms resistant caprock and cuesta in west part of quadrangle. 111 ft thick

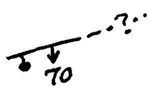
Moenkopi Formation (Lower and Middle? Triassic)--Two members exposed in quadrangle, the entire upper red member and the upper 20-60 ft of the Shnabkaib Member

TRmu **Upper red member**--Light-brown, dusky-red, pale-red, grayish-orange-pink, and moderate-brown alternating gypsiferous siltstone, very fine grained quartzose sandstone, clayey siltstone, and silty mudstone; thin-bedded to laminated; thin veins and veinlets of small selenite crystals common

TRms **Shnabkaib Member**--Grayish-orange-pink gypsiferous siltstone alternating with light-brown and yellowish-gray soft crumbly mudstone that weathers to earthy slopes. Exposed strata are about 20-60 ft thick, but the entire member is probably about 425 ft thick

MAP SYMBOLS

CONTACT--dashed where approximate or inferred

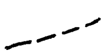


FAULT--bar and ball on downthrown block; dotted where concealed, dashed where approximate or inferred, queried where uncertain. Arrow and number show dip of fault plane in degrees

LARGE MOVED BLOCK OF NAVAJO SANDSTONE

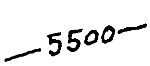
SCARP--at head of landslide or slump

JOINT



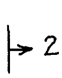
LINEAR FEATURE OBSERVED ON AERIAL PHOTOGRAPHS--may be fault or joint trace

TOPS OF PROMINENT SANDSTONE--In Kayenta Formation, may be distal part of Lamb Point Tongue

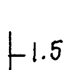


STRUCTURE CONTOUR--Datum, top of Springdale Sandstone Member of Moenave Formation; extrapolated where land surface is below datum; contour interval 100 feet

STRIKE AND DIP OF BEDS--number is dip in degrees



Calculated from aerial photograph measurements using three-point method



Calculated by computer-assisted photogrammetric methods on stereographic plotter

	BORROW PIT
	PROSPECT PIT
fh	**HIGHWAY FILL**
	SAND AND GRAVEL PIT

CORRELATION OF MAP UNITS