DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

Geologic map of the Jumpup Canyon and Big Springs Quadrangles, Mohave and Coconino Counties, Arizona.

by

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LIST OF FIGURES

INTRODUCTION

The Jumpup Canyon and Big Springs quadrangles together encompass approximately 476 square miles of the southern Colorado Plateau. The map area is about 6 mi north of the Colorado River of central Grand Canyon, and about 10 mi south of Fredonia, Arizona (fig. 1). Altitudes range from about 3,080 to 8,560 ft above sea level. The mapped area is entirely within federally managed land: the Kanab Creek and Kanab Canyon Roadless areas lie within the Grand Canyon Game Preserve of the Kaibab National Forest in the eastern two-thirds of the map area; the Bureau of Land Management lands comprise the western third and extreme northern part of map area (fig. 1).

Part of the area was previously mapped by Billingsley and others (1983). The ares is covered by State geologic maps at scales of 1:500,000 (Wilson and others, 1969) and 1:1,000,000 (Reynolds S.J., 1988).

GEOLOGIC SETTING

The map area can be divided into three geomorphic subprovinces: the Kanab Plateau, Kaibab Plateau, and Grand Canyon (fig. 2; Billingsley and Hendricks, 1989). Kanab Plateau is a relatively flat tableland averaging about 5,000 ft in elevation but gradually rising to an average elevation of about 6,300 ft near its eastern boundary along the Muav and Big Springs faults. The Muav fault is the main boundary between the Kanab and Kaibab Plateaus in the southeastern two-thirds of the map area. It merges with and becomes the Big Springs fault near the northern part of the map (fig. 2).

The Kaibab and Kanab Plateaus are underlain by gently dipping Paleozoic strata. The Paleozoic strata dip about 2° to the west on the Kaibab Plateau which is at elevations of 7,200 to 8,400 ft. The regional 2° dip to the west continues into strata of the eastern part of Kanab Plateau but beds are nearly horizontal elsewhere.

The Kanab Plateau is dissected by Kanab Creek, a deeply incised northern tributary to the Colorado River and is the boundary between Mohave and Coconino Counties (fig. 2). Kanab Canyon and its tributary canyons are part of the Grand Canyon geomorphic province, which is separated from the Kanab Plateau by an arbitrary topographic boundary along the canyon rims.

The Canyon of Kanab Creek and its tributaries exposes more than 2,500 ft of Paleozoic strata of Upper Mississippian to Lower Permian age. The Paleozoic rock units exposed are, in ascending order: the Redwall Limestone (Lower and Upper Mississippian); the Supai Group, including the Watahomigi, Manakacha, and Wescogame Formations undivided (Lower, Middle, and Upper Pennsylvanian); the Esplanade Sandstone, Hermit Shale, Coconino Sandstone, Toroweap Formation, and Kaibab Formation (Lower Permian; fig. 3). These units were deposited on a continental shelf area between highland regions to the east and deeper basin regions to the west.

Approximately 200 ft of the upper Redwall Limestone (Mooney Falls and Horseshoe Mesa Members) is exposed in lower Kanab Creek. The Redwall is a gray marine limestone that is typically cliff-forming. An erosional surface with about 10 ft of relief marks the unconformity between the Redwall Limestone and overlying Supai Group. The erosional surface is overlain by light purple mudstone and minor conglomerate of the Supai. At this erosional boundary, the Surprise Canyon Formation (Upper Mississippian) crops out discontinuously in the Grand Canyon just south of the map area, but not within it.

The lower three Pennsylvanian units of the Supai Group, the Watahomigi (bottom), Manakacha (middle), and Wescogame (top) Formations, are not mapped separately because it is difficult to distinguish mappable boundaries between them. These formations consist of a sequence of interbedded pale red sandstone, red, light-purple, and gray shale and mudstone, yellow calcareous sandstone, pale-red sandy dolomite, and some thin gray limestones, all forming a staircase

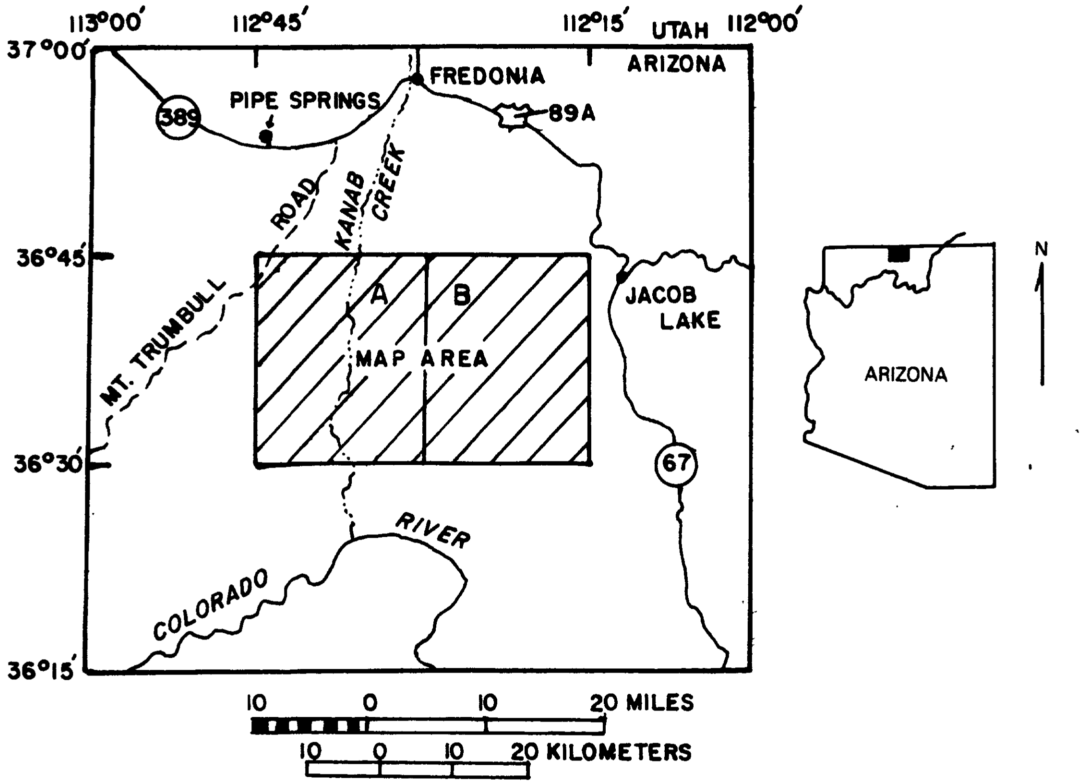

Figure 1. Location map of the Jumpup Canyon (A) and Big Springs (B) 15 minute quadrangles, Mohave and Coconino Counties, Arizona.

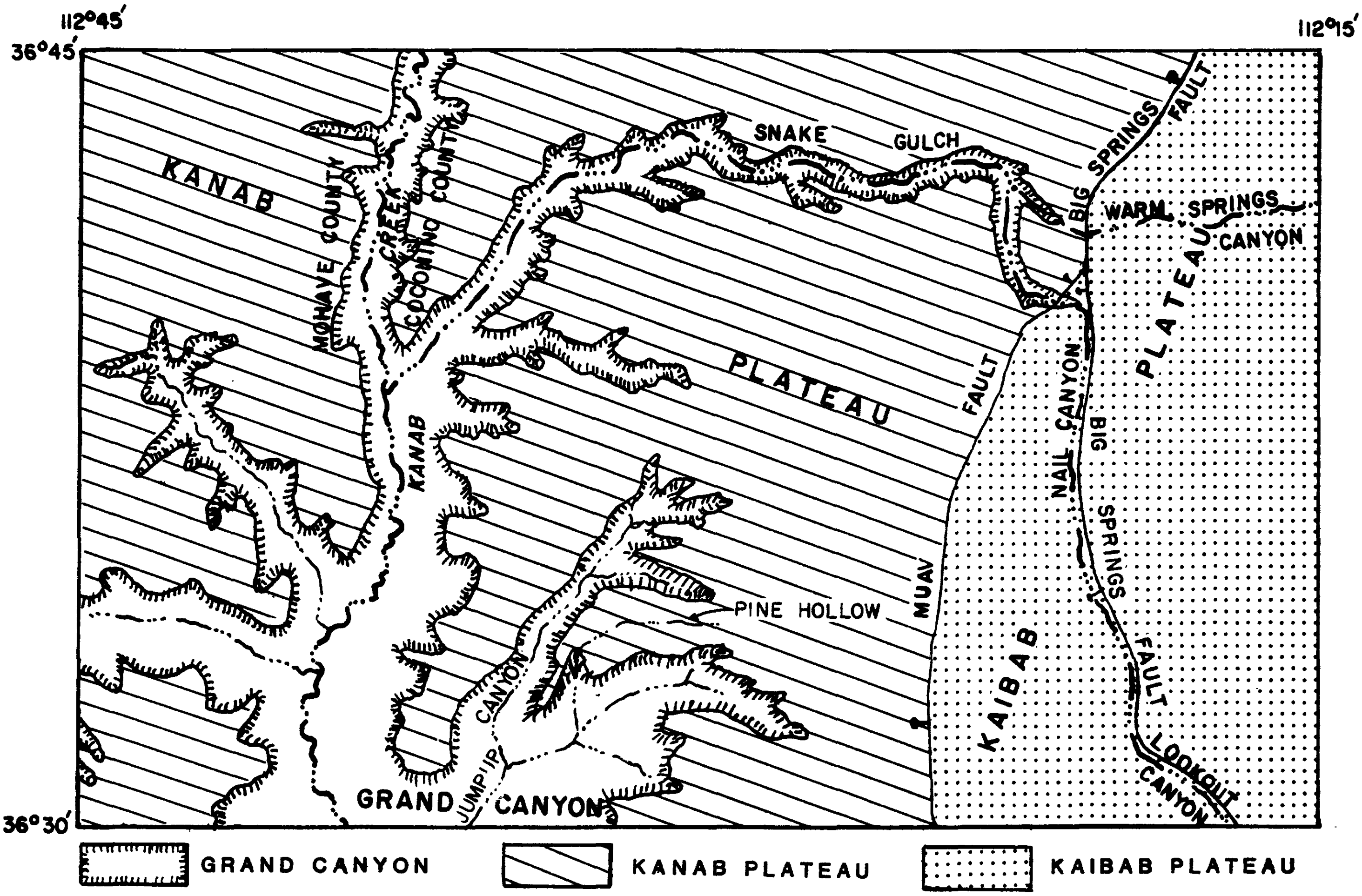

Figure 2. Map showing geomorphic subprovinces of the Jumpup Canyon and Big Springs quadrangles, Mohave and Coconino Counties, Arizona.

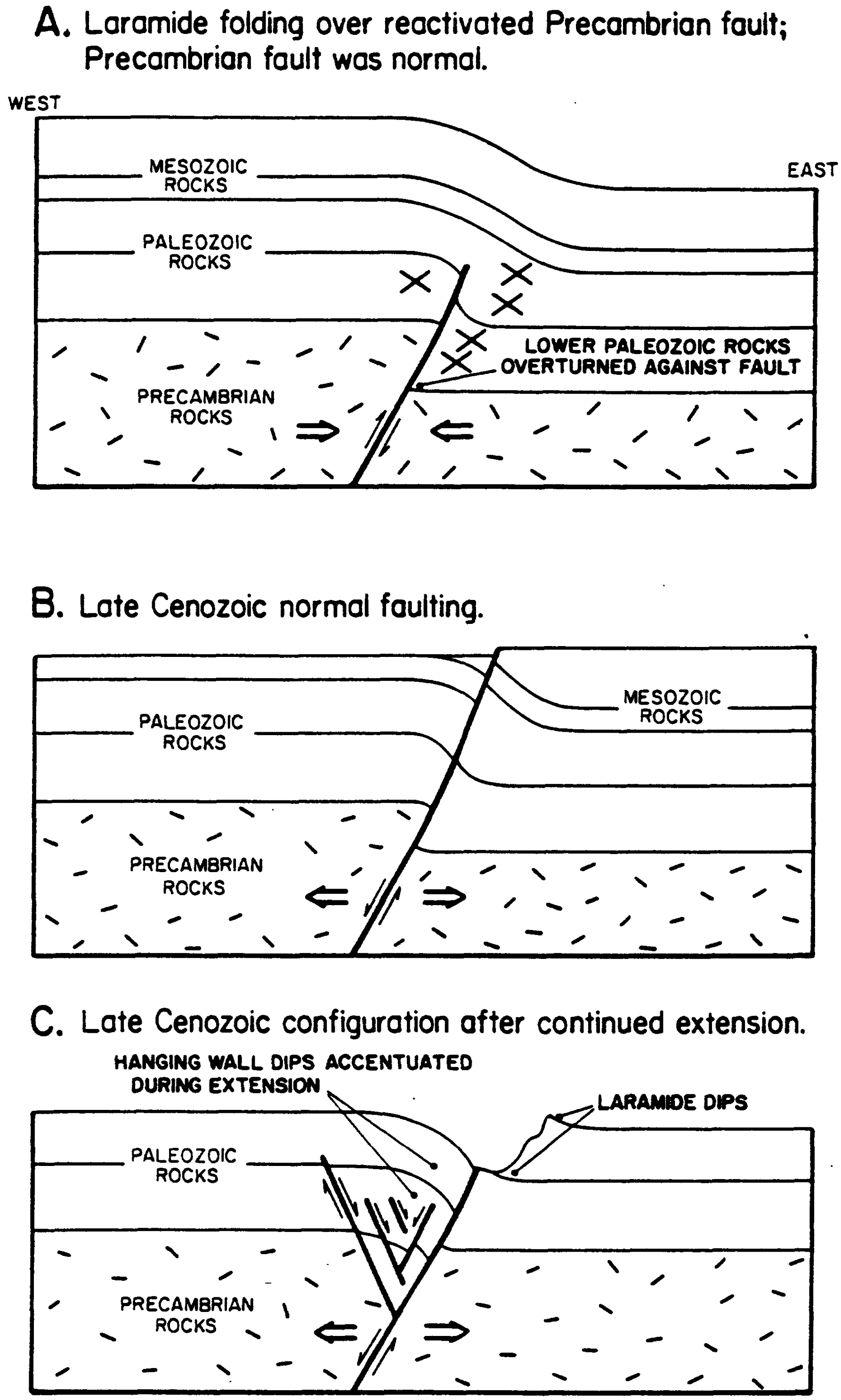

Figure 3. Stages in the development of a typical north-trending monocline-fault zone, Grand Canyon region, Arizona (Huntoon, 1989, p. 80).

sequence of reddish ledges and slopes representing shallow marine and coastal environments.

An erosional unconformity with relief as great as 15 ft marks the Pennsylvanian-Permian boundary and the contact between the Wescogame Formation and Esplanade Sandstone. This unconformity can be located in a slope unit of red shale about 50 ft below the Esplanade Sandstone cliff, commonly marked by a thin gray, limestone-pebble conglomerate.

The Esplanade Sandstone (Lower Permian), is the fourth and uppermost unit of the Supai Group and basically represents a coastal marine and near- shore environment. The Esplanade is easily distinguishable in the field because it forms a cliff and persistent prominent topographic bench or platform called the "The Esplanade" in the lower reaches of Kanab Canyon and its tributaries. It is mapped separately because of the clearly defined upper and lower boundaries.

An erosional surface with relief of as much as 80 ft marks the unconformity between the Esplanade Sandstone and overlying Hermit Shale. The Hermit fills erosional valleys cut into the Esplanade and is easily removed by present day erosion. The removal of Hermit from these valleys exposes a sinuous, incised drainage pattern on the Esplanade surface which eventually becomes part of some modern-day tributary canyons to Kanab Creek. The bright red, slope-forming siltstone and sandstone of the Hermit represents a coastal tidal and river floodplain environment and is commonly mantled with thick talus deposits. The contact of the Hermit with the overlying Coconino Sandstone is a distinctive sharp and planar erosion surface. Large tension cracks that extend into the Hermit are filled with Coconino sand.

The Coconino Sandstone is present only in the southern two-thirds of the map area and pinches out to the north. Where the Coconino is absent, the Hermit Shale is in planar erosional contact with the Toroweap Formation. In either case, the boundary is marked by a distinctive color change from red Hermit to yellow and tan Toroweap or Coconino. The frosted, rounded quartz sand of the Coconino suggests an eolian, near-coastal environment.

The Toroweap Formation is subdivided into three members; the basal slope-forming Seligman Member; the middle cliff-forming Brady Canyon Member; and the upper slope-forming Woods Ranch Member, all separated by gradational boundaries and not subdivided on this map because the map scale is not adequately large enough to show these units separately (Billingsley and others, 1983). The Seligman Member represents the transgressive phase of the Toroweap sea from the west. The Brady Canyon represents the shallow water marine conditions at the peak of transgression and the beginning of regression back to the west. The Woods Ranch represents the regressive phase of the sea with evaporitic conditions. Originally, the Woods Ranch probably was of uniform thickness, but has been thinned locally by post-depositional solution of gypsum. An erosional unconformity with relief as much as 10 ft, separates the Toroweap and Kaibab Formations.

The Kaibab Formation is subdivided into two members; the basal cliff-forming Fossil Mountain Member and the upper slope-forming Harrisburg Member (Billingsley and others, 1983). Both Members are separated by a gradational boundary and are not subdivided on this map because the map scale is not adequately large enough. The Fossil Mountain represents a transgressive and period of shallow marine embayment of the western sea after a brief period of erosion of the Toroweap Woods Ranch Member. The Fossil Mountain sediments are similar to the Brady Canyon sediments of the Toroweap and often difficult to tell apart. Fossil faunas are slightly different in both units, but the most distinctive difference is the abundant chert in the Fossil Mountain compared to relatively little chert in the Brady Canyon. The Harrisburg represents the regression of the Kaibab sea to the west, leaving a series of evaporitic and tidal flat deposits very similar to the Woods Ranch Member of the Toroweap. A resistant cherty limestone unit at the top of the Harrisburg forms a "caprock" erosional surface over most of the Kanab and Kaibab Plateaus.

Rocks of Mesozoic age once covered the area but have been removed by erosion. Strata of Triassic age are still present a few miles north of the map area. Clasts from the Shinarump Member of the Chinle Formation and also from older Tertiary gravel deposits north of the map area form a minor Tertiary deposit on the Kanab Plateau, south rim of Pine Hollow drainage (south-central part of map, fig.2) and at one locality on the Kaibab Plateau near highway 89A (northeast corner of map, fig. 2; Narcisco, 1989). Other rocks of Cenozoic age are scattered throughout the area in the form of alluvium, talus, and landslide deposits ranging in age from Holocene to Miocene(?).

STRUCTURAL GEOLOGY

Faults

The most conspicuous structural features of the area are the Muav and Big Springs faults in the eastern half of the map (Huntoon, 1969 and 1971). The Muav fault is a high-angle normal fault that displaces Paleozoic strata down to the west as much as 550 ft (estimated) in the southeastern part of the map. Displacement is opposite to the monoclinal dip of strata which reflects two periods of deformation: (1) Laramide compressional stress that produced monoclinal folds in upper Paleozoic strata over reactivated Precambrian faulted basement rocks; (2), Late Cenozoic tensional stresses opposite to Laramide compression producing normal faults in the Paleozoic strata and a reverse movement of the original Laramide fault planes in the lower Paleozoic and basement rocks; and (3) Late Cenozoic continued extension accentuated hanging wall dips during extension (fig. 3; after Huntoon, 1989, p. 80).

Displacement along the Muav fault decreases northward to about 240 ft near where the fault joins the Big Springs fault. The Muav fault marks the topographical boundary between the Kanab and Kaibab Plateaus to the junction with Big Springs fault near Warm Springs Canyon (fig.2). The Big Springs fault is a high-angle normal fault with down-to-the-west displacement with the same tectonic history as the Muav fault. Displacement increases from about 340 ft at the south edge of the map to nearly 1,200 ft at the north edge near Warm Springs Canyon. North of Warm Springs Canyon the Big Springs fault becomes the boundary between the Kanab and Kaibab Plateaus (fig. 2).

The Big Springs monocline parallels the strike of the Big Springs fault and has an average dip of about 3° east. The Crazy Jug monocline, associated with the Muav fault, dips an average of about 2° east but dies out about 2 miles south of the Big Springs and Muav fault junctions. The Big Springs fault and monocline jointly control a north drainage valley whose southern part is called Lookout Canyon and northern part Nail Canyon (fig. 2).

The Gunsight Point fault, located in upper Kanab Creek, is the only fault of any consequence in the western half of the map. The Gunsight Point fault strikes north-south and has an estimated down to the west displacement of about 180 to 200 ft (Billingsley and others, 1983). A few minor northeast trending faults are present in the northeast quarter of the map. These faults are conspicuous in synthetic-aperture radar images but are difficult to locate in the field because of forest and alluvial cover. These faults would not be recognized easily without the aid of the X band radar images (U.S.G.S. SAR System, 1988), especially the northeast-trending Sinyala fault in the southeast corner of the map.

Regional structure and geomorphology

Paleozoic strata in the northern part of the map dip about 2° northwest on the east side of Kanab Creek drainage, and about 1° northeast on the west side (determined photogeologically). Thus, Kanab Creek follows the axial trough of a major, but subdued, north plunging synclinal downwarp; the axial trace is not shown on the map because of its broad general characteristics. Kanab Creek flows south to the Colorado River, opposite the synclinal plunge. All tributaries to Kanab Creek on the Kanab and Kaibab Plateaus flow down local regional dips, except Kanab Creek itself. The deepening Colorado River probably initiated headward erosion and stream capture of Kanab Creek and its tributaries creating a barbed dendritic drainage pattern from the original northerly direction.

The age of drainage reversal is not known but regional compressive stresses in Laramide time (Early Tertiary) produced the folds, followed by Late Cenozoic tensional stresses that formed the normal faults beginning in the Miocene and continuing to the present (Huntoon, 1989). Most tributary drainages of the area are regionally and structurally controlled suggesting that the drainages were probably structurally controlled as early as Laramide time. Headward erosion of Kanab Creek occurred at an unknown time but most likely after Laramide uplift between the Paleocene and Miocene (Young, 1987).

Collapse Structures

Collapse structures, which may correspond to breccia pipes at depth, are scattered on the Kanab and Kaibab Plateaus as well as within the Grand Canyon. These structures are circular depressions characterized by strata that dip gently (1°-20°) towards a central point (fig. 4). The collapsed areas range in size from about 50 ft to more than three quarters of a mile in diameter (Billingsley and others, 1983). Deep seated collapse structures are believed to result from ground-water solutioning in the underlying Redwall Limestone. The roofs of karstic caverns in the Redwall gradually collapsed with time allowing the overlying Pennsylvanian, Permian, and Triassic rocks to fall in and form a breccia pipe (Wenrich and Verbeek, 1980). The Woods Ranch Member of the Toroweap and the Harrisburg Member of the Kaibab Formations contain substantial amounts of gypsum that also is subject to solution by ground water (Wenrich and others 1986). Field observation reveal that gypsum beds in the Toroweap and Kaibab Formations are thickest in the Hacks Canyon area west of Kanab Canyon, thinning substantially to the east of Kanab Canyon. Therefore, collapse features resulting from gypsum solutioning are most numerous west of Kanab Canyon.

Solution of gypsum has produced not only several major collapses, but also sags and drapes of rock strata into drainages on the surface of the Kanab Plateau west of Kanab Canyon and, to a lesser extent, east of Kanab Canyon. The solution of gypsum makes it difficult to identify collapses due chiefly to solution of the Redwall Limestone verses those of the Toroweap and Kaibab. The matter is of importance because of economic interest. Collapses originating in the Redwall Limestone are most likely to host valuable mineral deposits such as copper and uranium (Wenrich, 1985).

Uranium is currently being mined from at least 4 breccia pipes on the Kanab Plateau because of the unusually rich concentrations of this commodity. Currently, drilling programs seems to be the best way to identify those collapse structures that are deep-seated breccia pipes. On this map, collapse features that are most circular with inward dipping strata and are judged to be a potential deep-seated breccia pipe are marked with a dot and the letter "C" along with estimated dips or dip symbols.

Steep-sided sinkhole collapses in the Kaibab Formation are particularly common from the boundary area between the Kanab and Kaibab Plateaus and onto the Kaibab Plateau. This is due in part to increased precipitation at the higher elevations seeping down through joints and fractures in the resistant limestone beds of the Fossil Mountain Member of the Kaibab, allowing solutioning of gypsum in the Woods Ranch Member of the Toroweap. They are probably very young because they are bounded by steep walls or steep talus-covered slopes. On this map, sinkholes are indicated with the letter "S" and a small triangle symbol.

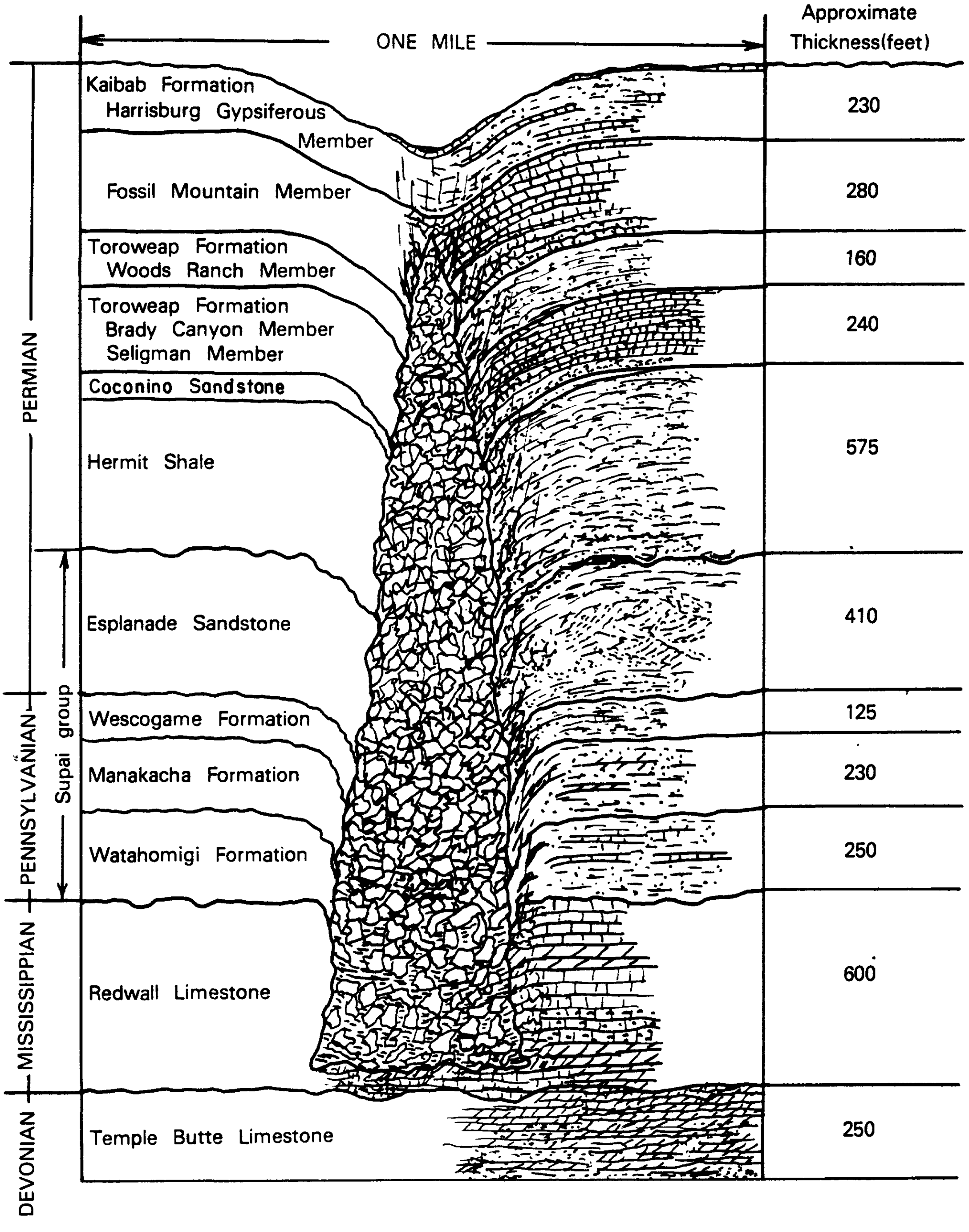

Figure 4. Schematic cross section of a collapse structure (breccia pipe) based on exposed sections in the Grand Canyon, Arizona (from Billingsley and others, 1983; Van Gosen and Wenrich, 1989).

DESCRIPTION OF MAP UNITS
SURFICIAL DEPOSITS

Qc **Channel deposits (Holocene)**--Unconsolidated, unsorted to poorly sorted deposits of silt, sand, gravel, and boulders in active stream channels. Commonly associated with flood plain and alluvial deposits with which it intertongues. Subject to flash floods and severe erosive activity. Little to no vegetation. Thickness ranges from 0 to several ten's of feet

Qf **Floodplain deposits (Holocene and Pleistocene?)**--Unconsolidated silt, sand, gravel, and boulders adjacent to and intertonguing with channel-, alluvial fan-, and talus deposits. Composed mostly of finer-grained material. Forms flat terraces adjacent to stream channels where they are subject to occasional flooding or severe erosion. Thickly vegetated with grass, cactus, and sage brush in Kanab Canyon and its tributaries. Unknown thickness from 0 to several ten's of feet

Qa **Colluvial deposits (Holocene and Pleistocene?)**--Combination of channel, floodplain, and sheetwash deposits that accumulate in shallow valleys and sinkhole depressions on Plateau surfaces; commonly associated with shallow talus and alluvial fan deposits along valley margins. Arroyo cutting is common in wide valley areas. Subject to sheetwash flooding and temporary ponding of runoff. Heavily vegetated with sagebrush and grass below an average elevation of 6,000 ft; occasional juniper, pinion pine, and ponderosa pine trees at higher elevations. Thickness unknown

Qaf **Alluvial-fan deposits (Holocene and Pleistocene?)**--poorly sorted to unsorted, interbedded silt, sand, gravel, and boulders. Contains subangular to subrounded clasts. Forms a slightly elevated fan or tear-drop shaped areas adjacent to and slightly above channel and flood plain deposits. Commonly grades into talus deposits. Lightly vegetated with shrubs, sagebrush and grass. Thickness unknown but at least several ten's of feet

Qt **Travertine deposits (Holocene and Pleistocene?)**--Calcium carbonate deposited by spring water at or near springs. Light brown to gray; porous; cements associated talus and other alluvial deposits. Forms gray, vuggy mounds; heavily vegetated. Contains impressions of plants such as ferns, cattail, reeds, tree leaves, and grasses which are coated and preserved in calcium within a very short time. Thickness is variable and unknown

Qtr **Talus and rockfall deposits (Holocene and Pleistocene?)**--Unconsolidated to partly consolidated, unsorted silt, sand, gravel, and breccia of large and small boulders. Some talus deposits are partially cemented with calcite, gypsum, or both. Only large bodies of talus deposits shown; commonly mantles the Hermit Shale. Lightly vegetated with grasses, cactus, and sage brush. Thickness ranges from about 2-60 ft

Ql **Landslide debris (Holocene and Pleistocene?)**--Unconsolidated and unsorted rock debris. Forms small rotated blocks along cliff faces, mostly involving the Kaibab Formation. Lightly vegetated to no vegetation consisting mostly of grass. Thickness is unknown and variable

QTs **Older Alluvial sediments (Pleistocene? to Pliocene?)**--Consolidated and unconsolidated, poorly sorted to sorted stream sediments consisting of sand, silt, gravel, cobbles, and boulders; subrounded to well rounded limestone and sandstone clasts up to 2 ft diameter. Occurs as high terraces from about 5-120 ft above stream or floodplain deposits along parts of Kanab Creek and some of its tributaries. Light to moderate vegetation, mostly grass and cactus. Thickness averages between 5 and 15 ft

Tg **Tertiary gravel (Pliocene? to Miocene?)**--Mostly unconsolidated, poorly sorted silt, sand, gravel, pebbles, cobbles and boulders as much as 12 inches in diameter. Quartzite is the dominant clast with lesser amounts of chert and volcanic clasts, all of which are very well rounded; also contains minor limestone and petrified wood clasts which are subangular to rounded. Sediments are reworked from the Triassic Shinarump Member of the Chinle Formation and older Tertiary gravel deposits north of the map area (Narcisco, 1989). Approximately 20-30 ft thick

SEDIMENTARY ROCKS

Pk **Kaibab Formation (Lower Permian)**--Upper part, Harrisburg Member, consists of ledge forming, light-gray, fine- to medium-grained, sandy, fossiliferous limestone interbedded with slope-forming, red and gray siltstone and sandstone, and gray white gypsum beds, several feet thick. Gypsum and siltstone commonly occur together. Calcareous sandstone beds locally contain lenses of conglomerate in the upper part. In places, erosional channels are filled with red siltstone, shale, and resistant sandy limestone or conglomerate. Undulating and contorted beds in the western two-thirds of the map area reflect solution of underlying gypsum. The Harrisburg Member is about 230 ft thick in the Kanab Canyon area, thinning eastward to about 100 ft on the Kaibab Plateau where the gypsum content is less. The lower part of the Kaibab, Fossil Mountain Member, consists of approximately 280 ft of cliff-forming, yellowish-gray to gray, fine-grained to sandy, cherty, fossiliferous limestone. Commonly weathers to conical pillars along canyon rims. Gradational contact between Harrisburg and Fossil Mountain Members at or near topographic break. Total maximum thickness is about 530 ft

Pt **Toroweap Formation (Lower Permian)**--Upper part of the Toroweap, Woods Ranch Member, is a pale-red and gray siltstone and shale with interbedded thick, massive, white to gray gypsum; forms a slope. Thickness ranges from 50-160 ft. Gypsum beds are thickest in the Hack Canyon area and thin eastward. The middle part of the Toroweap, Brady Canyon Member, is a gray, medium- to coarse-grained, medium-bedded, fossiliferous, cliff-forming limestone averaging about 240 ft thick. Has a gradational contact with overlying Woods Ranch and underlying Seligman Members. The lower part of the Toroweap, Seligman Member, consists of a white to purple, fine-grained, thin-bedded, well-sorted sandstone, derived from the underlying Coconino Sandstone and Hermit Shale; also contains gray and white, fine-grained, thin-bedded dolomite and gypsum beds; forms a slope or recess below Brady Canyon unit about 40 ft thick. Locally overlies the Coconino Sandstone in the southern two-thirds of the map area and the Hermit Shale in the northern one-third. The contact with the Coconino and Hermit is sharp. Basal sandstone fills large dissociation cracks in the Hermit Shale. Total maximum thickness is about 440 ft

Pc **Coconino Sandstone (Lower Permian)**--White, fine-grained, well-sorted, crossbedded, frosted-grained, quartz sandstone; weathers buff to light yellowish-tan; forms a cliff. An eolian deposit with variable thickness from about 170 ft in southern two-thirds of map to discontinuous in northern one-third. Forms a minor local aquifer producing several small springs and seeps in many canyon drainages

Ph **Hermit Shale (Lower Permian)**--Red-brown, thin-bedded, slope-forming, shaly siltstone interbedded with pale red and red-brown, fine-grained, thin-bedded, ledge-forming sandstone. Fills erosional channels locally as deep as 140 ft cut into Esplanade Sandstone. Thickness ranges from about 700 ft in southwestern part of map to approximately 575 ft in southeastern part

Pe **Upper Supai Group; Esplanade Sandstone (Lower Permian)**--Upper unit of the Supai Group consists of a resistant, reddish-brown to white, fine- to medium-grained, thick-bedded, crossbedded sandstone with dark-red, thin shale partings between sandstone sets. Forms cliff with receding ledges at top. The basal 45 ft consists of dark red, fine-grained, thin-bedded, interbedded siltstone and sandstone that overly gray, medium- to coarse-grained limestone-pebble conglomerate in channel cuts. Forms a prominent, light-red sandstone bench or platform in lower Kanab Canyon and tributaries approximately 380-410 ft thick

IPs **Lower Supai Group (Upper, Middle, and Lower Pennsylvanian)**--Includes the Watahomigi (bottom), Manakacha (middle), and Wescogame (upper) Formations, undivided on this map. Consists of a red- to pale-red, fine- to medium-grained, thin- to thick-bedded, partly calcareous siltstone, shale, and sandstone interbedded with thick-bedded, gray fine-grained, dolomite and sandy limestone. Sandstone and dolomite units are locally cross-stratified; limestone units are commonly separated by thin, light purple siltstone and mudstone beds. Some limestone units contain thin lenses of red or white chert. Forms a sequence of ledges and small cliffs in a general blocky slope profile. Thickness is about 600 ft

Mr **Redwall Limestone (Upper and Lower Mississippian)**--Light gray, cliff-forming, massive to thick-bedded, aphanitic to coarsely-crystalline, fossiliferous limestone and dolomite. Contains a few thin, discontinuous lenses of white chert that weathers brown. About 200 ft of the Redwall is exposed

Units for cross section only:

The following units are not exposed but are assumed to be present in subsurface based on exposures in Grand Canyon about 6 miles south.

Dt **Temple Butte Limestone (Upper, and Middle? Devonian)**--Gray limestone and dolomite; interbedded with purple siltstone and sandstone; forms ledges. Thickness about 300 ft

Ꞓm **Muav Limestone (Middle Cambrian)**--Dark to light gray dolomite and limestone; contains some green shale beds in lower part. Includes unclassified dolomites beds of Upper Cambrian(?) age in upper part. Thickness is about 450 ft

Ꞓba **Bright Angel Shale (Middle Cambrian)**--Green and purple-red shale; gray, thin-bedded dolomite; brown sandstone; forms slope. Thickness averages about 400 ft

Ꞓt **Tapeats Sandstone (Middle and Lower Cambrian)**--Brown, coarse-grained sandstone and pebble conglomerate; forms cliff. Thickness ranges from 0-300 ft

pꞒ **Proterozoic rocks undivided**--Sedimentary, igneous, and metamorphic rocks; thickness unknown

Contact between map units

Fault--Dashed where approximately located; short dashed where inferred; dotted where concealed; bar and ball on downthrown side; number along strike indicates estimated displacement in feet

Anticline--Showing trace of axial plane and direction of plunge; dashed where approximately located; dotted where concealed

Syncline--Showing trace of axial plane and direction of plunge; dashed where approximately located; dotted where concealed

Monocline--Showing trace of axial plane located approximately midway between top and bottom hinges of fold; dotted where concealed

Strike and dip of strata

Inclined--Strike and dips measured in the field

Approximate--Strike and dips determined topographically or photogeologically

Strike and dip of joints--Vertical

Collapse structure--Circular collapses with strata dipping inward towards a central point. Most are assumed to be due to local gypsum-solution collapses at shallow depths, but some may reflect deep-seated breccia-pipe collapses originating in the Redwall Limestone

Breccia pipe--Shown in cross section only

Sinkholes--Steep-walled collapse features not associated with inward dipping strata. Most sinkhole walls are covered by talus and occur in the Toroweap and Kaibab Formations

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CORRELATION OF MAP UNITS

SURFICIAL DEPOSITS

Qc | Qf | Qa | Qaf | Qt | Ql | QTs | Tg

Holocene
Pleistocene(?)
Pliocene(?)
Miocene(?)

QUATERNARY
TERTIARY(?)

SEDIMENTARY ROCKS

Unconformity

Pk
Pt
Pc

Unconformity

Ph

Unconformity

Pe

Unconformity

PPu

Supai Group

Unconformity

Mr

Lower Permian — PERMIAN

Upper, Middle, and Lower Pennsylvanian — PENNSYLVANIAN

Upper and Lower Mississippian — MISSISSIPPIAN

CROSS SECTION UNITS

Unconformity

Dt

Upper and Middle(?) Devonian — DEVONIAN

Unconformity

€m
€ba
€t

Tonto Group

Middle Cambrian
Lower Cambrian — CAMBRIAN

Unconformity

p€ — PROTEROZOIC