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MINERAL RESOURCE POTENTIAL OF THE KANAB CREEK ROADLESS AREA, COCONINO AND MOHAVE COUNTIES, ARIZONA

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STUDIES RELATED TO WILDERNESS

Under the provisions of the Wilderness Act (Public Law 88-577, September 3, 1964) and related acts, the U.S. Geological Survey and the U.S. Bureau of Mines have been conducting mineral surveys of wilderness and primitive areas. Areas officially designated as "wilderness," "wild," or "canoe" when the act was passed were incorporated into the National Wilderness Preservation System, and some of them are presently being studied. The act provided that areas under consideration for wilderness designation should be studied for suitability for incorporation into the Wilderness System. The mineral surveys constitute one aspect of the suitability studies. The act directs that the results of such surveys are to be made available to the public and be submitted to the President and the Congress. This report discusses the results of a mineral survey of the Kanab Creek Roadless Area, Kaibab National Forest, Coconino and Mohave Counties, Ariz. The Kanab Creek Roadless Area was classified as a further planning area during the Second Roadless Area Review and Evaluation (RARE II) by the U.S. Forest Service, January 1979.

MINERAL RESOURCE POTENTIAL SUMMARY STATEMENT

A moderate resource potential for uranium, copper, and other metals in breccia pipes is assigned to collapse structures (see fig. 3), four of which extend into or are near the boundary of the roadless area. Energy Fuels Nuclear, Inc., Denver, Colo., has located a significant deposit of uranium in one of these breccia pipes on the north rim of Snake Gulch at Pigeon Point. The other three collapse structures along the boundary of the roadless area have not been explored, but geochemical sampling on the surface has shown enrichment of several metals.

Gypsum, which occurs in the Woods Ranch Member of the Toroweap Formation along the rim of the canyon, is a common mineral in the region. Historic prospects in the Kanab Creek Roadless Area are nonexistent. No significant geochemical anomalies, other than those related to collapse structures on both the east and west rims of the Kanab Creek Roadless Area, were found within the roadless area.

No oil or gas occurrences are known in the roadless area, but there is a low potential for such resources in the area and the surrounding areas, on the basis of known shows or production relatively nearby in rocks correlative with those exposed in or underlying the roadless area.

INTRODUCTION

The Kanab Creek Roadless Area is comprised of the canyon of Snake Gulch about 15 mi south of Fredonia, Ariz., between Kanab Creek and the Kaibab Plateau (fig. 1). It is contiguous with the Kanab Canyon Roadless Area on the west side and lies within the Grand Canyon Game Preserve of the Kaibab National Forest. The Kanab Creek area encompasses just over 14 mi^2 at altitudes ranging from 3,720 to 6,200 ft above sea level. Dirt roads provide access to both the north and south rims of the canyon and a four-wheel drive trail provides access down the floor of the canyon for its entire 22 mi length.

A generalized geologic map of the area (part of the State geological map at a scale of 1:500,000) was produced by the Arizona Bureau of Mines (Wilson and others, 1969). Detailed geologic mapping done for this study included aerial photointerpretation and field checking.

GEOLOGIC SETTING

Snake Gulch (in the Kanab Creek Roadless Area) lies within the Colorado Plateau province 18 mi north of the central region of Grand Canyon, Ariz. Horizontal layers of sandstone, shale, and limestone, all of Early Permian age, have been incised by Snake Gulch and crop out along the canyon walls. The exposed rock units include (in ascending order) the Esplanade Sandstone, Hermit Shale, Coconino Sandstone, Toroweap Formation (including the Seligman, Brady Canyon, and Woods Ranch Members), and the Kaibab Formation (including the Fossil Mountain and Harrisburg Gypsiferous Members; fig. 2). The Triassic Moenkopi Formation is not present in

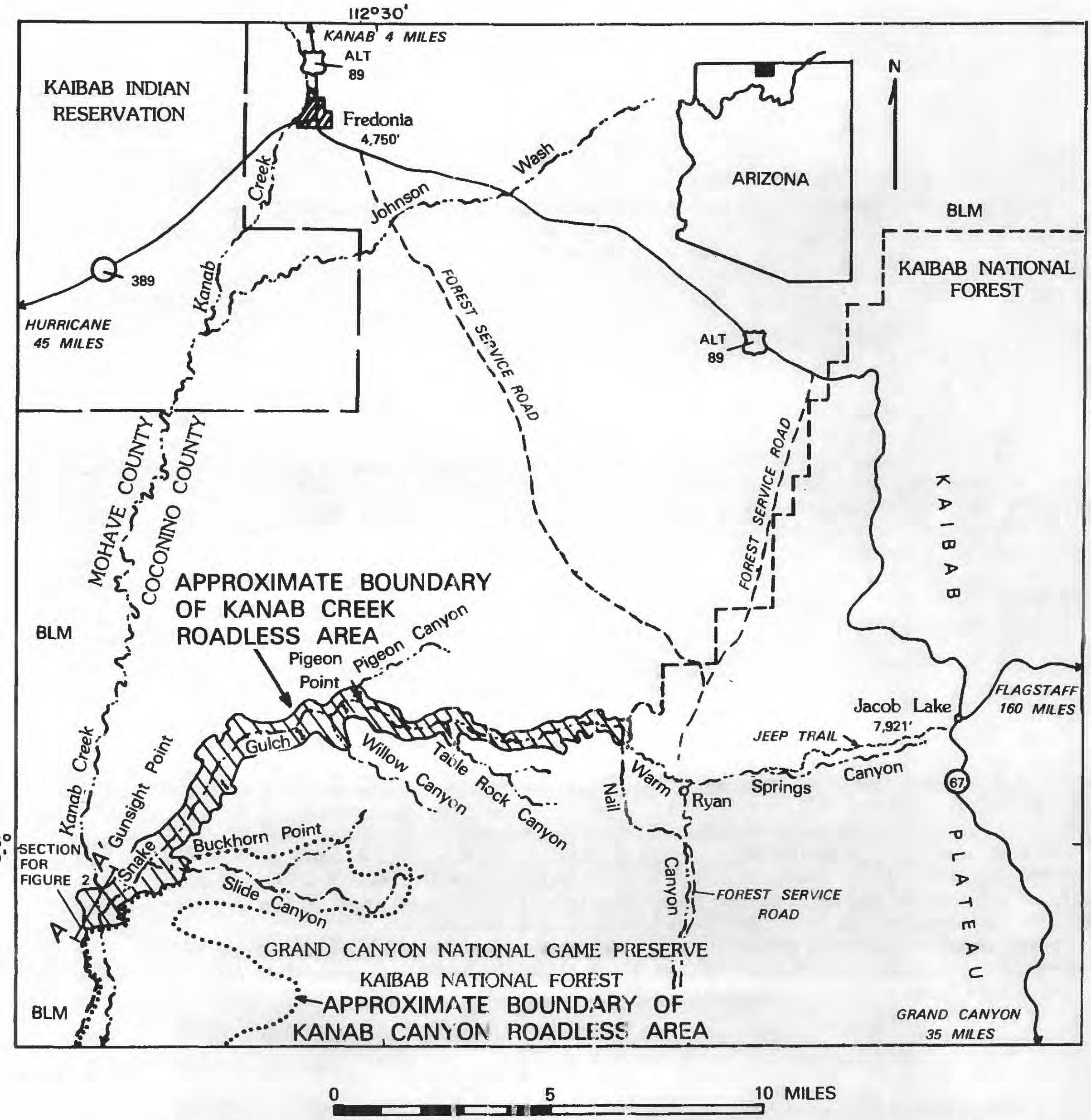


Figure 1.--Location map of the Kanab Creek Roadless Area (B3060), Coconino and Mohave Counties, Ariz.

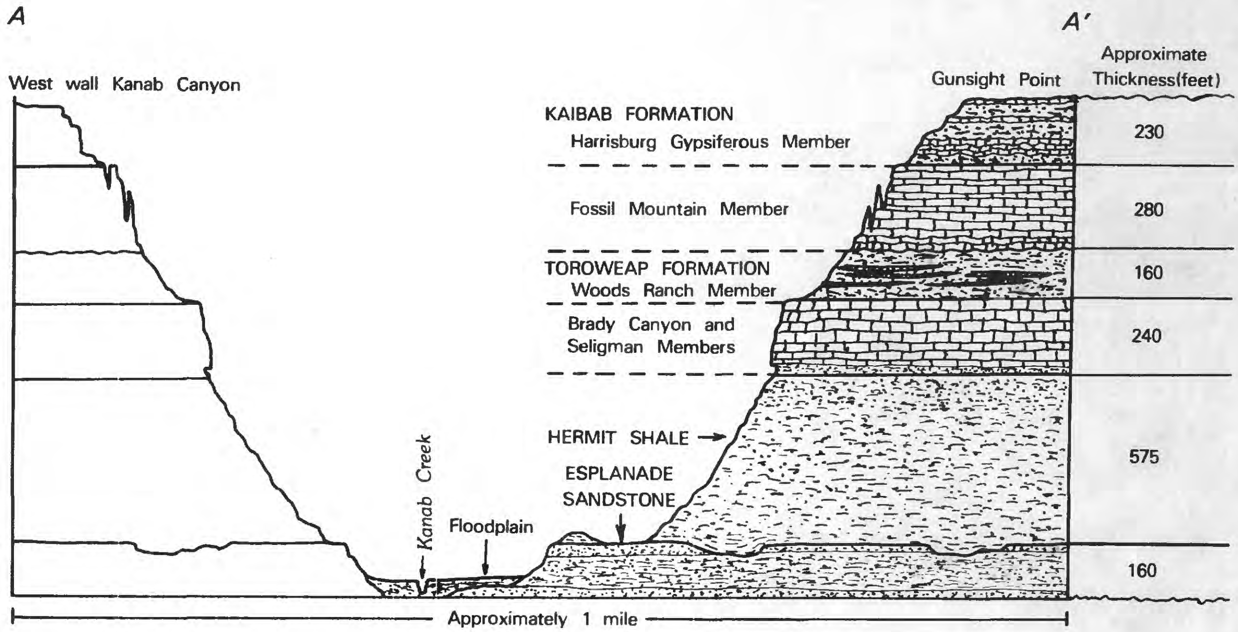
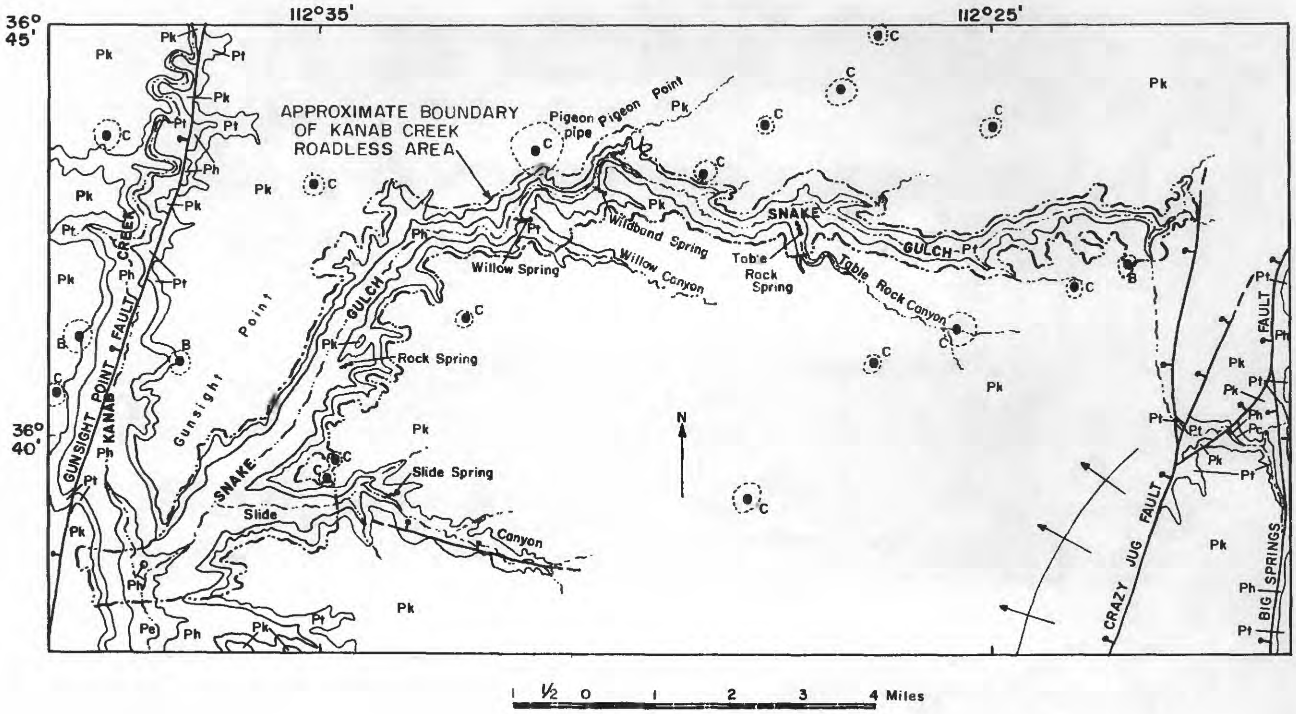


Figure 2.--Geologic cross section of the western Kanab Creek Roadless Area. (See fig. 1 for section location.)



EXPLANATION

CONTACT

FAULT—Bar and ball on downthrown side

MONOCLINE--Axis located approximately midway between anticlinal and synclinal hinges of fold. Length of arrow indicates the map distance between fold hinges

AREAS OF MODERATE MINERAL RESOURCE POTENTIAL

C Collapse structure—Circular depression with inward dipping beds

B Collapse structure--Collapse structure with exposed breccia

Figure 3.--Generalized geologic map of the Kanab Creek Roadless Area, Coconino and Mohave Counties, Ariz., showing areas having moderate resource potential for uranium, copper, and other metals. Pk, Kaibab Formation; Pt, Toroweap Formation; Pc, Coconino Sandstone; Ph, Hermit Shale; Pe, Esplanade Sandstone of the Supai Group.

the Snake Gulch area due to erosion but it is found 15 mi to the north.

Approximately 160 ft of the upper Esplanade Sandstone is exposed at the mouth of Snake Gulch where it consists mainly of deep-reddish-brown mudstone and siltstone capped with a resistant reddish-brown to white, massive, ledge-forming sandstone. An erosional surface with relief of approximately 20 ft marks the unconformity between the Esplanade Sandstone and Hermit Shale. The slope-forming Hermit Shale (approximately 575 ft thick) consists of alternating bright-red-brown shaly mudstone and siltstone interbedded with pale-red-brown, ledge-forming, massive sandstone. The contact with the overlying Coconino Sandstone contains large tension cracks that extend into the Hermit Shale and are filled with sand from the Coconino Sandstone. The Coconino Sandstone occurs only in the upper 6 mi of Snake Gulch and consists of a cross-laminated, white sandstone 14 ft in thickness. Reworked white Coconino Sandstone and red Hermit Shale form interbedded layers of sandstone and shale in the basal Seligman Member of the Toroweap Formation (approximately 30 ft thick). The Seligman Member forms a continuous cliff of sandstone with the overlying limestone of the Brady Canyon Member (approximately 210 ft thick) and is undifferentiated from it on the geologic map. Fossiliferous, gray limestone of the Brady Canyon Member grades upward into slope-forming, pale-red and gray shale and siltstone of the Woods Ranch Member of the Toroweap Formation (approximately 160 ft thick). Thick layers of massive gypsum occur throughout the Woods Ranch Member. An erosional unconformity with relief as much as 10 ft marks the boundary between the Toroweap Formation and Kaibab Formation. The base of the Kaibab Formation is composed of a yellowish-gray, fossiliferous, cherty limestone representing the Fossil Mountain Member (approximately 280 ft thick). A gradational contact exists between the cliff-forming Fossil Mountain Member and the overlying slope-forming Harrisburg Gypsiferous Member. The Harrisburg Gypsiferous Member of the Kaibab Formation (approximately 200 ft thick) consists of a series of alternating gray and pale-red shale and siltstone beds interbedded with gray limestone and gypsiferous siltstone. The Harrisburg Gypsiferous Member forms the semiresistant plateau surface around the Snake Gulch area and varies in thickness due to present-day erosion. Unconsolidated Quaternary surficial deposits are scattered on the floor and slopes of the canyon as talus slides, flood-plain deposits, alluvial valley deposits, alluvial fans, and a few travertine deposits; however, they have been omitted from the geologic map (fig. 3) of this report.

The rock-stratigraphic names, Seligman, Brady Canyon, and Woods Ranch Members of the Toroweap Formation and the Fossil Mountain Member of the Kaibab Limestone have been used in numerous reports relating to Grand Canyon geology. The names of Sorauf (1962), utilized by Bissell (1969), Billingsley (1978), Rawson and Turner-Peterson (1979), Cheevers and Rawson (1979), and Altany (1979) are used in this report as formal rock-stratigraphic units (as suggested by J. E. Sorauf, written commun., 1981). This terminology will be most useful in the western and northern Grand Canyon region.

STRUCTURE

At least two fault systems, including the Crazy Jug fault and the Big Springs fault, occur at the east end of Snake Gulch. They have a minimum displacement of 1,200 ft. One large fault, the Gunsight Point fault, having an estimated displacement 180-200 ft down to the west, occurs in Kanab Canyon just west of Snake Gulch (fig. 3). The sedimentary rocks of Snake Gulch dip from east to west with a regional dip of 1°. Collapse structures (possible breccia pipes at depth), as well as breccia pipes exposed at the surface, are randomly scattered on the plateau surface on both sides of the canyon (fig. 3). These structures are circular depressions characterized by strata that dip gently (1°-10°) towards the central point (fig. 4). The collapsed areas vary in size from 40 ft to more than 0.75 mi in diameter. These structures are believed to have originated due to solution of the underlying Redwall Limestone by ground water. The roof of the produced caverns then collapsed under the burden of the overlying rocks forming a brecciated "pipe" at depth (Wenrich-Verbeek, 1980).

GEOCHEMISTRY

A reconnaissance geochemical study to assess the mineral resource potential of the Kanab Creek Roadless Area, Ariz., was conducted in March 1982 by J. C. Antweiler. Stream-sediment samples and panned concentrates were collected at the confluence of all the major tributaries in the main drainage (Snake Gulch) of the roadless area, and from Snake Gulch proper. Similar samples were also collected outside the roadless area from drainages that crossed collapse structures (with possible breccia pipes at depth) on the surrounding plateau. Water samples were collected from six springs that emerge from side canyons of Snake Gulch. Rock and soil samples were collected at several localities in Snake Gulch and from collapse structures outside yet near the roadless area.

A total of 80 minus-80-mesh stream-sediment, soil, and clay samples; 16 panned concentrates, 23 rock samples, and 6 water samples were collected from the Kanab Creek Roadless Area. Water samples were divided into a portion that was analyzed for anions, and a filtered portion that was acidified with nitric acid immediately after collection and subsequently analyzed for cations. All samples except the water samples were analyzed for 31 elements by semiquantitative spectrographic methods (Grimes and Marranzino, 1968). Water samples were analyzed for Cu, Pb, Zn, Mo, U, Cl-, F, SO_4=, and conductivity, using methods described by Miller and others (1982).

Separate analytical data sets were prepared for each sample type, and selections for geochemically anomalous values were based on several criteria (J. C. Antweiler, unpub. data, 1983). Anomalous thresholds were based primarily on concentration contrasts for selected elements and are shown in table 1. The most significant anomalous metals in rocks include Ag, As, Ba, Cu, Mo, Pb, and Zn; in panned concentrates Ag, B, Ba, Cu, Mo, Pb, and Sr; in stream sediment, clay, and soil samples B, Ba, Cu, Mo, Pb, and Sr; and in water samples U and Zn.

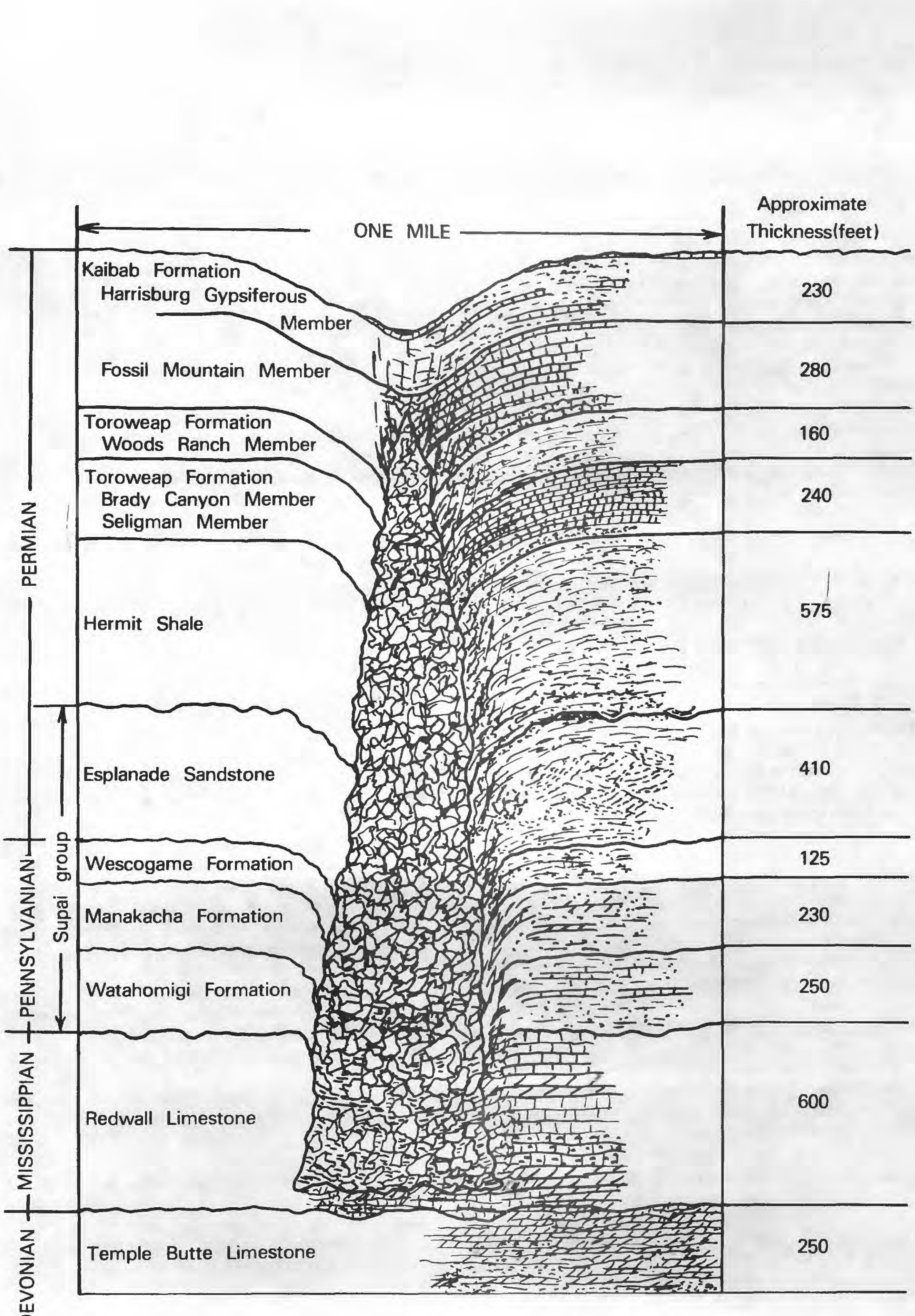


Figure 4.--Schematic cross section of a collapse structure (breccia pipe) based on exposed sections in the Grand Canyon, Ariz.

Table 1.--Background range and anomalous concentrations of selected elements in four sampling media, Kanab Creek Roadless Area, Coconino and Mohave Counties, Ariz.

[N, not detected; <, detected but below level of satisfactory measurement; >, greater than amount shown; ≥ equal to or greater than amounts showing; nf, none found; numbers in parentheses indicate detection limit. Values in parts per million except water samples, which are in parts per billion]

Element	Background		Weakly anomalous		Strongly anomalous	
	Range	Percent of samples	Range	Percent of samples	Range	Percent of samples
80 minus-80-mesh stream-sediment, soil, and clay samples						
Ag	N(0.5)-<0.5	100	nf	0	nf	0
As	N(200)-<200	100	nf	0	nf	0
B	20-200	98	>200	2	nf	0
Ba	200-1000	86	1000-5000	14	nf	0
Cu	10-30	98	70-200	2	nf	0
Mo	N(0.5)-5	94	5-100	6	nf	0
Pb	20-50	98	50-700	2	≥1500	2
Sr	N(100)-200	86	200-1500	12	nf	0
Th	N-23	100	nf	0	nf	0
U	N-9	100	nf	0	nf	0
16 panned-concentrate samples						
Ag	N(0.5)-(0.5)	88	0.5-5	6	>5	6
As	N(200)-<(200)	100	nf	0	nf	0
B	100-500	80	700-1000	20	nf	0
Ba	200-5000	56	≥10,000	44	nf	0
Cu	10-70	88	>70	12	nf	0
Mo	N(0.5)-<(0.5)	82	>5	18	nf	0
Pb	N(30)-150	82	≥150	18	nf	0
Sr	N(200)-1000	70	1000-5000	6	≥5000	6
23 rock samples						
Ag	N(0.5-(0.5)	35	0.5-5	62	>5	4
As	N(200)-<(200)	82	200-700	14	>700	4
Ba	N-1500	91	>1500	9	nf	0
Cu	N-70	82	70-200	18	nf	0
Mo	N(0.5)-<(0.5)	64	5-50	27	>50	9
Pb	N-70	91	≥70	9	nf	N
Zn	N-(200)	91	200-700	4.5	>700	4.5
6 water samples						
U	1-9	33	10-40	50	>40	17
Zn	1.8-50	83	51-200	17	nf	0

Only a few geochemically anomalous areas were identified within the boundaries of the Kanab Creek Roadless Area. Panned concentrates were anomalous in Ba, Mo, and Pb at the mouth of Slide Canyon (fig. 3); the anomalous elements may be related to a collapse structure on Buckhorn Point because samples from the drainage of Slide Canyon above Buckhorn Point did not show geochemical anomalies. Altered limestone collected from the collapse structure near Buckhorn Point was anomalous in Ag, As, Cu, and Mo, although not strongly so.

The strongest anomalies in the roadless area were found in float consisting of iron-rich concretions collected in the drainage below Willow Spring (fig. 3). These concretions were enriched in Ag, As, Cu, Mo, Pb, and Zn; however, their bedrock source is unknown. The most likely source is the Fossil Mountain Member of the Kaibab Limestone because they are noted almost everywhere Fossil Mountain is exposed. A water sample from Willow Spring contained 120 ppb (parts per billion) Zn and 10 ppb U, and was therefore slightly anomalous in those elements. Rock, panned concentrate, and stream-sediment samples from Willow Spring had normal background levels for elements.

Water from Pigeon Spring contained 44 ppb U, the highest uranium concentration found in the roadless area. Although Pigeon Spring is east of the breccia pipe at Pigeon Point, a possibility exists that the water which emerges in Pigeon Spring has dissolved uranium from another mineralized collapse structure (breccia pipe) similar to the one at Pigeon pipe. No other geochemical anomalies were found associated with this area.

Water from Wildband, Rock, and Willow Springs ranged in uranium content from 10 to 15 ppb, and thus is slightly anomalous in that element. This may suggest that high background levels of uranium occur in some of the rocks through which the water travels or the water is a mixture of water that traveled through breccia pipes with uranium and "normal" ground water. The ground water is assumed to flow downdip along bedding planes from east of Snake Gulch.

Geochemical anomalies in samples from the main drainage of Snake Gulch are probably attributable to contamination from former mining of the Jacob Lake-Warm Springs copper deposits and ore-processing activity at Ryan, just east of the roadless area. Geochemical anomalies (Cu, Ba, As, and Mo), although weak, increase in intensity at the upper end of the roadless area in the drainage directly below Ryan. No samples of the Ryan-Warm Springs area were collected.

The plateau surrounding Snake Gulch has a number of collapse structures, some of which may be mineralized breccia pipes. The most notable of these is the Pigeon pipe on the north rim of Snake Gulch (fig. 3). At the time of the field studies for this report overburden there was being removed preparatory to mining by Energy Fuels Nuclear, Inc., Denver, Colo. Through the courtesy and permission of Energy Fuels Nuclear, Inc., we collected several rock, soil, and clay samples from fresh machine-made cuts around the perimeter of the area. The mineralized areas had not yet been exposed; however, analytical data from the samples showed an anomalous group of elements in limonitically altered rock and clay samples that included Ag, Ba, B, Co, Mo, Ni, Pb, and Sr. All the anomalies were in the weakly anomalous range of table 1.

Stronger geochemical anomalies were found in samples from other collapse structures, particularly the one in Table Rock Canyon (fig. 3). In these samples, the strongest geochemical anomalies were of Ag, As, Mo, and Zn, both in panned concentrates and rock samples. Subsurface sampling would be required to evaluate the significance of these areas.

In summary, the geochemical sampling study resulted in identification of several anomalous concentrations in samples from the Kanab Creek Roadless Area. Geochemical anomalies associated with collapse structures on both rims of the canyon outside the roadless area are much stronger than anomalies in the canyon itself and may warrant further study. Some of the breccia pipes, including the Pigeon pipe, may be partially within the area. Alluvium within the canyon may conceal other collapse features.

MINING DISTRICTS AND MINERALIZED AREAS

Near Jacob Lake, east of the roadless area (fig. 1), the Jacob Lake-Warm Springs district includes a few copper deposits. These deposits consist of ribbonlike bodies of azurite and malachite at the intersection of vertical joints and favorable beds of cherty, sandy limestone in the Kaibab Limestone. The closest deposit to the Kanab Creek Roadless Area is 4 mi to the east.

The deposits were known by 1900, and mills to process the ore were built in 1901 and 1928 at Ryan, near the mouth of Warm Springs Canyon, 2.5 mi southeast of the head of Snake Gulch. Both mills were destroyed by fire within a year of construction (Tainter, 1947).

No significant production occurred until 1942 when the U.S. Government closed gold mines to concentrate mining efforts on critical war materials. Gold mines had provided much of the siliceous flux needed by copper smelters, and copper deposits such as these alleviated the shortage of flux. In 1944, the U.S. Bureau of Mines drilled 152 holes on claim groups about 6 mi east of Snake Gulch. Only one group was active after the end of World War II (Tainter, 1947).

The district produced 241 oz of gold, 29,504 oz of silver, 6,821,826 lb of copper, and 2,010 lb of lead from 1937 to 1956 when all activity ceased (Tainter, 1947).

MINING ACTIVITY

As of September 1982, considerable exploration interest in mineral resources was evident on the plateau surrounding the Kanab Creek Roadless Area. The main commodity being sought is uranium; however, precious and base metals accompany uranium in some of the mineralized areas in the Grand Canyon area and thus conceivably can occur near Kanab Creek. Uranium is currently being produced from the Hacks Canyon mine about 6 mi west of the roadless area (Energy Fuels Nuclear, Inc., oral commun., 1982).

Large blocks of claims were staked on both the north and south rims of Snake Gulch, bordering the Kanab Creek Roadless Area during 1980-82 by Energy Fuels Nuclear, Inc., Denver, Colo. Corners of these claim blocks extend into the Kanab Creek Roadless

Area. At least one block of claims on the north rim, known as the Pigeon pipe, was found to be sufficiently mineralized to encourage further development (fig. 3). In March 1982, several men were employed there, operating earth-moving equipment to remove overburden. Several drill rigs were also in operation.

ASSESSMENT OF MINERAL RESOURCE POTENTIAL

The majority of the area included within the Kanab Creek Roadless Area has no indications of metallic mineral resource potential. Layers of gypsum occur in the Woods Ranch Member of the Toroweap Formation along the rim of the canyon of Snake Gulch. Because of the remoteness, relative inaccessibility, and distance from markets, the gypsum deposits are less attractive than many other deposits in southern Utah and northern Arizona. Collapse structures are randomly scattered on the surrounding plateau just outside the roadless area and some extend a short distance into the area (fig. 3). The areas having potential for mineral resources are in the Grand Canyon region from mineralized breccia pipes found underneath collapse structures. Most of the breccia pipes are not mineralized, but substantial production of uranium, copper, and other metals has come from some of them, such as the Grandview mine on Horseshoe Mesa, eastern Grand Canyon; the Orphan mine, south rim of the Grand Canyon; and the Hacks Canyon mine about 6 mi west of Kanab Creek.

A moderate mineral resource potential for uranium, copper, and other metals is assigned to collapse structures, four of which extend into or are near the Kanab Creek Roadless Area (fig. 3).

A low resource potential for oil and gas is assigned to the Kanab Creek Roadless Area because the Paleozoic section in northwestern Arizona is considered favorable for the occurrence of oil and gas resources. Although canyon cutting generally reduces the possibility of accumulations in the incised rocks near the canyons, the unexposed rocks should not be adversely affected (Pierce and others, 1970). The closest drill hole, about 12 mi northwest of Snake Gulch, penetrated Cambrian strata but was dry.

The breccia pipe at Pigeon Point, called Pigeon pipe (fig. 3), has inferred resources of uranium and is currently being developed by Energy Fuels Nuclear, Inc., Denver, Colo. (fig. 3). Although many of the collapse structures on the surrounding plateau may not mark the location of mineralized breccia pipes at depth, the probability is high that some of them may be mineralized. Geochemical sampling on the surface has shown enrichment of several metals, most notable Ag, As, Mo, and Zn (but also at some localities Ba, B, Co, Ni, Pb, and Sr). These geochemical anomalies were strongest just south of the Kanab Creek Roadless Area.

The conceptual model for metallic mineralization in this study is that of collapse structures in sedimentary rocks, which indicate the possibility of brecciated rock at depth creating a mineral trap. In some instances these pipes are mineralized with several metals, most notably uranium and copper. These metals may have come from metal-rich rocks such as Triassic rocks, which at one time blanketed the region. Percolating waters, during the erosional process, dissolved the metals, traveling through channels in the subsurface and contributed to collapse of the overlying rocks, as well as depositing their metals in the brecciated rock.

The best technique known at the present time to recognize these features is through close examination of aerial photographs to locate circular depressions (some approaching 0.75 mi or more in diameter) that dip inward from the circumference towards the center at angles of 1°-10° or more. Conventional reconnaissance geochemical sampling of stream sediments and panned concentrates may fail to locate geochemical anomalies because of the lack of an exterior drainage. Moreover, rock or soil samples collected at the surface over a collapse feature may be too far away from a zone of mineralization to show anomalies. At the Pigeon pipe, as noted above, most of the geochemical samples were within the normal background range of element concentrations. Nonetheless, when collapse features or breccia pipes are located by examination of aerial photographs or by other methods, geochemical sampling is desirable as the next step in exploration.

Although there are no known oil or gas occurrences in the Kanab Creek Roadless Area and there are no truly petroliferous rocks exposed, the limestone of the Brady Canyon Member of the Toroweap Formation has a fetid odor from a freshly broken surface, and there is dead oil in scattered dark zones along the outcrop. In addition, sedimentary rocks are present that correlate with units that are productive or petroliferous in relatively nearby areas. For example, Peterson (1973) reported oil production from both the Moenkopi Formation and the Kaibab Limestone at the Upper Valley field in Garfield County, Utah, about 75 mi northeast of the roadless area. E. B. Heylmun (1980) pointed out that some dozen wells had been drilled in the Arizona Strip and that the Kaibab Limestone, Toroweap Formation and Coconino Sandstone all had live or dead oil shows in some of the wells, and that helium had been reported from several unidentified zones in one well. In addition he noted oil shows in the Permian Queantoweap and Pakoon Formations (of McNair, 1951), in the Pennsylvanian Callville Limestone, and in the Mississippian Redwall Limestone, which probably underlie but are not exposed in the roadless area. The closest drill hole is a dry hole that penetrated the Cambrian strata about 12 mi northwest of Snake Gulch.

The narrowness of the roadless area along Snake Gulch and the fact that a number of the potential reservoir formations are exposed along virtually the entire length of the area do reduce the possibility of accumulations in the breached rocks near the canyon, but the unexposed rocks should not be adversely affected (Pierce and others, 1970). Accordingly, a low resource potential for oil and gas resources is assigned to the roadless area and the surrounding areas.

REFERENCES

Altany, R. M., 1979, Facies of the Hurricane Cliffs tongue of the Toroweap Formation, northwestern Arizona, in Baars, D. L., ed., Permianland: Four Corners Geological Society Guidebook, 9th Field Conference, p. 101-104.

Billingsley, G. H., 1978, A synopsis of stratigraphy in the western Grand Canyon: Museum of Northern Arizona Research Paper 16, 27 p.

Bissell, H. J., 1969, Permian and Lower Triassic transition from the shelf to basin (Grand Canyon, Arizona to Spring Mountains, Nevada), in Baars, D. L., ed., Geology and natural history of the Grand Canyon region--Powell Centennial River Expedition, 1969: Four Corners Geological Society, 5th Field Conference, p. 135-169.

Cheevers, C. W., and Rawson, R. R., 1979, Facies analysis of the Kaibab Formation in northern Arizona, southern Utah and southern Nevada, in Baars, D. L., ed., Permianland: Four Corners Geological Society Guidebook, 9th Field Conference, p. 105-113.

Grimes, D. J., and Marranzino, A. P., 1968, Direct-current arc and alternating-current spark emission spectrographic field methods for the semiquantitative analysis of geologic materials: U.S. Geological Survey Circular 591, 6 p.

Heylmun, E. B., 1980, Arizona Strip--new recovery techniques could transform area: Western Oil Reporter, v. 37, no. 1, p. 40-42.

McNair, A. H., 1951, Paleozoic stratigraphy of part of northwestern Arizona: American Association of Petroleum Geologists Bulletin, v. 35, no. 3, p. 525-526.

Miller, W. B., Ficklin, W. H., and Learned, R. E., 1982, Hydrogeochemical prospecting for porphyry copper deposits in the tropical-marine climate of Puerto Rico: Journal of Geochemical Exploration, v. 16, p. 217-233.

Peterson, P. R., 1973, Upper valley field: Utah Geological and Mineralogical Survey Oil and Gas Field Studies 7, 4 p.

Pierce, H. W., Keith, S. B., and Wilt, J. C., 1970, Coal, natural gas, helium, and uranium in Arizona: Arizona Bureau of Mines Bulletin 182, 289 p.

Rawson, R. R., and Turner-Peterson, C. E., 1979, Marine-carbonate, Sabka, and eolian facies transitions within the Permian Toroweap Formation, in Baars, D. L., ed., Permianland: Four Corners Geological Society Guidebook, 9th Field Conference, p. 89-99.

Sorauf, J. E., 1962, Structural geology and stratigraphy of the Whitmore area, Mohave County, Arizona: Lawrence, Kansas, University of Kansas Ph. D. dissertation, 361 p.

Tainter, S. L., 1947, Apex Copper property, Coconino County, Arizona: U.S. Bureau of Mines Report of Investigations RI 4013, 23 p.

Viets, J. G., Clark, J. R., and Cambell, W. L., 1979, A rapid, sensitive, partial leach and organic separation for the determination of Ag, Bi, Cd, Co, Pb, Sb, and Zn by atomic absorption spectrometry [abs.]: Tucson, Arizona Association of Exploration Geochemists, Basin and Range Symposium, April 9-10, 1979, p. 32.

Wenrich-Verbeek, K. J., and Verbeek, E. R., 1980, Collapse breccia pipes, in Weinrich-Verbeek, K. J., and others, National uranium resource evaluation, Flagstaff quadrangle, Arizona: U.S. Geological Survey NURE Folio; available from U.S. Department of Energy Open-File Report PGJ-014(82), 483 p.

Wilson, E. D., Moore, R. T., and Cooper, J. R., 1969, Geologic map of Arizona: Arizona Bureau of Mines, scale 1:500,000.