UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

Drilling of a U-mineralized breccia pipe near Blue Mountain, Hualapai Indian Reservation, northern Arizona

by

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ABSTRACT

The Blue Mountain pipe is a solution-collapse breccia pipe located on the Hualapai Indian Reservation of northwestern Arizona, about 7 miles north of Blue Mountain and 4 miles southeast of Diamond Creek. The pipe formed intially by collapse of strata into large dissolution caverns within the underlying Mississippian Redwall Limestone. The caverns formed during the Late Mississippian; dissolution may have been continuous from the Mississippian into the Triassic or reactivated during the Triassic. Like all northern Arizona breccia pipes, strata collapsed downward into dissolution voids--no clasts have been found above their normal stratigraphic position. Continued collapse from the ceiling and steep walls of the cavern resulted in upward propagation of the pipe; the free fall of rock caused extensive brecciation. Distinguishable clasts from within the Blue Mountain pipe indicate a minimum downward displacement of at least 290 ft.

The Blue Mountain pipe is exposed along a cliff of Coconino Sandstone on the western edge of the Coconino Plateau. At the surface the pipe contains a prominent silicified breccia column about 130 ft high, 200 ft wide, and 300 ft long. The pinnacle consists of highly silicified, angular fragments and blocks, primarily derived from the Coconino Sandstone, with some fragments recognizable as belonging to the overlying Toroweap Formation. Evidence that the silicified pinnacle is part of a uranium-mineralized breccia pipe, includes: 1) polylithologic, chaotically-oriented clasts, 2) brecciated quartz veins with quartz crystal-lined vugs exhibiting radioactivity up to 1,200 counts per second (40 times background), 3) extensive Liesegang banding of iron minerals, indicating secondary fluid movement, and 4) evidence of secondary copper-mineralization in the form of malachite, azurite, and chrysocolla.

Petrographic studies indicate that silicification of the pinnacle occurred prior to supergene alteration (malachite, azurite, chrysocolla, smithsonite, and hematite). Fluid inclusion temperatures of quartz from the pinnacle are bimodal. Lower temperature inclusions have homogenization temperatures from 91-110°C with salinities greater than 23 weight percent NaCl equivalent; these inclusions may be related to the typical northern Arizona breccia pipe mineralization event. Homogenization temperatures from other inclusions range from 256-317°C, having much higher values than other breccia pipe inclusions, and may be associated with nearby Tertiary volcanism.

Western Nuclear, Inc. drilled 23 exploratory drill holes at the Blue Mountain pipe from 1976 to 1978. A total of 11,624 ft of rotary drilling and 1,202 ft of diamond drilling were completed within and around the pipe.

Holes drilled into the pipe by Western Nuclear, Inc. and the U.S. Geological Survey (USGS) penetrated uranium-mineralized rock. The most persistent and high-grade horizon was intersected by 13 Western Nuclear holes and 3 of the 4 USGS holes. The top of this uranium-bearing zone ranges from depths of 311 ft (elevation about 5,606 ft) to 451 ft (elevation about 5,651) and varies from 43 ft to 3 ft in thickness. The highest grade within this zone (and also in the pipe) is 10 ft of 0.085 percent eU_3O_8. The top of this uranium-rich zone dips about 12-19° southeast.

Downhole geophysical logging reached a depth of 1,430 ft in one hole (within the lower Supai Group). Logs from several holes confirm that the feature is a uranium-mineralized pipe, but this study was unable to delineate an economic orebody. The Blue Mountain pipe may not be vertical, but instead may bend to the southeast. If so, the silicified pinnacle may lie along the west side of the enclosing ring fracture, with the center of the pipe, and a

still unintersected orebody, bending beneath the hill southeast of the pinnacle. If this is the case, additional drilling angled toward the center of the pipe might locate a uranium orebody.

INTRODUCTION

The Blue Mountain pipe is a solution-collapse breccia pipe located about 7 miles (11 km) north of Blue Mountain and 4 miles (6 km) southeast of Diamond Creek on the Hualapai Indian Reservation of northwestern Arizona (figs. 1, 2), and in the eastern half of Section 25, Township 27 North, Range 9 West of the Robber's Roost 7 minute quadrangle, Arizona (latitude: 35°41'49", longitude: 113°11'01").

The first recorded examination of the pipe was in 1953 by R.D. Miller (1954, 1970) as part of a uranium reconnaissance program conducted by the U.S. Atomic Energy Commission. Miller (1954, p. 15) noted the "outcrop of altered Coconino sandstone" which forms a "conspicuous pinnacle protruding from the canyon floor", and is "characterized by contorted bedding which is alternatively banded with iron and manganese oxides". Contrary to observations made during this study, Miller (1954) also added that "radioactivity was not above normal."

Few breccia pipes stand above the country rock as does the Blue Mountain pipe. The silicification of the breccia at the Blue Mountain pipe retarded erosion to the extent that the pinnacle presently protrudes 130 ft (40 m) above the surrounding terrain. Although breccia in many breccia pipes has undergone minor subsequent silicification, those pipes rarely protrude more than a few feet above the surrounding terrain. Several exceptions to this are pipes #241, #243, and #253 on the northeastern part of the Hualapai Reservation and a pipe directly north across the Colorado River from pipe #243 (each mapped in Wenrich, Billingsley, and Huntoon, 1986), some silicified breccia at the Orphan mine (fig. 1), and several silicified pinnacles presumably located in the ring fracture zone of the West collapse on the Marble Plateau (Sutphin, 1986; Sutphin and Wenrich, 1988). Nevertheless, none of these silicified breccia masses are as intensely silicified as the Blue Mountain pipe pinnacle.

Western Nuclear, Inc. conducted exploratory drilling at the Blue Mountain pipe from 1976 to 1978; 4 holes were drilled in 1976, 14 holes in 1977, and 5 holes in 1978. A total of 11,624 ft (3,543 m) of rotary drilling and 1,202 ft (366 m) of diamond drilling were completed within and around the pipe (unpublished data, Hualapai Tribe, 1983[1]). Western Nuclear, Inc. abandoned their claim on the lease in November 1978 and transmitted drilling records to the Hualapai Tribe in April 1979; these records include a drill hole location map, drilling reports, downhole geophysical logs, and descriptions of drill cuttings. Several hundred feet (exact footage unknown) of drill core were also recovered from the Western Nuclear drilling project. This core (now, 1988, is stored at the U.S. Bureau of Mines facility in Reno, Nevada) has not yet been studied by the authors and is not discussed in this report.

The USGS began study of the Blue Mountain pipe in 1983, as part of a mineral resource assessment of the Hualapai Reservation. Nine surface samples were collected from the pipe for petrographic and geochemical analysis; four rotary drill holes were completed by the USGS in 1984 (Van Gosen and Wenrich,

[1]The Hualapai Tribe requested through a tribal resolution that the authors review and publish these data.

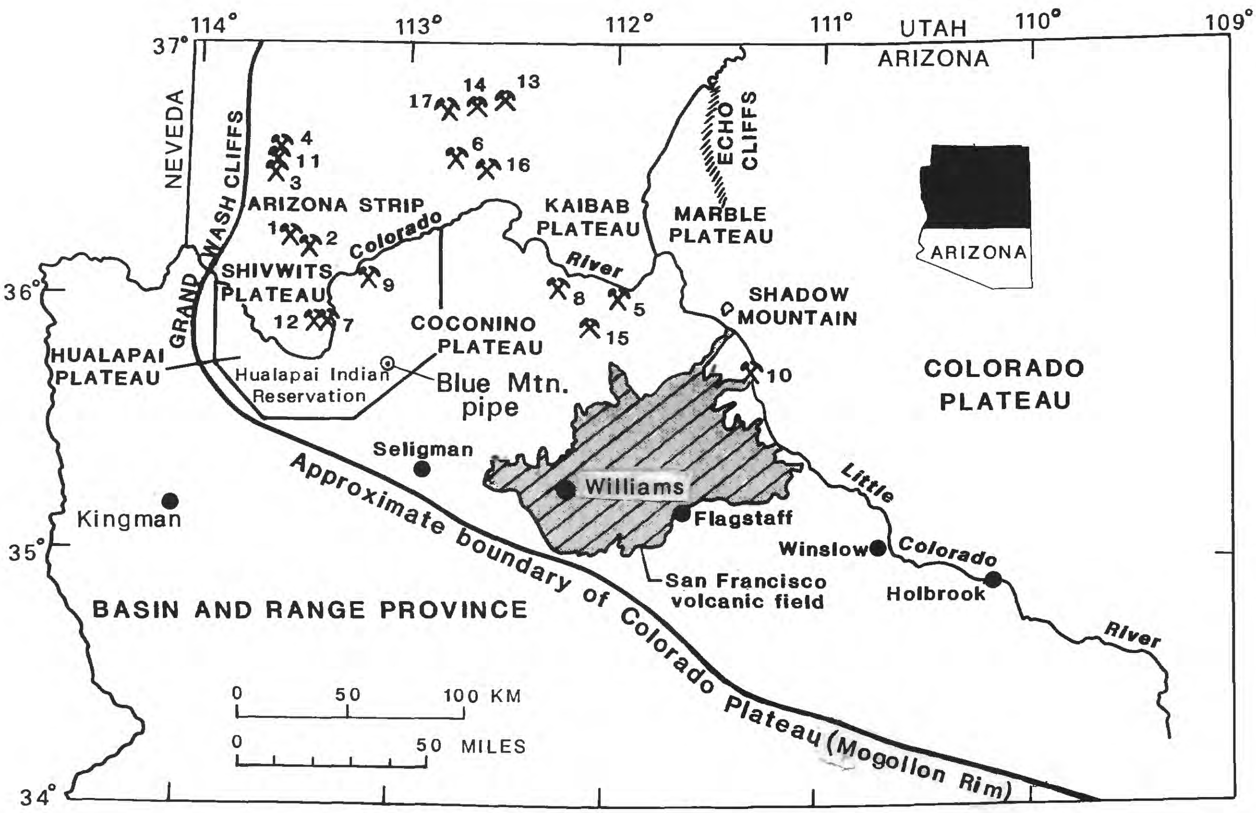


Figure 1. Index map of northern Arizona showing the location of plateaus; Hualapai Indian Reservation; the Blue Mountain pipe; boundary of the Colorado Plateau (Mogollon Rim); the San Francisco volcanic field, which buries terrane with high potential for pipes; and breccia pipes presently or previously developed into mines. Numbers refer to the following mines:

1. Copper House
2. Copper Mountain
3. Cunningham
4. Grand Gulch
5. Grandview
6. Hack Canyon
7. Old Bonnie
8. Orphan
9. Ridenour
10. Riverview
11. Savanic
12. Snyder
13. Pigeon
14. Kanab North
15. Canyon
16. Pinenut
17. Hermit

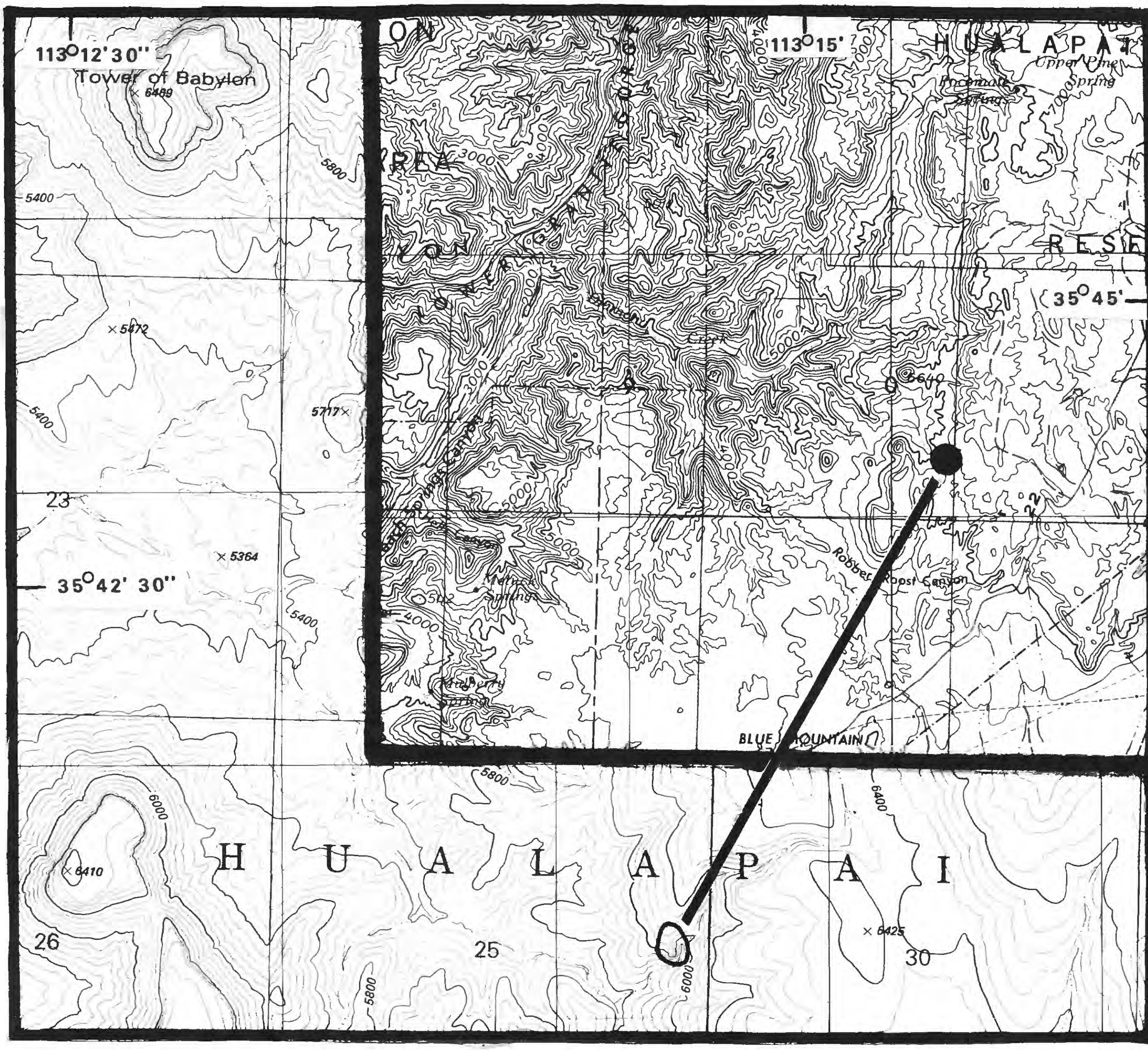


Figure 2. The Blue Mountain pipe is located on the Robbers Roost 7 -minute quadrangle (each section is 1 mi^2; scale about 1:24,000). The inset map is from the Williams 2^{o} quadrangle (scale about 1:250,000).

1985). Three of these holes were drilled inside the pipe, reaching depths of 1,445, 1,345, and 805 ft (440, 410, and 245 m), and the fourth was drilled outside the pipe, to a depth of 805 ft (245 m). The recovered drill cuttings are described and downhole geophysical logs are shown for each drill hole in appendixes 1-5. Drill cuttings, sampled in each hole at intervals of about 30 ft (9 m), were submitted for geochemical analyses; the results will be summarized in a later report.

Acknowledgements

This study and the USGS-contracted drilling was funded by the Bureau of Indian Affairs in cooperation with the Hualapai Tribe. The authors thank George Billingsley (USGS) for expert stratigraphic consulting during the drilling and manuscript preparation. The manuscript improvements by Susan B. Bartsch-Winkler and Alfred L. Bush are appreciated. T. James Reynolds completed the fluid inclusion homogenization temperatures and salinities. Special thanks goes to the Hualapai Tribe for permission to publish and evaluate the Blue Mountain pipe drilling records.

BRECCIA PIPES OF NORTHERN ARIZONA

More than 900 confirmed and suspected breccia pipes have been mapped on the 1,550 mi^2 Hualapai Reservation from 1982-1986 (fig. 3) (Billingsley and others, 1986; Wenrich, Billinglsey, and Huntoon, 1986, 1987). The breccia pipe density on the Hualapai Reservation typifies the density of solution-collapse breccia pipes that occur throughout the Colorado Plateau of northern Arizona.

The northern Arizona pipes are not classic breccia pipes in that their formation was not associated with volcanic activity. The pipes formed initially during the Late Mississippian by local collapse of strata into large dissolution caverns existing within the Redwall Limestone of Mississippian age. The Redwall contained an extensive karst system by the end of the Mississippian, with some of the caves becoming infilled by terrestrial and marine sediments of the Surprise Canyon Formation during the Late Mississippian (Billinglsey, 1986). Collapse continued after the Late Mississippian karstic event, as evidenced by thickening and sagging of the Surprise Canyon Formation and overlying Watahomigi Formation (of Early Pennsylvanian age) within Mississippian karst features (Billingsley, 1986). Collapse may have continued from the Early Pennsylvanian through the Triassic, or at least was reactivated during the wet Triassic period, resulting in upward propagation of pipe-shaped structures. Locally the breccia pipes extend upward into the Chinle Formation of Triassic age (fig. 4). Rock spalled free and fell from the ceiling and steep walls of dissolution voids, causing brecciation within the pipe. All strata collapsed downward--no clasts have been found above their normal stratigraphic position. Documented downdropping of blocks and clasts within Grand Canyon breccia pipes includes as much as 370 ft at the Orphan pipe (Chenoweth, 1986), 500 ft at the Ridenour pipe (Verbeek and others, 1988), 740 ft at the Kanab North pipe (Wenrich, 1986a), and 290 ft at the Blue Mountain pipe (this paper).

The uranium ore produced from the northern Arizona pipes is exceptionally high grade; 10 million pounds of ore recovered from four of the mines shown in figure 1 averaged 0.65 percent U_3O_8 (Mathisen, 1987). An extensive suite of

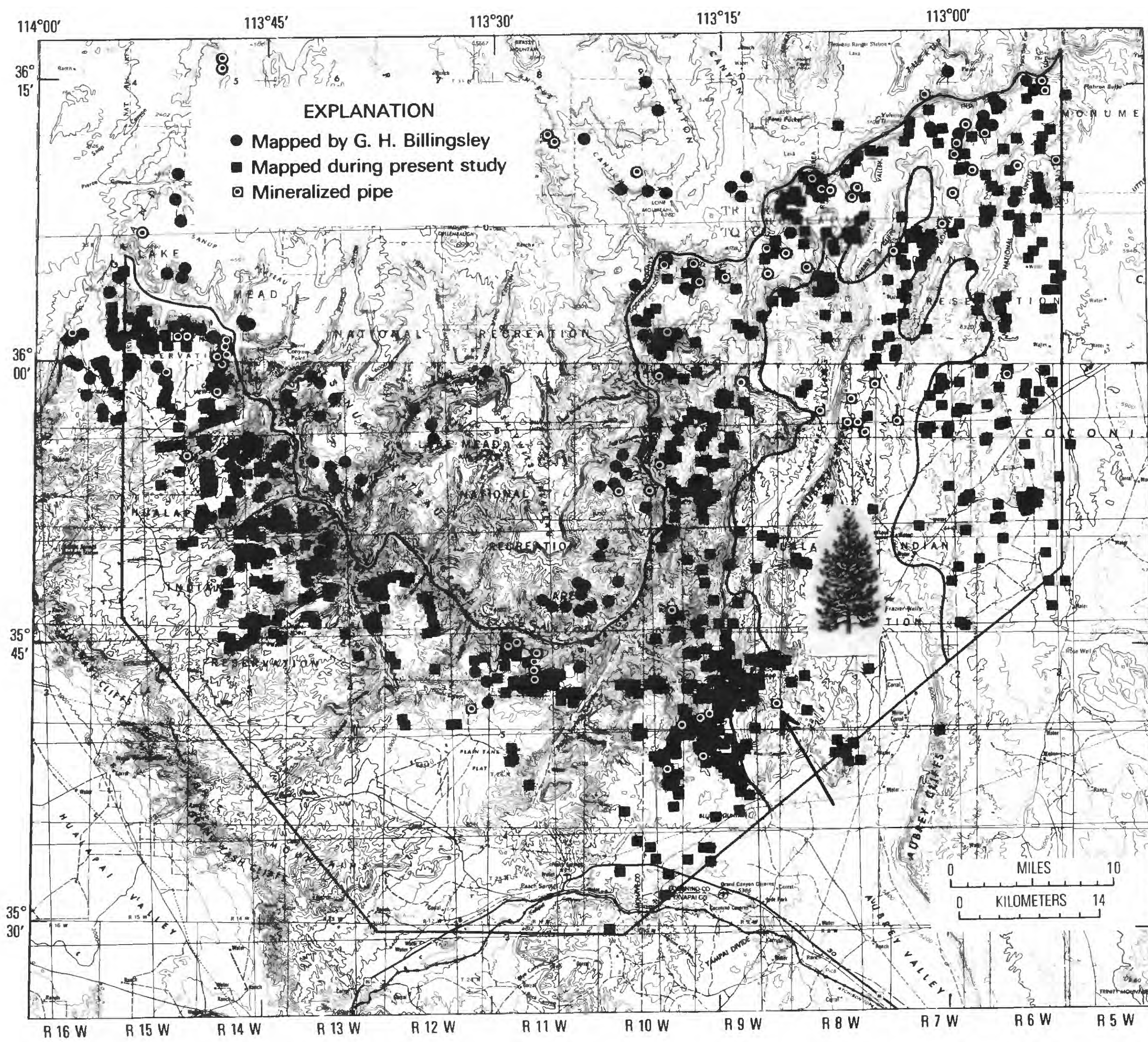


Figure 3. Map of the Hualapai Indian Reservation showing the density of solution collapse features in northern Arizona. Over 900 confirmed and suspected breccia pipes have been mapped in and around the reservation from 1982 to 1986. Vegetation is sparse on the western side, which is reflected in the greater density of identified collapses. The Blue Mountain pipe is identified by the arrow near the southeastern border of the reservation. The central portion of the eastern side of the reservation (outlined in black with tree symbol in center) is densely tree covered, preventing recognition of most pipes.

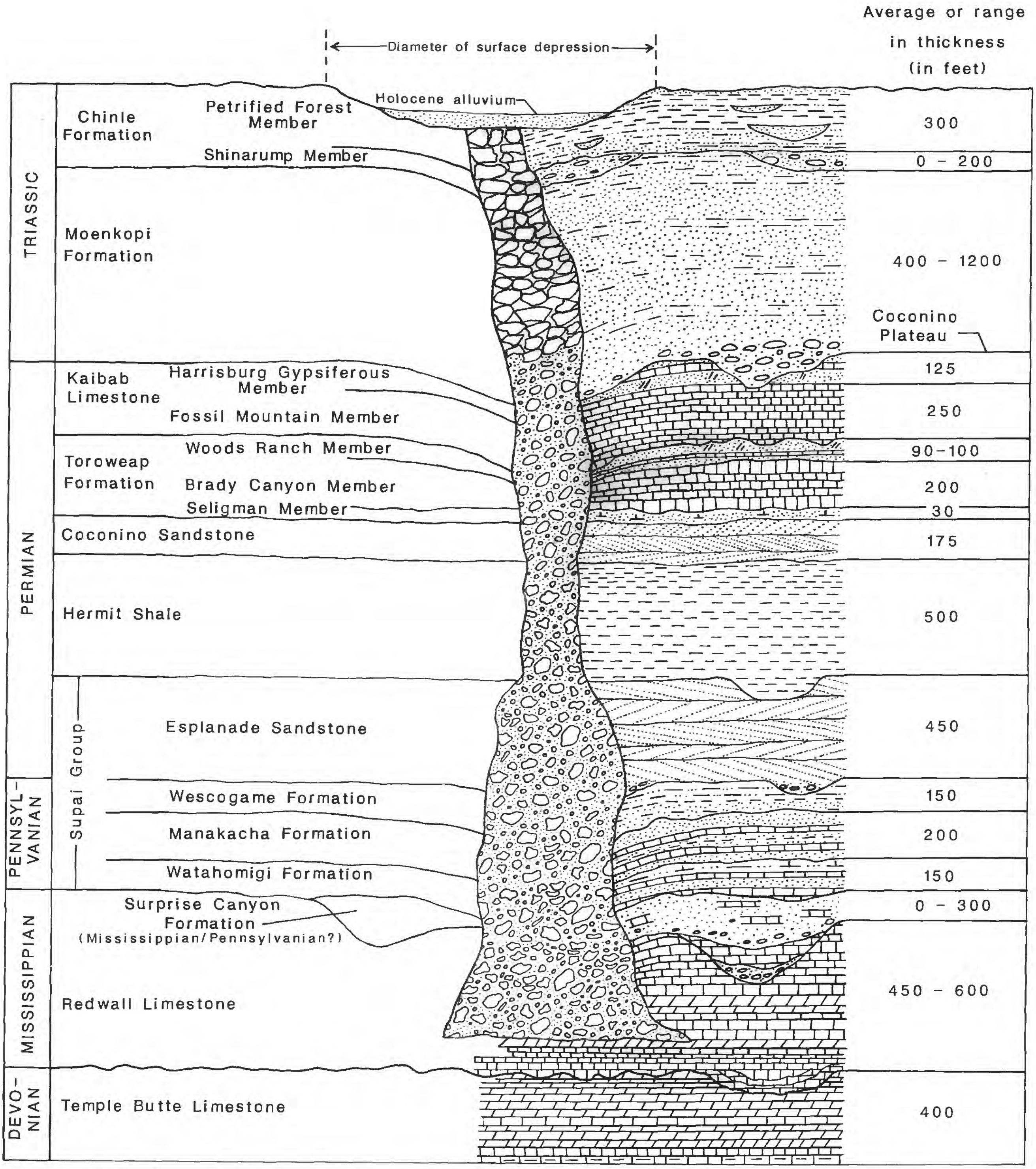


Figure 4. Schematic cross section of a breccia pipe (based on cliff exposures in the Grand Canyon of Arizona). The unit thicknesses shown for the Triassic Chinle and Moenkopi Formations represent their thickness range in the Grand Canyon region. Thicknesses for the upper Paleozoic strata correspond to the average unit thickness in the Coconino Plateau of the eastern Hualapai Reservation (Wenrich, Billingsley, and Huntoon, 1986).

elements--including Cu, Ag, Pb, Zn, Co, and Ni--are anomalously concentrated and commonly associated with the high-grade uranium ore in mineralized breccia pipes. Discussion of breccia-pipe mineralization and geochemistry is provided in Wenrich (1985) and Wenrich and Sutphin (in press), and discussion of geochemical exploration for mineralized pipes is provided in Wenrich (1986b).

If the breccia pipe is mineralized, a significant portion of the introduced minerals are concentrated within the fracture zone bounding the pipe. A steeply-dipping (subvertical), roughly circular, fracture zone formed during stoping in the country rock along the perimeter of the breccia pipe, separating the breccia body from the relatively undisturbed wall rock. In this paper we refer to this fracture zone as the "ring fracture", the term that has been applied by recent workers (Wenrich, 1985). Verbeek and others (1988) provide a detailed description of the ring fracture zone at the Ridenour mine breccia pipe, which is also located on the Hualapai Reservation (fig. 1).

Solution-collapse breccia pipes have been recognized throughout northern Arizona dominantly located in the region between the Mogollon Rim, the Grand Wash Cliffs, the Echo Cliffs, and the Utah border (southern Colorado Plateau) (fig. 1). Similar breccia pipes undoubtedly exist beneath the lavas of the San Francisco and Mt. Floyd volcanic fields (fig. 1). Evidence for structural alignment of breccia pipes on the Marble Plateau is presented in Sutphin and Wenrich (1988). Recent studies have indentified the Ga- and Ge-rich Apex mine in the Beaver Dam Mountains of southwestern Utah as an oxidized Colorado Plateau-type collapse breccia pipe (Wenrich, Verbeek, and others, 1987); this breccia body was previously believed to be a fault breccia (Bernstein, 1986). The occurrence of the Apex pipe suggests that the Arizona pipes extend into the southern Basin and Range province in areas underlain by the Redwall Limestone or equivalent units.

BRECCIA PIPES ON THE HUALAPAI RESERVATION

The Hualapai Indian Reservation is situated on the southwestern corner of the Colorado Plateau (fig. 1). It is bounded on the west by the Grand Wash Cliffs that are the western edge of the Colorado Plateau and the western limit of (known) uranium-mineralized breccia pipes (fig. 1). The eastern half of the Hualapai Reservation includes the western edge of the Coconino Plateau (fig. 1), which is capped primarily by the Harrisburg Member of the Kaibab Limestone (fig. 4).

The Coconino Plateau contains all of the Upper Paleozoic strata that commonly host breccia pipe orebodies in northern Arizona--the Coconino Sandstone, the Hermit Shale, and the formations that comprise the Supai Group (fig. 4). Mapping of breccia pipes on the Coconino Plateau is complicated by the presence of two types of shallow collapse features surficially resembling breccia pipes: 1) relatively recent karst development on the Kaibab Limestone surface (sinkholes), and 2) collapses formed by dissolution of gypsum units within the Kaibab Limestone and Toroweap Formations; both types of features are not known to have been mineralized. The collapse features, as well as possible breccia pipes in the National Tank area of the eastern Hualapai Reservation, are described in Wenrich, Billingsley, and Van Gosen (1986).

The Blue Mountain pipe crops out on the western edge of the Coconino Plateau within the Coconino Sandstone. Few other pipes on the Hualapai Reservation crop out in Coconino Sandstone cliffs, although breccia pipes in the Coconino Sandstone occur elsewhere in northern Arizona (most notably the

Orphan pipe) (fig. 1).

The area to the west of the Blue Mountain pipe contains a high density of collapse features (fig. 3). During this study about 200 collapse features (possible breccia pipes) were mapped within a 10 mile (16 km) radius of the Blue Mountain pipe (Billingsley and others, 1986); six of these features exhibit anomalous gamma radiation (greater than 2 times background).

BLUE MOUNTAIN PIPE

Surficial geology

At the surface, the Blue Mountain pipe contains a prominent silicified breccia column about 130 ft (40 m) high, 200 ft (61 m) wide, and 300 ft (91 m) long (fig. 5). The breccia column, or pinnacle, consists of strongly silica-cemented angular fragments and blocks (up to 1 m in diameter). Silicification is so complete that samples from the pinnacle were not easily cut with a standard diamond saw. The breccia is primarily derived from the Coconino Sandstone, with some fragments recognized as belonging to the overlying Toroweap Formation, as discussed below. Although the characteristic crossbedding is obscured, Coconino Sandstone is easily identified by the large and well-rounded grains, and their unimodal composition (>90 percent quartz). The silicified breccia also contains Liesegang-banded blocks (fig. 6) and spotty occurrences of malachite, azurite, gypsum, smithsonite, and chrysocolla. The Liesegang banding consists of alternating bands of Fe-minerals, primarily limonite and hematite.

The pinnacle is accentuated by stream erosion around three-fourths of its perimeter, which enhances the arcuate morphology of the hill immediately east of the pinnacle (fig. 5, right of center). While the strata exposed in the hill are unaltered, outcrops of brecciated Coconino that are less silicified and Fe-stained than the pinnacle are exposed on the valley floor and extend from the base of the pinnacle to the base of the hill (fig. 7). The position of these breccia masses, and the drilling data, suggests that the amphitheatre walls to the east of the pinnacle that contain normally stratified Coconino Sandstone mark the approximate location of the pipe's enclosing ring fracture. The lower Toroweap Formation is exposed near the top of the hill to the east and above the pinnacle and amphitheatre.

Veins containing hematite-stained, brecciated quartz fragments and vugs lined with small quartz crystals cut nearly vertically through the pinnacle. These veins exhibit anomalous gamma radiation, including one hematite-rich vein which emmitted 1,200 counts per second (40 times background)--the highest surface radiation recorded on the Hualapai Reservation during this study. The top of the silicified pinnacle appears to consist of two peaks with a shear zone between them; the anomalous veins are concentrated along this shear zone.

A silicified sample of breccia chiseled from the base of the pinnacle consists of clasts with pelmatozoan fragments, opaline lenses of algal origin, and a large fragment of a brachiopod (productid) shell (W.H. Henry, USGS, written commun.). Except for silicification, the clasts are similar to fossiliferous limestone of the Brady Canyon Member of the Toroweap Formation that crops out 290 ft (88 m) vertically above the base of the pinnacle (fig. 8), thus, documenting the minimum downward displacement that occurred within the pipe.

Figure 5. Helicopter view of the Blue Mountain pipe looking north along a cliff of Coconino Sandstone. The pinnacle in the middle of the pipe is about 130 ft (40 m) high and composed of silicified breccia. Note the semicircular shape of the base of the hill east of the pinnacle.

Figure 6. Closeup of the silicified pinnacle that consists of Coconino Sandstone and Toroweap Formation blocks and fragments. Note the well developed Liesegang banding of Fe minerals within the blocks.

Figure 7. Cemented breccia consisting primarily of Coconino Sandstone fragments, located at the base of the hill east of the pinnacle.

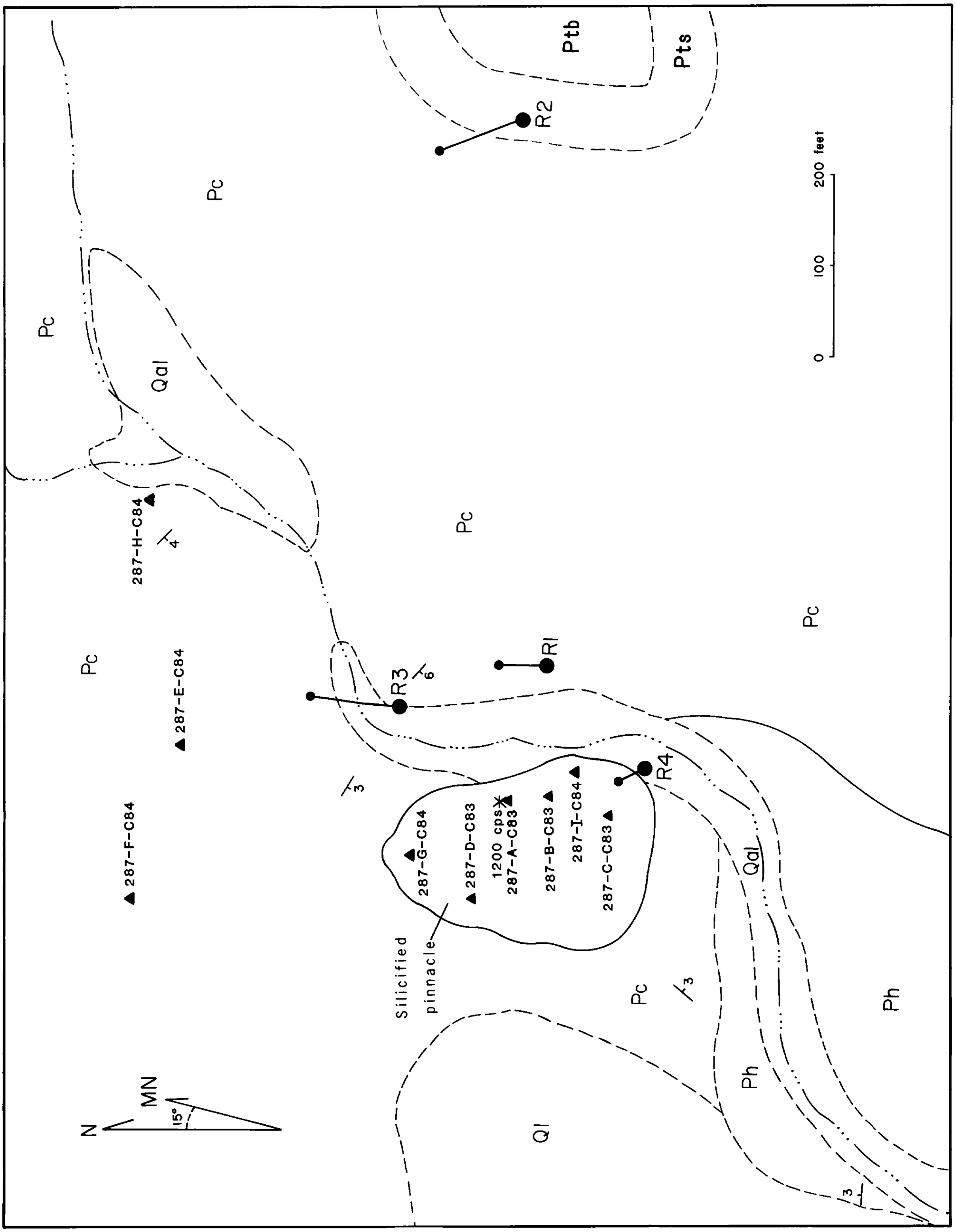


Figure 8. Geologic map of the Blue Mountain pipe showing the collar locations and drifts for the USGS-contracted drill holes.

EXPLANATION

Qal **Recent alluvium**--Unconsolidated sand, gravel and boulders

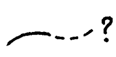
Ql **Quaternary debris flow**--Unconsolidated yellowish-gray conglomerate composed of gravel- to boulder-size clasts in a coarse-grained sandstone matrix. Gravel is composed of fragments from the Toroweap Formation and Coconino Sandstone. More than 10 ft thick

Ptb **Permian Toroweap Formation, Brady Canyon Member**--Light gray to yellowish-gray, thin-bedded, fossiliferous, micritic limestone. About 200 ft thick

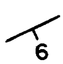
Pts **Permian Toroweap Formation, Seligman Member**--Light red to yellowish-gray, fine-grained, well-sorted, calcareous sandstone. About 30 ft thick

Pc **Permian Coconino Sandstone**--Very pale orange, very fine- to fine-grained, well-sorted, thick-bedded sandstone. Characterized by large-scale wedge planar cross-stratification. About 180 ft thick

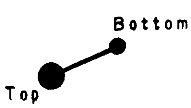
Ph **Permian Hermit Shale**--Moderate red siltstone and fine-grained sandstone. Near the collapse structure color changes to a light bluish-gray to light gray. Thin- to thick-bedded. About 675 ft thick



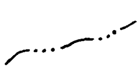
Contact of map units--Dashed where inferred, queried where uncertain



Strike and dip of bedding



Drill holes with bottom location in map view



Intermittent streams

Surface rock sample location

Petrography of surface samples

Nine representative surface samples were collected from the Blue Mountain pipe for petrographic and geochemical study. The sample locations are shown in figure 8, and petrographic descriptions for seven of these samples are provided in appendix 6. Appendix 7 provides the results of chemical analyses for six of these samples as well as analyses of four background samples of Coconino Sandstone, taken from the south rim of the eastern Grand Canyon.

Locations 287-B-C83 and 287-C-C83 (fig. 8) mark spotty occurrences of pipe-related secondary carbonates and sulfates. At location 287-B-C83, a very pale green crust of gypsum covers the rock. The gypsum was deposited on top of minute scattered flecks of a pale blue mineral, perhaps smithsonite, which apparently imparts the "greenish" color to the otherwise clear gypsum. A second sample from location 287-B-C83 is similarly covered with a thin gypsum crust. The sandstone in this second sample from 287-B-C83 is impregnated with malachite and an unidentified mineral, which stained the sandstone matrix black. The fact that the malachite surrounds these black areas in a halo-like fashion suggests that the black coloration is due to the presence of a disseminated copper sulfide, such as chalcocite.

Location 287-C-C83 is an area of highly fractured, hematitic and silicified sandstone. The fracture surfaces are stained with malachite, azurite, and chrysocolla. Small (1-inch diameter) fragments of the fractured host rock are encrusted with the same minerals.

While the pinnacle is primarily composed of Coconino Sandstone blocks and clasts, it also contains blocks from the Toroweap Formation, specifically on the lower eastern edge of the pinnacle (samples 287-A-C83 and 287-I-C84). An examination of these two samples reveals a similar petrography to descriptions of the Toroweap by Rawson and Turner (1974), confirming a Toroweap lithology for both samples. Sample 287-A-C83 corresponds to the grain-supported skeletal limestone of the Brady Canyon Member, and 287-I-C84 correlates with the Woods Ranch Member. The presence of clasts of the Toroweap Formation on the east side of the pinnacle is significant in that it indicates the minimum measurable downdrop of 290 ft (88 m) that occurred within the pipe. It also provides additional evidence that the breccia pipe is indeed wider in extent than just the pinnacle. Displacement of breccia clasts appears to increase towards the center of some breccia pipes (Kofford, 1969; Gornitz and Kerr, 1970), suggesting that clasts of the Toroweap Formation on the east side of the pinnacle may be positioned towards the center of the pipe. Thus, the pinnacle represents only the western side of the breccia pipe.

The unaltered Coconino Sandstone is a cross-bedded eolian sandstone unit that contains over 90 percent quartz and is classified as a quartz arenite. Recrystallized quartz overgrowths are a common cementing agent. The SiO_2 contents of four samples of unaltered Coconino Sandstone from below the south rim of the eastern Grand Canyon are given in appendix 7. SiO_2 content in the four samples ranges from 92.1 to 95.6 percent, averaging 94.1 percent. Three additional background samples of the Coconino Sandstone were taken near the pipe (287-E-C84, 287-F-C84, 287-G-C84; fig. 8). These three samples contain 94.5 percent, 95.0 percent, and 93.4 percent SiO_2, respectively, averaging 94.3 percent SiO_2. In contrast, a sample of color-banded Coconino Sandstone from the "silicified" pinnacle (287-G-C84) contains 95.5 percent SiO_2.

The values given above indicate that silicification of the pipe involved an increase in SiO_2 of about 1 percent. However, this apparent increase may be suspect for two reasons: (1) only one sample of Coconino lithology from the pinnacle was analyzed. Although the SiO_2 content of this sample is over 1 percent higher than each of the background averages, one of the background samples (PCU-D-C84) contains more SiO_2. Stronger evidence for the addition of silicia is provided by two samples of Toroweap Formation clasts from the pinnacle. While the Toroweap Formation is generally less siliceous than the Coconino Sandstone, these two samples contain 95.1 percent and 96.9 percent SiO_2. (2) Samples 287-E-C84, 287-F-C84, and especially 287-H-C84, may have been close enough to the pipe to be affected by the mineralizing fluids and hence are not truly background samples. Sample 287-H-C84 contains very coarsely crystalline, euhedral kaolinite, similar to occurrences of kaolinite in breccia pipes such as the Orphan mine (fig. 1). Sample 287-H-C84 also contains spotty hematite and goethite which occur both as blebs in the sandstone matrix and as cubes which are apparently pseudomorphs of pyrite (fig. 9).

While the amount of increase in SiO_2 may remain uncertain, the pinnacle's resistance to erosion can be shown to be a function of the strongly sutured and interlocking contacts between adjacent quartz grains. Petrographic examinations of background samples of Coconino Sandstone show that the contacts between adjacent grains are commonly straight or curved, with the quartz overgrowths crystallizing into the characteristic six-sided habit. The grain-to-grain contacts in Coconino Sandstone samples from the pinnacle are quite different. The texture is a mosaic of strongly sutured and interlocking grains (fig. 10). Dust rims and other obvious contacts between the detrital quartz grains and their enveloping overgrowths show that the suture texture is the result of secondary overgrowth.

Fluid inclusion data

Distinctly bimodal filling temperatures have been obtained from fluid inclusions in quartz crystals that line small vugs in sample 287-A-C83. This sample was collected from the east side of the silcified pinnacle (fig. 8) along a shear zone that bisects the pinnacle vertically; this zone contains the radioactively-anomalous brecciated veins discribed earlier. Temperatures were measured from primary inclusions and the results fall into two distinct groups: (1) 90-110°C (six inclusions) with all measured salinities greater than 23 weight percent NaCl equivalent, and (2) 256-317°C (15 inclusions) with salinites from 5 to greater than 23 weight percent NaCl equivalent. The first group of inclusions recorded temperatures and salinites indistinguishable from those determined from fluid inclusions within sphalerite, dolomite, and calcite located in ore-bearing, northern Arizona breccia pipes. The second group of inclusions recorded higher fluid temperatures probably associated with the silicification of the pinnacle. The second group of fluid inclusions, and thus the silicification, may be associated with Tertiary volcanism, such as that of Blue Mountain (14.6 Ma (million years ago), Damon, 1968), located 6 mi (10 km) south of the Blue Mountain pipe, and/or several, probably related, Tertiary intrusives located within 3 mi (5 km) of the pipe.

SILICIFIED PINNACLES IN NORTHERN ARIZONA BRECCIA PIPES

Silicified pinnacles occurring in association with breccia pipes, though not typical, are not unique to the Blue Mountain pipe. On the Marble Plateau, six conspicuous silica plugs averaging about 30 ft in height (Wenrich and Billingsley, 1986, fig. 10) occur on the periphery of the West collapse. In one of the plugs, beds dip inward toward the collapse. These silicified

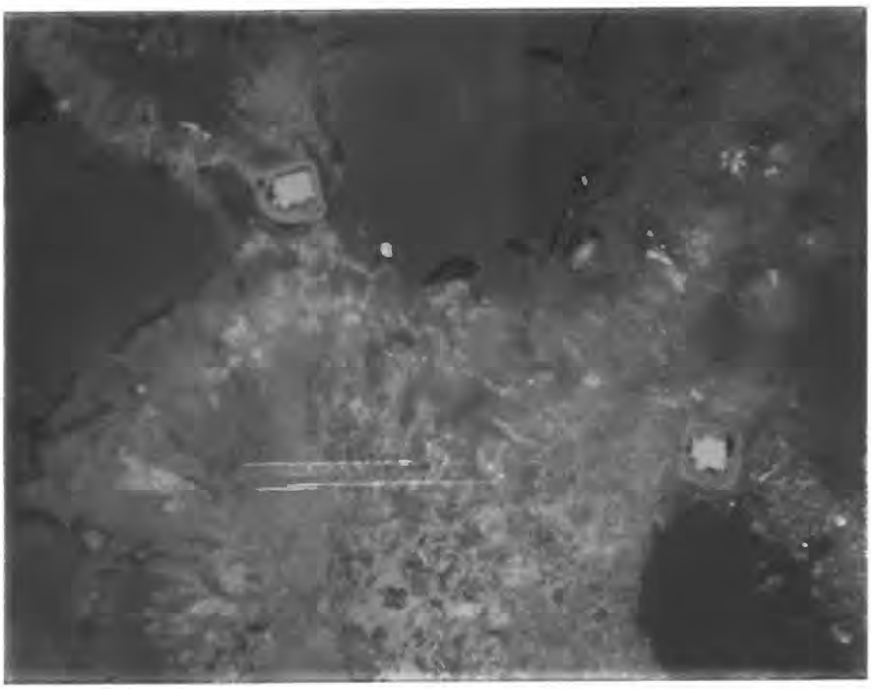


Figure 9. Photomicrograph showing evidence of pyrite mineralization. Matrix between framework quartz (gray) contains two cubes pseudomorphic after pyrite with hematite cores (white) and goethitic/limonitic edges. Sample #287-H-C84. Reflected light. Long axis of photo = 0.24 mm.

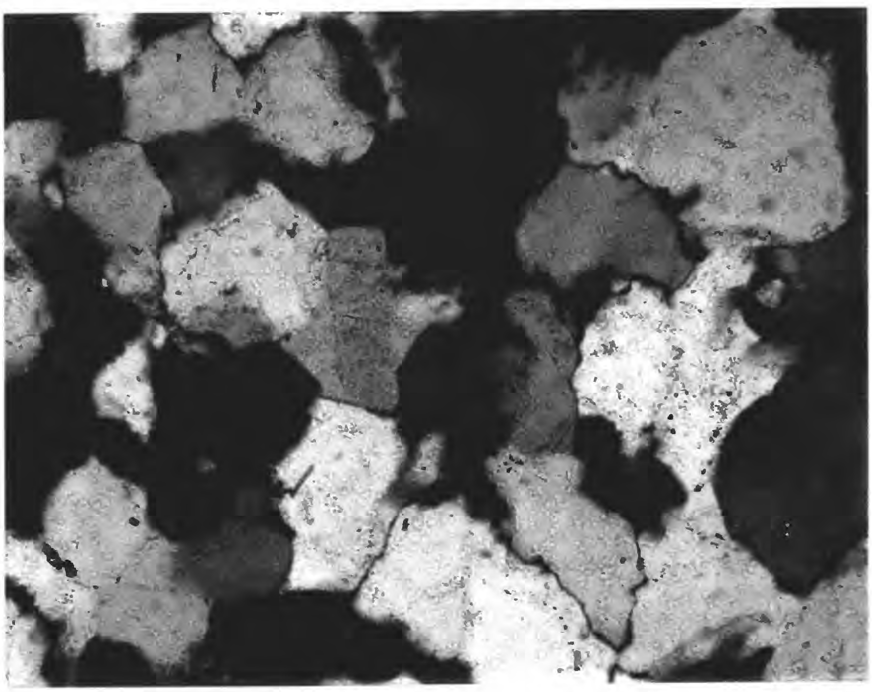


Figure 10. Photomicrograph of silicified Coconino Sandstone from the pipe. Suturing and interlocking of adjacent quartz grains makes the pinnacle more erosion resistant than the surrounding country rock. Sample #287-G-C84. Transmitted light. Long axis of photo = 0.24 mm.

plugs, as well as the silicified pinnacle that forms Black Rock on the Marble Plateau, are located in unbrecciated strata over 1,600 ft stratigraphically higher than the Blue Mountain pipe. Similar silicification permitted brecciated Coconino Sandstone to resist erosion and form a large plug at mineralized pipe #243 (Wenrich, Billinglsey, and Huntoon, 1986), located about 35 mi (21 km) north of the Blue Mountain pipe on the Hualapai Reservation. All of these silicified pinnacles probably lie along the ring fractures of their respective pipes. This (along with the local geomorphology) suggests, in the case of the Blue Mountain pipe, that the silicified pinnacle may occur within the ring fracture zone on the pipe's western edge. Thus, the center (and presumably most mineralized portion) of the Blue Mountain pipe may exist beneath the hill to the east of the pinnacle, and future drill holes should be angled underneath this hill.

USGS DRILLING AT THE BLUE MOUNTAIN PIPE

Four holes were drilled at the Blue Mountain pipe in 1984 by USGS-contracted drillers; all holes were rotary drilled with a button bit. Their collar locations and drifts are shown in figure 8.

Hole 1 (R1) is located within the pipe at the base of the east wall (as discussed above) that forms part of the natural amphitheatre enclosing the pipe (fig. 11). This wall consists of normally stratified Coconino Sandstone and is the approximate location of the enclosing ring fracture. Hole 1 reached a total depth of 1,445 ft (440 m). Nearly constant loss of drilling circulation, due to very high porosity inherent to the breccia body, prevented recovery of drill cuttings from 585 ft (178 m) to 1,405 ft (428 m).

Hole 2 (R2) was drilled on a hill east of the amphitheatre (and east of the breccia pipe) on a bench formed by the Seligman Member of the Toroweap Formation. The location of this hole outside of the pipe resulted from of an unsuccessful attempt to excavate a road and drilling platform to a site about 200 ft east of R1. A decision was made to take advantage of the completed road and drill a hole that would provide background data. The hole is about 550 ft (165 m) outside the pipe, reaching a total depth of 805 ft (245 m). Only background uranium values were recorded in downhole gamma logs of the hole. Drill cuttings were recovered to a depth of 685 ft (209 m).

Hole 3 (R3) was drilled near the gully draining into the amphitheatre, reaching a total depth of 1,345 ft (410 m). Drill cuttings were recovered for most of the drill hole, but were lost from 1,195 to 1,245 ft (364 to 379 m) and from 1,265 to 1,345 ft (386 to 410 m). Drilling results show that rotary drilling into breccia pipes tends to drift toward the outside of the pipe (fig. 8), due to its brecciated, vuggy nature and the outward dip of the ring fractures.

Hole 4 (R4) drifted beneath the silicified pinnacle to a total depth of 805 ft (245 m). Unfortunately, circulation was lost frequently during the drilling of hole 4; cuttings were not recovered from 285 to 325 ft (89 to 99 m) and from 405 ft (123 m) to the bottom of the hole.

Lithologic logs

Lithologic and geophysical logs for the four USGS drill holes are presented in appendixes 1-5. Lithologies are derived from drill cuttings; however, it was usually impossible to determine from the cuttings if the rock was brecciated. The downhole geophysical logs for USGS holes R1, R3, and R4

Figure 11. In 1984 the USGS rotary drilled three holes inside the Blue Mountain pipe and one hole outside the pipe. Here, the drill rig sits over hole 1.

recorded anomalous gamma radiation, suggesting these three holes were drilled within the pipe, and thus, probably penetrated brecciated rock. The contacts between the Seligman Member of the Toroweap Formation, the Coconino Sandstone, and the Hermit Shale were placed where cuttings first began to express the lithologic characteristics of the underlying unit. Contacts between deeper units were not located due to the sparsity of drill cuttings.

The Hermit Shale is normally a red unit but, within the Blue Mountain pipe, reducing fluids altered large portions of the unit to shades of gray. Drill cuttings recovered from the Hermit Shale within the pipe exhibit the following: hole 1 contains about 40 percent gray, reduced rock (where cuttings were available), hole 3 about 20 percent, and hole 4 about 70 percent. Assuming that the reducing fluids were more prevalent toward the center of the pipe, this pattern of gray, reduced rock and the geometry of the pipe, suggests that hole 4 was nearest the center of the pipe and hole 3 was furthest from it. The hole drilled outside the pipe, hole 2, contains no gray, reduced rock within the Hermit Shale for the 435 ft (133 m) of cuttings recovered. While the cuttings from hole 2 reveal only oxidized rock, the coloration is more subdued than the normally red Hermit Shale, possibly indicating that some alteration had affected rocks in the vicinity of the pipe. The extensiveness of such alteration beyond pipe boundaries can be observed at pipe #243 (Wenrich, 1985, fig. 3B), where the reduction of the most porous Hermit Shale beds extends over 200 ft beyond the pipe walls.

The most conspicuous mineralization observed in the drill cuttings is in the scattered occurrence of finely disseminated, silt-size pyrite found in drill holes 1 and 4. The pyrite, where present, always occurs within reduced intervals of the Hermit Shale. This compares well with core samples from an unbrecciated section of the Mohawk Canyon pipe, which contains Hermit Shale with intervals of similarly reduced rock; these reduced sections also contain finely disseminated pyrite (Wenrich and others, 1988). Hematite and in one interval, limonite, occasionally stain areas within reduced cuttings from the Blue Mountain pipe.

In the area surrounding the Blue Mountain pipe, the Hermit Shale is about 675 ft (206 m) thick, the Esplanade Sandstone is about 200 ft (61 m) thick, and the remainder of the Supai Group is about 600 ft (183 m) thick (George Billingsley, USGS, oral commun., 1987) (fig. 4). The limestone and chert recovered in drill cuttings near the bottom of hole 1, from 1,405 to 1,425 ft (428 to 434 m), are from carbonate horizons within the Manakacha or Watahomigi Formation. Based on drill cuttings and apparent thicknesses of units, hole 2 bottoms out within the Hermit Shale, hole 3 bottoms within the Manakacha or Watahomigi Formation, and hole 4 bottoms within the Esplanade Sandstone.

Geophysical logs

Downhole geophysical logs were completed for each USGS drill hole. Gamma ray, magnetic susceptibility, density, and caliper logs were made on all of the USGS holes. Induced polarization (IP) and resistivity logs were run for those sections of holes 2, 3, and 4 that would hold water. However, the cavernous porosity inherent to breccia pipes made it impossible to maintain water-filled holes through the duration of the logging; the dry sections of the holes could not be logged for IP and resistivity.

A uranium-mineralized zone in the Hermit Shale was intersected by each of the three USGS holes drilled within the pipe. The zone is 34 ft thick in hole 4, at a depth of 395-429 ft, and contains four lenses, 2-3 ft thick, averaging 0.012 percent eU_3O_8. One of these lenses is 3 ft of 0.018 percent eU_3O_8, which is the highest gamma radioactivity logged in the USGS drilling. In hole 1, a 12-ft thick uranium-mineralized zone consists of two lenses (depth of 425-437 ft)--a 3 ft lens of 0.008 percent eU_3O_8 and a 5 ft lens of 0.016 percent eU_3O_8. In hole 3 the same uranium-mineralized horizon contains a single lens 4 ft thick of 0.007 percent eU_3O_8.

Another anomalous uranium-mineralized zone, totalling 19-ft thick, occurs at a depth of 123 to 142 ft in hole 4; this zone consists of four lenses 2-3 ft thick, averaging 0.008 percent eU_3O_8. This anomalous zone is stratigraphically higher in the pipe than the zone described in the paragraph above. Hole 2, drilled outside the pipe, shows only background radioactivity throughout the hole, with values less than 0.002 percent eU_3O_8.

Cuttings were recovered from nine of the 11 uranium-mineralized lenses discussed above. Of these, eight of the intervals contain reduced rock, and one contains oxidized rock. (Due to the small thickness--4 ft--of the zone, and the lag time involved between when the cuttings are actually drilled and when they are blown onto the surface, the drill cuttings for the oxidized interval may not accurately reflect the rocks present; that is, reduced rocks may actually be present within the interval.) Disseminated pyrite was noted in four of the eight reduced, uranium-mineralized lenses. The relative amount of uranium-mineralization that occurred within the Hermit Shale in each of the four holes is in direct proportion to the amount of rock that was reduced. Hole 4 underwent the most reduction (70 percent) and contains the most uranium-mineralization; hole 2, drilled outside the pipe, contains no reduced rock for the intervals recovered, and no anomalous radioactivity. This association of reduced to uranium-mineralized rock is consistent with occurrences in other uranium-rich, Colorado Plateau breccia pipes (Wenrich, 1985).

Under normal conditions, density logs record the bulk density of the rock. In breccia pipes, low density peaks commonly reflect the fractured rock and solution caverns within the pipe and, thus, the density log is generally a mirror image of the caliper log.

The downhole geophysical logs show that the magnetic susceptibility in the holes is relatively low. This is probably a reflection of the high content of reduced rock present within the pipe. The following evidence explains this association of reduced rock and low magnetic susceptibility: As organic matter has been found in only sparse occurrences within these pipes, Gornitz and others (1988) propose that the Fe^{+3} was reduced by H_2S. Bleaching by these H_2S-bearing fluids probably altered the detrital ilmenite and magnetite to nonmagnetic Fe and Ti-bearing minerals, such as pyrite and leucoxene. A petrographic study of drill core from the Mohawk Canyon pipe, also located on the Hualapai Reservation (Wenrich and others, 1988), across a sharp oxidation/reduction contact within the Hermit Shale, found that the oxidized side of the contact contains about 0.5 percent framework ilmenite grains, while the reduced/pyritic side does not contain even a trace of ilmenite--it has been replaced by leucoxene. Similar ilmenite depletion has been noted in at least three other mineralized breccia pipes (Wenrich, 1986b). Within the Blue Mountain pipe, dark opaque minerals occur from 1,030 to 1,060 ft depth in hole 3, and the magnetic suspectibility log shows an anomalous increase over this interval, suggesting these minerals are magnetic. In fact, below the 430 ft depth in hole 3 the continuous red to orange color of the cuttings suggests that reducing fluids did not reach this lower portion of the pipe, or that the hole is no longer within the pipe, but to one side of it.

Portions of holes 2, 3, and 4, held water long enough for induced polarization (IP) and resistivity logs to be made. Only in hole 4 was the water level adequate to run the IP log across the uranium-mineralized zones described above. In hole 4, increased IP values occur at a depth of 389 ft, indicating sulfide mineralization just above the uranium-mineralized zone that was logged from 395-429 ft depth (appendix 5). Within this zone, increased IP values coincide with the upper two lenses of uranium mineralization (395 to 403 ft), again indicating that sulfide (pyrite) is present in the associated reduced rock. Drill cuttings contained disseminated pyrite in hole 4 for the entire interval (325-405 ft). Within the upper uranium-mineralized zone of hole 4, anomalous IP values from the 126-128 ft depth suggest sulfide mineralization that was not obvious in the drill cuttings.

Geochemistry of drill cuttings

Samples of drill cuttings were submitted for geochemical analyses. A cuttings sample was taken about every 30 ft within the intervals recovered, with 26 samples analyzed from hole 1, 23 from hole 2, 33 from hole 3, and 13 from hole 4. The geochemical data will be presented in another report.

The highest-grade uranium-mineralized rock encountered in the USGS drilling occurred at 395-403 ft depth in hole 4. Cuttings taken from the top of this interval, at 395 ft, have the highest U content--41 parts per million--of all the samples analyzed. This sample's geochemistry is listed in table 1.

DRILLING BY WESTERN NUCLEAR, INC. AT THE BLUE MOUNTAIN PIPE

Downhole gamma-ray logs are the only geophysical logs available in the tribal records for the Western Nuclear drilling. Table 2 summarizes the uranium-mineralized intervals on these gamma ray logs which are $\geq$200 counts per second (cps). For holes containing no interval >200 cps, the most anomalous interval is listed. Average eU_3O_8 values were calculated for each of the listed intervals by multiplying the average cps for each zone by 2 times the K factor for the drill hole (air). For example, drill hole BM-12 has a 0.5 ft K factor (air) of 2.76×10^{-5}. The interval 418 to 428 ft in this hole displays 1,533 cps. So, the average eU_3O_8 for this interval is determined by 1,533 cps x $(2 \times 2.76 \times 10^{-5})$= 0.085 percent eU_3O_8. This value represents the highest radioactivity recorded in the Western Nuclear drilling.

Figure 12 shows the collar locations and drifts for the Western Nuclear drill holes based on records sent to the Hualapai Tribe. A field check revealed that some of the cement plugs capping each hole were labelled differently from that shown on the drill records. The authors suspect that the hole location map on record (fig. 12) is correct, because it matches the gamma ray logs, but that the hole plugs were mislabelled by the reclamation crew. Also, accurate collar elevations are not available to normalize the elevations of each uranium- mineralized zone recorded. The gamma-ray logs on record list collar elevations for each of the Western Nuclear holes, but these elevation values are consistently at least 300 ft less than that shown on the Robbers Roost 7 minute quadrangle (the map was published after Western Nuclear drilling). USGS drill hole R1, with a collar elevation of 6,000 ft, and Western Nuclear drill hole BM-12, with a reported collar elevation of 5,688 ft, were drilled within 10 ft of distance and 5 ft of elevation from each other (fig. 13). The 312 ft elevation difference between these two drill holes was used as an adjustment factor for the remaining collar elevations reported for the Western Nuclear drill holes. This adjustment produced reasonable collar

Table 1--Geochemistry of cuttings sample taken from the 395 ft depth in USGS hole 4. All values in parts per million except where indicated otherwise.

Element	Concentration	Element	Concentration
Ag	<2	Mn	51
Al_2O_3 %	7.1%	Mo	60
As	560 **	Na %	0.03%
Au	<8	Nb	<4
Ba	36	Nd	19
Be	1	Ni	28
Bi	<10	P %	0.04% **
Inorganic C%	0.23%	Pb	17
Organic C%	0.04%	Rb	44
Total C%	0.27%	Total S%	4.3% **
CaO %	0.63%	Sb	3.8 **
Cd	<2	Sc	5.0
Ce	39	Se	1
Co	10	SiO_2 %	76.%
Cr	46	Sm	4.1
Cs	3	Sn	<20
Cu	16	Sr	270. **
Eu	0.78	Ta	0.73
F %	0.05%	Tb	0.53
Total Fe_2O_3%	6.6% **	Th	5.6
Ga	9	Ti %	0.22%
Hf	8.0	U	41 **
Hg	0.07	V	39
Ho	<4	Y	11
K_2O %	1.9%	Yb	1.9
La	19	Zn	170
Li	13	Zr	250
Lu	0.29	LOI	5.1%
MgO %	0.85%		

** >1 standard deviation above mean value for the sample set (drill cuttings).
LOI= Loss on ignition at 900^{o}C

elevations and allows correlation of the uranium-mineralized zones recorded in the Western Nuclear and USGS drill holes. The adjusted (approximate) collar elevations for the Western Nuclear drill holes are listed in table 2.

Fourteen of 23 holes drilled by Western Nuclear encountered uranium-mineralized rocks, all within the same horizons in which the USGS drilling intersected uranium-mineralized rocks. Two mineralized zones in the Hermit Shale were intersected in Western Nuclear drill hole BM-7--a zone from 313 to 321 ft depth (elevation about 5,658 to 5,650 ft) averaging 0.012 percent eU_3O_8, and a zone from 381 to 394 ft depth (elevation about 5,590 to 5,577 ft), averaging 0.028 percent eU_3O_8. By inspection and comparison of the approximate elevations, it is clear that the lower (deeper) uranium-mineralized zone in hole BM-7 is the same anomalous zone encountered in each of the three USGS holes drilled within the pipe. This lower uranium-mineralized zone was also present in Western Nuclear holes BM-1, 3, 4, 5, 6,

Table 2--Summary of drilling at the Blue Mountain pipe by the USGS in 1984, and by Western Nuclear, Inc. from 1976 to 1978. Locations of the individual drill holes are shown in figs. 8 and 12. The column on the right below, lists those intervals in each drill hole where logged gamma ray values are ≥200 counts per second (cps); where no interval is >200 cps, the most anomalous interval is listed. All elevation and drilling depth values are in feet.

The numbers in parentheses are average eU_3O_8 values that were calculated by multiplying the average cps for each zone by 2 times the K factor for the drill hole (air). This calculation method is valid for obtaining an approximate average grade, though values for zones ≤2 ft thick may be slightly underestimated. A more precise technique for calculating U grades is described in Scott (1963).

Drill hole	Drilling depth	Total depth logged	Collar elevation	Intervals with gamma ray values >200 cps
USGS holes				
R1	1,000′	1,430′	6,000′	432′ - 437′= 0.016% eU_3O_8
R2	805′	800′	6,250′	no lenses >0.0025% eU_3O_8
R3	1,345′	1,345′	6,020′	410′ - 414′= 0.007% eU_3O_8
R4	805′	795′	5,980′	123′ - 125′= 0.010% eU_3O_8
				126′ - 128′= 0.008%
				140′ - 142′= 0.011%
				395′ - 398′= 0.013%
				400′ - 403′= 0.018%
				425′ - 427′= 0.014%
				427′ - 429′= 0.010%
Western Nuclear holes			Adjusted collar elevation	
BM-1	1,000′	490′	5,967′	353′ - 356′= 206 cps (0.011%)
				357′ - 360′= 198 cps (0.011%)
				378′ - 383′= 444 cps (0.024%)
				384′ - 390′= 339 cps (0.018%)
BM-2	938′	928′	5,953′	275′ - 285′= 319 cps (0.017%)
BM-3	520′	508′	5,958′	381′ - 388′= 1,111 cps (0.06%)
				389′ - 393′= 622 cps (0.034%)
				394′ - 404′= 1,000 cps (0.054%)
BM-4	500′	491′	5,952′	385′ - 390′= 244 cps (0.013%)
				392′ - 398′= 228 cps (0.012%)
BM-5	520′	511′	5,999′	358′ - 362′= 171 cps (0.009%)
BM-6	505′	498′	5,982′	389′ - 398′= 367 cps (0.020%)
				399′ - 403′= 372 cps (0.021%)

Table 2--Continued

Drill hole	Drilling depth	Total depth logged	Adjusted collar elevation	Intervals with gamma ray values >200 cps
BM-7	445′	433′	5,971′	313′ - 317′= 200 cps (0.011%)
				318′ - 321′= 244 cps (0.013%)
				381′ - 385′= 222 cps (0.012%)
				385′ - 387′= 222 cps (0.012%)
				388′ - 391′= 700 cps (0.039%)
				391′ - 394′= 856 cps (0.047%)
BM-8	445′	440′	5,953′	376′ - 382′= 266 cps (0.015%)
				389′ - 396′= 289 cps (0.016%)
				396′ - 402′= 1,133 cps (0.063%)
BM-9	500′	493′	5,962′	373′ - 383′= 622 cps (0.034%)
				390′ - 397′= 422 cps (0.023%)
				398′ - 402′= 305 cps (0.017%)
BM-10	460′	459′	5,945′	397′ - 398′= 240 cps (0.013%)
				404′ - 412′= 205 cps (0.011%)
BM-11	545′	536′	6,000′	488′ - 495′= 67 cps (0.004%)
BM-12	560′	551′	6,000′	412′ - 418′= 420 cps (0.023%)
				418′ - 428′= 1,533 cps (0.085%)
BM-13	602′	595′	6,102′	451′ - 456′= 380 cps (0.021%)
				457′ - 460′= 313 cps (0.017%)
BM-14	502′	497′	6,082′	27′ - 31′= 77 cps (0.004%)
BM-15	575′	572′	6,117′	106′ - 108′= 50 cps (0.003%)
BM-16	500′	496′	6,102′	145′ - 150′= 68 cps (0.004%)
BM-17	505′	499′	6,000′	431′ - 439′= 622 cps (0.034%)
				441′ - 446′= 450 cps (0.025%)
				450′ - 454′= 570 cps (0.031%)
				454′ - 457′= 275 cps (0.015%)
				458′ - 459′= 220 cps (0.012%)
				460′ - 463′= 530 cps (0.029%)
				463′ - 464′= 385 cps (0.021%)
				464′ - 469′= 365 cps (0.020%)
				470′ - 474′= 250 cps (0.014%)
BM-18	600′	589′	5,962′	81′ - 85′= 44 cps (0.002%)
BM-19	500′	491′	5,917′	311′ - 314′= 190 cps (0.010%)
BM-20	500′	493′	5,919′	212′ - 213′= 44 cps (0.002%)
BM-21	490′	483′	5,908′	344′ - 347′= 40 cps (0.002%)
BM-22	520′	516′	6,052′	512′ - 516′= 52 cps (0.003%)
BM-23	600′	414′	6,007′	307′ - 309′= 42 cps (0.002%)

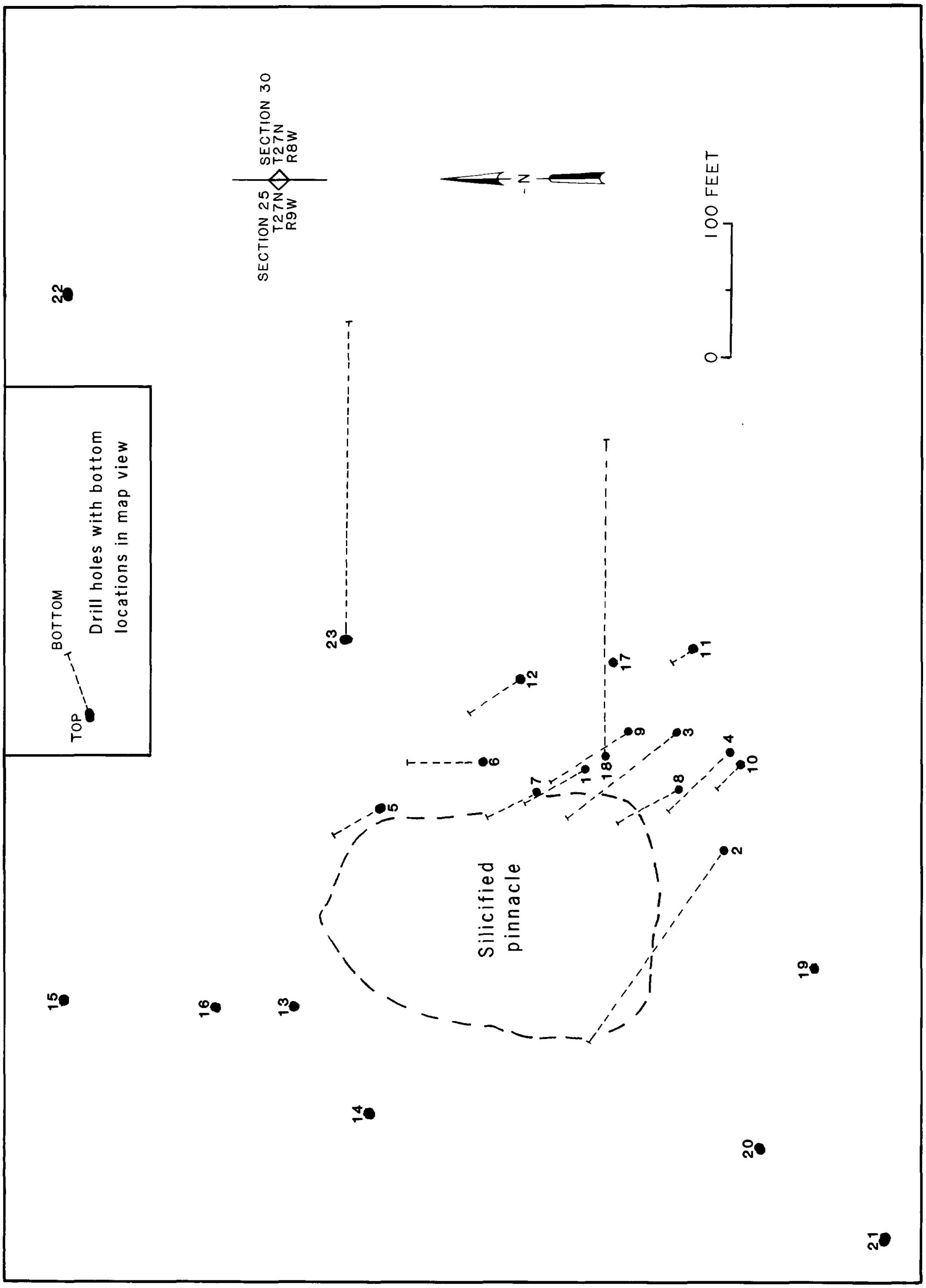


Figure 12. Map showing collar locations and drift for holes drilled by Western Nuclear, Inc. from 1976 to 1978. Complete drill hole designation includes the prefix "BM- ", as listed in table 2, but omitted here.

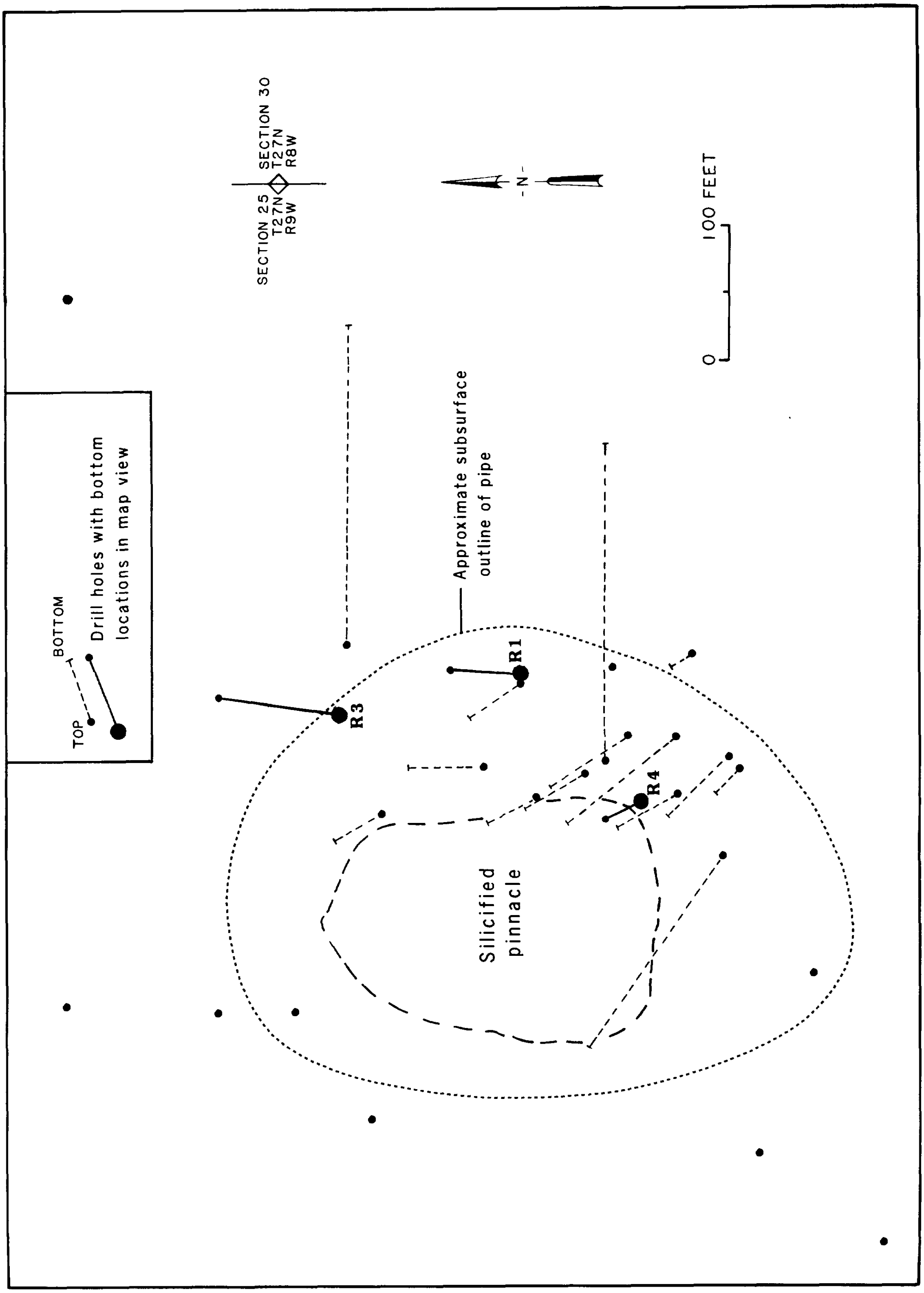


Figure 13. Map showing approximate shallow (upper 400 ft) subsurface extent of the Blue Mountain pipe based on the downhole gamma ray logs conducted in the USGS drill holes (R1, R3, and R4) and the Western Nuclear, Inc. drill holes (see table 2).

8, 9, 10, 12, 13, 17, and 19. All of the aforementioned holes were apparently drilled within the pipe core or intersected the enclosing ring fracture, locations where substantial amounts of alteration and (or) ore occur in mineralized breccia pipes. (For descriptions of widths of ring fracture zones and their associated mineral deposits see Krewedl and Carisey (1986), Kofford (1969), and Verbeek and others (1988), which provide discussions on the EZ-2 pipe, Orphan mine, and Ridenour mine respectively.)

This relatively continuous, lower uranium-mineralized zone within the Blue Mountain pipe varies from 43 ft thick in hole BM-17 (approximate top elevation of 5,569 ft) to only 3 ft thick in BM-19 (approximate top elevation of 5,606 ft). The lower uranium-mineralized zone dips about 12-19^{o} to the south and east within the pipe; the top occurs at approximate elevations of 5,651 ft in hole BM-13, 5,593 in hole BM-6, 5,577 ft in hole BM-3, and 5,548 ft in hole BM-10. The upper (stratigraphically higher) uranium-mineralized zone of hole BM-7 is much less persistent; it was also found in hole BM-2 about 5,678 ft elevation (the only U-mineralized rock in this hole) and in USGS hole 1 at 360-362 ft depth (5,640-5,638 ft elevation).

In conclusion, the Western Nuclear drill holes and the USGS holes detected the same uranium-mineralized horizons within the pipe, with the most persistent and high-grade horizon occurring at depths of 311 ft (in BM-19, elevation of about 5,606 ft) to 451 ft (in BM-13, elevation of about 5,651 ft). The highest grade lens occurs within this horizon in hole BM-12--a 10-ft-thick interval averaging a calculated 0.085 percent eU_3O_8 (1,533 cps). In comparison to the average grade of ore from actively mined breccia pipe mines--0.65 percent U_3O_8 (Mathisen, 1987)--these horizons within the Blue Mountain pipe would not be economic.

Figure 13 shows the approximate extent of the shallow subsurface (upper 400 ft) anomalous radiation at the Blue Mountain pipe, based on Western Nuclear and USGS gamma-ray logs. As discussed above, this area of alteration probably includes the pipe core and the enclosing ring fracture zone, although it was generally not possible to determine from the drill cuttings whether the rock was brecciated. The drill collar position of hole 18 is apparently within the collapse, but because of the original angle of the hole, the bottom of the hole is probably outside the pipe; the results show only background radioactivity.

CONCLUSIONS

Evidence that the prominent silicified pinnacle on the surface of the Blue Mountain pipe is part of a uranium-mineralized breccia pipe includes: 1) blocks and fragments of brecciated Coconino Sandstone and Toroweap Formation within the pinnacle, 2) brecciated quartz veins with quartz crystal-lined vugs exhibiting radioactivity up to 1,200 cps (40 times background), 3) extensive Liesegang banding of Fe minerals, indicating secondary fluid movement, and 4) evidence of secondary Cu-mineralization in the form of malachite, azurite, and chrysocolla.

Fourteen holes drilled inside the pipe by Western Nuclear, Inc. and the three holes drilled into the pipe by the USGS penetrated uranium-mineralized rock. The most persistent and high-grade uranium horizon was intersected by 13 of the Western Nuclear holes ("BM- " holes) and all 3 of the USGS holes ("R" holes) drilled within the pipe. This uranium-mineralized zone occurs from a depth of 311 ft (hole BM-19; elevation about 5,606 ft) to 451 ft (hole BM-13; elevation about 5,651 ft) and varies in thickness from 43 ft in BM-17 to only 3 ft in BM-19 (4 ft in USGS hole 3). The highest grade within this zone and found, to date, within the Blue Mountain pipe is 10 ft of 0.085 percent eU_3O_8 from 418-428 ft depth (elevation about 5,582-5,572 ft) in hole BM-12. The top of this uranium-mineralized zone dips southeast within the pipe.

Samples from rock chips recovered during drilling of the two radioactively anomalous horizons contain pyrite. Other than pyrite, all metal-containing minerals exposed at the surface are supergene (malachite, azurite, chrysocolla, smithsonite, and hematite). Silicification of the pinnacle appears to have occurred prior to the supergene alteration.

Homogenization temperatures from fluid inclusions in quartz samples from the pinnacle are bimodal. Lower temperature inclusions range from 91-110^{o}C, having salinities greater than 23 weight percent NaCl equivalent; these inclusions may be related to the normal breccia pipe-mineralization event. The second mode of inclusion temperature ranges from 256-317^{o}C, unlike any temperature ranges found elsewhere in breccia-pipe fluid inclusions. These inclusions may be reflect a later silicification event, perhaps associated with nearby Tertiary volcanism, such as the emplacement of Blue Mountain.

Downhole geophysical logging reached a depth of 1,430 ft (436 m) (the lower Supai Group) in one hole. Logs from several holes confirm that the feature is a uranium-mineralized pipe, but an economic orebody was not encountered. Nevertheless, several breccia pipe orebodies elsewhere in northern Arizona required over 20 drill holes to delineate, particularly where the pipe is not vertical, such as at the EZ-2 breccia pipe (Krewedl and Carisey, 1986, fig. 4). There is a possibility that the Blue Mountain pipe has a bend to the southeast. This assumption is based on (1) the southeast dip of the uranium-mineralized zone, (2) the greater thickness of the uranium-mineralized zone southeast of the pinnacle, (3) the lack of reduced rock below 430 ft in USGS hole 3, located in the northeast corner of the pipe, and (4) the northwesternly drift of the holes that are southeast of the pinnacle (because drill holes tend to drift along pipe ring fractures, this northwest drift suggests these holes are nearest the northwest-dipping ring fractures on the northwest edge of the pipe). So, although the present results do not indicate the presence of an orebody, the Blue Mountain pipe should not be eliminated from consideration for future drilling. If the silicified pinnacle lies along the west side of the ring fracture, with the center of the pipe bending under the hill to the southeast of the pinnacle, additional drilling that angles beneath this hill might produce favorable results.

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Appendix 1--Abbreviations and symbols used in appendixes 2-5

Abbreviations

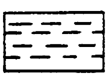
Elev= Elevation of drill collar in feet
TD= Total depth drilled
PD= Total depth reached by geophysical probe

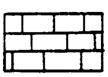
Lith= Lithology
Mineral.= Mineralization
v= very

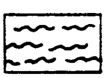
Color
blu= bluish
brn= brown
dk= dark
lt= light
med= medium
mod= moderate
orng= orange
purpl= purple
v= very
ylw= yellow

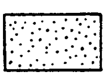
Description (derived from drill cuttings)
calc= calcareous
dk= dark
fg= fine-grained
med= medium
mod= moderately
oxid= oxidizing or oxidation
qtz= quartz
reduc= reduction
ss= sandstone
subang= subangular
subrnd= subrounded
v= very
vfg= very fine-grained
w/= with

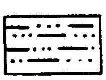
Lithology symbols

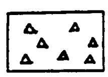

Claystone

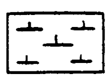

Limestone

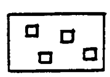

Mudstone


Sandstone


Siltstone


Chert


Limy or calcareous

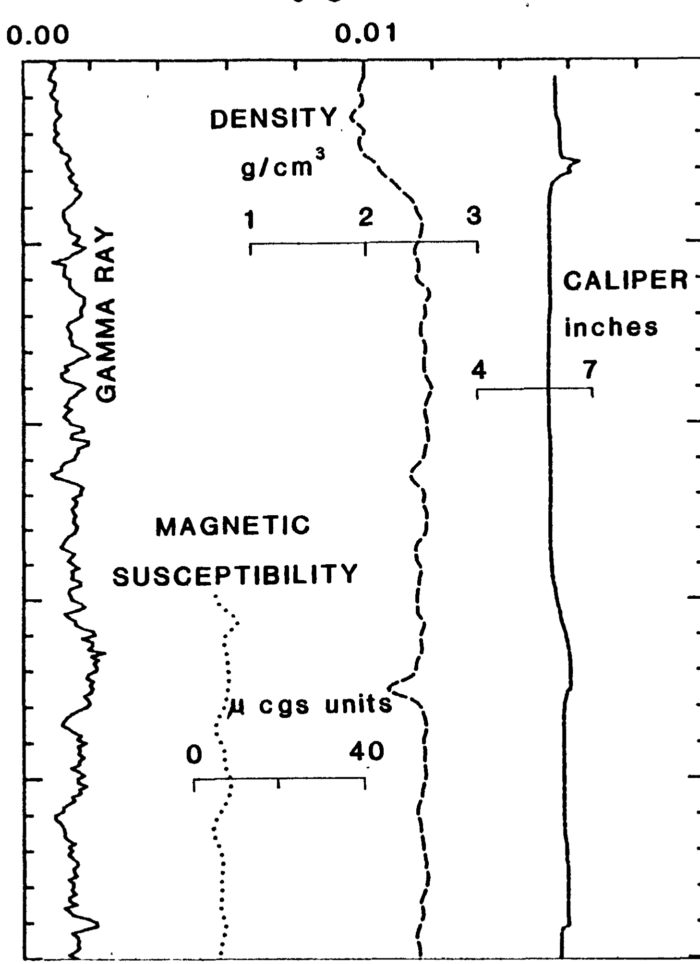

Pyrite

Appendix 2.--Lithologic and geophysical logs for hole 1R, Blue Mountain Pipe

Hole no.: 287-1R   Date: 7/20/84   Page 1 of 12

T.: 27N R.: 9W Section: 25 County: Coconino State: AZ

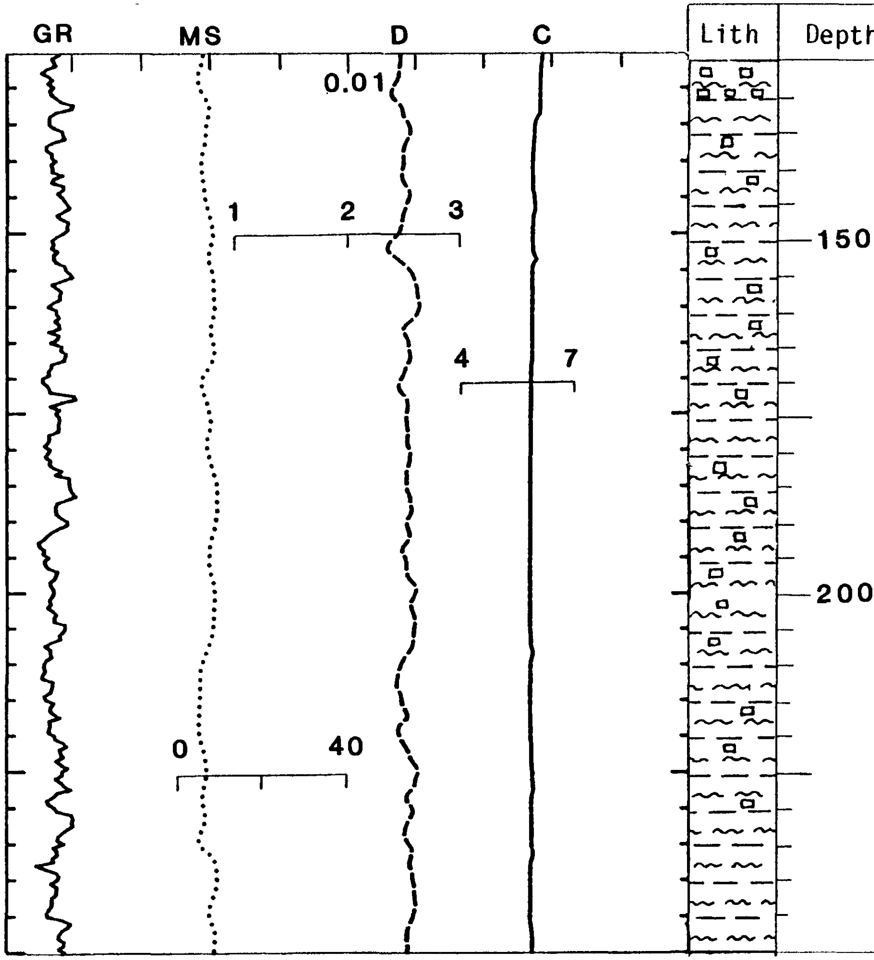
Lat: 35°41'48" Long: 113°10'59" Elev: 6000' TD: 1445' PD: 1430'



Lith	Depth	Mineral.	Color	Description
	COCONINO SAND-STONE		0'-±20' tan grades to	0'-20'. Qtz arenite, fg, well-sorted. Contains subrnd, frosted grains. Lower 5' contains med sand, poorly sorted.
	HERMIT SHALE	20'-50' Pyrite	±20'-±50' bluish-gray grades to	20'-50'. Claystone & mudstone. Unit contains disseminated, silt-size pyrite.
	50	50'-85' Pyrite, limonite, hematite	±50'-125' brn-orng	50' - 85'. Claystone, mudstone, & siltstone. Some of unit reduced to bluish-gray w/ pyrite & black streaks, most is oxid w/ limonite or hematite staining. Liesegang banding on some cuttings. Pieces show oxid/reduc contacts. Oxid pieces slightly calc.
	100	85'-125' Hematite		85'-125'. Claystone & mudstone. Unit mostly oxid w/ hematitic (black to red) pieces composing ±3% of cuttings; contains minor bluish-gray, reduced claystone.

Appendix 2--continued

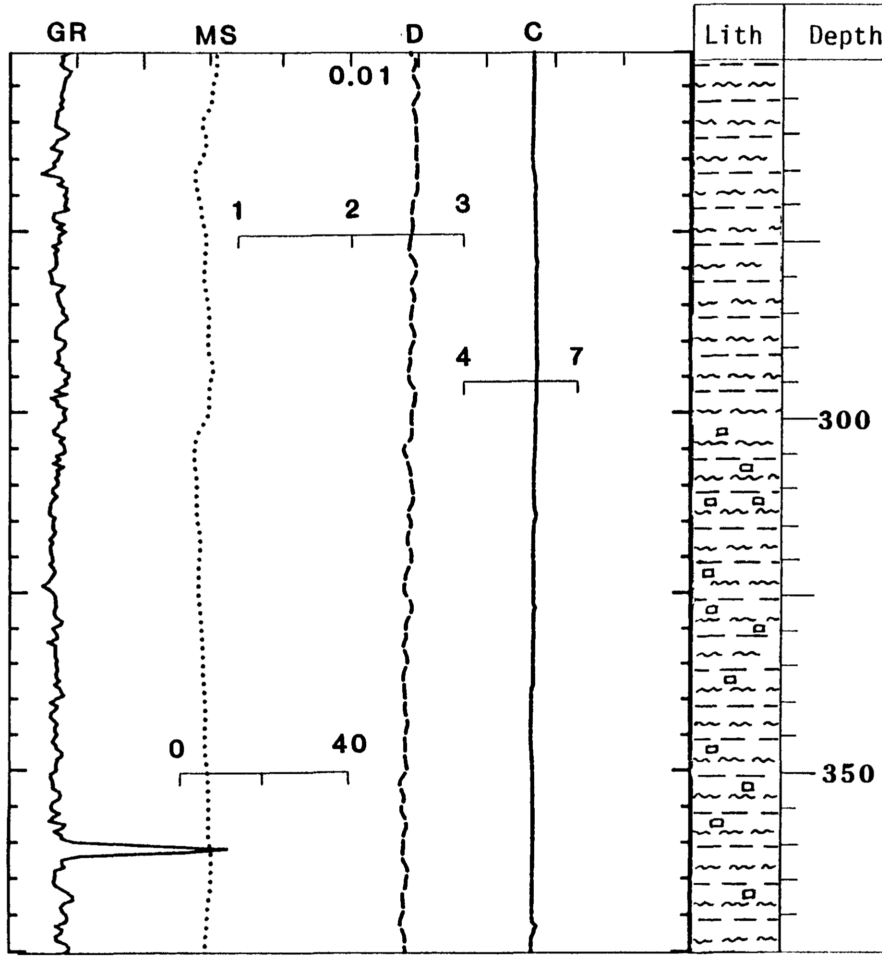
Hole no.: 287-1R



Mineral.	Color	Description
125'-230' Abundant pyrite, minor hematite	125'-145' bluish-gray 145'-180' olive-brn 180'-230' bluish-gray	125'-230'. Claystone & mudstone. Unit is reduced & contains abundant disseminated silt-size pyrite; minor oxid intervals. Some cuttings coated w/ pyrite-rich rind (indication of brecciation?)
	230'-300' mod red	230'-300'. Claystone & mudstone. Unit is typical oxidized, bright red Hermit Shale.

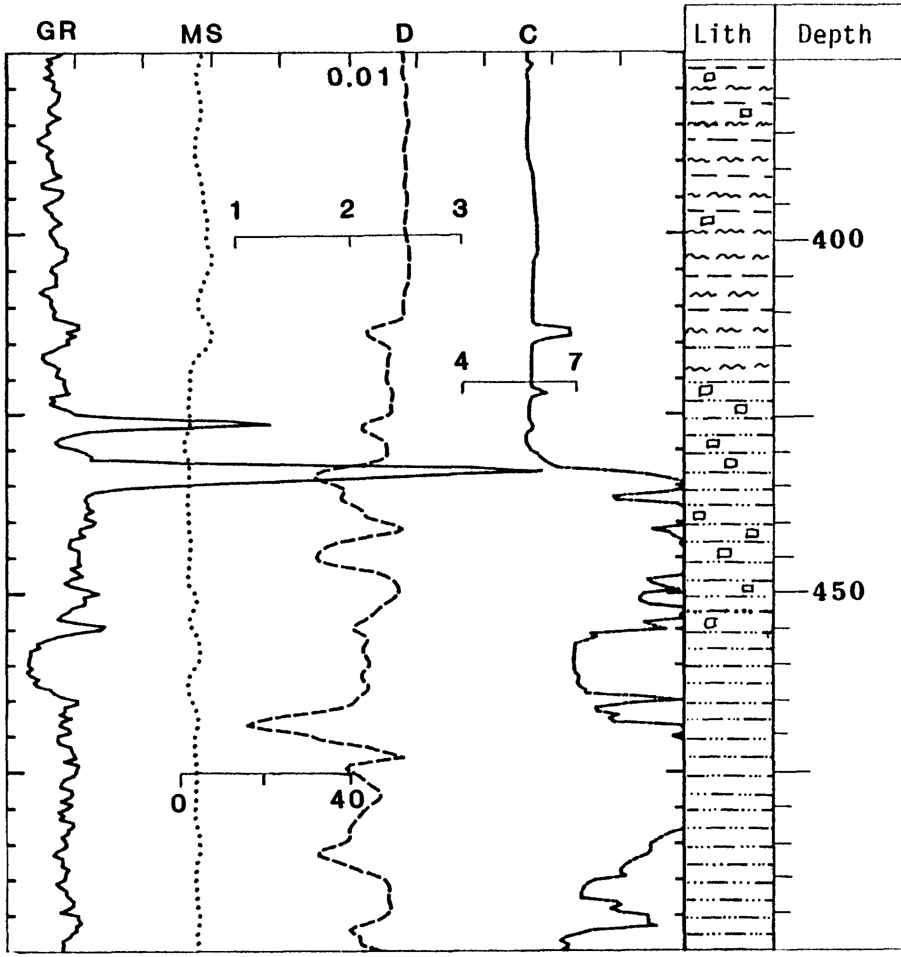
Appendix 2--continued

Hole no.: 287-1R



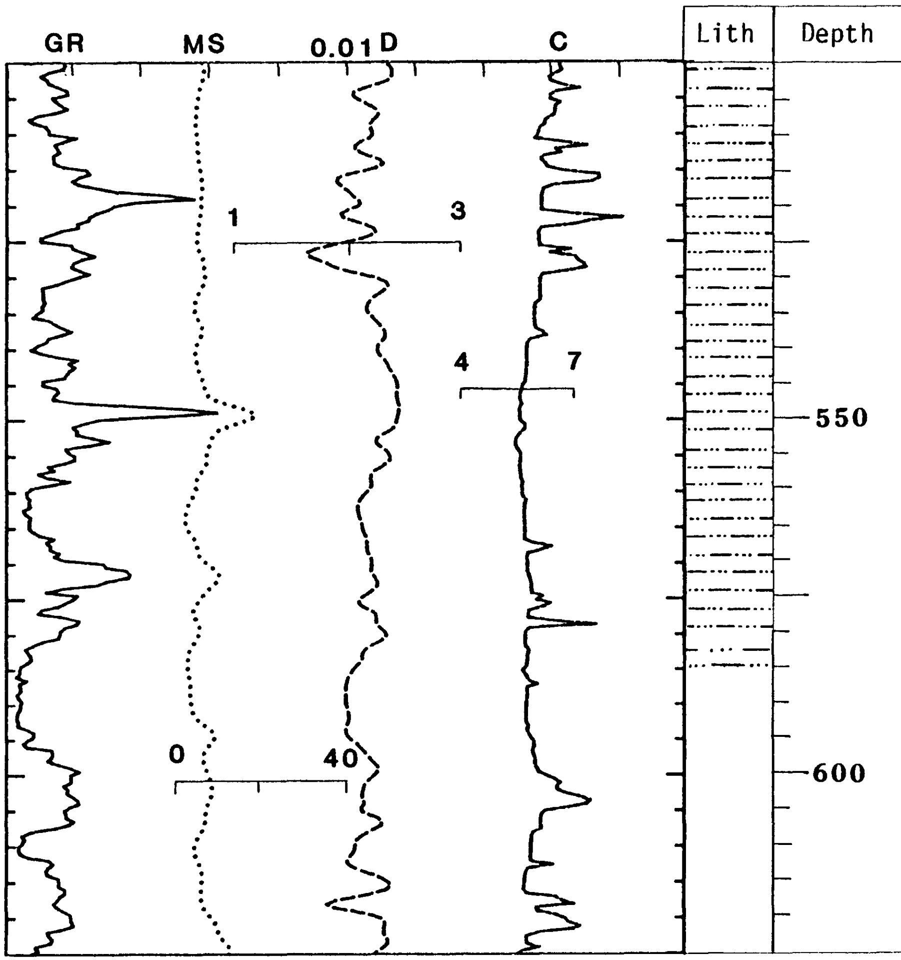
Mineral.	Color	Description
300'-410' Pyrite, v minor hematite, limonite	300'-410' lt bluish-gray	300'-410'. Mudstone & claystone. Unit contains disseminated, silt-size pyrite; v minor red (hematite) & orange (limonite) cuttings.

Appendix 2--continued



Mineral.	Color	Description
	410'-420' orng-red	410'-420'. Oxid transition zone, mudstone to siltstone.
420'-450' Abundant pyrite	420'-450' dk bluish-gray	420'-450'. Siltstone, clayey. Contains qtz silt grains; abundant silt-size pyrite.
	450'-470' mod red	450'-585'. Siltstone, clayey. Contains oxid hematite.
	470'-485' purpl-red	V minor reduction @ 470'-485'.
	485'-585' mod red	

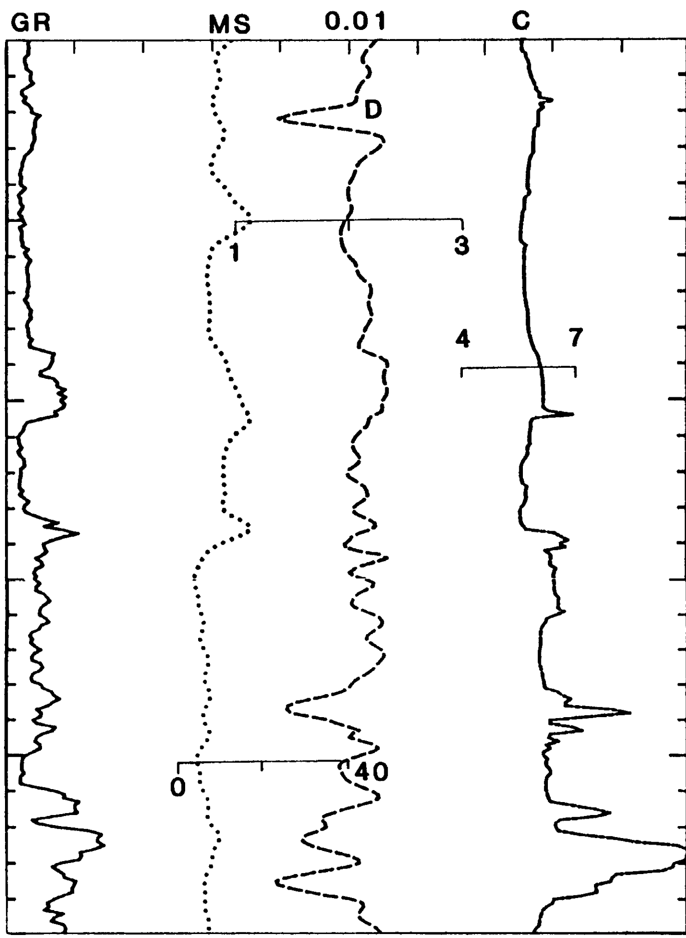
Hole no.: 287-1R



Mineral.	Color	Description
		585'-1405'. No samples.

Appendix 2--continued

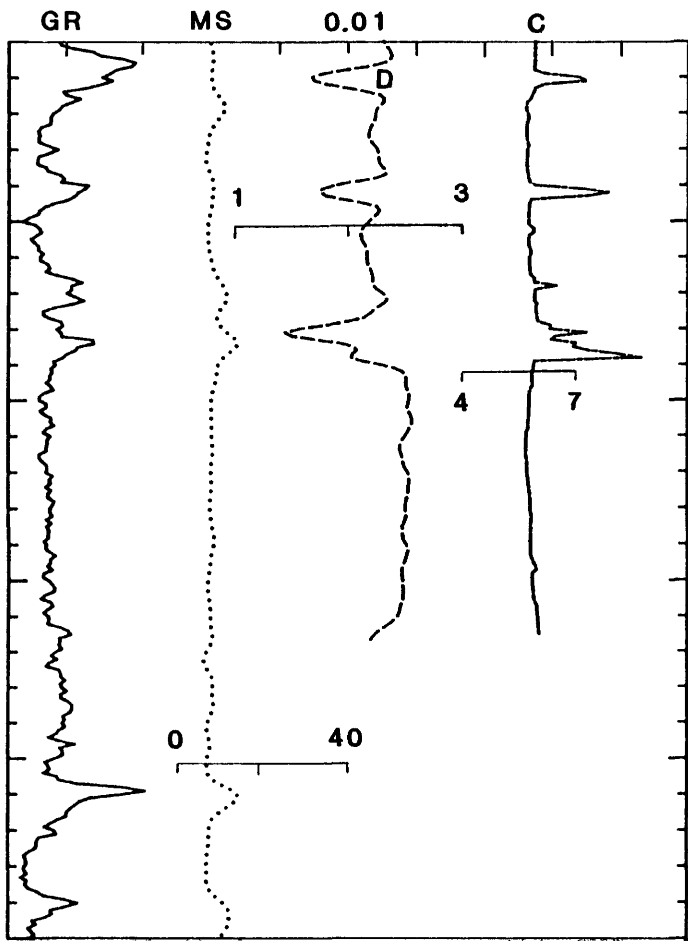
Hole no.: 287-1R



Lith	Depth	Mineral.	Color	Description
	650 700			No samples.

Appendix 2--continued

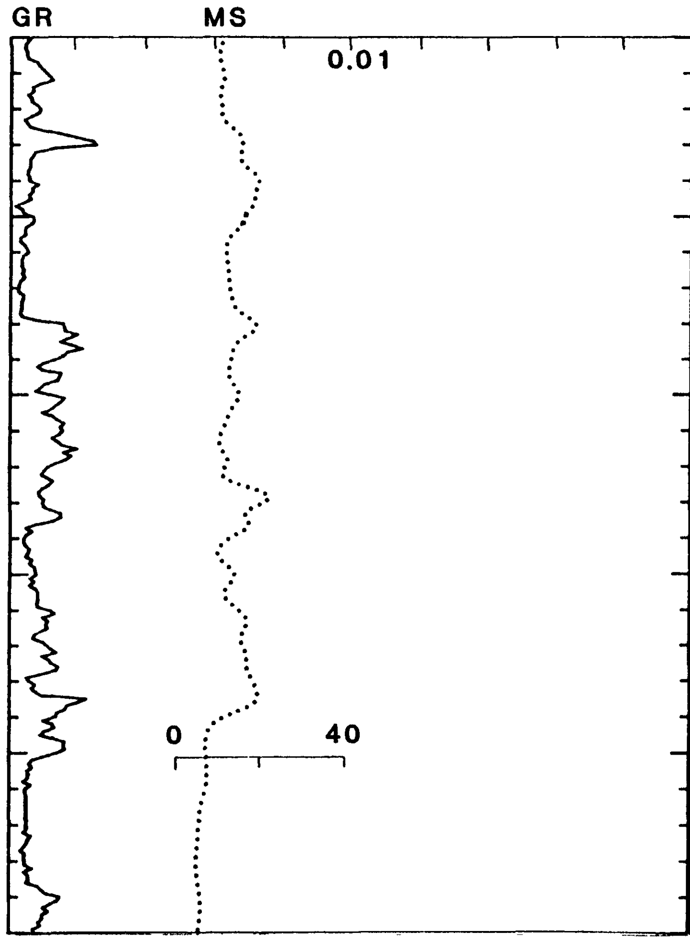
Hole no.: 287-1R



Lith	Depth	Mineral.	Color	Description
	800 850			No samples.

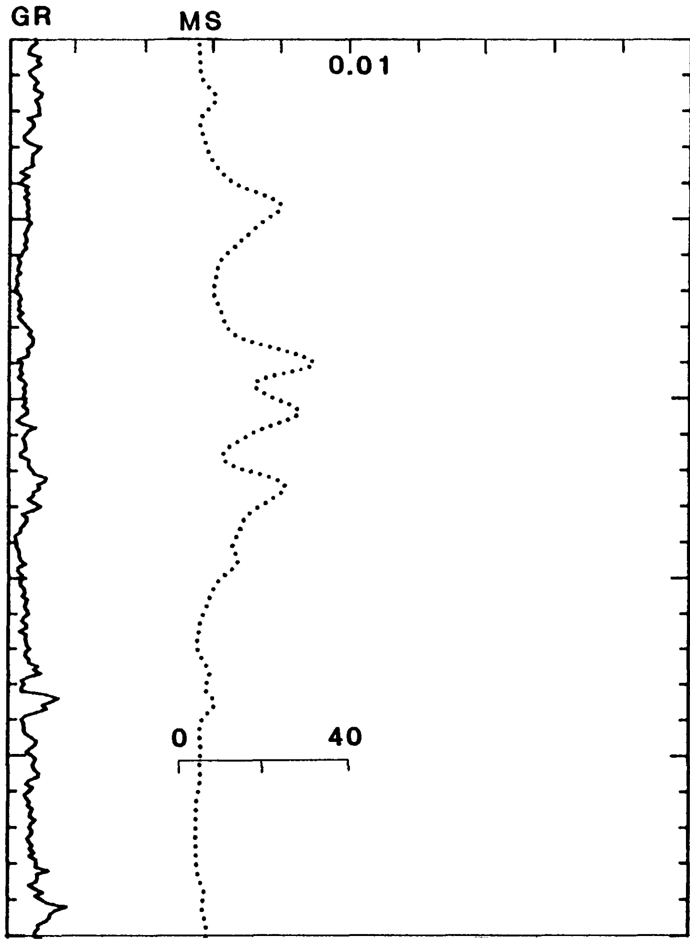
Appendix 2--continued

Hole no.: 287-1R



Lith	Depth	Mineral.	Color	Description
	900 950			No samples

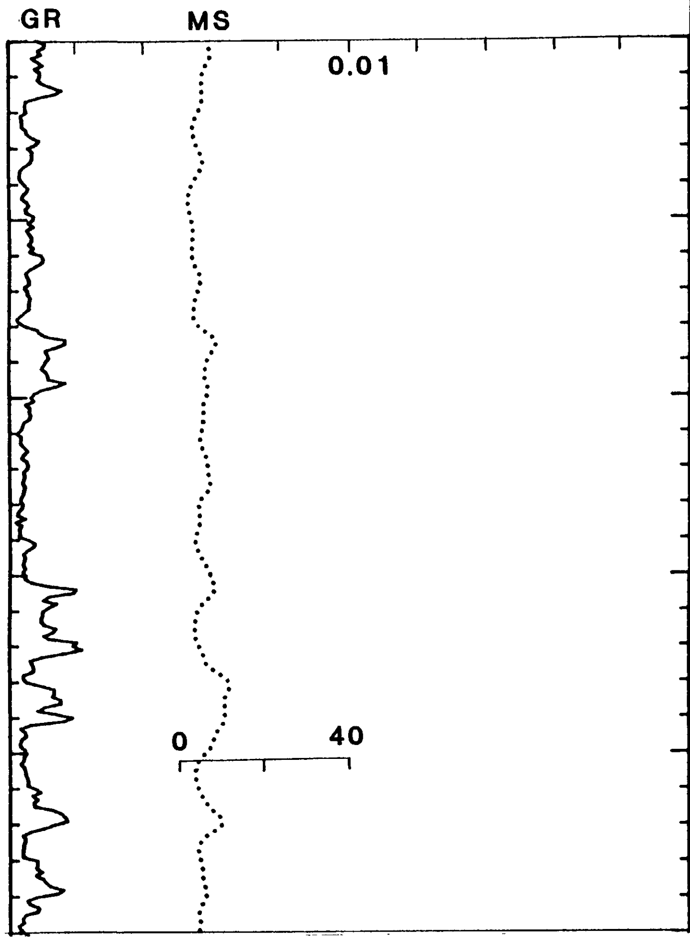
Hole no.: 287-1R



Lith	Depth	Mineral.	Color	Description
	1050 1100			No samples.

Appendix 2--continued

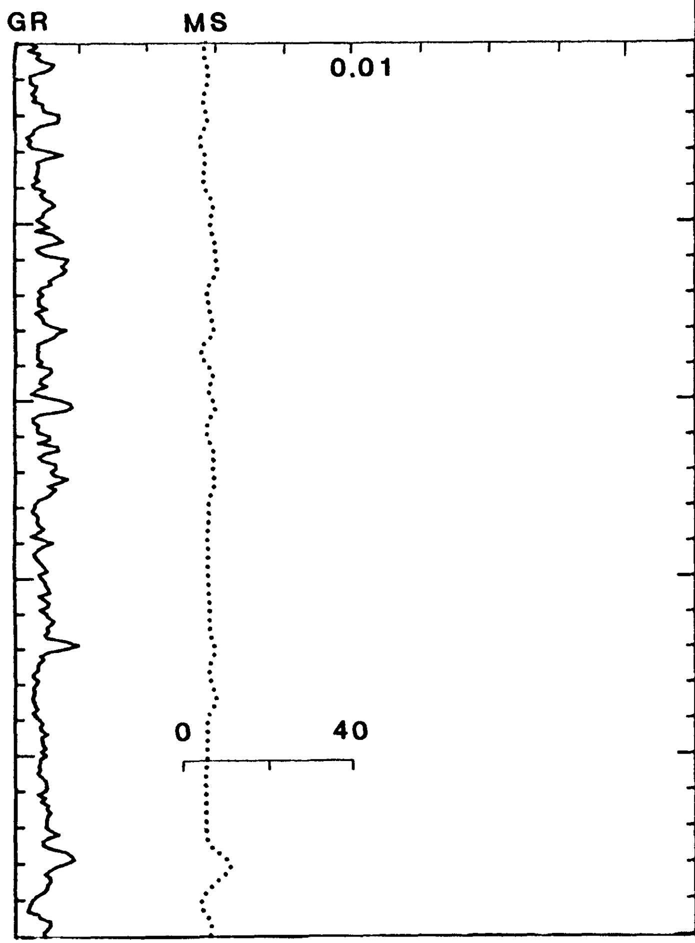
Hole no.: 287-1R



Lith	Depth	Mineral.	Color	Description
	1150 1200			No samples.

Appendix 2--continued

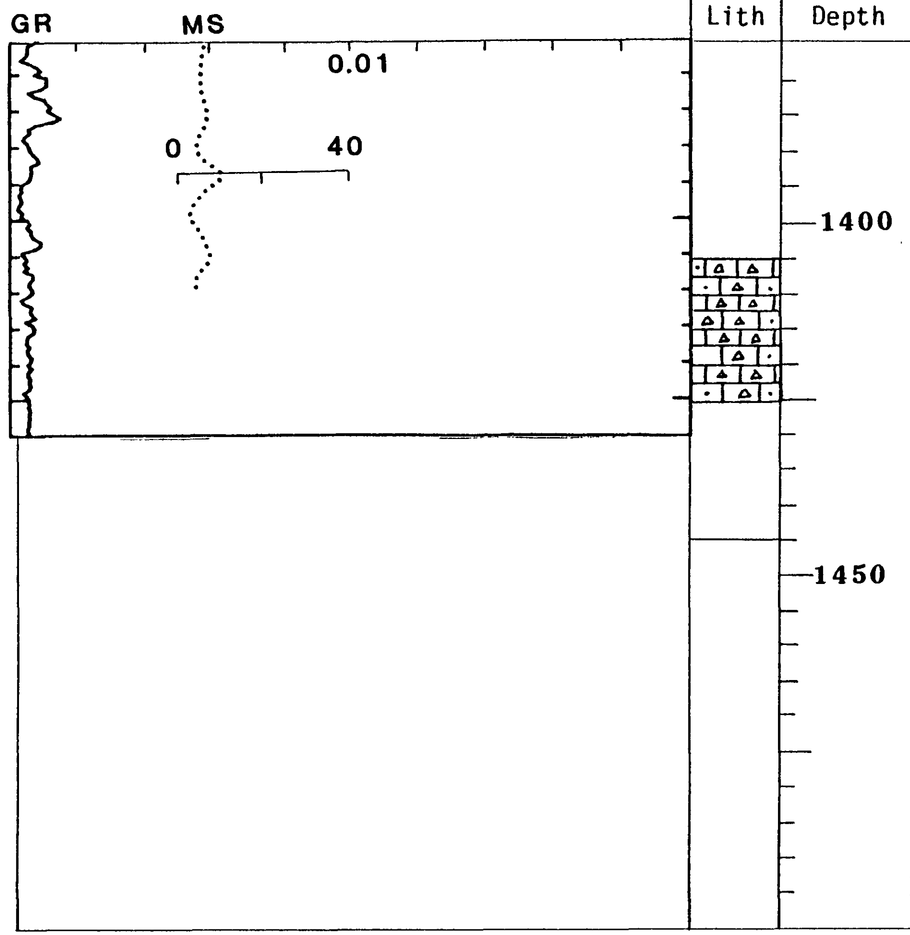
Hole no.: 287-1R



Lith	Depth	Mineral.	Color	Description
	1300 1350			No samples.

Appendix 2--continued

Hole no.: 287-1R



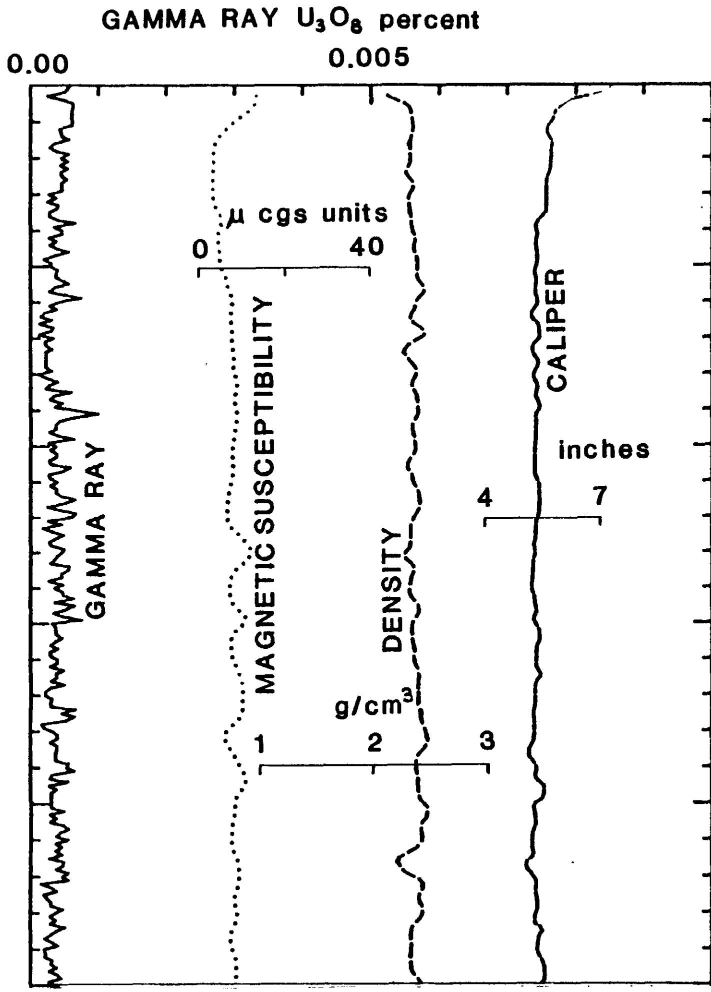
Mineral.	Color	Description
	1405' - 1425' white to tan	1405'-1425'. Limestone & chert. Unit contains minor med to coarse qtz sand.
		1425'-1445'. No samples.

Appendix 3.--Lithologic and geophysical logs for hole 2R, Blue Mountain Pipe

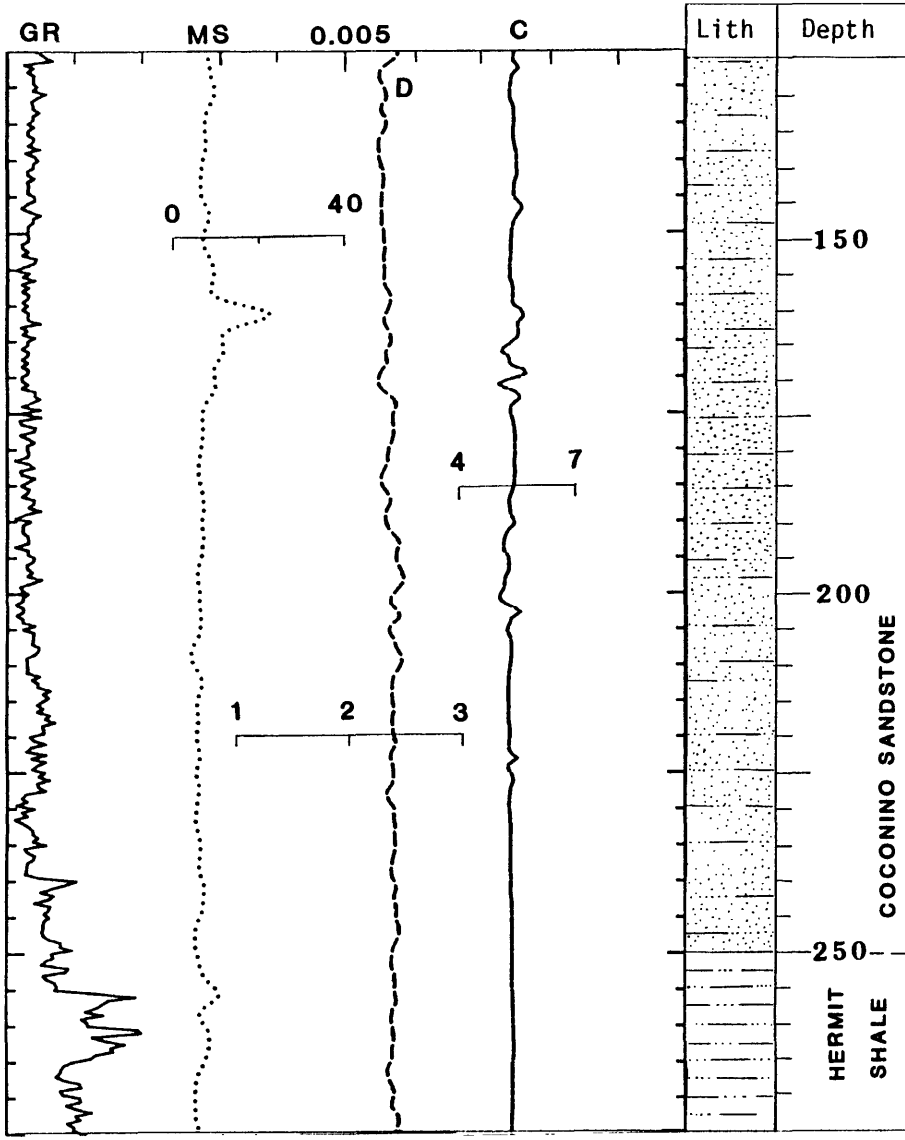
Hole no.: 287-2R   Date: 9/02/84

T.: 27N R.: 8W Section: 30 County: Coconino State: AZ

Lat: 35°41'48" Long: 113°10'53" Elev: 6250' TD: 805' PD: 800'



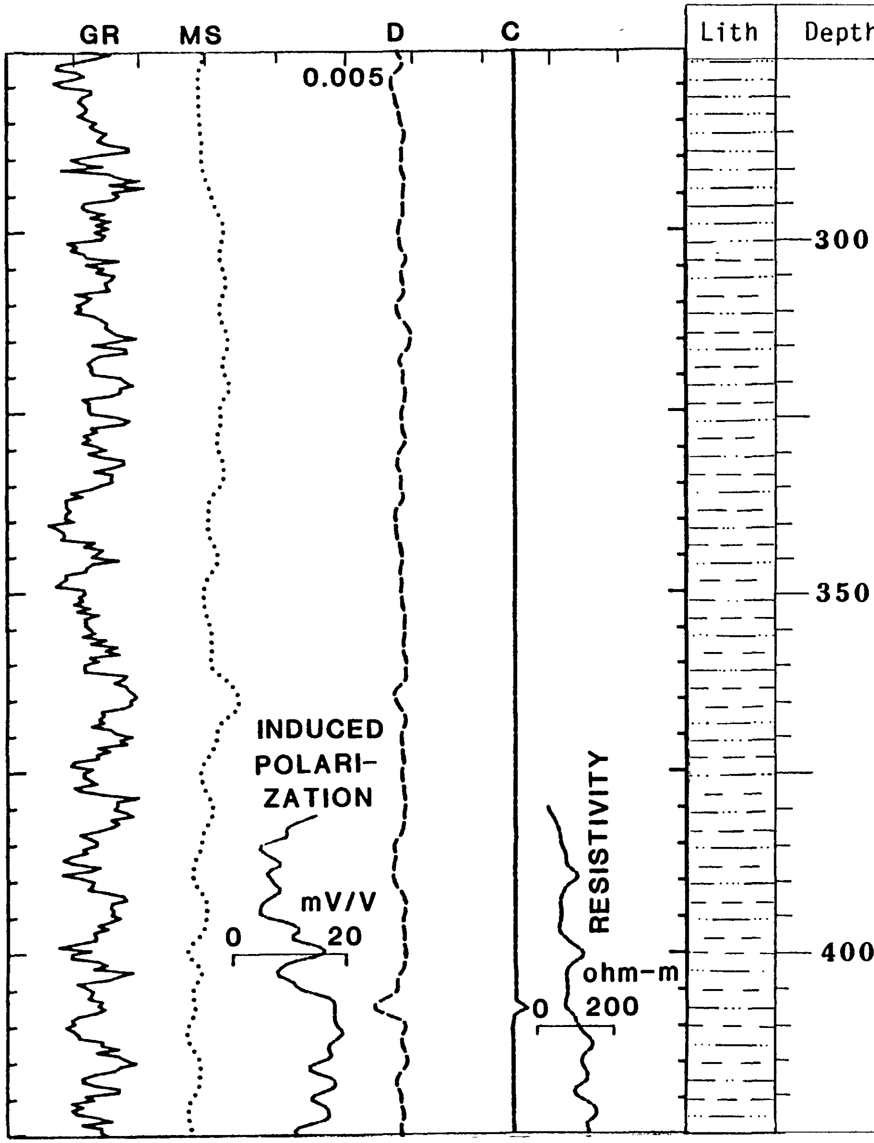
Lith	Depth	Mineral.	Color	Description
	SELIGMAN MEMBER OF TOROWEAP FORMATION		0-5' ylw-gray	0-5'. SS, fg, well-sorted, limy. Contains frosted, subrnd grains.
	COCONINO SANDSTONE (50, 100)	15'-250' Minor hematite	5'-15' blu-white	5'-15'. SS, vfg, silty, limy, well-sorted, w/ frosted grains.
			15'-30' ylw-gray	15'-250'. SS, vfg, silty to v silty, well-sorted. Contains frosted, subang grains; minor hematite-altered grains.
			30'-85' blu-white	
			85'-185' pinkish-gray	



Mineral.	Color	Description
	185'-250' v pale orng	
	250'-295' gray-orng to gray-orng pink	250'-295'. Siltstone, sandy, well-sorted.

Appendix 3--continued

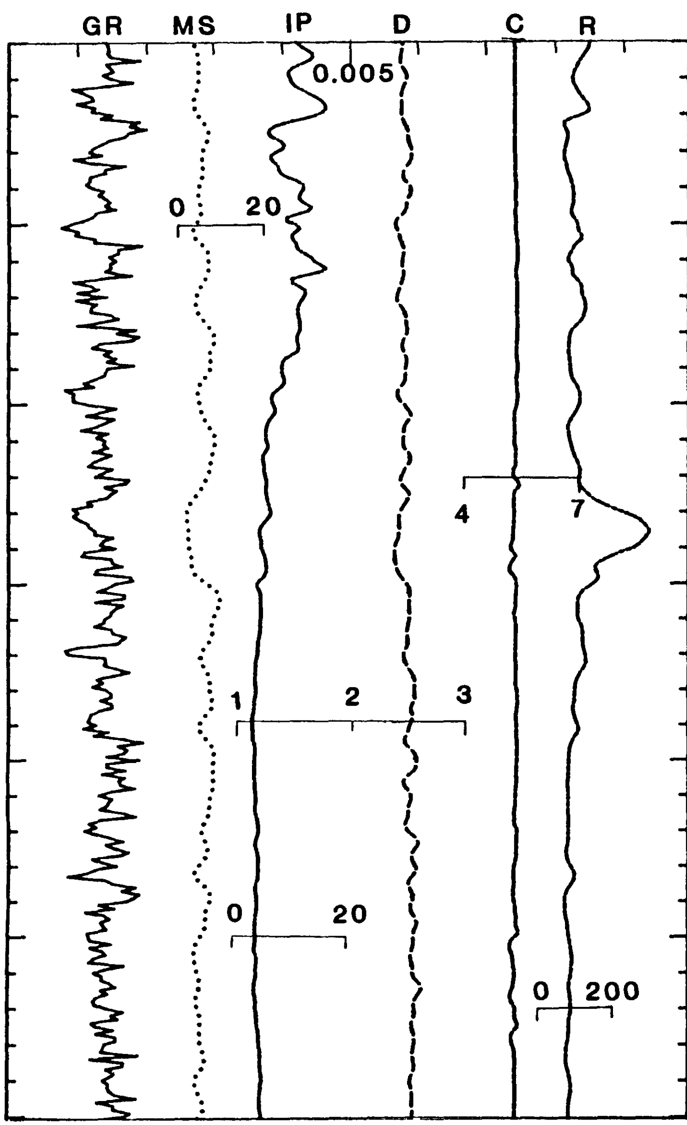
Hole no.: 287-2r



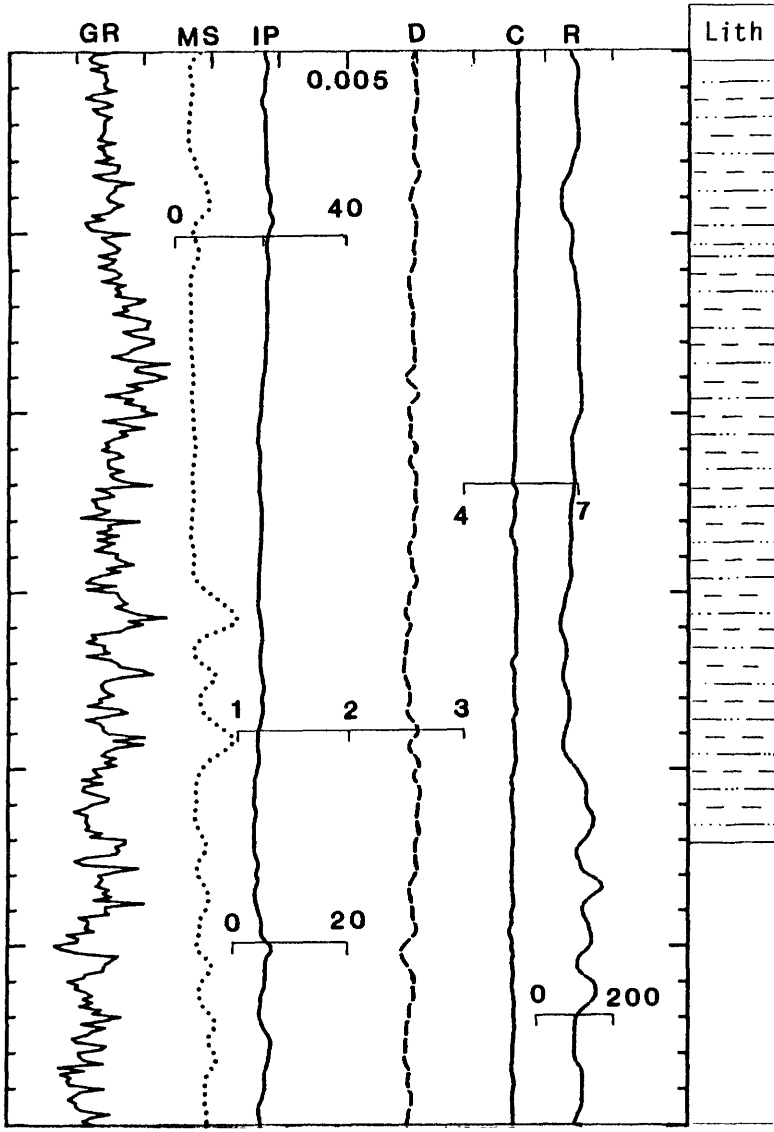
Mineral.	Color	Description
	295'-485' mod red-orng	295'-485'. Siltstone & claystone, slightly sandy. Unit is Fe oxid & contains minor dk opaque minerals.

Appendix 3-continued

Hole no.: 287-2R



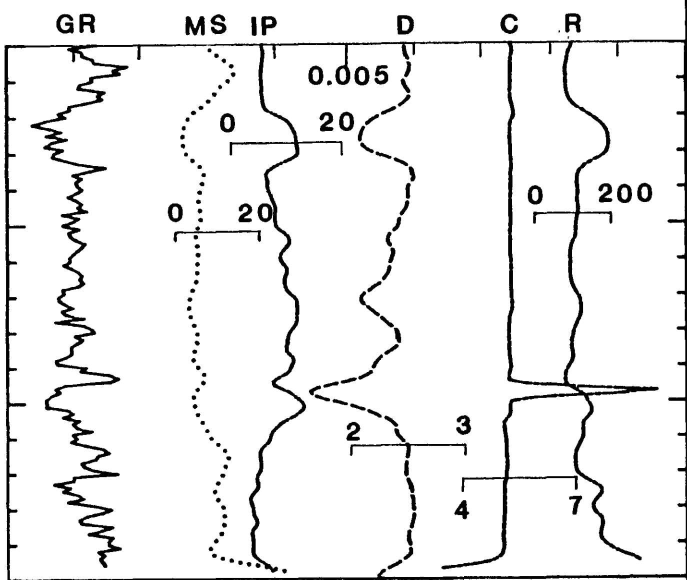
Lith	Depth	Mineral.	Color	Description
	450			
		485'-500' Minor hematite	485'-500' grayish-orng	485'-500'. Siltstone & claystone. Unit is well-sorted.
	500		500'-685' mod red-orng	500'-685'. Siltstone & claystone. Unit is slightly sandy, well-sorted, & Fe oxid.
	550			



Lith	Depth	Mineral.	Color	Description
	600			
	650			
	700			685'-805'. No samples.

Appendix 3-continued

Hole no.: 287-2R



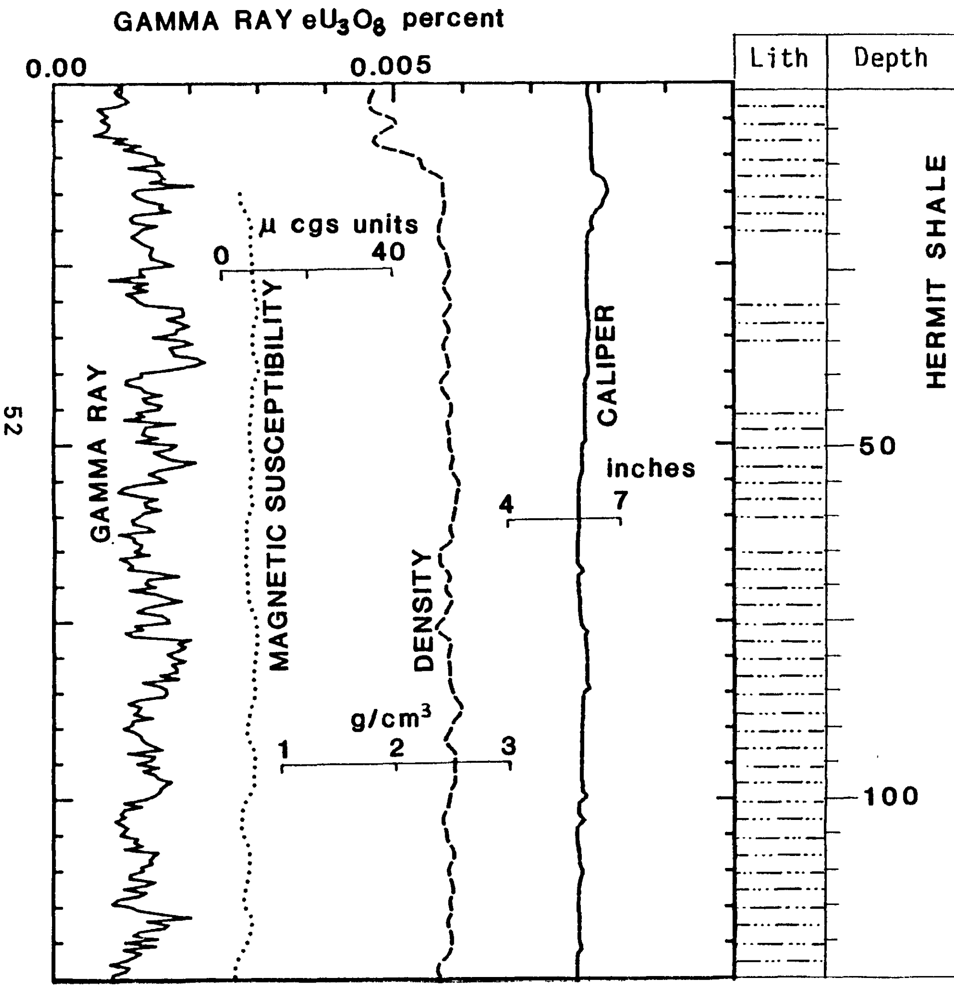
Lith	Depth	Mineral.	Color	Description
	750			
	800			
	850			

Appendix 4.--Lithologic and geophysical logs for hole 3R, Blue Mountain Pipe

Hole no.: 287-3R Date: 8/30/84

T.: 27N R.: 9W Section: 25 County: Coconino State: AZ

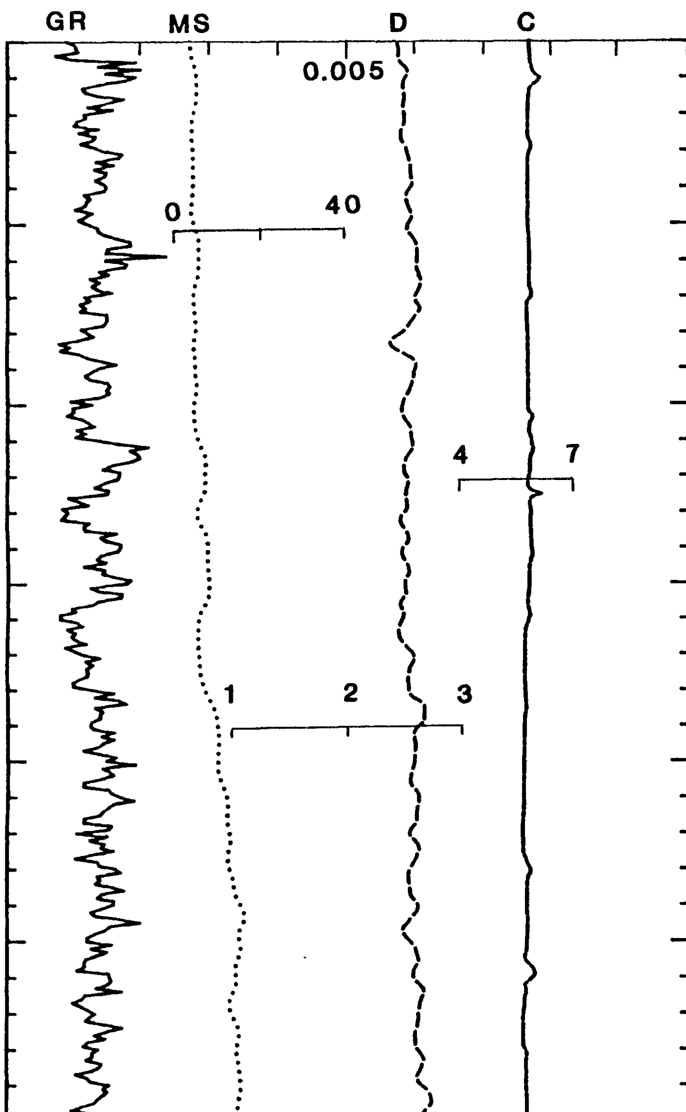
Lat: 35°41'48" Long: 113°10'59" Elev: 6020' TD: 1345' PD: 1345'



Mineral.	Color	Description
0-20' Hematite	0-20': mod orng-pink	0-20'. Siltstone, mod well-sorted, slightly sandy. Contains hematite alteration.
		20'-30'. No sample.
	30'-35' lt blu-gray	30'-35'. Siltstone, well-sorted.
		35'-45'. No sample.
	45'-60' grayish-orng pink	45'-60'. Siltstone, well-sorted. Contains sulphur streaks.
		60'-65'. No sample.
	65'-80' See description	65'-80'. Siltstone, pale ylw-orng to lt bluish-gray. Contains sulphur streaks.
	80'-105' pale ylw-orng to gray-orng pink	
	105'-125' gray-orng to pale ylw-orng	80'-390'. Siltstone, well-sorted.

Appendix 4-continued

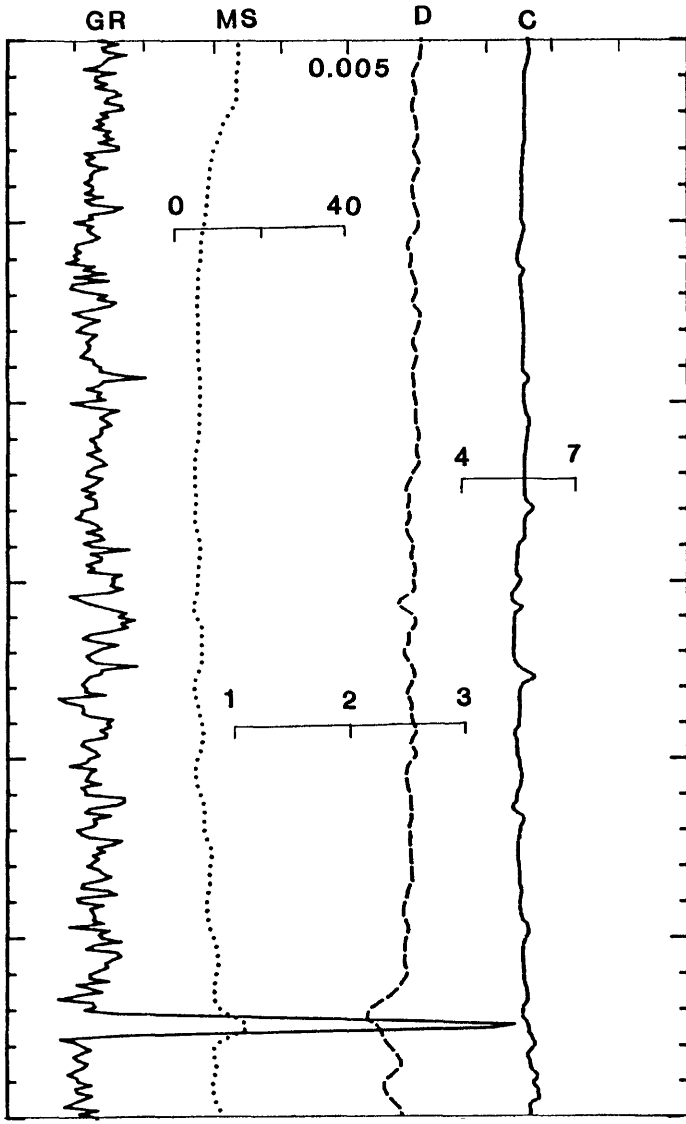
Hole no.: 287-3R



Lith	Depth	Mineral.	Color	Description
	150		125'-130' lt blu-gray; 130'-140' pale ylw-orng; 140'-180' lt blu-gray	
	200		180'-205' pale ylw-orng to gray-orng; 205'-±245' lt blu-gray grades to	
	250		±245'-285' mod red-orng	

Appendix 4-continued

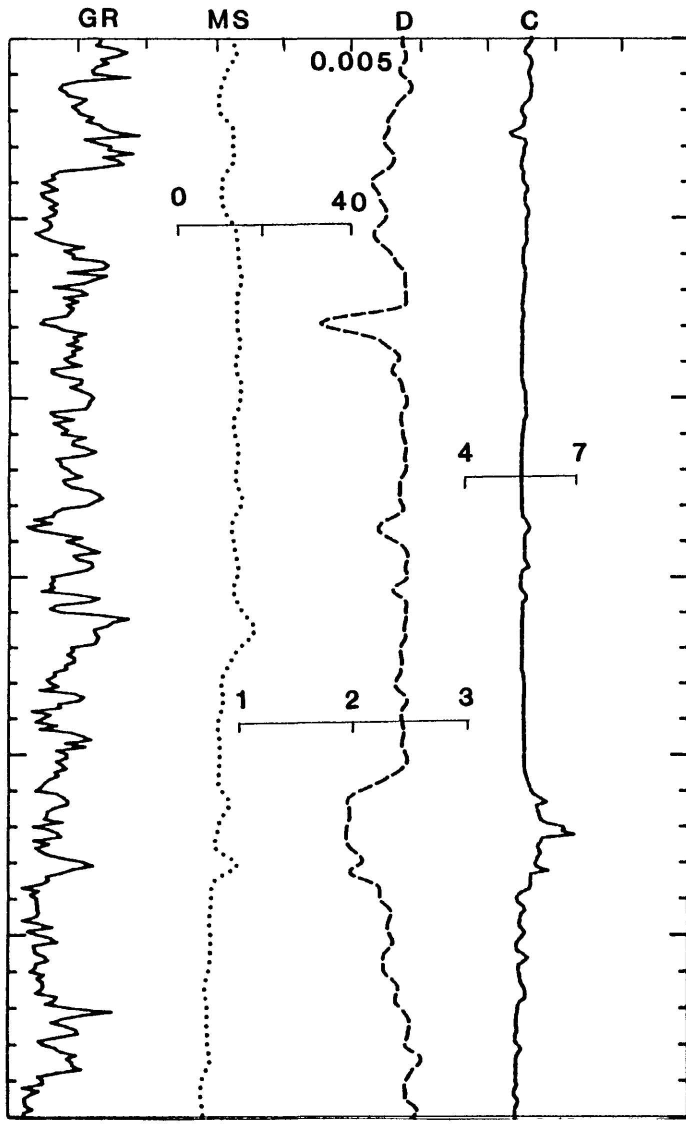
Hole no.: 287-3R



Lith	Depth	Mineral.	Color	Description
	300		285'-360' lt blu-gray	
	350		360'-365' pale ylw-orng	
			365'-390' lt blu-gray	
	400		390'-430' gray-orng to mod red-orng	390'-430'. Siltstone, slightly sandy. Contains Fe oxidization.

Appendix 4-continued

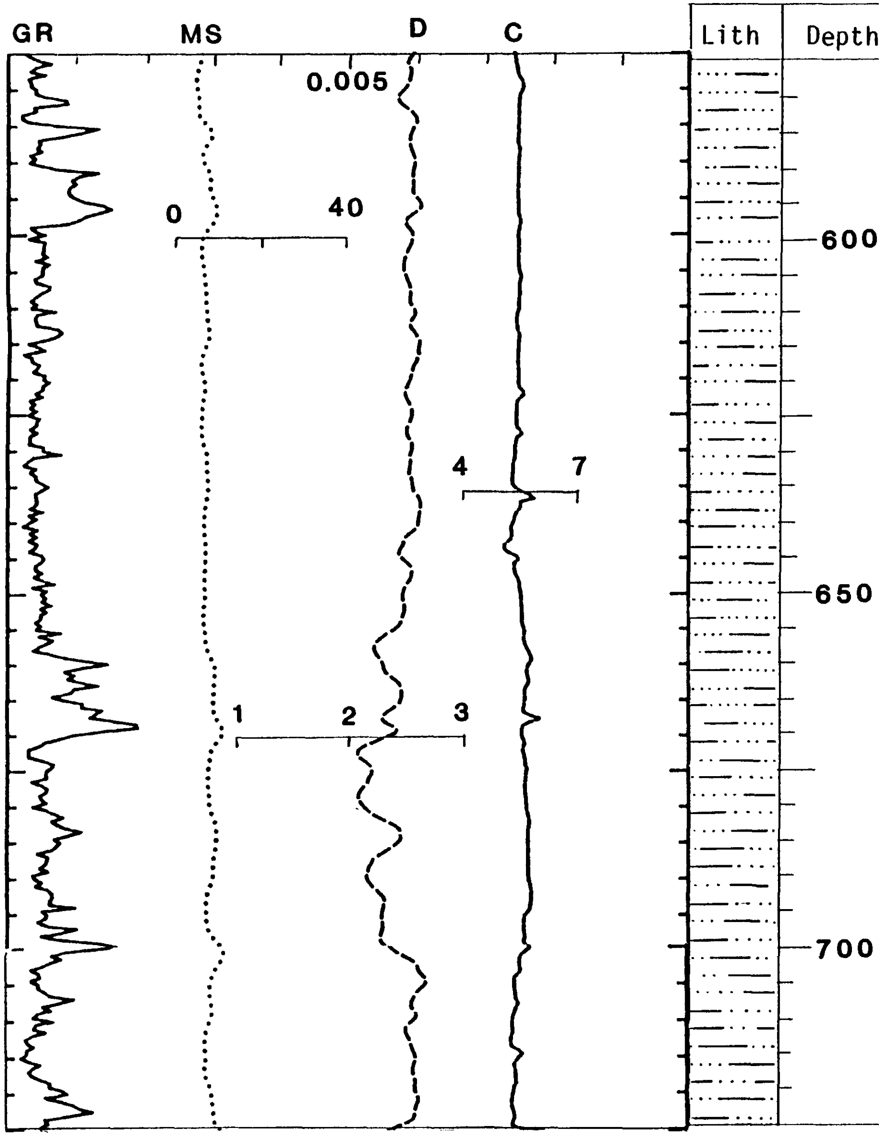
Hole no.: 287-3R



Lith	Depth	Mineral.	Color	Description
	450		430'-490' pale ylw-orng	430'-505'. Siltstone, well-sorted, slightly sandy.
	500		490'-495' mod red-orng	
			495'-505' pale ylw-orng	
			505'-525' v pale orng	505'-535'. SS, vfg, v silty, well-sorted.
			525'-535' pale ylw-orng	
	550		535'-560' mod red-orng	535'-560'. Siltstone, sandy, well-sorted.

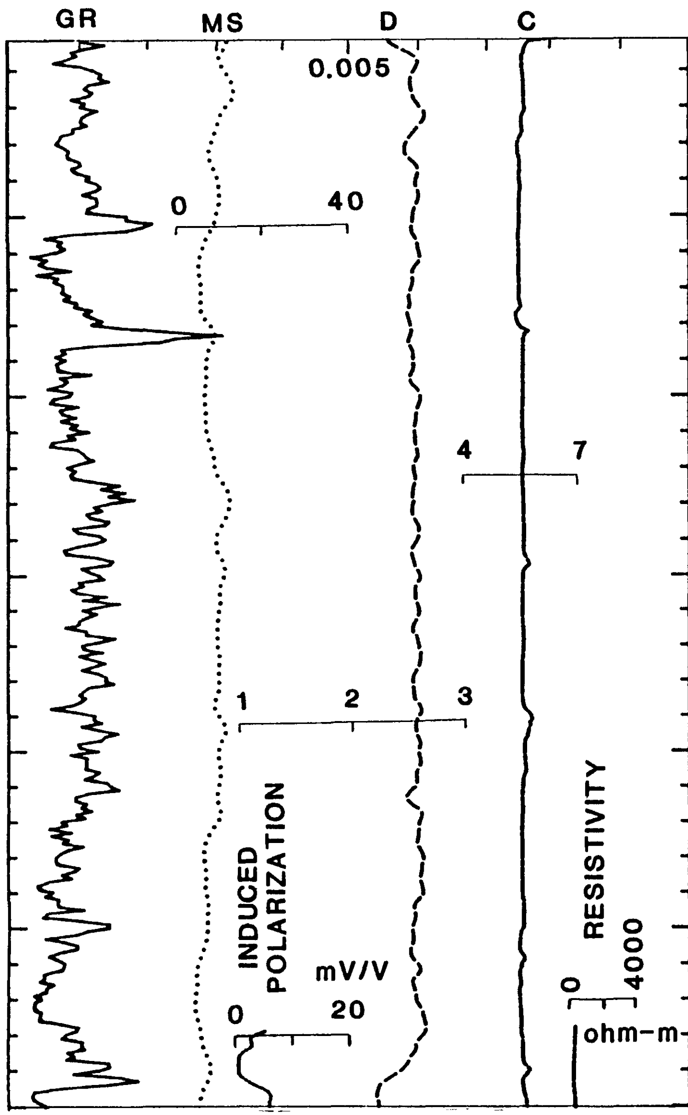
Appendix 4-continued

Hole no.: 287-3R



Mineral.	Color	Description
	560'-660' gray-orng pink	560'-665'. Siltstone, v sandy, well-sorted, Fe oxidized.
	660'-665' pale ylw-orng	
	665'-670' mod red-orng	665'-705'. Siltstone, sandy.
	670'-705' pale ylw-orng	
	705'-790' v pale orng	705'-790'. Siltstone, slightly sandy, well-sorted.

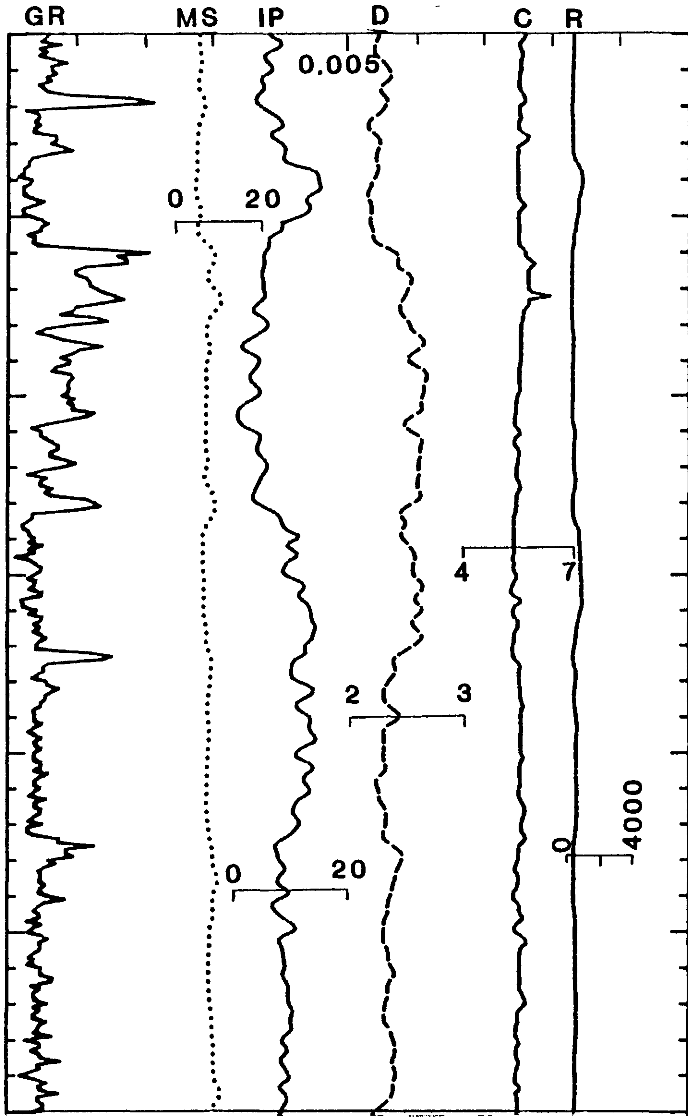
Appendix 4-continued
Hole no.: 287-3R



Lith	Depth	Mineral.	Color	Description
	750			
	800		790'-845' mod red-orng	790'-845'. Siltstone, slightly sandy, well-sorted, Fe oxidized.
	850		845'-±875' pink-gray grades to	845'-950'. Siltstone, well-sorted to poorly-sorted.

Appendix 4-continued

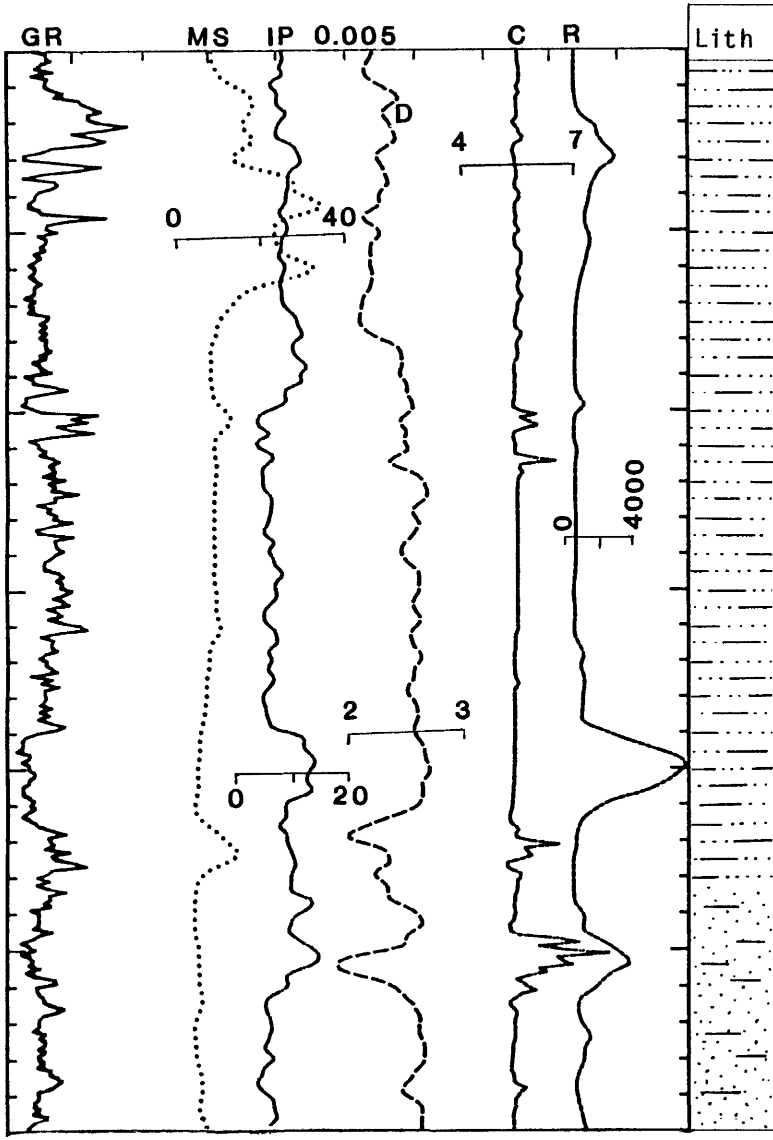
Hole no.: 287-3R



Lith	Depth	Mineral.	Color	Description
			±875'-900' v pale orng	V sandy @ 875'-920'.
	900		900'-905' mod red-orng	
			905'-950' v pale orng	Slightly sandy @ 920'-950'.
	950		950'-1030' pale ylw-orng	950'-1030'. Siltstone, v sandy to slightly sandy. Contains mod red-orng streaks.
	1000			

Appendix 4-continued

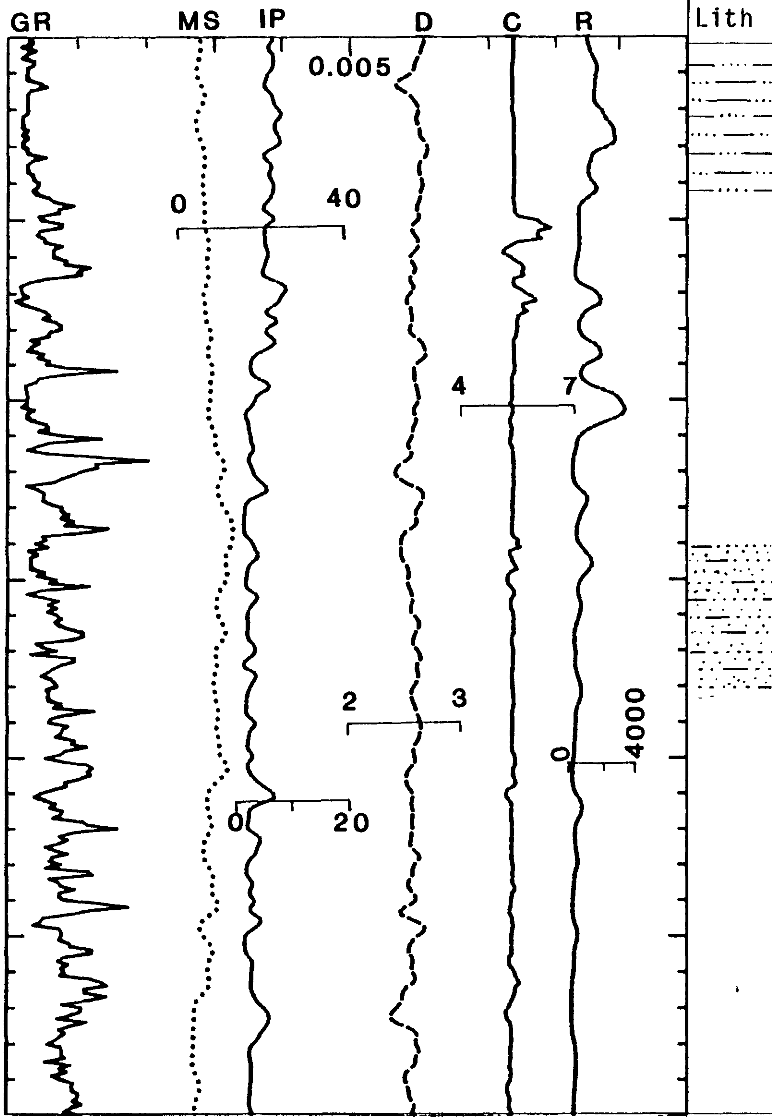
Hole no.: 287-3R



Depth	Mineral.	Color	Description
1050		1030'-1040' dk ylw-orng; 1040'-1060' mod red-brn	1030'-1060'. Siltstone, v sandy to sandy. Contains minor dark opaque minerals.
1100		1060'-1080' mod red-orng; 1080'-1140' v pale orng	1060'-1140'. Siltstone, slightly sandy, well-sorted. Mod red-orng streaks @ 1100'-1105'.
1150		1140'-1175' dk ylw-orng	1140'-1175'. SS, vfg, v silty, mod well-sorted.

Appendix 4-continued

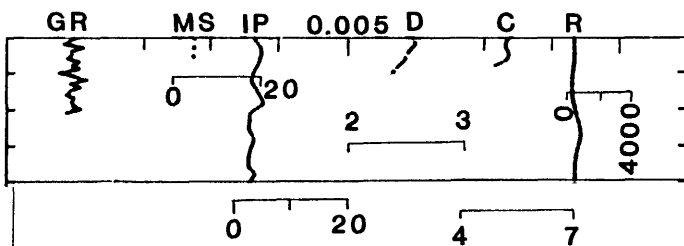
Hole no.: 287-3R



Lith	Depth	Mineral.	Color	Description
			1175'-1195' v pale orng	1175'-1195'. Siltstone, slightly sandy, well-sorted.
	1200			1195'-1245'. No samples.
	1250		1245'-1265' See description	1245'-1265'. Grayish-red & pale ylw-green chips in mod red-orng, vfg, v silty, ss matrix.
	1300			1265'-1345'. No samples.

Appendix 4-continued

Hole no.: 287-3R



Lith	Depth	Mineral.	Color	Description
				No samples.

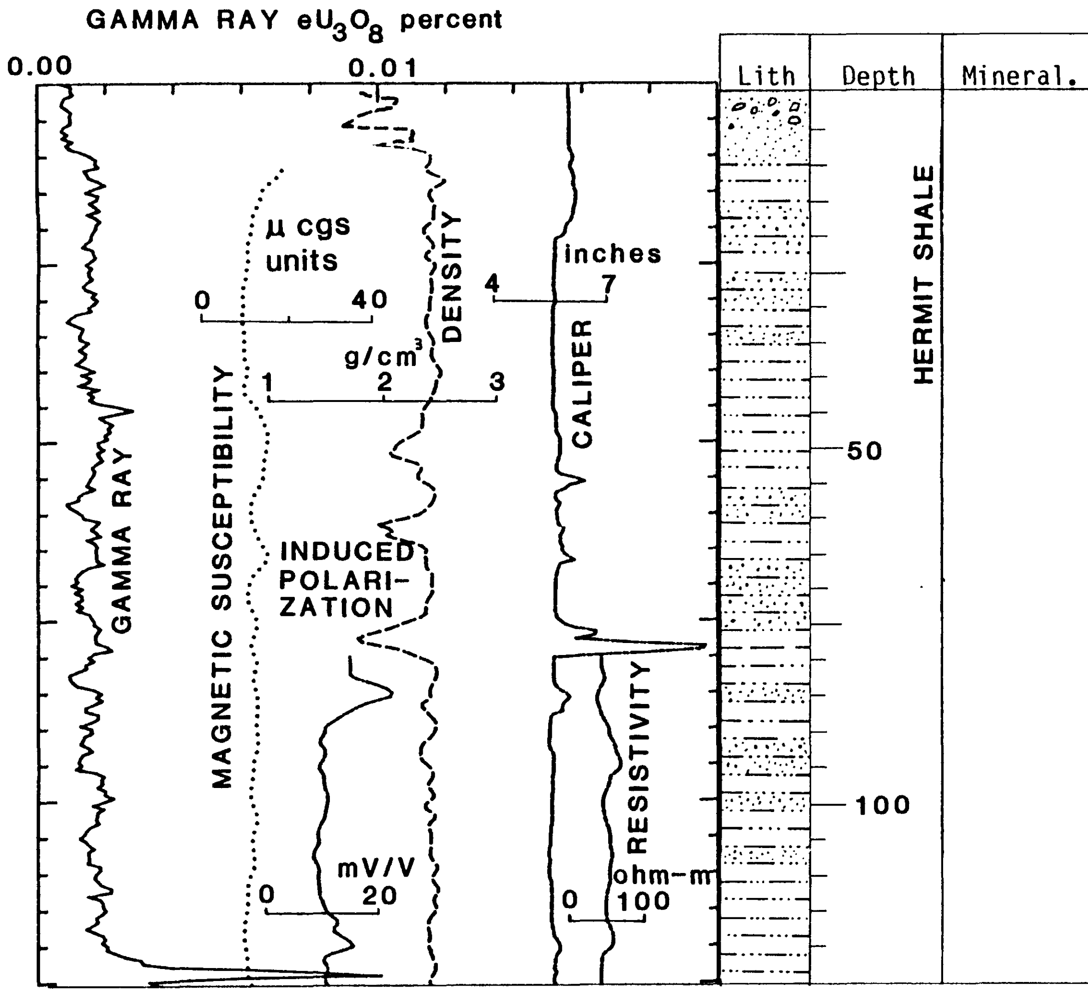
Depth: 1350, 1400, 1450

Appendix 5.--Lithologic and geophysical logs for hole 4R, Blue Mountain Pipe

Hole no.: 287-4R   Date: 9/01/84   Page 1 of 6

T.: 27N R.: 9W Section: 25 County: Coconino State: AZ

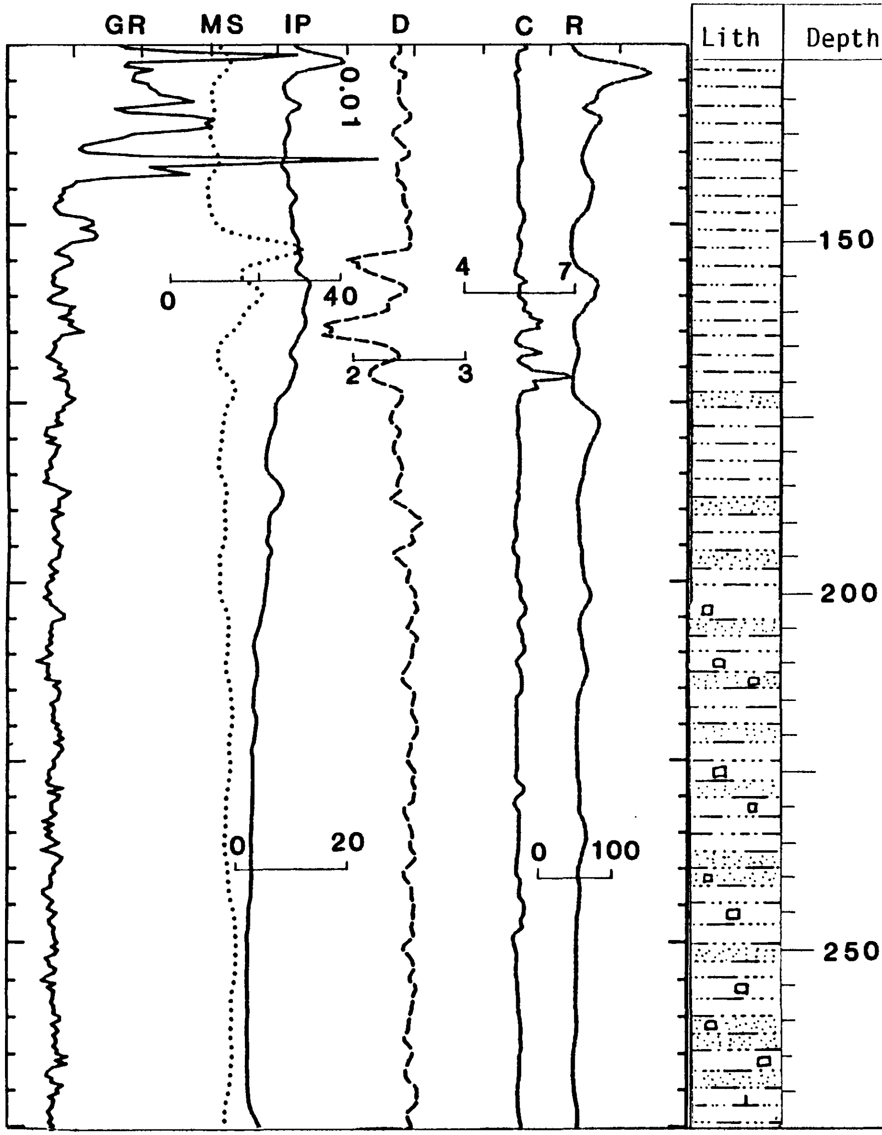
Lat: 35°41'48" Long: 113°10'59" Elev: 5980' TD: 805' PD: 795'



Color & Description
0-5'. Pink-gray, silicified chips & ss, mod red-orng to gray-orng, med-grained.
5'-10'. SS, mod red-orng, fg, mod well-sorted.
10'-30'. Siltstone & ss, mod orng-pink, vfg; poorly sorted w/ gray-orng, silty streaks.
30'-35'. Siltstone & ss, fg to vfg. Unit is mod orng-pink to pink gray w/pale ylw-orng streaks.
35'-45'. Siltstone, v lt gray w/ mod red-orng lenses.
45'-55'. Siltstone, mod red-orng, sandy. Contains v lt gray streaks.
55'-60'. SS, v pale orng, silty, well-sorted.
60'-65'. Siltstone, mod red-orng, sandy.
65'-75'. SS, v pale orng to pale ylw-orng, silty. Contains mod red-orng siltstone lenses.
75'-80'. Siltstone, dk ylw-orng, clayey.
80'-85'. SS & siltstone. Unit is pink-gray w/ dk ylw-orng streaks.
85'-90'. Siltstone, mod orng-pink to pink-gray, well-sorted.
90'-95'. SS, gray-orng, vfg, silty.
95'-105'. Siltstone & ss, vfg. Unit is v pale orng to pale ylw-orng.
105'-110'. Siltstone & ss. Unit is v lt gray to pale ylw-orng.

Appendix 5--continued

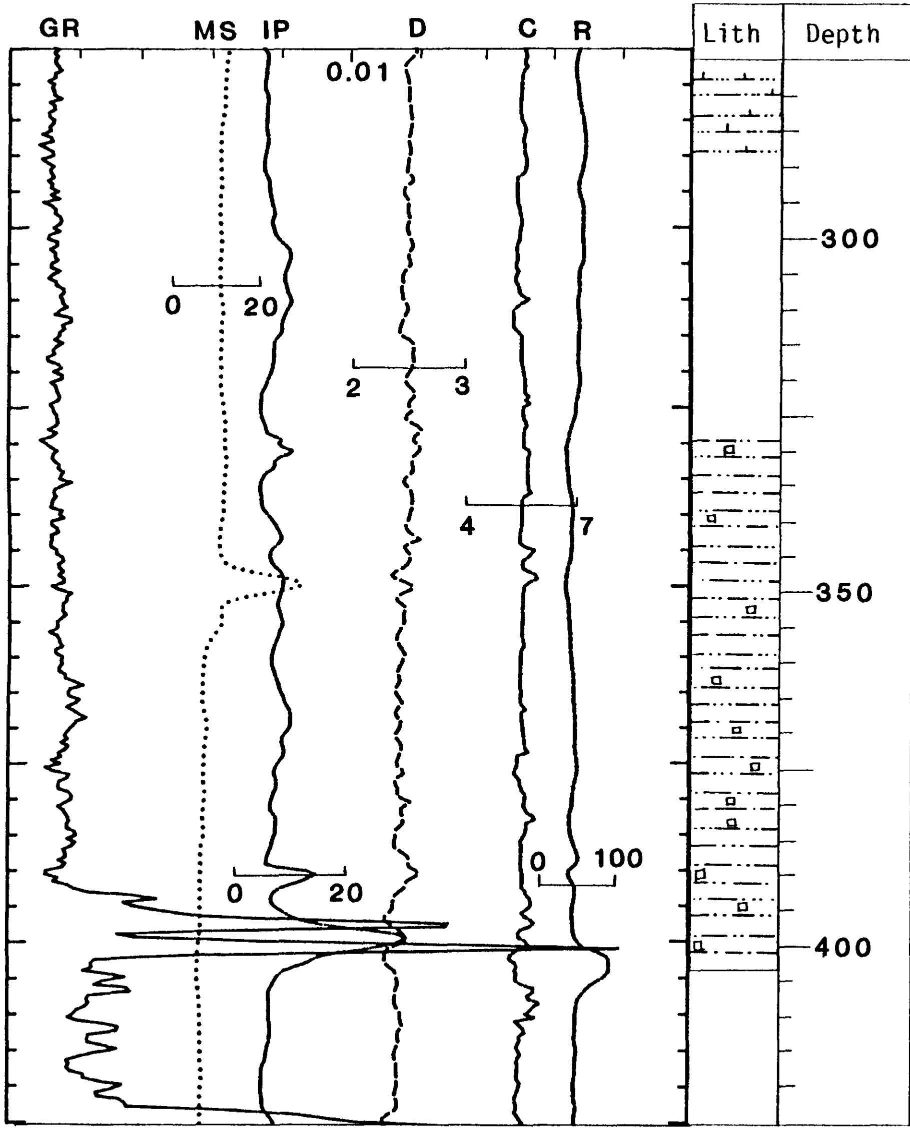
Hole no.: 287-4R



Mineral.	Color & Description
125'-155' Minor hematite	110'-155'. Siltstone, v lt gray, well-sorted, slighlty sandy. Contains dk ylw-orng & mod pink streaks; minor hematitic alteration @125'-155'.
	155'-170'. Siltstone, lt brn, clayey. Contains mod red-brn streaks @ 160'-165'.
	170'-180'. SS & siltstone; dk ylw-orng. SS is vfg, v silty, well-sorted.
	180'-190'. SS, vfg & siltstone. Unit is pink-gray to gray-orng.
190'-270' Minor hematite; pyrite	190'-270'. Siltstone & ss, vfg, v silty. Unit is pink-gray; contains hematite-altered grains & silt-size disseminated pyrite.

Appendix 5--continued

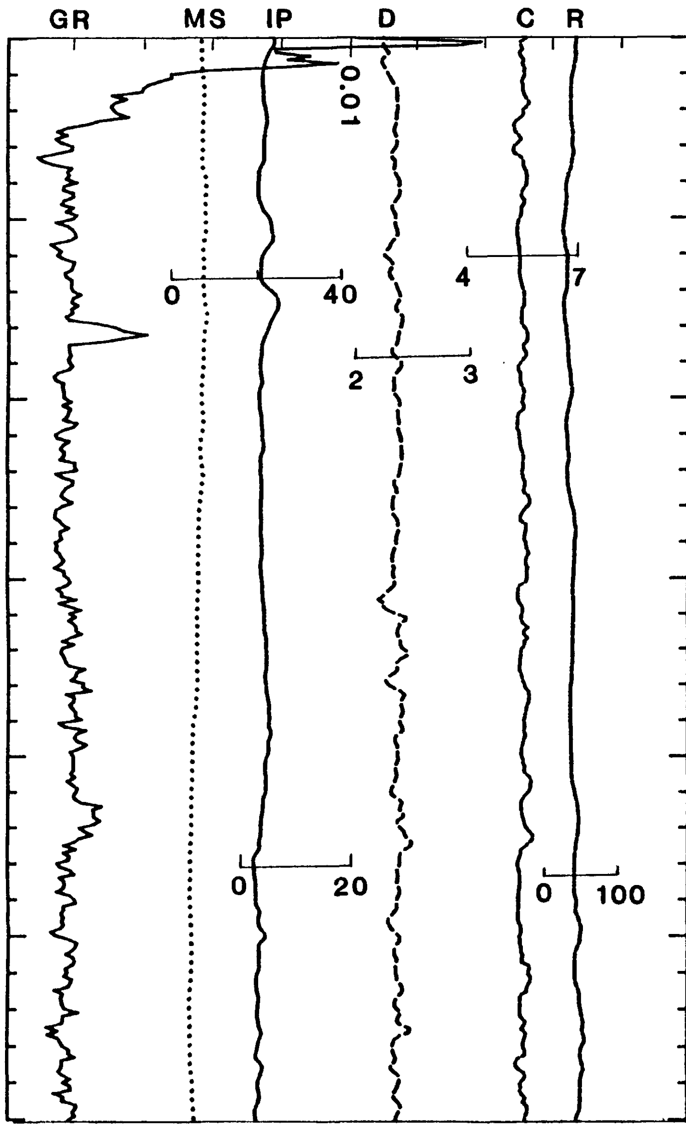
Hole no.: 287-4R



Mineral.	Color & Description
270'-285' V minor hematite	270'-285'. Siltstone, v lt gray, limy, well-sorted. Contains v minor hematite-altered grains.
	285'-325'. Circulation lost - no cuttings.
325'-385' V minor hematite, pyrite	325'-385'. Siltstone, pink-gray, clayey, well-sorted. Contains v minor hematite-altered grains & pyrite.
385'-405' Pyrite	385'-405'. Siltstone, med dk gray to lt gray, well-sorted. Contains minor silt-size, disseminated pyrite.
	405'-505'. Lost circulation - no cuttings.

Appendix 5--continued

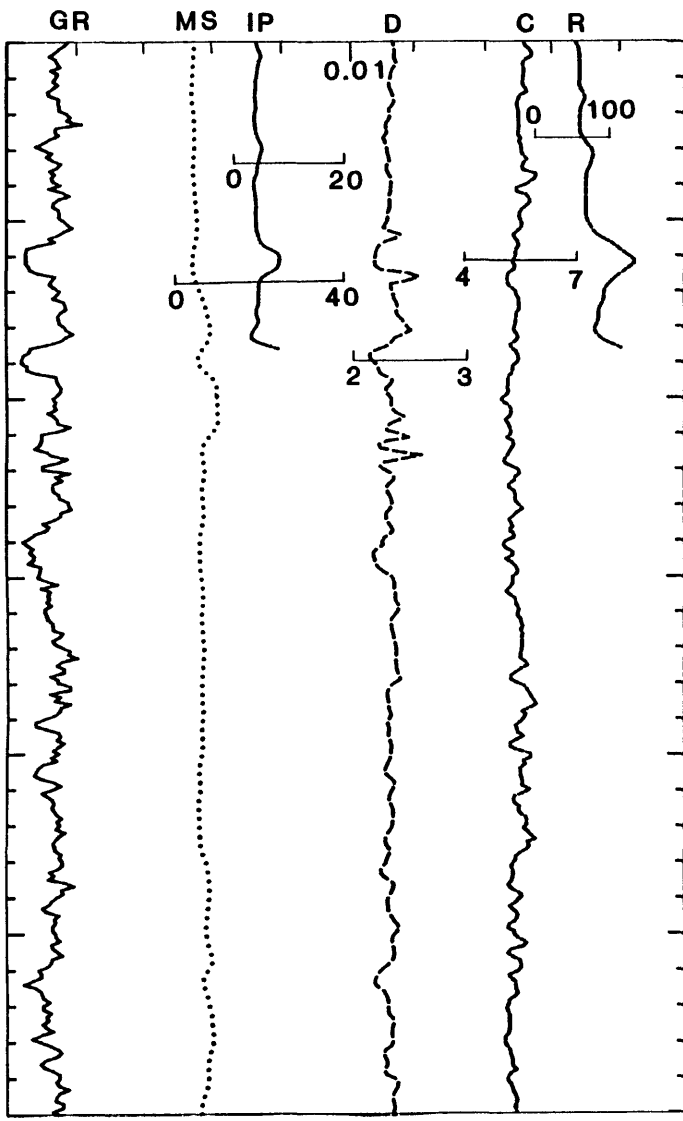
Hole no.: 287-4R



Lith	Depth	Mineral.	Color & Description
	450		
	500		
			505'-805'. No cuttings - color taken from foam when available. 505'-525': v lt gray
	550		

Appendix 5--continued

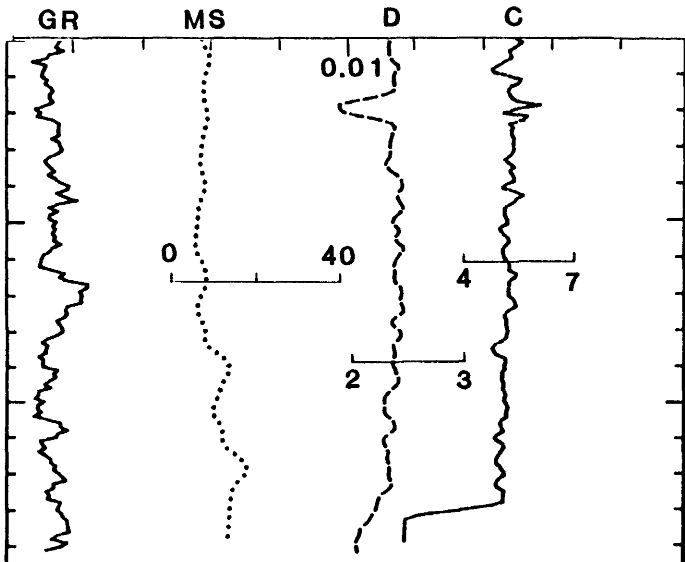
Hole no.: 287-4R



Lith	Depth	Mineral.	Color & Description
	600		
			605'-625': pale red-brn
	650		645'-685': gray-orng pink
			685'-725': pale red-brn
	700		

Appendix 5--continued

Hole no.: 287-4R



Lith	Depth	Mineral.	Color & Description
	750		725'-765': mod red
			765'-785': mod red-brn
	800		785'-805': pale red-brn
	850		

Appendix 6--Petrographic descriptions of surface samples from the Blue Mountain pipe. Locations of the samples are shown in fig. 8.

Sample 287-A-C83: Hematitic and silicified, medium to fine-grained, fossiliferous, quartz arenite. Sample of "vein" that exhibits 1,200 cps.

Texture: Slight fluxion texture--cataclasis and parallel alignment of elongated grains. Two textural types: (1) Medium grain quartz arenite with well developed overgrowths that tend to occlude any porespace. Contacts are straight triple-point margins, but more often are slightly mosaiced with concavoconvex contacts. (2) Fine-grained fossiliferous arenite, in which the allochemical constituents have been completely replaced by silica. Quartz grains have quartz overgrowths with concavoconvex intergranular contacts.

Clastic framework: Comprises 99% of the section in medium-grained sandstone and 90-95% in the fossiliferous lithology.

Quartz--Medium-grained sandstone (#1 from above) contain 99% quartz. Well rounded, slight undulose extinction, monocrystalline, 0.2-0.5 mm, abundant overgrowths. The fossiliferous zone (#2 above) contains about 45% quartz, 0.1 mm, but smaller very fine silt sizes are abundant in a cataclastic zone.

Allochems--49% of fossil-bearing zone. Fossils are generally pelmatozoan fragments. Also, (1) several fractured opaline lenses 1/8 inch in diameter with parallel bedded fabric, at least some of coralline algal origin, and (2) a large fragment of a brachiopod (productid) shell (T.H. Henry, USGS, written commun., 1988). All fossils are replaced by quartz. Cellular structure is faintly preserved. Geode-like filling of interior cavities is not complete and some porosity remains.

Heavy minerals

Tourmaline--trace

Matrix fraction: 0-10% (0% in nonfossiliferous part). Cement and matrix is all quartz overgrowths. Up to 10% translucent Fe oxides around grains and concentrated in fractures in the finer grained fossiliferous lithology.

Pore space: 0%; locally 5% in the hollow, unfilled centers of fossils.

Mineralization/alteration: Trace amounts of azurite line the pore space in several of the fossil vugs.

Sample 287-D-C83: Fine to very fine-grained, color banded, quartz arenite.

Texture: Moderately well sorted. Combination of grains in point contact and grains with subhedral overgrowths in which the overgrowths make up 100% of matrix/cement.

Clastic framework: Comprises 95%; grain size 0.1-0.17 mm

Quartz--94% monocrystalline, <1% polycrystalline, subhedral overgrowths.
Chert--trace
Feldspar--
Orthoclase <1%; unaltered
Biotite--trace; unaltered
Heavy minerals--
Tourmaline--trace

Matrix fraction: 5%; 2% hematite of varying density and color, locally up to 5%. 1% microcrystalline quartz in areas without hematite (probably continuous in areas with hematite, only obscured by the color). About 1% sericite.

Pore space: Amount unknown due to plucking of grains during slide preparation.

Mineralization/alteration: Hematite, limonite, and other varicolored Fe oxides deposited after quartz overgrowths. Some quartz grains contain very thin dust rims of hematite beneath quartz overgrowth.

Sample 287-E-C84: Medium-grained, buff-colored, quartz arenite.

Texture: Horizontally laminated, very-fine graded bedding.

Clastic framework: Comprises 96%; average grain size 0.25 mm

Quartz--95%; monocrystalline, concavoconvex contacts, anhedral quartz overgrowths. Both straight and undulose extinction.
Chert--trace; ferruginous and nonferruginous.
Feldspars--
 Orthoclase--1%
 Plagioclase--trace
 Microcline--trace
Muscovite--trace; bent flakes
Rock fragments--
 Metamorphic--trace schist
Heavy minerals--
 Tourmaline--trace
 Hematite--trace, dense, irregular shaped. May be alteration product of another detrital opaque oxide mineral.

Matrix fraction: 4%; 3% microcrystalline quartz, mainly pore-filling. 1% translucent Fe oxides.

Pore space: Unknown (poor thin section preparation, plucking of grains).

Mineralization/alteration: None

Sample 287-F-C84: Light tan, medium-grained quartz arenite; finely parallel-bedded, with minor hematite on fracture surfaces.

Texture: Very slight pressure cataclasis. Trace of sutured margins and minor amounts of undulose extinction in framework quartz grains. Euhedral, well developed quartz overgrowths.

Clastic framework: Comprises 95%; bimodal, 0.25 mm and 0.5 mm size grains.

Quartz--94%; monocrystalline (trace of polycrystalline), straight extinction, subrounded, many with euhedral overgrowths. Trace of sutured pressure contacts.
Chert--<1%; similar to quartz grains in size and shape, but lacking overgrowths.
Feldspars--
Plagioclase--<1%; some are altered along cleavages, others unaltered.
Microcline--<1%; unaltered, subangular.
Orthoclase--trace
Muscovite and biotite--trace; bent flakes, some with frayed edges.
Rock fragments--
Metamorphic--trace; schistose grains
Heavy minerals--
Tourmaline--trace

Matrix fraction: 2-3%; 1% silica, microcrystalline quartz "dust"; 1% illite and kaolinite, pore-filling; trace sericite; <1% limonite as rims around select framework grains, and as pigment of sericite/clay-filled pores.

Pore space: 3%; intergranular voids between euhedral overgrowth crystal faces.

Mineralization/alteration: Scarce. Hematite-coated fractures (hand sample) and a hint of fluxion texture in one zone.

Sample 287-G-C84: Silicified and densely color-banded, medium-grained quartz arenite.

Texture: Well sorted. Exhibits slight cataclastic texture, shown by (1) sutural quartz grains, (2) undulose extinction, and (3) minor schistose horizons.

Clastic framework: Comprises 96%; locally over 99% in areas of overgrowth with sutured contacts. Average grain size 0.35 mm; some are >0.6 mm.

Quartz--95-100%; monocrystalline. About 50% have slight undulatory extinction. Grains and overgrowths on rounded detrital grains have interpenetrating grain boundaries. Trace of polycrystalline quartz.
Chert--3-4%; ferruginous, lacking overgrowths, unlike the quartz grains. Preferentially have rims/rinds of goethite.
Feldspars--
Microcline--trace; irregular shape, altered rims partially replaced by geothite.
Muscovite--trace; very small, undeformed plates.
Rock fragments--
Metamorphic--trace; schistose chert grain.
Heavy minerals--trace amounts of zircon, tourmaline, and sphene.

Matrix fraction: 0-4%. Trace of illite. Average of 2% hematite and limonite stringers along grain boundaries. Some denser hematite is in the shape of small squares.

Pore space: >1%; highly variable, along with the matrix. Up to 4% in the purple color-band areas.

Mineralization/alteration: Liesegang banded, due to color of matrix (light yellow-red-purple), resulting from oxidation state of Fe. "Colored" areas contain overgrowths with straight margins and intergranular pore space. White or nonpigmented parts have no pore space for the pigment to exist in.

Sample 287-H-C84: Buff colored, fine-grained quartz arenite with scattered, brown, 1-3 mm Fe oxide-rich spots.

Texture: Well sorted, with prominent euhedral quartz overgrowths. Overgrowths tend to meet at 120° triple-point junctions. Very faint parallel bedding laminations. Locally the sandstone consists of mosaiced quartz grains, with 0% matrix and pore space.

Clastic framework: Comprises 95%; moderately well sorted, sand-size grains. Most have well developed, euhedral, quartz overgrowths which act as the cementing agent.

Quartz--93%; monocrystalline with <1% polycrystalline. Equant to elongated grains, generally unimodal, averaging 0.17 mm in diameter. Scarce larger grains up to 0.4 mm. All bear overgrowths and visible dust rims showing the original very well rounded detrital grain shape.
Chert--2%; finely crystalline composite grains with same morphology as the above quartz, only without overgrowths. Trace of microcrystalline opaques.
Muscovite--trace; very thin, long, slightly bent needles.
Rock fragments--
Sedimentary--<1%; ferruginous, silty chert grains.
Heavy minerals--
Zircon--trace

Matrix fraction: 3%. Matrix components are restricted to occupying interstitial space between adjacent quartz overgrowth crystal faces. 1-2% very coarsely crystalline kaolinite, with euhedral hexagonal basal section and accordian-like stacks or "books" up to 0.04 mm long. <1% illite, fine-grained, detrital. 1% hematite and goethite. Occasionally some goethite staining of kaolinite, otherwise the majority is opaque hematite.

Pore space: 1-2%. Open pores between adjacent overgrowth junctions. Percentage may be higher than actual, due to plucking of matrix during preparation of the thin section.

Mineralization/alteration: Kaolinite is very coarsely crystalline and definitely not detrital. It is very similar to coarse kaolinite in the Orphan mine, and background Coconino thin sections do not contain it. Areas of denser hematite contain squares of still denser hematite, suggestive of pseudomorphs after pyrite cubes. Hematite also lines a few minor fractures.

<u>Sample 287-I-C84</u>: Variably colored, hematitic to limonitic to white (bleached?), quartz siltstone. Appears silicified in hand sample.

Texture: Structureless, massive, well sorted.

Clastic framework: 99%. Well sorted, silt-size grains, angular to subangular, well sorted.

Quartz-98%; monocrystalline, with concave-convex contacts, and undulose extinction. Minor overgrowths show straight contacts. Average 0.04-0.07 mm in diameter, 0.09 mm maximum diameter.
Muscovite--<1%; small undeformed needles.
Heavy minerals--1%; at least three unidentified different mineral types.

Matrix fraction: 1%. Hematite and brown Fe oxides concentrated along grain boundaries.

Pore space: 0%. No detectable vugs or pore space.

Mineralization/alteration: Matrix hematite appears to have been formed prior to the quartz overgrowths, as grains with overgrowths have dust rims of hematite. Crystalline quartz coats fractures in the hand sample.

Appendix 7--Chemical analyses of rock samples collected from the Blue Mountain pipe (see fig. 8a for locations) and from four background Coconino Sandstone outcrops (from various locations below the south rim of the eastern Grand Canyon).

Sample #	LATITUDE	LONGITUDE	Ag ppm ICP	Al_2O_3% XRF	As ppm AA	Au ppm HBR	Ba ppm ICP	Be ppm ICP	Total-C% CID	T-Org C%**
Blue Mountain pipe samples										
287-A-C83	35°41'49"	113°11'01"	<4	.80	300	-	477	<2	.03	<.01
287-E-C84	35°41'53"	113°11'00"	<2	2.83	* 30	<.1	130	<1	<.01	<.01
287-F-C84	35°41'53"	113°11'02"	<2	1.93	30	<.1	110	<1	.03	.01
287-G-C84	35°41'50"	113°11'01"	3	.16	470	<.1	61	<1	<.01	<.01
287-H-C84	35°41'53"	113°10'57"	<2	2.16	80	<.1	26	<1	.07	.07
287-I-C84	35°41'48"	113°11'01"	3	.60	60	<.1	110	<1	.02	<.01
Coconino Sandstone background samples										
PCL-D-C84	36°03'41"	112°05'15"	+ <.05	3.47	.8	<.1	110	<1	<.01	<.01
PCU-D-C84	36°03'40"	112°05'10"	+ <.05	1.79	1.7	<.1	140	<1	<.01	<.01
PCL-E-C85	36°00'05"	111°58'00"	<2	3.53	13	-	110	<1	.09	<.01
PCL-F-C85	36°03'15"	112°13'08"	<2	2.04	.4	-	76	<1	.04	<.01
			+ AA data		* ICP data					

ICP= Inductively Coupled Argon Emission Plasma Spectroscopy
AA= Atomic Absorption
XRF= X-ray Fluorescence
HBR= Sample is digested in hydrobromic acid and bromine and analyzed using AA
CID= Combustion with Infrared Detection
** T-Org C% is calculated by (Total-C%) - ($T-CO_3$ C%)

Appendix 7--Continued.

Sample #	$T-CO_3$ C%	CaO%	Cd ppm	Ce ppm	Co ppm	Cr ppm	Cs ppm	Cu ppm	Dy ppm	Er ppm
	CT	XRF	ICP	INAA	INAA	INAA	INAA	ICP	INAA	ICP
Blue Mountain pipe samples										
287-A-C83	.04	.23	<4	26.8	3.79	31.9	+<1	170	2.90	<8
287-E-C84	<.01	.05	<2	14	.93	11.6	.95	12	-	-
287-F-C84	.02	.36	<2	8	1.22	5.87	.56	21	-	-
287-G-C84	.01	.11	<2	4	2.87	7.35	<.15	45	-	-
287-H-C84	<.01	.09	<2	7	9.33	7.81	.55	94	-	-
287-I-C84	.02	.13	<2	45	1.94	16.5	.20	35	-	-
Coconino Sandstone background samples										
PCL-D-C84	.01	.14	<2	10.9	.70	19.8	1.27	2	-	-
PCU-D-C84	.04	.21	<2	6.5	1.56	6.67	.65	3	-	-
PCL-E-C85	.16	.88	<2	12.2	1.0	15.3	1.11	4	-	-
PCL-F-C85	.09	.52	<2	7.47	.40	4.43	.58	3	-	-

+ AA data

CT= Coulemetric titration
XRF= X-ray fluorescence
ICP= Inductively Coupled Argon Emission Plasma Spectroscopy
INAA= Induced Neutron Activation Analysis
AA= Atomic Absorption

Appendix 7--Continued.

Sample #	Eu ppm INAA	F% ISE	T-Fe_2O_3% XRF	Ga ppm ICP	Gd ppm INAA	Hf ppm INAA	Hg ppm AA	K_2O% XRF	LOI-900**	La ppm INAA
Blue Mountain pipe samples										
287-A-C83	1.30	.01	1.31	<8	3.62	5.16	.02	.04	.62	11.5
287-E-C84	.17	.01	.32	<4	-	2.42	<.02	1.13	.75	5.41
287-F-C84	.20	.01	.33	<4	-	1.46	<.02	.73	.96	4.06
287-G-C84	.11	<.01	2.17	<4	-	3.38	.14	<.02	.68	2.78
287-H-C84	.21	.01	1.94	<4	-	1.90	.06	.38	1.32	3.74
287-I-C84	.54	.01	.31	<4	-	9.93	.02	.08	.67	20.4
Coconino Sandstone background samples										
PCL-D-C84	.28	.02	.18	4	-	6.90	<.02	.86	1.01	6.11
PCU-D-C84	.17	.01	.09	<4	-	1.87	<.02	.42	.85	3.86
PCL-E-C85	.30	.02	.39	<4	-	4.97	<.02	.73	2.20	6.55
PCL-F-C85	.15	.01	.09	<4	-	1.17	<.02	.54	1.23	3.83

INAA= Induced Neutron Activation Analysis
ISE= Ion Selective Electrode
XRF= X-ray fluorescence
ICP= Inductively Coupled Argon Emission Plasma Spectroscopy
AA= Atomic Absorption
** LOI-900= Loss of ignition at 900° C

Appendix 7--Continued.

Sample #	Li ppm	Lu ppm	MgO%	Mn ppm	Mo ppm	Na%	Nb ppm	Nd ppm	Ni ppm	P%
	ICP	INAA	XRF	ICP	ICP	ICP	ICP	INAA	ICP	ICP
Blue Mountain pipe samples										
287-A-C83	+ 13	.15	.16	49	48	.01	<8	24.7	19	.12
287-E-C84	7	.64	.24	10	<2	.02	<4	5.2	6	.01
287-F-C84	7	.51	.27	20	<2	.02	<4	4.11	8	.04
287-G-C84	17	.05	.13	93	31	<.01	<4	2.2	9	.01
287-H-C84	9	.07	.19	31	<2	.01	<4	3.27	40	.01
287-I-C84	34	.25	.16	33	6	.01	<4	8.1	5	.01
Coconino Sandstone background samples										
PCL-D-C84	4	.13	.23	11	<2	.02	<4	5.56	7	.01
PCU-D-C84	3	.05	.19	12	<2	.20	<4	3.50	5	.01
PCL-E-C85	6	.12	.17	58	<2	.02	-	6.44	6	.01
PCL-F-C85	4	.05	.14	7	<2	.01	-	3.33	3	.01

+ AA data

ICP= Inductively Coupled Argon Emission Plasma Spectroscopy
AA= Atomic Absorption
INAA= Induced Neutron Activation Analysis
XRF= X-ray fluorescence

Appendix 7--Continued.

Sample #	Pb ppm ICP	Rb ppm INAA	Total-S% CID	Sb ppm INAA	Sc ppm INAA	Se ppm AA	SiO_2% XRF	Sm ppm INAA	Sr ppm ICP	Ta ppm INAA
Blue Mountain pipe samples										
287-A-C83	120	+<10	.05	17.2	1.76	.2	95.1	6.10	290	.32
287-E-C84	7	20.7	<.01	.21	1.09	<.1	94.5	.85	26	.13
287-F-C84	9	15	.06	.22	.77	.3	95.0	.90	23	.08
287-G-C84	20	-	.02	5.6	.32	2.2	95.5	-	12	.16
287-H-C84	15	6.54	<.01	.58	.79	.9	93.4	.75	13	.08
287-I-C84	23	3.28	.02	3.36	1.60	.4	96.9	3.15	63	.74
Coconino Sandstone background samples										
PCL-D-C84	<4	19.6	<.01	<.14	1.31	<.1	93.1	1.34	37	.22
PCU-D-C84	<4	10.4	<.01	.11	.61	<.1	95.6	.75	23	.10
PCL-E-C85	4	17.6	<.01	.25	1.85	.2	92.1	1.42	50	.24
PCL-F-C85	<4	11.8	<.01	.12	.55	<.1	95.4	.71	27	.09

+ AA data

ICP= Inductively Coupled Argon Emission Plasma Spectroscopy
INAA= Induced Neutron Activation Analysis
AA= Atomic Absorption
CID= Combustion with Infrared Detection
XRF= X-ray fluorescence

Appendix 7--Continued.

Sample #	Tb ppm	Th ppm	Ti%	Tm ppm	U ppm	V ppm	Y ppm	Yb ppm	Zn ppm	Zr ppm
	INAA	INAA	ICP	INAA	DN	ICP	ICP	INAA	INAA	INAA
Blue Mountain pipe samples										
287-A-C83	.52	4.56	.09	.18	104	20	11	1.05	+282	<320
287-E-C84	.08	1.14	.04	-	.78	13	2	.34	55.2	81.9
287-F-C84	.10	.81	.03	-	.71	12	3	.33	93.5	51.1
287-G-C84	.07	.50	.06	-	12.8	20	<2	.30	166	79
287-H-C84	.14	.86	.03	-	7.18	21	4	.42	808	46
287-I-C84	.24	4.37	.24	-	3.16	10	8	1.49	103	302
Coconino Sandstone background samples										
PCL-D-C84	.18	1.73	.05	-	.81	7	4	.76	7.62	239
PCU-D-C84	.10	.94	.02	-	.61	4	2	.35	4.38	59.6
PCL-E-C85	.19	1.83	.06	-	.74	12	4	.75	11.4	143
PCL-F-C85	.08	.96	.03	-	.37	4	2	.31	3.7	41.4

+ AA data

INAA= Induced Neutron Activation Analysis
ICP= Inductively Coupled Argon Emission Plasma Spectroscopy
DN= Delayed Neutron Activation Analysis
AA= Atomic Absorption