

A Mineralized Breccia Pipe in Mohawk Canyon, Arizona— Lithologic and Geophysical Logs

U.S. GEOLOGICAL SURVEY BULLETIN 1683-A



Chapter A

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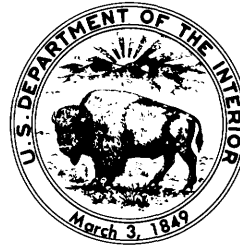
This research was funded by the
Bureau of Indian Affairs
in cooperation with the
Hualapai Indian Tribe

U.S. GEOLOGICAL SURVEY BULLETIN 1683

BRECCIA PIPES IN NORTHERN ARIZONA

DEPARTMENT OF THE INTERIOR
DONALD PAUL HODEL, *Secretary*

U.S. GEOLOGICAL SURVEY
Dallas L. Peck, Director



UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON: 1988

For sale by the Branch of Distribution
Books and Open-File Reports Section
U.S. Geological Survey
Federal Center
Box 25425
Denver, CO 80225

Library of Congress Cataloging-in-Publication Data

A Mineralized breccia pipe in Mohawk Canyon, Arizona—lithologic and geophysical logs.

(U.S. Geological Survey bulletin ; 1683A)

Bibliography: p.

Supt. of Docs. no.: I 19.3:1683-A

1. Intrusions (Geology)—Arizona—Mohawk Canyon. 2. Breccia—Arizona—Mohawk Canyon. 3. Ore-deposits—Arizona—Mohawk Canyon. 4. Geology—Arizona—Mohawk Canyon. I. Wenrich-Verbeek, Karen J. II. Series: Geological Survey bulletin ; 1683A.

QE75.B9 no. 1683A

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86-600178

[QE611.6.U6] [551.8'8]

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A Mineralized Breccia Pipe in Mohawk Canyon, Arizona—Lithologic and Geophysical Logs

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Abstract

Hundreds of solution-collapse breccia pipes crop out in the canyons and on the plateaus of northern Arizona. The pipes originated in the Mississippian Redwall Limestone and stopped their way upward through the upper Paleozoic strata, locally extending into the Triassic Moenkopi and Chinle Formations. High-grade U ore, associated with potentially economic concentrations of Ag, Pb, Zn, Cu, Co, and Ni in some of these pipes, has stimulated mining activity in northern Arizona despite the depressed market for most of these elements.

More than 900 confirmed and suspected breccia pipes have been mapped during the past 6 years as a part of this study. Many exploration criteria for detecting mineralized breccia pipes were developed during the mapping. One pipe discovered on the west side of Mohawk Canyon in 1983 was selected for exploratory drilling in 1984 because it exhibited the following exploration criteria:

1. Concentrically inward-dipping strata
2. Erosion along an encircling ring
3. Anomalous radioactivity
4. Goethite pseudomorphs and molds of pyrite
5. Colloform celadonite-stained chalcodony
6. Supergene Cu mineralization
7. Breccia
8. Anomalous concentrations in surface exposure of such trace elements as Ag, As, Cd, Co, Cr, Cu, Mo, Ni, Pb, Se, U, V, and Zn

Five rotary and core holes were drilled into this pipe. Drilling problems such as lost circulation, lost casing into 30-ft-high caverns within the breccia, and great water consumption limited the drilling results. Core recovered from holes in the center of the pipe shows breccia to the total depth of 1,010 ft, abundant pyrite, and minor galena, sphalerite, arsenopyrite, and brovoite. Gamma logs of a rotary hole penetrating to 1,335 ft (no cuttings were obtained below 1,000 ft) show a 1-ft interval of 0.52 percent eU_3O_8 at a depth of 1,191 ft, and a 20-ft zone averaging 0.04 percent eU_3O_8 ; this is at the same stratigraphic level as the tops of orebodies in mines located on similar plateaus capped with the Permian Harrisburg Gypsiferous Member of the Kaibab Limestone. Sufficient mineralization, specifically the presence of Pb, Zn, and Ni minerals common to breccia pipes hosting economic mineralization, was verified in the Mohawk Canyon pipe that further drilling is warranted to assess its economic potential.

INTRODUCTION

The Colorado Plateau of northern Arizona is host to hundreds of breccia pipes. Despite the depressed uranium market, exploration activity for mineralized breccia pipes in north-central and northwestern Arizona has remained high.

These are not classic breccia pipes in that there are no volcanic rock associations in time or space; instead, they are a result of solution collapse within the Redwall Limestone and stoping of the overlying strata. The pipes and associated mineralization transgress formation boundaries from the Mississippian Redwall Limestone to the Triassic Chinle Formation (fig. 1). No pipes have been observed during this study (nor during studies by Huntton, Billingsley, and Clark (1981, 1982) and Billingsley and Huntton (1983)) to occur in rock below the base of the Thunder Springs Member of the Redwall Limestone. The solution collapse produced extensive brecciation of the rock within the steep walls of the pipe. No rocks from underlying formations have been observed in any pipe; all material has been dropped downward into the pipe. As a result of the collapse, brecciated rock is surrounded by a steeply dipping (commonly near vertical) ring fracture that separates the breccia from the flat-lying wall rock.

Mining activity in breccia pipes of the Grand Canyon region began during the 19th century when essentially all ore produced was for copper. It was not until the 1950's that these mines were first recognized to contain uranium-mineralized rock. Metals produced from one or more pipes during the past century include Cu, U, Ag, Au, Pb, and Zn (Foord and others, 1978). Uranium ore from mines within these pipes is exceptionally high grade; 450,000 tons of ore from the Orphan Mine averaged between 0.30 and 0.60 percent U_3O_8 (Pierce and others, 1970). Other mined breccia pipes have, or had, uranium grade and tonnage similar to the Orphan Mine. These mines are presently being operated essentially for their uranium content (uraninite is the ore mineral), although perhaps silver could be extracted as a byproduct; the Orphan mine produced 81,000 oz of Ag from 1963 through

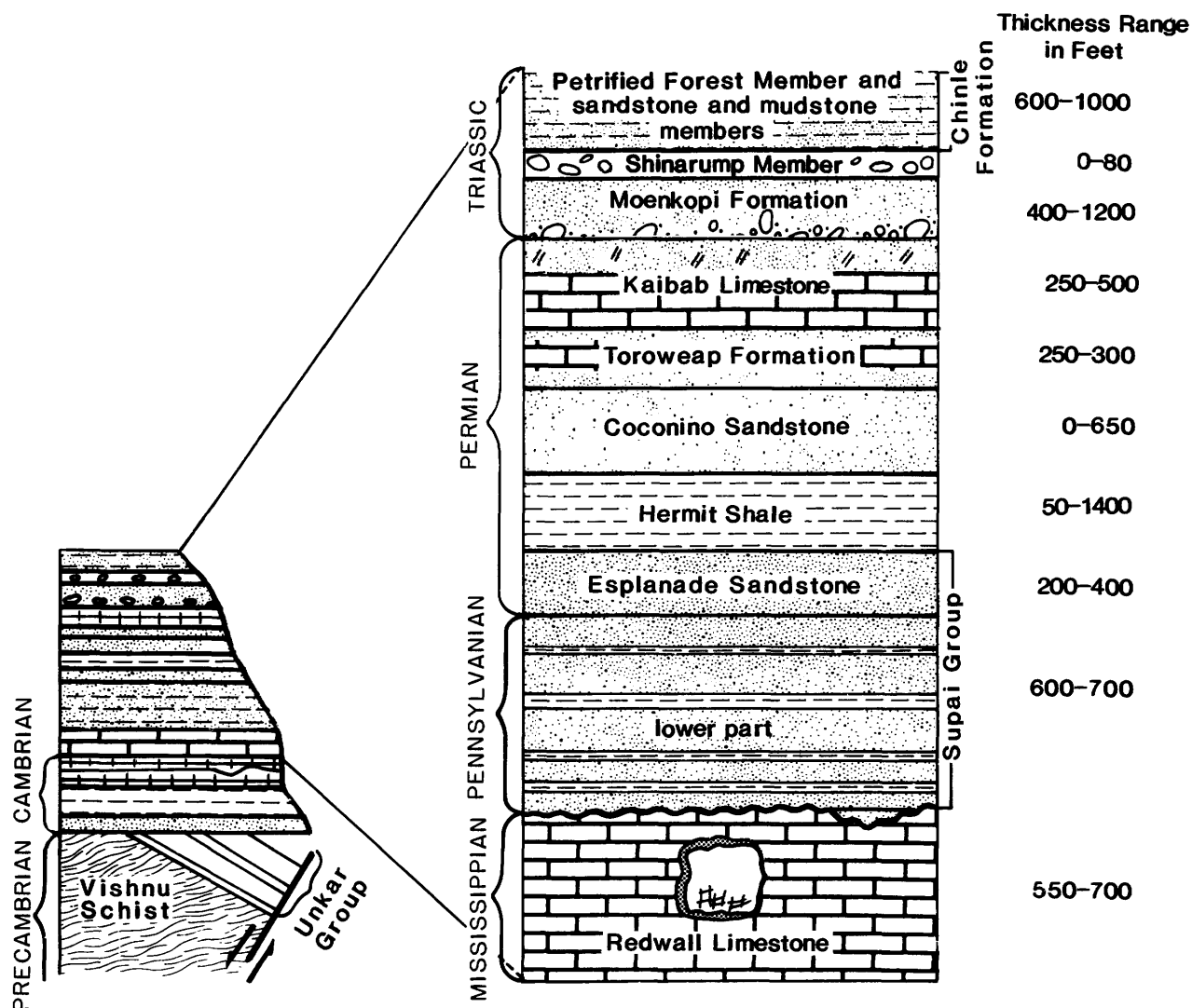


Figure 1. Stratigraphic column showing rock units found in and near the Grand Canyon of Arizona. The thicknesses shown for each unit are those which occur over the area shown in figure 2 (thickness measurements from George H. Billingsley, personal communication).

1966 (USGS file material). Analyses of uranium-mineralized rock from breccia pipes throughout the Grand Canyon region routinely yield silver concentrations of 10 to 100 ppm, with samples containing as much as 1,150 ppm (35 oz/ton) (Wenrich, 1985). Minerals common in the unoxidized rock from these pipes are pyrite, marcasite, chalcopryrite, galena, sphalerite, enargite, tetrahedrite-tennantite, millerite, gersdorffite, barite, and calcite.

The breccia pipes extend across northern Arizona to the Utah border and south to the Mogollon Rim, the southern margin of the Colorado Plateau. They are abundant from the edge of the Grand Wash Cliffs (the western margin of the Colorado Plateau), across the Hualapai Indian Reservation (which includes Mohawk Canyon), and eastward across the Coconino Plateau to the Marble

Plateau of the Navajo Reservation (fig. 2). No pipes are known east of the Echo Cliffs. Perhaps the area best known for breccia pipes is the Arizona Strip extending from the Grand Canyon north to the Utah border. The flurry of mining ventures during the past 6 years, including the Hack Canyon mines and the Pigeon Mine, has brought prominence to the Arizona Strip. The pipes likely exist along the southern margin of the Colorado Plateau but for the most part are buried beneath the lavas of the San Francisco volcanic field.

Dissolution of the Redwall Limestone began during the Mississippian, creating an extensive karst terrain; the Pennsylvanian Supai Group was deposited into many of these karst features. The breccia pipes include strata up through the Triassic Chinle Formation, but no pipes have been observed to extend into rocks younger than

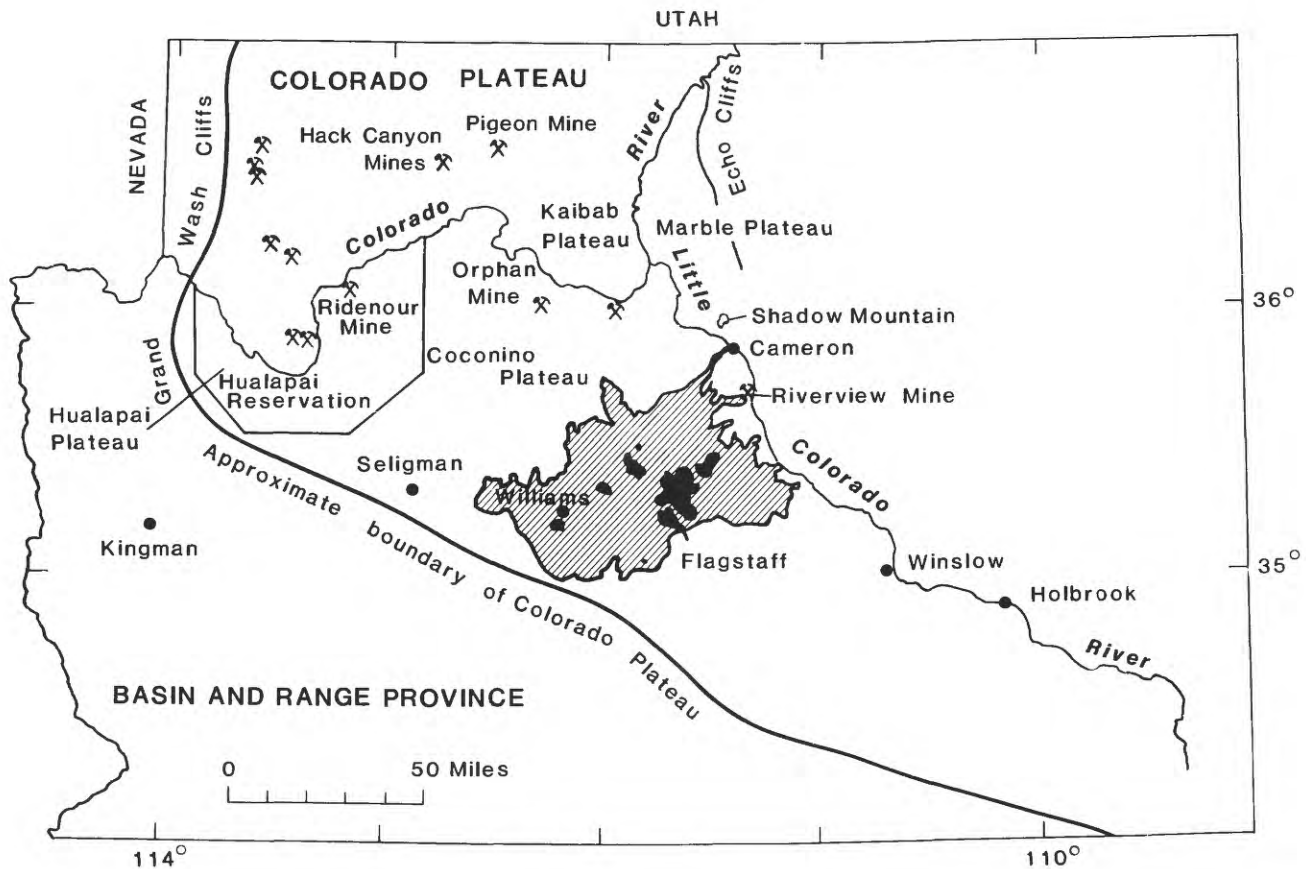


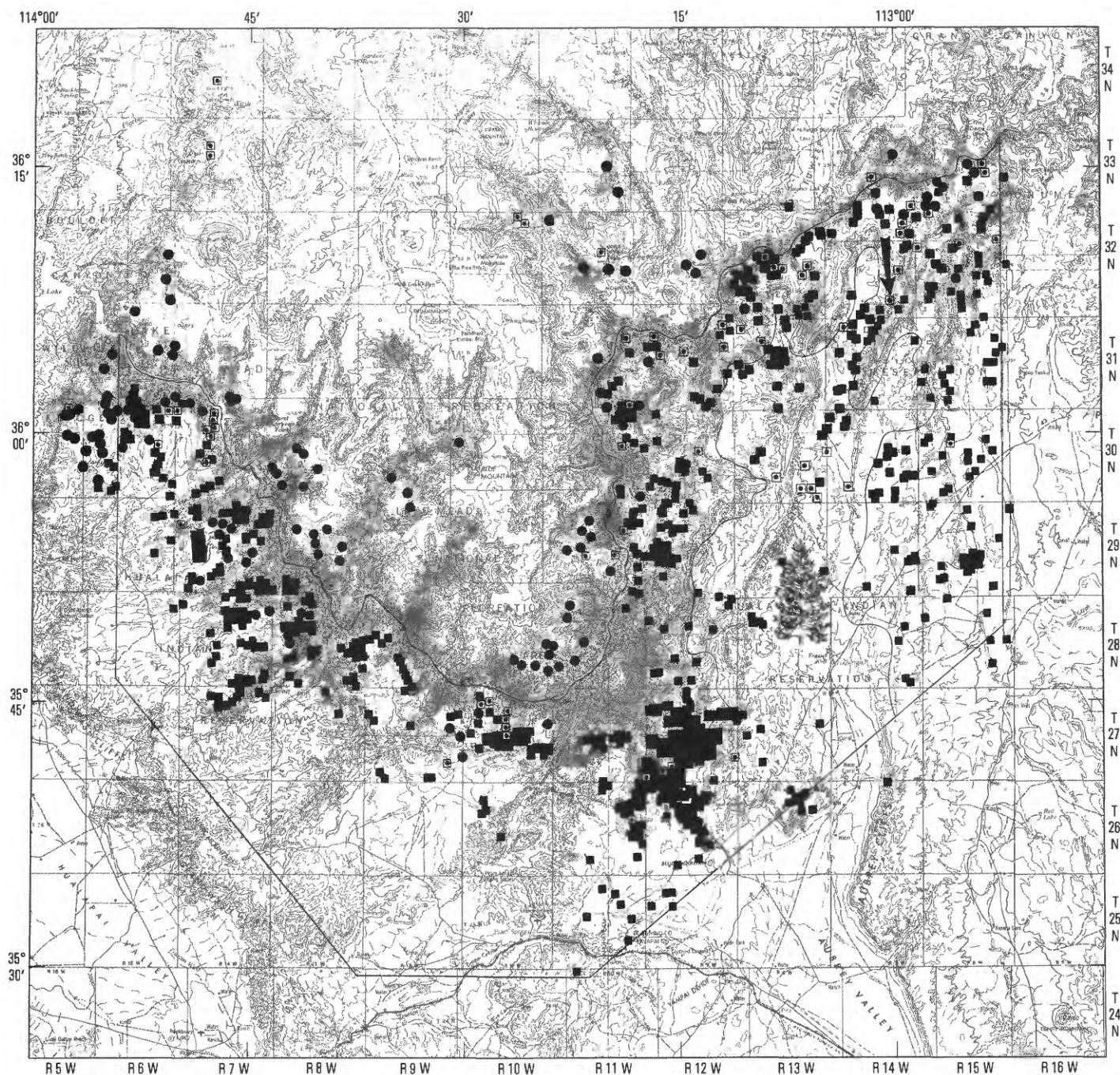
Figure 2. Index map of northern Arizona showing the location of plateaus, Hualapai Reservation, breccia pipes developed into mines, and the San Francisco volcanic field (shaded area) which buries terrane with high potential for breccia pipes.

the Chinle Formation. Thus, it is probably safe to assume that the karst development in the Redwall, and hence breccia pipe formation, continued until, or at least reactivated, in the Triassic. A minimum age of 141 million years (m.y.) was determined for uraninite from the Orphan Mine by U/Pb dating (Gornitz and Kerr, 1970). Preliminary U-Pb isotope data for uraninite from the Hack breccia pipes suggest a main period of mineralization roughly 200 m.y. ago (Ludwig, K. R., 1983, oral commun.). Such an age is in good agreement with the break in observed mineralized rock between the Triassic and Jurassic; that is, there are known pipes with Triassic strata but none with Jurassic or younger rock.

The geological and geochemical controls on the mineralization of these breccia pipes are poorly understood at present. A more detailed discussion of the mineralogy and geochemistry of breccia pipes in northern Arizona is provided by Wenrich (1985). There is strong evidence that the pipe location is structurally controlled on the Marble Plateau (Sutphin and others, 1983; Sutphin and Wenrich, 1983). It is also known that the pipes occur in clusters (fig. 3 and Sutphin and Wenrich, 1983). This occurrence would be expected for karst-formed breccia pipes exposed above underlying cave systems; where

there is no cave, there are no pipes. In addition, mineralized pipes occur in clusters (see the Bat Cave area of fig. 3). This clustering of mineralized pipes is especially obvious in the area of Hack Canyon where the Hack I, II, III, and old Hack Canyon Mines (four separate pipes) all occur within 1 mi² (3 sq km) of each other. This suggests that the mineralizing fluids used a hydrologic system that connected multiple pipes and moved through those pipes connected by the same cavern. Each mineralized cluster of pipes probably represents one Redwall Limestone cave system.

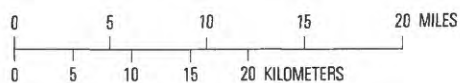
An extensive suite of elements is anomalously concentrated in mineralized rock within breccia pipes throughout northern Arizona. This association is remarkably consistent from pipe to pipe: Ag, As, Ba, Cd, Co, Cr, Cs, Cu, Hg, Mo, Ni, Pb, Sb, Se, Sr, U, V, Zn, and, less commonly, the rare-earth elements. In addition to this suite of elements, a black, glassy bitumen material is found associated with the brecciated rock in many of the mineralized pipes, including the Mohawk Canyon pipe discussed in this report. This material appears to have solidified after such minerals as pyrite, barite, and quartz, which are included as blebs and veins within the pyrobitumen. Samples from the breccia pipes



EXPLANATION

- Mapped by G.H. Billingsley
- Mapped during this study
- ▣ Mineralized pipe

Area outlined in black (shown with a tree symbol in the center) on east side of map is densely tree covered, preventing recognition of most pipes. The Mohawk Canyon pipe is marked by the arrow in the northeast part of the map.



containing pyrite and bitumen are visually indistinguishable (fig. 4A) from samples collected from Mississippi Valley deposits (fig. 4B).

Primary and secondary fluid inclusions in sphalerite, quartz, calcite, and dolomite yield filling temperatures in the range of 80–173 °C. Salinities in sphalerite are consistently above 10 wt. percent NaCl equivalent. Secondary inclusions in sphalerite range from 86 to 173 °C, while the few positively identified primary inclusions tend to be lower temperature, ranging from 80 to 105 °C. Primary inclusions in dolomite range from 105 to 161 °C with high salinities consistently greater than 17 wt. percent NaCl equivalent. Two groups of primary inclusions in quartz were found in a silicified breccia spire. One group ranged from 91 to 107 °C and the other from 256 to 317 °C. These fluid inclusion-filling temperatures and salinities are in agreement with those of 80–137 °C found in sphalerite from Mississippi Valley-type deposits (Hagni, 1983). Although this suggests a moderately low temperature fluid for the genesis of minerals such as sphalerite and galena and the Co and Ni phases, it does not preclude the uraninite coming from a later different mineralizing fluid, as there are no known uranium occurrences in Mississippi Valley deposits (D. L. Leach, personal commun., 1985).

ACKNOWLEDGMENTS

The authors wish to thank George H. Billingsley (USGS), Russell L. Wheeler (USGS), and Earl R. Verbeek (USGS) for valuable criticisms concerning the manuscript. George Billingsley provided continual stratigraphic consulting throughout the duration of the project. James Rasmussen, Energy Fuels Nuclear, provided invaluable drilling advice during preparation of the drilling contract and throughout the drilling operation. Both George and Jim contributed significantly to the success of the drilling operation.

PIPES ON THE HUALAPAI INDIAN RESERVATION

The Hualapai Indian Reservation is situated on the southwestern corner of the Colorado Plateau (fig. 2). The western half of the reservation is located on the Hualapai Plateau capped by the Redwall Limestone. This location provides no more than 500 ft (175 m) of possible rock (vertically) to host an orebody, and in general the Redwall Limestone is not as favorable a host for uranium mineralization as are the overlying sandstones. Thus, this area is not considered favorable for economic breccia pipes



Figure 4. Glassy organic material (bitumen) collected from (A) breccia pipes in northern Arizona looks similar to that collected from (B) Mississippi Valley-type deposits (specimen of D. L. Leach).

Figure 3 (facing page). Over 700 confirmed and suspected breccia pipes have been mapped on the Hualapai Reservation during the past 3 years. The western side has sparse vegetation which is reflected in the greater density of collapses. This area provides an example of the solution-collapse density when detailed mapping is completed. ● Mapped by G. H. Billingsley. ■ Mapped during this study. ■ Mineralized pipe. Area outlined in black (shown with a tree symbol in the center) on east side of map is densely tree covered, preventing recognition of most pipes. The Mohawk Canyon pipe is marked by the arrow in the northeast part of the map.

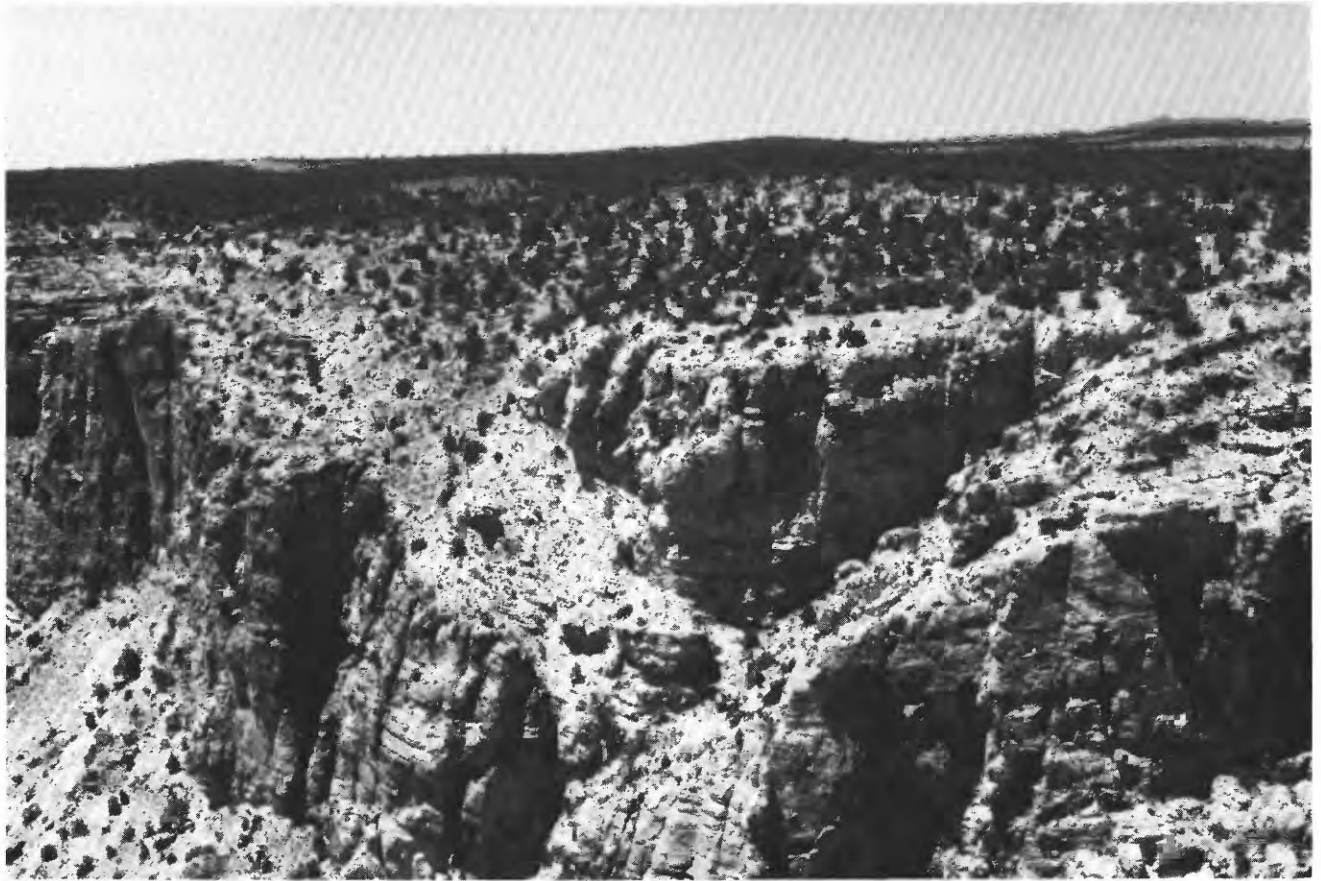


Figure 5. Mohawk Canyon pipe (photo taken looking west from Mohawk Canyon). Note the beds of Kaibab Limestone dipping toward the center from both sides and the drainage eroded along the ring fracture.

and was eliminated for potential drilling targets. In contrast, the eastern part of the reservation occupies the western edge of the Coconino Plateau which is capped, for the most part, by the Harrisburg Gypsiferous Member of the Kaibab Limestone. This location provides a potential column of brecciated rock in excess of 2,500 ft (800 m) high and places the top of the mesas in the eastern part of the reservation at the same stratigraphic horizon as that above most breccia pipes hosting orebodies in northern Arizona.

More than 700 confirmed and suspected breccia pipes have been mapped on the Hualapai Reservation during the past 3 years (fig. 3). This density of collapse features is not unique to the Hualapai Reservation (the western edge of this pipe-rich region) but extends eastward where a similar concentration has been mapped on the Marble Plateau (Sutphin and Wenrich, 1983). Many exploration criteria for detecting mineralized breccia pipes were developed during the mapping. Mapping was begun on 1:24,000 color aerial photography, and then field checked. Many pipes exposed in the cliffs are not recognizable on the aerial photographs and are best spotted from a helicopter. One such pipe, discovered while mapping

from the helicopter on the west side of Mohawk Canyon in 1983, was selected for exploratory drilling in 1984 because it exhibited the following exploration criteria:

1. Concentrically inward-dipping beds of Kaibab Limestone (fig. 5)
2. A circular erosion pattern with erosion preferentially occurring along an encircling ring fracture
3. Anomalous radioactivity: Although the maximum gamma radiation at the Mohawk Canyon pipe is only five times background, this is unusually high for oxidized surface exposure of breccia pipes
4. Goethite pseudomorphs and molds of pyrite
5. Colloform celadonite-stained chalcedony
6. Copper mineralization: expressed on surface exposure as the supergene minerals malachite, azurite, brochantite, and chrysocolla
7. Brecciated Kaibab Limestone fragments within a comminuted matrix
8. Anomalous concentrations in surface samples of such trace elements as Ag, As, Cd, Co, Cr, Cu, Mo, Ni, Pb, Se, U, V, and Zn

MOHAWK CANYON PIPE

Physiography and Geology

The intermittent streams of Mohawk Canyon have incised a canyon more than 2,000 ft (600 m) deep beneath the Kaibab Limestone surface (fig. 6). At least 15 breccia pipes (fig. 4) are exposed along the cliff walls, at least 7 of which show some sign of surface mineralized rock. One of these, mapped as pipe no. 494 during this study and locally referred to as the Mohawk Canyon pipe, was drilled between July and November of 1984. Five holes were drilled into this pipe: two rotary drilled from top to bottom, one cored from top to bottom, and two rotary drilled to an approximate depth of 900 ft (300 m) and cored to bottom. The pipe is located in the SW $\frac{1}{4}$ of sec. 26, T. 32 N., R. 7 W. of the Vulcan's Throne SE $7\frac{1}{2}'$ quadrangle, Coconino County, Ariz. (lat.: 36°07'30", long.: 113°00'24") (fig. 7).

The pipe is exposed on two sides along the cliff of Mohawk Canyon and a side tributary, which provides a three-dimensional exposure of the upper 160 ft (50 m) of the pipe (fig. 5). The pipe is collared in the Harrisburg Gypsiferous Member of the Permian Kaibab Limestone (fig. 8) approximately 2,500 ft (770 m) stratigraphically above the Redwall Limestone. A sheer cliff, formed by the Fossil

Mountain Member of the Kaibab Limestone 160 ft (50 m) below the rim of the canyon, prevents access to the formations outcropping below.

At the surface, the Mohawk Canyon pipe is approximately 400 ft (125 m) in diameter. At least three concentric ring fractures bound the pipe (fig. 8). The innermost ring fracture is vertical, displays the most downward displacement, and forms the contact between a subhorizontal to shallowly dipping central plug of strata and the concentrically dipping outer beds. Outward from the innermost ring fracture, adjacent concentric ring fractures display shallower dips and less downward displacement away from the center of the pipe. Mapping and drilling data indicate that the overall downward displacement at the center of the pipe is approximately 100 ft (30 m). Several near-vertical radial normal and reverse faults extend from outside into the central part of the pipe, cutting and displacing the ring fractures. These faults are later than the formation of the ring fracture and breccia pipe. Movement along these faults is less than that along the ring fracture.

Copper- and uranium-mineralized rock is exposed in outcrop along the eastern side of the pipe and occurs on, or immediately adjacent to, the ring fractures. Two adits (fig. 9) were driven into the Mohawk Canyon pipe just



Figure 6. Looking south from the Mohawk Canyon pipe at 2,000 ft of sedimentary rock exposed along the fault-controlled Mohawk Canyon. Edgar Walema (Hualapai Tribal Chairman) on right, Justin Powski (Hualapai Tribal councilman) on left, and Karen Wenrich (USGS geologist) in center.

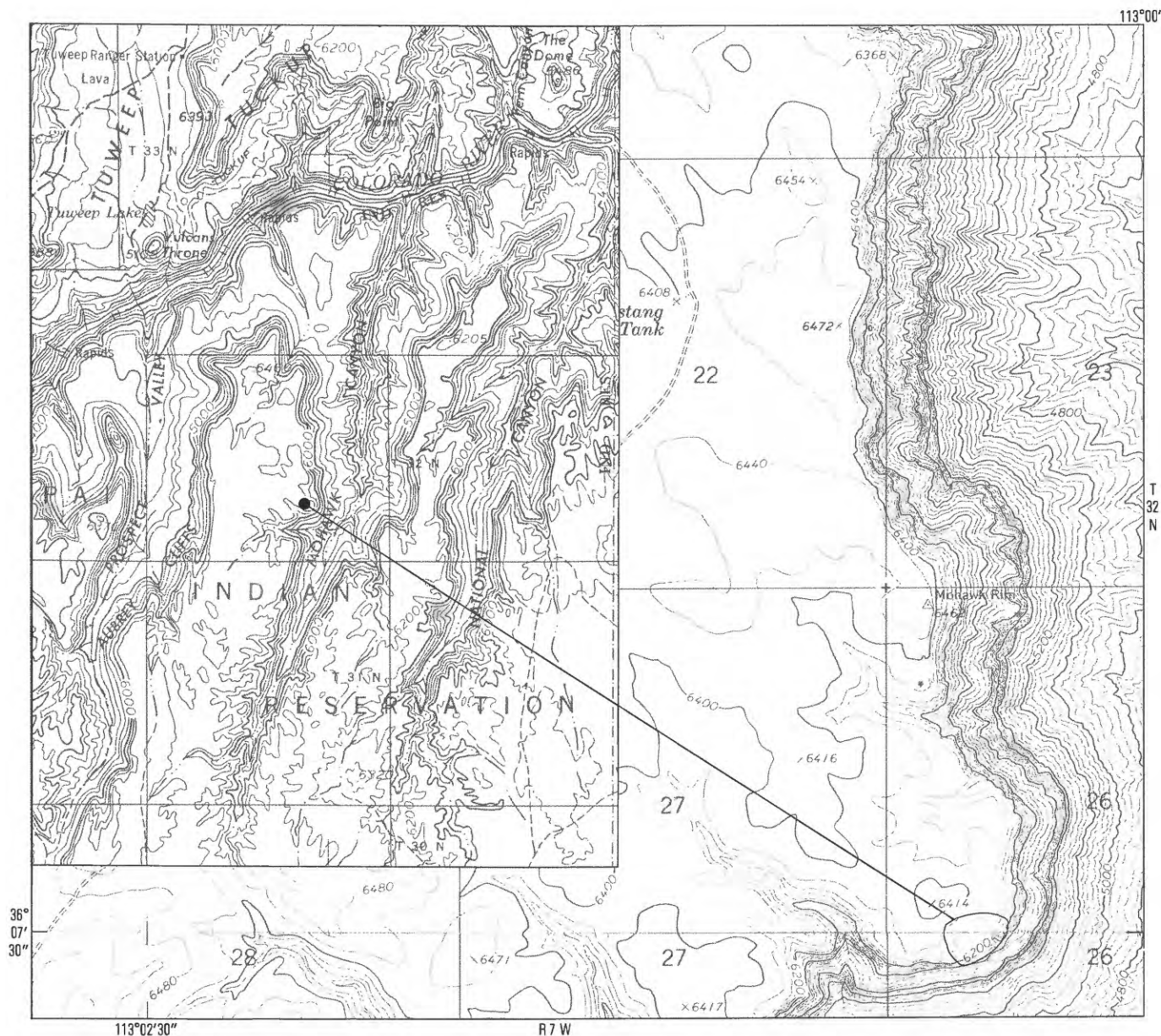


Figure 7. The Mohawk Canyon pipe is located on the boundary between the Vulcan's Throne and Vulcan's Throne SE 7½' quadrangles (each section is 1 sq mi). The inset (smaller scale map) map is from the Grand Canyon 2° quadrangle. North is up. Refer back to figures 2 and 4 for smaller scale locations.

above the sheer cliff on the east side of the pipe (fig. 8). They are located directly on the outermost ring fracture and extend about 20 ft (6 m) back into the shear zone of the pipe. There is no known written record of this mining venture, although Herb Voight, the former Hualapai Tribal Planner, suggested that these might be the "lost turquoise mines of Mohawk Canyon" of which he had heard rumors. The presence of square nails used in the timbers suggests the mining activity probably occurred before the turn of the century. Samples removed from the adit and scattered about on the ground contain malachite, azurite, chrysocolla (perhaps mistaken for turquoise), bitumen, and minor uranium mineralization (sample

494-C-C83 location is shown in fig. 8). An exposure of fault gouge located due west of the adits on the next inward ring fracture yields gamma-ray counts 12 times background. Along this same zone are numerous cubes of limonite pseudomorphed after pyrite and interspersed with pyrite casts.

Geochemistry of Surface Samples

Surface samples taken from the Mohawk Canyon pipe contain an identical suite of anomalous elements similar to those found in mineralized breccia pipes throughout northern Arizona (Wenrich, 1985). Table 1

shows 55 elements for each of three samples collected during 1983 when the pipe was discovered. Sample 494-A-C83 was collected from near the center of the pipe on top of the plateau (near drill hole R1 on the geologic map, fig. 8). This sample is a vuggy silicified limestone with abundant celadonite-stained chalcedony. Small goethite concretions are scattered across the rock and the vugs are filled with quartz crystals. Although this is not a mineralized sample and SiO_2 makes up over 92 percent of this sample and Fe_2O_3 2.7 percent, it does contain anomalous concentrations of As, Ba, Cu, Se, V, and Zn (as compared to the average value for the Kaibab Limestone, and especially a silicified Kaibab Limestone).

Sample 494-B-C83 was collected from an outcrop of fault gouge located due west of the adits. The sample is a clay rich, (as can be seen from the Al_2O_3 content of 14.4 percent) finely comminuted sandstone with abundant goethite concretions and bands of celadonite (the Fe_2O_3 content is 15.2 percent). This outcrop was $4\frac{1}{2}$ times background in gamma-ray counts (the uranium concentration is 17 ppm, which is approximately 4 times the average U concentration for the Kaibab Limestone).

Sample 494-C-C83 was collected from the northernmost of the two adits. It is a very fine grained, brecciated, malachite- and azurite-encrusted sandstone. Gamma-ray counts from this outcrop were more than 12 times background (the U content is 50 ppm, which is approximately 12 times the background U content for the Kaibab Limestone). Both samples 494-B-C83 and 494-C-C83 have enrichment ratios of more than 10 (as compared to background Kaibab Limestone samples) for Ag (only 494-C), As, Ba, organic C (only 494-C), Cd, Cr, Cs (only 494-B), Cu (only 494-C), Lu, Mo (only 494-C), Ni, Pb, Sb, Se, Sm, Sr, Ta, Th (only 494-B), U, V, Zn, and Zr.

Soil Sampling Survey

Seven soil samples were collected from the Mohawk Canyon pipe just prior to drilling; the data are shown in table 2 and the sample locations are shown on the geologic map (fig. 8). The samples were collected approximately 4 in. (1.2 cm) below the surface, although there was considerable difficulty in acquiring a sample of soil as opposed to one that was predominantly chips of Kaibab Limestone. The samples were dry-sieved through 80-mesh (177- μm) stainless steel sieves to remove the large rock chips and organic debris. Two traverses were made across the pipe; unfortunately no samples were collected outside of the pipe, so there is no background for comparison. Figure 10 shows plots of these two traverses for selected elements (Co, Cr, Cu, Fe, La, Mg, Nd, P, Y,

and Zn). Sample 494-B-S is plotted at 0 ft, the center of the pipe, on figure 10. For some of the metallic elements, Co, Cu, and Fe, concentrations increase from the center to the outermost ring fracture, probably due to later remobilization by supergene fluids which migrated more freely along the ring fracture than in the less fractured center of the pipe. Elements such as Cr, La, Mg, Nd, P, and Y increase toward the center of the pipe. The increase in Mg over the center of the pipe is what would be expected considering the dolomitization that was observed in the drill core. Although more soil samples, particularly background samples, are desirable, the concentration of these elements, particularly Zn, in the soil above the Mohawk Canyon pipe are relatively higher than the background soils on this same plateau several miles away.

DRILLING RESULTS

Five holes were drilled into the Mohawk Canyon pipe (fig. 11). Their collar locations and drifts are shown in figure 8. Hole 1 (R1) was rotary drilled to a total depth of 1,120 ft (345 m); drill cuttings were recovered from top to bottom. Drilling was discontinued at 1,120 ft (345 m) because the cuttings became oxidized and it was assumed that the hole had drifted out of the reduced and potentially mineralized part of the pipe. The hole was originally begun with a tri-cone tooth bit, but when drift exceeded the 5 degree limitation placed on the drillers by the U.S. Geological Survey contract, the bit was switched to a hammer.

Hole 2 (R2) was also a rotary hole drilled to a total depth of 1,335 ft (411 m); a hammer bit was used on the entire hole and produced cuttings to 870 ft (268 m), at which point circulation was lost and minor cuttings were available to 975 ft (300 m). Cuttings were again recovered from this point to a depth of 1,020 ft (314 m), after which circulation was lost again and never recovered. The drillers refused to drill deeper without a pipe guarantee.

Hole 3 (R3) was rotary drilled to a depth of approximately 1,014 ft (313 m), at which point coring began and continued until 1,421 ft (437 m). The bottom 84 ft (26 m) were no longer reduced or brecciated and appeared to be undisturbed Hermit Shale. Therefore, it was assumed that the hole was no longer in the pipe and the drilling was stopped.

Hole 4 (R4) was rotary drilled to a depth of 1,001 ft (308 m) with circulation lost below 855 ft (263 m). Coring began at 1,001 ft (308 m), at the base of what the drillers interpreted to be a 30 ft (9 m) cavern, and continued to 1,008 ft (310 m) where oxidized rock was encountered and the drill string, along with 900 ft (277 m) of casing, plummeted into a 40 ft (12 m) high cavern. The hole, drill string, and casing were lost.

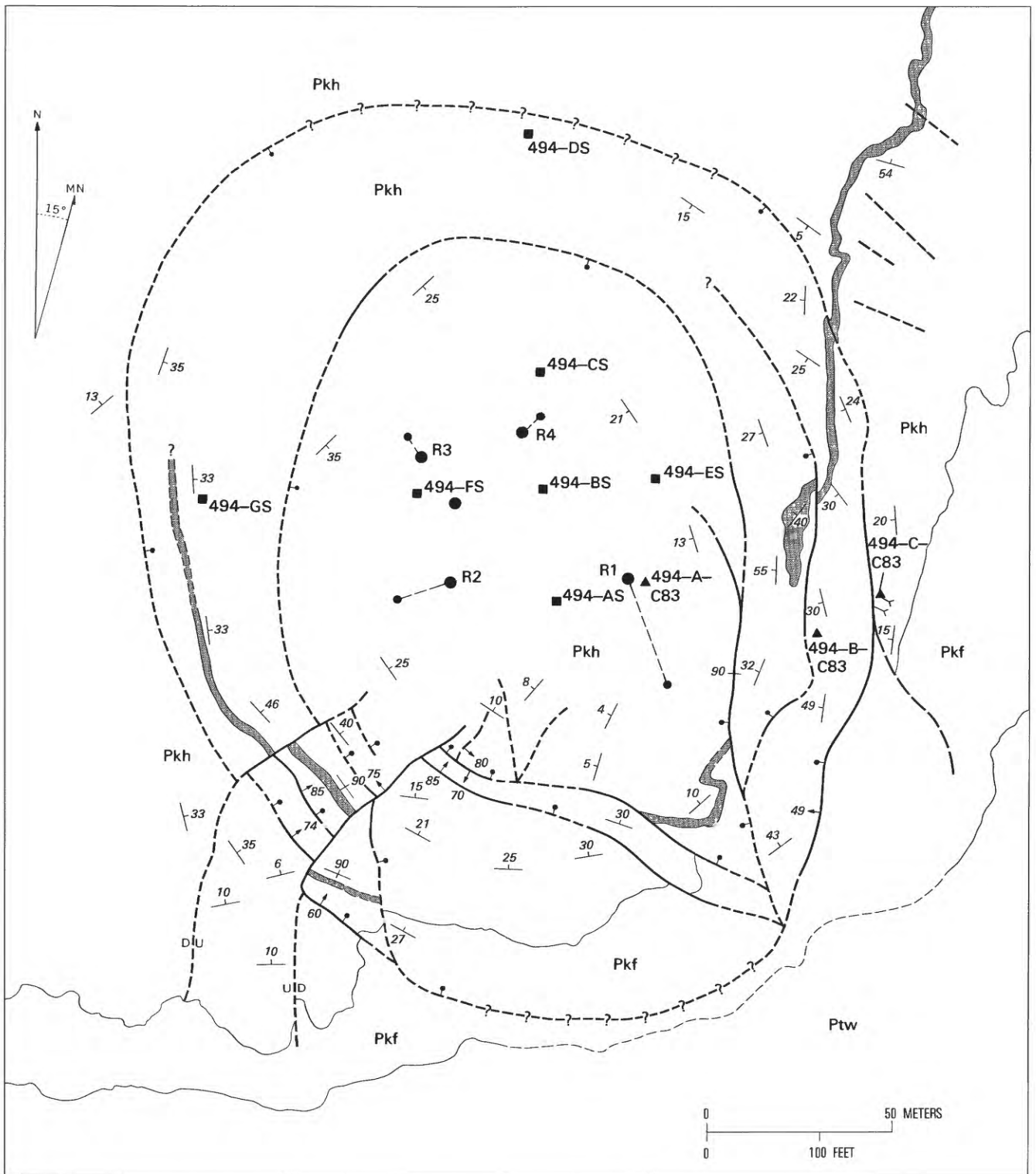
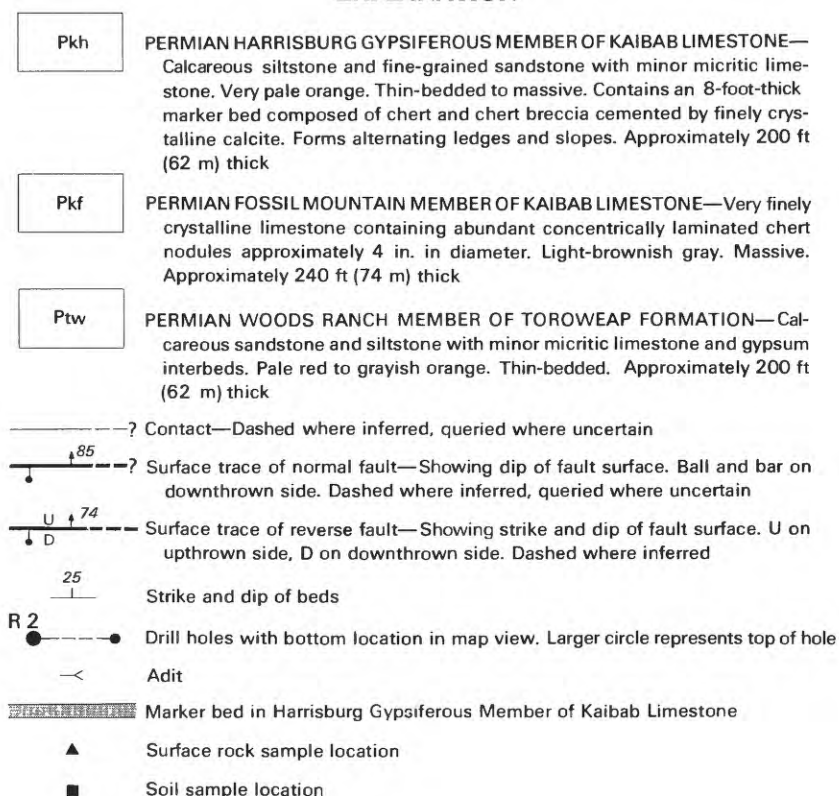


Figure 8 (above and facing page). Geologic map of the Mohawk Canyon pipe.

EXPLANATION



Hole 5 (C5) was cored to a total depth of 1,012 ft (311 m), at which point the project ran out of money and drilling was terminated. With the exception of hole 1, the drift of the holes was minor, although as is common for these pipes, all holes drifted toward the outside of the pipe.

Lithologic Logs

Lithologic and geophysical logs for the five drill holes are shown in appendixes 1–5. Because most of the holes penetrated brecciated rock, as opposed to the normal stratigraphic sequences, the formation contacts were placed at levels where the first clasts were observed that could be recognized as belonging to the next formation in question. In most cases, it was impossible to determine from the chip samples whether or not the rock was brecciated. The contact between the Fossil Mountain Member of the Kaibab and the underlying Woods Ranch Member of the Toroweap was difficult to determine from the breccia, as most of the Woods Ranch Member appears to have been removed by solution, and the chert fragments from the Fossil Mountain Member appear to have been carried downward as much as 600 ft (184 m). Even though the Woods Ranch Member is present along the cliffs on either side of the Mohawk Canyon pipe, the pipe itself

was apparently such an efficient conduit for fluids that the gypsum in the Woods Ranch Member has been almost totally removed.

With the exception of hole 3, all holes commonly contain celadonite in the Harrisburg Gypsiferous Member of the Kaibab Limestone and in the upper 150 ft (46 m) of the Fossil Mountain Member of the Kaibab Limestone. Again, with the exception of hole 3, all holes have copper carbonate (azurite, malachite, or both) present in the Kaibab Limestone; it appears to be particularly prevalent between about 280 ft (86 m) and 320 ft (98 m).

Hole 3 is apparently outside or at the edge of the bleached, unoxidized, central pipe of breccia. Pyrite does not appear to be as common above 1,016 ft (313 m) in hole 3 as it is in other holes. The bottom 400 ft (120 m) that was cored (below 1,014 ft, 313 m) is not brecciated and beneath 1,215 ft (373 m) the core becomes typical reddish-brown Hermit Shale, with the exception of occasional reduction spots and associated blebs and veins of pyrite.

Hole 1 is apparently at the opposite (northwest) edge of the bleached, unoxidized portion of the breccia pipe (fig. 8), although cuttings are bleached and contain pyrite throughout most of the hole below 635 ft (195 m). At 1,085 ft (334 m) the cuttings became typical reddish-brown Hermit Shale and the hole was terminated, as it apparently either drifted out of the pipe or at least out of the bleached/reduced zone.



Figure 9. Two adits were driven into the west side of Mohawk Canyon, probably sometime during the 19th century. These adits are located on the outermost east ring fracture of the Mohawk Canyon pipe, and extend back into the pipe about 20 ft (6 m).

Holes 2, 4, and 5 are entirely within the brecciated, reduced part of the pipe. All three holes encountered difficulty with lost circulation after the Coconino Sandstone was entered. Pyrite is moderately common in the cuttings and core from all three holes. The core from hole 5 and the 8 ft (2.5 m) of core from hole 4 were the most informative.

Hole 5 is brecciated from 125 ft (38 m) to the bottom of the hole (figs. 12a and 12b). In addition, at 969 ft (298 m) the movement of iron oxides was sufficient to produce liesegang banding (fig. 13) in the porous Seligman Member of the Toroweap Formation. The core from hole 5 provides a complete observable sequence of the brecciated center of the pipe, including clasts of strata from the top of the Kaibab Limestone down to the Coconino Sandstone.

The 8 ft (2.5 m) of core at the bottom of hole 4 (1,000 ft, 307 m) that was recovered just prior to losing the drill string is probably some of the more interesting rock. The top 2 ft are strongly oxidized and the contact with the underlying pyrite-rich reduced rock is very sharp. This oxidation was apparently caused by later oxidizing ground water, which must have flowed through the

overlying 30 ft (9 m) cavern the drillers had carefully proceeded through. The 4 in. (1.2 cm) of oxidized core at the bottom of this hole should perhaps have been taken as a warning by the drillers that they were about to enter another cavern through which oxidizing ground waters must have flowed. The 6 ft (1.8 m) of reduced rock contain approximately 1–3 percent pyrite as specks, thin, wispy, veinlets, elliptical-to-round patches up to 2 inches (6 cm) long and as disseminated grains throughout the sandstone matrix. Several vugs, especially at 1,007 ft (310 m), contain galena crystals. Arsenopyrite, sphalerite, and bravoite, are scattered throughout the reduced zone 1,003 ft (308 m) to 1,007.5 ft (310.2 m). Within the oxidized zone pyrite blebs and veins have been altered to hematite. In addition, 1 mm blebs of black, glassy bitumen material are scattered throughout the sandstone matrix in the reduced zone between the two caverns.

The downward displacement in the center of the Mohawk Canyon pipe is shown in figure 14. Here, all five holes have been projected to one plane to illustrate the downdropping of as much as 170 ft (52 m) at the base of the Coconino Sandstone. The downward displacement becomes less toward the top of the pipe (in the Harrisburg

Table 1. Geochemistry of surface samples collected from Mohawk Canyon pipe.
[The first three digits of the sample number are the Mohawk Canyon pipe number]

Sample #	Ag ppm ICP	Al2O3% X-ray	As ppm AA	Au ppm	Ba ppm ICP	Be ppm ICP	Total-C% X-ray	T-Org C% X-ray		
494-A-C83	<10	.49	36	-	150	<5	.17	.05		
494-B-C83	<2	14.4	72	-	* 329	<5	.88	.06		
494-C-C83	100	2.24	400	<.05	* 180	<5	1.58	.57		
	T-CO3 C%	CaO% X-ray	Cd ppm ICP	Ce ppm ICP	Co ppm ICP	Cr ppm ICP	Cs ppm AA	Cu ppm ICP	Dy ppm ICP	Er ppm ICP
494-A-C83	.12	.63	10	<20	<5	31	<1	40	<20	<20
494-B-C83	.74	2.28	10	*33.2	* 5.32	*110	*11.4	20	<20	<20
494-C-C83	1.01	2.8	30	*26.5	*11.9	*244	* 1.27	14000	<20	<20
	Eu ppm ICP	F%	T-Fe2O3% X-ray	Ga ppm ICP	Gd ppm ICP	Hf ppm INAA	Hg ppm AA	K2O% X-ray	LOI-900 X-ray	La ppm ICP
494-A-C83	<10	.01	2.68	<20	<50	-	.0500	.07	1.25	<10
494-B-C83	* .51	.33	15.2	<20	<50	7.46	.2000	4.6	11.5	* 19.3
494-C-C83	* .67	.16	18	<20	* 3.5	2.81	.3000	.35	12.2	* 27.4
	Li ppm AA	Lu ppm ICP	MgO% X-ray	Mn ppm ICP	Mo ppm ICP	Na2O% X-ray	Nb ppm ICP	Nd ppm ICP	Ni ppm ICP	P2O5% X-ray
494-A-C83	7	-	.23	40	<10	.08	<20	<20	20	.16
494-B-C83	99	.51	3.94	60	<10	* .35	<20	* 16.1	130	.45
494-C-C83	10	.18	2.34	70	140	* .92	<20	13.7	70	1.47
	Pb ppm ICP	Rb ppm AA	Total-S%	Sb ppm INAA	Sc ppm ICP	Se ppm AA	SiO2% X-ray	Sm ppm ICP	Sr ppm ICP	Ta ppm ICP
494-A-C83	50	<10	.01	-	<10	1.5	92.3	<50	20	<200
494-B-C83	130	*107	.02	2.22	* 8.86	4.6	45.5	* 2.96	870	* 1.32
494-C-C83	12000	* 13	.22	106	* 2.4	350	53.7	* 3.62	1600	* .26
	Tb ppm ICP	Th ppm ICP	TiO2% X-ray	Tm ppm ICP	U ppm DN	V ppm ICP	Y ppm ICP	Yb ppm ICP	Zn ppm AA	Zr ppm INAA
494-A-C83	<100	<20	<.02	-	4.99	60	<10	<5	440	-
494-B-C83	* .37	* 14.8	.5	.46	16.7	90	20	* 3.37	* 1740	238
494-C-C83	* .45	* 3.03	.16	.22	49.5	290	20	* 1.29	*12000	-

* INAA data
INAA-Induced Neutron Activation Analysis
ICP-Inductively Coupled Argon Emission Plasma Spectroscopy
AA-Atomic Absorption
DN-Delayed Neutron
X-ray-X-ray Fluorescence

Gypsiferous Member) because of the bulking effect. The contacts were difficult to determine in many cases, particularly where strongly brecciated and only rotary-drilled chip samples (such as hole 4R), or no samples, were available. These contacts are queried in figure 14.

Geophysical Logs

Downhole geophysical logs were made of each hole. Top-to-bottom logs are available for holes 1 and 2, but the bottom 260 ft (80 m) in hole 3, the bottom 160 ft (50 m) in hole 4, and the bottom 234 ft (72 m) in hole 5 have no logs because the holes either caved in or were too narrow for the probe. Gamma-ray, density, and caliper logs are available for all other intervals. Magnetic-

susceptibility logs were also made on all holes except holes 3 and 5 (the core holes lined with steel casing). Resistivity and induced-polarization logs were run in water-filled sections of the holes wherever possible, but due to the cavernous nature of the pipe there were few holes that held water long enough so that more than the bottom 350 ft (107 m) could be logged.

The gamma logs show radiation levels below 0.002 percent eU_3O_8 for all holes except hole 2 (note the gamma log scale for hole 2 is twice what it is for the other holes), and one interval around 650 ft (200 m) in all holes. At this horizon, just above the Woods Ranch-Brady Canyon contact, there is an interval of about 50 ft (15 m) in which the gamma-ray response ranges from two to four times the normal background for the hole. Thus the gamma logs provide a good marker horizon for the base of

Table 2. Geochemistry of soil samples collected from Mohawk Canyon pipe.
[The first three digits of the sample number are the Mohawk Canyon pipe number]

Sample #	Al % ICP	As ppm ICP	Ba ppm ICP	Be ppm ICP	Ca % ICP	Ce ppm ICP	Co ppm ICP	Cr ppm ICP		
494-A-SC84	3.2	<10	330	<1	10	41	7	170		
494-B-SC84	2.3	<10	260	<1	12	34	4	150		
494-C-SC84	3.4	<10	330	<1	9.9	41	8	99		
494-D-SC84	4.3	<10	450	1	9	47	11	72		
494-E-SC84	3.1	<10	310	<1	9.4	38	7	110		
494-F-SC84	2.4	<10	370	<1	13	33	6	140		
494-G-SC84	4.5	<10	450	1	.89	61	11	63		
	Cu ppm ICP	Fe % ICP	Ga ppm ICP	K % ICP	La ppm ICP	Li ppm ICP	Mg % ICP	Mn ppm ICP	Na % ICP	
494-A-SC84	19	1.5	8	1.1	49	21	4.4	360	.33	
494-B-SC84	11	1	5	.87	47	16	4.3	310	.23	
494-C-SC84	20	1.6	7	1.2	38	19	4.2	460	.36	
494-D-SC84	22	2	11	1.6	31	26	2	470	.41	
494-E-SC84	17	1.4	7	.97	36	20	3.9	430	.32	
494-F-SC84	16	1.1	7	.89	38	17	4.7	290	.26	
494-G-SC84	17	2.1	11	1.4	36	31	.56	400	.59	
	Nb ppm ICP	Nd ppm ICP	Ni ppm ICP	P % ICP	Pb ppm ICP	Sc ppm ICP	Sr ppm ICP	Th ppm ICP	Th ppm DN	Ti % ICP
494-A-SC84	7	34	23	1.1	13	5	300	<4	7.7	.16
494-B-SC84	7	41	12	1.4	10	4	290	5	6.4	.11
494-C-SC84	9	31	18	.7	16	5	260	5	6.92	.17
494-D-SC84	7	28	34	.19	16	6	240	5	4.8	.23
494-E-SC84	8	28	15	.79	16	5	270	<4	4.7	.16
494-F-SC84	<4	32	19	1	11	3	320	<4	3.9	.13
494-G-SC84	7	31	21	.07	16	7	130	12	11.5	.3
	U ppm DN	V ppm ICP	Y ppm ICP	Yb ppm ICP	Zn ppm ICP					
494-A-SC84	4.17	40	49	3	84					
494-B-SC84	3.94	31	56	3	60					
494-C-SC84	3.25	41	34	2	77					
494-D-SC84	3.3	51	21	2	68					
494-E-SC84	3.58	36	35	2	72					
494-F-SC84	3.81	31	44	2	74					
494-G-SC84	3.68	49	22	2	55					

ICP-Inductively Coupled Argon Emission Plasma Spectroscopy
DN-Delayed Neutron

the Woods Ranch Member. In hole 2, gamma logs from the lost-circulation portion of the hole show a 1-ft interval of 0.52 percent eU_3O_8 at a depth of 1,191 ft (366 m), underlain by a 20-ft (6 m) zone of 0.04 percent eU_3O_8 (fig. 15). This is the same stratigraphic horizon as the top of the orebodies in the Hack I, II, III, and Pigeon mines located on similar plateaus capped with Kaibab Limestone (fig. 2).

An interesting problem in using gamma-logs to evaluate ore reserves became apparent at this horizon (fig. 16). The initial gamma log, run just after the high-grade horizon was encountered, and the drill string was removed once, is shown on the right side of figure 16. On the left is the gamma log that resulted after the hole was completed, and the drill string had been repeatedly pulled from and put back into the hole. From this diagram the hole appears to have more than 150 ft (46 m) of anomalous radiation, when, in fact, it is really 20 ft (6 m). The

1-ft interval of high grade material was evidently smeared over 150 ft (46 m) of drill hole. If this contamination had not been recognized it could have resulted in an erroneously high estimate of ore reserves.

Under normal conditions density logs indicate the bulk density of the rock. However, in highly fractured rock, where hole diameter increases abruptly, the density log appears to be a mirror image of the caliper log. Thus, most of the anomalously low density peaks indicate fracture zones in the breccia pipe.

In general, the logs show that the magnetic susceptibility in the holes is low, which may be a reflection of the porosity of the pipe. This porosity may permit oxidizing ground waters to alter many of the ferromagnetic minerals that were originally present in the sandstones to limonite and other iron minerals with low susceptibilities. There is some suggestion that surface magnetic surveys (Senterfit and others, 1985) over breccia pipes

show magnetic lows along the ring fractures where oxidizing ground waters have probably flowed. Just below the high-grade uranium horizon (1,191 ft, 366 m) in hole 2, the bottom 75 ft (23 m) of the hole show a significant increase in magnetic susceptibility. This increase suggests that the oxidizing fluids may not have penetrated this lower part of the pipe, and if an orebody did form at or below this interval, it may still be preserved.

Because of the difficulty in filling the holes with water there are few intervals with induced polarization (IP) and resistivity logs. It is fortunate that the logs are available in the high-grade uranium interval near the bottom of hole 2 where no samples were recovered due to lost circulation. The positive response of IP measurement to sulfide mineralization can be seen in hole 1 at a depth of 925 ft (285 m). Here pyrite is very abundant in the Hermit Shale (app. 1—lithologic log under mineralization column) and the IP measurement suddenly increases. In hole 2 the IP measurement becomes quite high for 40 ft (12 m) between 1,100 and 1,140 ft (338 and 351 m). This is immediately above the high-grade uranium interval and may represent the pyrite cap over the orebody. In addition, the highest IP spike lies directly beneath the high-gamma ray anomaly at 1,191 ft (366 m), suggesting the uranium is associated with high-grade sulfide mineralization, as it is in all uranium-mineralized breccia pipes that have been mined in northern Arizona.

Geochemistry

The geochemical data and petrographic descriptions will be published in a separate report following completion of all chemical analyses by the U.S. Geological Survey analytical laboratory. Preliminary analyses of core from hole 5 show intervals of high concentrations of As, Pb, and Zn. The core was sampled and analyzed at approximately 15 ft (4.6 m) intervals. With the exception of from 407 ft, (125 m) to 419 ft (129 m) (2 samples) within the Fossil Mountain Member, all As concentrations above 748 ft (230 m) were less than 100 ppm. At this interval, 407–419 ft, the Ni, Pb, and Zn concentrations also increase dramatically, although, except for a sharp decrease in the density log, there is nothing unusual about this interval. Between 490 ft (151 m) and 540 ft (166 m), starting at the contact of the Kaibab Limestone and Toroweap Formation and going downward, there are some sharp increases in Pb and Zn, but none in As and Ni. The most dramatic geochemical anomaly begins at 748 ft (230 m), where As suddenly increases from 10 ppm to 3,600 ppm and remains well above 100 ppm until the bottom of the hole at 1,008 ft (310 m) where it is 2,300 ppm. This increase is accompanied by an abrupt decrease in density due to a lithology change from a siltstone to a limestone. In fact, there is a sizable cavern at 748 ft

which is indicated by the caliper log. Although there are two high Zn samples around 748 ft, the Zn concentrations aren't consistently high above a depth of 950 ft (292 m) where Ni is also enriched. This geochemical anomaly occurs in the middle of the Seligman Member where the grain size is larger, and hence the permeability is greater. Hole 5 was terminated because contract money ran out. However, the most interesting geochemical anomalies occurred near the bottom of the hole.

CONCLUSIONS

The Mohawk Canyon pipe was selected for drilling because it contained eight criteria deemed to be surface indicators of a mineralized breccia pipe. Drilling has verified that this collapse feature (1) is a breccia pipe, and (2) contains reduced mineralized rock. Although the 1-ft-thick zone of high-grade uranium encountered in hole 2R is hardly an orebody, the grade of 0.52 percent eU_3O_8 is the average grade mined from those breccia pipes which host orebodies. Besides hole 2R, only 2 other holes of the five drilled penetrated to the depth of 1,181 ft (366 m), where the uranium-mineralized rock is present; both of these other holes were either outside the breccia pipe or outside the reduced zone. This is the same horizon (1,181 ft, 366 m—at approximately the Coconino Sandstone-Hermit Shale contact) as that at the top of the orebodies in the Hack Canyon and Pigeon mines, located beneath a similar Kaibab Limestone-capped plateau. Hole 4, which was lost when a 40-ft (12-m) cavern was encountered, contained the most sulfide mineralization, including galena, sphalerite, arsenopyrite, bravoite, and 1–3 percent pyrite in the reduced rock just above the cavern. The rocks in this hole appear to have been dropped slightly more than the other holes, suggesting that they are closer to the center of the pipe.

Sufficient mineralized rock was verified in the Mohawk Canyon pipe that further drilling is warranted to assess its economic potential. Results from this study suggest that the ideal place for the next hole would be about 25 ft (8 m) south of hole 4, where the downward displacement and brecciation is probably greatest, and hence the permeability and U mineralization would have been highest. Hole 4 showed the most sulfide mineralization at the shallowest level (1,000 ft), so future holes should be located near it.

REFERENCES CITED

- Billingsley, G. H., Jr., and Huntoon, P. W., 1983, Geologic map of Vulcans Throne and vicinity, western Grand Canyon, Arizona: Grand Canyon Natural History Association.

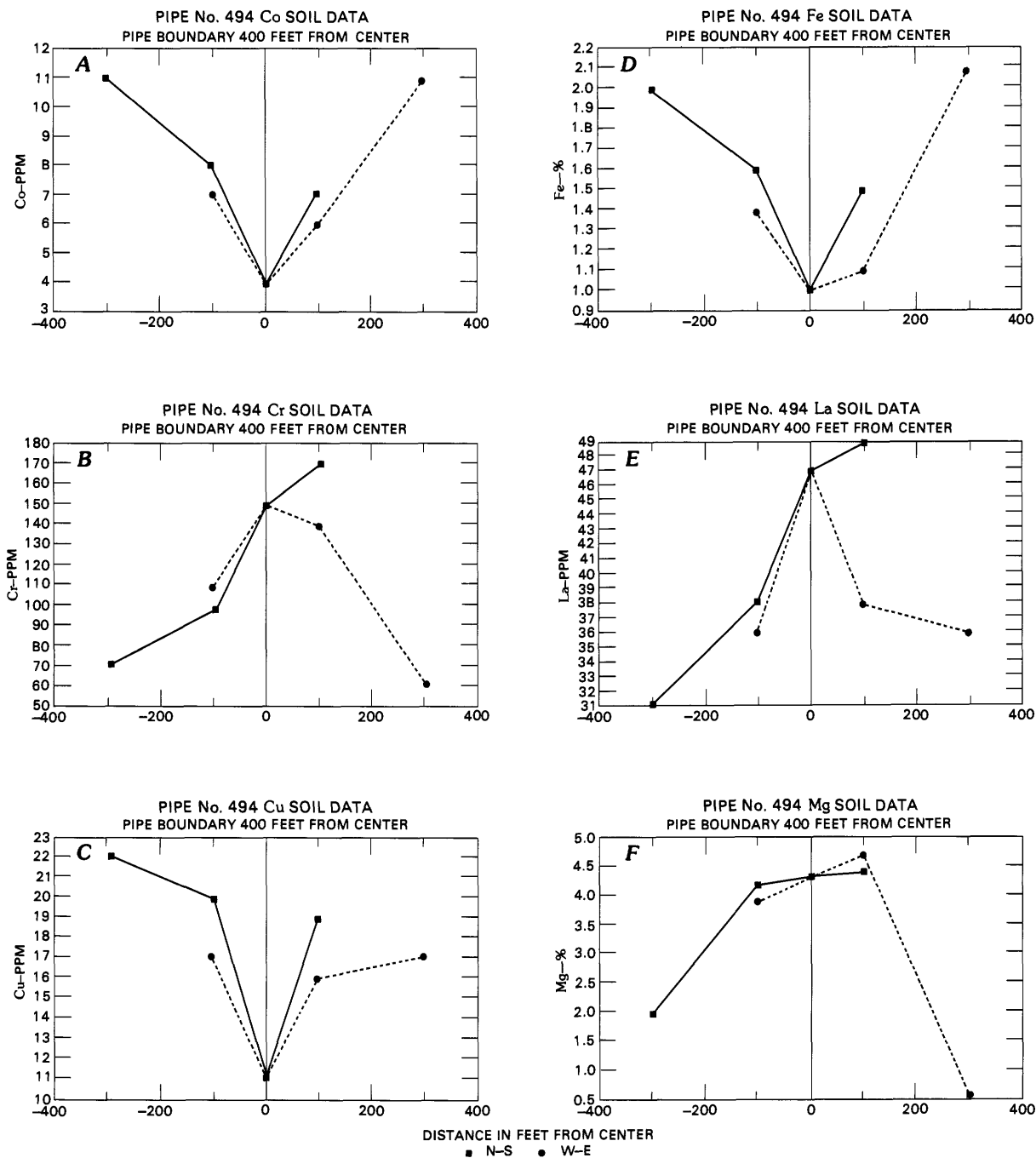
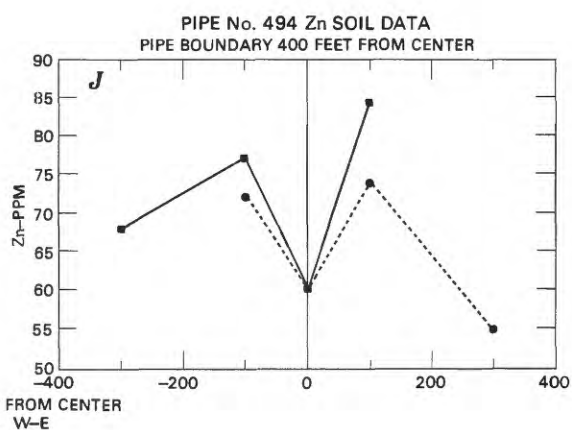
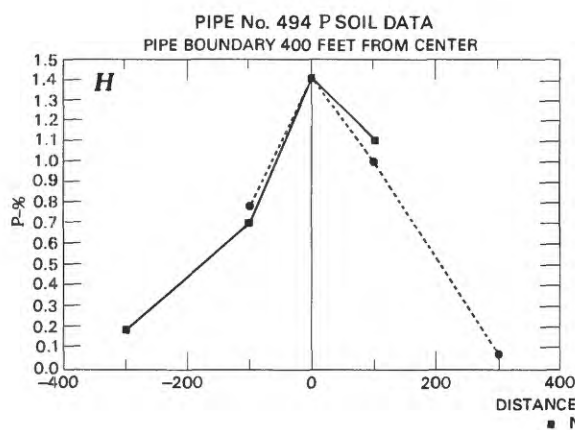
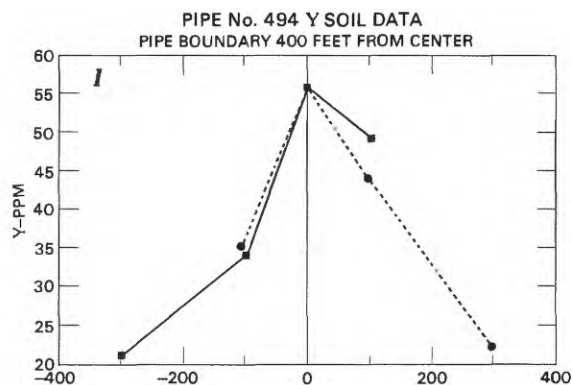
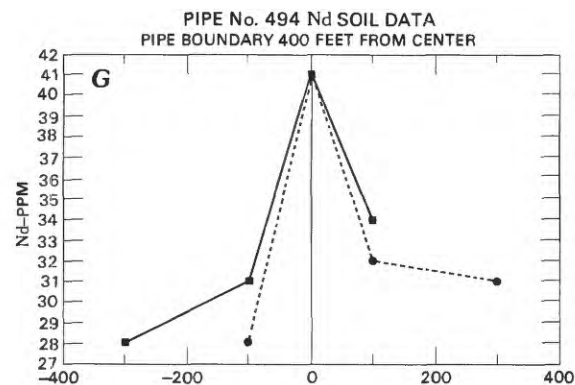


Figure 10 (above and facing page). Plots of results from a soil sampling survey for Co, Cr, Cu, Fe, La, Mg, Nd, P, Y, and Zn. Element concentration is shown versus distance from the center of the pipe.



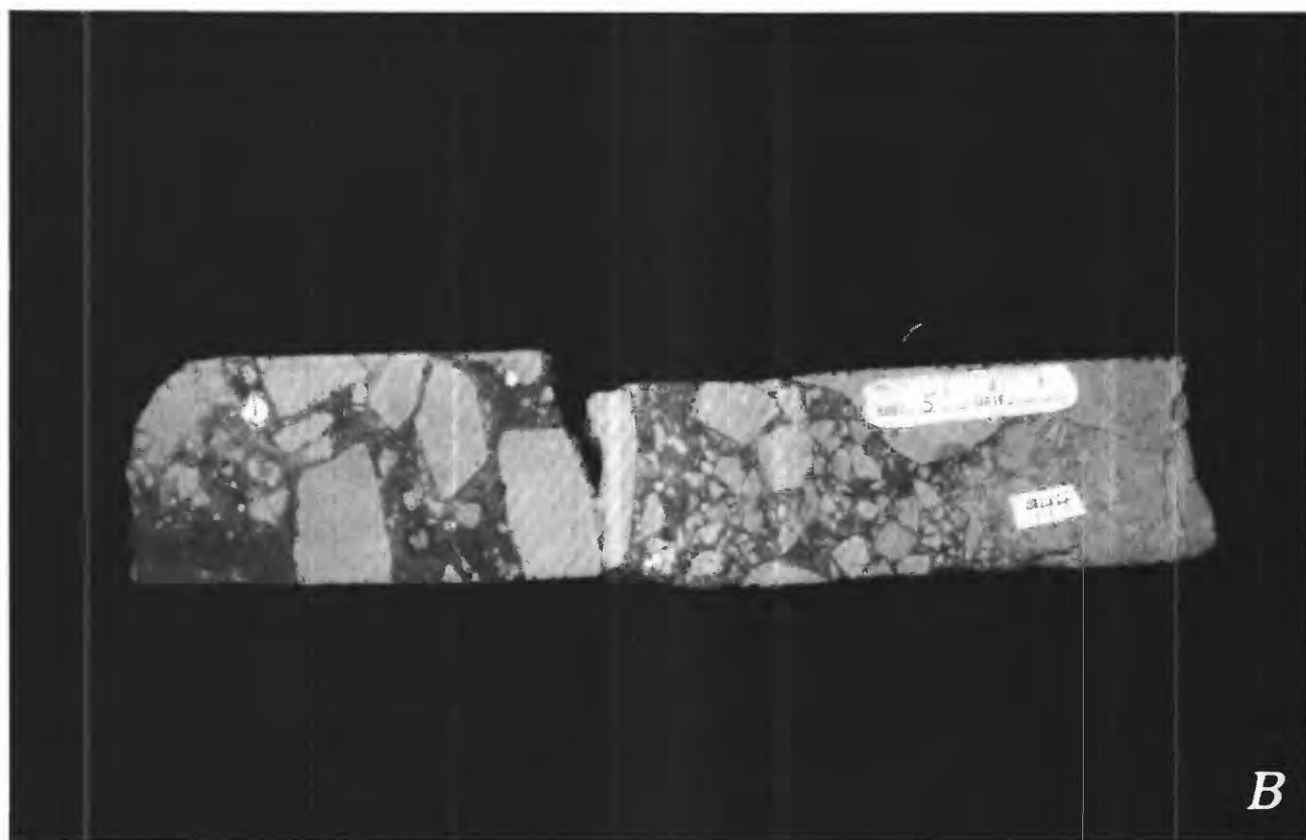
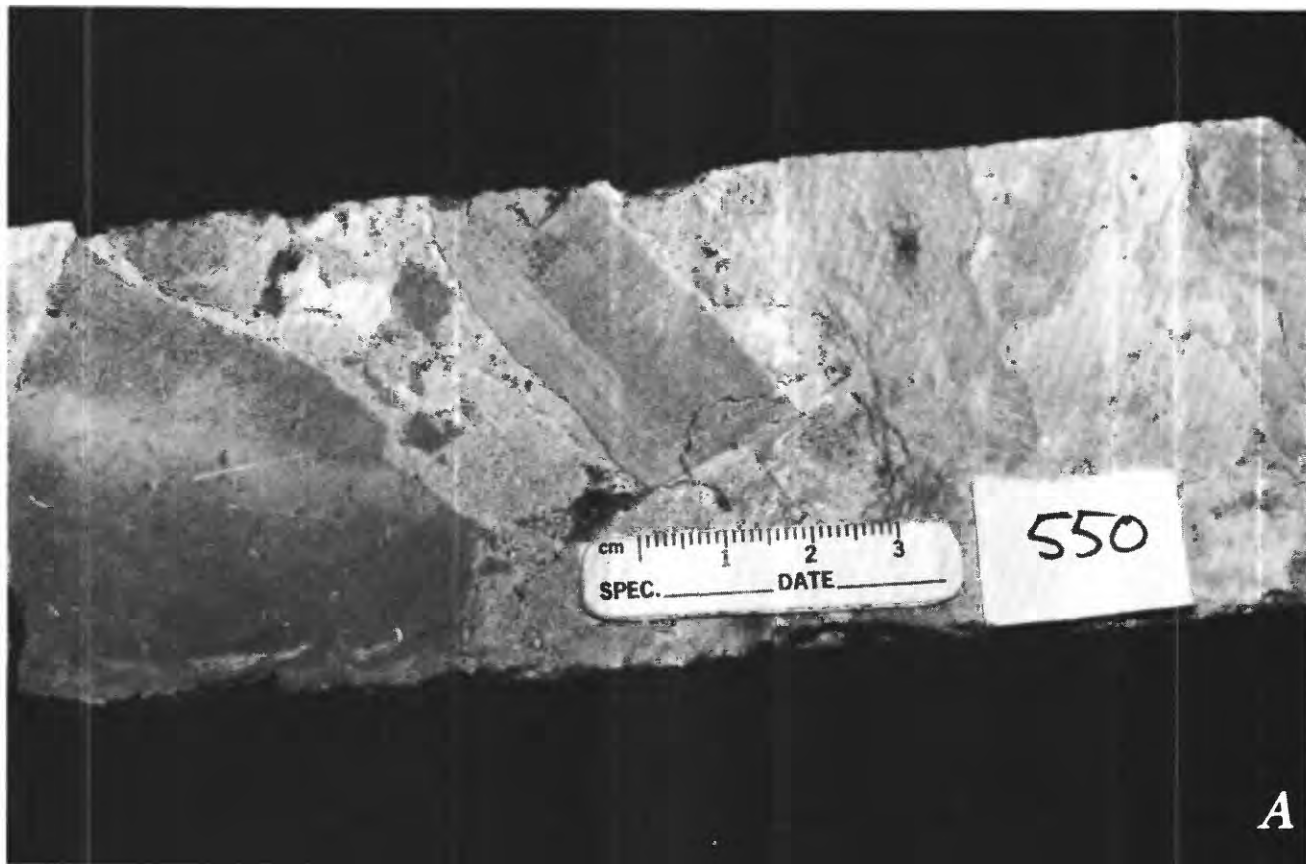
- Foord, E. E., McKee, E. D., and Bowles, C. G., 1978, Status of mineral resource information for the Shivwits Plateau, Parashant, Andrus, and Whitmore Canyons, and Kanab Canyon areas, Grand Canyon, Arizona: U.S. Geological Survey Administrative Report for the National Park Service, 30 p.
- Gornitz, Vivian, and Kerr, P. F., 1970, Uranium mineralization and alteration, Orphan Mine, Grand Canyon, Arizona: *Economic Geology*, v. 65, p. 751-765.
- Hagni, R. D., 1983, Ore microscopy, paragenetic sequence, trace element content, and fluid inclusion studies of the copper-lead-zinc deposits of the southeast Missouri lead district, in *Kisvasanyi and others, International Conference on Mississippi Valley Type Lead-Zinc Deposits*, proceedings volume, p. 243-256.
- Huntoon, P. W., Billingsley, G. H., Jr., and Clark, M. D., 1981, Geologic map of the Hurricane fault zone and vicinity, Western Grand Canyon, Arizona: Grand Canyon Natural History Association.

- _____, 1982, Geologic map of lower Granite Gorge and vicinity, Western Grand Canyon, Arizona: Grand Canyon Natural History Association.
- Pierce, H. W., Keith, S. B., and Wilt, J. C., 1970, Coal, oil, natural gas, helium, and uranium in Arizona: The Arizona Bureau of Mines Bulletin 182, 289 p.
- Senterfit, R. M., Mohr, P., and Horton, R., 1985, Geophysical studies on the Hualapai Indian Reservation, Arizona: U.S. Geological Survey Open-File Report 85-400, 30 p.
- Sutphin, H. B., and Wenrich, K. J., 1983, Structural control of breccia pipes on the southern Marble Plateau, Arizona: U.S. Geological Survey Open-File Report 83-908, scale 1:50,000.
- Sutphin, H. B., Wenrich, K. J., and Verbeek, E. R., 1983, Structural control of breccia pipes on the southern Marble plateau, Arizona: *Geological Society of America Abstracts with Programs*, v. 15, no. 5, p. 376.
- Wenrich, K. J., 1985, Mineralization of breccia pipes in Northern Arizona: *Economic Geology*, v. 80, no. 6, p. 1722-1735.



Figure 11. Five holes were drilled in the Mohawk Canyon pipe to an average depth of 1,100 ft (338 m). The eastern inner ring fracture forms this cliff of the Harrisburg Gypsiferous Member of the Kaibab Limestone. The drill rig is sitting over hole R1.

Figure 12. Drill hole 5 is brecciated from 125 ft (38 m) to the bottom of the hole (1,012 ft, 311 m). *A*, Breccia at 550 ft (169 m) is composed dominantly of fragments from the Fossil Mountain Member of the Kaibab Limestone. The Woods Ranch Member of the Toroweap has been largely dissolved out of the pipe. Although this sample is in the Woods Ranch and the matrix material is probably finely comminuted sand from the Woods Ranch, the fragments are downdropped from the Fossil Mountain Member above. *B*, Sandstone breccia at 944 ft (290 m) from the Seligman Member of the Toroweap Formation.



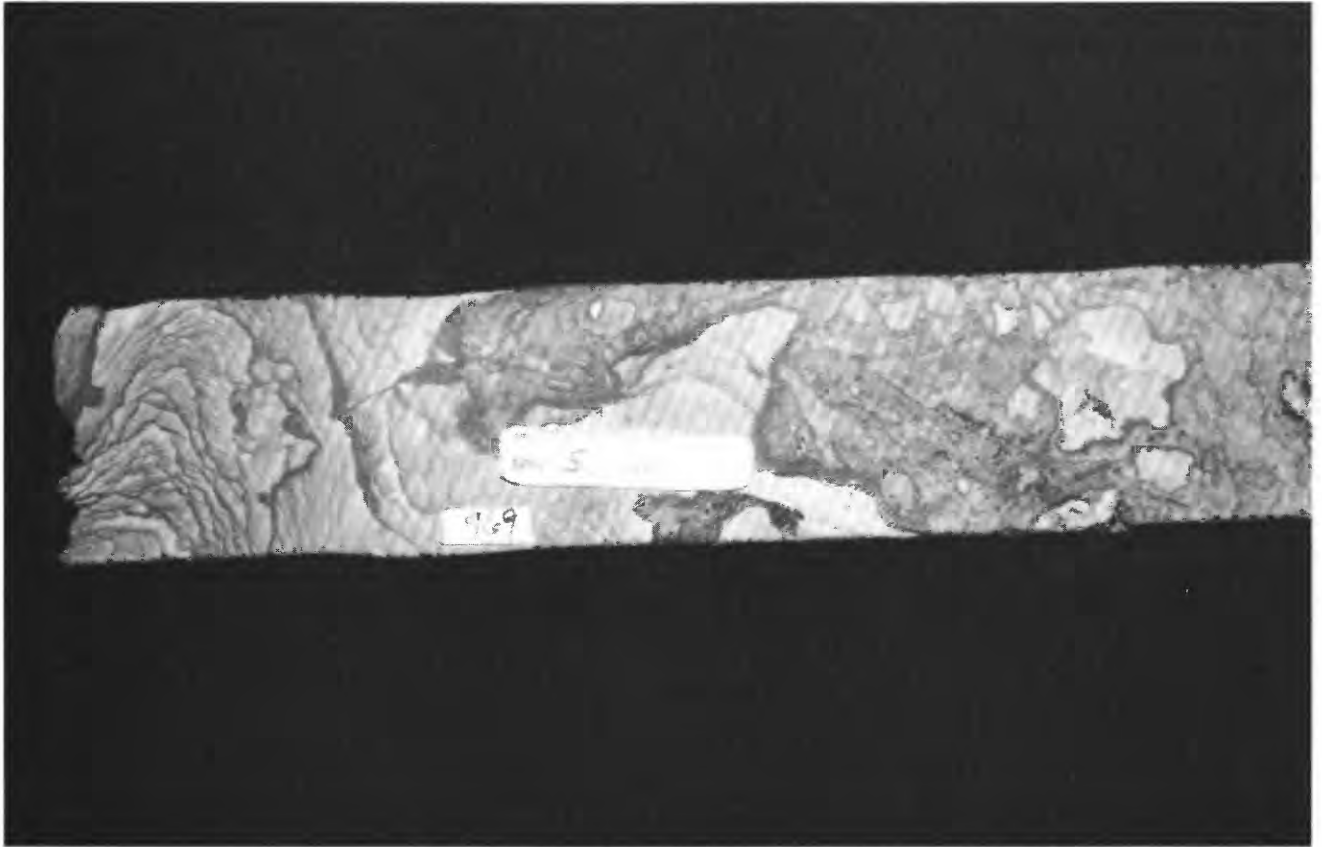


Figure 13. At 969 ft (298 m) the movement of iron oxides within the Seligman Member breccia was sufficient to form lieegang banding.

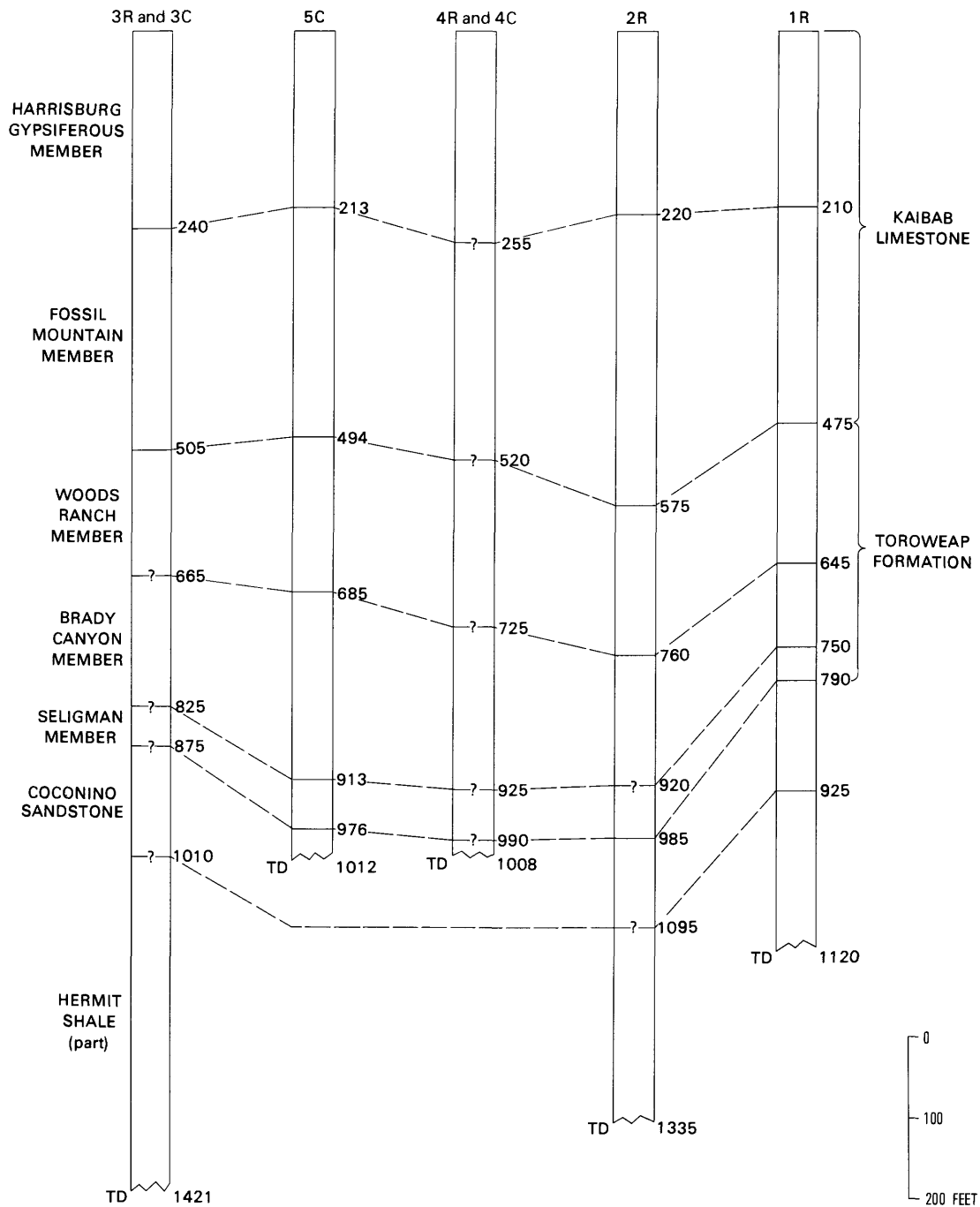


Figure 14. Projection of the data for all five drill holes onto a cross section summarizing the approximate stratigraphic contacts. Note the downdropping of the strata by as much as approximately 170 ft (52 m) in the center of the pipe.

MOHAWK CANYON BRECCIA PIPE
DRILL HOLE NO. 2

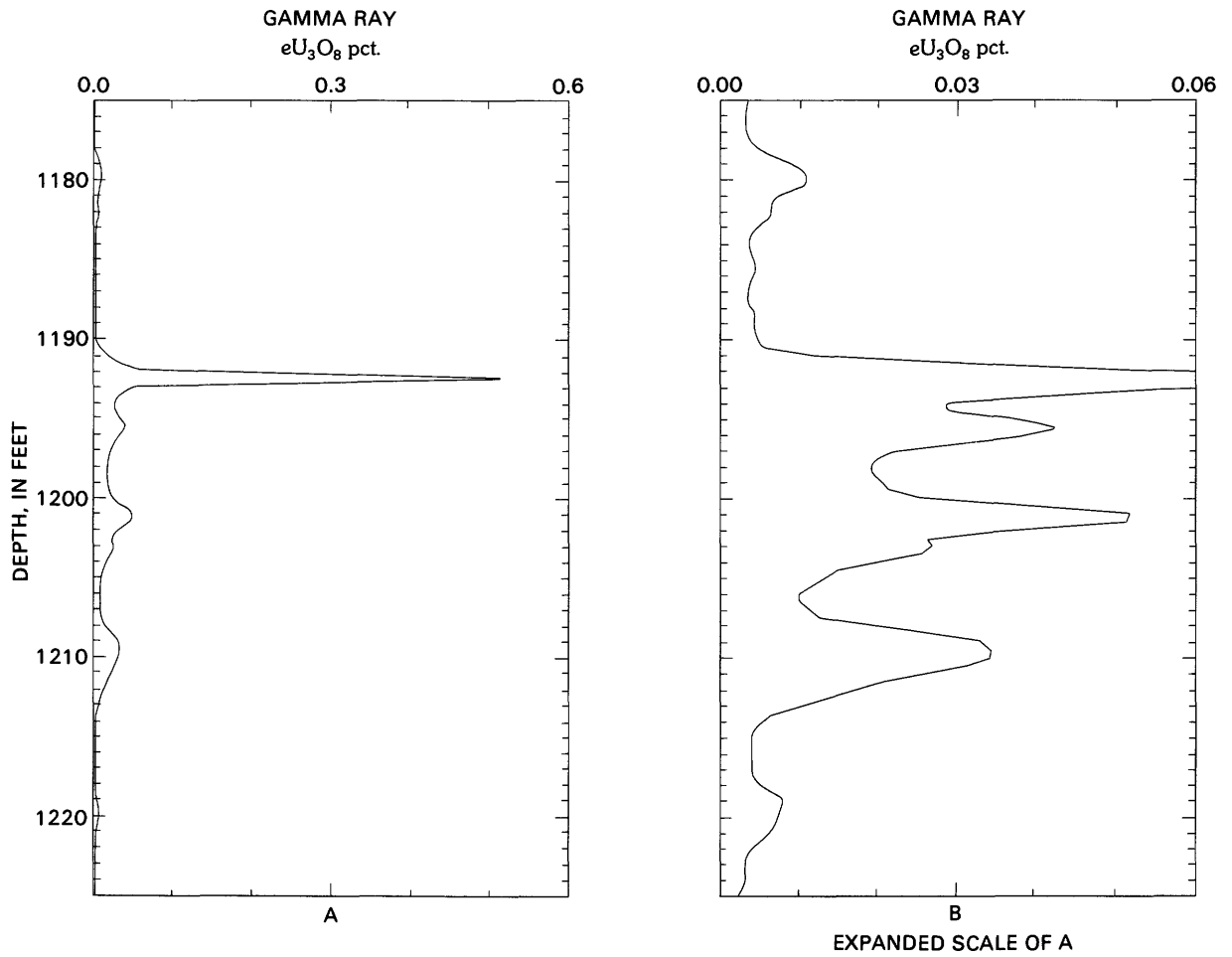


Figure 15. Gamma-ray log of hole 2R, 900 ft (277 m) to 1,300 ft (400 m), showing a zone of high-grade uranium mineralization (20 ft of average grade 0.04 with 1 ft of 0.6 percent eU_3O_8).

MOHAWK CANYON BRECCIA PIPE
DRILL HOLE NO. 2

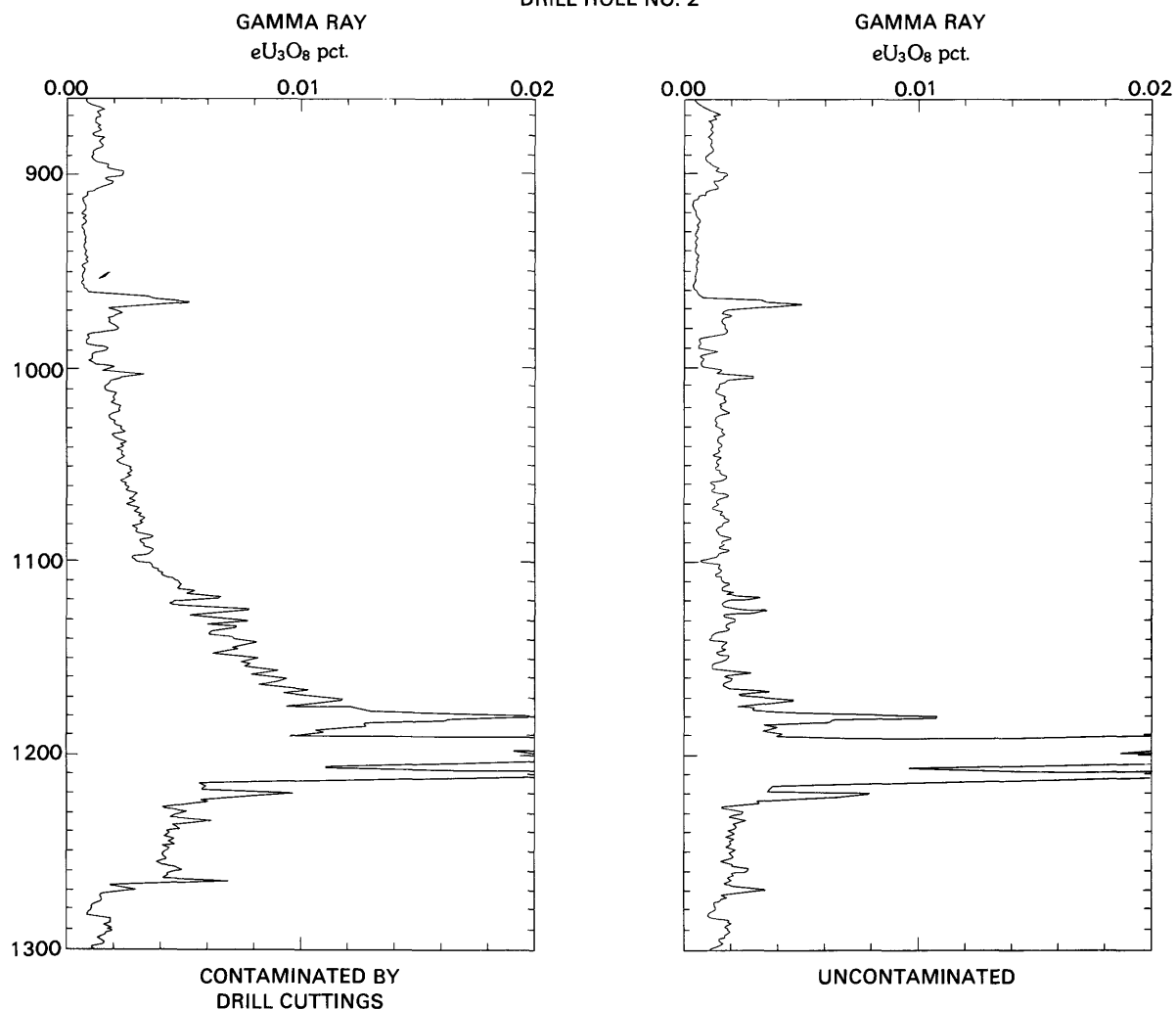
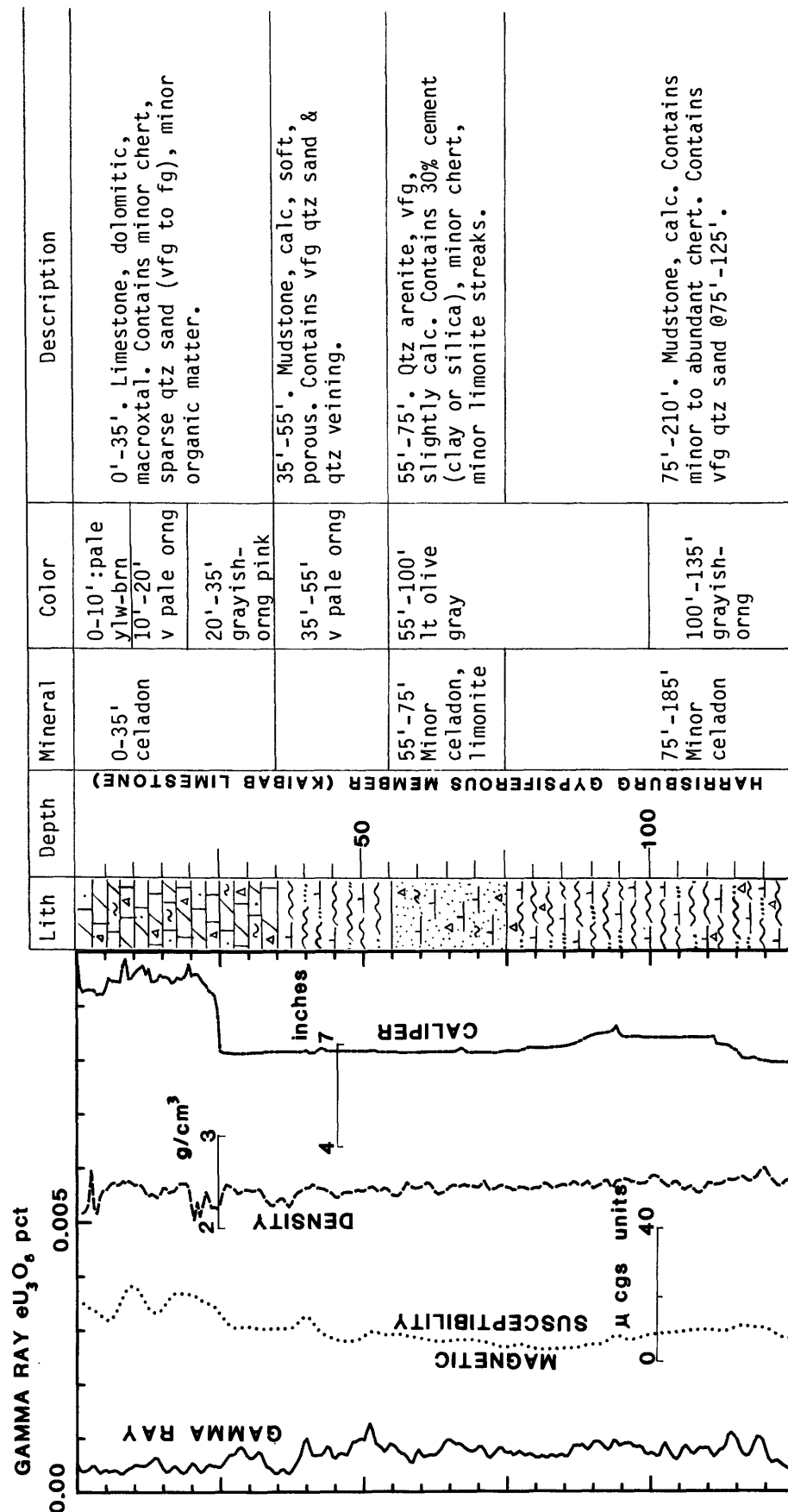


Figure 16. Gamma-ray logs showing the log made immediately after the high-grade zone was penetrated (log on the right), and the log run after repeated trips with the drill string (log on left), which contaminated almost 150 ft of the drill hole with the higher-grade cuttings. Logs such as this would result in an overestimate of ore reserves.

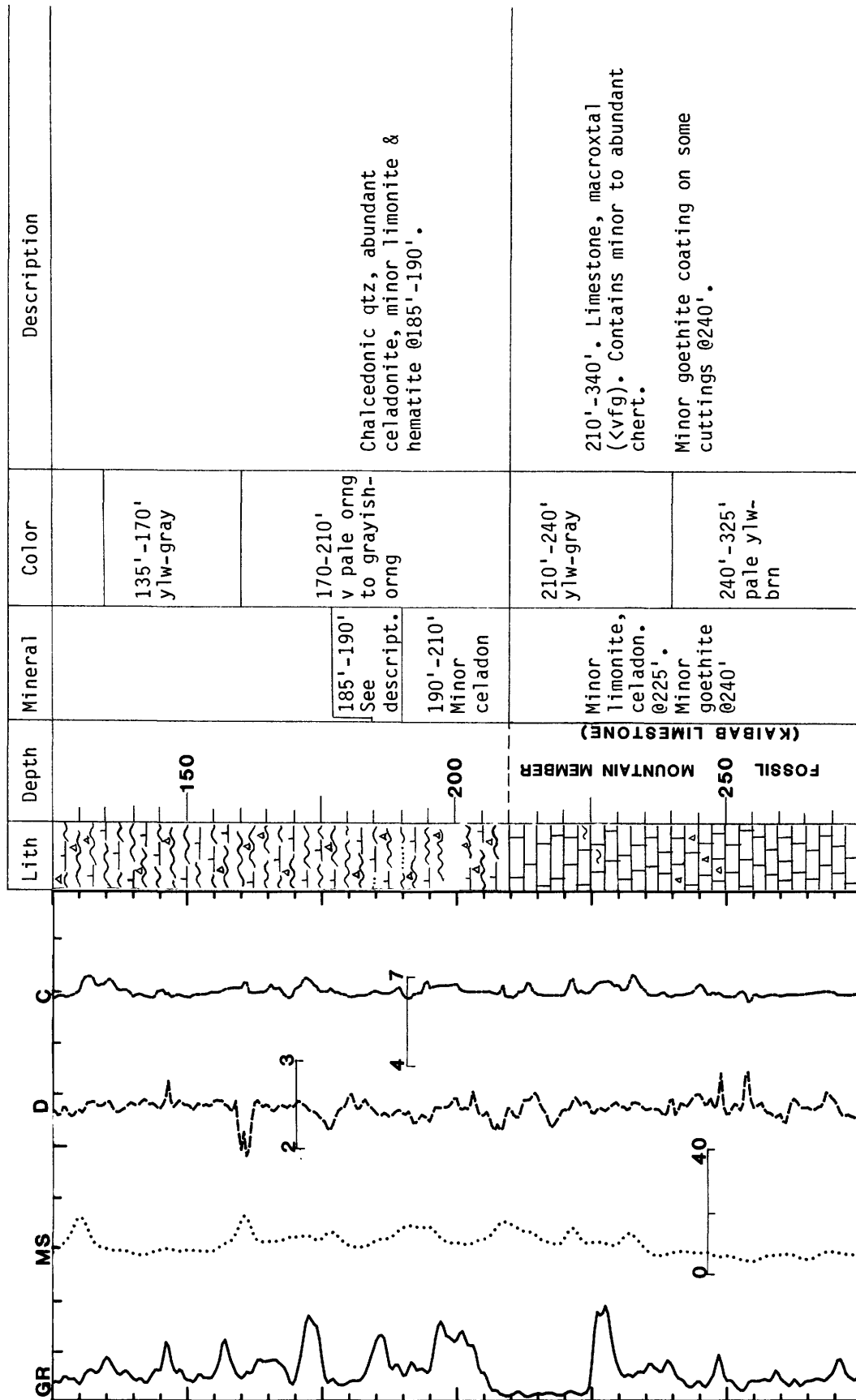
APPENDIXES 1–5

Appendix 1.-- Lithologic and geophysical logs for hole 1R, Mohawk Canyon Pipe

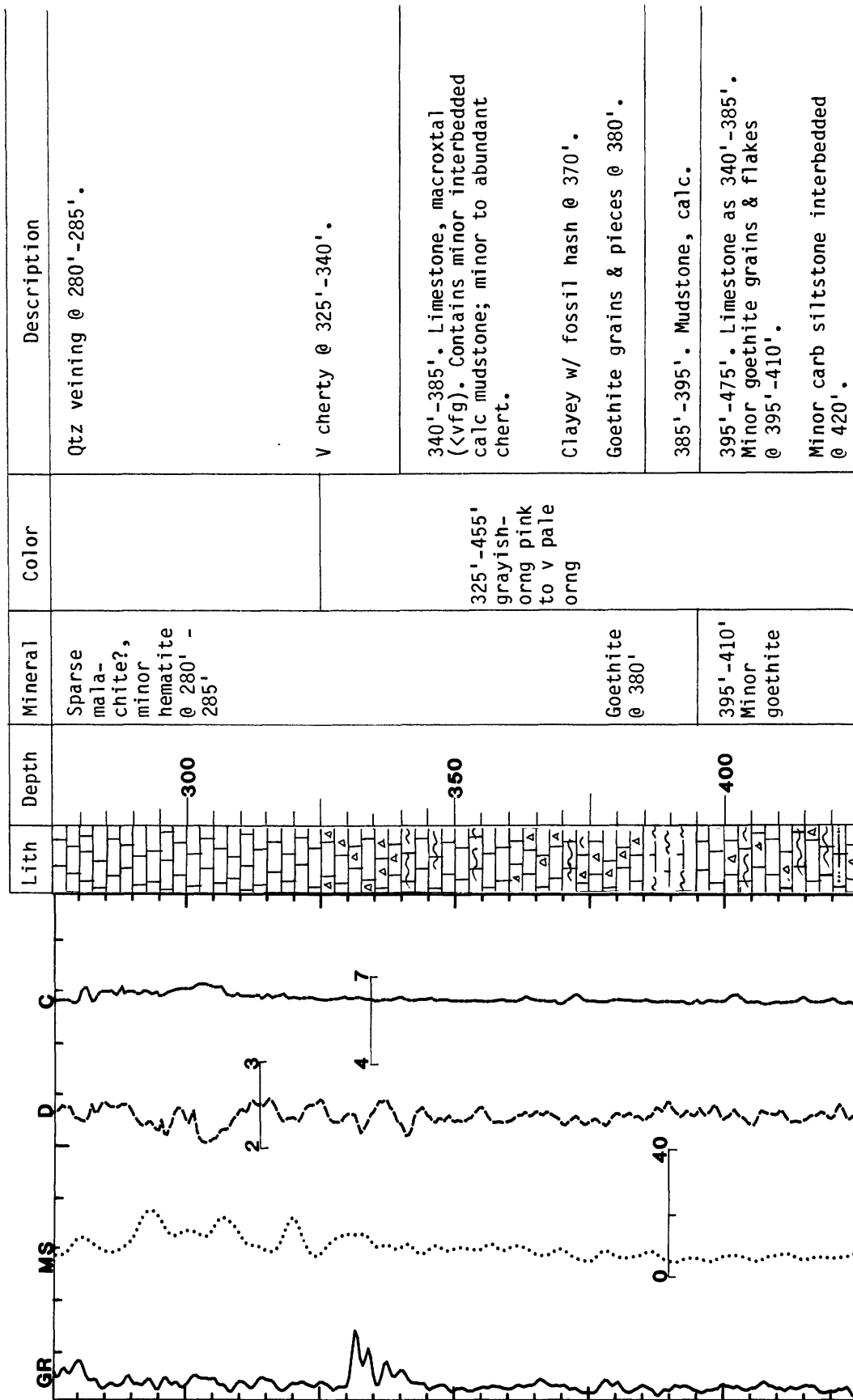
Hole no.: 494-1R Date: 7/18/84
T.: 32N R.: 7W Section: 26 County: Coconino State: AZ
Lat: 36°07'30" Long: 113°00'24" Elev: 6340' TD: 1120' PD: 1119'



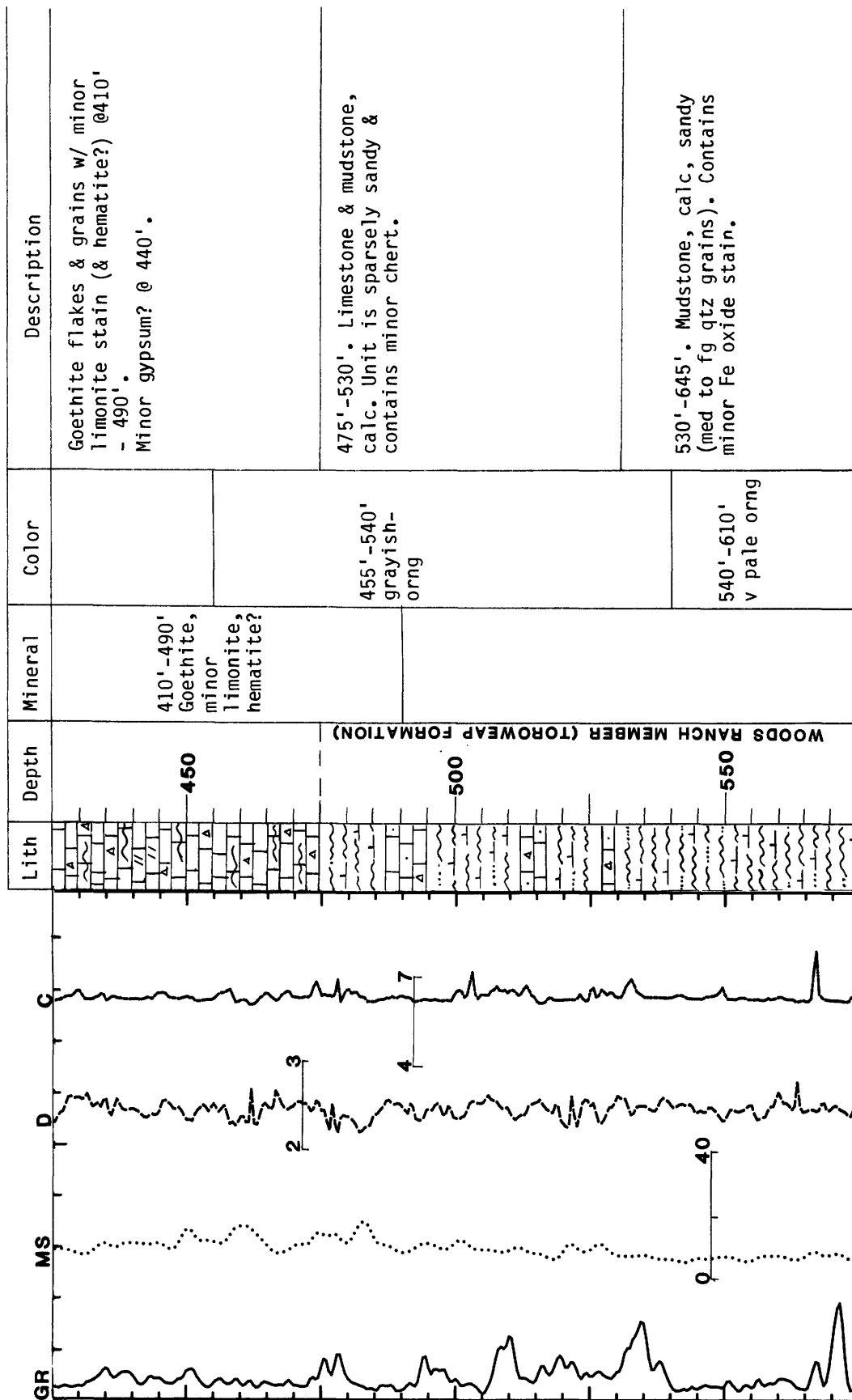
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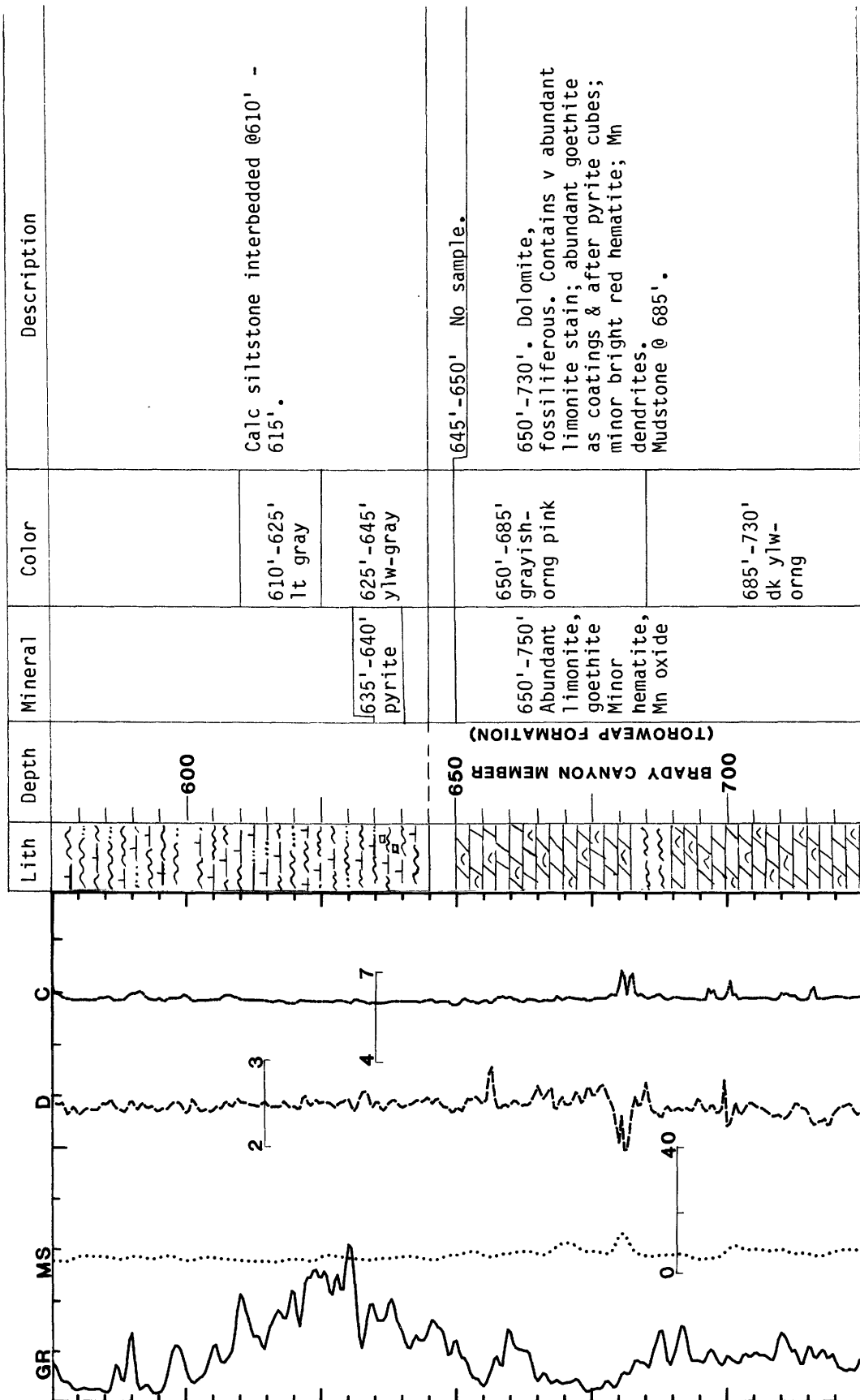
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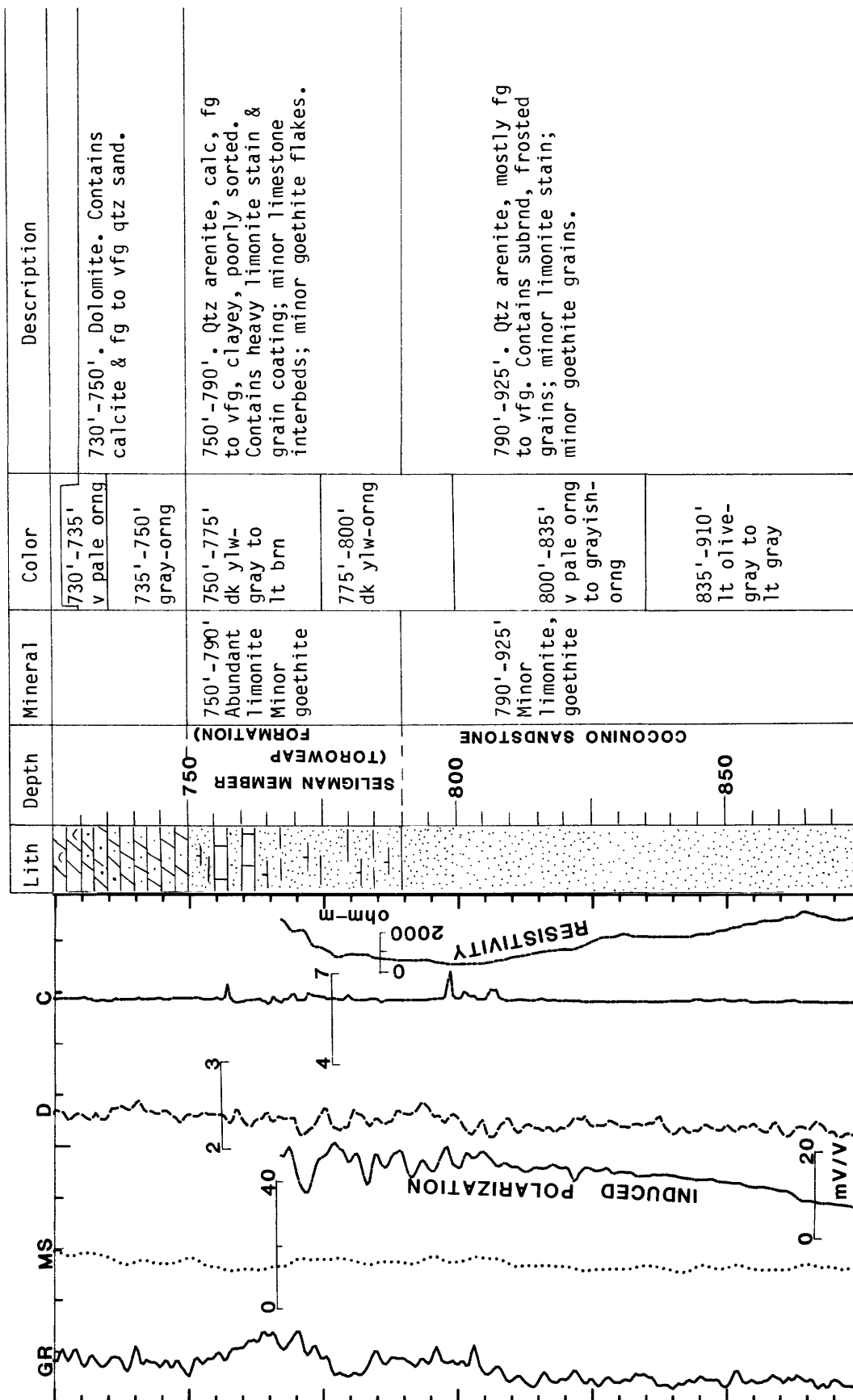
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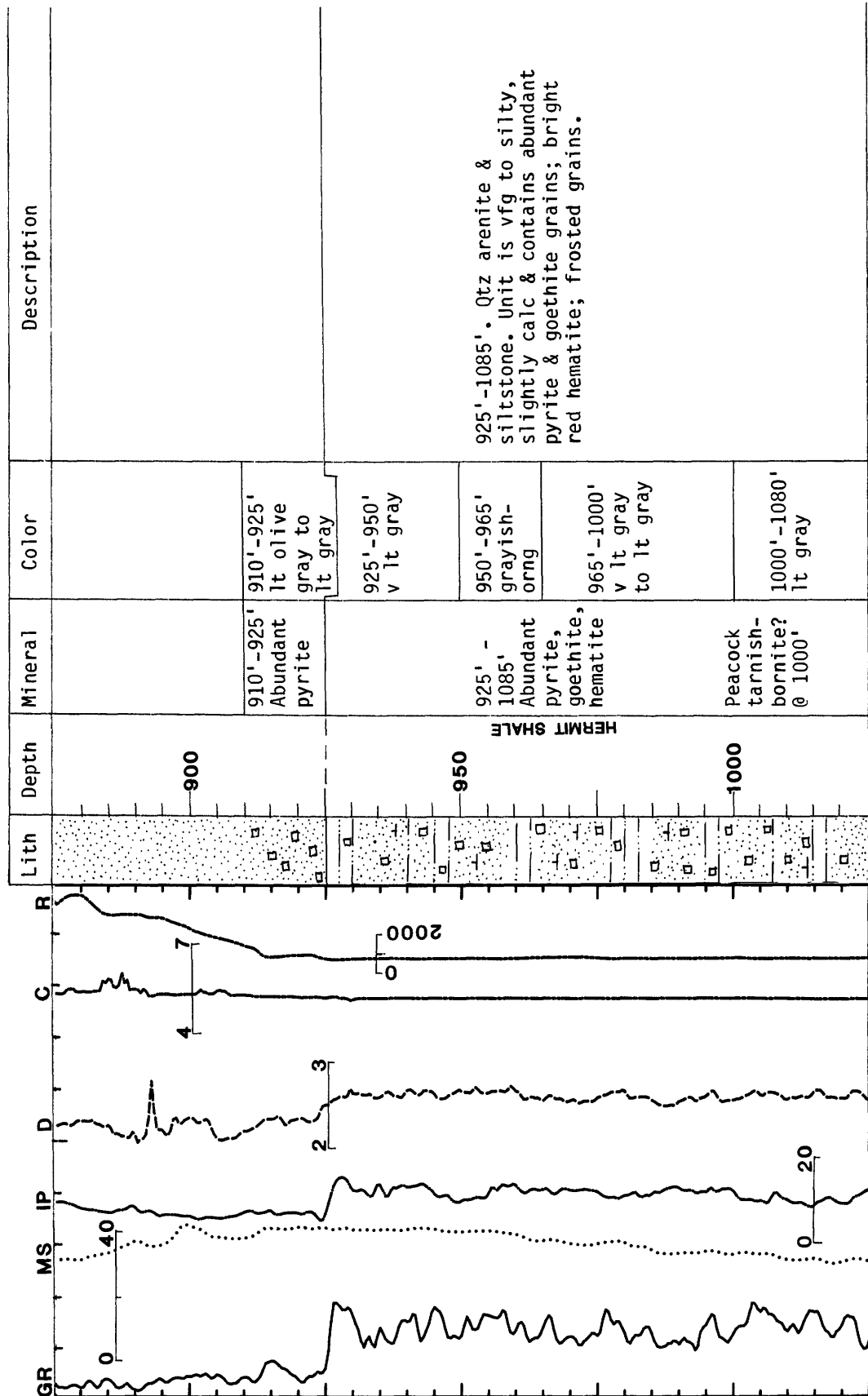
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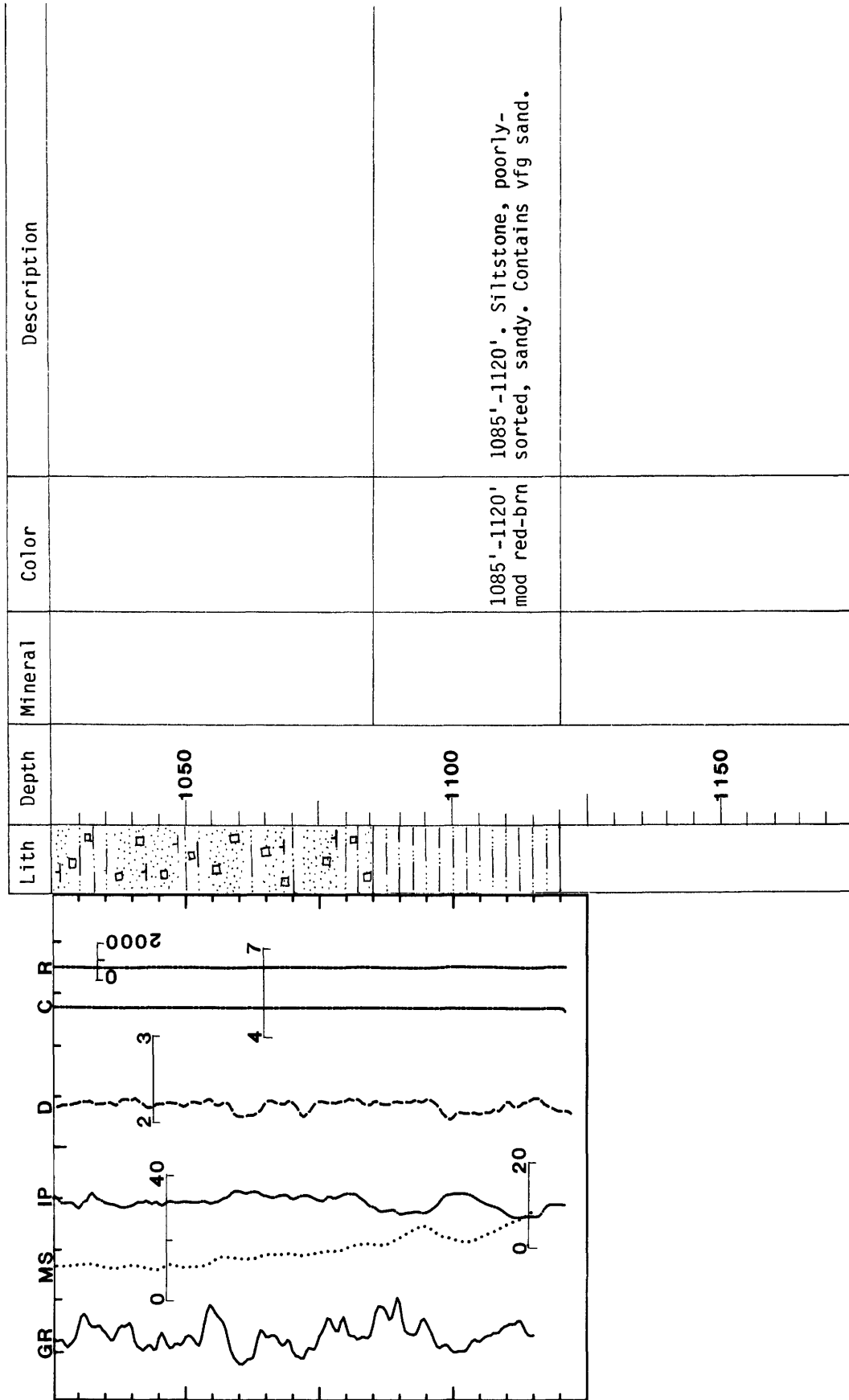
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Hole no.: 494-1R



Hole no.: 494-1R

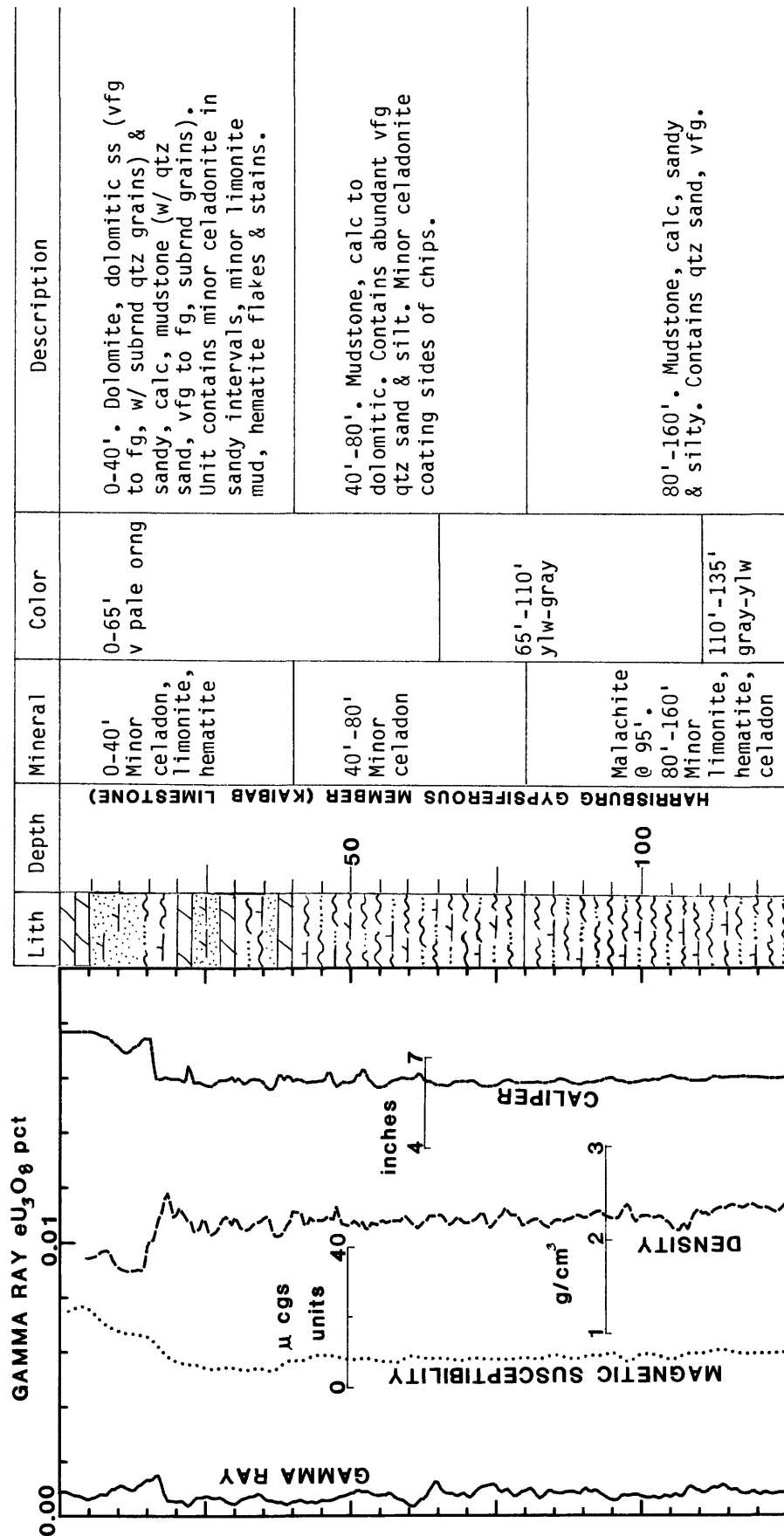


Appendix 2.--Lithologic and geophysical logs for hole 2R, Mohawk Canyon Pipe

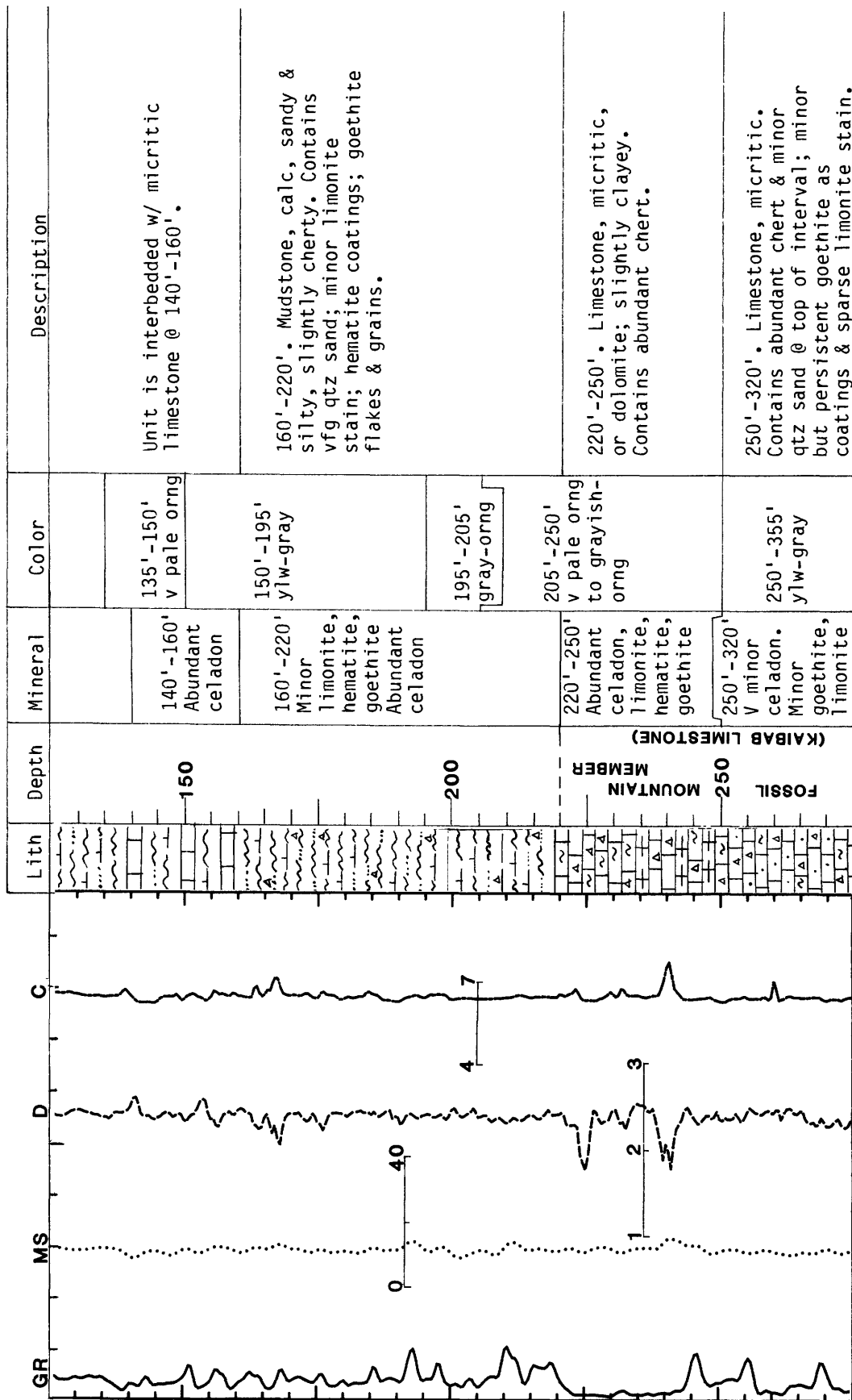
Hole no.: 494-2R Date: 7/25/84

T.: 32N R.: 7W Section: 26 County: Coconino State: AZ

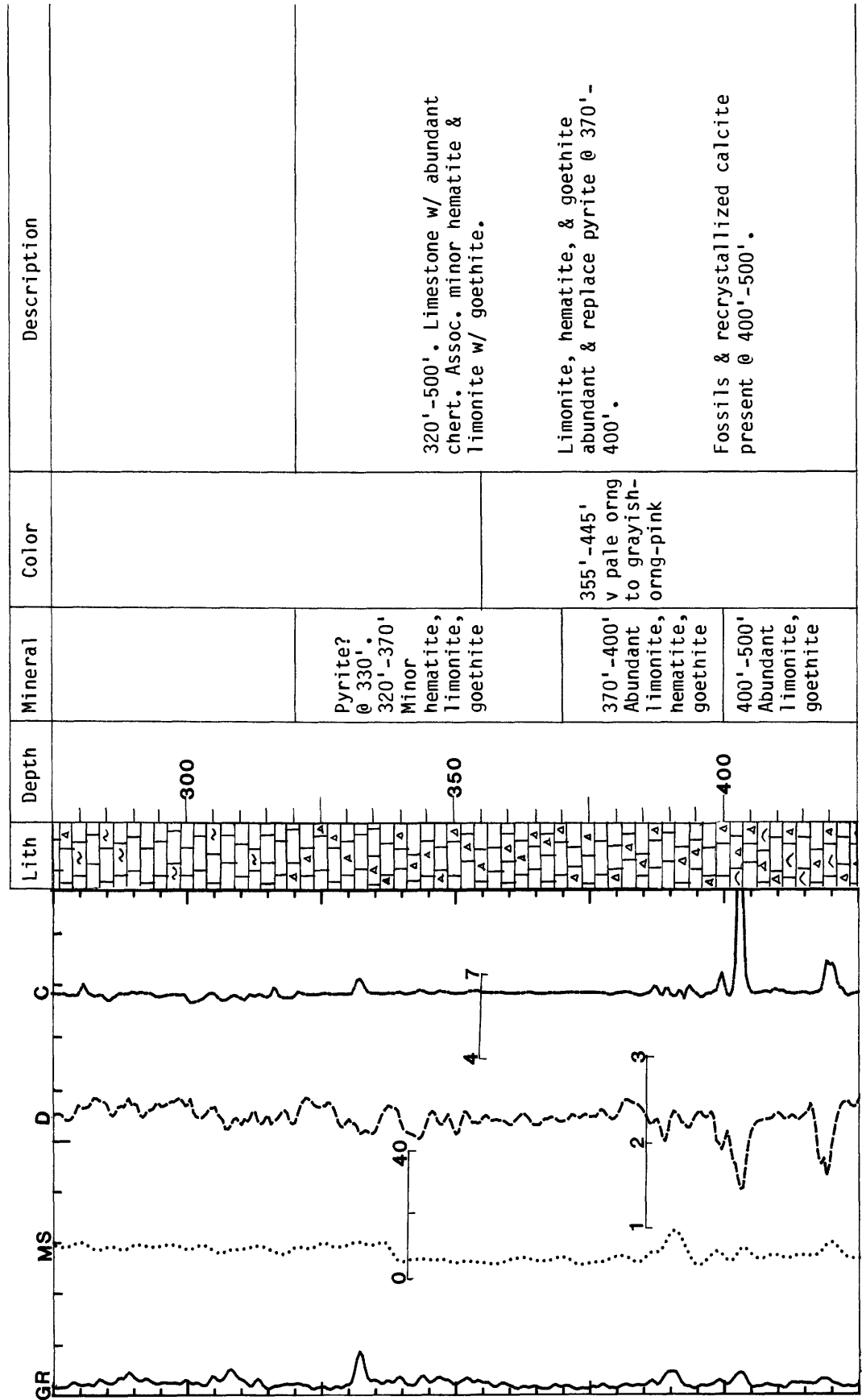
Lat: 36°07'30" Long: 113°00'24" Elev: 6345' TD: 1335' PD: 1324'



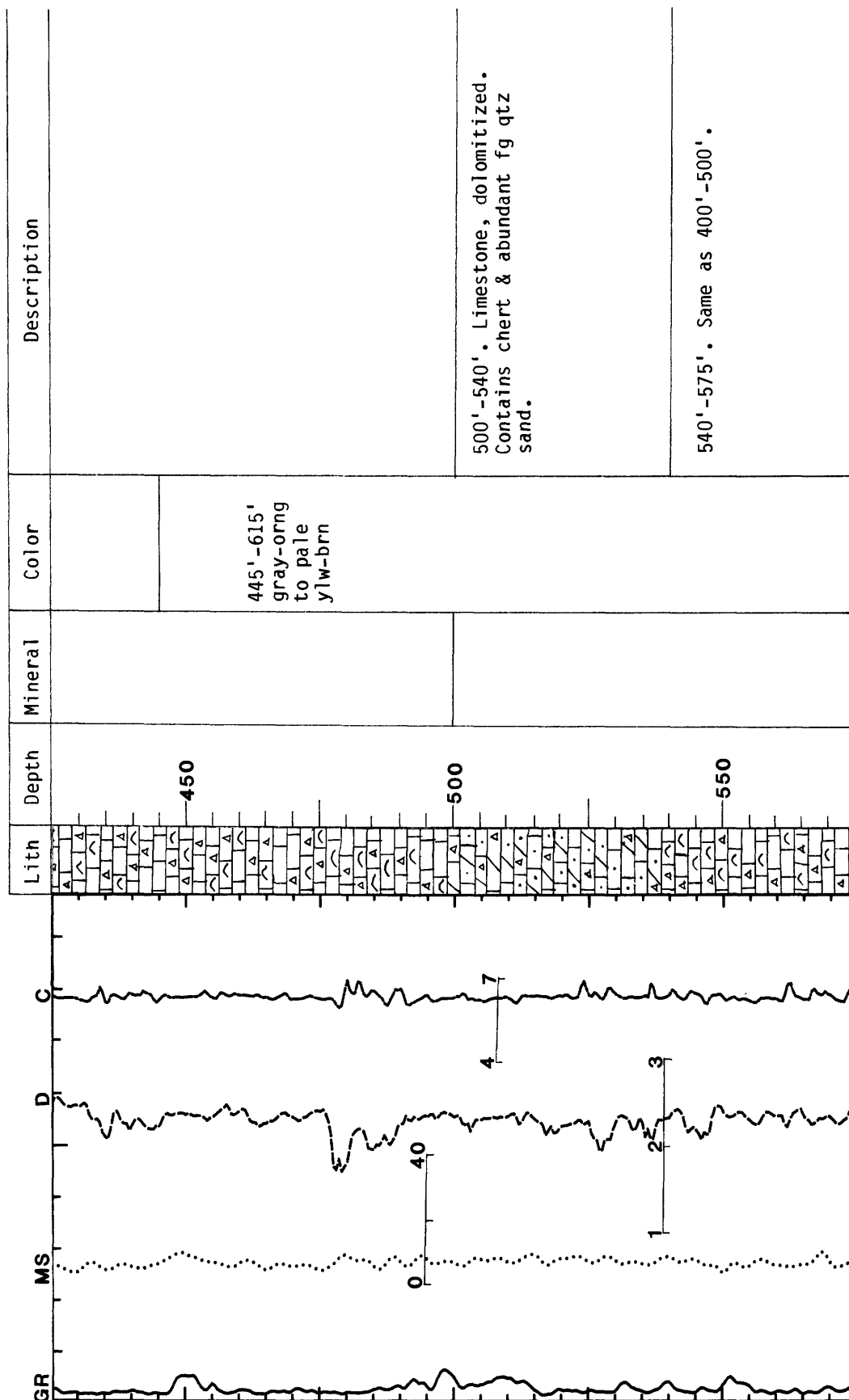
Hole no.: 494-2R

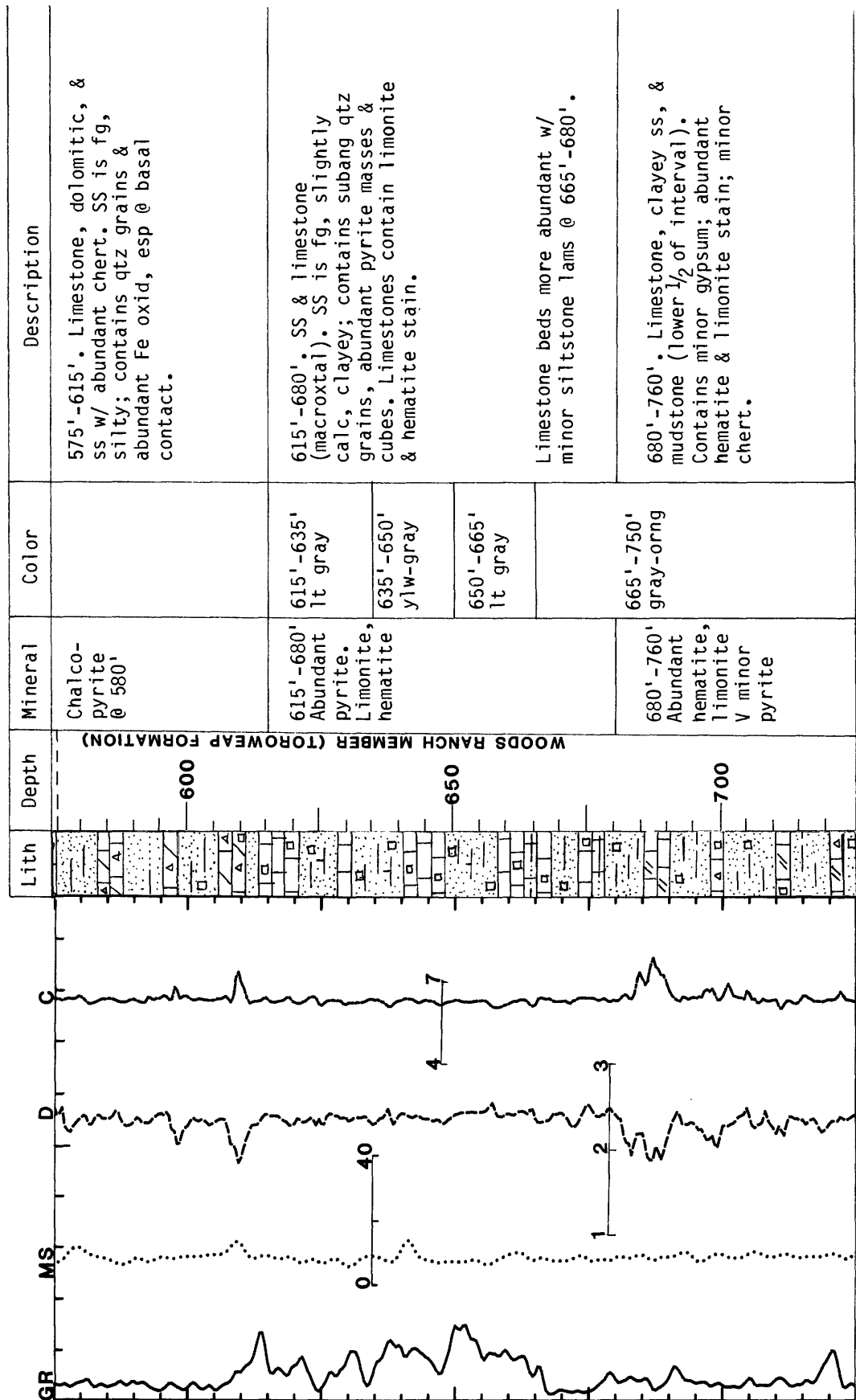


Hole no.: 494-2R



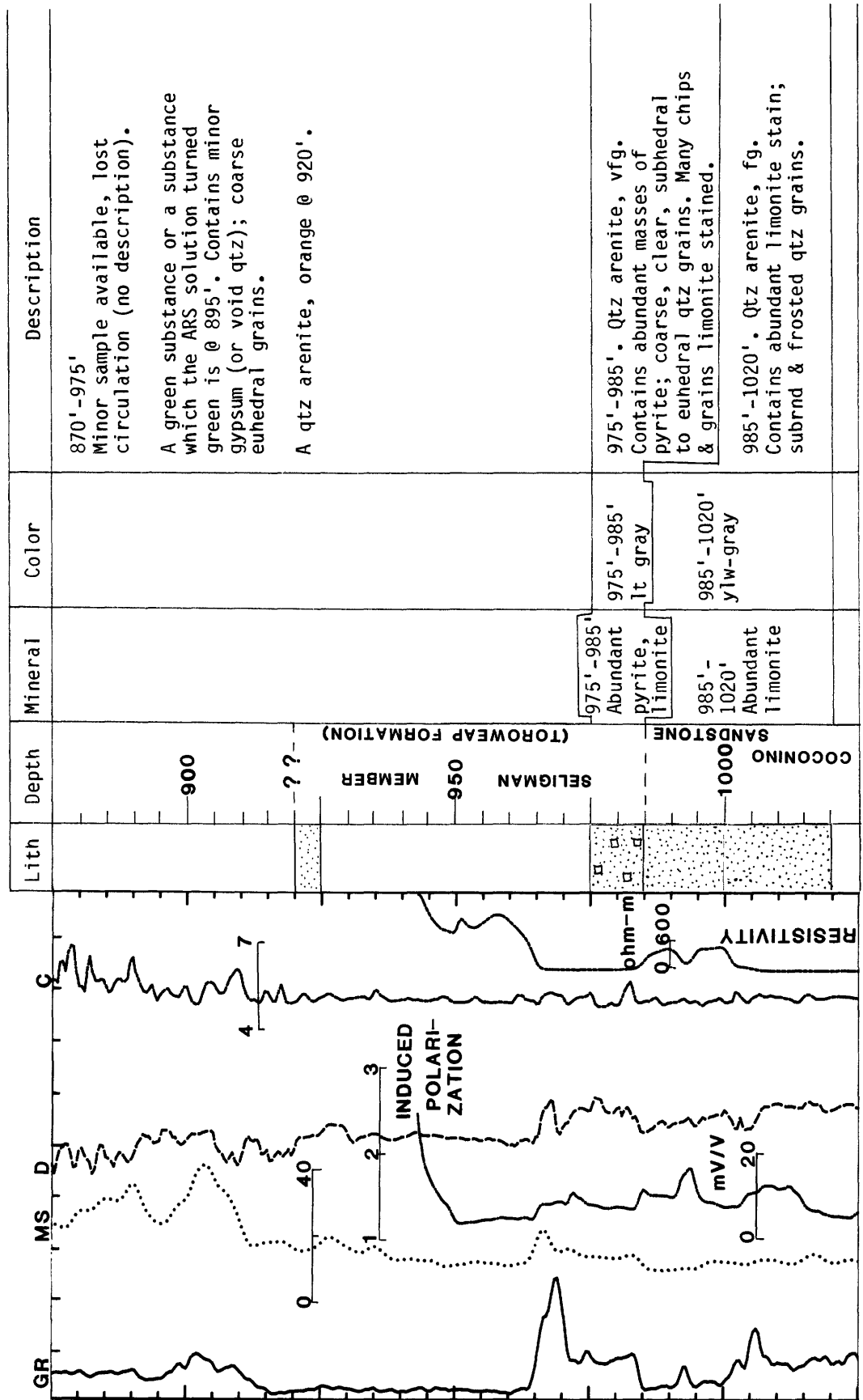
Hole no.: 494-2R



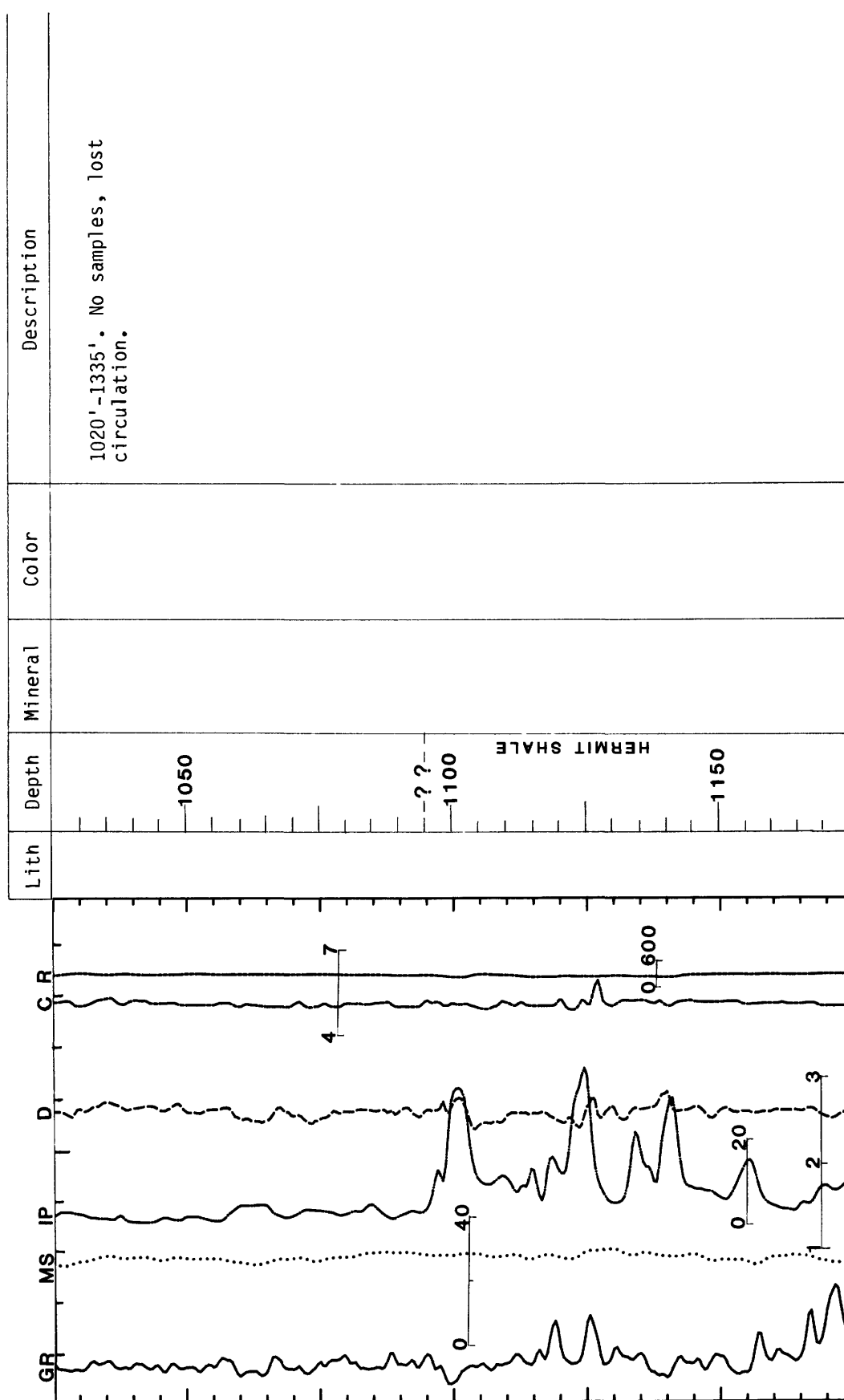


[illegible]

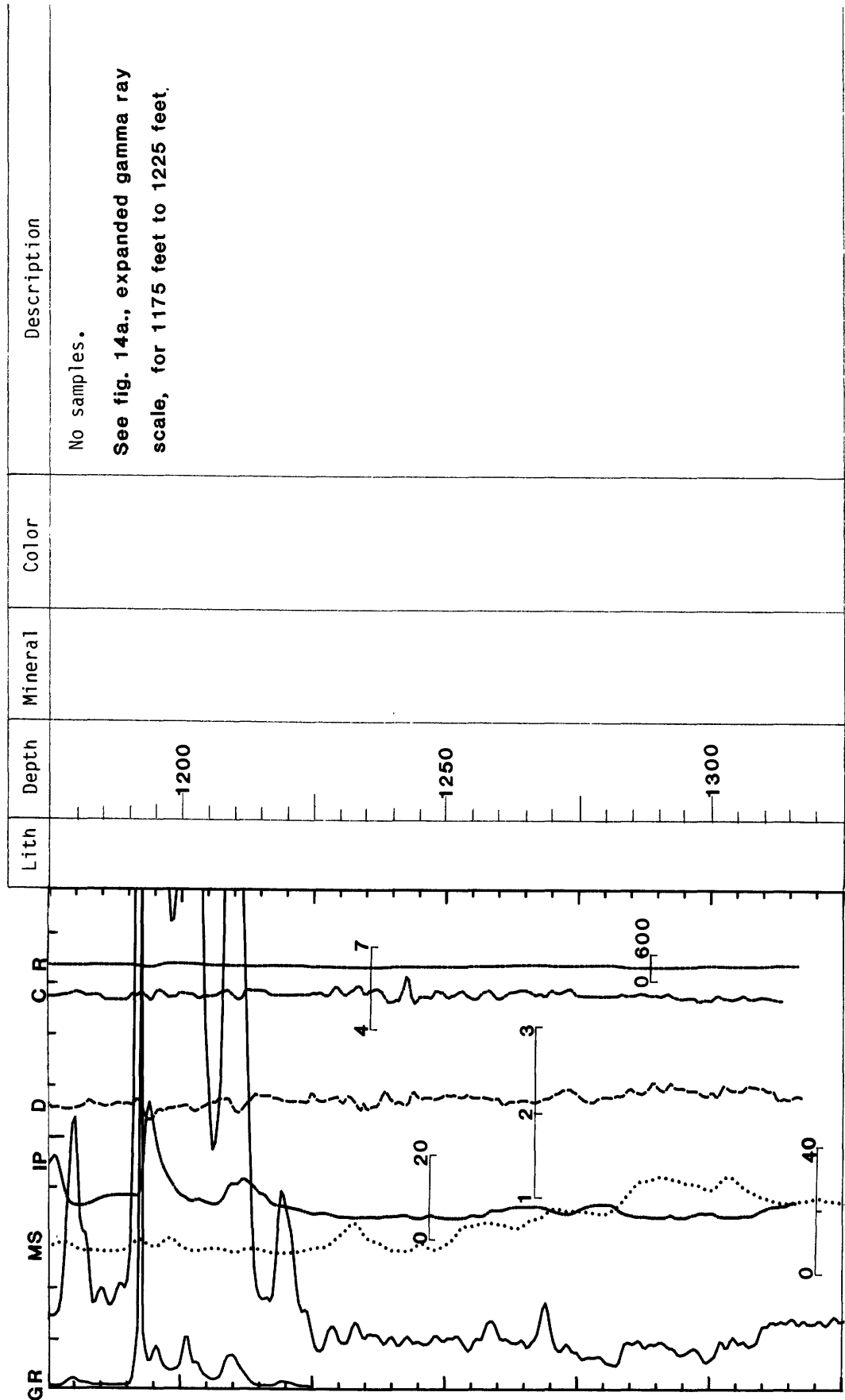
Hole no.: 494-2R



Hole no.: 494-2R



Hole no.: 494-2R

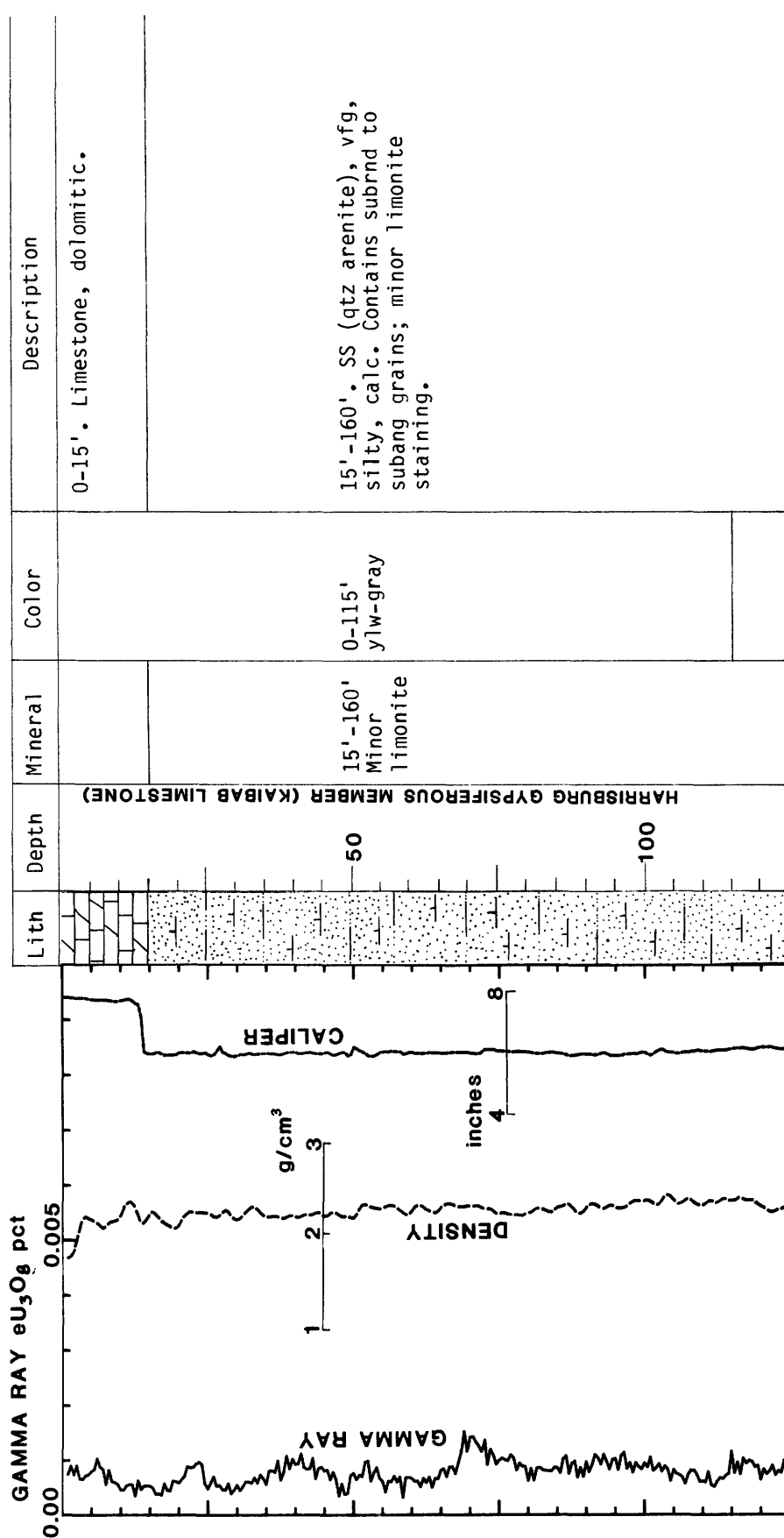


Appendix 3.-- Lithologic and geophysical logs for hole 3R and 3C, Mohawk Canyon Pipe

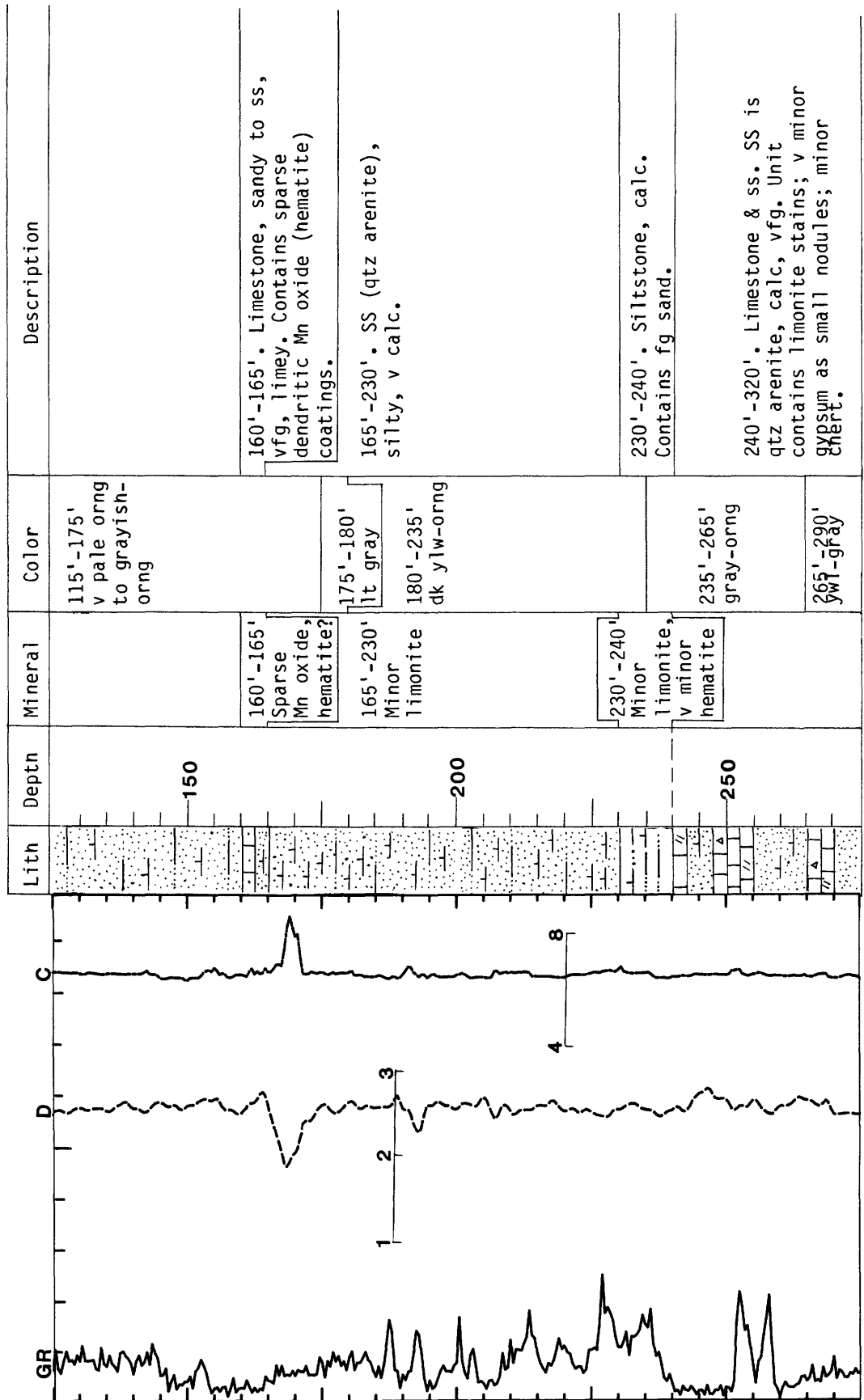
Hole no.: 494-3R & 3C Date: 8/07/84

T.: 32N R.: 7W Section: 26 County: Coconino State: AZ

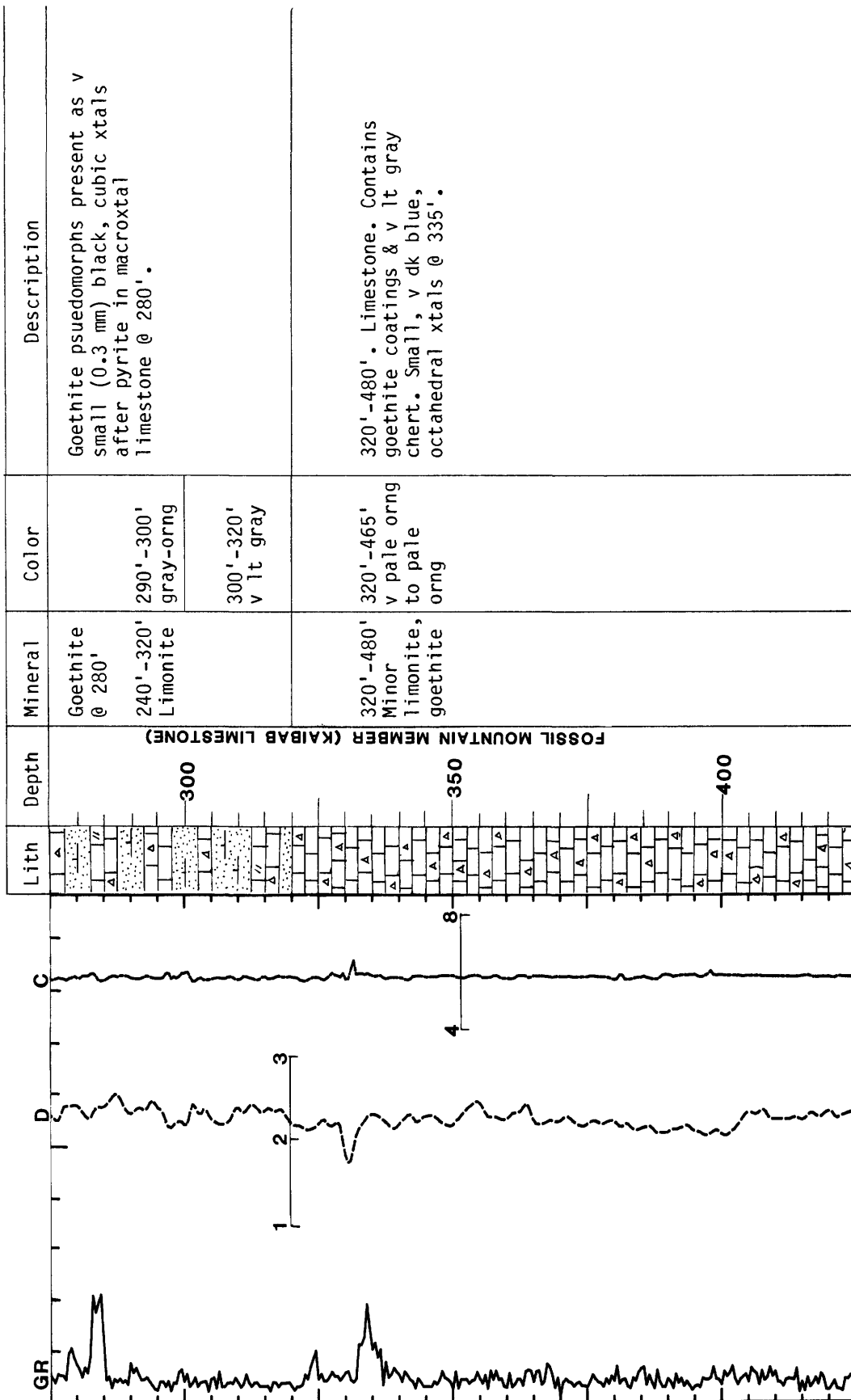
Lat: 36°07'30" Long: 113°00'24" Elev: 6340' TD: 1421' PD: 1170'



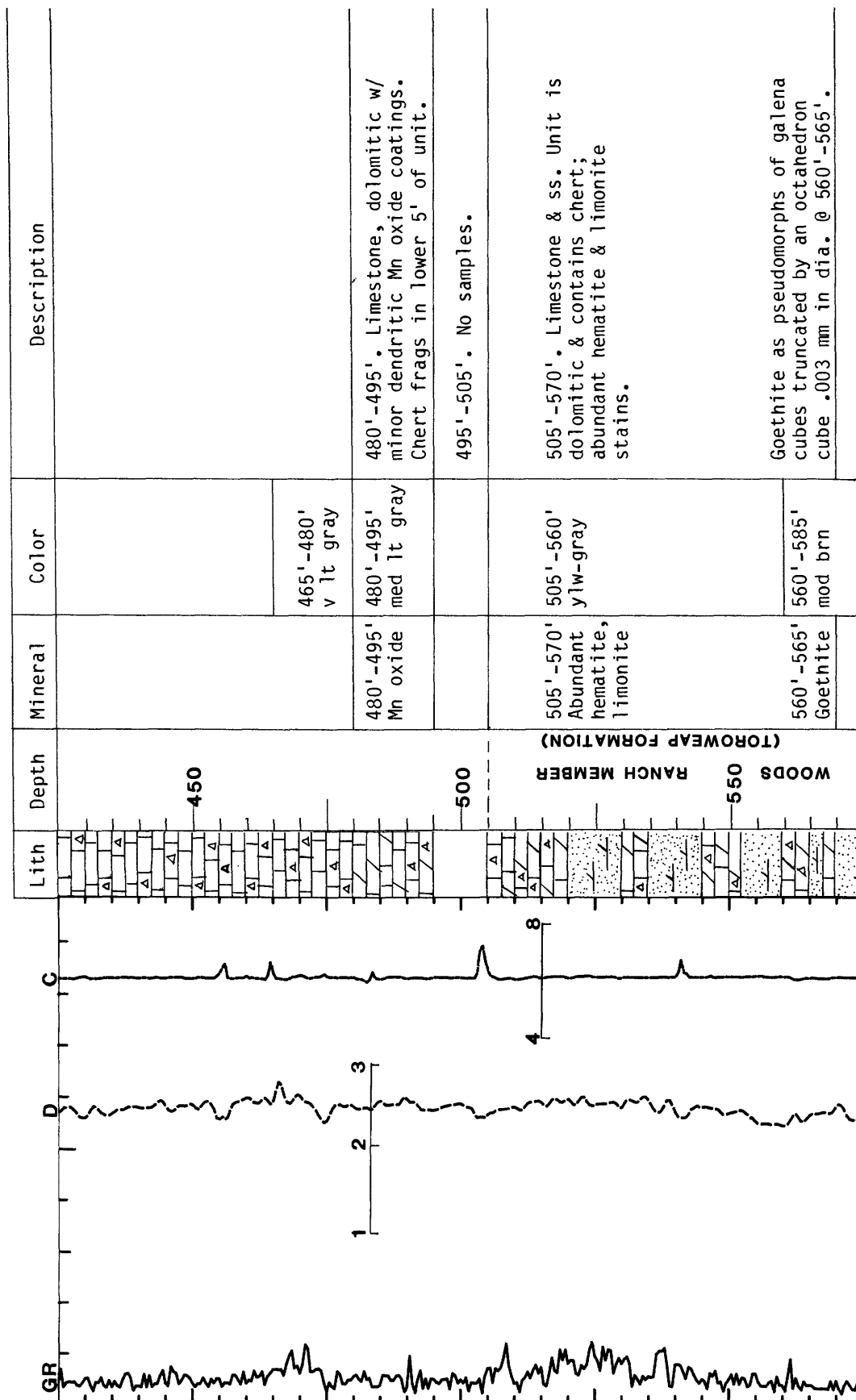
Hole no.: 494-3R



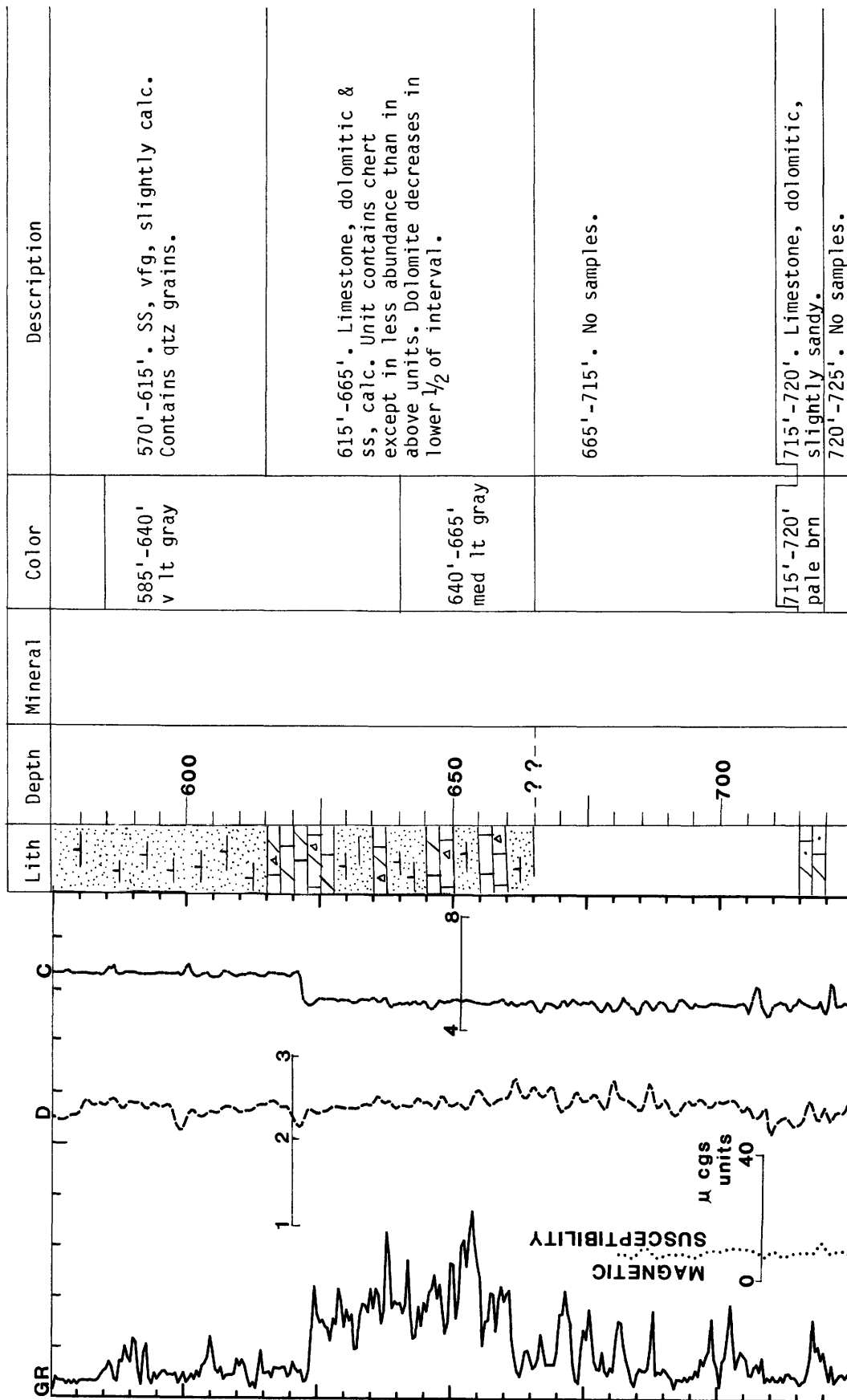
Hole no.: 494-3R



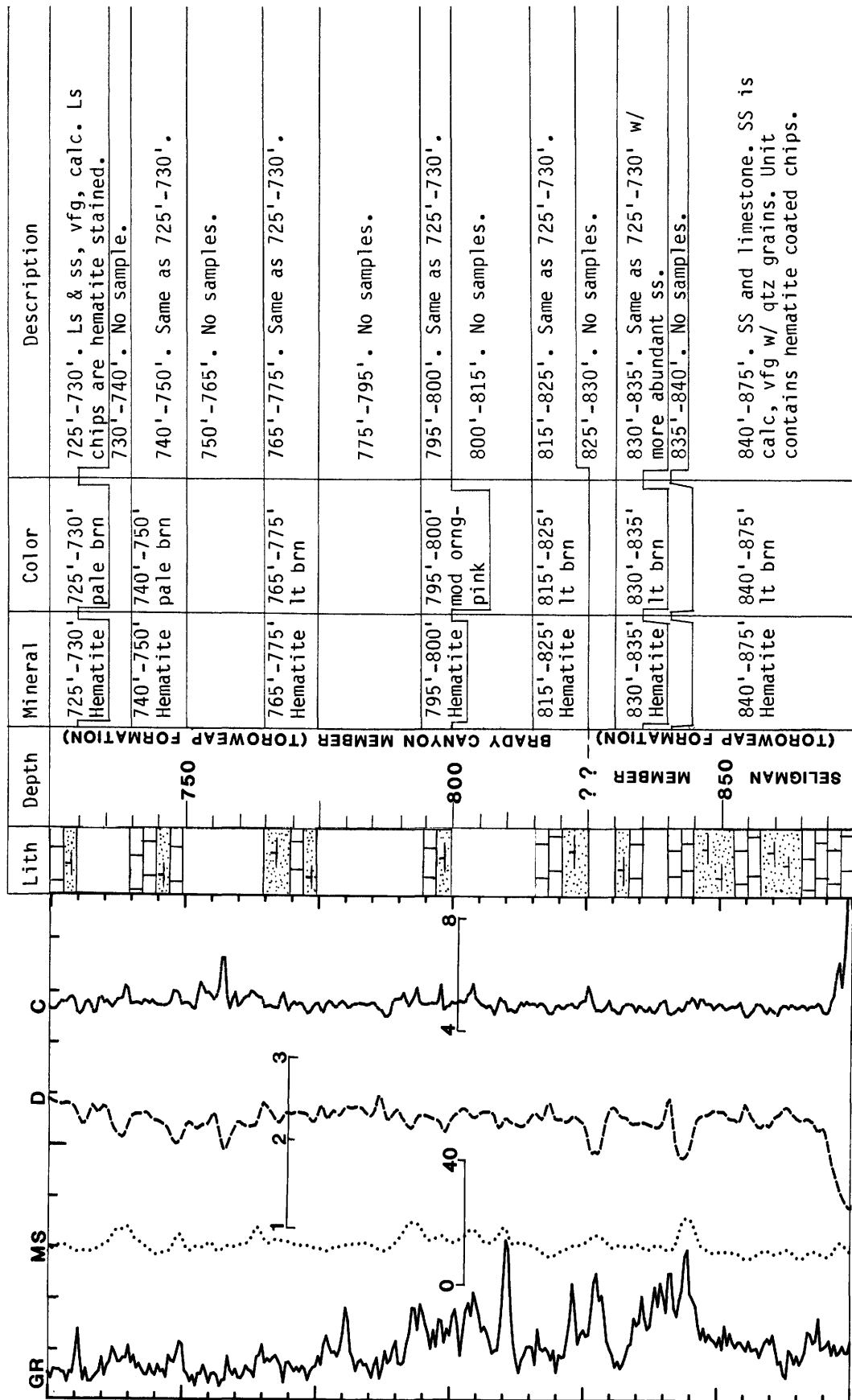
Hole no.: 494-3R



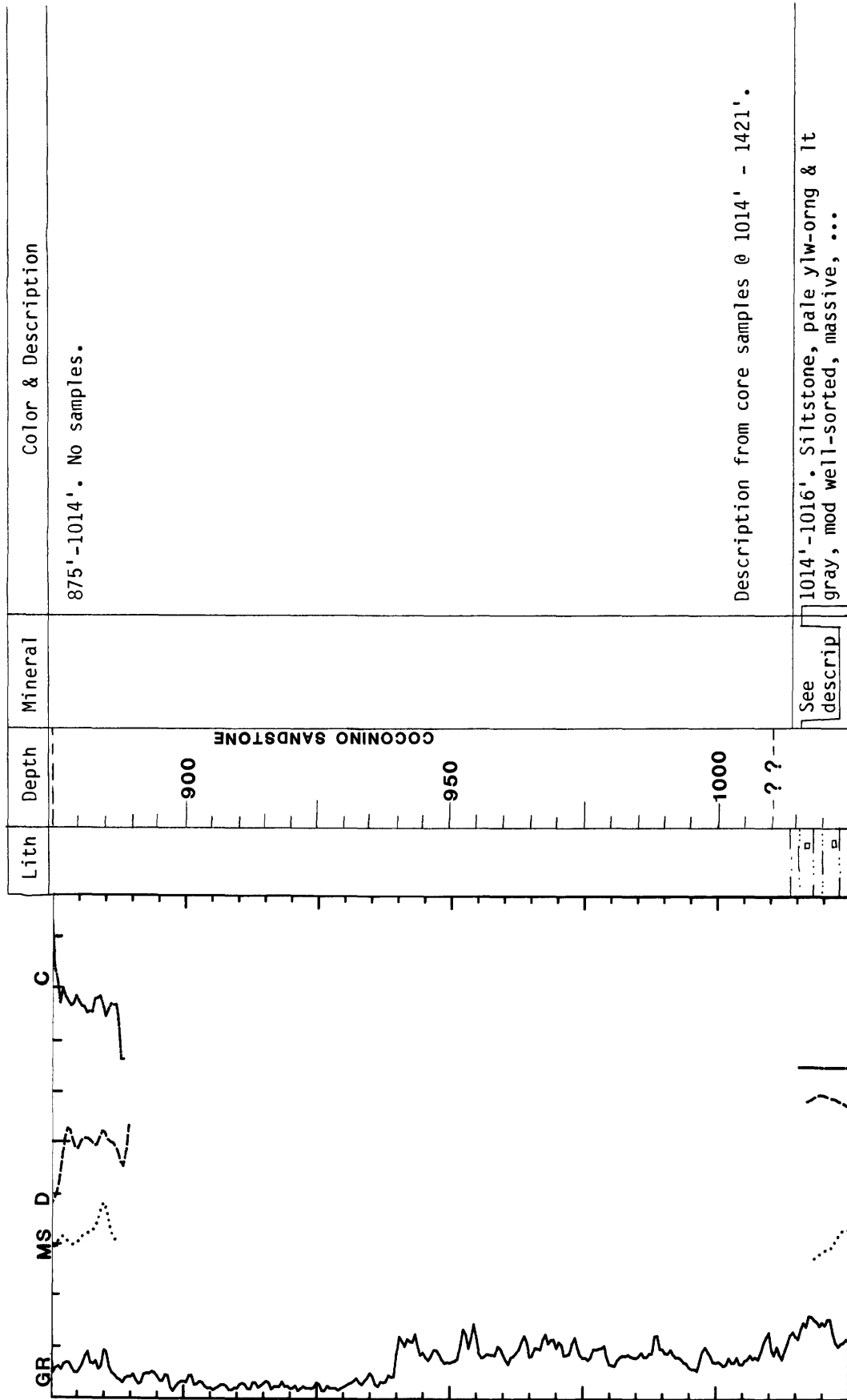
Hole no.: 494-3R



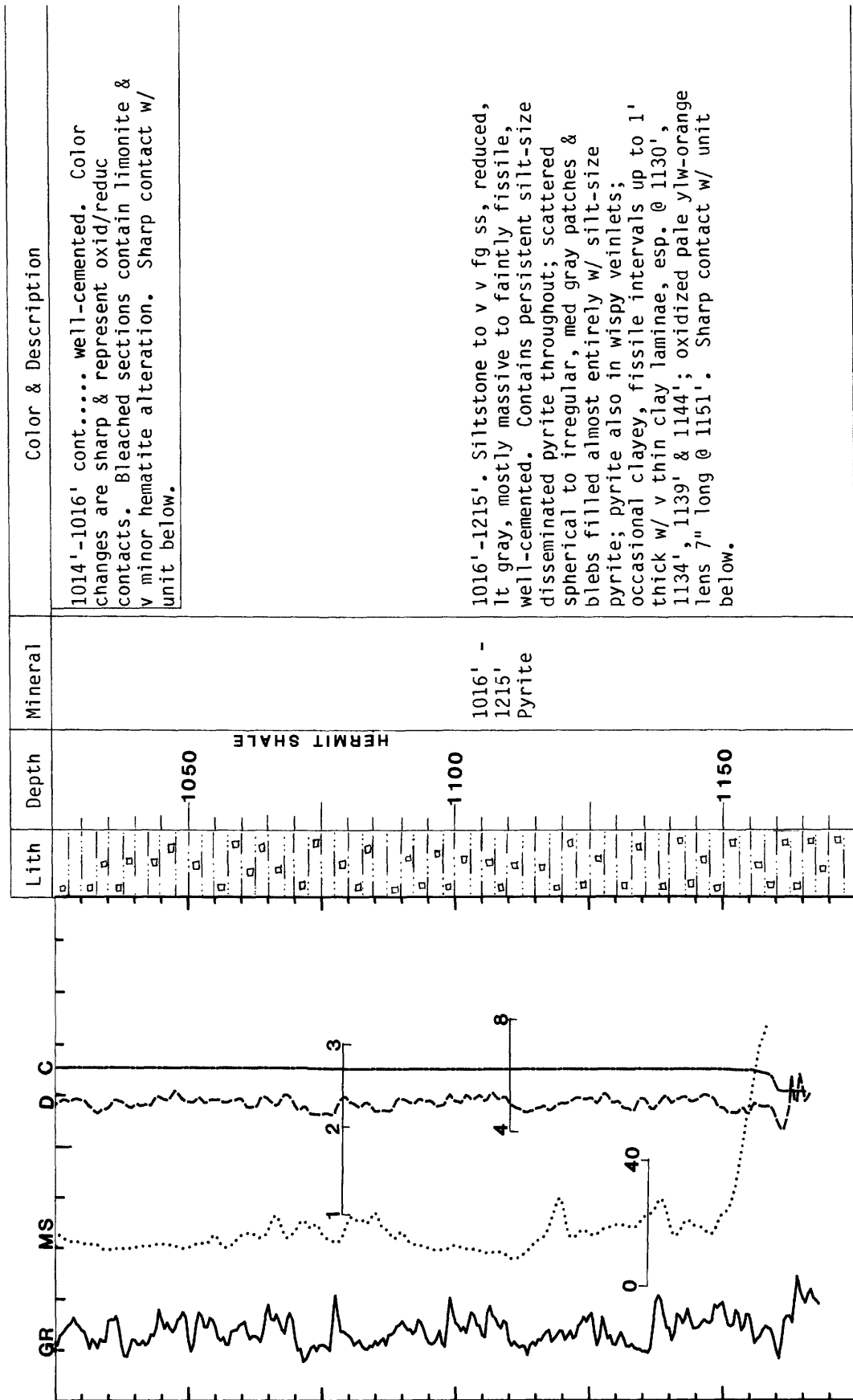
Hole no.: 494-3R



Hole no.: 494-3R & 3C



494-3C



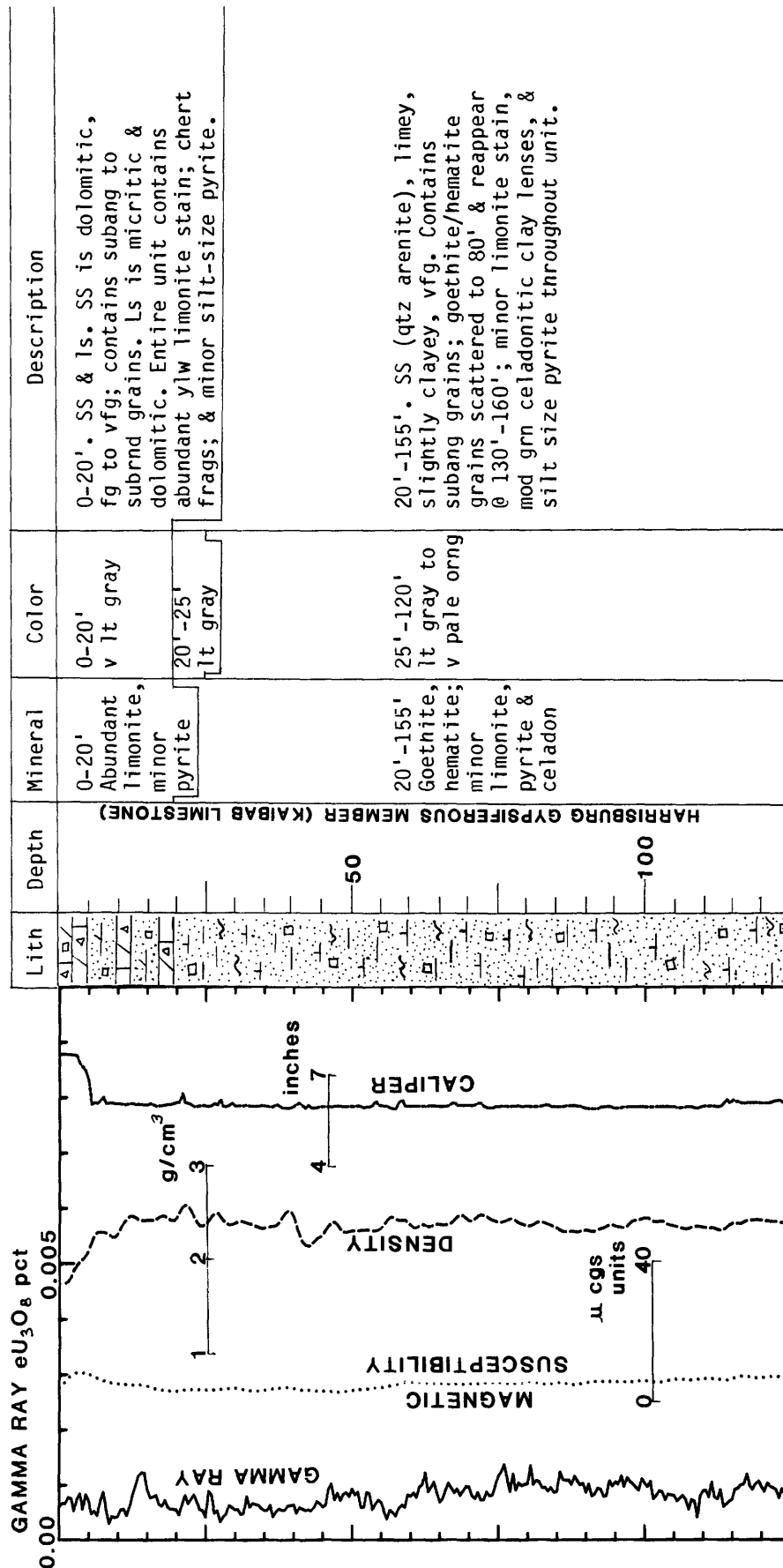
Lith	Depth	Mineral	Color & Description
			Page 9 continued. Sharp contacts between all units below.
	1300	1291' - 1295' Pyrite, minor Mn oxide	1291'-1295'. Siltstone to v vfg ss, lt gray & v pale orgng, mod well-srted, massive, well-cmted. Color changes are sharp oxid/reduc contacts. Reduced lt gray sections contain blebs & veinlets filled w/ pyrite. Oxid sections are devoid of pyrite w/ minor blebs of Mn oxide. 1295'-1297'. Siltstone, reduced, lt gray, bioturbated (worm tubes) w/ wavy fissility. No sulfides apparent.
		1320' - 1337' Pyrite	1297'-1320'. Siltstone, Fe oxid, mod red-brn to dk red-brn, mod well-srted, mainly well-cmted to poorly cmted; mottled staining; massive bedding to fissile w/ wavy lams (massive in lower 5'; clayey & v fissile @1314'-1315'); primarily qtz grains, ±10% mica grains, trace dk opaque min. 1320'-1337'. Siltstone, reduced, v lt gray, mod well-srted, homo, massive, well-cmted; shaly & sandy in lower 0.5'; v thin veinlets of swelling clay @1330'; occasional v small pods of pyrite & silt size pyrite scattered throughout.
	1350		
	1400		1337'-1421'. Siltstone, Fe oxidized, mod red-brn to dk red-brn, mainly massive to fissile, fractured (esp. @ 1394'-1401'). Contains scattered spherical to irregular, lt gray reduction spots; v thin laminae of dk opaque minerals; mainly qtz grains, ±10% mica grains, trace dk opaque minerals; shaly intervals a few cm to several ft thick w/ mildly wavy lams (ie @1380'-1382'); intervals of mottled staining.

Appendix 4.-- Lithologic and geophysical logs for hole 4R and 4C, Mohawk Canyon Pipe

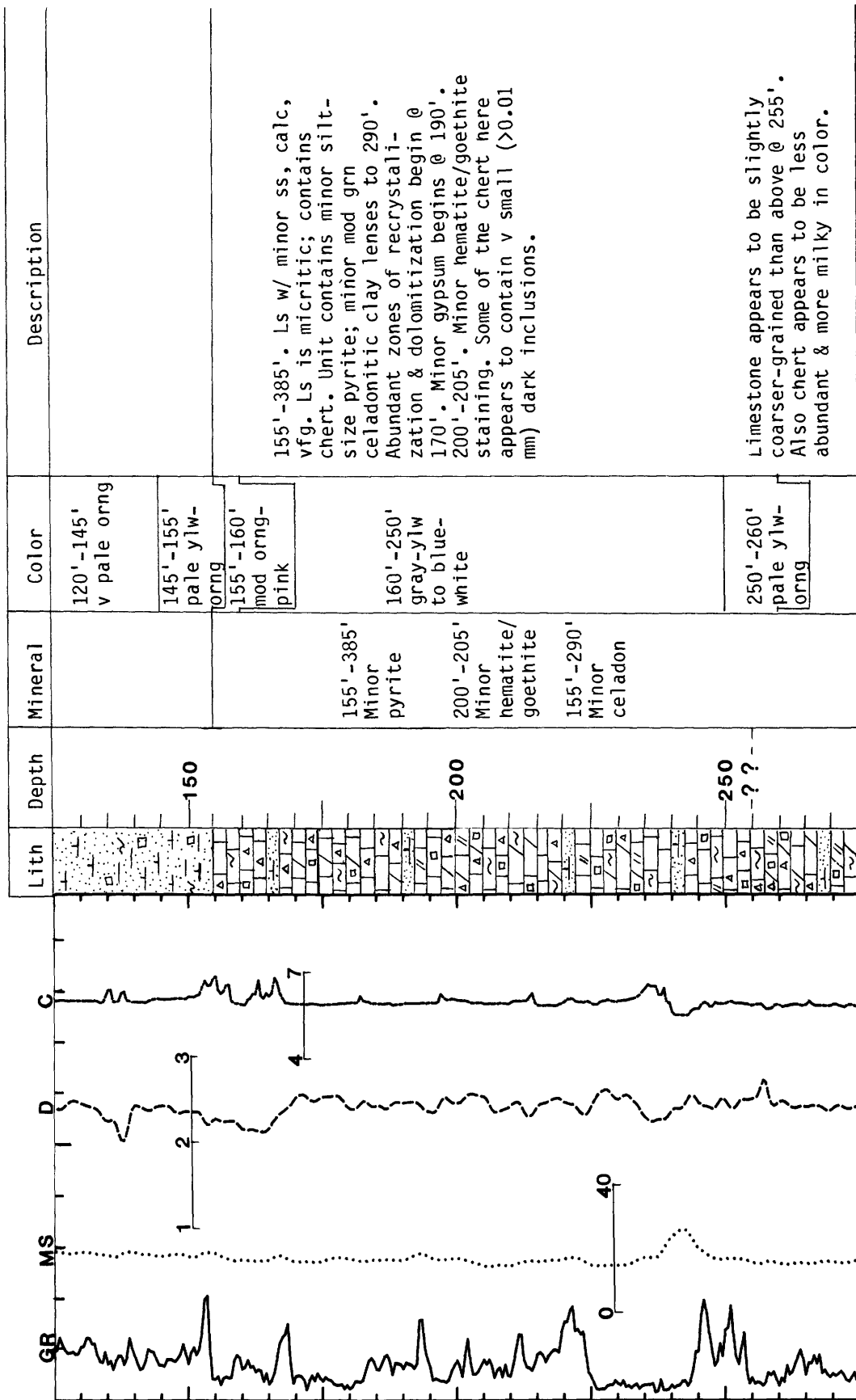
Hole no.: 494-4R & 4C Date: 8/11/84

T.: 32N R.: 7W Section: 26 County: Coconino State: AZ

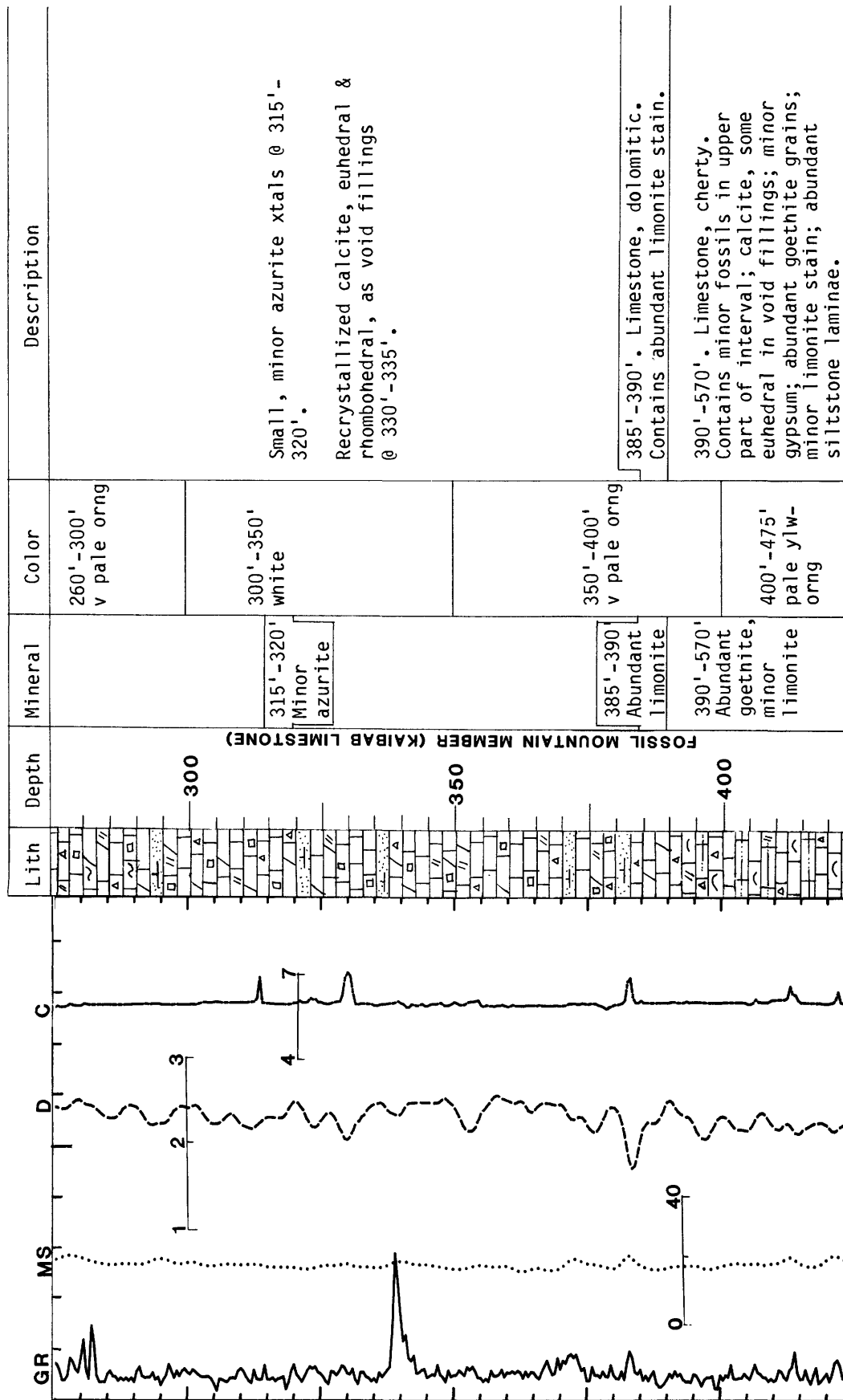
Lat: 36°07'30" Long: 113°00'24" Elev: 6345' ID: 1008' PD: 948'



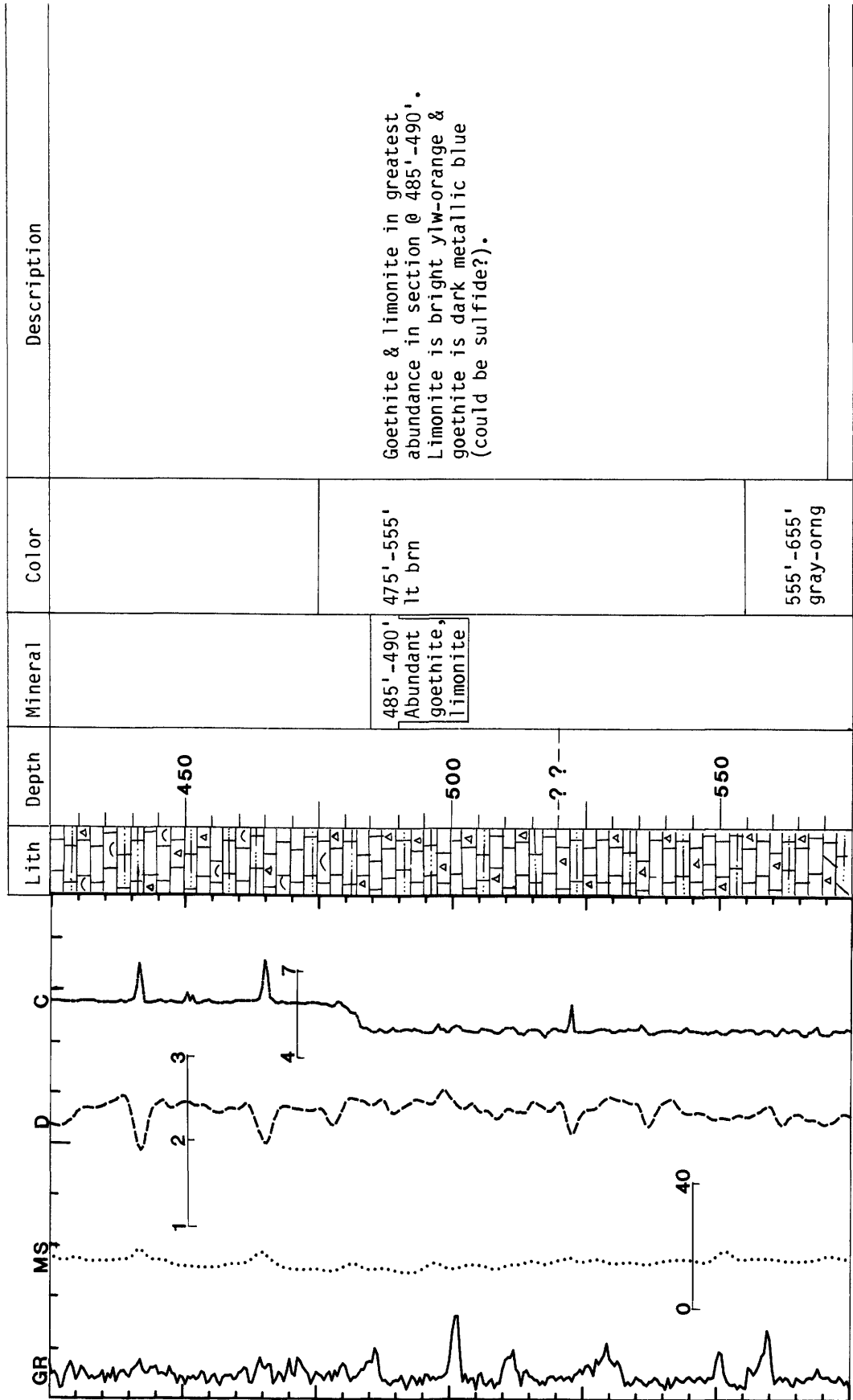
Hole no.: 494-4R



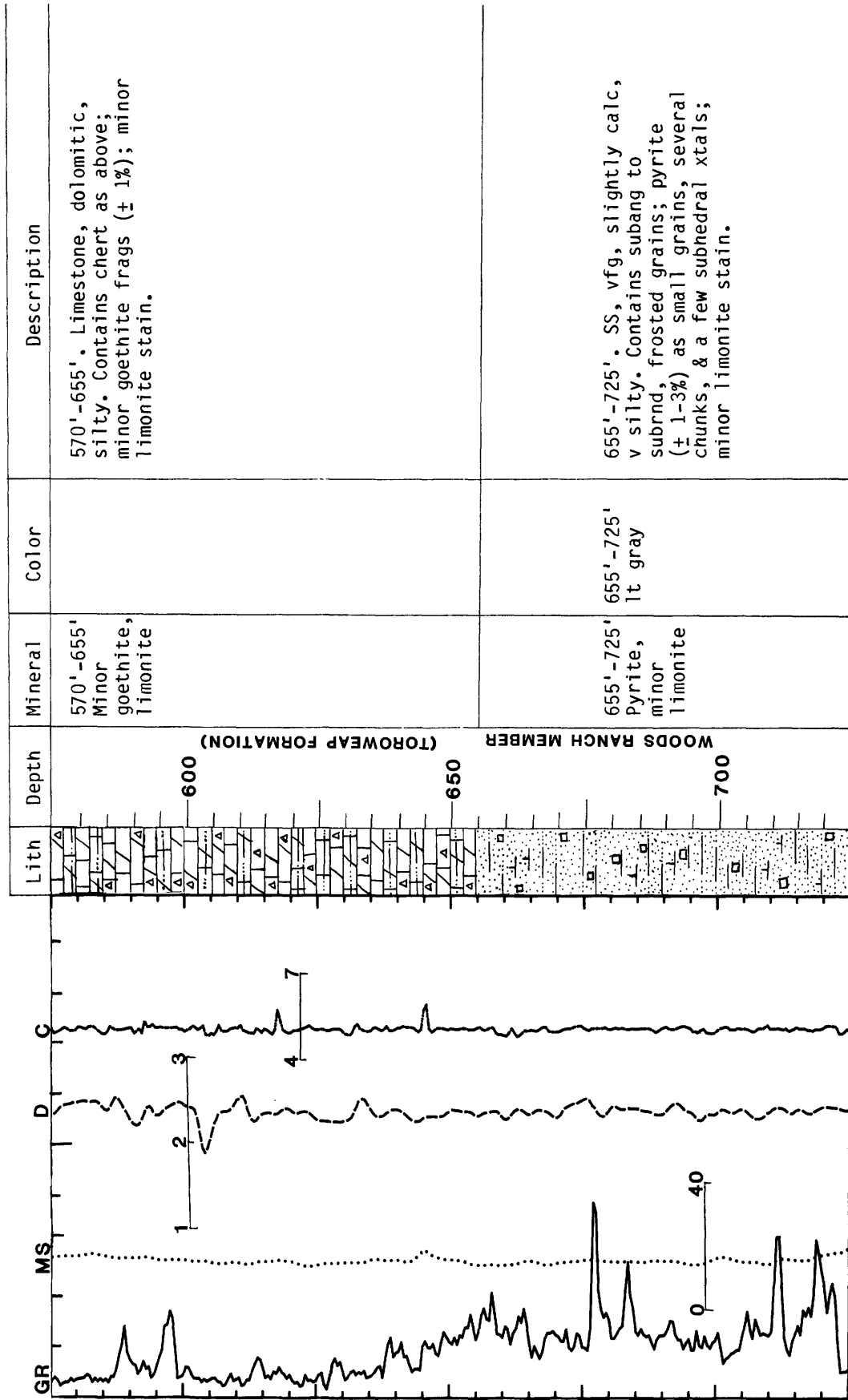
Hole no.: 494-4R



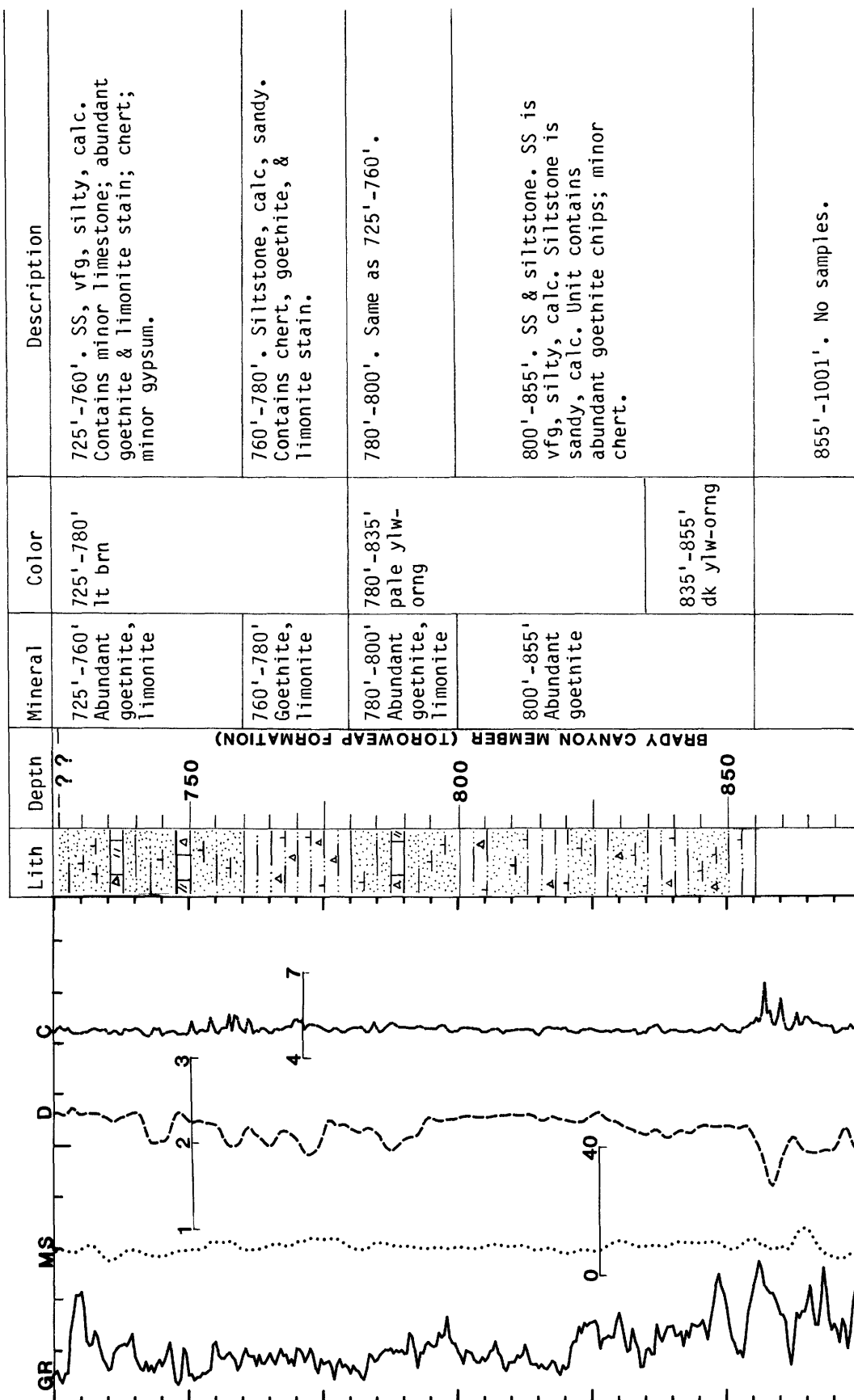
Hole no.: 494-4R



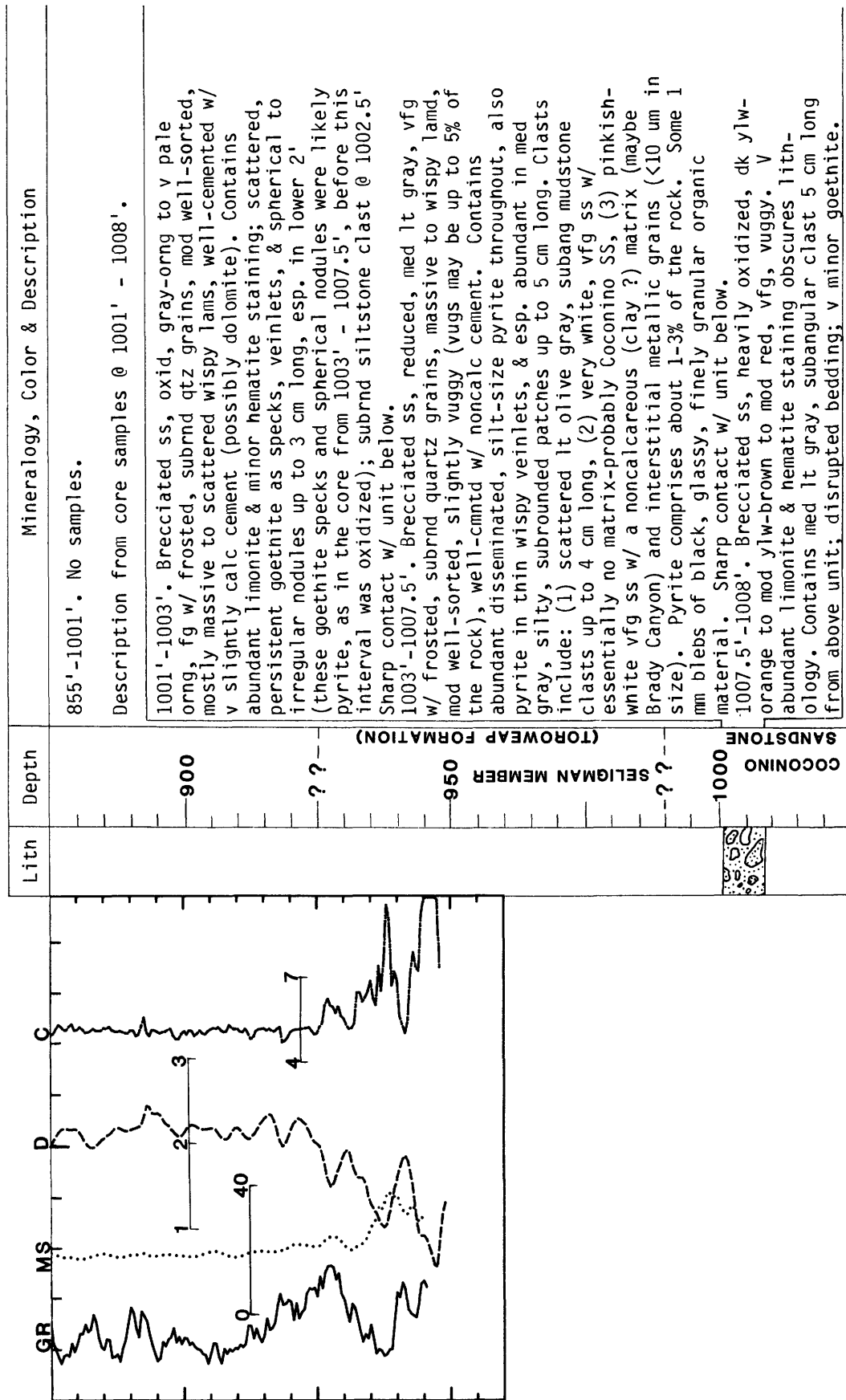
Hole no.: 494-4R



Hole no.: 494-4R



Hole no.: 494-4R & 4C



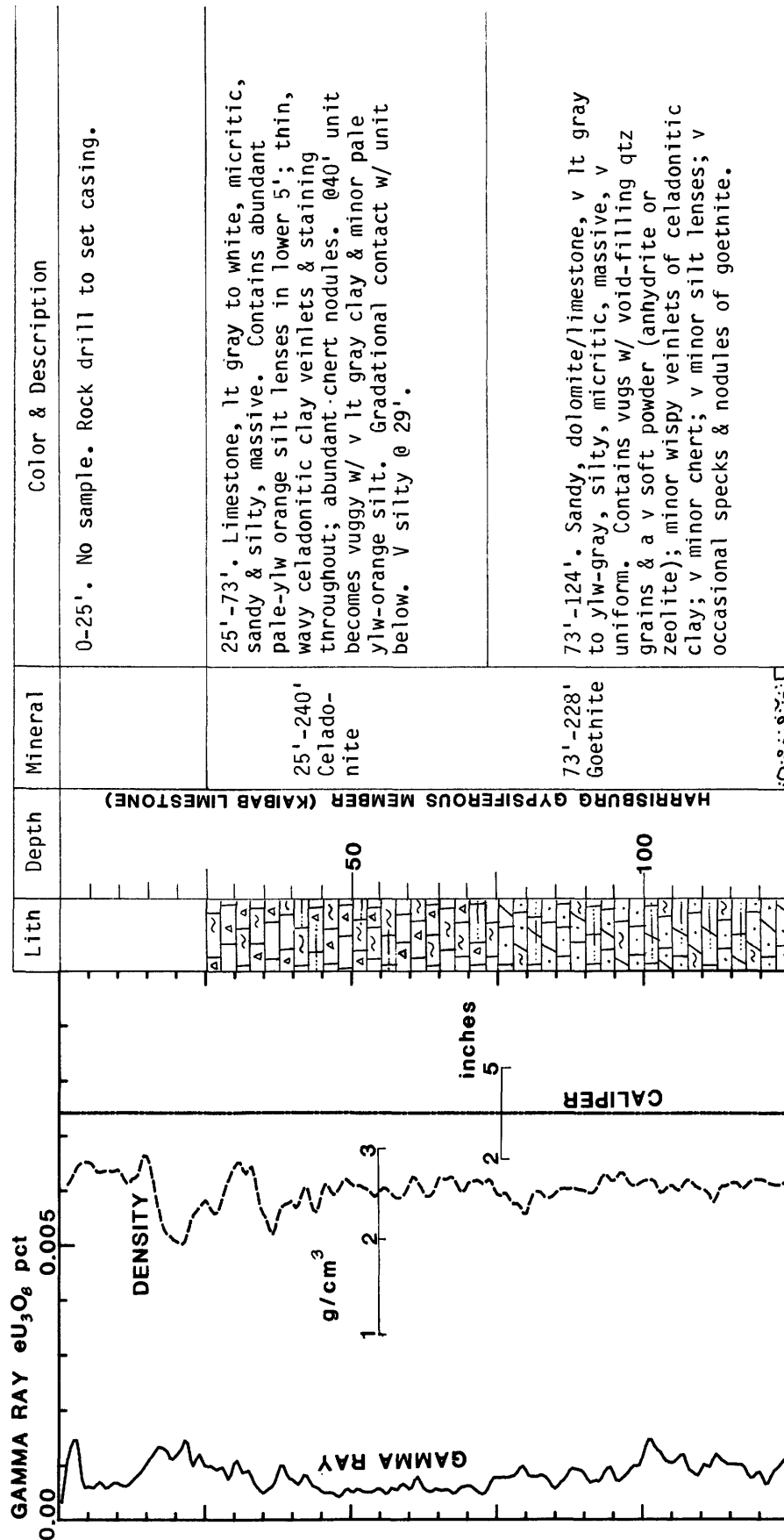
Depth	Lith	Mineralogy, Color & Description
855'-1001'		No samples.
		Description from core samples @ 1001' - 1008'.
1001'-1003'		Brecciated ss, oxid, gray-orng to v pale orng, fg w/ frosted, subrnd qtz grains, mod well-sorted, mostly massive to scattered wispy lams, well-cemented w/ v slightly calc cement (possibly dolomite). Contains abundant limonite & minor hematite staining; scattered, persistent goethite as specks, veinlets, & spherical to irregular nodules up to 3 cm long, esp. in lower 2' (these goethite specks and spherical nodules were likely pyrite, as in the core from 1003' - 1007.5', before this interval was oxidized); subrnd siltstone clast @ 1002.5'. Sharp contact w/ unit below.
1003'-1007.5'		Brecciated ss, reduced, med lt gray, vfg w/ frosted, subrnd quartz grains, massive to wispy lamd, mod well-sorted, slightly vuggy (vugs may be up to 5% of the rock), well-cmntd w/ noncalc cement. Contains abundant disseminated, silt-size pyrite throughout, also pyrite in thin wispy veinlets, & esp. abundant in med gray, silty, subrounded patches up to 5 cm long. Clasts include: (1) scattered lt olive gray, subang mudstone clasts up to 4 cm long, (2) very white, vfg ss w/ essentially no matrix-probably Coconino SS, (3) pinkish-white vfg ss w/ a noncalcareous (clay ?) matrix (maybe Brady Canyon) and interstitial metallic grains (<10 um in size). Pyrite comprises about 1-3% of the rock. Some 1 mm blebs of black, glassy, finely granular organic material. Sharp contact w/ unit below.
1007.5'-1008'		Brecciated ss, heavily oxidized, dk ylw-orange to mod ylw-brown to mod red, vfg, vuggy. V abundant limonite & hematite staining obscures lithology. Contains med lt gray, subangular clast 5 cm long from above unit; disrupted bedding; v minor goethite.

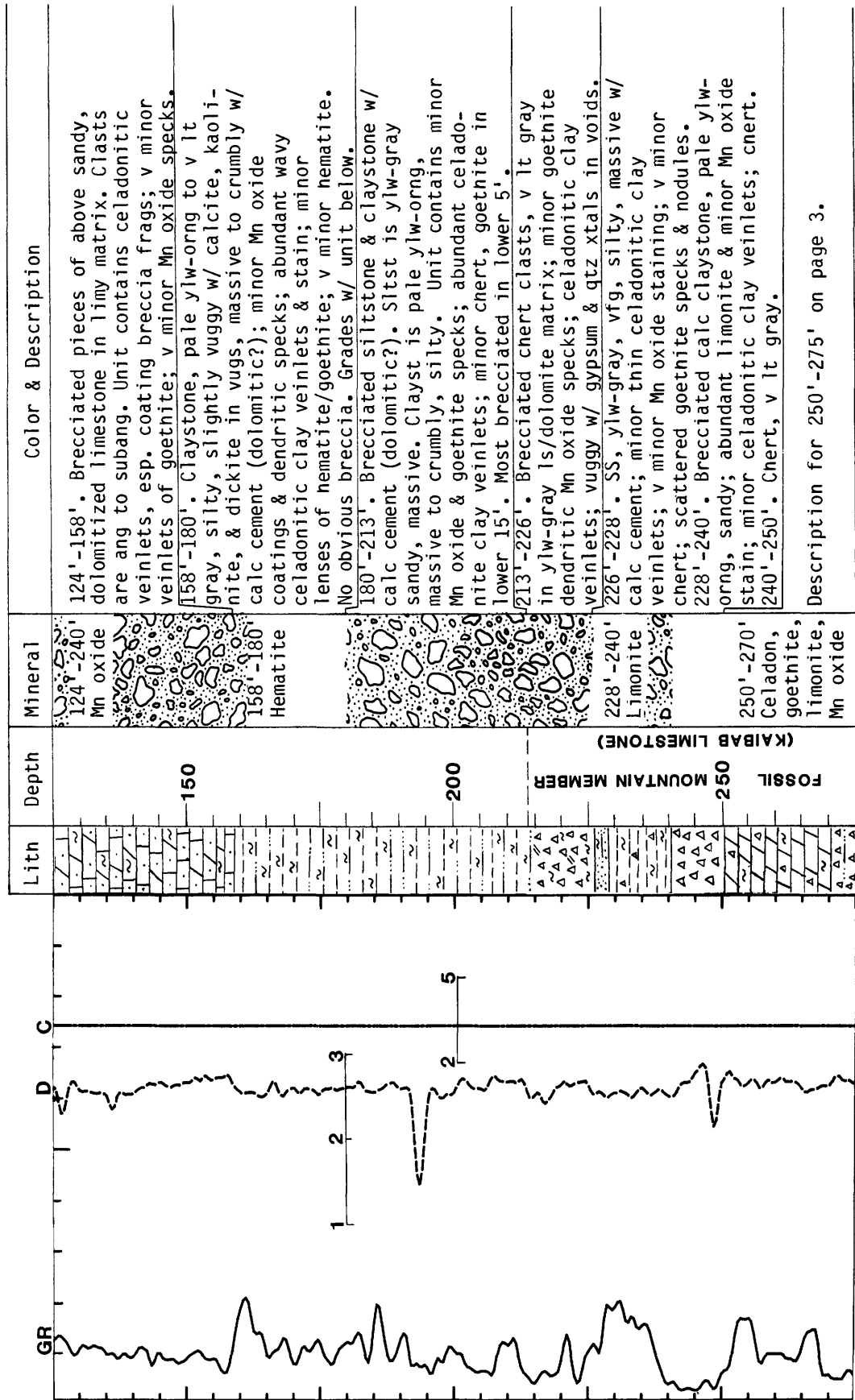
Appendix 5.-- Lithologic and geophysical logs for hole 5C, Mohawk Canyon Pipe

Core no.: 494-5C Date: 9/28/84

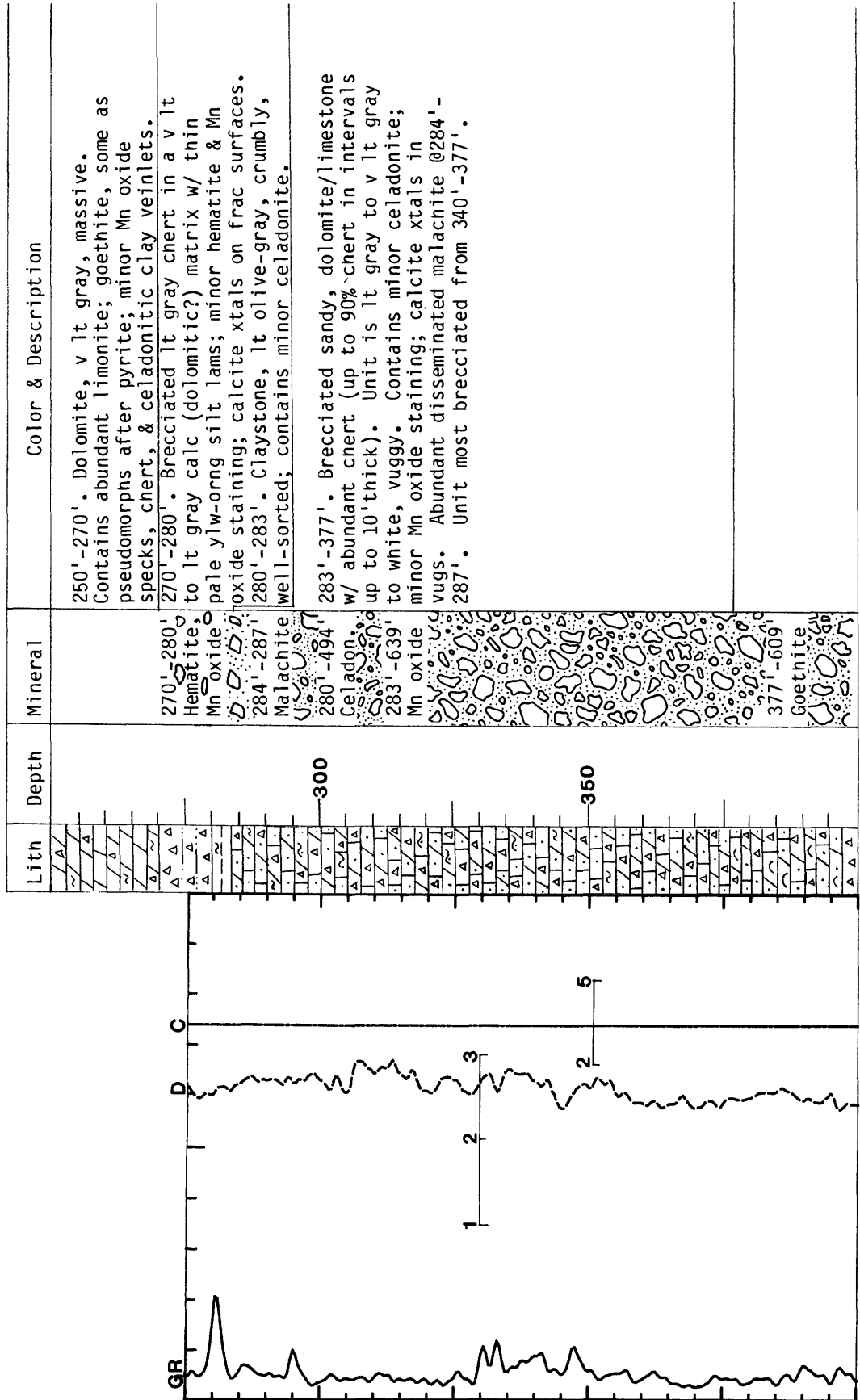
T.: 32N R.: 7W Section: 26 County: Coconino State: AZ

Lat: 36°07'30" Long: 113°00'24" Elev: 6340' TD: 1012' PD: 770'

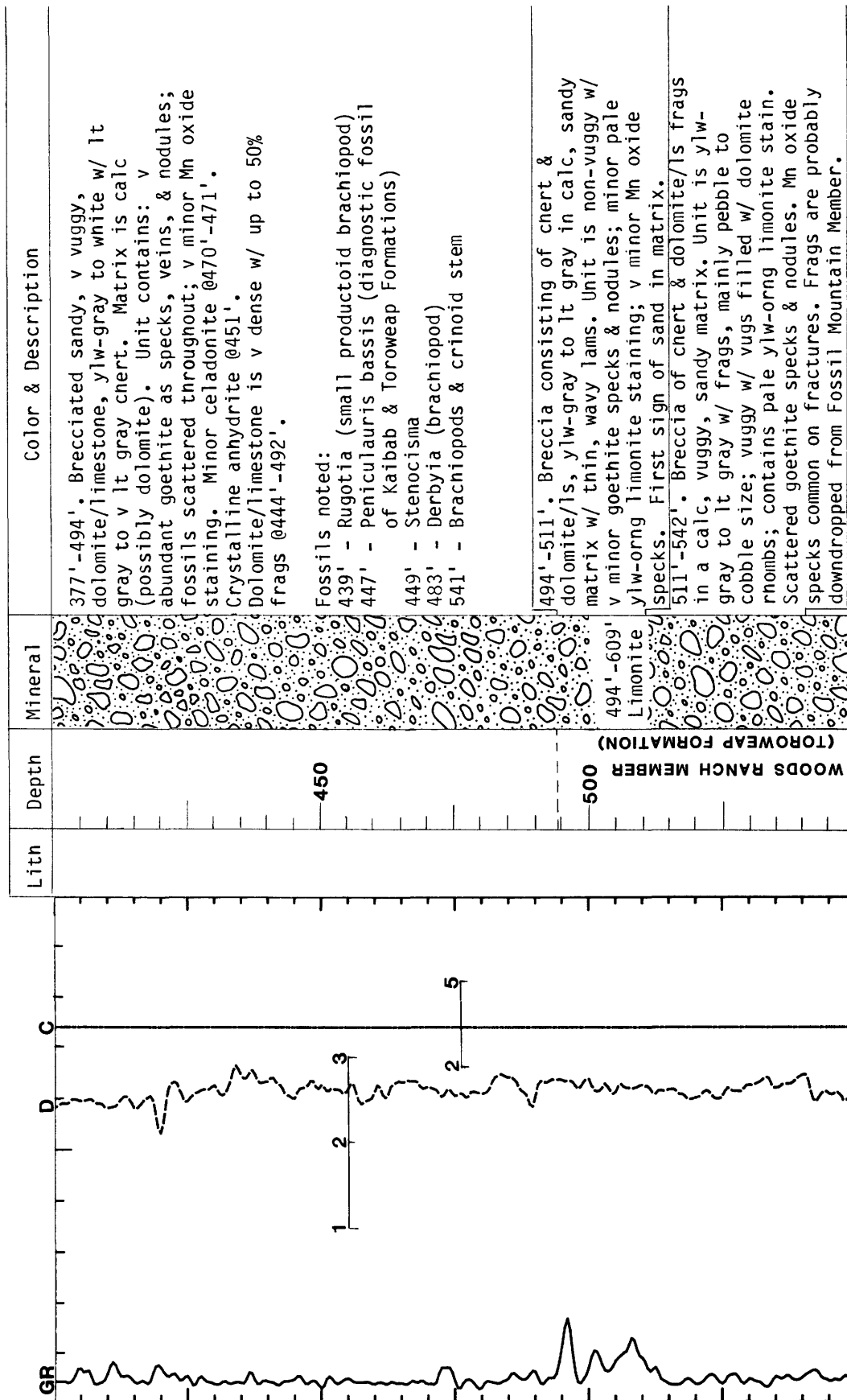




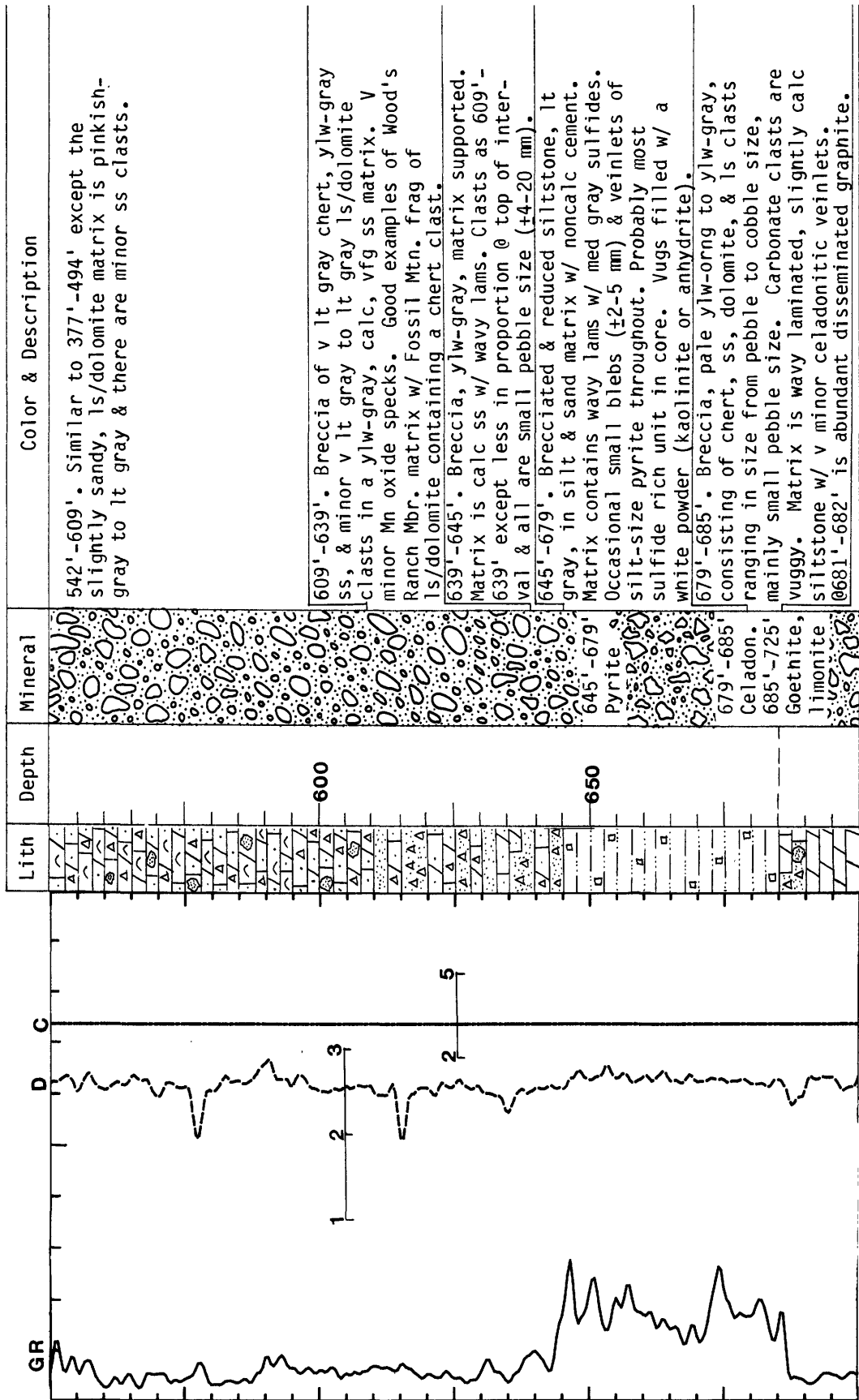
494-5C

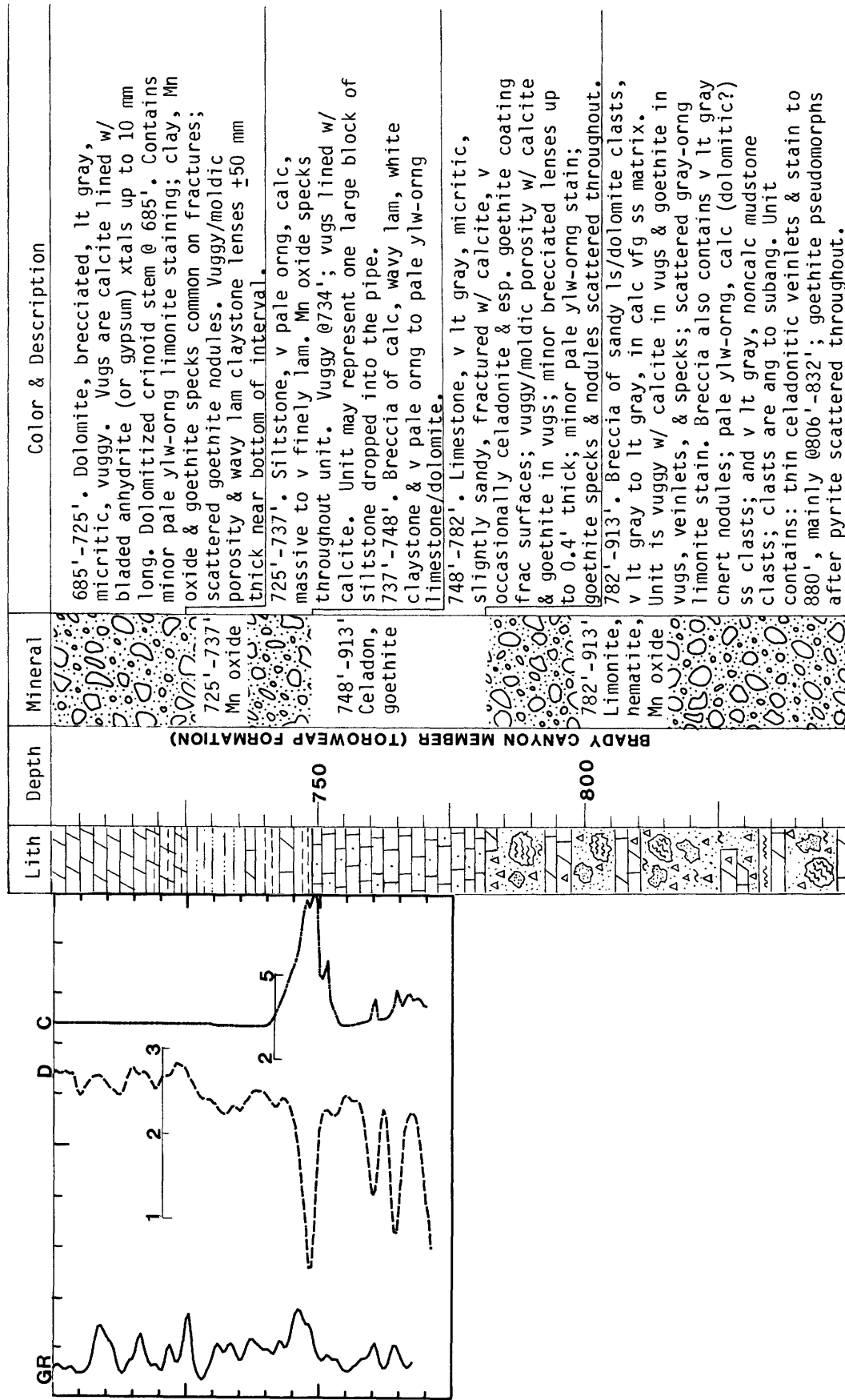







494-5C



494-5C





Lith	Depth	Mineral	Color & Description
			782'-913' cont.....scattered dendritic Mn oxide specks; v minor dusky red hematite stain in lenses; rare dk ylw-orng mudstone lenses up to 0.5' thick w/ abundant goethite. V sandy @871'-882' w/ vfg sand. Limonite stain most abundant @782'-882'. Chert nodules v minor @817'-913'. Calcite replaces fossils @807' & 823'. Mudstone lenses abundant @782', 784', & 799'.
	900		913'-976'. Brecciated frags of fg, calc ss in a more limonite stained fg, calc matrix. Breccia contains pale to dk ylw-orng to gray-orng pink, ang to subang clasts; mainly massive bedded w/ zones of leisegang banding. "picture ss" @969'-971'. Unit is heavily Fe-oxid w/ abundant limonite stain (dk to pale ylw-orng to mod ylw-brn); vuggy; fractured w/ fractures stained w/ goethite & minor calcite. Contains: calc cement (dolomitic?); heavily hematite altered zones (dusky red to mod red), esp. in lower 8'; goethite pseudomorphs replacing pyrite scattered throughout; occasional silty lenses; vugs filled w/ calcite & goethite.
	950		976'-1012'. Brecciated med to fg, noncalc ss in med to fg sand matrix w/ noncalc cement. Breccia contains v abundant dk ylw-orng to mod ylw-brn limonite stain & abundant mod red-brn to dk red-brn hematite stain; goethite as stain & in veinlets common. Clasts are v lt gray & pale to dk ylw-orng, ang to subang, porous, massive to leisegang banding. Occasional pink-gray mudstone clasts. Unit is heavily Fe-oxid; vuggy w/ goethite common in vugs, calcite less common. Sylvite & celadonite @1009'.
		Goethite, limonite, hematite	
		913' - 1012'	
