

UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

The Potential for Breccia Pipes in the National Tank Area,
Hualapai Indian Reservation, Arizona

by

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This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey Editorial standards and stratigraphic nomenclature.

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THE POTENTIAL FOR BRECCIA PIPES IN THE NATIONAL TANK AREA, HUALAPAI INDIAN RESERVATION, ARIZONA

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ABSTRACT

The Hualapai Indian Reservation is located on the southwestern corner of the Colorado Plateau in northern Arizona. Thousands 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. The occurrence of high-grade U ore, associated with potential byproduct concentrations of Ag, Pb, Zn, Cu, Co, and Ni in some of these pipes, has stimulated exploration and 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 on the Hualapai Reservation during the past 3 years. Although breccia pipes are easily recognized within canyons where their vertical dimension is exposed, large expanses of northern Arizona are comprised of undissected high plateaus. Recognition of pipes in these areas is particularly important because mining access to the plateaus is significantly better than to the canyons and the greater volume of overlying sandstones provides more rock to precipitate ore from mineralizing fluids. Shallow structural basins on these adjacent plateaus are commonly the surface expression of the upper part of breccia pipes.

The National Tank area on the Hualapai Indian Reservation, Arizona, was selected to demonstrate the high density of collapse features (suspected to be breccia pipes) that lie on these plateaus. Because most of the area is soil covered with little rock outcrop, soil geochemical, helium-soil gas, Bacillus cereus, and geophysical surveys are being used to evaluate the potential that mapped collapse features are breccia pipes rather than more shallow rooted solution features. Circular erosion patterns and vegetation changes are the only visible signs of collapse structures in the National Tank area. Twenty-five collapse features were mapped and described within this region; of these, three--534, 569, and 570--appear to have the greatest potential to be breccia pipes.

INTRODUCTION

The Colorado Plateau of northern Arizona is host to thousands of breccia pipes, many of which were mineralized by Cu, U, Ag, Pb, Zn, Co and Ni-bearing fluids. Despite the depressed uranium market, exploration activity for mineralized breccia pipes in north-central and northwestern Arizona has remained high.

The Hualapai Tribal Council requested in 1985 that the U.S. Geological Survey select two areas of potentially mineralized breccia pipes on the Hualapai Reservation (fig. 1) that the tribe could consider leasing to the

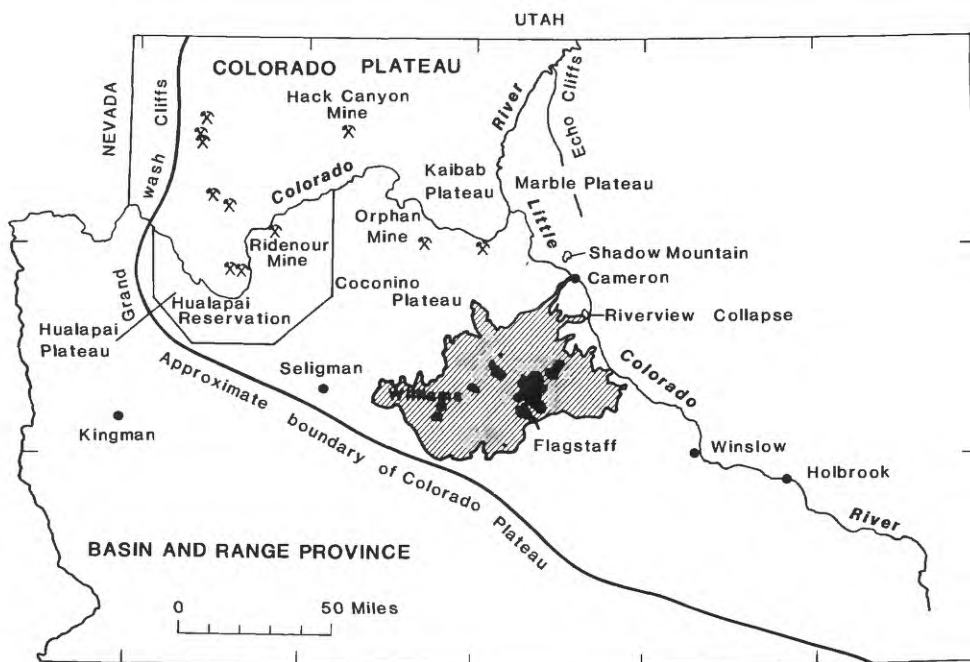


Figure 1.--Index maps of northern Arizona showing the location of plateaus, boundary of Colorado Plateau (Mogollon Rim), Hualapai Reservation, breccia pipes developed into mines, and the San Francisco volcanic field which buries terrane with high potential for breccia pipes.

mining community. The area selection was based on maximum number of collapse features per area and distance from residential communities. The two areas selected represent, in general, two very different exposures of breccia pipes: (1) In the Mohawk Canyon area, mineralized rock is commonly exposed in cliff faces and along canyon bottoms, occurring in all formations from the Permian Kaibab Limestone to the Mississippian Redwall Limestone (fig. 2). Much of this area is not easily accessible, and cannot be reached by motor vehicle (2) In the National Tank area mineralized rock is not exposed, in fact, little rock of any sort is exposed, and most of the area is soil-covered. Consequently, mapping is restricted to recognition of collapse features at the surface, which may or may not be mineralized at depth. However, most of the area is readily accessible by road. The National Tank area is the focus of this report; the Mohawk Canyon area is discussed in a separate report.

BRECCIA PIPES OF NORTHERN ARIZONA

The breccia pipes of northern Arizona differ from classic breccia pipes in that there are no volcanic rock associations in time or space; instead, they result from solution collapse within the Redwall Limestone and stoping of the overlying strata. Dissolution of the Redwall Limestone created caverns into which blocks of overlying strata collapsed. This led to gradual upward stoping of a rubble-filled, approximately 300 ft (100 m) in diameter, pipe-like structure. The pipes and associated mineralized rock transgress formational boundaries from the Mississippian Redwall Limestone to the Triassic Chinle Formation (fig. 2) a vertical distance on the order of 4000 ft (1300 m). No pipes have been observed to occur in rock below the base of the Thunder Springs Member of the Redwall Limestone during this study [nor during studies by Huntoon and others (1981, 1982) and Billingsley and Huntoon (1983)]. The stoping process produced extensive brecciation of the rock within the steep walls of the pipe. At no level in any pipe have breccia clasts been observed from deeper beds; all material has been dropped downward into the pipe from stratigraphically higher units. As a result of collapse, brecciated rock within each pipe abuts against generally well-stratified, relatively undeformed sedimentary rock; the plane demarking this contact is obviously one along which the breccia slid downward and is therefore, by definition, a fracture (see fig. 1b, Wenrich, 1985). This nearly vertical fracture is referred to here as the ring fracture.

The breccia pipes of northern Arizona extend 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, through Coconino National Forest to the Marble Plateau of the Navajo Reservation (fig. 1). 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 northward to the Utah border; the flurry of mining ventures during the past 6 years, including the Hack Canyon mines, Kanab North mine and the Pigeon mine, has brought recent prominence to this region. Pipes undoubtedly also 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.

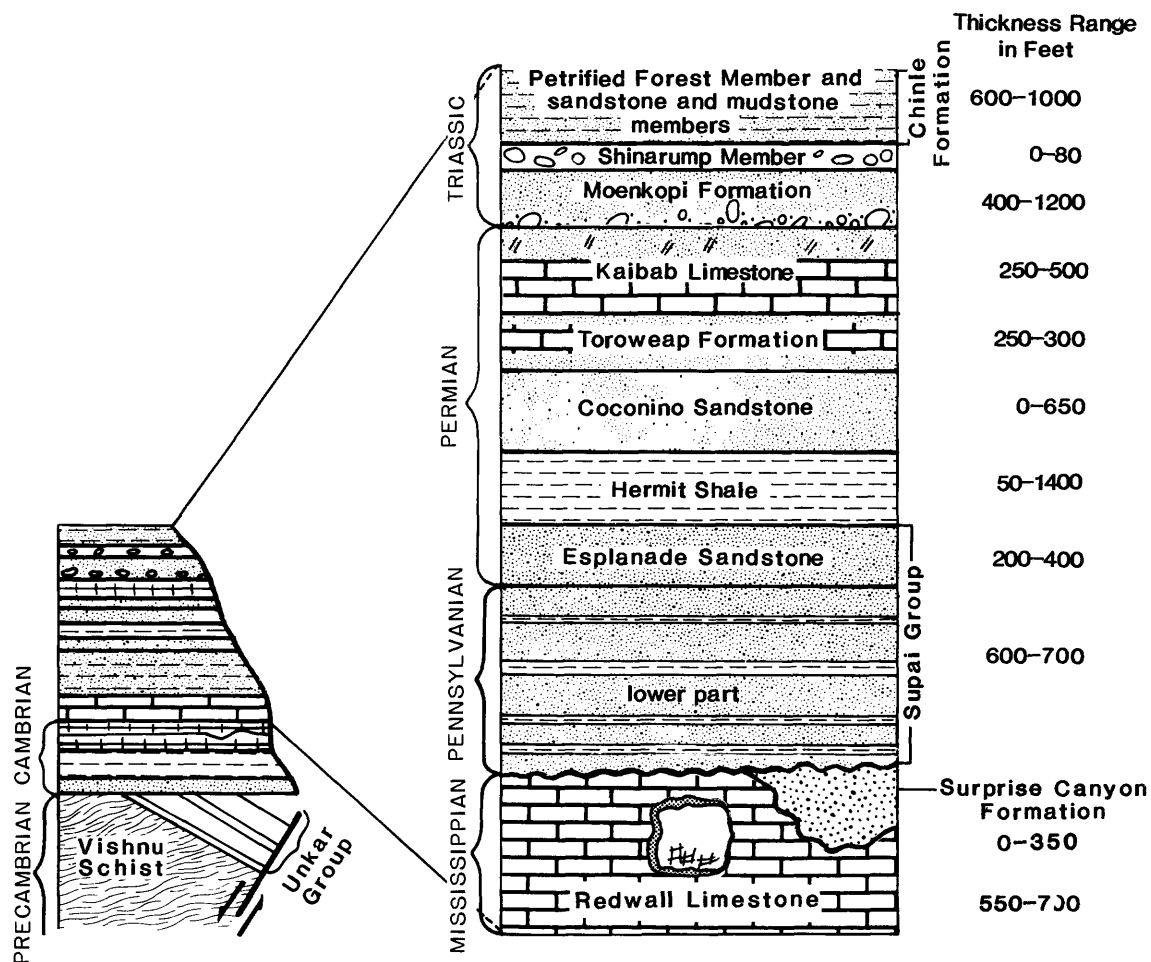


Figure 2.--Stratigraphic column showing rock units that host breccia pipes in the Grand Canyon region of Arizona. The thickness shown for each unit are those characteristic of the area shown in figure 2.

Mining activity in breccia pipes of the Grand Canyon region began during the 19th century; at that time essentially all ore produced was copper. It was not until 1951 when high gamma radioactivity was discovered on the Orphan Mine dump (Chenoweth, 1986) 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; 4.26 million lbs U_3O_8 , comprised primarily of uraninite, was removed from the Orphan Mine averaging 0.43 percent U_3O_8 (Chenoweth, 1986). Other mined breccia pipes have, or had, grades and tonnages similar to the Orphan Mine. All active mines are presently being operated essentially for their uranium content, although silver could be extracted as a by-product in some if an appropriate mill were available; the Orphan mine produced 107,000 oz of Ag from the copper ore during 1962 through 1969 at a grade of 0.35-0.45 oz/ton (11-14 ppm) (Chenoweth, 1986). Analyses of uranium-mineralized rock from breccia pipes throughout the Grand Canyon region routinely yield silver values of 10 to 100 ppm, with some samples containing as much as 1150 ppm (35 oz/ton) (Wenrich, 1985).

Dissolution of the Redwall Limestone began during the Late Mississippian, creating an extensive karst terrain. The breccia pipes include strata up through the Triassic Chinle Formation, but no pipes have been observed to extend into younger rocks. Thus, it is probably safe to assume that formation of breccia pipes by stoping began at least by Early Pennsylvanian time and continued until, or at least was reactivated, in the Triassic. A minimum age of 141 million years (latest Jurassic-earliest Cretaceous) 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 of roughly 200 m.y. ago (late Triassic-early Jurassic) (Ludwig, K. R. and others, 1986). The latter age is in better 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.

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 little doubt that pipe location are in part structurally controlled, particularly on the Marble Plateau (Sutphin and others, 1983; Sutphin and Wenrich, 1983). It is also known that the pipes occur in clusters, as do those that are mineralized. Clustering of mineralized pipes is especially obvious in the area of Hack Canyon, where the Hack I, II, III, and old Hack Canyon Mines (4 separate pipes) all occur within a square mile (2.5 sq km) of each other. This implies a hydrologic connection between multiple pipes and suggests that the mineralizing fluids circulated through all four pipes at the same time. Such a connecting system can be observed in a Redwall cave, with over a mile of passages, located on the west side of Peach Springs Canyon. Here the bottoms of 4 breccia pipes aligned in a straight row, and equally spaced, form broad chimneys in the ceiling of one passage.

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, Cs, Cu, Hg, Mo, Ni, Pb, Sb, Se, Sr, V, Zn, and less commonly, the rare-earth elements. In addition to this suite of elements, a black glassy pyrobitumen is found with the brecciated rock in many mineralized pipes, including the Mohawk Canyon Pipe (Wenrich and others, 1985). This material appears to have solidified after such associated minerals as pyrite, barite, and quartz. Samples from the breccia pipes containing pyrite and pyrobitumen are visually indistinguishable from samples collected from Mississippi Valley-type deposits (Wenrich and others, 1985).

Primary and secondary fluid inclusions in sphalerite, dolomite, quartz, calcite, and anhydrite from several pipes scattered across northern Arizona yield filling temperatures in the range of 86° -222°C. Salinities of fluids included in sphalerite are consistently above 10 wt. % NaCl equivalent. Sphalerite (secondary inclusions) filling temperatures range from 86° to 173°C, dolomite (primary inclusions from 130° to 145°C, quartz (secondary inclusions within a silicified spire of one pipe) from 275° to 305°C, and anhydrite (primary inclusions) from 187° to 222°C. These fluid inclusion filling temperatures and salinities are also in agreement with those found in Mississippi Valley type deposits. This suggests a similar genesis for pipe minerals such as sphalerite and galena, and the Co and Ni phases. Nevertheless, the absence of known uranium occurrences in Mississippi Valley-type deposits (D. L. Leach, personal communication, 1985) contrasts sharply with the pipe mineralogy. This may not preclude the base metal breccia pipe assemblage from having a similar genesis to Mississippi Valley-type deposits, as the uraninite is paragenetically later than the base metal minerals in the breccia pipes and may well have precipitated from later mineralizing fluids. These data suggest that the base metals were probably precipitated from a moderately low temperature brine solution, which exceeded the temperature that would be expected from the normal geothermal gradient on the Colorado Plateau with a burial depth of 3000-5000 ft (900-1500 m).

PIPES ON THE HUALAPAI INDIAN RESERVATION

The Hualapai Indian Reservation is situated on the southwestern corner of the Colorado Plateau (fig. 1). The western half of the reservation, located on the Hualapai Plateau and bounded on the west by the Grand Wash Cliffs, is capped by the Redwall Limestone. No more than 500 ft (175 m) of possible rock thickness is available to host an orebody and little of it is sandstone. Most is limestone which is a relatively unfavorable host for uranium mineralization; thus, the Hualapai Plateau is not considered favorable for economic breccia pipes, and has been 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 provides a stratigraphic column of rock in excess of 2500 ft (800 m) for potential mineral deposits, and places the plateau surface at the same horizon as that above most breccia pipes hosting orebodies in northern Arizona.

Over 900 confirmed and suspected breccia pipes have been mapped on the Hualapai Reservation during the past 4 years (fig. 3). This density of collapse features is not unique to the Hualapai Reservation, the western edge of this pipe-rich region in Arizona, but extends eastward where a similar concentration of pipes had been mapped earlier on the Marble Plateau (Verbeek and Wenrich-Verbeek, 1980; Wenrich-Verbeek and Verbeek, 1980; Sutphin and Wenrich, 1983; Sutphin, 1986).

Mapping collapse features as manifestations of breccia pipes on high plateaus (such as the Coconino, Kaibab, and Marble Plateaus) capped by the Kaibab Limestone or younger units is complicated both by the karst development in the Kaibab Limestone and the solution collapses formed where gypsum is dissolved from the underlying Toroweap Formation, or from the Harrisburg Gypsiferous Member of the Kaibab Limestone. It is generally assumed that those collapse features resembling ordinary sink holes, that is, with vertical walls, no tilted beds, and a bottom covered by uncemented rubble, are recent karst landforms. In contrast, collapse features with inward-tilted beds and alteration appear to be favorable indicators of concealed breccia pipes. Unfortunately, drilling results indicate that not all collapses possessing these favorable characteristics have breccia pipes beneath them, suggesting that geochemical and geophysical exploration techniques should be used before drilling.

Although the dissolution of gypsum in the Toroweap Formation and of both limestone and gypsum in the Kaibab Limestone is a complicating factor, the process apparently enhances the surface expression of those features that are, indeed, breccia pipes. Most of the lower plateau surfaces, most notably the Esplanade surface (located at the top of the Esplanade Sandstone, fig. 2), do not have the density of features exposed that the Kaibab-, Moenkopi-, and Chinle-capped plateaus have. Initially this might appear to suggest that most of the features on these latter plateaus are merely sinkholes of the Kaibab and Toroweap. To the contrary, apparently the presence of a breccia pipe increases the movement of fluids not only within the pipe itself, but also laterally in various formations adjacent to the pipe. The effects of enhanced circulation can be seen in the core from the Mohawk Canyon Pipe (Wenrich and others, 1985); here the gypsiferous Woods Ranch Member of the Toroweap Formation has been almost entirely removed from the brecciated column. Dissolution of the upper soluble units in the vicinity of pipes may well account for the discrepancy in size between the pipes and the much larger collapse features that are commonly mapped above them. The known ore bodies are all from 100 to 400 ft (most commonly around 250 ft) in diameter, whereas many of the collapse features on plateau surfaces are as much as 1300 ft across (most notable is the Pigeon Pipe, fig. 1). The largest known collapse, Shadow Mountain collapse on the Marble Plateau, is over one mile in diameter and is within a mile of Shadow Mountain, a Tertiary basaltic cinder cone. The actual Shadow Mountain breccia pipe may be no more than the average 250 ft in diameter, but the Tertiary solutions associated with the volcanism must have caused extensive recent dissolution of some of the formations underlying the pipe (such as large scale dissolution of the Redwall or Muav Limestones, as there is no soluble rock within the Toroweap and Kaibab on the Marble Plateau). Thus, locating the actual breccia pipe, and perhaps an orebody, will be more difficult at Shadow Mountain than in a small collapse, such as the Mohawk Canyon pipe. Exploration for mineralized breccia pipes may be more successful on the upper plateaus where the collapse is enlarged because of

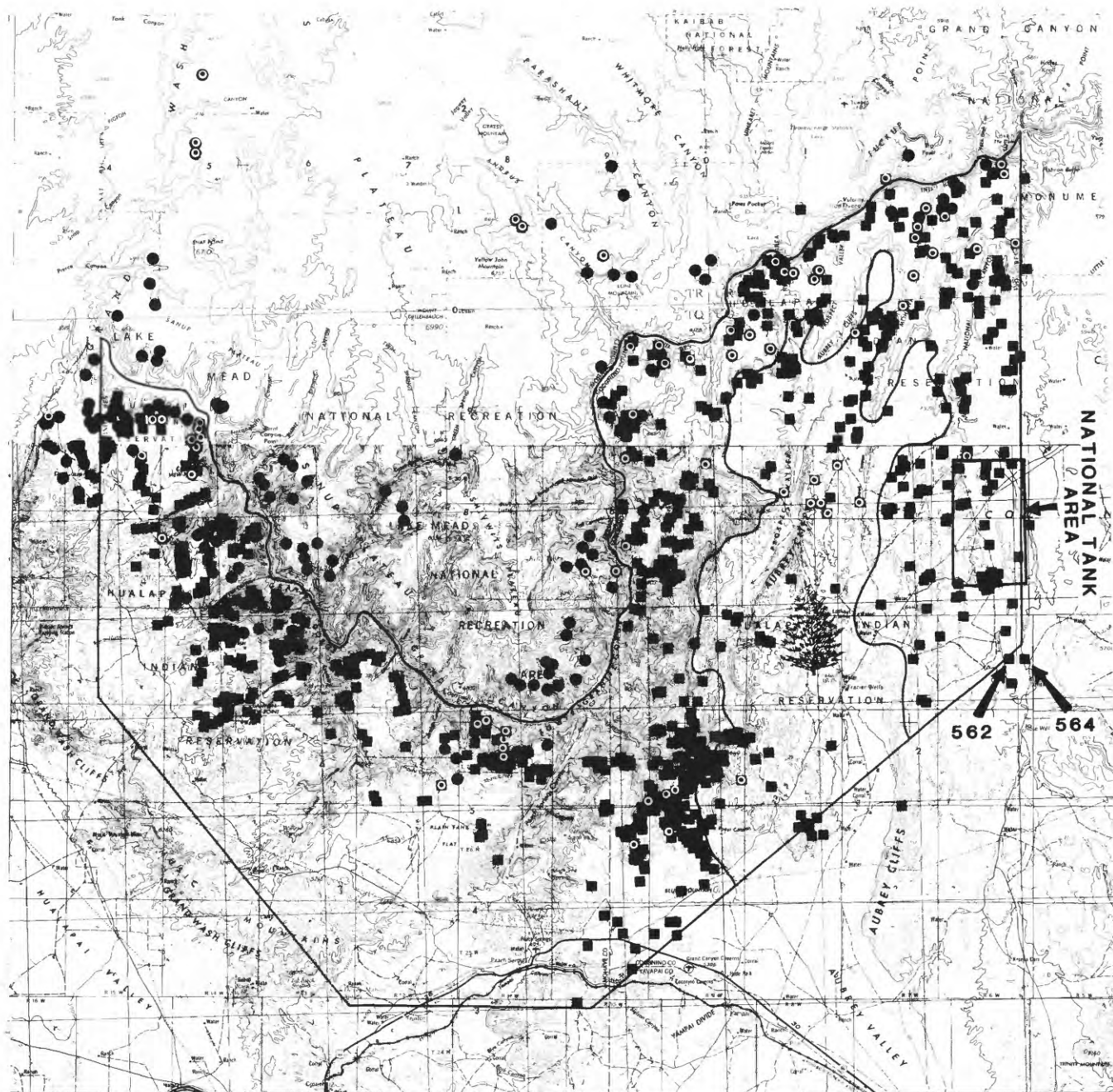


Figure 3.--The National Tank area is located on the eastern edge of the Hualapai Indian Reservation (outlined by rectangle). Over 900 confirmed and suspected breccia pipes have been mapped on the Hualapai Reservation during the past 3 years. The western side has sparse vegetation which is reflected in the greater density of identified 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.

dissolution within the upper Paleozoic units, than on lower plateaus, because the lower plateaus are capped mostly by insoluble rock such as the Esplanade Sandstone.

This increase in solution collapse beneath the upper plateaus, which are capped by soluble late Permian and younger rocks, emphasizes the importance of mapping all solution features in these areas. Thus, throughout the paper the terms solution collapse, structure or feature are defined as those areas that apparently have undergone collapse due to dissolution of any underlying rock, whereas the term breccia pipe refers specifically to dissolution of the Redwall Limestone which resulted in stoping and brecciation of the overlying rock.

Many exploration criteria for detecting mineralized breccia pipes were developed during mapping. Mapping on the Hualapai Reservation began on 1:24,000 color aerial photographs, and was then field checked. Many pipes exposed along cliff faces are not recognizable on vertical aerial photographs and are best spotted from a helicopter.

The following exploration criteria are considered favorable indicators of mineralized breccia pipes:

1. Concentrically inward-dipping beds.
2. A circular topographic pattern. These are commonly expressed as a topographically high rim around a central depression.
3. Anomalous radioactivity; 2.5 times background, or higher, is considered anomalous in this report.
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. Breccia, other than intraformational breccias.
8. Anomalous concentrations in surface samples of such trace elements as Ag, As, Cd, Co, Cu, Mo, Ni, Pb, Se, V, and Zn.
9. A circular vegetation or color pattern.

To verify that a collapse feature mapped from the air is a breccia pipe, it is essential to check these criteria in the field. Few pipes exhibit all of the above criteria on surface exposure, but the more that are present, the greater the certainty that the feature is a breccia pipe as opposed to a collapse structure.

Although breccia pipes are easily recognized within canyons where they are exposed in cross section, large expanses of northern Arizona are comprised of undissected high plateaus. Recognition of pipes in these areas is particularly important because ease of access would promote mining that would be difficult or uneconomic in the canyons. In addition, pipes exposed in canyon walls have commonly lost much of their rock, including mineralized rock, to erosion and perhaps their metals to leaching. Shallow structural basins on the adjacent plateaus are probably surface expressions of the upper part of breccia pipes. This assumption is supported by the occasional exposure of a breccia pipe in a canyon wall directly beneath a shallow structural basin on the plateau surface (Wenrich, 1985, Fig. 5). Because the ring fracture, which delineates the actual pipe, is well exposed in less than

half of the mapped collapse features, and in order to be consistent throughout the mapped area, the boundaries of the breccia pipes were mapped as the outermost extent of inward-dipping beds. It should be emphasized that this area mapped as a solution collapse can be as much as 5 times the size of the actual breccia pipe, due to dissolution of the Toroweap and Kaibab adjacent to the pipe.

THE NATIONAL TANK AREA

The National Tank area (fig. 3) is located on the National Tank 7 1/2' quadrangle, on the Coconino Plateau along the eastern edge of the Hualapai Reservation (fig. 3). The area is capped almost entirely by the Harrisburg Gypsiferous Member of the Kaibab Limestone, with the Fossil Mountain Member exposed only in a small canyon in the northwest corner (fig. 4). The area is essentially undissected. Relative to much of the Hualapai Reservation, this area has significant vegetation cover, primarily rangeland grasses with pinyon pine and juniper.

Mapping of Collapse Features in the National Tank Area.--Most of the National Tank area is soil covered with little rock outcrop. This makes it difficult to use any of the first 8 exploration criteria outlined above. Circular topographic patterns and vegetation changes are the only observable features that permit mapping of collapse structures in the area. Because of the extremely limited rock outcrop, it is impossible to determine from the surface whether these are breccia pipes that extend downward into the Redwall Limestone, or merely collapse features that may bottom in the Kaibab Limestone or Toroweap Formation. Nevertheless, this area is of potential economic importance because (1) all features are readily accessible by 4-wheel drive vehicle, with the paved Supai highway passing through the middle of the area, and (2) the entire 2500 ft (800 m) of stratigraphic sequence are present, permitting maximum preservation of any orebody that might be present.

The collapse features were originally mapped from 1:24,000 color aerial photographs. In the National Tank area 25 features (fig. 4) have been mapped, field checked, verified as collapse features, and are considered likely to be breccia pipes. Many of these features appear circular from low-altitude aerial photographs, and also directly overhead in a helicopter, but once on the ground the circular nature of the feature is difficult to recognize. In most cases this circular nature is merely a circular color patch, although a few do appear to have inward-tilting beds. Unfortunately, recognition of such features is almost entirely dependent on the vegetation, which is uniformly brown except during summer, when the centers of the collapse structures tend to be greener than surrounding areas. This is due in some cases to the negative topographic expression of some features, so that water drains into them, and in other cases it is probably due to the highly fractured rock, which could permit enhanced water movement into the overlying soil. In any event, mapping in these areas of high plateaus, with little or no rock outcrop, should be restricted to the summer months during the monsoon season when the collapse structures are green.

The 25 collapse features listed in table 1 merit further study. Each feature is numbered on table 1 and is identified by that number on figure 4. The collapses are grouped into three categories C2, C4 and C?, based on their surface expression: Those features which show (1) concentric, inward-dipping

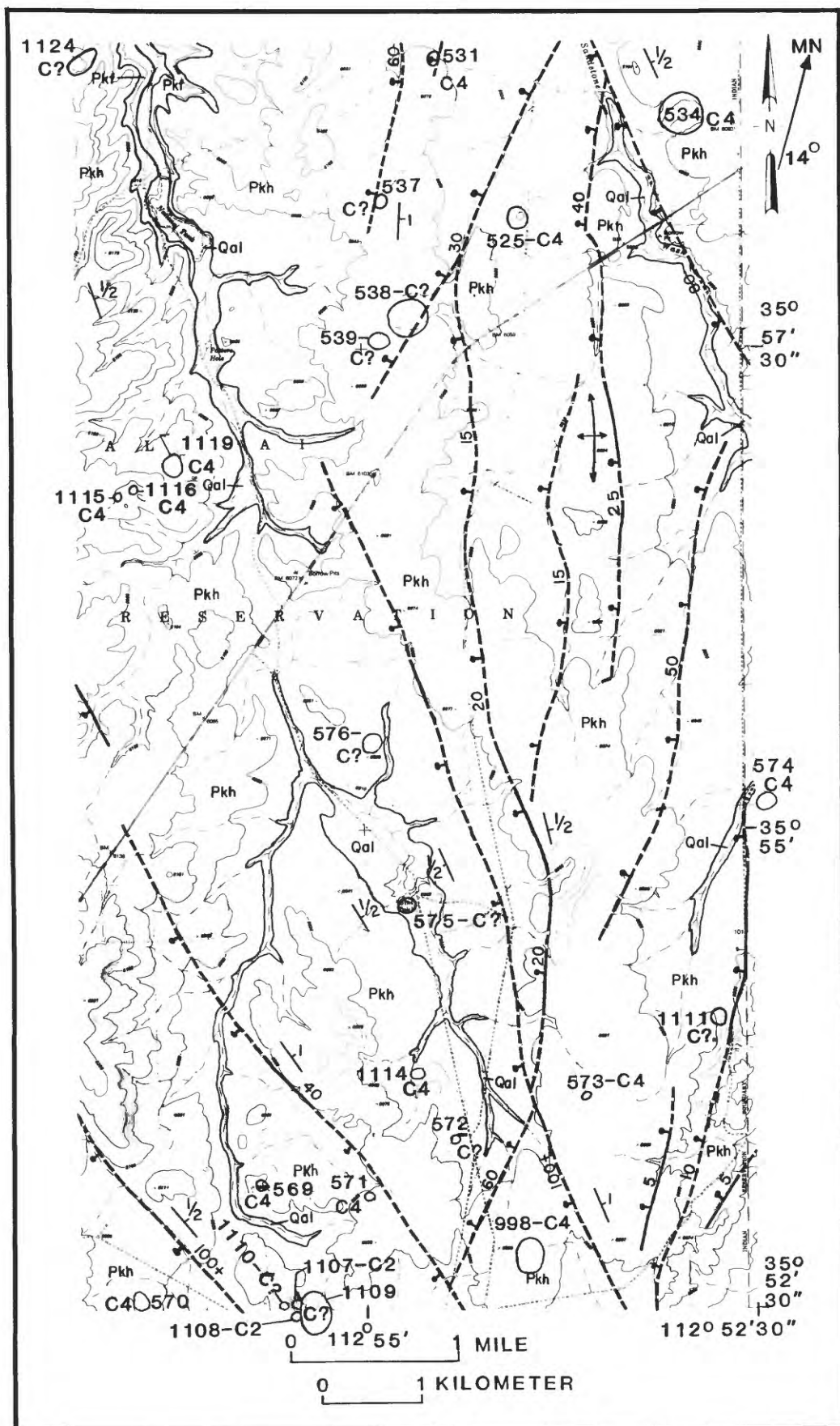


Figure 4a.--Geologic Map of the National Tank Area showing collapse features.

DESCRIPTION OF MAP UNITS

- | | |
|---|--|
| <div style="border: 1px solid black; padding: 2px; display: inline-block;">Qal</div> | ALLUVIUM (HOLOCENE)--
Silt, sand, and gravel. Not all alluvium is shown |
| <div style="border: 1px solid black; padding: 2px; display: inline-block;">Pkh</div> | KAIBAB LIMESTONE (LOWER PERMIAN)--
Harrisburg Gypsiferous Member - Slope- and ledge-forming gray and pale-red shales and gypsiferous siltstone interbedded with gray, ledge-forming limestone and dolomitic sandstone. Includes in lower part intraformational breccia beds of ripup chert clasts recemented with chert. |
| <div style="border: 1px solid black; padding: 2px; display: inline-block;">Pkf</div> | KAIBAB LIMESTONE (LOWER PERMIAN)--
Fossil Mountain Member - A yellowish-gray fossiliferous cherty limestone and sandy limestone, forms cliff |

SYMBOLS


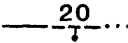



-  **CONTACT BETWEEN MAP UNITS**
-  **FAULT--**
Dashed where position uncertain; dotted where concealed; bar and ball on downthrown side; 20 indicates approximate stratigraphic offset in feet
-  **STRIKE AND DIP OF BEDS**
-  **AXIAL TRACE OF ANTICLINE**
-  **COLLAPSE FEATURES--**
538-C? Collapse feature number used in text to identify each collapse.
- COLLAPSE FEATURE CLASSIFICATION**
- C2** Concentric, inward-dipping beds; no visible alteration.
- C4** Distinctly circular feature, either due to vegetation or topography; no visible alteration or dipping beds.
- C?** Questionable. A circular feature appears to be present, but with no obvious dipping beds, alteration, vegetation change or topography delineation.
-

Figure 4b.--Index to the geologic map of the National Tank area.

Table 1.--List of Mapped Collapse Features in the National Tank Area

Pipe	Quadrangle	Location	Lat/Long	Category	Host Formation	Comments
525.....	National Tank	Section 23, T 30N, R 6W	35° 58' 11" 112° 53' 58"	C4	Harrisburg Gypsiferous Member of Kaibab Ls	Circular depression; no outcrop; reddish-soil & vegetation in a complete circle.
531.....	National Tank	Section 15, T 30N, R 6W	35° 59' 00" 112° 54' 32"	C4	"	Circular depression of sage brush 80% surrounded by a rim with trees and reddish soil.
534.....	National Tank	Section 13, T 30N, R 6W	35° 58' 43" 112° 52' 54"	C4	"	Circular depression; no outcrop.
537.....	National Tank	Section 22, T 30N, R 6W	35° 58' 16" 112° 54' 53"	C?	"	Slight bowl-shaped depression; no outcrop. Subtle soil & vegetation change.
538.....	National Tank	Section 27, T 30N, R 6W	35° 57' 40" 112° 54' 42"	C?	"	Very questionable; reddish soil patch.
539.....	National Tank	Section 27, T 30N, R 6W	35° 57' 32" 112° 54' 51"	C?	"	Circular pattern of sage brush; slight bowl-shaped depression.
569.....	National Tank	Section 21, T 29N, R 6W	35° 53' 08" 112° 55' 40"	C4	"	Oblong closed reddish soil-covered depression, rimmed by hill of Kaibab float.
570.....	National Tank	Section 20, T 29N, R 6W	35° 52' 34" 112° 56' 29"	C4	"	Semi-circular shape; reddish soil in center; raised white soil-covered rim.
571.....	National Tank	Section 22, T 29N, R 6W	35° 53' 06" 112° 54' 28"	C4	"	Circular depression; darker soil & denser plant growth within depression, surrounded by a rim of lighter-colored soil.
572.....	National Tank	Section 22, T 29N, R 6W	35° 53' 24" 112° 54' 26"	C?	"	Circular, fairly green patch of grass surrounded by sage brush. depression, surrounded by a rim of lighter-colored soil.
573.....	National Tank	Section 14, T 29N, R 6W	35° 53' 38" 112° 53' 36"	C4	"	Circular depression with grass patch inside.
574.....	Supai Camp	Section 12, T 29N, R 6W	35° 52' 37" 112° 52' 25"	C4	"	Large reddish soil-covered center surrounded by circular (somewhat elliptical) hill with some trees.
575.....	National Tank	Section 10, T 29N, R 6W	35° 54' 07" 112° 54' 44"	C?	"	Sink Tank; possibly a C-2; outcrop with tilted beds.

Table 1.--List of Mapped Collapse Features in the National Tank Area--Continued

Pipe	Quadrangle	Location	Lat/Long	Category	Host Formation	Comments
576....	National Tank	Section 3, T 29N, R 6W	35° 55' 27" 112° 54' 57"	C?	Harrisburg Gypsiferous Member of Kaibab Ls	Questionable; reddish soil. 2/3rds surrounded by a ridge.
998....	National Tank	Section 23, T 29N, R 6W	35° 52' 47" 112° 53' 59"	C4	"	Slight bowl in center filled with soil surrounded by a very low hill on 3 sides. Some gravels present covered with basalt float.
1107...	National Tank	Section 21, T 29N, R 6W	35° 52' 33" 112° 55' 27"	C2	"	Central hill surrounded by a concentric drainage and outer rim of Harrisburg Gypsiferous Member dipping inward 12°-15°.
1108....	Dike Tank	Section 28, T 29N, R 6W	35° 52' 28" 112° 55' 28"	C2	"	Adjacent to 1107. A slight depression which is identical in size and shape to 1107. Inward dipping beds of Harrisburg Gypsiferous Member.
1109....	National Tank/ Dike Tank	Section 21, 28, T 29N, R 6W	35° 52' 30" 112° 55' 21"	C?	"	Large semi-circular ridge with some trees bounding a broad low grassy plain. Adjacent to 1108.
1110....	National Tank	Section 21, T 29N, R 6W	35° 52' 32" 112° 55' 32"	C?	"	Well developed circular drainage around a central small hill covered with Kaibab float.
1111....	National Tank	Section 13, T 29N, R 6W	35° 54' 01" 112° 52' 47"	C?	"	Arcuate row of trees surrounding a grassy plain on 3 sides.
1114....	National Tank	Section 15, T 29N, R 6W	35° 53' 44" 112° 54' 38"	C4	"	A green grassy slight depression which contrasts sharply with the surrounding browner grassland.
1115....	National Tank	Section 32, T 30N, R 6W	35° 56' 45" 112° 56' 34"	C4	"	Relatively well developed closed depression. Small goethite concretions present.
1116....	National Tank	Section 32, T 30N, R 6W	35° 56' 47" 112° 56' 28"	C4	"	Small depression of grass amid sagebrush surrounded by scattered junipers.
1119....	National Tank	Section 28, T 30N, R 6W	35° 56' 55" 112° 56' 46"	C4	"	Reddish soil covered depression with grass and sagebrush surrounded by scattered junipers.
1124....	National Tank	Section 17, T 30N, R 6W	35° 59' 00" 112° 56' 46"	C?	"	Irregular shaped depression with grass and sagebrush surrounded by scattered junipers.

beds are classified as "collapse 2" (C2); (2) a centripetal and concentric drainage or a concentric vegetation pattern, but no outcrop, are classified as "collapse 4" (C4); those which appear to be, at best, only a somewhat circular color change, or are otherwise questionable are classified as "collapse ?" (C?). None of the 25 collapse features showed any evidence of anomalous surface gamma radioactivity, or supergene copper mineralization.

One feature, similar in surface expression to collapses #569 and #570, was drilled intermittently between 1984 and 1986 by Rocky Mountain Energy. This collapse is located approximately one mile southeast of the reservation boundary, just south of the sharp bend along the eastern boundary (shown on fig. 3 by the number 562). Another very similar collapse, 564 (fig. 3), was drilled in 1986 by Energy Fuels Nuclear. All 4 collapses have a white circular rim around a central depression with reddish soil. This slightly raised rim may be due to silicification resulting from fluids moving along the ring fracture of the breccia pipe, and hence, may be a favorable exploration criterion for locating breccia pipes.

Description of Specific Collapse Features in the National Tank Area.

525-C4: This feature is readily discernible as a circular structure, but appears to be merely a sink hole (fig. 5). The mapped area is a circular depression that is intermittently filled with water, and rimmed by vegetation darker than the surrounding terrain. Nevertheless, because of the dissolution of the Harrisburg Gypsiferous Member of the Kaibab Limestone and the Woods Ranch Member of the Toroweap Formation above known breccia pipes, it is impossible to unequivocally distinguish between a sink hole and a breccia pipe from surface evidence. This feature does not have the vertical walls of a classical sink hole, but then there is no outcrop and the unconsolidated soil cover could have accumulated in the hole. Soil samples were collected from this feature in May, 1986, but the data have not yet been compiled and plotted.

531-C4: This area was mapped as a solution collapse because of its raised arcuate rim around a nearly-closed basin (fig. 6). The basin contains sagebrush, and the rim supports has a denser growth of junipers than does the surrounding landscape. The rim of Kaibab Limestone resembles the rim around collapse features 562, 564, 569, and 570, of which, 562, in light of the continued drilling of that property, is probably a breccia pipe. Nevertheless, the depression and rim in feature 531 are not as pronounced or complete as they are in the above mentioned 4 collapse features. This area has no outcrop. Soil samples were also collected from this feature in May, 1986 and the data results are in a similar state to those from feature 525. AMT soundings do not show any significant conductive zone beneath the center of the collapse, although 2 minor zones occur beneath the rim.

534-C4: This locality is a more obvious circular feature than the previously discussed two areas, although the relief of the rim does not look pronounced in either the helicopter photograph (fig. 7a) or the aerial photographic view (fig. 7b). The area is a relatively large almost-closed depression, although there is no enhanced vegetation growth, and no outcrop.



Figure 5.--Collapse feature 525 (indicated by arrow) has been classified as a C4 because of its concentric drainage and vegetation growth. The photograph was taken from a helicopter. View to the northwest.



Figure 6.--Collapse feature 531, (indicated by arrow) photographed from a helicopter, is expressed as a depression bordered on 3 sides by a low rim of Kaibab Limestone crowned with junipers. View to the west.

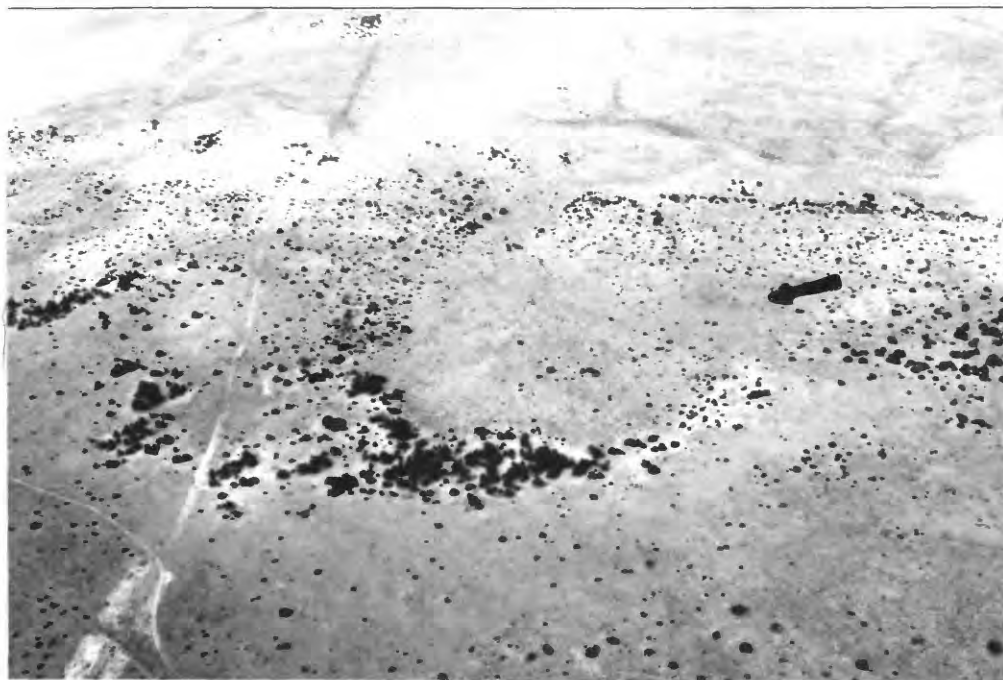


Figure 7a.--Collapse feature 534 (indicated by arrow) photographed from the helicopter is an obvious circular feature, although there are no concentric vegetation or soil patterns. View to the southwest.

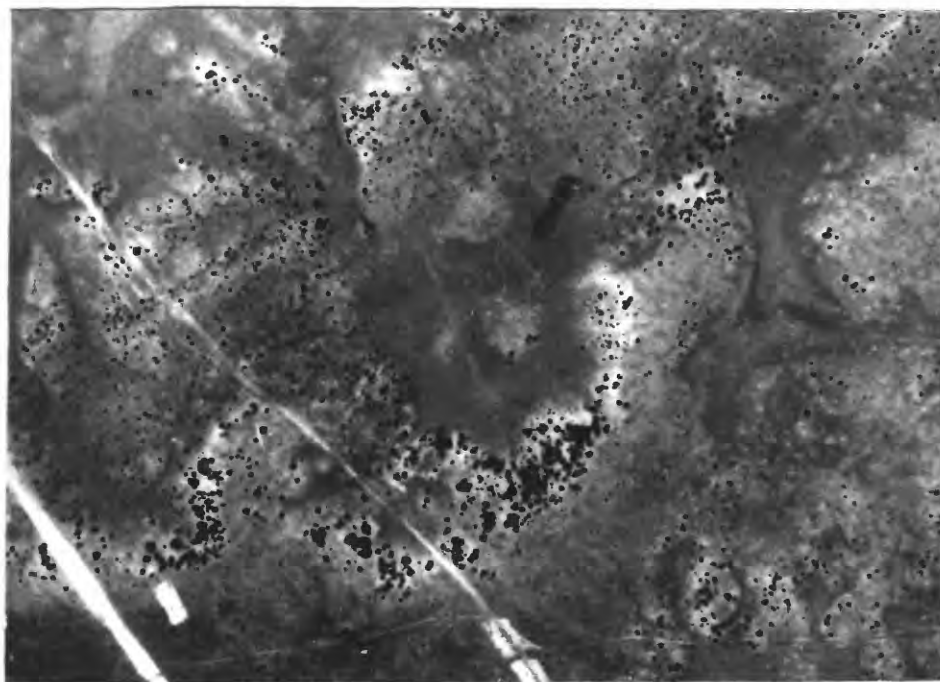


Figure 7b.--Collapse feature 534 (indicated by arrow) can be seen from the low-altitude aerial photograph to be in the C4 category. Up on the photo is to the west.

Because many such collapse features on the high plateaus are covered by soil and low ground vegetation, with little outcrop, soil geochemistry appears to be an inexpensive means of acquiring some additional information on the possible presence of subsurface mineralization. Good analytical accuracy, precision, and low detection limits are necessary because soil anomalies over the breccia pipes are very low level. A soil survey was made of this collapse feature in 1984 and 1986. preliminary results from the 1984 study show some significant element anomalies in the soil over the structure. Of the 33 elements determined for 23 samples Co, Cu, Fe, Mn, Ni, Pb, and Zn appear to increase in the soil over the collapse compared to the surrounding terrain and Mg appears to decrease. With the exception of Mn, all of the elements enriched in the soil over the collapse are ones which are commonly enriched in, or form, the breccia pipe orebodies.

Helium surveys over breccia pipes have shown minor success. Positive helium anomalies were observed over one known mineralized pipe but not over another. Collapse feature 534 is one of the few collapse features surveyed that showed a helium anomaly, although it was only twice background.

Slingram and very low frequency (VLF) data, a time-domain electromagnetic (TDEM) profile, and an electric section are presented in Senterfit and others (1985). The TDEM data show a distinct change in resistivity at a depth of about 960 ft (290 m); this is approximately the same depth as the top of the Seligman (sandstone) Member of the Toroweap Formation in the center of the Mohawk Canyon breccia pipe. At the margin of the Mohawk Canyon pipe, the Seligman Member was encountered over 100 ft (at a depth of approximately 825 ft) higher than in the center of the pipe. So, because the rocks within the Mohawk Canyon Pipe have been downdropped over 100 ft, the top of the Seligman Member within the center of the pipe is at about 925 ft. Thus, assuming that the thicknesses of the units are approximately the same in the National Tank area as at the Mohawk Canyon pipe over 15 miles away, the top of the Seligman Member in the middle of this structure is perhaps 130 ft lower than in the adjacent section. Hence, structure 534 is likely a breccia pipe.

The results from soil geochemistry, helium soil gas, and TDEM geophysical surveys for collapse feature 534 all appear encouraging. Further studies may prove this to be a mineralized breccia pipe.

537-C?: This feature (fig. 8) is similar to 525 in that it is a circular depression. The depression apparently accumulates water more than the surrounding terrain, as the vegetation within it is greener and forms a green circle. There also appears to be a slightly redder color to the soil than the soil in the surrounding terrain. This collapse feature has about the same low probability as 525 of being a breccia pipe.

538-C?: On the aerial photograph this area appears as an anomalous round reddish soil patch. Yet, from the helicopter (fig. 9) it is difficult to recognize anything that resembles a distinctly circular feature; on the ground there is little to distinguish it from the surrounding terrain. The area in question is located in the center of figure 9 and, as reproduced here, is approximately 2" by 1.5"; the oblique angle from which the photograph was taken distorts the circularity of the patch. This is probably the most questionable of the 25 collapse features listed in table 1.



Figure 8.--Photograph of collapse structure 537 taken from a helicopter. The feature is in the right center of the picture (indicated by arrow) and stands out because of the darker green circular vegetation patch.



Figure 9.--Photograph of collapse structure 538 taken from a helicopter. The feature is located in the center of the picture (indicated by arrow) as a 2" by 1.5" circular darker patch that appears from this oblique view as two smaller dark patches. Dark patches on the right side of the photo are cloud shadows.



Figure 10.--Photograph of collapse structure 539 (indicated by arrow) taken from a helicopter. The feature, a slightly greener circular patch of sage, is located slightly to the right of center.

539-C?: This feature is almost as questionable as 538. It is a circular patch of sagebrush (fig. 10), which appears somewhat greener than the surrounding terrain during the summer months, as if water were accumulating in a slight depression.

569-C4: Based on surface morphology this collapse structure is one of the more favorable features in the National Tank area, in that it has a closed depression surrounded by a low rim of Harrisburg Gypsiferous Member of the Kaibab Limestone. This feature also resembles, except for its more elliptically shaped depression, collapse structure 562 that was drilled by Rocky Mountain Energy. As is commonly the case, the collapse structure does not appear as obvious in a photograph from a helicopter (fig. 11a), as it does in a low-altitude aerial photograph (fig. 11b). Unfortunately, there is little outcrop, and the few exposed beds appear to be flat lying, in contrast to the more favorable characteristic of inward-tilted beds.

A preliminary soil survey, completed over this structure in July 1984, was not very informative because only 7 samples were collected. The sparse data suggest that Mn, Ni and Sr may be enriched in the soil over the collapse, as compared to the surrounding terrain, and Ca, Mg, and Pb may be depleted.

A helium-soil gas survey was completed over this structure in March, 1985 (Reimer, 1985). The mean helium concentration measured inside the depression was identical to that observed in the background area, 1500 ft to the southwest. A similar survey (also in March, 1985) run over a structure known to be a mineralized breccia pipe showed that helium concentrations were approximately 50 ppb higher in the pipe than around it (Reimer, 1985); in addition, in the central part of the mineralized pipe the helium values were over 200 ppb higher than background. In June, 1985, a second helium survey was made over collapse feature 569 (G. M. Reimer, 1986, pers. commun.); a couple of samples, on the east side of the peanut-shaped depression, were anomalous, but an inadequate number of background samples were collected to accurately define "anomalous".

Audio-magnetotelluric (AMT) soundings over this collapse detected a conductive zone lying southeast of the center of the depression (Flanigan and others, 1986). Although Flanigan and others (1986) believe this conductive zone to be small, and questionably indicates the feature may be a breccia pipe, it is interesting to note that this zone is the same area where Reimer detected the highest helium-soil-gas measurements. In addition, ground magnetometer surveys show a strong positive and negative (dipole) anomaly in the north-south traverse (fig. 12a) and a positive one in the east-west traverse (fig. 12b). The profiles are identical to those modeled for a vertical dipole (a shape similar to a breccia pipe).

570-C4: This collapse structure is essentially identical in morphology to the drilled feature 562, except that it is not a closed depression. It rather is breached on one side. The depression is bordered on 3 sides by a rim of Kaibab Limestone. Both near-surface (fig. 13a) and low-altitude (fig. 13b) aerial views show a distinctly circular feature with a raised rim of, possibly whiter, Kaibab Limestone.

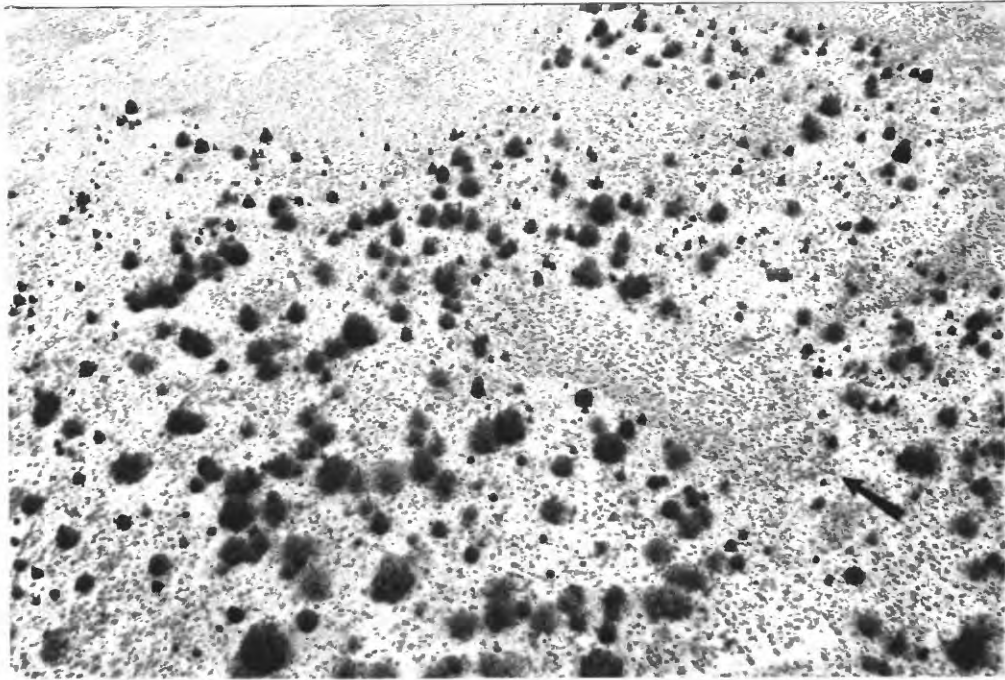


Figure 11a.--This photograph shot from a helicopter shows collapse feature 569 (indicated by arrow) as a closed depression, surrounded by a low rim mantled by junipers and pinyon pines. The views in both this photo and figure 11b are to the north.

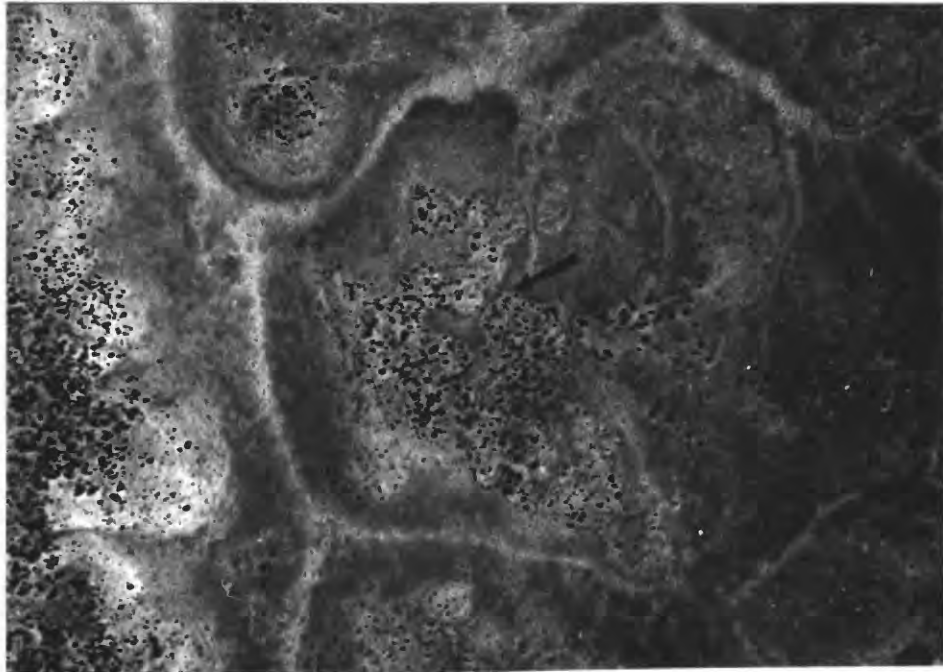


Figure 11b.--This photograph taken from a 1:24,000 aerial photograph (but reproduced at a different scale) shows collapse feature 569 (indicated by arrow) as a distinct circular white rim of rocks, mantled by scattered trees, surrounding a peanut-shaped closed depression. The collapse feature depression shown in the center of the photo is approximately 150 ft by 300 ft.

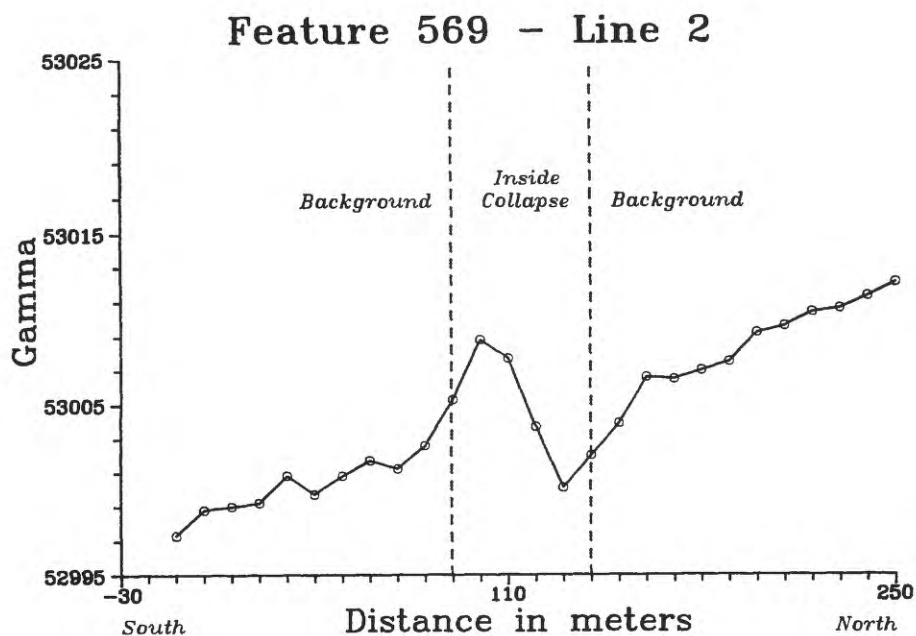


Figure 12a.--North-south ground magnetometer traverse over collapse feature 569. Note the strong positive and negative (dipole) anomaly.

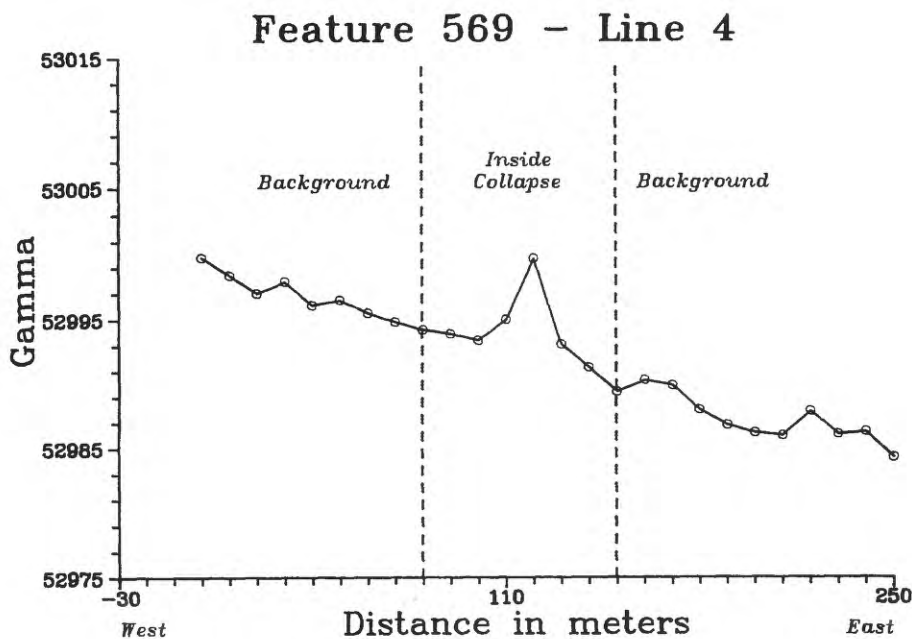


Figure 12b.--East-west ground magnetometer traverse over collapse feature 569. Note the positive anomaly over the center of the pipe.

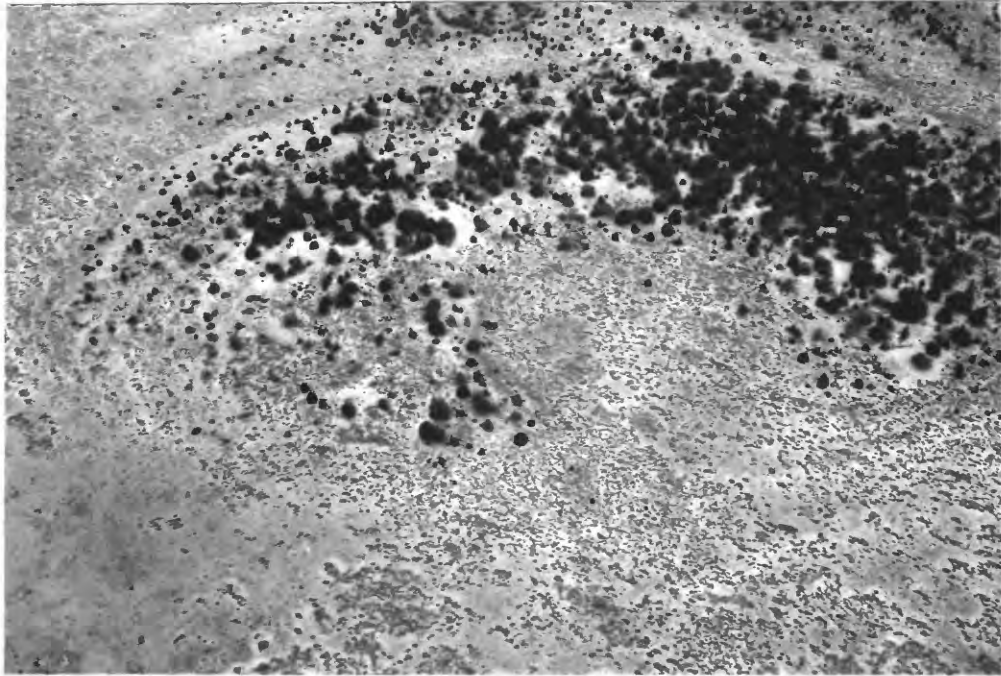


Figure 13a.--This photograph, taken several hundred feet above the ground surface from a helicopter, of collapse 570 shows a low rim of white rock (Harrisburg Gypsiferous Member of the Kaibab Limestone) bordering a depression on three sides. The depression is about 600 ft in diameter. View is to the west.

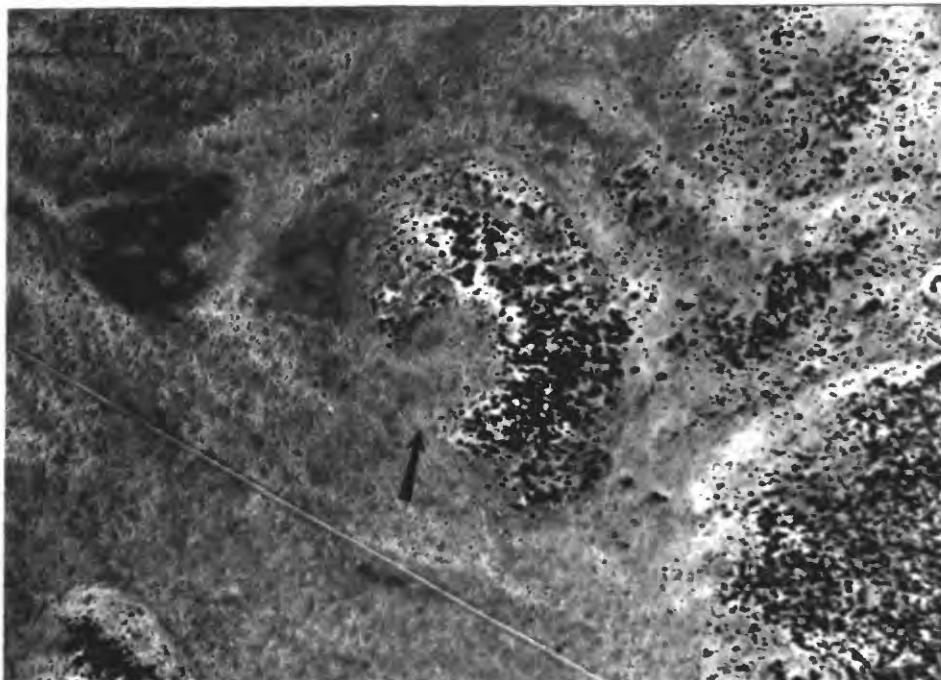


Figure 13b.--This low-altitude view of collapse feature 570 (indicated by arrow) looks very similar to the helicopter view, except that with the smaller scale it is apparent that this feature has a slightly greater concentration of trees on its slightly whiter rim of rock than the adjacent terrain. View is to the southwest.

Soil sampling traverses across collapse 570 show significant positive enrichments that are 1.5 to 10 times background for Cu, Pb and Zn concentrations in soil over the center of the collapse. Concentrations of Ag and Tl are also anomalous, but to a lesser degree.

AMT soundings over collapse 570 reveal a pipe-shaped strongly conductive zone with a diameter of about 300 ft, extending to a depth of at least 1900 ft (Flanigan and others, 1986). The most conductive part of the breccia pipe throat appears to plunge to the southwest. The shape of the highly conductive zone of this collapse is similar to that of the EZ-2 ore containing breccia pipe (also shown in Flanigan and others, 1986). This apparent tilt to the presumed breccia pipe should be incorporated into the design of any future drilling project; that is, if a breccia pipe orebody is present it is probably located under the southwest part of the depression. Ground magnetometer surveys over this collapse feature show a low broad positive and negative anomaly (dipole) suggesting there may be a "deep vertical body".

A helium soil-gas survey over collapse 570 shows no significant anomalies within the feature (Reimer, G. M., 1986, pers. commun.). Helium surveys don't appear to provide definitive results even over known orebodies, so the helium results for collapse 570 do not particularly deter from the favorable AMT and soil survey results. This collapse, of the 25 described here, has perhaps the greatest potential for being a breccia pipe. In addition to the favorable geochemical and geophysical surveys the morphology is similar to that of breccia pipes 562 and 564 that have been drilled by Rocky Mountain Energy and Energy Fuels, respectively.

571-C4: Collapse feature 571 is approximately half the size of 570, but is also a circular depression surrounded by a white rim (figs. 14a and 14b). The soil inside this 10-13 foot deep depression is somewhat darker, and the vegetation growth denser, than the surrounding terrain.

A soil survey conducted over this collapse structure showed significant anomalies that suggest that this feature is at least a sink hole, if not a mineralized breccia pipe. Samples shown in Figures 15a - 15h were all collected approximately 4 in. (10 cm) below the surface. The samples were dry sieved through 80 mesh (177 μ m) stainless steel sieves to remove the large rock chips and coarse organic debris. Four traverses were made across the pipe, and four background samples were collected, each approximately 100 ft beyond the margin of the pipe. The background samples are consistently lower in metal content than the samples taken within the pipe; those taken in the ring fracture (100-150 ft from center), with the exception of Cu and Mg, are as low as the background samples. Supergene copper minerals are commonly found in the ring fracture of mineralized pipes, so it would not be surprising to find a Cu anomaly in the soil overlying the ring fracture in a mineralized pipe. The raw data are shown in Table 2. Of the 29 elements determined all but 3 appear to have some positive enrichment over the center of the collapse as compared to background samples from outside the collapse. Of these 14 of them, Al, Co, Ce, Cr, Cu, Fe, Mg, Mn, Pb, Sc, Tl, V, Y, and Zn are strongly enriched in soil within the depression as compared to that on the rim or outside of the feature. Although several of the above elements, Co, Cu, Fe, Pb, V, and Zn (figs. 15a-15h) are ones that are enriched in breccia pipe orebodies such that their enrichment in the soil suggests similar underlying mineralized rock. Nevertheless, the enhancement of so many elements within

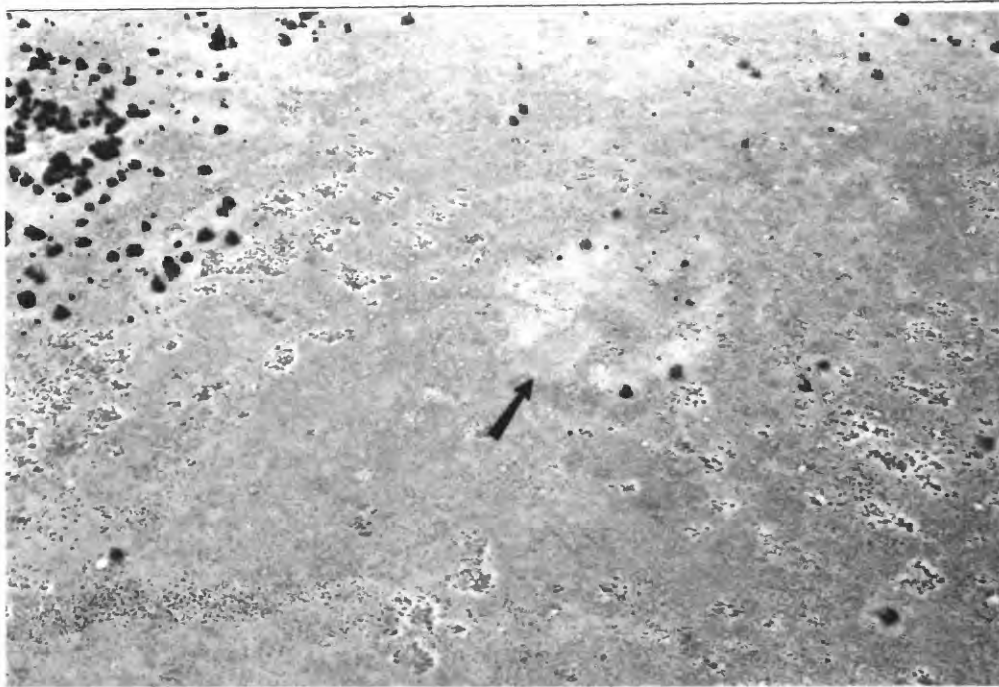


Figure 14a.--Collapse structure 571 (indicated by arrow) is expressed in this photograph taken from a helicopter as a 10-13 ft deep depression surrounded by a white rim. View is to the northeast.

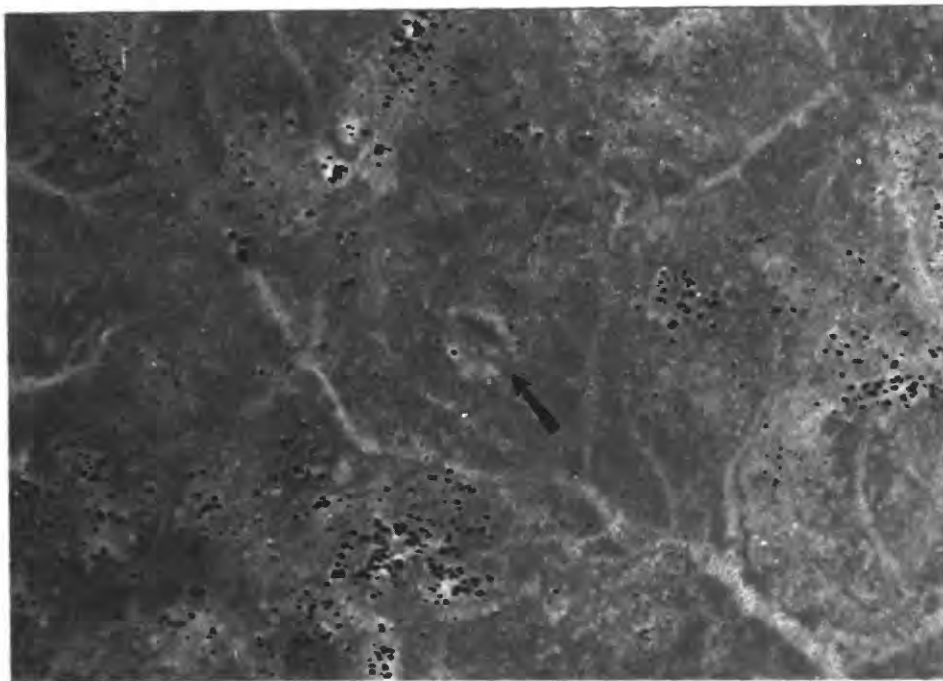


Figure 14b.--From the low-altitude aerial photograph the 300 ft in diameter collapse structure 571 (indicated by arrow) resembles a small sink hole, with darker vegetation than the surrounding terrain. View is to the northwest.

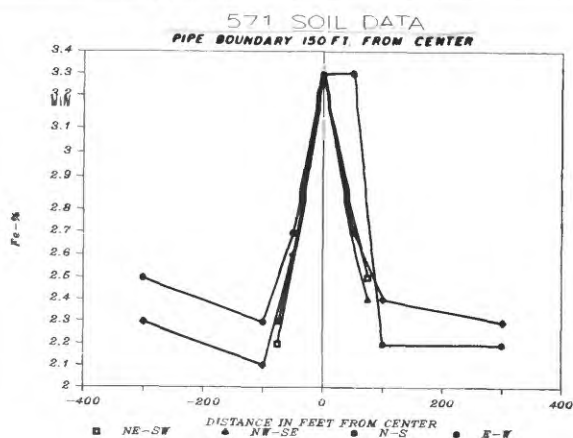
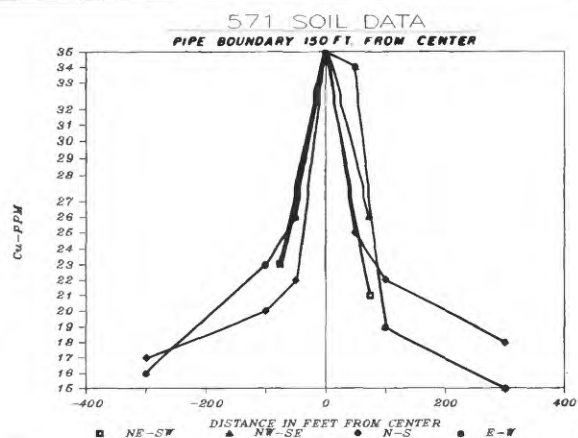
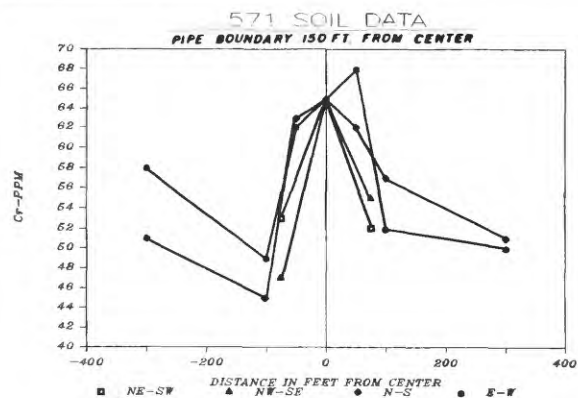
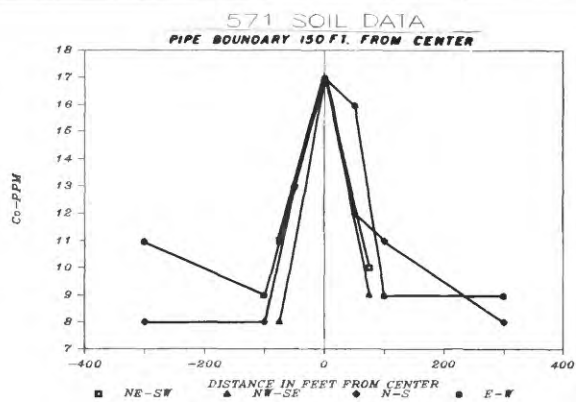


Figure 15.--Soil sampling survey results from collapse feature 571. Distance across the pipe is plotted on the abscissa; "0" represents the center of the pipe. The edge of the pipe is located 150 ft from "0"; the pipe is 300 ft in diameter. Concentrations of the metals Co (a), Cr (b), Cu (c), Fe (d), Mg (e), Mn (f), Pb (g), and Zn (h) are shown on the ordinate. A comparison is shown for Cr (i) between samples taken at 4" depth and at 8" depth. Samples from the same location are shown with the same shape symbol, but different size.

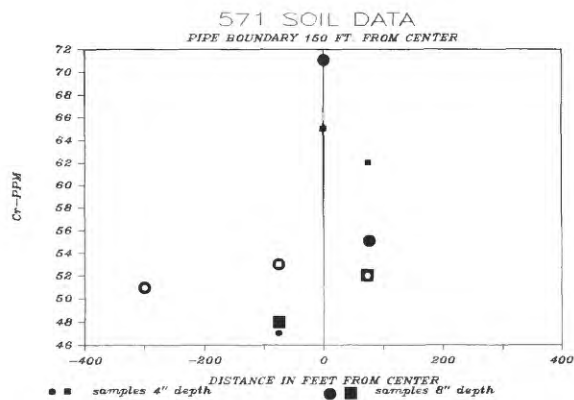
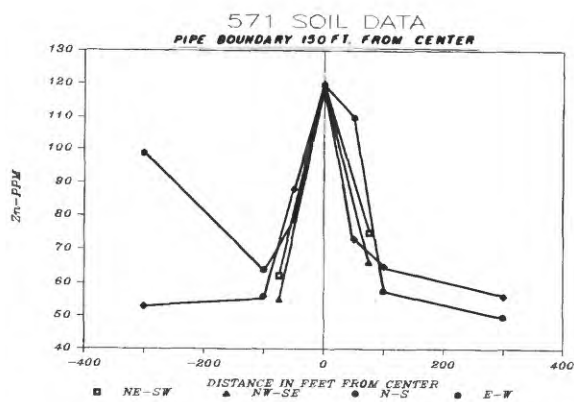
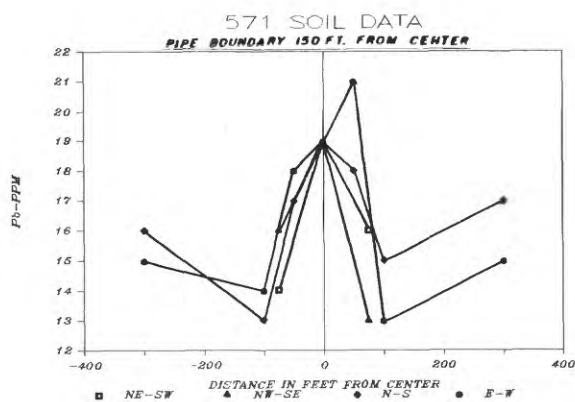
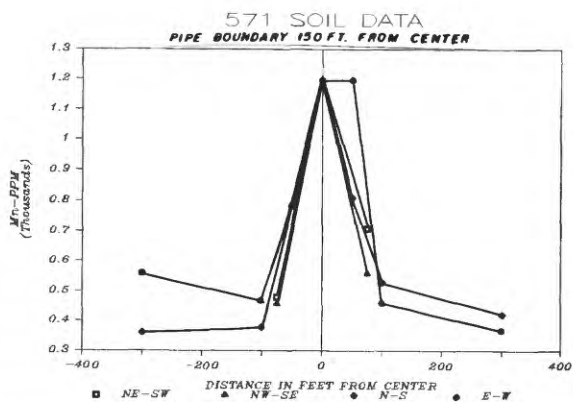
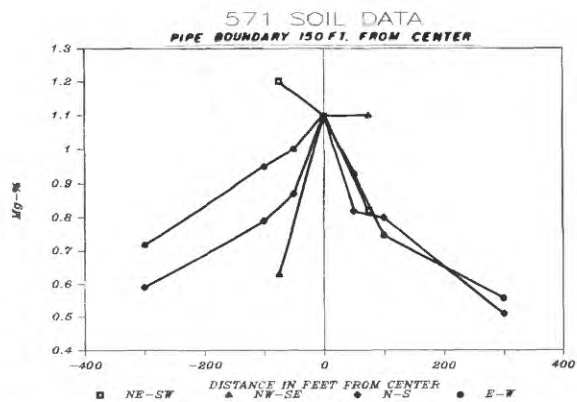


Figure 15.--continued.

Table 2.--Chemical Analyses of Soil Samples Collected from Collapse Feature 571.

[Lat. 35° 53' 06", long. 112° 54' 06". Samples with an "R" rather a "C" in the 5th digit are analytical replicate samples of the preceding sample with the same first 4 digits]

SAMPLE NUMBER	Traverse	Sample Depth (in.)	Distance from center (ft)	Al % ICP	As PPM ICP	Ba PPM ICP	Be PPM ICP	Ca % ICP	Ce PPM ICP	Co PPM ICP	Cr PPM ICP
1 571ASC84.....	All	4	0	6.6	<10	560	2	1.0	75	17	65
2 571BSC84.....	All	8	0	7.2	<10	580	2	1.1	77	14	71
3 571CSC84.....	NE-SW	4	75	4.9	<10	480	1	5.6	54	11	53
4 571DSC84.....	NE-SW	8	75	4.6	<10	450	1	8.5	50	10	48
5 571ESC84.....	NE-SW	4	75	5.5	<10	550	1	0.9	61	10	52
6 571FSC84.....	NE-SW	8	75	5.9	<10	570	2	0.9	63	12	62
7 571GSC84.....	NW-SE	4	75	4.9	<10	500	1	0.6	55	8	47
8 571HSC84.....	NW-SE	8	75	5.3	<10	520	1	0.6	56	11	53
9 571ISC84.....	NW-SE	4	75	5.3	<10	500	1	3.0	60	9	55
10 571JSC84.....	NW-SE	4	75	5.1	<10	480	1	4.7	61	10	52
11 571JSRC4.....		8		5.1	<10	480	1	4.7	61	9	52
12 571KSC84.....	N-S	4	50	5.7	<10	590	1	1.1	72	13	63
13 571LSC84.....	N-S	4	100	4.7	<10	490	1	4.4	53	8	45
14 571OSC84.....	N-S	4	50	5.7	<10	590	2	0.9	67	12	62
15 571PSC84.....	N-S	4	100	5.2	<10	520	1	0.8	61	11	57
16 571RSC84.....	E-W	4	50	6.6	<10	630	2	0.9	77	16	68
17 571SSC84.....	E-W	4	100	4.6	<10	500	1	1.1	58	9	52
18 571USC84.....	E-W	4	50	5.9	<10	580	2	1.1	6	13	62
19 571VSC84.....	E-W	4	100	5.1	<10	480	1	5.1	62	9	49
BACKGROUND SAMPLES											
20 571MSC84.....	N-S	4	300	4.9	<10	480	1	1.7	53	8	51
21 571MSRC4.....	N-S	4	300	5	<10	500	1	1.8	62	8	50
22 571NSC84.....	N-S	8	300	5.1	<10	470	1	2.2	55	8	51
23 571QSC84.....	N-S	4	300	4.8	20	500	1	0.6	59	8	51
24 571TSC84.....	E-W	4	300	4.8	<10	510	1	0.7	62	9	50
25 571WSC84.....	E-W	4	300	5.3	<10	550	2	0.8	71	11	58

- not determined
 INAA-Induced Neutron Activation Analysis
 ICP-Inductively Coupled Argon Emission Plasma Spectroscopy
 AA-Atomic Absorption
 DN-Delayed Neutron
 X-ray - X-ray Fluorescence

Table 2.--Continued.

SAMPLE NUMBER	Cu PPM ICP	Fe % ICP	Ga PPM ICP	Hg PPM ICP	K % ICP	La PPM ICP	Li PPM ICP	Mg % ICP	Mn PPM ICP	Na % ICP	Nb PPM ICP	Nd PPM ICP	Ni PPM ICP
1 571ASC84.....	35	3.3	16	-	1.9	39	34	1.1	1200	0.71	11	32	33
2 571BSC84.....	37	3.5	18	.03	2.2	40	37	1.1	1100	0.67	11	36	36
3 571CSC84.....	23	2.2	12	-	2.1	30	28	1.2	480	0.50	6	27	38
4 571DSC84.....	23	2.1	11	-	1.9	28	27	1.2	390	0.46	7	28	37
5 571ESC84.....	21	2.5	12	-	2.3	33	28	0.8	710	0.70	9	28	24
6 571FSC84.....	26	2.8	11	-	2.3	36	30	0.9	710	0.69	7	28	26
7 571GSC84.....	23	2.3	11	-	2.0	31	30	0.6	460	0.44	8	26	23
8 571HSC84.....	33	2.5	13	-	1.8	33	31	0.7	480	0.49	7	30	25
9 571ISC84.....	26	2.4	12	-	2.0	33	28	1.1	560	0.58	8	30	25
10 571JSC84.....	27	2.3	12	-	2.2	32	27	1.1	500	0.54	8	30	24
11 571KSC84.....	28	2.3	12	-	2.0	31	27	1.1	510	0.55	6	29	25
12 571LSC84.....	22	2.6	15	-	2.2	39	28	0.9	790	0.72	<4	30	39
13 571MSC84.....	20	2.1	12	-	1.7	28	24	0.8	380	0.59	7	28	22
14 571OSC84.....	25	2.7	12	-	2.4	37	28	0.8	810	0.73	8	29	25
15 571PSC84.....	22	2.4	13	-	2.2	34	27	0.8	530	0.55	<4	28	36
16 571RSC84.....	34	3.3	15	-	2.1	42	35	0.9	1200	0.75	10	36	32
17 571SSC84.....	19	2.2	11	-	1.7	31	25	0.8	460	0.51	7	28	23
18 571TSC84.....	26	2.7	15	-	2.3	36	30	1.0	790	0.71	11	32	42
19 571VSC84.....	23	2.3	12	-	1.8	32	26	1.0	470	0.60	8	28	25
BACKGROUND SAMPLES													
20 571MSC84.....	17	2.3	12	-	1.8	31	34	0.6	360	0.41	8	28	24
21 571MSRC4.....	19	2.4	13	-	1.7	35	34	0.6	370	0.45	7	33	25
22 571NSC84.....	17	2.4	13	.04	1.4	33	35	0.6	360	0.38	8	31	25
23 571QSC84.....	18	2.3	11	-	2.0	32	31	0.5	420	0.48	9	27	23
24 571TSC84.....	15	2.2	12	-	1.9	37	30	0.6	370	0.40	6	31	35
25 571WSC84.....	16	2.5	13	-	1.8	39	31	0.7	560	0.58	6	32	23

- not determined
 INAA-Induced Neutron Activation Analysis
 ICP-Inductively Coupled Argon Emission Plasma Spectroscopy
 AA-Atomic Absorption
 DN-Delayed Neutron
 X-ray - X-ray Fluorescence

Table 2.--Continued.

SAMPLE NUMBER	P % ICP	Pb PPM ICP	Sc PPM ICP	Se PPM ICP	Sr PPM ICP	Th PPM ICP	Th PPM DN	Ti % ICP	U PPM DN	V PPM ICP	Y PPM ICP	Yb PPM ICP	Zn PPM ICP
1 571ASC84.....	0.09	19	10	-	140	12	12.4	0.37	2.9	64	24	2	120
2 571BSC84.....	0.09	16	11	<.1	130	12	-	0.38	-	67	25	2	120
3 571CSC84.....	0.10	14	7	-	130	8	8.9	0.27	2.6	48	16	2	62
4 571DSC84.....	0.09	12	7	-	130	7	10.0	0.24	2.3	45	15	2	55
5 571ESC84.....	0.08	16	8	-	130	10	11.3	0.30	2.8	50	19	2	75
6 571FSC84.....	0.08	19	9	-	130	9	9.3	0.32	3.1	54	20	2	77
7 571GSC84.....	0.04	16	7	-	100	10	11.0	0.26	2.2	50	17	2	55
8 571HSC84.....	0.04	25	7	-	110	12	11.1	0.28	2.6	53	19	2	62
9 571ISC84.....	0.09	13	8	-	120	10	10.2	0.29	3.1	51	19	2	66
10 571JSC84.....	0.10	14	7	-	120	9	9.6	0.27	2.6	48	18	2	62
11 571JSC84.....	0.09	12	7	-	120	9	9.6	0.27	2.9	49	18	2	62
12 571KSC84.....	0.09	17	9	-	140	9	10.7	0.33	3.0	52	22	2	88
13 571LSC84.....	0.08	13	7	-	130	9	11.7	0.27	2.6	44	15	2	56
14 571OSC84.....	0.07	18	8	-	140	12	11.2	0.32	3.0	55	20	2	73
15 571PSC84.....	0.06	15	8	-	120	9	10.8	0.28	2.9	51	19	2	65
16 571RSC84.....	0.07	21	11	-	150	12	13.1	0.39	3.0	66	25	3	110
17 571SSC84.....	0.11	13	6	-	110	11	10.6	0.27	2.6	44	18	2	58
18 571USC84.....	0.11	18	9	-	140	10	11.7	0.32	2.8	56	20	2	79
19 571VSC84.....	0.08	14	7	-	140	9	10.1	0.28	2.5	49	16	2	64
BACKGROUND SAMPLES													
20 571MSC84.....	0.05	16	7	-	100	11	11.4	0.27	2.6	52	20	2	53
21 571MSRC4.....	0.05	14	7	-	110	13	9.4	0.28	3.0	54	19	2	56
22 571NSC84.....	0.05	14	7	.2	100	9	-	0.27	-	55	20	2	54
23 571QSC84.....	0.06	17	7	-	100	10	11.0	0.29	3.3	51	19	2	56
24 571TSC84.....	0.03	15	7	-	110	10	9.3	0.27	2.6	53	18	2	50
25 571WSC84.....	0.04	15	8	-	130	11	10.6	0.31	2.7	53	21	2	99

- not determined
 INAA-Induced Neutron Activation Analysis
 ICP-Inductively Coupled Argon Emission Plasma Spectroscopy
 AA-Atomic Absorption
 DN-Delayed Neutron
 X-ray - X-ray Fluorescence

the collapse depression soil may reflect a false anomaly; that is, the depression has permitted development of a thicker soil horizon containing more organic material, or Fe + Mn oxides, which adsorb metals. So, the anomalies may not reflect a mineralized breccia pipe but rather enrichment of metals due to better adsorption conditions.

Figure 15i shows a comparison of Cr content in soils collected from two different soil depths. Soil samples were collected at both 4 inch and 8 inch depths and are both plotted for comparison. Apparently neither level is consistently more enriched in Cr than the other (the results are similar for most of the other metals); so, the 4-inch depth is preferable to sample because of greater ease and speed in sample collection.

Although it is certain that the soil overlying this structure is enriched in many metals relative to the surrounding terrain, it has not been determined as to whether or not the movement of ground water within a shallow sink hole could also cause such low level metal enrichment. In any event, the soil survey over collapse feature 571 appears favorable enough to merit additional study.

A helium-soil-gas survey shows some anomalous samples along the rim of the collapse feature. Nevertheless, this feature had relatively low helium, and the background was exceptionally low, as compared to other collapse features surveyed for helium on the Hualapai Reservation. Bacillus cereus soil bacterial surveys were completed over collapse feature 571 (Parduhn, N. L., written commun., 1986). When penicillin concentrations of 10 ppm are used during the B. cereus assay a distinct B. cereus low occurs over the collapse feature. This is in contrast to surveys completed over known mineralized pipes which contain high concentrations over the breccia pipe orebody.

AMT soundings over collapse feature 571 did not yield results that were as encouraging as many of the other collapses studied on the Hualapai Reservation. The conductivity anomalies that are present have a much lower intensity than those at other features, and instead of underlying the center of the collapse there appears to be a high under the rim on both sides of the traverse (Flannigan and others, 1986). The absence of a good conductivity high under the center of this feature tends to suggest that the soil metal anomalies may be more of a reflection of increased soil development over a sink hole, and subsequent metal enrichment, than a reflection of a mineralized breccia pipe. Nevertheless, additional studies should be completed over this feature before it is determined to be unfavorable for ore.

572-C?: This feature appears as a dark, circular vegetation patch (fig. 16). It resembles a recent sink hole in that it does not appear to have a raised rim around it, although there is evidence of a white halo in the soil (fig. 16). It does not have a high probability of having a breccia pipe beneath the recent solution feature, although the probability certainly is higher than features 538, and 539.

573-C4: This feature (figs. 17a and 17b) is similar, but more pronounced and circular than 572. It is intermittently filled with water, and probably represents a recent sink hole. In addition, it is surrounded by a white rim of soil. The white rim may suggest that this is more than a recent sink hole. A soil sampling survey was completed over the feature, but the results are not yet available.

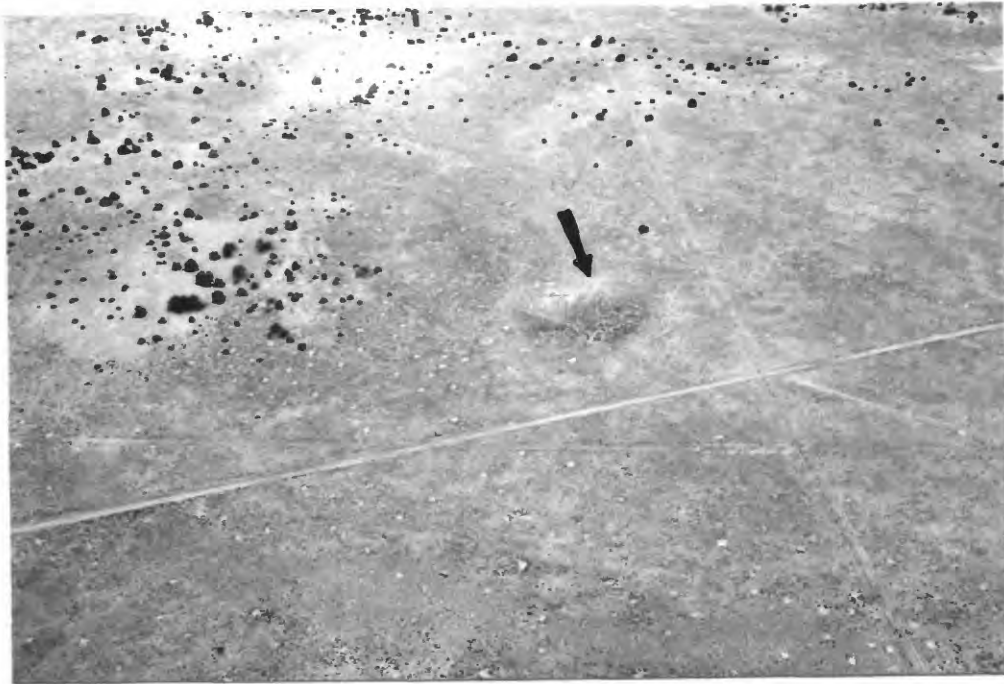


Figure 16.--Feature 572 (indicated by arrow), photographed from a helicopter, shows a shallow depression surrounded by a white halo in the soil. The presently low center suggests recent solutioning.



Figure 17a.--This photograph of collapse feature 573 (indicated by arrow), taken from a helicopter, suggests a modern sink hole.

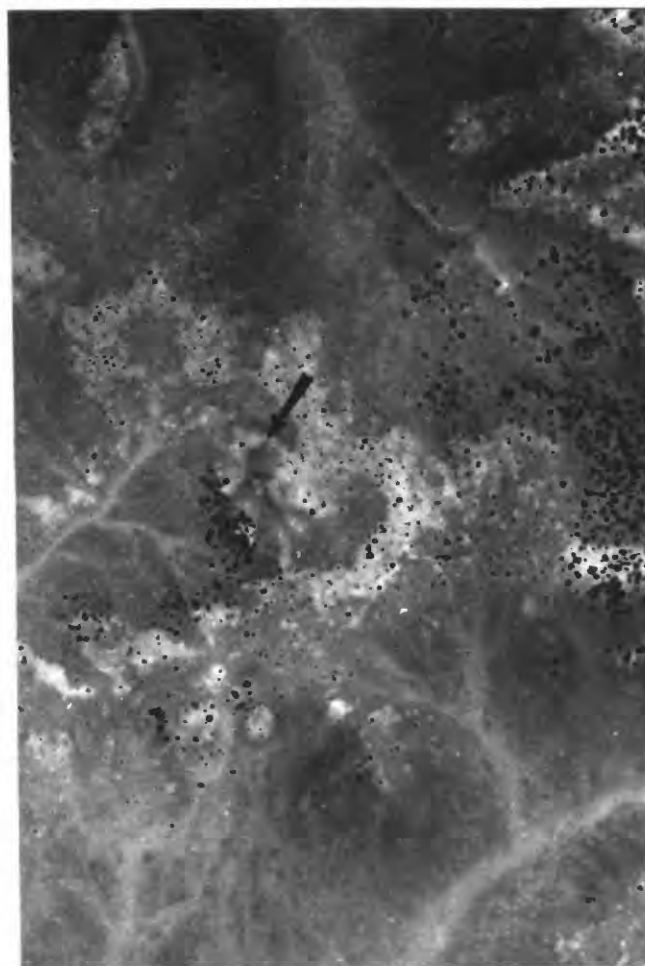


Figure 17b.--This view taken from a low-altitude aerial photograph of feature 573 (indicated by arrow) shows it to be located on a ridge of Kaibab Limestone. This picture is oriented in the same direction as Figure 17a.

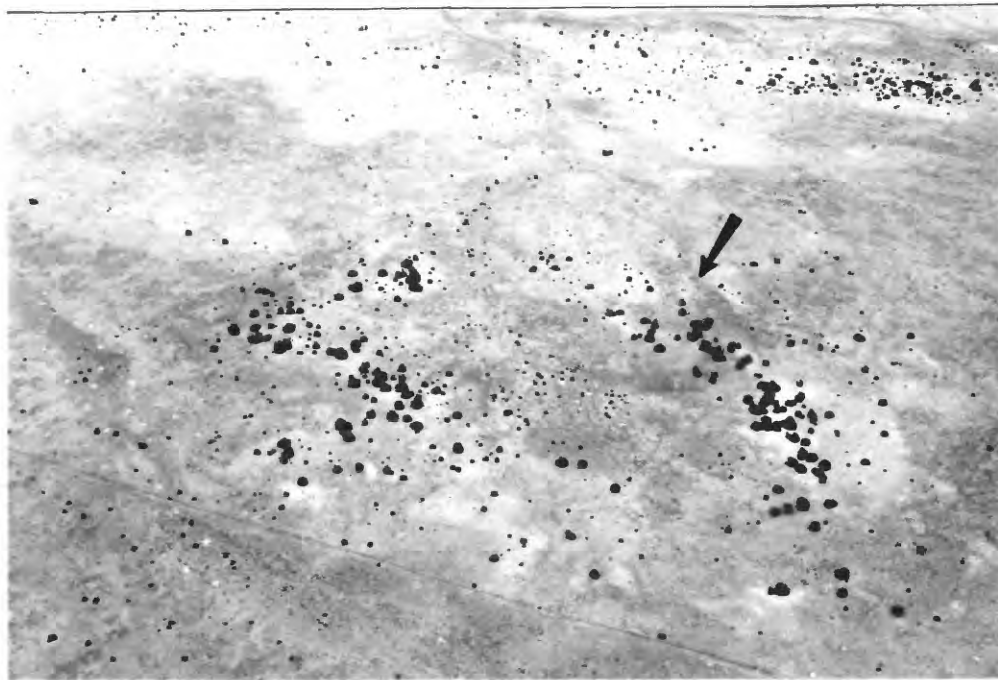


Figure 18.--Collapse feature 574 (indicated by arrow), shown in this view from a helicopter, is not located on the Hualapai Reservation, although it is less than 400 ft beyond the fence line. The structure is delineated by the circular ring of trees that probably lies along the ring fracture. This may suggest a deeper-seated feature than merely a recent sink hole. View is to the east.



Figure 19.--Photograph of Sink Tank (indicated by arrow) (collapse feature 575) taken from a helicopter. Whether there is a deeper-seated breccia pipe under the more recent karst feature is not known. View is to the northwest.

574-C4: This collapse feature has a large reddish center surrounded by a nearly circular (somewhat elliptical) tree covered rim. It lies outside the Hualapai Reservation by approximately 400 ft, as can be seen from the road and fence line in figure 18 that follows the reservation boundary. The ring of trees growing on a slightly raised rim suggests that this may be a deeper seated solution feature than just a recent sink into the Kaibab Limestone or Toroweap Formation.

575-C?: This collapse feature is clearly a recent sink hole (fig. 19), as reflected by its name--Sink Tank on the National Tank Quadrangle. What is not clear, though, is whether this is a deeper-seated solution feature that has long been a conduit for fluid movement. This would have resulted in accentuated recent solutioning of the upper Paleozoic formations within the National Tank area, an actively spreading tectonic basin (Huntoon, P. W., 1986, pers. commun.). Sink tank is filled intermittently with water.

576-C?: This feature appears from the air (fig. 20) to be a depression filled with reddish soil. There also appears to be an increase in tree growth; junipers are more concentrated within this feature than outside it. The collapse may be only a sink hole, although a ridge with spotty outcrop of Kaibab Limestone borders part of the depression.

998-C4: This collapse feature is merely a circular depression (fig. 21), but not a closed basin because it drains on the east side. It nevertheless is a conspicuous depression on the other 3 sides, and resembles the "amphitheaters" formed by erosion of breccia pipes in canyon areas.

1107-C2: An elongate depression with a concentric drainage around a central hill forms this collapse (fig. 22). Beds of the Harrisburg Gypsiferous Member of the Kaibab Limestone dip inward toward a central hill. Such rock exposure is rare in the National Tank area and collapses 1107 and 1108, immediately adjacent to the southeast, are the only collapses in the National Tank area with inward-dipping beds. Soil-sample traverses made over this feature don't reveal any significant anomalies compared to background samples. AMT soundings were also completed, but the results did not show a strongly conductive zone under collapse site 1107 (Flanigan and others, 1986).

1108-C2: Collapse 1108 (fig. 22) sits adjacent to 1107 and exhibits a similar morphology of inward-dipping beds, although outcrop is more sparse at 1108 and there is no central hill. As with the soil-sample traverses at 1107 those at 1108 don't show any strongly significant anomalies, although some elements appear to be slightly enriched over 1108 as compared to the background, at least more so than at 1107. The AMT soundings were similar to 1107 and did not show any strongly conductive zones under 1108 (Flanigan and other, 1986).

1109-C?, 1110-C?, 1111-C?: All 3 of these collapse features are considered questionable, particularly 1109 which is near 1108 and 1107, but is merely an arcuate hill with sparse junipers bordering a soil covered flat. Collapse 1110 has a nearly circular drainage around a hill that, when viewed from the air, visually appears quite circular. Kaibab Limestone on the central hill appears to be flat lying. Collapse 1111 is merely a soil covered treeless flat three-quarters enclosed by a rim of trees.



Figure 20.--Photograph from a helicopter of collapse feature 576 (indicated by arrow). The surface morphology of the structure is a depression with reddish-white soil and a stand of junipers in the right center of the photograph.

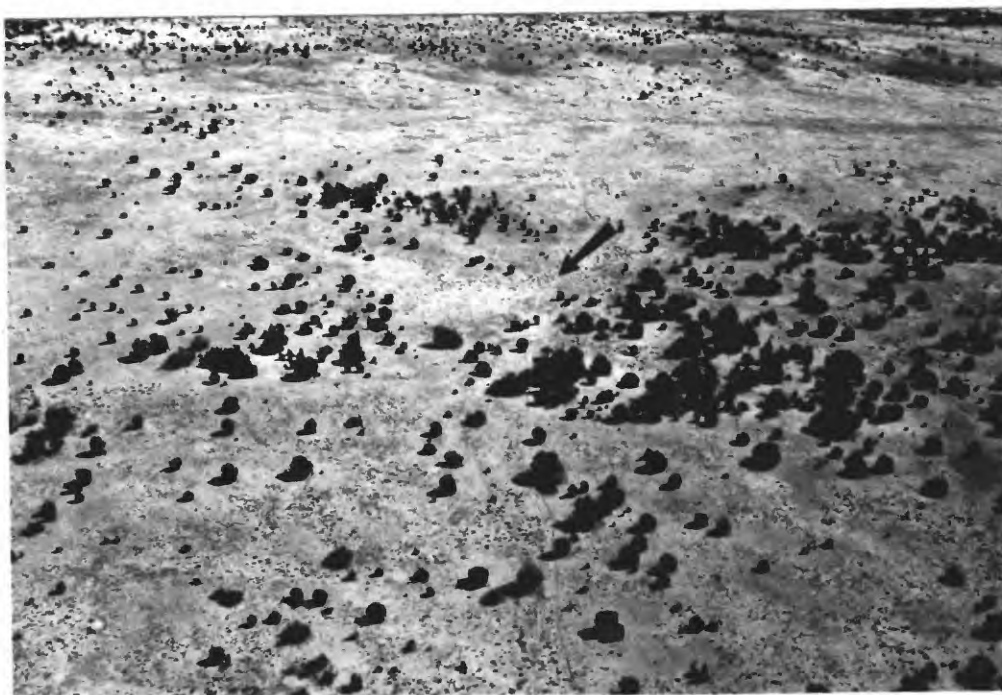


Figure 21.--Photograph from a helicopter of collapse feature 998 (indicated by arrow). The only surface expression here that may indicate a possible underlying breccia pipe is the depression that is lower than the surrounding plateau on 3 sides.

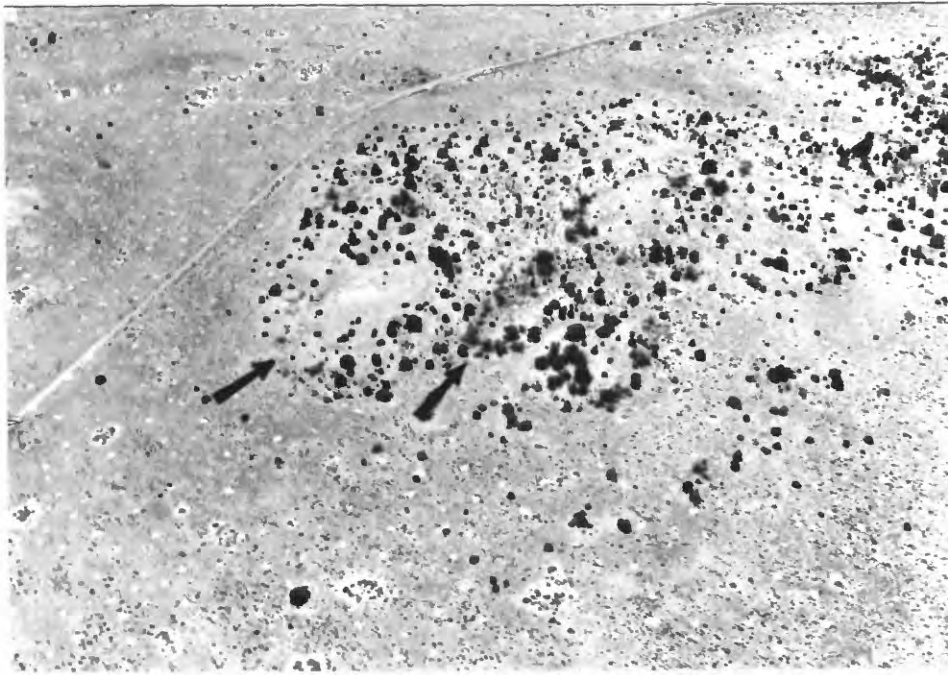


Figure 22.--View to the southwest of collapse features 1107 (indicated by right arrow) and 1108 (indicated by left arrow). Both are basins elongated in an east-west direction.



Figure 23.--View to the southwest of collapse feature 1114 (indicated by arrow). This shallow depression with green grasses contrasts with the surrounding browner less densely vegetated terrain.

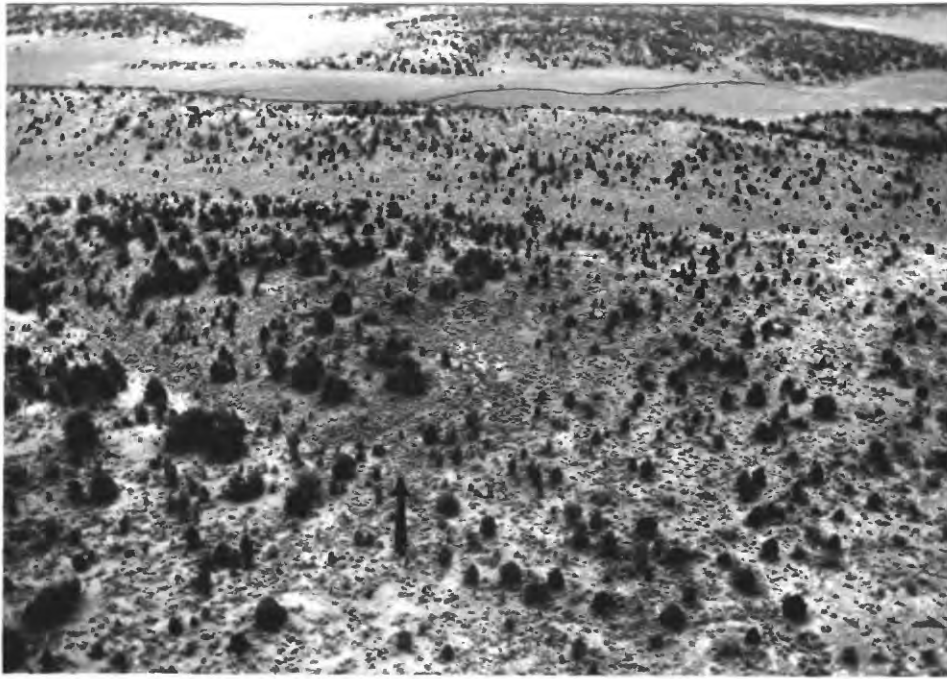


Figure 24.--Collapse feature 1115 (indicated by arrow) forms a relatively well developed closed depression with a lower lying drainage of sage enclosing (on 3 sides) a central hill of sparse junipers. View is to the south.

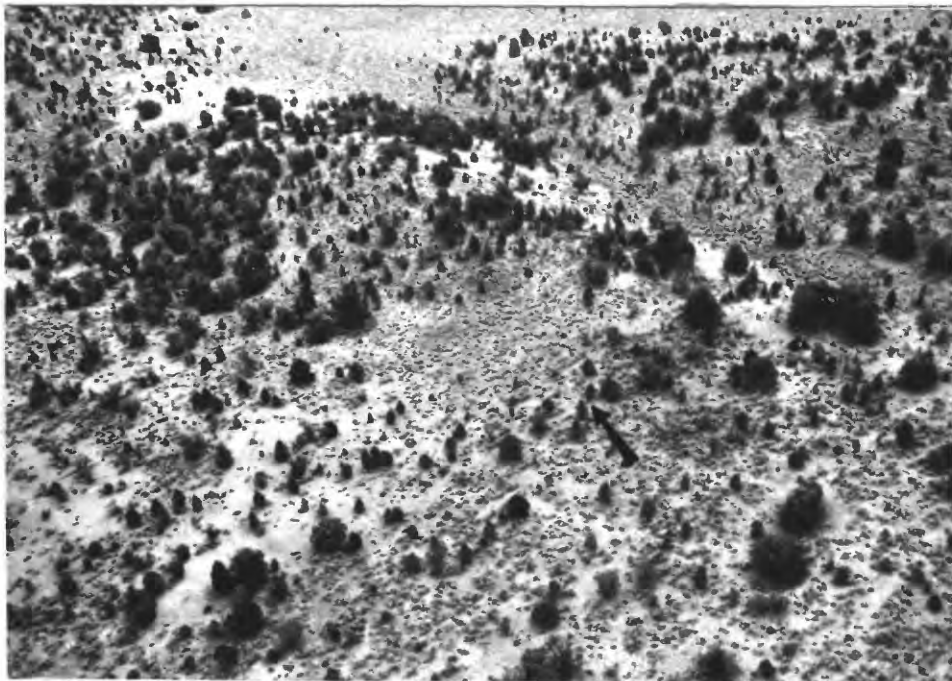


Figure 25.--View to the south of collapse feature 1116 (indicated by arrow). This feature, adjacent and immediately east of collapse 1115, forms a slight depression of sage that contrasts with the surrounding terrain of sparse junipers.



Figure 26.--View to the east of collapse feature 1119 (indicated by arrow), which has a morphology and vegetation cover identical to collapse 1115.

1114-C4: Collapse 1114 (fig. 23) is a slight depression with greener grasses compared to the remainder of the flat that it lies in. This feature is perhaps more questionably a breccia pipe than some of the others in the C4 category. No geophysical surveys were made over this collapse, and the only geochemical surveys are soil and the data are not yet available.

1115-C4: This collapse is a relatively well-developed, closed basin (fig. 24). No geophysical surveys have been made on this collapse, and the only geochemical surveys are soil and the data are not yet available. This feature appears quite favorable for further exploration; it is the only collapse in the National Tank area where goethite nodules were found.

1116-C4: This collapse forms a well-developed small depression filled by sagebrush amongst a terrain of sparse junipers (fig. 25). It is located adjacent to the northeast of 1115. This is the type of morphology, but on a much smaller scale, that is expressed on the surface by the Canyon Pipe, a known uranium orebody.

1119-C4: This collapse is morphologically identical to collapse 1116 (fig. 26). The depression is filled by reddish-brown soil and surrounded by scattered junipers. The center of the feature contains some red chert, whereas outside of the depression the ridge contains typical white to cream Kaibab Limestone that caps most of the surrounding plateau. Since the exposed surrounding Kaibab at the same topographic horizon as that of the depression does not contain red chert, the center of the depression was probably downdropped from a higher stratigraphic position. Soil geochemistry traverses were made over this collapse, but the data are not yet available. AMT soundings were made, and reflect a narrow vertical (about 1800 ft deep) conductive zone that appears to go to the Redwall Limestone, and is therefore probably a breccia pipe.

1124-C?: Collapse 1124 is very questionable and represents an irregular-shaped depression with grass and sagebrush surrounded by scattered junipers.

CONCLUSIONS

The National Tank area has good access, particularly when compared to most other areas in northern Arizona where breccia pipes can be recognized. The asphalt Supai road bisects the area, and would provide good mining access. Unfortunately, the area has little outcrop, no surface mineralized rock, and no anomalous gamma radioactivity in the soil or rock in excess of 2.5 times background.

Collapse features 562 and 564 (for locations see fig. 3) have been drilled by Rocky Mountain Energy and Energy Fuels respectively. The persistence with which these have been drilled over the past several years suggests strongly that they are both breccia pipes. Within the National Tank area collapse features 570 and 569 most strongly resemble these other two. In addition, 531 and 534 also have some morphologic similarities.

In the National Tank area there are several collapse features, (1116, 1119, and, to a lesser extent, 998) which resemble the Canyon Pipe, but are somewhat smaller. The Canyon Pipe, a known orebody, is expressed on the surface as a circular depression of grass and sage surrounded by Ponderosa pines. Perhaps this suggests that mineralized pipes produce a sufficient

trace metal halo above the orebody to prevent the growth of trees.

The reliability of soil geochemistry as a tool for locating breccia pipes has not yet been determined. The results from 571 leave doubt as to whether anomalous values over depressions might simply be a result of increased thickness of fine-grained soil, and hence more metal adsorption, compared to the surrounding terrain where the "soil" tends more to be fine-grained chips of Kaibab Limestone. Yet, for collapse feature 534, of the 33 elements determined only Co, Cu, Fe, Mn, Ni, Pb, and Zn appear to be significantly enriched over the collapse as compared to the background terrain. Since these metals are all ones that are enriched in breccia pipe orebodies, perhaps soil geochemistry may be a useful tool in breccia pipe exploration.

Audio-magnetotelluric (AMT) soundings appear to show vertical conductive zones over several of the more morphologically favorable collapse structures. The AMT soundings are very favorable for collapse feature 570, in that they closely resemble the results from the EZ-2 survey, a known breccia pipe orebody (Flanigan and others, 1986). In fact, 570 appears to even have a slight tilt to the upper part, as does EZ-2. AMT results for 569 are encouraging, whereas those for 531, 571, 1107, and 1108 are not, although 571 W-E traverse closely resembles the results from the 562 N-S traverse (Flannigan and others, 1986). TDEM data from a geophysical survey on collapse structure 534 show a distinct change in resistivity at a depth of about 960 ft (290 m); this is approximately the same depth as the top of the Seligman Member of the Toroweap Formation in the center of the Mohawk Canyon breccia pipe (Wenrich and others, 1985). Outside of the Mohawk Canyon pipe the top of the Seligman Member lies about 100 ft stratigraphically higher. Thus, this suggests that collapse structure 534 is down dropped to the same level as the Mohawk Canyon Pipe, which is lower than the surrounding terrain, and thus may well be a breccia pipe. Ground magnetometer traverses over feature 569 show dipole highs and lows that would be expected over a narrow vertical body of rock heterogeneous from the surrounding rock.

Initial results from B. cereus surveys for most of the collapse features did not appear particularly useful (Nancy Parduhn, written commun., 1986). Then penicillin amended agars were prepared and many of the B. cereus traverses showed significant highs over collapses compared to the background. Helium soil-gas surveys over several collapse structures were not as promising as some of the other techniques.

Within the National Tank area two northeast alignments of pipes are quite striking. Toward the top of the area 6 collapse features (1115, 1116, 1119, 539, 538, and 534) are aligned in a N56 E direction. At the bottom of the National Tank area 4 collapses (570, 569, 1114, and 574) are perfectly aligned N53 E, essentially the same direction as the upper 6 collapses. This may be useful for exploration; that is, if collapse feature 570 is a mineralized breccia pipe, which it well may be, then there is probably a good chance that 569, 1114, and 574 are also. The northeast alignments on the Marble Plateau mapped by Sutphin and Wenrich (1983) tend to be closer to N40 E. Perhaps the basement structures, which they suggest control the pipe locations, have been slightly rotated westward toward the Grand Wash Cliffs (edge of the Colorado Plateau).

Of the 25 features described from the National Tank area collapses 534, 569, and 570 appear to have the most potential as mineralized breccia pipes. Collapse features 1107 and 1108 have concentrically inward-dipping beds and thus have an excellent potential for being breccia pipes rather than recent collapses. Features 525, 531, 571, 572, 573, 574, 575, 576, and 1114 are undoubtedly at least recent karst features, but the possible presence of underlying breccia pipes still needs to be assessed. Features 537, 538, 539, 998, 1109, 1110, 1111, and 1124 are not even certain to be collapse structures. In all cases, additional surveys and techniques are needed. Additional soil, helium, Bacillus cereus, magnetometer, AMT, and TDEM surveys over all of these features would be most helpful. Of these, the natural source, scalar audio-magnetotelluric (AMT) is the most promising.

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