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INTRODUCTION

Investigation of breccia pipes in collapse-breccia pipes on the southern Marble Plateau, Arizona is presently being conducted by the U.S. Geological Survey, Reston, Virginia. The breccia pipes are believed to be the result of collapse of the upper part of the Marble Plateau. A detailed study of breccia pipes in the Marble Plateau is being conducted by the U.S. Geological Survey, Reston, Virginia. The area is located between the Grand Canyon and the Colorado Desert, and is dissected by the Little Colorado River.

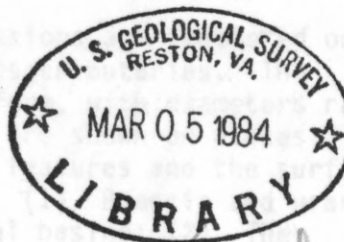


STRUCTURAL CONTROL OF BRECCIA PIPES ON THE SOUTHERN MARBLE PLATEAU, ARIZONA

by

Hoyt B. Sutphin and Karen J. Wenrich

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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. Use of trade names is for descriptive purposes only and does not constitute endorsement by the U.S. Geological Survey

PREVIOUS WORK

Other pipes and collapse features located below the 36° latitude line were mapped by Billingsley and others (1963), Verbeek and others (1969), and 169 respectively on plates 1 and 2.

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INTRODUCTION

Exploration for uranium in collapse-breccia pipes on the southern Colorado Plateau of northern Arizona is presently booming despite the general decrease in activity within the uranium industry. The high grade of the uranium in these pipes makes recovery economical. Breccia pipes in northern Arizona are scattered throughout the area that stretches eastward from the Lower Grand Wash Cliffs to the Echo Cliffs. A detailed study of breccia pipe occurrences was conducted on the southern Marble Plateau, situated along the eastern margin of this region. The area is located between the Grand Canyon and the Painted Desert, and is dissected by the Little Colorado River.

Breccia pipes are crudely cylindrical bodies of rock with highly inclined to vertical axes, and are composed wholly or partly of angular to rounded rock fragments, with or without a matrix (Bryner, 1961). In northern Arizona these breccia pipes are believed by most recent workers (Wenrich and Sutphin, 1983; Sutphin and others, 1983; O'neil and others, 1981; Baillieu and Zellinger, 1980; Wenrich-Verbeek and Verbeek, 1980; Bowles, 1977; Hoffman, 1977; Gornitz and Kerr, 1970; and Billingsley, personal comm.) to have a base in the cavernous Mississippian Redwall Limestone. Collapse of the overlying Supai Group into the original Redwall caverns, and successive upward sloping into younger Paleozoic rocks, is the mechanism proposed by Bowles (1965) for the formation of these pipes. Other theories of origin include solution by rising hydrothermal fluids (Gornitz and Kerr, 1970; Barrington and Kerr, 1983), and collapse following magma withdrawal (Perry, 1961). A diatreme origin was proposed by Kofford (1969) and a cryptovolcanic origin has been suggested by Watkins (1976), Chenoweth and Blakemore (1961) and Gableman and Beyer (1958).

Numerous circular, shallow, structural depressions are scattered on the plateau surfaces bordering the Grand Canyon and its tributaries. The perimeters of such depressions on the Marble Platform, with diameters ranging from 2.4 km (1.5 miles) to about 30 m (100 feet), are shown on plates 1 and 2. Evidence that these small basins are collapse features and the surface expressions of underlying breccia pipes includes: (1) Breccia and uranium - mineralized rock recovered by drilling into several basins; (2) The occurrence of several such basins on a plateau surface directly above and contiguous with breccia pipes that are exposed in canyon walls; (3) The similarity in alteration, mineralogy, and geochemistry of surface samples from the structural depressions mapped for this study, including the Riverview mine, to samples from the Grandview pipe and published analyses by Kofford (1969) and Gornitz and Kerr (1970) on the Orphan mine (these are the two closest known mineralized breccia pipes to the study area.); and (4) Exposed breccia in the interior of some of the collapse basins, presumably the tops of pipe-like bodies of breccia beneath.

PREVIOUS WORK

Some of the collapse features in the map area were first identified by Barrington and Kerr (1963), who described and named seven of them (the East, West, Lookout, Sunset, Morning Glory, Coconino Point, and the Shadow Mountain collapse, numbered 1, 5, 21, 30, 32, 159 and 169 respectively on plates 1 and 2). Other pipes and collapse feature locations below the 36° latitude line were mapped by Billingsley and others (1983), Verbeek and others (1980), and

Ulrich and others (1979). Many of the collapse features in the area have also been mapped by Loughlin (1983). The Riverview mine (number 172), the only collapse feature in the study area that has produced uranium ore, was described by Chenoweth and Blakemore (1961) and subsequently by Barrington and Kerr (1963). Additional collapse features shown on plates 1 and 2 were mapped initially from aerial photographs and later studied in the field. The area is nearly ideal for locating collapse features as it lacks the alluvial cover and forest vegetation that effectively mask these features on higher plateaus, such as the Coconino and Kaibab.

DESCRIPTION OF THE COLLAPSE FEATURES

The surface rocks in the map area consist of three sedimentary rock formations, the sandstone and dolomitic limestones of the Kaibab Limestone in the western and southern portions, and sandstones, siltstones, mudstones, and conglomerates of the Moenkopi and Chinle Formations in the remainder. The rims of collapse features cropping out in the Kaibab Limestone are flush with the land surface, and their centers are depressed below it, forming bowl- or funnel- shaped features. In contrast, most of the collapse features that crop out in the Moenkopi and Chinle Formations, retain silicified rims that stand out in relief above the less resistant sandstone terrane. Silicification is also common to collapse features in the Kaibab, however, differential erosion around the rims is inhibited by the equally resistant nature of the Kaibab Limestone. Beds within all the collapse features dip inwards, typically 15° to 50°, and locally up to 90°. Diameters of the collapse basins range from 30 m (#2) to over 2.4 km #169-Shadow Mountain Collapse.

In some of the collapse features, mineral occurrences on the surface are indicative of an underlying breccia pipe, as mentioned earlier. Malachite, brochantite and azurite were noted in several of the collapse features in the Moenkopi and Chinle Formations. Collapse features numbers 1 and 5 yielded small copper sulfide nodules composed primarily of chalcocite, diginite, djurleite, covellite, bornite, pyrite, goethite and hematite, with a secondary coating of malachite and brochantite. In addition, some pipes in the Kaibab Limestone contain numerous goethite nodules.

Surface gamma-radiation was also noted to be above background over quite a few of the collapse features (Plates 1 and 2). This is yet another indication for the possibility of an underlying breccia body containing uranium-bearing minerals.

Several sinkholes also occur in the Kaibab Limestone surface, but are much smaller and are different features. One major difference is they lack inward tilting beds. The perimeters of the sinkholes are squared and the walls are vertical, reflecting the joint pattern of the Kaibab, as opposed to the distinctly round breccia pipe related collapse features. The sinkholes also lack gamma-radiation levels above background, as well as surface alteration and minerals common to the collapse features. Contrasting with the breccia found in breccia pipes, the sinkhole fill consists solely of jumbled angular blocks devoid of matrix fill. Although these sinkholes and the breccia pipes have the same ultimate origin and both are technically "collapse features", the sinkholes are younger structures and probably bottom out in the Kaibab Limestone or the Toroweap Formation. As referred to in this report "collapse features" are only those circular features thought to overlie a

breccia pipe that extend down to the Redwall Limestone. Sinkholes were not mapped on plates 1 and 2.

STRUCTURAL CONTROL

The collapse features, and hence the underlying breccia pipes on this portion of the Marble Plateau, are aligned along northeast and northwest trends (see inset map on Plate 2). Within the study area, 78 of the 94 (83%) collapse structures fall within northwest- and northeast- trending zones that cover only 23% of the total surface area. Perhaps more convincing are the trends indicated by dashed lines within these zones which show alignment of 4 to 12 pipes.

Major fault zones and lineaments defined by aligned cinder cones, fractures and fault traces on the Colorado Plateau show preferred northeast and northwest directional trends, as has been noted previously (McClain, 1965; Eastwood, 1974; and Shoemaker and others, 1978). Shoemaker and others (1978) established boundaries for the principal fault systems of the southern Colorado Plateau. The study area contains the eastern parts of the northwest-trending Kaibab system, the northeast-trending Mesa Butte system, and the northern part of the north-trending Oak Creek Canyon system, the presence of which is less pronounced in this area. The observed fault systems probably extend to deep within the crust and have been active since Precambrian time (Shoemaker and others, 1978). Rejuvenations along Precambrian faults during Laramide time resulted in many of the monoclines in the Grand Canyon region (Huntoon, 1974).

The karst features in the Redwall consist of solution widened fractures and joint-controlled caves. In the vicinity of faults, a system of master joints is present in the Redwall that is parallel and perpendicular to the faults (Huntoon, 1981, 1970). Individual cave passages in the Redwall Limestone would thus be oriented parallel and perpendicular to the major fault and the cave system should directly overlie the fault zone. On the southern Marble Plateau, this would result in NE- and NW-trending fracture controlled karst features. Those collapse features in the area, having bases in the Redwall Limestone, might also be expected to reflect cavern alignment, and indeed this is precisely what is observed and illustrated on plate 2 (inset map). The collapse features seem to occur in linear zones, which probably represent areas of higher fracture density, thus facilitating the upward stopping of the pipes. Extrapolation of the NE- and NW-trending zones of collapse features successfully led to the discovery of additional collapse features. Over a large part of the area, the joint systems and fault traces seen in the surface rocks are related to Laramide deformation and do not reflect the NE and NW trends of the pipes related to an earlier stress field propagated upward from the basement rocks. In some cases the NE-NW fracturing in the Redwall limestone extends upward through several overlying units and may be reflected on the surface (Huntoon, 1970). An example is evident on plate 1 in the trend of pipes around $111^{\circ} 38' 30''$ W. longitude and $36^{\circ} 07' 30''$ N. latitude. In this area the line of collapse features parallels the joints and small faults. If this relationship of pipe alignment can be applied to other areas of pipe occurrences in the Grand Canyon Region, it would facilitate exploration by providing a preferred direction in which to search for new collapse features and breccia pipes.

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