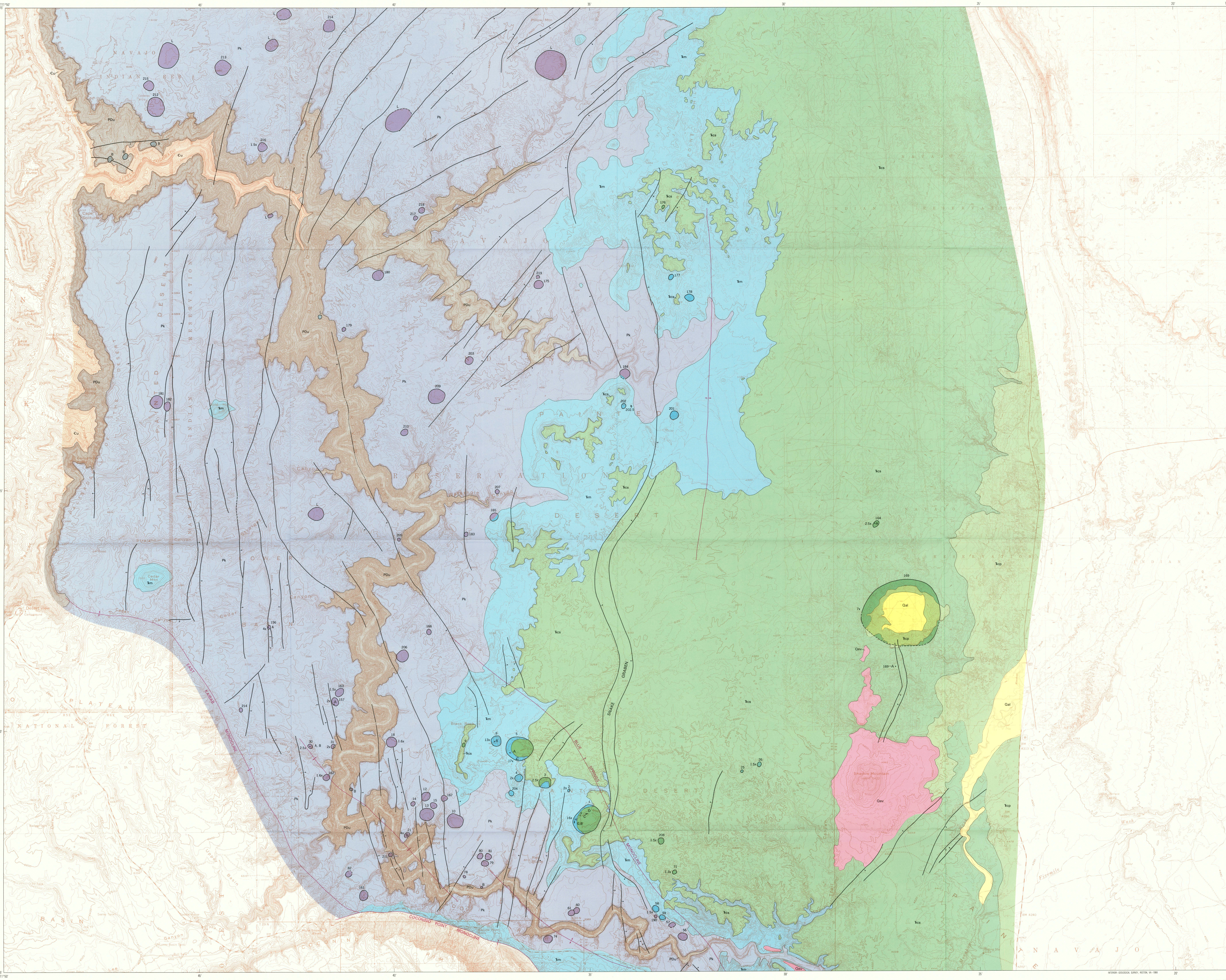

CORRELATION OF MAP UNITS

Unit	Age
Qal, Qev	QUATERNARY
Ƚcp, Ƚcs, Ƚm	TRIASSIC
Pk	PERMIAN
PDu	PERMIAN TO DEVONIAN
Єu	CAMBRIAN

LIST OF MAP UNITS

- Qal — Alluvium (Quaternary)
- Qev — Extrusive volcanic rocks (Quaternary)
- Ƚcp — Chinle Formation, Petrified Forest Member (Triassic)
- Ƚcs — Chinle Formation, Shinarump Member (Triassic)
- Ƚm — Moenkopi Formation (Triassic)
- Pk — Kaibab Limestone (Permian)
- PDu — Toroweap Formation (Permian), Coconino Sandstone (Permian), Hermit Shale (Permian), Supai Group (Permian-Pennsylvanian), Redwall Limestone (Mississippian), and Temple Butte Limestone (Devonian), undivided
- Єu — Muav Limestone, Bright Angel Shale, and Tapeats Sandstone, undivided (Cambrian)

Contact—Approximately located; dotted where concealed

Fault—Bar and ball on downthrown side. Dashed where approximately located; dotted where concealed

Anticline—Showing trace of crestline

Syncline—Showing trace of trough plane

Monocline—Showing trace of lower axis unless both axes shown. Length of arrows inversely proportional to relative dip of beds

Monocline—Showing approximate trace of center of monocline

(A) 4
2.5x
Collapse feature—Showing outline of feature, number (4), sample location for geochemical analysis (A), and maximum surface gamma radiation (3.5x). Dashed where approximately located. Maximum surface gamma radiation detected by traverses using a scintillometer and expressed as the number of times the background level. For the features not showing a radiation level, the surface radiation was not above the background level. Features designated solely by a B or an L are additional collapse features or breccia pipes supplied by Billingsley and others (1983; B) or by Loughlin (1983; L) and have not been field checked. Map units are deeper color within collapse features

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, which is 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 (see inset map on sheet 2).

Breccia pipes are crudely cylindrical bodies of rock that have 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; Baillieul and Zollinger, 1980; Wenrich-Verbeek and Verbeek, 1980; Bowles, 1977; Hoffman, 1977; Gornitz and Kerr, 1970; and Billingsley, personal commun., 1981) to have their base in the cavernous Mississippian Redwall Limestone. Collapse of the overlying Permian and Pennsylvanian Supai Group into the original Redwall caverns, and successive upward stoping into younger Permian 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, 1963) 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 Gabelman and Boyer (1958).

Numerous circular, shallow, structural depressions are scattered on the plateau surfaces bordering the Grand Canyon and its tributaries. These depressions on the Marble Plateau, shown as collapse features in the map area, have perimeters that range from about 30 m (100 ft) to 2.4 km (1.5 mi). We find strong evidence that these small basins are collapse features that are the surface expressions of underlying breccia pipes. This evidence 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 two known mineralized breccia pipes closest to the study area, the Grandview mine (see inset map on sheet 2) and published analyses by Kofford (1969) and Gornitz and Kerr (1970) on the Orphan mine (located 16 km (10 mi) northwest of the Grandview mine); and (4) exposed breccia in the interior of some of the collapse basins, presumably the tops of pipelike 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 Shadow Mountain collapse features, numbered 1, 5, 21, 30, 31, 159, and 169, respectively, in sheets 1 and 2). Other pipe 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 initially by Chenoweth and Blakemore (1961) and subsequently by Barrington and Kerr (1963). Additional collapse features shown in sheets 1 and 2 were mapped first 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 mostly consist of three sedimentary rock formations, the sandstone and dolomitic limestones of the Kaibab Limestone in the western and southern parts 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, so that they form 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, but differential erosion around the rims is inhibited by the equally resistant nature of the Kaibab Limestone. Beds within all the collapse features dip inward, typically 15° to 50° and locally up to 90°. Diameters of the collapse basins range from 30 m (100 ft) (number 2) to over 2.4 km (1.5 mi) (number 169, Shadow Mountain collapse).

In some of the collapse features, mineral occurrences on the land surface indicate 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 numbered 1 and 5 yielded small copper sulfide nodules composed primarily of chalcocite, digenite, djurleite, covellite, bornite, pyrite, goethite, and hematite, plus a secondary coating of malachite and brochantite. In addition, some pipes in the Kaibab Limestone contain numerous goethite nodules.

Surface gamma radiation was noted to be above the background level over quite a few of the collapse feature (sheets 1 and 2). This is another indication of the possibility that a breccia body containing uranium-bearing minerals underlies individual collapse features.

Several sinkholes also occur in the Kaibab Limestone surface, but are much smaller than and are different from the collapse features. One major difference is that they lack inward-tilting beds. In addition, the perimeters of the sinkholes are squared and the walls are vertical, which together reflect the joint pattern of the Kaibab, as opposed to the distinctly rounded collapse features related to the breccia pipes. The sinkholes also lack gamma-radiation levels above the background level, and they lack the surface alteration and minerals common to collapse features. Contrasted 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 initial origin and both are technically "collapse features," the sinkholes are younger structures and probably just extend down to the Kaibab Limestone or the Toroweap Formation. As defined in this report, "collapse features" are only those circular features thought to overlie breccia pipes that extend down to the Redwall Limestone. Therefore, sinkholes are not shown in sheets 1 and 2.

STRUCTURAL CONTROL

The collapse features, and hence the underlying breccia pipes on this part of the Marble Plateau, are aligned along northeast and northwest trends (see inset map on sheet 2). Within the study area, 77 of the 90 (86 percent) collapse structures fall within northeast-trending and northwest-trending zones that cover only 23 percent of the total surface area. Particularly noteworthy are the prominent alignments of 4 to 12 pipes within 3 of these zones.

Major fault systems and lineaments defined by aligned cinder cones, joints, and fault traces on the Colorado Plateau show preferred northeast and northwest trends, as has been noted previously (McLain, 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 system (see inset map on sheet 2), the presence of which is less pronounced in this area. The observed fault systems probably extend deep within the crust and have been active since Precambrian time (Shoemaker and others, 1978). Rejuvenations along Precambrian faults during Laramide time resulted in the formation of many of the monoclines in the Grand Canyon region (Huntoon, 1974).

The karst features in the Redwall Limestone 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 faults, and the cave system should directly overlie the fault zones. On the southern Marble Plateau, this would result in northeast- and northwest-trending fracture-controlled karst features. The collapse features that have bases in the Redwall Limestone might also be expected to reflect cave alignment, and indeed this is precisely what is observed and illustrated (inset map on sheet 2). The collapse features seem to occur in linear zones, which probably represent areas of higher fracture density that would facilitate the upward stoping of the breccia pipes. In the study area, extrapolation of the northeast- and northwest-trending zones of collapse features successfully led to the discovery of additional collapse features.

The principal fault systems of Shoemaker and others (1978) are constructed from composite lineament trends covering large areas, and, thus, the directional trend may be locally undetectable. For instance, many of the faults shown in sheets 1 and 2 vary from the preferred directions, and the northeast and northwest fracturing in the Redwall Limestone is not always reflected in the surface rocks (Huntoon, 1970). However, an excellent example that does show the corresponding lineament and feature alignment is evident in the map area in the trend of pipes around lat 36°07'30'' N. and long 111°38'30'' W. (numbers 175, 203, 209, 210, and 219). There the line of collapse features parallels the major joint direction 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.

ACKNOWLEDGMENTS

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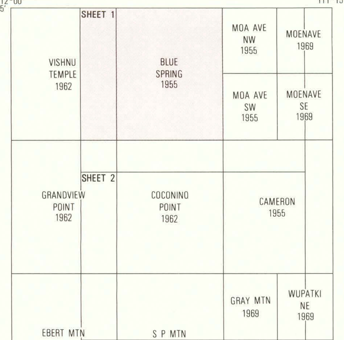

INDEX SHOWING LOCATION OF STUDY AREA AND 1:24,000- and 1:62,500-SCALE TOPOGRAPHIC MAPS

NORTHERN PART

MAP SHOWING STRUCTURAL CONTROL OF BRECCIA PIPES ON THE SOUTHERN MARBLE PLATEAU, NORTH-CENTRAL ARIZONA

By
Hoyt B. Sutphin and Karen J. Wenrich

1988