THE GEOLOGY AND PRODUCTION HISTORY OF THE MORALE URANIUM MINE, HOPI BUTTES AREA, NAVAJO COUNTY, ARIZONA

by

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INTRODUCTION

During the uranium boom of the mid-1950's, some 192 tons of low-grade ore were produced at the Morale mine in the Hopi Buttes area of Navajo County, Arizona (Figure 1). The host rocks for the orebody were lacustrine sediments of late Miocene to early Pliocene age in the Seth-La-Kai maar. This feature has been referred to in the past as a diatreme (Lowell, 1956; Wenrich and Mascarenas, 1982a,b; Wenrich-Verbeek and others, 1982). It is herein referred to as a maar because the uranium-bearing sedimentary rocks were deposited within a crater (maar), and the volcanic neck (diatreme) is not actually exposed, but is inferred to underlie the maar.

The purpose of this report is to provide an overview of the geology of uranium deposits in the Hopi Buttes area and to publish complete production statistics for the Morale mine (a previous report [Shoemaker and others, 1962] published only partial statistics). Production data were obtained while the author was employed by the U.S. Atomic Energy Commission (AEC) as a geologist on the Navajo Indian Reservation.

LOCATION

The Morale mine is on unsurveyed land approximately 40 mi north-northeast of Holbrook, Arizona in NE $^1/_4$ sec. 19, T. 24 N., R. 22 E., Gila and Salt River Baseline and Meridian, projected. To reach the mine, turn north onto Arizona State Highway 77 east of Holbrook and travel 33 mi to the Bidahochi Trading Post. Four miles north of the trading post, turn right (east) onto Navajo Route 15 and proceed for 2 mi. The mine workings are approximately $^1/_2$ mi to the north and may be reached by a dirt road.

The area is within the Navajo Indian Reservation. All prospecting and mining activities are controlled by the Navajo Tribal Council. Mining Permits are issued by the Navajo Tribe and approved by the Bureau of Indian Affairs, U.S. Department of the Interior. Mining permits may only be obtained by individual Navajos, who may assign the mining rights to an individual or company. Assignments are also approved by the Tribal Council and the Bureau of Indian Affairs. No more than 960 acres of tribal land may be held by any one individual or company.

PREVIOUS WORK

Eugene M. Shoemaker (1956) of the U.S. Geological Survey (USGS) was the first to recognize anomalously high uranium concentrations in maars containing lacustrine sediments. His work still stands as the most comprehensive and most cited publication on the Hopi Buttes (Shoemaker and others, 1962). More recent mapping of the area and an excellent summary of the geology of the Hopi Buttes was done by Sutton (1974).

The maar-lake sediments, mineralized by uranium, were mapped and their geochemistry was studied by Wenrich and Mascarenas (1982a,b). Wenrich-Verbeek and others (1982) described the USGS drilling project at the Seth-La-Kai maar. Lowell (1956) had previously investigated the Seth-La-Kai maar for the AEC. The Morale mine is included as a stop in a road log through the Hopi Buttes (Wenrich, 1989).

GEOLOGIC SETTING

Regional Geology

The regional geology given below is summarized from Wenrich and Mascarenas (1982a) and Wenrich (1989).

The dark-colored Hopi Buttes dominate the landscape north of Holbrook, Arizona, commonly rising to heights of 600 ft above the surrounding countryside. Most are underlain by individual diatremes and some by a complex of diatremes. Several sediment-filled maars also crop out as inconspicuous low hills; others may be buried beneath the alluvium. The diatremes and maars erupted into the late Miocene-early Pliocene Hopi Lake (Sutton, 1974). No region in the world is known to contain a greater density of such structures than the Hopi Buttes, where more than 300 diatremes have been discovered within a 1,000-sq-mi area. The lacustrine sediments are the hosts for uranium mineralization, which was probably syngenetic. In addition to these sediments, the maar vents contain limburgite tuff and tuff breccia; agglomerate; monchiquite dikes, necks, and flows; fine-grained clastic and carbonate rocks; and blocks of sedimentary rocks, especially the Wingate Sandstone, derived from the vent walls. Within many of the maars, these deposits dip inward at steep angles.

The diatremes themselves are not mineralized; however, most of the overlying maar-lake sediments that contain travertine deposits also contain anomalous uranium concentrations. Approximately 25% of the diatremes in the area are overlain by maar-lake sediments; the bulk of these are within the eastern part of the volcanic field, where erosion has been less intense. Uranium-rich travertine deposits were probably also present on the western side of the field, but the volcanic structures are eroded to a level beneath the maar-lake sediments. Of the 58 maars sampled, 23 contain travertine beds with uranium concentrations exceeding 100 ppm (Wenrich and Mascarenas, 1982a).

Many of the diatremes were once filled by maar-lake travertine, siltstone, and water-laid tuff deposits, which are locally interbedded with thin layers of gypsum and chert. The aggregate thickness of the lake beds preserved in some diatremes exceeds 1,000 ft (Sutton, 1974, p. 661). The travertine is believed to have been deposited from rising thermal waters, whereas the interbedded clastic rocks were derived from eolian debris, ejecta from adjacent diatremes, and sediments that were washed into the lake from the maar rim. Although the clastic rocks do contain a volcanic component, they are dominantly composed of quartz fragments with minor amounts of feldspar and mafic minerals in a fine-grained clastic or calcite matrix. More than half of the analyzed samples are travertine. These samples are chemical precipitates and are very fine grained relative to the clastic rocks. X-ray diffraction studies have shown that the travertine primarily contains calcite and dolomite with minor amounts of quartz and goethite. Essentially no clay was identified, despite the argillaceous appearance of many specimens. Even X-ray analyses of samples soaked in hydrochloric acid to remove all calcite and dolomite showed no kaolinite, montmorillonite, or sericite; very small amounts of illite, however, may be present in one sample. The travertine and clastic rocks were the hosts for syngenetic uranium mineralization, as well as unusually high concentrations of SO_4, P_2O_5, Ag, As, Ba, Be, Co, Cs, Eu, F, Fe, Hf, Li, Mn, Mo, Nd, Ni, Rb, Sc, Se, Sr, Ta, Th, V, Zn, and Zr.

Within each maar, the highest uranium concentrations are in the travertine and clastic rocks; lower concentrations have been found in limburgite tuffs and monchiquite flows. No uranium minerals, other than the opaque oxides discussed below, were discovered by Wenrich (1989) in any of the rock types of the Hopi Buttes. Gamma radioactivity above background levels was not detected in tuffaceous sandstones and other clastic rocks within the maars that do not contain travertine deposits. Drilling has shown that the highest concentrations of uranium in the travertine deposits are near the base, just

above the contact with the limburgite tuffs. Fission-track maps indicate that the uranium is disseminated throughout the lacustrine sediments and mimic the sedimentary structures to the extent that it is difficult to distinguish thin-section from fission-track maps. Some uranium is concentrated in iron-titanium-oxide opaque rims surrounding detrital quartz grains within the clastic rocks, lapilli within the limburgite tuffs, and oolites or other detrital grains within travertine.

The lacustrine sediments within most maars show evidence of abundant organic activity. Thin laminations in many travertine deposits are indicative of depositional control by algal mats, which in some places have stromatolitic form. Thin sections reveal that pelmicrites are common in the lake beds. A thin layer of organic-rich material was initially deposited at the bottom of several lakes, as evidenced by its location immediately above the limburgite tuff and below other lacustrine sediments. Epigenetic uranium mineralization occurred at this contact on the crests and flanks of small anticlinal folds. Chalcedony and opal fill fractures within travertine and also appear to have replaced organic material within the travertine beds. Slumping and collapse of volcanic rocks and sediments into the central vent occurred in most of the maars, both before and after deposition of the lacustrine sediments.

The volcanic rocks of the diatremes are limburgite tuffs and monchiquite, which are distinguished from normal alkalic basalts of the Colorado Plateau by their extreme silica undersaturation and high water, TiO_2, and P_2O_5 content. Many trace elements are also unusually abundant, including Ag, As, Ba, Be, Ce, Dy, Eu, F, Gd, Hf, La, Nd, Pb, Rb, Se, Sm, Sn, Sr, Ta, Tb, Th, U, V, Zn, and Zr. The monchiquites, as massive unaltered flows, cap many mesas in the area. The limburgite tuffs are generally water laid, although some are air-fall tuffs. Both the monchiquites and limburgites contain augite, olivine, and biotite phenocrysts. The monchiquite groundmass contains plagioclase, pyroxene, and equant opaque microphenocrysts. The limburgite tuffs are essentially composed of volcanic clasts and minor amounts of phenocrysts of augite, biotite, and olivine in a glassy to devitrified glassy, calcite, or rarely analcime-rich matrix with plagioclase microlites. Many samples also have abundant calcite cement in the interstices.

Local Geology

The Seth-La-Kai maar is 4 $^1/_2$ mi northeast of the Bidahochi Trading Post. This maar, with a diameter of approximately 2,000 ft, is adjacent to the southwestern edge of the monchiquite-lava-capped Red Clay Mesa. The maar was mapped by E.M. Shoemaker in 1957 (Figure 2).

The following description of the Seth-La-Kai maar is taken from Shoemaker and others (1962, p. 340):

> "The lower exposed part is filled with a chaotic assemblage of blocks and finer debris derived from prevolcanic members of the Bidahochi Formation and the volcanic 'White Cone' member, which range from detrital particles of the original sediments to large masses a few hundred feet long emplaced by inward slumping of the walls of the vent.... Resting unconformably on the chaotic slump debris is a sequence of laminated to massive siltstone, limy siltstone, and carbonate rock, which interfingers toward the walls of the vent with tuff and coarse volcanic breccia."

In the fall of 1979, the USGS, in cooperation with the Bureau of Indian Affairs and the Navajo Tribe, drilled 24 holes into the Seth-La-Kai maar. Twenty-one of these holes were rotary noncored and three were cored (Wenrich-Verbeek and others, 1982). This drilling has shown that the presently preserved, maximum thickness of travertine beds is 92 ft. All holes were drilled through the entire preserved thickness of lacustrine sediments, limburgite tuffs, and slump debris and penetrated the underlying Wingate

Sandstone at an average depth of approximately 200 ft.

On the outcrop of the Seth-La-Kai maar, uranium was present in the basal travertine sediments just above the chaotic slump debris. At the portal of the Morale mine, these sediments were arched into a small anticlinal flexure over the debris. The strongest mineralization occurred in a 6- to 8-in.-thick, coarse-grained nonvolcanic sandstone and in adjacent calcareous tuff beds. The maximum thickness of this mineralized zone, as noted by the author, was 2 ft. Grab samples taken by the author from the mineralized horizon ranged up to 0.22% U_3O_8, whereas selected grab samples by Shoemaker and others (1962) from the thinnest parts of the host beds contained as much as 0.40% to 0.50% U_3O_8.

Based on the drilling at Seth-La-Kai, the USGS has estimated that a 50-ft-thick interval contains nearly 400,000 lb U_3O_8 with an average grade of 0.01% U_3O_8 (Wenrich-Verbeek and others, 1982). Drilling has shown that uranium tends to be consistently enriched in these basal, organic-rich lacustrine sediments (K.J. Wenrich, unpublished data, 1979).

At the Morale mine, sufficient selenium is associated with the uranium to encourage the growth of "loco weed," *Astragalus pattersoni*. In some areas, this plant accumulates so much selenium that it is toxic to livestock, hence the common name.

PRODUCTION HISTORY

During the winter of 1953-54, M.K. Robinson and M.J. O'Haco of Winslow, Arizona began aerial prospecting for uranium in the Hopi Buttes area of the Navajo Indian Reservation. They became interested in the area because the USGS had found uranium there in 1952 and had begun geologic studies the next year (Shoemaker, 1956).

Robinson and O'Haco's reconnaissance surveys were made using a small single-engine aircraft and a handheld scintillation counter. After several weeks of flying with negative results, a radioactive anomaly was detected in the Seth-La-Kai maar, approximately 4.5 mi northeast of the Bidahochi Trading Post. This discovery would be called "Morale" because it boosted the same for Robinson and O'Haco (M.J. O'Haco, oral commun., 1957).

Robinson and O'Haco asked their Navajo friends, Calvin and Ruth Chee of Leupp, Arizona, to apply for a mining permit to cover the radioactive rocks in the maar. Navajo Tribal Mining Permit No. 105 was issued to the Chees on March 31, 1954. It covered 47 acres. Because the land was unsurveyed, the permit was tied to valve no. 16 of the El Paso Natural Gas Company's pipeline (Figure 3). The mining rights to the permit were assigned to a partnership of Robinson, O'Haco, and Robert Lukius, also from Winslow. The assignment was approved by the Bureau of Indian Affairs on April 24, 1954.

Using a bulldozer, air compressor, and jackhammer, two Navajo miners removed some uraniferous material from the east rim of the maar during May 1954. An initial shipment was made to the AEC's ore-buying station at Bluewater, New Mexico in June 1954. This 13.32-ton shipment averaged 0.18% U_3O_8 and 0.05% V_2O_5 (Table 1).

The property was inactive until January 1955, when small-scale mining commenced again. During the winter and spring of 1955, some 129.77 tons of ore were shipped to the AEC's ore-buying station at Shiprock, New Mexico. These shipments averaged 0.15% U_3O_8 and 0.04% V_2O_5 (Table 1). The shippers in 1954 and 1955, as recorded at the ore-buying stations, were Robinson and O'Haco.

An AEC aerial radiometric survey of the Hopi Buttes in February 1955 detected a strong radiometric anomaly over the Morale workings (Stehle, 1955). At that time, a small adit was noted off the rim cut.

When Mining Permit No. 105 was renewed in March 1956, the assignment was changed to the Twin States Uranium Co., Inc. (Robinson and O'Haco). There were no shipments in 1956.

During the summer of 1957, 42.22 tons of ore were shipped to an ore-buying station near Tuba City, Arizona. This station was operated by Rare Metals Corporation of America for the AEC. The 1957 shipments averaged 0.14% U_3O_8 and 0.04% V_2O_5 (Table 1). When mining was discontinued in the spring of 1957, a stockpile of some 150 to 200 tons of low-grade material (0.08% to 0.10% U_3O_8) was left in the rim cut. Because the shipping grade was below 0.15% U_3O_8 and the higher-grade mineralized horizon was thin and very spotty, Twin States Uranium Co. became discouraged with the property. The property was inactive from May 1957 to February 1959. During February 1959, some 5.7 tons of the most radioactive material were handpicked from the stockpile. This material was shipped to the Rare Metals Corporation of America's mill near Tuba City. The shipment averaged only 0.17% U_3O_8 (Table 1). During 1958, Rare Metals reported to the AEC at Grand Junction, Colorado that amenability tests on the Morale ore showed low recoveries in their acid-leach circuit because of a high (0.75% to 1.00%) P_2O_5 content.

When the author contacted O'Haco in February 1960, the latter indicated that Twin States Uranium Co. would ship the stockpile before abandoning the property. The stockpile was never shipped, however, and Twin States cancelled the assignment of the mining permit on March 31, 1960.

In the 6 months that the property was worked during the years 1954 to 1959, a total of 192.01 tons of ore averaging 0.15% U_3O_8 and 0.04% V_2O_5 was produced (Table 1). With the exception of a USGS drilling project in 1979, no activity has occurred at the Morale mine since February 1959.

OTHER EXPLORATION IN THE HOPI BUTTES

According to information provided to the AEC by the Navajo Tribal Minerals Department, Window Rock, Arizona, three other mining permits were issued in the Hopi Buttes area. These three permits covered five diatremes.

Mining Permit No. 174, issued to Calvin Chee on August 6, 1954, included claims in two widely separated diatremes. The assignment of the permit to Robinson and O'Haco was approved on October 21, 1954. When the permit was renewed in August 1956, the assignment was changed to the Twin States Uranium Co., Inc. The 40-acre Gwen claim covered radioactive lacustrine sediments at diatreme no. 27 (Wenrich and Mascarenas, 1982b), which is 1.5 mi south of the Morale mine. Twin States reported to the AEC that test pits at the Gwen claim uncovered a 6-in. uraniferous zone containing autunite. Shoemaker and others (1962) published a geologic map of a portion of the Gwen claim. Mining Permit No. 174 also covered 40 acres of a diatreme located 3.7 mi north of the Greasewood Trading Post. This property, called the Sjodin claim by Twin States, was 13 mi northeast of the Morale mine.* Drilling by Twin States, as reported to the AEC, encountered some uraniferous zones estimated to contain as much as 0.09% U_3O_8. Twin

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* Because the location of the diatreme that was covered by the Sjodin claim is not shown on any large-scale maps, the following legal description is reprinted here: "Beginning at a point that is N 6°48' W, 19,402 feet from the northwest corner of the Greasewood Trading Post, and is also N 41°35' E, 75,216 feet from USGS triangulation station "Indian," located at latitude 35°27'13" and longitude 110°00'20". This is point of beginning, corner no. 1 or the northeast corner of the Sjodin claim; thence S 12°23' W, 3,000 feet to corner no. 2 (southeast corner); thence N 78°23' W, 600 feet to corner no. 3 (southwest corner); thence N 12°23' E, 3,000 feet to corner no. 4 (northwest corner); thence S 78°23' E, 600 feet to point of beginning. A discovery monument is S 12°23' W, 2,500 feet from corner no. 1. Contains 40 acres, more or less." -- From the files of the Navajo Tribal Minerals Department, Window Rock, Arizona.

States cancelled their assignment of this permit on October 7, 1960. Both properties have been idle ever since.

Mining Permit No. 234 was issued to Leroy Begay and John H. Lee on December 14, 1954 and was assigned to Kachina Uranium Corporation of Phoenix, Arizona in early 1955. This permit, called the Hoskie Tso No. 1, covered the radioactive rocks at diatreme no. 2 (Wenrich and Mascarenas, 1982b), which is 3.5 mi south-southwest of the Morale mine in sec. 24, T. 23 N., R. 21 E. Kachina did some rim stripping on the northwest rim of the maar, but made no shipments. Shoemaker and others (1962) identified schroeckingerite from the Hoskie Tso claim. In their report, this claim is written as one word, a spelling variation taken from the mining records in Window Rock, Arizona. The permit and assignment expired on December 14, 1958. A geologic map of the Hoskie Tso No. 1 claim was published by Shoemaker and others (1962). During 1979 the USGS, in cooperation with the Bureau of Indian Affairs and the Navajo Tribe, drilled six rotary holes into the lacustrine sediments at diatreme no. 2. Elevated uranium values, based on gamma ray logs, were encountered in all of the holes and ranged from 1 to 26 ft of 0.007% U_3O_8 to 18 ft of 0.012% U_3O_8 (Wenrich-Verbeek and others, 1982).

Mining Permit No. 344, covering two separate diatremes, was issued to Begay and Lee in the summer of 1955 and assigned to Harnard and Associates of California. The Mail Box claim covered diatreme no. 8 (Wenrich and Mascarenas, 1982b), located 2.5 mi west of the Morale mine at the common corner of secs. 14, 15, 22, and 23, T. 24 N., R. 21 E. Harnard and Associates did a small amount of rim stripping on the northeast rim of the maar. Diatreme no. 8 is also known as the Doughnut diatreme (Fair, 1956) and as the Roanhorse diatreme (Shoemaker and others, 1962). The Flat Tire claim of Mining Permit No. 344 covered diatreme no. 36 (Wenrich and Mascarenas, 1982b), located 4.5 mi north of the Dilcon Trading Post in secs. 28 and 29, T. 24 N., R. 19 E. No exploration is known at this locality. This permit and the assignment to Harnard and Associates expired in the summer of 1957.

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Table 1. Uranium ore production, Morale mine, Navajo County, Arizona.

YEAR	QUARTER	TONS OF ORE	LB U_3O_8	% U_3O_8	LB V_2O_5	% V_2O_5
1954	2d	13.32	48.87	0.18	12.01	0.05
1955	1st	87.78	278.64	0.16	70.23	0.04
1955	2d	41.99	109.17	0.13	41.99	0.05
1957	2d	42.22	124.21	0.14	38.26	0.04
1959	1st	5.70	19.37	0.17	NA	NA
TOTAL		192.01	580.26	0.15	162.49	0.04

NA = Not Analyzed.

Source: Unpublished data, U.S. Atomic Energy Commission files, Grand Junction, Colorado.

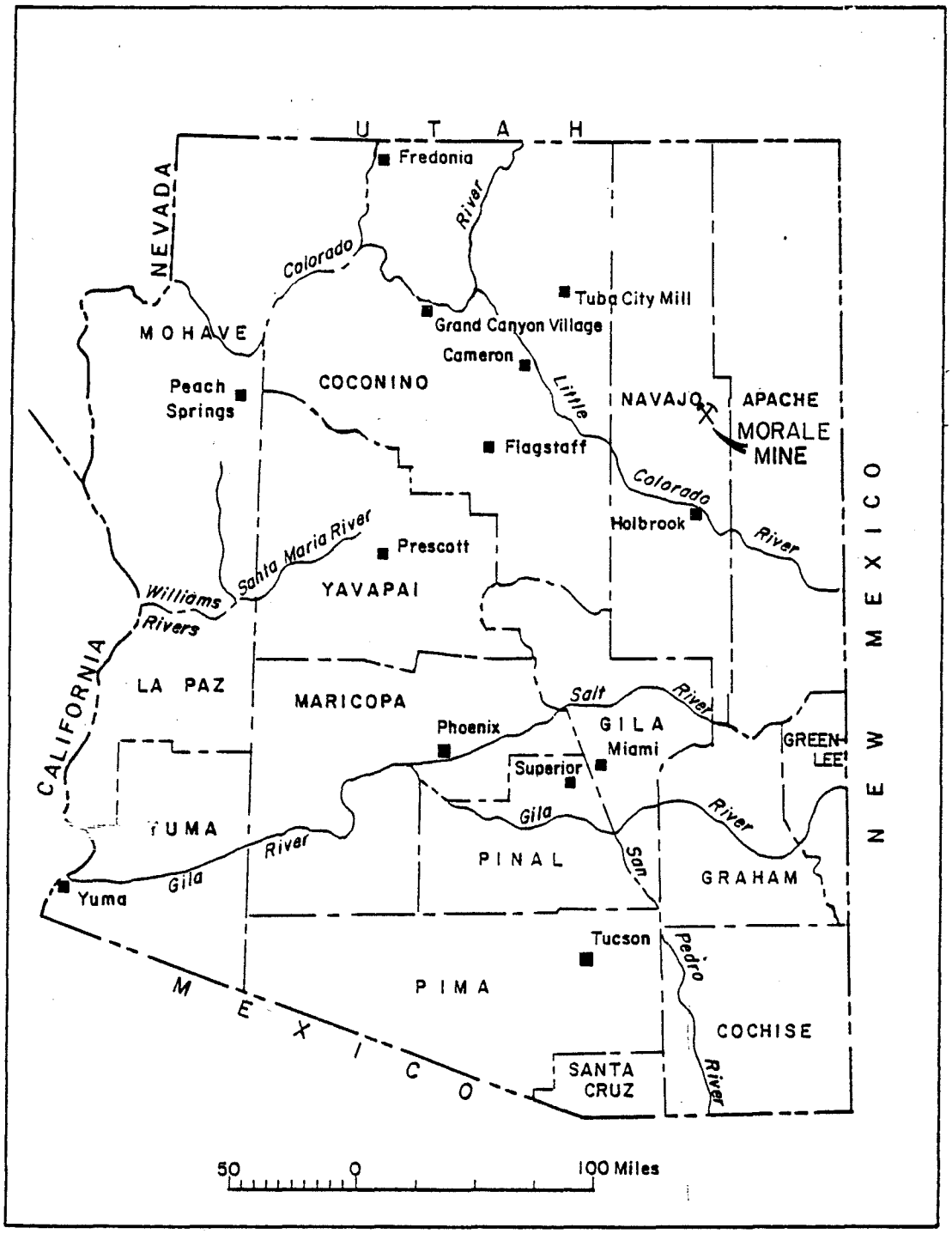
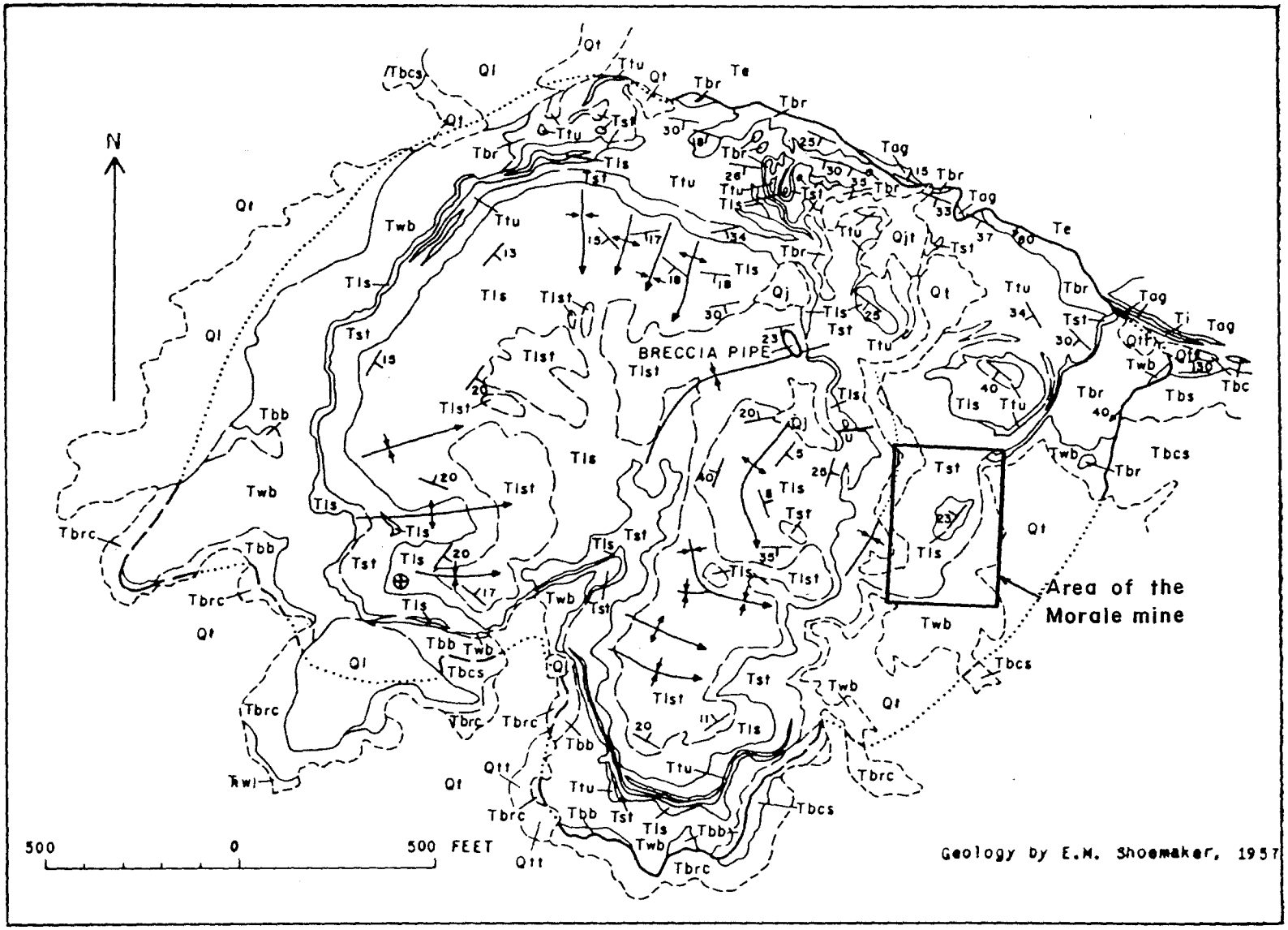


Figure 1. Index map of Arizona showing the location of the Morale mine



Contact (dashed where approximately located; short dashes where indefinitely located)

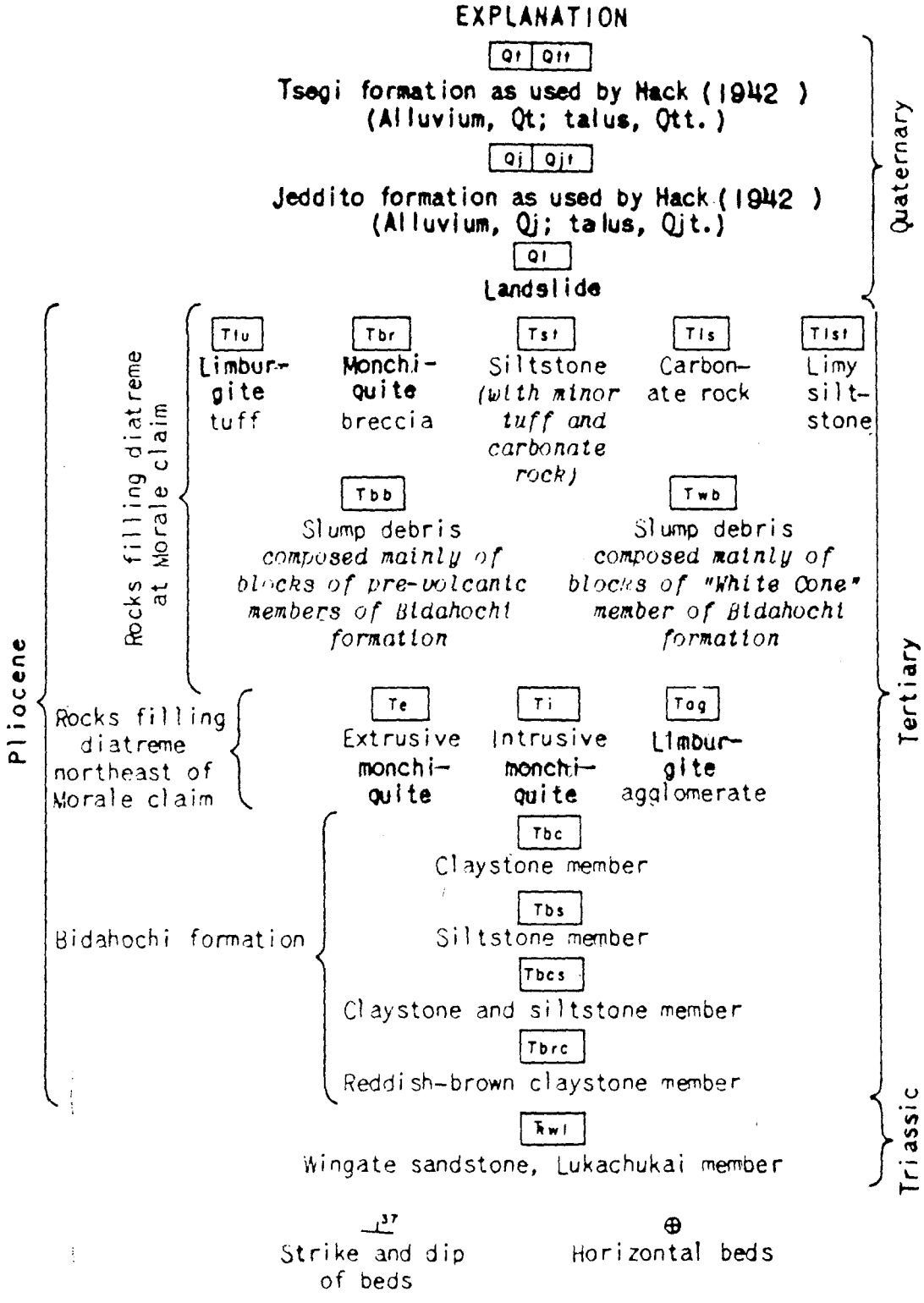
Wall of diatreme, showing dip (dashed where approximately located; dotted where concealed)

High angle fault
U, upthrown side
D, downthrown side

Anticline, showing trace of axial plane and direction of plunge of axis (dotted where concealed)

Syncline, showing trace of axial plane and direction of plunge of axis (dotted where concealed)

Figure 2. Geologic map of the Seth-la-kai diatreme. After Shoemaker and others, 1962



Explanation for Figure 2

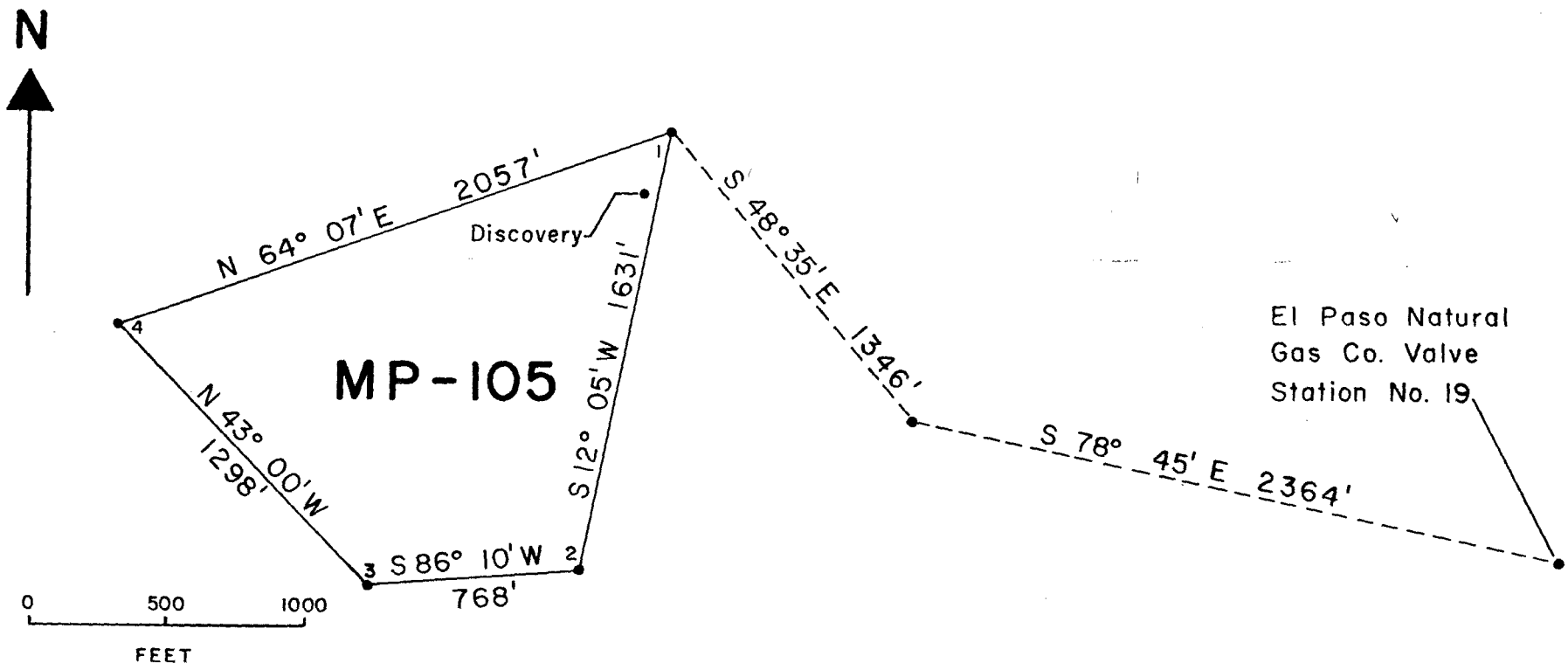


Figure 3. Map of the Morale claim, Navajo Tribal Mining Permit No. 105. From AEC files.