STATUS OF MINERAL RESOURCE INFORMATION, HOPI INDIAN RESERVATION, COCONINO AND NAVAJO COUNTIES, ARIZONA

By

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SUMMARY AND CONCLUSIONS

The principal mineral resources identified on the Hopi Indian Reservation include coal, sand and gravel, and clay. There may be undiscovered mineral resources of oil and gas, metallics, and uranium.

Coal is the most abundant and valuable mineral resource on the reservation. It is possible that oil and gas exploration in the McCracken Sandstone pinch-out could result in a discovery. Further exploration of Tertiary terrain in the southeastern portion of the reservation may identify metallic and/or uranium mineralization in association with diatremes related to Hopi Buttes Volcanic Field. Clays, shales, and glass sand on the reservation may have some potential for development. Exploration for breccia pipes in the Red Wall limestone could result in discovery of economic deposits of base and precious metals and uranium.

INTRODUCTION

This report was prepared for the Bureau of Indian Affairs (BIA) by the Bureau of Mines (BOM) under an interagency agreement to compile and summarize available information on the geology, mineral resources, and potential for economic development of certain Indian lands. Source material used in this report included published and unpublished reports and personal communications.

This report essentially presents the results of a literature search, although a brief visit to the reservation was made in June 1986 to gather additional information. No field work was undertaken.

Location and Access

The Hopi Indian Reservation is located in northeastern Arizona about 13 miles east of Tuba City and about 50 miles north of Holbrook (Figure 1). The reservation encompasses 1,561,213 acres in Coconino and Navajo Counties, Arizona (J. R. Crowther, oral commun.). Primary access to the area is by State Highway 264, which crosses the study area west to east from Tuba City, and by County Highway 2 and State Highways 77 and 87 from the south. Numerous unpaved roads provide access throughout the interior of the reservation. The Black Mesa and Lake Powell Railroad parallels a portion of the reservation boundary to the northwest and operates between the Peabody loadout site and Page, Arizona. Tribal headquarters are at Kykotsmovi, and the local BIA office is at Keams Canyon.

Physiography

The Hopi Indian Reservation is situated in the Black Mesa Basin portion of the Colorado Plateau Physiographic Province. Black Mesa is a tectonically elevated structural basin, the upper surface of which has been eroded to form mesas and buttes bounded by broad rolling plains. Elevations range from 4,800 to 7,220 feet above mean sea level. Drainage of the area under study is primarily to the southwest.

Land Status (modified from Harvey, 1982)

The Hopi became subject to United States jurisdiction in 1848 with the signing of the Treaty of Guadalupe Hidalgo. The original reservation was designated by President Chester A. Arthur through an Executive Order dated December 16, 1882, and was statutorily confirmed by Congress July 22, 1958, 72 Stat. 403. This act vested beneficial title to the Executive Order Reservation in the Hopi and Navajo Tribes. Healing v. Jones quieted title to Land Management District Six, comprising 640,000 acres of the 1,882 Reservation, in the Hopi Tribe. The Navajo-Hopi Settlement Act, P.L. 93-531, 88 Stat. 1712, led to the 1977 partition between the two Tribes of the remaining 1,800,000 acres of the 1882 Reservation known as the Joint Use Area. The 1980 Navajo and Hopi Indian Relocation Amendments Act, P.L. 96-305, 94 Stat. 929, conferred jurisdiction in the 911,000 acres known as the Hopi Partition Lands to the Hopi Tribe effective April 18, 1981. Subsurface mineral rights throughout the Former Joint Use Area continue to be shared equally by both Tribes. The General Allotment Act of 1887, 25 USCA 331, et seq, was never implemented on the 1882 Hopi Executive Order Reservation. Thus, no lands within the 1882 Reservation are held in fee simple by individuals or organizations.

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PREVIOUS INVESTIGATIONS

Geologic references to the Hopi Reservation date back to the 1800's. Cretaceous strata were recognized by Newberry (1861) in the vicinity of the Hopi villages. Blake (1898), Dumble (1902), Rubel (1916), and Gregory (1917a) discussed coal in the region. Campbell and Gregory (1911) named the Cretaceous strata of Black Mesa, and Lee (1915) and Reeside and Baker (1929) correlated the sequence with its counterpart in the San Juan basin. Geologic maps of the study area include Moore, Wilson and O'Haire (1960); Wilson, Moore and O'Haire (1960); Cooley and others (1969); Haynes and Hackman (1978); and Ulrich and others (1984). Major works addressing the geology of the study area are Harshbarger, Repenning and Irwin (1957); Cooley and others (1969); Repenning, Cooley and Akers (1969); Akers, Shorty and Stevens (1971); and Irwin, Stevens and Cooley (1971). Mineral resource studies addressing the Hopi Indian Reservation include Kiersch (1955a-c), Boyer (1977), and Evans and others (1980). Mineral occurrence maps including the study area have been prepared by McCrory and O'Haire (1965) and Keith (1969).

GEOLOGY

Subsurface geologic data for the study area are quite limited. Previous investigators have made assumptions about the character of Paleozoic rocks beneath the Hopi Indian Reservation based upon the lateral projection of data among a few very widely spaced drill holes and distant outcrops. Because of this, the knowledge of subsurface geology for the Reservation is regional in nature. Rock units exposed on the Reservation are predominantly Cretaceous age strata. Jurassic and Triassic strata are exposed along the southeast to west periphery of the Cretaceous exposure. Tertiary units are exposed along the southeast edge of the study area. The stratigraphy of the Hopi Reservation is presented in Table 1.

Stratigraphy

Paleozoic

Cambrian

The Cambrian is undivided for the purpose of this study area.

Devonian

Devonian strata range from about 130 to 520 feet in thickness beneath the study area and consist of the Aneth and the Elbert formations. The Elbert Formation comprises a lower dolomite member, the McCracken Sandstone, and an upper member. The Devonian unconformably overlies Cambrian strata.

Mississippian

The Redwall Limestone is comprised of the Whitmore Wash, Thunder Springs, Mooney Falls, and Horseshoe Mesa members (Conley and Giardina Jr., 1979). Total thickness of the Redwall Limestone ranges from 0 to 400 feet in the study area and thins to the southeast. The Mississippian section, bounded by unconformities, is overlain by the Supai Group and is underlain by the Elbert Formation.

Pennsylvanian

Pennsylvanian strata are represented by the Supai Group. Total thickness of this time transgressive stratigraphic unit ranges from 0 to 500 feet. The Supai Group overlies the Redwall Limestone.

Permian

Permian strata range from 2000 to 2200 feet in thickness and are composed of the Supai Group, the upper member of the De Chelly Sandstone, the Coconino Sandstone, the Toroweap Formation, and the Kaibab Limestone.

Mesozoic

Triassic

Units representing the Triassic Period are the Moenkopi Formation; the Shinarump, Petrified Forest, Owl Creek, and Church Rock members of the Chinle Formation; and the Moenave Formation. Triassic strata are primarily underlain by the De Chelly Sandstone. Coconino Sandstone may underlie strata along the southern part of the study area. Total thickness of the Triassic section ranges from 1500 to 2000 feet.

Jurassic

The Jurassic Period is represented by the Navajo Sandstone, Carmel Formation, Entrada Sandstone, Cow Springs Sandstone, and Morrison Formation. The region was almost exclusively an area of deposition throughout the Jurassic. Strata in the study area have a total thickness of 500 to 2000 feet and are underlain by the Triassic Moenave Formation.

Cretaceous

The Dakota Sandstone, Mancos Shale, and Mesaverde Group compose the Cretaceous sequence of rocks. The Mesaverde Group includes the Toreva Formation, Wepo Formation, and Yale Point Sandstone. The Toreva Formation is composed of a lower sandstone member, a middle carbonaceous mudstone member, and an upper sandstone member; it is intertongued with the Mancos Shale in the southern portion of the study area. The Cretaceous is bounded by both a lower and an upper unconformity.

Cenozoic

Tertiary

Tertiary time is represented by the Bidahochi Formation and is composed of a lower calcareous member, an upper sandstone member, and volcanic vent deposits related to the development of the Hopi Buttes Volcanic Field. Volcanic vents in the area are manifested as diatremes expressed as maars at the surface (Sutton, 1974).

Quaternary

Accumulations of Quaternary age materials include dune, alluvial, playa, colluvial aprons, and alluvial terrace deposits.

Structural Geology

The structural fabric of the study area is dominated by subparallel northwest trending gentle folds (Conley and Giardina, Jr., 1979). These folds are part of a structural belt that extends northwestward from the southern end of the Defiance uplift, through the Black Mesa basin and into the Kaiparowits basin (Kelley, 1958). Black Mesa basin is a passive basin resulting largely from the northward tilting of the Mogollon slope and the rise of the Monument, and Defiance uplifts (Kelley and Clinton, 1960).

MINERAL RESOURCES

Historical Development

Mineral commodities known to have been extracted from reservation lands include coal, clay, and sand and gravel. Of these, coal has the greatest commercial significance since it is the only commodity transported off the reservation for consumption. Clay deposits have been utilized as a source of raw materials for the making of pottery. Sand and gravel extracted from deposits located on the reservation is utilized for the construction and maintenance of highways on the reservation. Approximate locations of mineral resources and occurrences are depicted on Figure 2. Exploration for mineral commodities on the reservation has been nominal since the mid 1970's when the Hopi Tribe, in a Tribal Resolution, declared a moratorium on all mineral exploration on all lands under its jurisdiction.

Reserves

Mineral lands involved under this study include land where the mineral interest is shared between the Hopi and Navajo tribes, and lands under lease to a third party. Reserve estimates are considered to be proprietary information and as such could not be made available for this study. All resource estimates referenced in this report are from non-proprietary sources.

Fuels

Coal and uranium are the only known mineral fuels on the Hopi Reservation. Only coal is currently produced. Potential exists, however, for discovery of petroleum and natural gas and helium.

Coal

Occurrences of coal in the study area are confined to the Dakota Sandstone, the Toreva Formation, and the Wepo Formation. Thickness of the Cretaceous coals varies throughout the Black Mesa region.

Mining of coal on the Hopi Reservation began about 1300 AD (Brew and Hack, 1939). The Hopi extracted coal by surface excavation and shallow drift development for use in domestic heating and pottery firing. Modern mines have been operated by conventional underground room and pillar methods during the 1940's and 50's in the Dakota, Toreva, and Wepo formations on Black Mesa (Kiersch, 1955a). Currently, Peabody Coal Company is strip mining on 68,000 acres acquired under lease. Three beds (the green, blue, and red) are being mined from the Upper Cretaceous Wepo Formation.

The Wepo contains at least 10 coal beds that are greater than 3 feet thick along the north rim of the basin. Coal is thickest in the northern portion of Black Mesa where the upper half of the Wepo Formation has not been eroded. Peirce (1975) reports the average sulfur content of the Cretaceous coals to be 0.58 percent for the Wepo, 1.09 percent for the Toreva, and 1.62 percent for the Dakota. Average quality of these coals is presented in Table 2. The coal resource for the entire Black Mesa basin is estimated to be about 5.65 billion tons of Wepo, 6.00 billion tons of Toreva, and 9.60 billion tons of Dakota (Peirce, 1975).

Oil and Gas

Thermal maturation studies of Paleozoic rocks based upon conodont color alteration indicate a potential for hydrocarbon generation throughout the study area and surrounding region (Wardlaw and Harris, 1984). It is indicated that the northern two-thirds of the Hopi Indian Reservation has potential for accumulation of hydrocarbons (Brown and Lauth, 1958, 1962; Conley and Giardina, 1979). Petroleum from Aneth source rocks could be trapped near the pinch-out of the McCracken Sandstone (Harrison, 1975). In light of the projected limit of occurrence of the McCracken

Sandstone (Conley and Giardina, 1979) the potential for reservoir location should be greater in the vicinity of Township 28 North, Range 14 and 15 East, and Township 29 North, Range 13 East.

The nearest producing oil and gas fields are about 50 miles to the northeast, near the Four Corners area. Production is from a zone near the lower part of the McCracken Sandstone or the upper part of the Aneth Formation of Devonian age, from the Redwall Limestone of Mississippian age, from a Tertiary sill intruding the lower portion of the Hermosa Formation, and from the Paradox Member of the Hermosa Formation of Pennsylvanian age (O'Sullivan, 1969a). Several dry test wells have been drilled on the Hopi Reservation (Table 3). Further tests would be necessary before the oil and gas potential of the reservation could be fully evaluated.

TABLE 2

Average Quality and Heat Contents of Black Mesa Coal (data from O'Sullivan, 1958)

Coal	Number of samples	Moisture content	Volatile material	Fixed carbon	As received Ash	As received BTU	Rank
		--------values in percent -----------					
Wepo	4	7.6	40.3	45.2	5.1	11,950	high vol C bituminous
Toreva	6	6.3	34.7	37.7	21.3	9,630	high vol C bituminous
Dakota	8	10.1	38.4	34.6	15.2	8,160	subbituminous B

TABLE 3

Oil and Gas Test Well Locations - Hopi Indian Reservation
(Compiled from Peirce, Keith, and Wilt, 1970;
Conley and Giardina, 1979; and Kent and Rawson, 1980)

Name	--------Location --------			Collar elevation in feet	Oil show
	Township	Range	Section		
Amerada 1 Hopi	29 N	19 E	SENE 8	7750	yes
Atlantic 9-1 Hopi	28 N	15 E	SWSE 9	6640	yes
Moore-Miller 1 Hopi	29 N	15 E	NWNW 6	6998	yes
Pennzoil 1-11 Hopi	29 N	14 E	NWNW 11	6940	yes
Skelly 1 Hopi	30 N	17 E	35	7980	
Texaco 1 Hopi-A	25 N	16 E	15	5915	

Helium

The nearest producing helium fields are at Pinta Dome, about 50 miles to the southeast, along the Puerco River. The producing zones are the Coconino Sandstone of Permian age and the Shinarump Member of the Chinle Formation of Triassic age (O'Sullivan, 1969c). Brown and Lauth (1962) believe that new fields will be discovered to the east, north, and northwest of Pinta Dome proper.

Uranium

Known deposits in northeastern Arizona are associated with the Morrison, Chinle, Toreva, and Bidahochi formations. All occurrences of any consequence in the Morrison Formation are in the Salt Wash Member and all the Morrison deposits are vanadiferous (V_2O_5:U_3O_8 = 1:1 to 10:1) (Butler, and Byers, 1969). Deposits in the Chinle Formation is also uraniferous (Gregory, 1917b). Only secondary uranium mineralization occurs in the Toreva Formation on Black Mesa (Birdseye, 1958). The deposits in the Bidahochi Formation volcanic member are associated with diatremes containing bedded carbonate rocks (Hack, 1942; Chenoweth and Malan, 1973). Uranium mineralization is also associated with breccia pipe deposits. This is further discussed under copper and silver in the following section. Uranium occurrences have been identified in association with diatremes in the southeast portion of the reservation.

Metallic Minerals

With the exception of manganese, no metallic mineral resources are known to be present on the reservation. The presence of copper and silver deposits near the reservation indicate potential for future discoveries on Hopi lands. Black Mesa coals have been analyzed for rare earths and germanium, but only trace amounts are present.

Copper and Silver

Copper and occasionally silver have been recovered as byproducts from two types of occurrences on the Colorado Plateau in northern Arizona:

(1) deposits in breccia pipes
(2) disseminated mineralization in sandstone.

Breccia Pipes

The more economically important of the two deposit types are the breccia pipe occurrences. Literally hundreds of these structures, many of which are mineralized, are scattered throughout northern Arizona. The pipe-like bodies of breccia were formed by karst-collapse into openings formed by solution of the Mississippian Redwall Limestone. Collapse into the Redwall Limestone began during the Mississippian Period and ended during the Triassic Period. Known vertical extent of the breccia pipes is as much as 3000 feet, and mineralization over a 600-foot vertical segment is not uncommon (Krewedl and Carisey, 1986). Diameters of the pipes range from a few hundred feet to two miles.

Breccia pipe mineralization, of Late Cretaceous-Early Tertiary age (Krewedl and Carisey, 1986), occurs within the breccia matrix. Mineralization consists of uraninite (UO_2), sphalerite (ZnS), galena (PbS), chalcopyrite ($CuFeS_2$), tennantite ($(Cu,Fe)_{12}As_4S_{13}$), millerite (NiS), siegenite ($(Ni,Co)_3S_4$), and molybdenite (MoS_2) (Wenrich, 1985). Metals that have been recovered as byproducts from these pipes include silver, gold, copper, lead, and zinc (Wenrich, 1985). For example, the Orphan Mine in the Grand Canyon produced 100,000 ounces of silver and 6.7 million pounds of copper in addition to several million pounds of rich uranium ore (Krewedl and Carisey, 1986).

Exploration for this type of occurrence in northern Arizona has been very active in spite of prevailing low uranium prices and is related to the high-grade uranium ore that characterizes these deposits. Recent discoveries and operating mines in northern Arizona include the Hack II and Hack III mines, the Pigeon Mine, the Canyon Mine (all owned and operated by Energy Fuels Nuclear), and the EZ-2 discovery (owned by Pathfinder Mines Corporation). The mines are currently being operated solely for their uranium content, although silver could be extracted as a byproduct (Wenrich, 1985).

Several mineralized collapse features are located south and west of Hopi lands on the Navajo Indian Reservation. They include the Shadow Mountain breccia pipe, the Riverview Mine, and others near Cameron, Arizona (Chenoweth and Blakemore, 1961; Bollin and Kerr, 1958; Kerr, 1958).

For several reasons, little or no exploration has occurred in the study area. One consideration has been that the Redwall Limestone thins and finally disappears as one makes a southeast traverse across the reservation (Kent and Rawson, 1980). Another reason is that a thicker section of rock overlies the Redwall Limestone in the study area than in other areas where the pipes are known to occur. Therefore, if mineralized solution-collapse pipes occur on Hopi Indian lands, they may be buried so deeply that they would have little or no topographic expression. Because of this, mineralized collapse breccia pipes would be more difficult to discern in the study area than they are elsewhere in northern Arizona.

Disseminated Mineralization in Sandstone

Sporadic showings of copper, uranium, and silver occur throughout the Colorado Plateau as disseminated mineralization in sandstone. These occurrences are too small to be developed economically. If uranium and copper prices increase in the future, however, it is possible that small operations could develop some of the occurrences at a profit.

These small accumulations are confined to fossil stream channels; the highest grade of ore favors channel bends, scour slopes, and meanders. The channels range from a few inches to several hundred feet in thickness. Both the copper and uranium mineralization tend to be confined to the lower parts of the channels (Reinhardt, 1952). Mineralization occurs along bedding-plane seams and also replaces fossil wood.

Copper mineralization in the sandstone-hosted deposits typically appears as spots and lenses of chalcocite (Cu_2S), bornite (Cu_5FeS_4), chalcopyrite ($CuFeS_2$)or covellite (CuS), with haloes of malachite ($Cu_2CO_3(OH)_2$). Some of the best copper occurrences contain little uranium. Grade of the copper mineralization at one occurrence was as high as 18 percent copper (Reinhardt, 1952).

The nearest known occurrences of this type appear on the Navajo Reservation a few miles west of the study area near Cameron, Arizona. The Cameron deposits occur in the Moenkopi Formation, the Shinarump and Petrified Forest members of the Chinle Formation, and in the Kayenta Formation, all of Triassic age (Austin, 1957). Most disseminated copper deposits in northern Arizona occur in the Petrified Forest and Shinarump, members. Similar mineralization is also known from the eastern part of Black Mesa in Apache County, where it occurs in the Toreva Formation of the Cretaceous Mesaverde Group (Elavatorski, 1978).

In addition, several small nearby occurrences of copper and silver mineralization are associated with brecciation and silicification along faults. Such deposits probably represent disseminated mineralization that has been remobilized and reconcentrated along fractures. The most important example of this type occurs northwest of the study area in the White Mesa District. Mineralization in the White Mesa District occurs in the Jurassic Navajo Sandstone in brecciated areas along small faults and fractures. Small high-grade bodies occur in fissure walls, with weaker mineralization dispersed through large areas of sandstone farther away from the fractures (Kiersch, 1955a).

Because disseminated copper deposits are regarded as being diagenetic, any ground underlain by the formations listed above should be regarded as favorable. Of those formations, only the Toreva and the Navajo Sandstone occur on the Hopi Indian lands.

Germanium and Rare Earths

Germanium and rare earths are recovered from coal ash of certain coals. Kiersch (1955a) sampled representative coals from Black Mesa to assess their potential as sources for germanium and rare earths. Only trace amounts (less than 0.01 percent) were detected by emission spectrographic analyses. Such trace concentrations are currently of no economic importance.

Manganese

Low-grade disseminated manganese occurrences are found in two geologic settings on the Hopi Indian Reservation:

(1)in the Recapture Member of the Jurassic Morrison Formation throughout the Four Corners Region
(2)in the Jurassic Cow Springs Sandstone on the northwestern flank of Black Mesa

Very little is reported in the literature concerning the first type of manganese occurrence. Two manganese occurrences of the second type are present in the northwest portion of the study area. One deposit occurs four to six miles northeast of Cow Springs Trading Post in approximate Township 35 North, Range 15 East, unsurveyed (Farnham, Stewarts, and Delong, 1961). According to Boyer (1977) the second occurrence lies north of Dot Klish Wash (Figure 2). Wad-like manganese-oxides occur as thin irregular gray to black lenses. The lenses appear locally along several bedding surfaces in a zone 80 to 100 feet below the upper contact of the Cow Springs Sandstone. Harshbarger (1949) noted that manganese bearing lenses can be found in the same stratigraphic horizon for at least five miles. The lateral dimensions of the lenses may be as great as 200 feet, and thickness ranges from a few inches to more than a foot. Disseminations of manganese-oxides averaging 0.51 percent manganese also occur over one area 200 by 1000 feet (Kiersch, 1955a). Although similar deposits could occur in the study area, such occurrences presently lack economic value because of their spotty distribution and low-grade mineralization.

Nonmetallic Minerals

Known nonmetallic minerals on the reservation are limited to clays, shales, sand and gravel, and possibly gemstones. Only sand and gravel and clays are known to have been produced.

Sand and Gravel

Sand and gravel resources on the Hopi Reservation are limited in size and extent, although they have been used locally. The majority of the deposits are in the southwest corner of the reservation. Table 3 shows the location of known deposits such as sand and gravel pits, borrow pits, and sand dunes. Detailed production information was not available for this study.

Sand and gravel resources in the study area were derived from sedimentary rocks of the region and are contaminated with silt, clay, gypsum., coal, humus, and salts which can be easily removed (Kiersch, 1955c). Primary constituents of the gravels are sandstone and shale with lesser amounts of hard limestone, quartzite, igneous rock fragments, and salts. Gravels are more contaminated than the sands. The extent of any deposit and its suitability for a particular use would require an individual site assessment. The gravel resource has not been analyzed in detail for alkali aggregate reaction, and much of the resource may be unsuitable for use in concrete. It may be acceptable for use as road metal.

Sand resources on the Hopi Reservation are extensive (Table 4). Two types of sand are of special interest: glass sands and poultry grit. The glass sands would require treatment to reduce the iron content. Poultry grit can be produced with little or no treatment (Kiersch, 1955b).

Sand and gravel resources in the study area are of sufficient quantity to provide an adequate supply for local usage for the foreseeable future. The resource of special-use sands is very large.

TABLE 4

Sand and Gravel Locations Hopi Indian Reservation.

Type	Sites	Past production*	LATITUDE deg	LATITUDE min	LATITUDE sec	LONGITUDE deg	LONGITUDE min	LONGITUDE sec
borrow pit	1	yes	35	38	20	110	32	33
borrow pit	1	yes	35	48	15	110	29	59
borrow pit	1	yes	35	58	10	110	58	00
borrow pit	1	yes	36	28	34	110	40	47
borrow pit	1	yes	36	29	18	110	23	20
borrow pit	1	yes	36	29	42	110	40	10
borrow pit	1	yes	36	32	05	110	38	55
glass sand	-	no	35	38	40	110	37	30
glass sand	-	no	35	33	10	110	42	50
gravel pit	1	yes	35	31	13	110	05	19
gravel pit	2	yes	35	32	32	110	27	29
gravel pit	2	yes	35	33	08	110	27	16
gravel pit	1	yes	35	33	10	110	27	10
gravel pit	1	yes	35	40	00	110	05	31
gravel pit	1	yes	35	46	38	110	40	35
gravel pit	1	yes	35	48	15	110	05	36
gravel pit	1	yes	36	27	45	110	23	35
poultry grit	-	no	35	52	30	110	14	30
sand dunes	-	no	35	29	30	110	58	30
sand dunes	-	no	35	30	00	110	45	00
sand dunes	-	no	35	31	30	110	30	34
sand dunes	-	no	35	32	35	110	41	30
sand dunes	-	no	35	33	00	110	23	00
sand dunes	-	no	35	35	30	110	55	30
sand dunes	-	no	35	42	20	110	51	30
sandhills	-	no	35	53	10	110	21	10

*Production figures are confidential.

Clay

Clay-bearing strata in the study area include the Bidahochi Formation, Mesaverde Group, and Mancos Shale; the latter two are the most significant, economically. Because these formations are exposed over a large area on the Hopi Reservation, it is assumed that fairly extensive clay resources could be developed. The Mancos Shale and Mesaverde Group have yielded structural clays of good quality (Kiersch, 1955b). Some beds of the Mancos Shale and Chinle Formation may possess bloating characteristics (Kiersch, 1955c) that could allow their use for lightweight aggregate production. The Mesaverde group also contains kaolinized sandstone that may yield kaolin usable as a refractory clay (Kiersch, 1955b).

Gemstones

Petrified wood is commonly found in certain horizons in the Triassic Chinle Formation, particularly in the Petrified Forest Member. Some of the wood is 'agatized' or replaced by colorful banded silica.. The Petrified Forest Member does not crop out on Hopi lands, although the Chinle is mapped in the extreme southwest corner of the study area (Ulrich and others, 1984). It is not known whether the unit carries petrified wood in this area.

Banded jasper is found in the Echo Cliffs area near Cedar Ridge, Arizona. The jasper occurs near the base of the Chinle (Kiersch, 1955b). None is likely to occur on the Hopi Indian Reservation because the basal Chinle does not crop out within the Reservation boundary.

Red pyrope garnets ($Mg_3Al_2Si_3O_{12}$) derived from kimberlitic intrusions are found about 30 miles north of Hopi lands on the Navajo Indian Reservation. Because no kimberlites are known to occur in the Hopi Buttes Volcanic Field (Williams, 1936), little or no potential exists for similar discoveries on Hopi lands.

Similarly, gem-quality olivine ($(Mg,Fe)_2SiO_4$) called peridot, is known to occur in the Navajo Volcanic Field, but little potential exists for peridot in the study area. Olivine-bearing intrusions do occur in the Hopi Buttes Volcanic Field (Williams, 1936), but the olivine crystals are small (rarely larger than 2 millimeters) and most of them are altered to the serpentine antigorite ($(Fe,Mg)_3Si_2O_5(OH)_4$) which detracts from their usefulness.

MAP COVERAGE

The U.S. Geological Survey (USGS) has published topographic maps in 7.5- and 15-minute quadrangles covering the entire reservation (Figure 3). Applicable maps in these series are:

7.5-Minute Quadrangles

Bat Canyon	Garces Mesa SE	Pinon
Bat Spring	Great Spring	Red Willow Spring
Begashibito Canyon	Hard Rocks	Red Slide Peak
Big Mtn. Dam	Howell Mesa	Rocky Ridge NE
Black Mesa Wash NW	Kydestea Spring	Rocky Ridge SE
Coal Mine Mesa	LittleBlack Spot Mtn.	Rocky Ridge SW
Coat Spring	Monument Point	Sand Springs
Cow Springs	Owl Valley	Tonelea
Dinnebito Spring	Padilla Mesa	Whippoorwill Spring
Garces Mesa NE	Pillars of Hercules	Yucca Hill

7.5-Minute Quadrangles (Preliminary)

Leupp NE	Oraibi 4 SW	Polacca 3 NE
Leupp NW	Polacca 1 NE	Polacca 3 NW
Oraibi 1 NE	Polacca 1 NW	Polacca 3 SE
Oraibi 1 NW	Polacca 1 SE	Polacca 3 SW
Oraibi 1 SE	Polacca 1 SW	Polacca 4 NE
Oraibi 1 SW	Polacca 2 NE	Polacca 4 NW
Oraibi 4 NE	Polacca 2 NW	Polacca 4 SE
Oraibi 4 NW	Polacca 2 SE	Polacca 4 SW
Oraibi 4 SE	Polacca 2 SW	

15-Minute Quadrangles

Egloffstein Butte	Oraibi Tovar	Mesa
Keams Canyon	Polacca	White Cone

The USGS has also published base and geologic maps of the State of Arizona, Marble Canyon and Flagstaff 1º x 2º Maps, and Gila River and Grand Canyon 1:1,000,000 scale maps. All listed maps may be ordered from the U.S. Geological Survey, Map Distribution, Federal Center, Bldg. 41, Box 25286, Denver, Colorado 80225.

Land status master title plats and historical indices may be ordered from the U.S. Bureau of Land Management, Arizona State Office, P.O. Box 16563, 3703 N. 7th Street, Phoenix, Arizona 85011; the appropriate township, range, and meridian should be designated.

The Arizona Department of Transportation publishes county road maps of Coconino and Navajo Counties. These are available from the Arizona State Department of Transportation, 1655 W. Jackson, Room 112, Phoenix, Arizona 85007.

The Arizona Bureau of Geology and Mineral Technology publishes a series of county geologic and mineral maps that may be purchased from the Arizona Bureau of Geology and Mineral Technology, 845 North Park Ave., Tuscon, Arizona 85719.

Aerial photographic coverage of the reservation is available from the U.S. Geological Survey NCIC, MS532, 345 Middlefield Road, Menlo Park, California 94025. Satellite imagery can be obtained from the EOSAT c/o Eros Data Center, Sioux Falls, South Dakota 57198.

OUTLOOK

Coal will continue to be a major resource for as long as the deposits can economically compete against other energy resources in the region. The higher quality Wepo Formation coals will probably have to approach depletion before coal from the Toreva or Dakota formations are given serious consideration. The use of coal can satisfy present and future energy demands for many years.

Sand and clay resources are probably substantial but are underdeveloped. It is possible that a structural clay products industry could be created on the Hopi Indian Reservation. This would involve the assessment of economic conditions to identify a product market, definition of product specifications, delineation of reserves of raw materials, and evaluation of site alternatives to optimize costs.

Metallic mineral and uranium resources might be defined by exploration of diatreme or breccia pipe structures.

Additional oil and gas exploration may identify a reservoir in the vicinity of the McCracken Sandstone pinch-out.

RECOMMENDATIONS

No specific recommendations are made for further work at this time. It would be valuable, however, for the tribe to have an assessment of construction materials, particularly bloating properties of the clays and shales on the reservation. An assessment of the glass sand potential would also be valuable. Similarly, an airborne magnetic survey may indicate the presence of breccia pipe occurrences in the Redwall Limestone that are hidden by overlying sediments; such surveys may also indicate areas of disseminated mineralization in sandstone and the location of mineralized diatremes. At such time as the moratorium on exploration is rescinded, oil and gas exploration should be pursued through commercial operators. Information such as this would aid the tribe in making future land-use decisions.

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Table 1. Stratigraphy of Hopi Indian Reservation and vicinity

Era	System	Unit	Description
CENOZOIC	Quaternary		
	Tertiary		
		Bidahochi Formation	
		upper sandstone member	Sandstone with some siltstone, claystone, and tuff.
		volcanic vent deposits	Lava flows and associated spring deposits, with tuff breccia, agglomerate, and lacustrine deposits in maar craters.
		lower calcareous member	Calcareous mudstone, siltstone, sandstone, and minor ryolite. Mostly lacustrine in origin.
		------------ unconformity ------------	
MESOZOIC	Cretaceous		
		Yale Point Sandstone of Mesaverde Group	Tan and brown sandstone.
		Wepo Formation of Mesaverde Group	Alternating beds of olive-gray siltstone, coal, and yellowish-gray sandstone.
		Toreva Formation of Mesaverde Group	
		upper sandstone member	Yellowish-gray to grayish-orange-pink.
		middle carbonaceous mudstone member	Silty sandstone, siltstone and coal.
		lower sandstone member	Light-brown to pale-yellowish-gray.
		Mancos Shale	Light- to dark-gray claystone and siltstone, lesser tan limestone.
		Dakota Sandstone	Tan, brown, and gray sandstone, carbonaceous siltstone, and lenticular coal.
		------------ unconformity ------------	
	Jurassic		
		Morrison Formation	
		Westwater Canyon Member	Yellowish-gray sandstone with conglomeratic lenses.
		Recapture Member	White and brown fine- to medium-grained sandstone, siltstone, and conglomerate.
		Salt Wash Member	White and moderate-orange very fine- to medium-grained sandstone, grayish-red shale, and gray limestone.
		Cow Springs Sandstone	Greenish-gray to light-yellowish-gray fine- to medium-grained crossbedded sandstone.
		Fntrada Sandstone	Reddish-brown fine-grained sandstone and siltstone.
		Carmel Formation	Red sandstone and siltstone.
		Navajo Sandstone	Grayish-orange-pink even-grained highly crossbedded sandstone.
	Triassic		
		Moenave Formation	Orangish-red crossbedded sandstone.
		Chinle Formation	
		Church Rock Member	Reddish-brown siltstone and silty sandstone and grayish-orange-pink mudstone.
		Owl Creek Member	Mottled light-gray and grayish-pink interbedded limestone and calcareous siltstone.
		Petrified Forest Member	Claystone, siltstone, and minor sandstone.
		Shinarump Member	Light-gray to yellowish-gray sandstone and conglomerate.
		Moenkopi Formation	Reddish-brown mudstone, siltstone, and silty sandstone.
		------------ unconformity ------------	
PALEOZOIC	Permian		
		Kaibab Limestone	Yellowish-gray to light-gray silty dolomite, dolomitic sandstone, minor sandstone and dolomitic limestone.
		Toroweap Formation	Light-colored, cross-stratified sandstone.
		Coconino Sandstone	White to light-yellowish-gray medium- to fine-grained well-sorted crossbedded eolian sandstone.
		De Chelly Sandstone	
		upper member	Wedge and trough crossbedded sandstone.
		Supai Group	Dark-red shaly siltstone alternating with buff fine-grained crossbedded sandstone.
	Pennsylvanian		
		Supai Group	Dark-red shaly siltstone alternating with buff fine-grained crossbedded sandstone, limestone and calcareous sandstone.
		------------ unconformity ------------	
	Mississippian		
		Redwall Limestone	
		Horseshoe Mesa Member	Aphanitic locally oolitic or fine- to coarse-grained limestone.
		Mooney Falls Member	Pale-yellowish-brown or brownish-gray dolomite and yellowish-gray or light-olive-gray limestone.
		Thunder Springs Member	Limestone, dolomite and thin beds and lenses of chert.
		Whitmore Wash Member	Dolomite and limestone.
		------------ unconformity ------------	
	Devonian		
		Elbert Formation	
		upper member	Fine- to coarse-grained pelleted dolomite containing minor interbedded shale.
		McCracken Sandstone Member	White to pink, medium- to coarse-grained, medium- to well-sorted quartz sandstone.
		lower dolomite member	Fine-grained to aphanitic dolomite with some gypsum.
		Aneth Formation	Dark gray aphanitic fetid dolomite.
		------------ unconformity ------------	
	Cambrian		
		undivided	

(After Cooley and others, 1969; Haynes and Hackman, 1978; Beus, 1980; and Ulrich and others, 1984)

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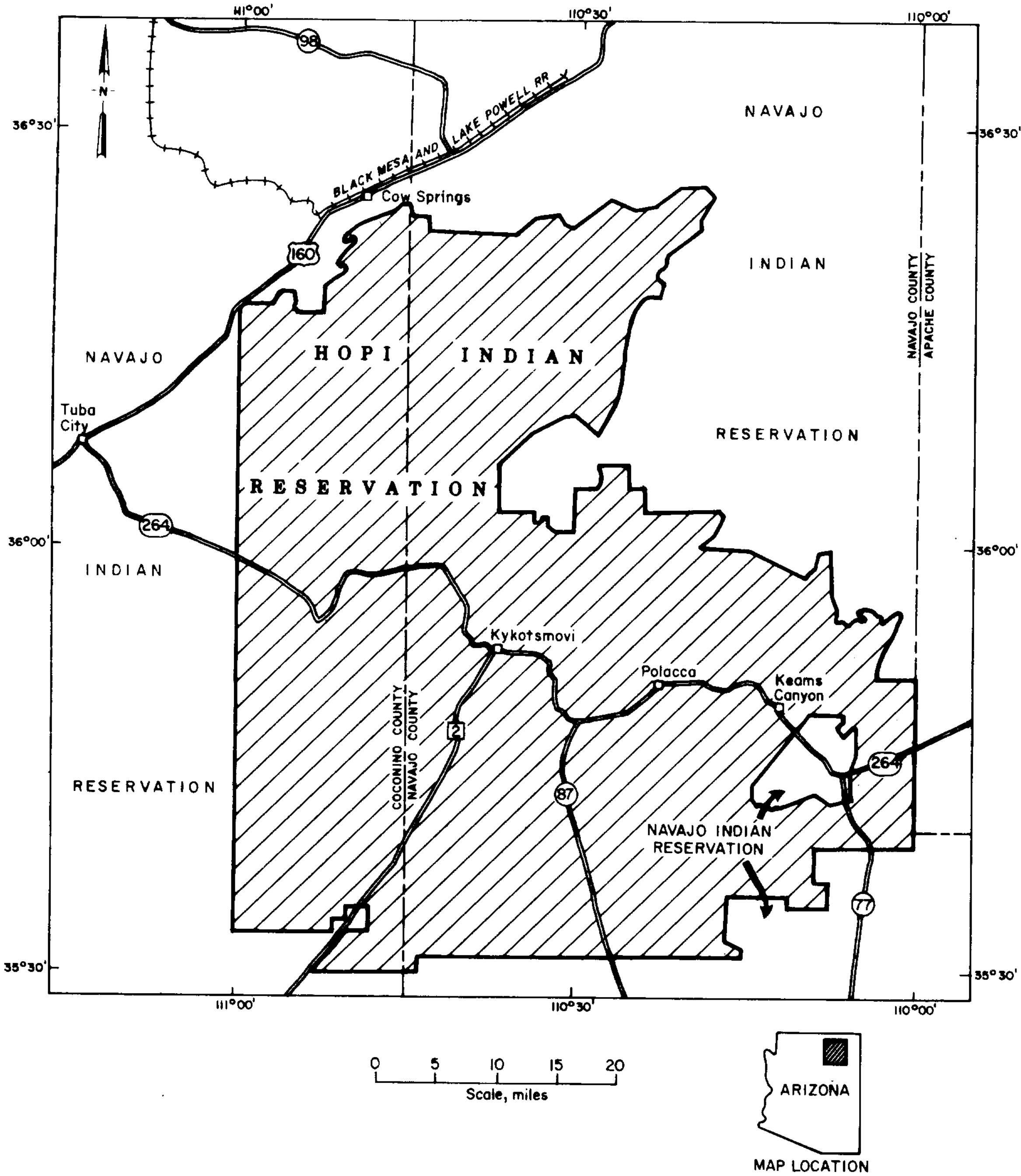

Figure 1. Study area location map - Hopi Indian Reservation.

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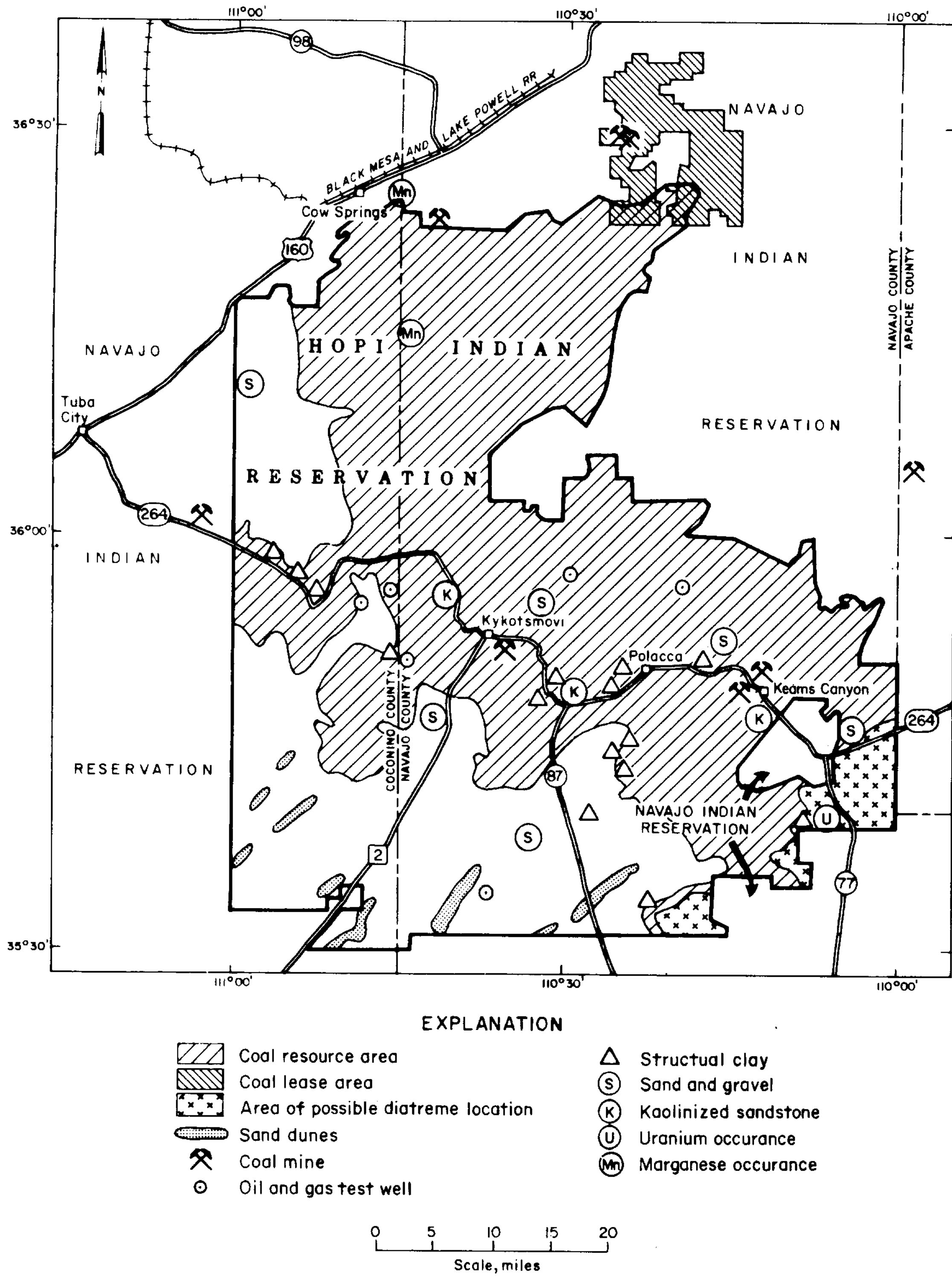

Figure 2. Mineral location map - Hopi Indian Reservation.

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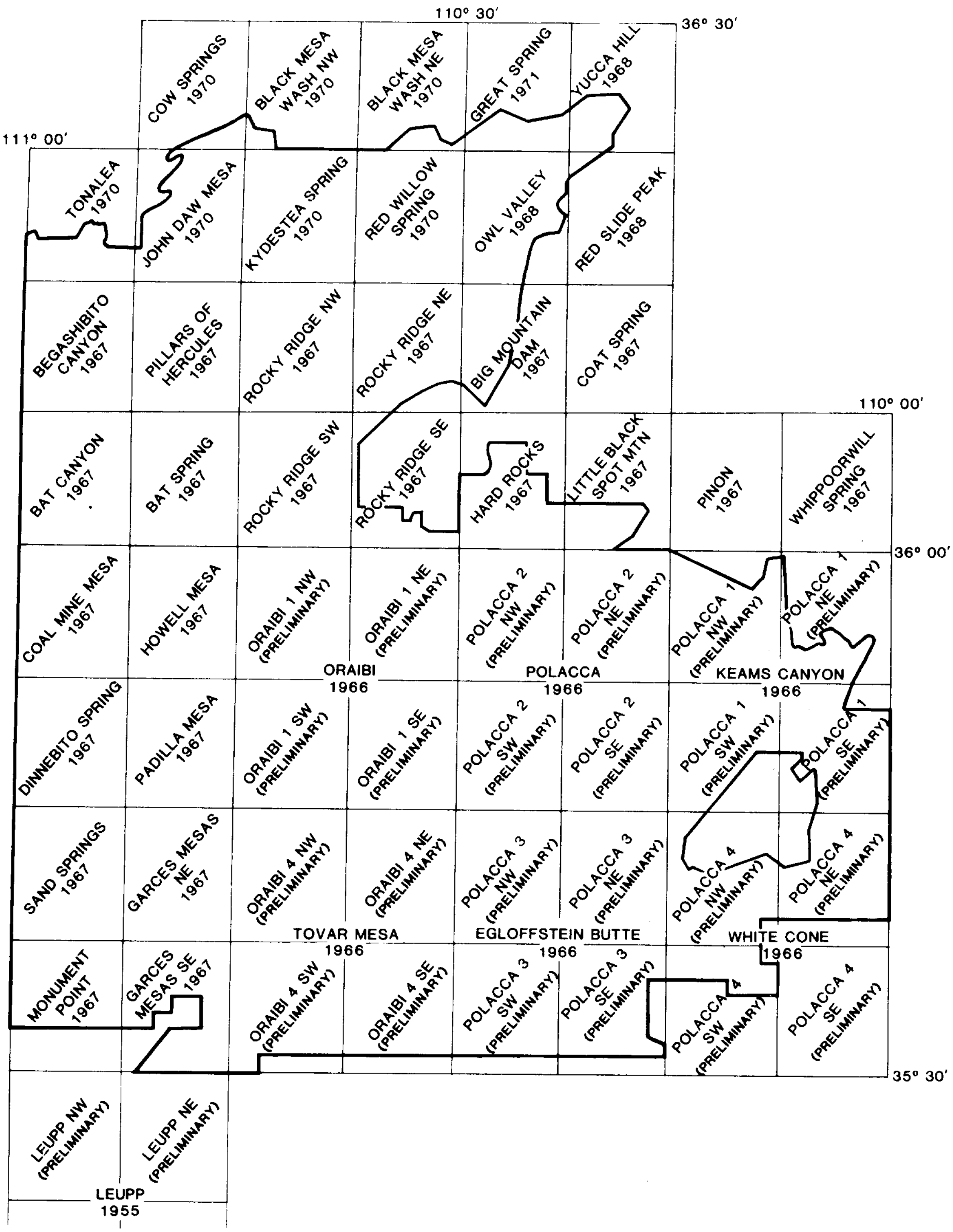

Figure 3. Index to topographic map coverage - Hopi Indian Reservation.