Gila County with the opening in 1921 of the Fort Apache and San Carlos Indian Reservations to nonmetallic mining (Bromfield and Shride, 1956). Production reached a peak in 1920 of 1,200 tons, a rate not duplicated again until 1927–28 (Stewart, 1955, p. 4). A break in the fiber market in 1921 and the depression of the 1930's virtually stopped asbestos mining in Arizona through the midpart of each decade. Mining increased in the late 1930's and by 1940 production again reached 1,200 tons—a level since matched or exceeded in all but a few years at the end of World War II.

The establishment by the General Services Administration in December 1952, of a depot at Globe for the purchase of strategic grades of chrysotile stimulated the local industry from the postwar decline. At the peak of this stimulus at least 16 deposits were producing asbestos or were being developed. Each year since 1962, when the purchase program was terminated, mining has been limited between two and four sites. With few exceptions since 1948 annual production has exceeded 2,000 tons and in several years has considerably exceeded 3,000 tons. Arizona asbestos production by 1966 apparently totaled at least 75,000 short tons of all grades with a value, as of the time of sale, of almost $17 million.

Though mills were built at several mines and used at least briefly prior to 1941, all but a small part of the production to that date was hand-cobbed fiber. Amounts of shorter fibers disapportionate to the content inherent in the ores were recovered in the 1940's because much of the production represents fiber milled from the backfill and mine and mill dumps of earlier operations. As milling became standard to all operations, progressively more of the shorter fibers were recovered, and by the early 1950's most of the recoverable fibers were being won from the newly mined ores. With postwar improvement of roads mill plants have been concentrated at Globe, where power facilities are adequate. Mills built since 1959 have improved greatly on prior cleaning and grading technology, so that recently a much greater variety of grades—especially of the shorter fibers—have become available.

During the first 30 years of asbestos mining, some fairly large (by Arizona standards) deposits of harsh fiber, were discovered. Because the main market was for textile fibers, most of these deposits were not exploited. At times since the early 1950's, however, harsh and semiharsh fibers from these deposits have been an appreciable part of Arizona porduction. Much of this low-iron asbestos has been marketed as a filter material.

Arizona Deposits

The chrysotile-asbestos deposits of east-central Arizona occur in the Mescal Limestone (Precambrian) and are genetically related to small dikes and extensive sills of diabase that were intruded in Precambrian time—about 1.2 billion years ago. Although the Mescal almost everywhere was split by at least one sill, and in some localities was injected at three to five horizons by multiple sills, which range from a few inches to more than 1,000 feet thick, strata generally remained horizontal. As part of the alteration process that accompanied diabase emplacement, the magnesia from the originally dolomitic strata migrated to combine selectively with silica of chert nodules and

layers to form aggregates of tremolite, diopside, talc, and serpentine that are crudely pseudomorphic after the chert masses.

The asbestos occurs as cross-fiber veins in the thin tabular serpentine layers that comprise the bulk of most silicate zones. Although both the lower member (150–170 feet thick) and the overlying algal member (40–130 feet thick) of the Mescal were largely converted to silicate-bearing calcitic (dedolomitized) limestone wherever invaded by diabase, only some of the stratiform serpentine layers contain minable amounts of asbestos. These are the layers that were abundantly fractured where transacted by small-scale thrust and bedding plane faults. Strata were fractured most widely in the vicinity of small domes, monoclines, and other folds, many so open and subtle in outline as to be difficult of recognition. Such faults and folds were formed mainly where strata drape across a discordant step in a sill boundary or where shouldered aside adjacent to dikes. Therefore few deposits are more than 25 feet stratigraphically above or below a diabase sill. The scanty deposits in northern Arizona are similarly disposed in the Bass Limestone, which with diabase sills make up an equivalent Precambrian terrane that is exposed through only a few square miles in the bottom of the Grand Canyon.

Asbestos was mined from about 160 deposits and perhaps another 60–70 occurrences have been explored. Most of the deposits are in two areas in northern Gila County (fig. 46) along the southern fringe of the Colorado Plateau where extensive remnants of the younger Precambrian strata are mostly flat lying. About 90 of these deposits are in the Salt River-Chrysotile area, which covers about 100 square miles, and is 25–35 miles northeast of Globe. There the Paleozoic and younger rocks have been largely stripped away, and the mesa-forming Mescal Limestone—everywhere intruded by sills—is intricately dissected and extensively exposed along the Salt River and its tributaries in canyons ½ to 3 miles wide and as much as 1,800 feet deep. Another 80 deposits are known in the Cherry Creek-Rock House area, which covers about 60 square miles and straddles the 34th parallel between Cherry Creek and Canyon Creek (35–45 miles north of Globe, or 8–15 miles southeast of Young). About 20 occurrences are scattered along rimrock exposures of the southern part of the precipitous Sierra Ancha, where outcrops of the Mescal are narrow and the cover of overlying formations in the intercanyon areas is thick so that little of the Mescal, compared to that in the two principal areas, is accessible for prospecting.

In the asbestos region south of the Colorado Plateau (fig. 46), during Cenozoic time the younger Precambrian strata were much faulted, tilted, and widely stripped away to expose the older Precambrian rocks; many of the decimated remnants are buried under Tertiary volcanics and continental sediments. Because remnants of the Mescal are sparse, asbestos occurrences are proportionally few in southern Gila County and contiguous areas. In these few occurrences much of the asbestos has been deleteriously altered by weathering.

Most of the minable asbestos-serpentine zones are 6–18 inches thick, and contain asbestos veins aggregating at least 2 inches in thickness.

If a large proportion of fiber is Crude No. 2 (longer than three-eighths inch) a zone with veins aggregating as little as 1½ inches can be mined (Stewart, 1961). As previously noted, a high content of long fiber is characteristic: Crudes Nos. 1 and 2 typically make up 20–35 percent of the asbestos, and 50–85 percent of the fibers are longer than one-eighth inch. In several deposits two zones occur within a stratigraphic interval of 4 to 6 feet, so both can be mined from one stope. Locally the entire interval may be serpentinized and asbestos bearing.

The shapes and sizes of the deposits reflect the numbers and trends of the folds in a given area. The typical Arizona deposit is mostly flat lying and elliptical in plan; it is elongated parallel to a single fold or along a belt of low-angle faults. Ore shoots of this simple setting occupy an area of 1,000 to 20,000 square feet and have a potential of 10 to 50 tons of recoverable asbestos; exceptionally such deposits yield a few hundred tons. The most extensive deposits occur where several folds related to diabase intrusions are closely spaced. In these deposits the amplitudes of folds tend to be greater than elsewhere, and parts of the ore bodies are inclined or even segmented and offset where favorable strata were displaced by discordant intrusions. Deposits of this multistructural association yield a few hundred to several thousand tons of asbestos; 10 such deposits have furnished more than 85 percent of Arizona production. Typical dimensions are given in the following enumerations of some of the larger deposits, selected to illustrate the variety of occurrences in the district.

Especially notable among the occurrences of the Salt River-Chrysotile area are the deposits at Chrysotile (fig. 46, locality No. 10). There, discordant steps in sills and dikelike connections between sills repeatedly truncated strata to provide a structural setting very favorable to asbestos localization through an area of almost a square mile. The discordant steps and dikelike connections are arranged in parallel along two trends, northeast and west-northwest, respectively, and are unique to the district. The discordancies, spaced at intervals of 50 to 1,000 feet, are sites of elongate folds, several of amplitude more than 25 feet, which is more than usual, and with limbs that locally dip as much as 20 degrees. At Chrysotile, asbestos has been mined at five horizons in the upper 40 feet of the lower member of the Mescal and at three horizons in the overlying algal member. In the two principal mines, the Victory and Eldorado, ore shoots 300–500 feet wide and as much as 1,000 feet long have been mined at horizons that are one, thirty-three, and thirty-nine feet below the contact between members. The serpentine zones at these horizons are the ones that are most productive throughout the region. There are few other deposits in which all three zones contain minable quantities of asbestos.

The Bear Canyon deposit (No. 11), an isolated occurrence 20 miles southeast of Chrysotile, is in a similar structural setting, but the area in which asbestos can occur is restricted to only a few acres because host strata are isolated in a thick diabase sill.

The American Ores (Asbestos Peak) deposit (No. 6), the largest yet discovered in the Sierra Ancha, is similarly localized where several small elongate folds—all of one trend—parallel discordant intrusions of diabase. This and the Pinetop (Lucky Seven) deposit (No. 9), 25 miles to the east, are the only known large deposits in the algal member of the Mescal.

The Regal deposit (No. 7), another of the larger deposits, is in a much simpler structural setting, one in part so subtly controlled that much of the deposit was long overlooked. During the first 35 years, asbestos was mined only from the north part of the deposit, where it was localized along a belt of small-scale thrust faults where they impinge on a dome about 400 feet in diameter. Where the strata flattened away from the dome the asbestos content of the serpentine zones diminished and further development seemed unwarranted. In 1953, drifts driven to prospect a poorly defined southward extension of the thrust belt showed that the dome merged subtly with a south-southeast-trending monocline, which proved to be the locus of an ore shoot 200–300 feet wide and, at least report, more than 1,300 feet long (Stewart, 1961). This ore body furnished a considerable part of Arizona production in the years 1953–66.

Occurrences in beds in the interval 100-110 feet below the top of the lower member of the Mescal Limestone yielded 15–20 percent of the total asbestos produced in the district; thus, the half dozen deposits in the interval have yielded a highly disproportionate part of the district total. Two of these, the Grandview and the Ladder deposits (No. 8), rank among the largest. They also are exceptional in that they are not localized against folds but are in strata that were thicker than usual and competent to sustain the localizing bedding faults over broad areas. The main Grandview stope, for instance, is as much as 350 feet wide and is more than 600 feet long. These strata are hosts for deposits only along the canyon of the Salt River; elsewhere in the region the equivalent part of the Mescal Limestone is a massive breccia, which is not a common host for diabase intrusions and was not structurally suitable for the localization of asbestos deposits.

Nearly all deposits of the Cherry Creek-Canyon Creek area are in a structurally simple setting that is adjacent to a single discordancy, and are therefore of limited extent. In a few areas, as between Wilson and Walnut Creeks (No. 3), along the upper reaches of Sloane Creek (No. 4) and at Rockhouse (No. 5) several such deposits occur within a small area. Some of these are among the largest of this type that have been found.

Outlook

The future of asbestos mining in Arizona will depend greatly on the approach taken in the search for undiscovered resources. To the present, only a few thousand tons of asbestos have been blocked out ahead of mining. Prior to 1940 such reserves were mainly in deposits that had been developed because minable parts cropped out. Many minable occurrences with only submarginal fringes exposed were accorded desultory exploration and then bypassed. The reserves in these deposits, and those in some deposits previously regarded as too remote or otherwise uneconomic, were delineated during the surge of activity in the 1950's, but in 1968 were largely depleted. As the deposits are metamorphic features that occur wherever suitable strata have been

deformed adjacent to discordant parts of the diabase intrusions, which are virtually ubiquitous with those strata, a great many additional hidden deposits remain to be found. The bulk of future production, if it is to be appreciable, must come from the hidden or "blind" deposits, namely those that are nearest the outcrop and most accessible and most easily found.

These deposits probably are similar in distribution to the known deposits. Their discovery will require the geologic guidance to favorable settings as exploration targets. A fairly high percentage of the blind targets—perhaps at least half of them—will contain asbestos. Only a small percentage of these, however, will be of sufficient size and grade to sustain mining operations.

Minable resources of asbestos in "blind" bodies are probably about equal to past production, or 75,000 tons. If controlling features at several localities are widespread, the potential resources might be twice as great. This estimate is based on an extrapolation of the geologic habits of the known deposits, the controlling geologic features, depth of burial, and the economic factors that may limit exploration and mining efforts.

The Salt River-Chrysotile area is likely to contain more and larger deposits than other parts of the region. The Cherry Creek-Rockhouse area, however, is more amenable to exploration, owing to the pattern of canyon dissection and the generally shallow depths to favorable strata. The rugged terrain and the adverse amount of cover will generally hamper the search for blind ore bodies in the Sierra Ancha. Because remnants of the host limestone are sparsely distributed in the southern part of the region, the odds for finding deposits there are considerably less than in the other areas.

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BARITE

(By D. A. Brobst, U.S. Geological Survey, Denver, Colo.)

Introduction

Barite ($BaSO_4$) is a relatively soft, generally white to gray, heavy crystalline mineral that has a specific gravity of 4.5. It occurs in vein, replacement, bedded, and residual deposits either alone or more com-

monly in association with quartz, chert, jasper, fluorspar, celestite and various carbonate and sulfide minerals (Brobst, 1958, p. 82).

The United States annually consumes between 1 and 2 million tons of barite, of which about 1 million tons is produced domestically and the remainder is imported from many parts of the world. Nearly 90 percent of the barite consumed is ground to minus 325 mesh for use as mud in drilling deep oil wells. The heavy weight of the mud assists in the drilling process and in confining high oil and gas pressures at depth. The other 10 percent is used in a great variety of products or in the preparation of barium compounds. Among these uses of barite are: pigments (lithopone); filler in paper, textiles, linoleum, rubber and asbestos products; heavy aggregate for concrete; paving material; electronic equipment; and the manufacture of ceramics and glass.

The standards of quality vary by use. A barite product for drilling mud must have a minimum specific gravity of 4.25 (about 92 percent $BaSO_4$) and at least 90 percent of the product must be minus 325 mesh. Many other uses require a product that is 95 to 98 percent $BaSO_4$ with not more than minor amounts of iron oxides, silica, and alumina (Brobst, 1960, p. 63). In February 1968, crude mud-grade barite sold for $12 to $16 per ton in carload lots f.o.b. the shipping point and crude chemical grade barite in similar lots sold for about $20 per ton.

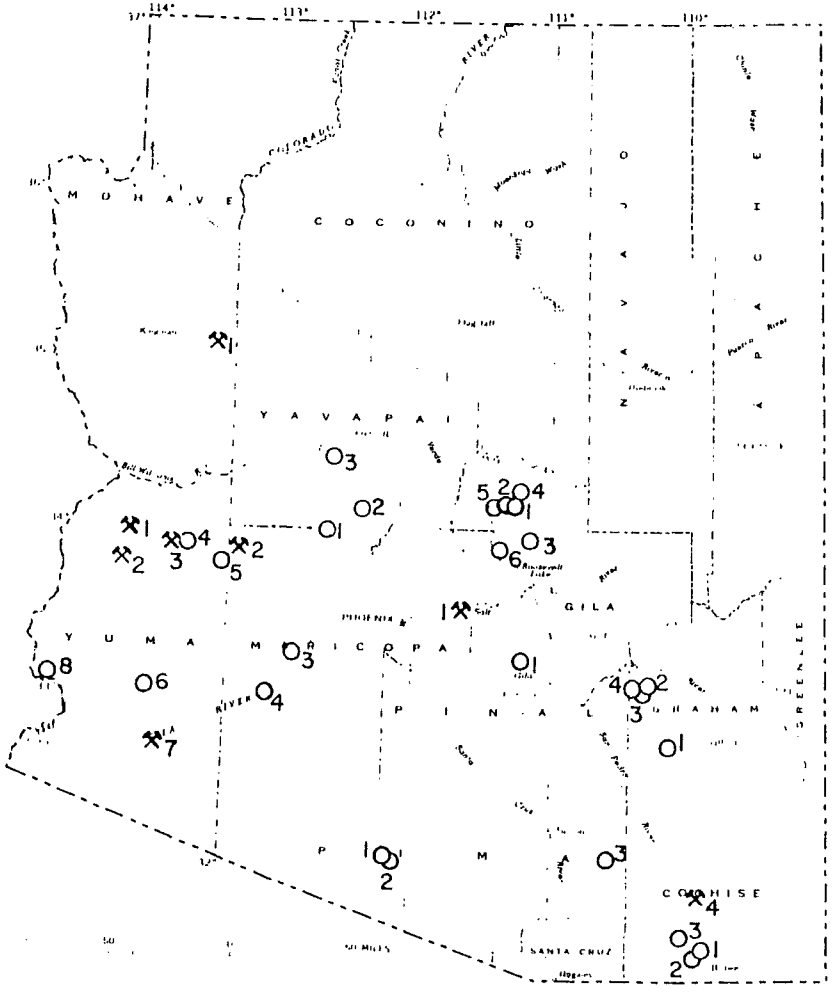
Production

Arizona has produced only about 1 percent of the approximately 30 million tons of barite mined in the United States since 1882. The first commercial barite production in Arizona came from Cochise County in 1925 (Stoll and Santmyers, 1928, p. 110). From available records, Steward and Pfister (1960, table 1, p. 4) estimate that Arizona's barite production between 1929 and 1955 amounted to only about 317,000 tons. About 312,000 tons came from the veins of the Granite Reef (Arizona Barite or Macco) mine, Maricopa County (fig. 47, No. 1) between 1931 and 1955. Eight other mines in five counties yielded the other 5,000 tons. Since 1955 there is no record of barite production in Arizona.

Arizona Deposits

Available data on the geology of 75 barite prospects, claims, deposits, and mines in nine counties of Arizona have been summarized by Stewart and Pfister (1960). Their major groups of barite prospects and mines are listed in table 26 and located in figure 47.

Nearly all of the barite deposits in Arizona occur in veins associated with faults, breccias, and fracture zones. Most of these are in igneous rocks, some are in sedimentary, and a few in metamorphic rocks. The veins generally are only a few feet wide and have been traced for only a few hundred feet in outcrop. Even less is known about the extent of the veins at depth. The barite in most deposits is associated with various combinations of fluorspar, calcite, silica, and ore minerals of base and precious metals.



EXPLANATION

District, mine, or property with recorded barite production

Mine, prospect, deposit, or property with no recorded production

(Numbers refer to localities listed by counties in table 26)

FIGURE 47.—Barite in Arizona.

TABLE 26.—BARITE PROSPECTS, CLAIMS, DEPOSITS, AND MINES IN ARIZONA

[Data from Stewart and Pfister, 1960]

Locality No. in fig. 47	County and property	Notes on barite production
	Cochise:	
1	Ramirez	None reported.
2	Hopeful claim	Do.
3	Ground Hog mine	Do.
4	Johnnie Boy No. 1	Produced about 75 tons in 1932.
	Gila:	
1	Gisela (Spook) deposit	Produced 112 tons near Payson in 1954.
2	Gilmore Spring prospect	
3	Top Hat group	
4	Baronite group	
5	Grey Fox group, Zulu and Green Valley prospects	
6	Lone Pine claim	None reported.
	Graham:	
1	Marcotte group and Graham prospect	Do.
2	Barium King group	Do.
3	Little Mule group	Do.
4	Coronado group	Do.
	Maricopa:	
1	Granite Reef (Arizona Barite, Macco) mine	Yielded 312,000 tons in 1931–55.
2	Princess Ann (Fay L) deposit and White Rock (Bluebird) claims.	Princess Ann produced 100 tons in 1930 and 800 tons in 1950.
3	B and H claim No. 6	None reported.
4	Rawley mine	Do.
1	Mohave: Rucker	Yielded 90 tons.
	Pima:	
1	White Prince claim	None reported.
2	Quijotoa mine	Do.
3	Heavy Boy group	Do.
1	Pinal: Gonzales Pass deposit	Do.
	Yavapai:	
1	MGM claims	Do.
2	French Creek deposit	Do.
3	White Spar claim	Do.
	Yuma:	
1	Bouse district	Black Mountain mine yielded 2,500 tons.
2	Keiser deposit	Yielded 100 tons.
3	Cottonwood Pass area	Ernest Hall property yielded 300 tons.
4	Sterling No. 1 claim	None reported.
5	Norps group	Do.
6	Nottbusch (Silver Prince) mine	Do.
7	Renner deposit	Yielded 900 tons.
8	Silver King claim	None reported.

OUTLOOK

Most of the barite deposits of Arizona cannot be exploited under the economic conditions of 1968. Many of the deposits could yield barite only as a coproduct and such sources are not generally attractive to steady users of barite because the supplies are tied to fluctuating demands for the other products. The preparation of marketable products from complex ores may require expensive beneficiation by flotation, especially if fluorspar is present. Variation in the tenor of the ore, even within deposits, further complicates problems of beneficiation. The barite deposits of Arizona are far from the markets and the high cost of transportation further reduces their value.

The reserves of barite in the vein deposits of Arizona are small. The resources are probably large, but they will not be utilized until there is a considerable change in the economic conditions. Arizona probably does not have extensive deposits of residual barite similar to those in Missouri and the southeastern United States. Arizona has not been thoroughly prospected for deposits of bedded barite similar to those in Arkansas and Nevada.

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BASALT AND RELATED ROCKS

(By S. B. Keith, Arizona Bureau of Mines, Tucson, Ariz.)

INTRODUCTION

In commercial usage, the terms "basalt" and "trap rock" generally denote all types of dense, dark-colored, fine-grained, intrusive and extrusive igneous rocks. Unfortunately, in actual practice and in published reviews and production statistics, even this broad definition is not followed. Basaltic rocks used for dimension stone, for example, are classed as "black granite" and are included with granitic rocks; textural varieties of basaltic rocks, such as volcanic scoria and cinders, have been grouped with pumice; and some basaltic rock has been classified under miscellaneous stone. Thus, production and use statistics on basalt and related rock can only be approximated.

Herein, basalt and related rocks include the normally fine-grained, dark-colored igneous rocks consisting mainly of calcic feldspar and ferromagnesian minerals with little or no quartz and also the less common gabbro and other ultramafic rocks, such as pyroxenite, which although usually more coarsely crystalline, are closely related in most physical characteristics. This classification includes basalt and diabase and also the dark-colored diorites and andesites as well as the various textural varieties of all of the above rocks. Slags resulting from the smelting of metallic ores are often similar, chemically and physically, to volcanic scoria. Although not a natural mineral resource, an important quantity of slag is produced in Arizona at copper smelters so it is briefly reviewed.

Dense basalts are relatively heavy, tough, and durable with colors ranging from dull black to dark gray, green, or purple. Weathering and alteration produce shades of red and brown. Olivine and iron oxides are commonly present. Basalts normally occur as widespread extrusive masses, and exhibit smooth, wavy and ropy or rough, jagged, and clinkerlike surfaces. The term "malpais" (bad land) is applied to lava fields of the latter type. The upper parts of the flows and the volcanic ejecta are commonly vesicular with the irregular open spaces constituting as much as 50 percent of the volume. These voids may be filled subsequently with quartz, calcite, chlorite, or zeolites. Vesicular basaltic rock is called "volcanic scoria" or "volcanic slag." Fragments of scoria less than 1 inch in diameter are called "volcanic cinders." Intrusive basalt is mostly dense and commonly exhibits platy or columnar jointing along which the rock breaks into blocks. Diabase is similar to basalt in composition and mineralogy but is more coarsely crystalline and granular in texture. It generally occurs as sills or thick

flows. Gabbro and ultramafic rocks are even more coarsely crystalline; they normally occur as intrusive masses or mafic segregations in other igneous rocks. Intrusive diorite and extrusive andesite contain some quartz and less calcic feldspar and thus may be somewhat lighter in color. When they contain abundant ferromagnesian minerals, however, they are dark gray or green. Diorite also may occur as segregations in large granitic masses and andesite normally occurs in flows.

Basaltic type rocks are not used extensively for dimension stone because of the dark and somber appearance, the difficulty in making finished products from them, and because of the irregular texture. The toughness of basalt and diabase make the extraction of large blocks difficult except where well-spaced jointing or planes of weakness, known as "rift," are present. Weathered boulders of basalt and diabase are used in wall construction and for decoration and landscaping and, in the past, they were widely used for paving blocks. Some gabbro and ultramafic rocks are prized as dimension stone because of their pleasing color or textural pattern and the ease with which they can be cut or shaped. In recent years, large blocks and panels of basaltic rocks have gained increasing use as bases for high precision optical and electronic equipment. Such blocks permit exacting standards of accuracy in finishing and resist chemical attack and deformation from stress and temperature changes.

Crushed and broken basaltic rocks, volcanic scoria, and volcanic cinders account for almost all the production and use of this class of rock. Where readily available they are important sources of concrete aggregate, roadstone, railroad ballast, riprap, road metal, and cinder blocks. To less extent, they are used in cement manufacture, for road base filtration and filler, and in making rock wool. Volcanic scoria and cinders compete with sand and gravel as construction aggregate. Fused, cast basaltic lining and floor blocks, produced by controlled melting, moulding, and annealing of high-alkali basalt, are finding favor where exceptional resistance to corrosion and abrasion is required. Artificial slag, particularly from iron blast furnaces, is used for the same purposes. Slag from copper and lead smelting is less favored because of its dark color which results from its higher iron content.

PRODUCTION AND USE

Production and use of basalt and related rocks in the United States have increased in recent years, reaching a reported 88.6 million short tons and a value of $147.6 million in 1966 (U.S. Bur. Mines, 1967, p. 577). Because some basaltic rocks are included with granite, pumice, and miscellaneous stone, the actual production of basaltic rocks is several million tons greater than reported, accounting for more than 10 percent of the total U.S. stone output. Arizona's reported production and use of basaltic rocks also is misleading for the same reason. Field observations and reclassification of available data indicate that there has been a growing production and consumption in the past 10 years. Production for 1966 is estimated to exceed 1 million short tons, with a value of more than $1.6 million.

There is little or no interstate commerce in basaltic rocks. Transportation costs are high in comparison with the value of these materials,

so they are seldom quarried and prepared for use without assured markets being within short shipping distances. Thus, production is limited to areas around population and industrial centers, near highway construction projects, and along major railroad lines where bulk shipments to places of use are economically feasible.

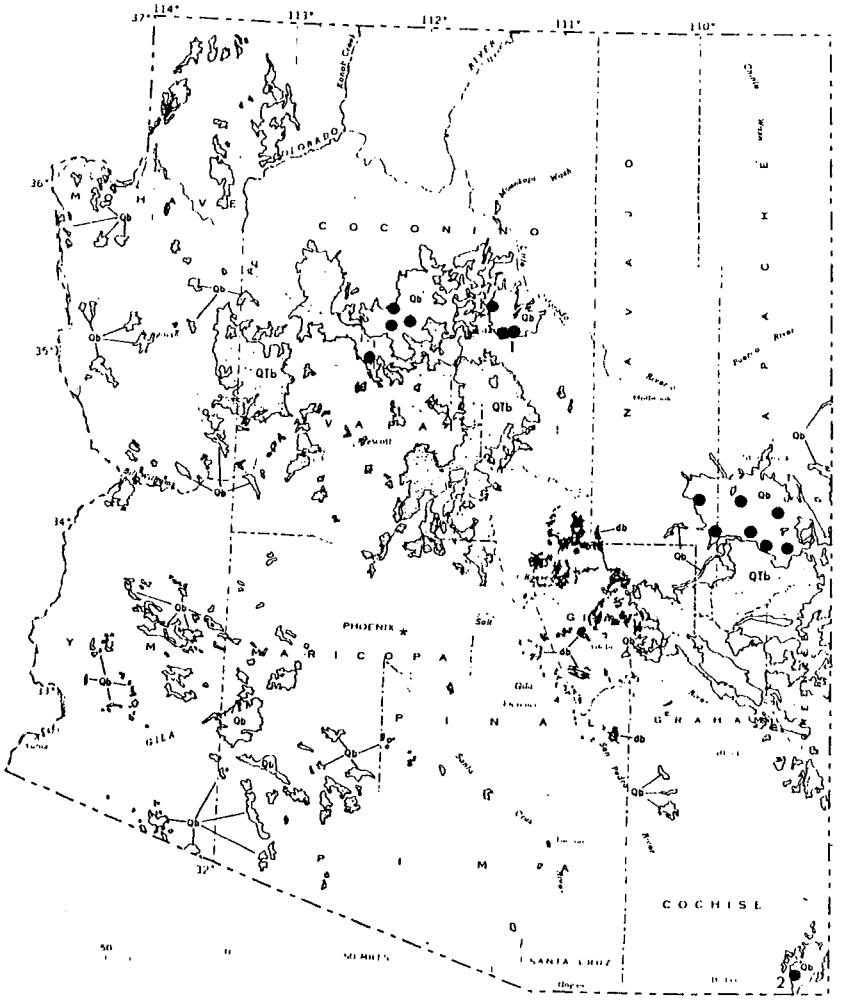
Table 27 lists the reported producers and uses of basalt and related rocks in Arizona in 1966 and the principal source areas and quarries are shown in figure 48. Coconino County supplied about 48 percent of the total with the Santa Fe Railway accounting for nearly three-quarters of that amount. Apache County contributed about 12 percent and the remaining 4 percent came from Yavapai, Navajo, and Graham Counties. Commercial operators, including the Santa Fe Railway, produced about 821,000 short tons which was used mainly for concrete aggregate, cinder block, and railroad ballast. Federal and county highway agencies produced about 214,000 short tons which were used in road construction and maintenance; as this material was not marketed it is indicated as noncommercial in table 27. Roughly 86 percent of this production was represented by volcanic cinder and most of the balance by scoria. An insignificant amount of basaltic blocks and boulders were produced and used for construction, decorative, and landscaping purposes.

TABLE 27.—PRODUCTION AND USE OF BASALT AND RELATED ROCKS IN ARIZONA IN 1966

County and area	Producer	Type of material	Use
Apache:			
Several	Contractors for U.S. Bureau of Indian Affairs.	Crushed basalt and scoria	Noncommercial; concrete aggregate and road metal.
Springerville	Apache County Highway Department.	Crude volcanic cinders	Noncommercial; road material.
Coconino:			
Winona	Atchison, Topeka & Santa Fe Railway Co.	Prepared volcanic cinders	Railroad ballast; also sold for ballast, concrete aggregate, and cinder block.
Flagstaff	Thomas N. Burns	Crude and prepared volcanic cinders.	Crude sold for road construction and prepared for concrete aggregate and cinder block.
	Coconino County Highway Department.	Prepared volcanic cinders	Noncommercial; road material.
	Superlite Builders Supply, Inc.	Crushed basalt scoria	Sold for concrete aggregate.
	Paul Zanzucchi	Crude volcanic cinders	Sold for concrete aggregate and cinder block.
Graham: Safford	Gila Valley Block Co.	Prepared volcanic cinders	Mainly cinder block.
Navajo: Several	Navajo County Highway Department.	Prepared basalt scoria	Noncommercial; concrete aggregate and road metal.
Yavapai: Ashfork	Yavapai Block Co.	Crushed basalt scoria	Concrete aggregate and cinder block.

Sources of Supply

The major center of commercial production of basaltic rocks has been from cinder cones around Flagstaff, Coconino County. The largest producer, the Santa Fe Railway, quarries and stocks volcanic cinders at Winona (fig. 48, No. 1) for its own use as railroad ballast and for rail shipment to other users throughout the State as ballast, aggregate for concrete, and for cinder blocks. Sporadically, smaller commercial amounts have been produced in other counties from north of Phoenix, west and southwest of Tucson, and from areas around Kingman, Ashfork, and Williams. The stone walls around the University of Arizona in Tucson were made with boulders of basaltic



EXPLANATION

Qb — Quaternary basalt

QTb — Quaternary and Tertiary basalt, undivided

db — Precambrian diabase

1 — Quarry

(Number refers to locality mentioned in text)

FIGURE 48.—Basalt and related rocks in Arizona.

scoria obtained locally. Until the railroad line northeast of Douglas was removed, volcanic cinders were quarried and shipped from a cone near the western edge of the large Quaternary basalt lava field in southeastern Cochise County (fig. 48, No. 2). Federal, State, county, and municipal agencies and their contractors have long used basaltic scoria and cinders, where locally available, for highway construction and concrete aggregate. Also, large amounts are being used in the construction of Interstate Highway 40 across northern Arizona. For specific sources of cinders in the Navajo country (see Haff and Kiersch, 1955, pp. 16–27).

The only slags being produced in Arizona are from copper smelters and, though figures on the output are not available, at least several hundred thousand short tons a year are being produced. Only a small fraction of this slag has been used for local road construction, railroad ballast, cement additive, and slag wool. A few hundred tons of slag are purchased yearly by the Arizona Portland Cement Co. of Rillito, Pima County, from the copper smelter at Douglas, Cochise County, as a source of iron for manufacturing portland cement. For a few years in the 1940's, the Paul Lime Plant at Paul Spur, west of Douglas, produced as much as 400 tons of slag wool a month using the Douglas smelter slag, along with locally mined silica, and coke. Reportedly the cost of coke made the operation uneconomic (Wilson and Roseveare, 1949). The Sun Valley Manufacturing Co. of Phoenix produced granulated slag wool in the late 1940's from smelter slag from Superior, Pinal County, basalt from north of Phoenix, and imported coke (Wilson and Roseveare, 1949); there is no known production at present. The old slag dumps at Clarkdale, Yavapai County, have been investigated by several private companies as a source of iron and other metals to be won through novel processes but so far these efforts have been unsuccessful. Varying according to the smelter feeds and flux additives, the slags contain as much as 35 percent iron, 38 percent silica, 10 percent calcium, 8 percent alumina, 3 percent zinc, and a few tenth's of a percent combined copper, lead, and sulfur.

Resource Outlook

Arizona has bountiful resources of basaltic rocks as indicated in figure 48. A major part of them is in large, generally scoriaceous, Cenozoic, lava flows which cover extensive areas in a belt across central Arizona, and in the southwestern part of the State (Ariz. Bur. Mines, 1962a, 1962c). Individual flows range from a few hundred feet to many miles in areal extent and from a few feet to several tens of feet in thickness. Many of these basaltic masses consist of several irregular and uneven coalescing flows that vary from place to place mineralogically and texturally and locally contain interbedded volcanic ash, tuff, agglomerate, and erosional debris. Volcanic necks or plugs are locally prominent and the Quaternary basaltic areas are dotted with numerous cinder cones. Large and small, simple and compound sills and dikes of upper Precambrian diabase occur over a wide area in east-central Arizona (Ariz. Bur. Mines, 1962b). Gabbro and ultramafic rocks are rare in the State, but dark diorite and andesite, Cretaceous to Tertiary in age, are relatively common throughout the

Copper smelter slags are produced at the Phelps Dodge Corp. operations at Douglas, Cochise County; Ajo, Pima County; and Morenci, Greenlee County. American Smelting and Refining Co. and Kennecott Copper Corp. have smelters at Hayden, Pinal County; Magma Copper Co. operates smelters at San Manuel and Superior, Pinal County; and Inspiration Consolidated Copper Co. has a smelter at Inspiration, Gila County. Millions of tons of slag resulting from smelter operations at the United Verde and United Verde Extension properties, occur near Clarkdale, Yavapai County.

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BRUCITE AND MAGNESITE

(By George E. Ericksen, U.S. Geological Survey, Washington, D.C.)

Introduction

Brucite, $Mg(OH)_2$, and magnesite, $MgCO_3$, are found in commercial-size deposits at only a few places in the United States. The principal magnesite deposits are those in the vicinities of Gabbs, Nev. and Chewelah, Wash. Many smaller deposits are in central to southern California and eastern and southern Nevada. In his summary of magnesite and brucite, deposits of the United States, Gildersleeve (1962) lists 62 magnesite occurrences or districts, of which only 7 are outside California, Nevada, and Washington. None is in Arizona. Brucite is much less abundant than magnesite, occurrinig in only a few commercial deposits in the world. The largest brucite deposit in the United States is at Gabbs, Nev., and is associated with magnesite deposits. This deposit has been mined almost continually since 1935. Gildersleeve (1962) lists only five other occurrences of brucite in the United States, of which only the deposits in the vicinity of Oatman, Mohave County, Ariz. (locality No. 6, fig. 49) were estimated to have total reserves greater than 10,000 tons.

The deposits in the Oatman district are the only ones in Arizona that contain potentially commercial amounts of brucite and are the only ones discussed in this report. They contain much less brucite than the Gabbs deposit and are of lower grade. They also contain small amounts of hydromagnesite, $Mg_4(OH_2(CO_3)_3 \cdot 3H_2O$ and magnesite (Galbraith and Brennan, 1959, p. 36; Ian Campbell, unpub. report, 1944). Galbraith and Brennan (1959, p. 36) also reported sparse mag-

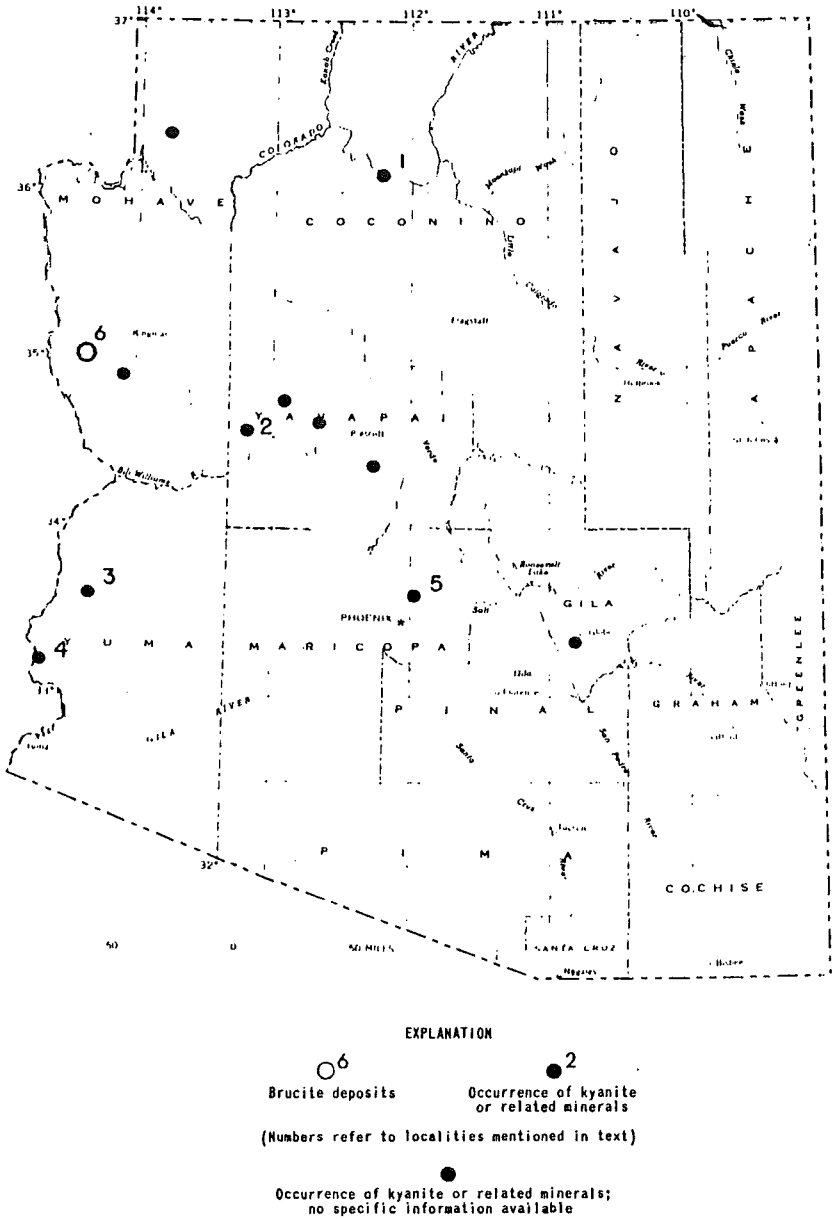

FIGURE 49.—Brucite and kyanite and related minerals in Arizona.

nesite in the Longfellow Limestone in Greenlee County, southeastern Arizona. Seemingly, this occurrence is of mineralogical interest only.

Magnesite and brucite are used to produce magnesia, MgO, for refractory and other purposes, including manufacture of ceramics, textiles, fertilizers, rubber, pigments, glass, chemicals, pharmaceuticals, and paper. During World War II, magnesite from Gabbs, Nev. was used for the manufacture of magnesium metal at a plant at Henderson, Nev. The brucite from Gabbs has been used chiefly in the manufacture of refractories.

Oatman District Brucite

The geology and ore deposits of the Oatman mining district have been described by several reports among which the most comprehensive are those of Schrader (1909), Ransome (1923), and Lausen (1931). The brucite was not recognized until 1943 so the pre-1943 reports do not discuss it. In August 1943 the brucite deposits were studied as part of the U.S. Geological Survey's evaluation of magnesium resources of the United States. The results of the examination, which are on file with the U.S. Geological Survey, Washington, D.C. (Ian Campbell, unpub. report, 1944) contain the only geologic description of the brucite deposits, and are the source of the information used in this report. The deposits were mentioned by Wilson and Roseveare (1949, p. 42) who included some historical information.

The Oatman mining district, well known for its gold deposits, is on the west side of the Black Mountains in western Arizona (fig. 49, No. 6). Gold was first discovered here in 1863 (Lausen, 1931, p. 12). The brucite deposits were explored in 1943 and again in 1953 when a small amount of brucite-bearing material was mined. However, the grade of this material proved to be too low for shipment to market areas on the west coast, and the operation was abandoned (U.S. Bur. Mines, 1956, p. 116). There is no record of further exploration or mining of brucite in the Oatman district since 1953.

Volcanic rocks of Tertiary age crop out extensively in the Oatman district. Wilson (1962, p. 53) reported these rocks to consist of a lower sequence of andesite and trachyte about 5,000 feet thick and associated latite, andesite, and siliceous volcanic flows about 1,600 feet thick. These rocks are unconformably overlain by a sequence of rhyolite flows and tuffs, 1,500 feet or more in thickness. The Black Mountains are in a tilted fault block in which the volcanic rocks strike northward and dip eastward; at Oatman the volcanic rocks dip about 12° E., but to the west they dip more steeply (Lausen, 1931, p. 50–52).

The following summarization of the brucite deposits of the Oatman district is abstracted from Ian Campbell (unpub. report, 1944).

The brucite deposits occur at several places in a northwest-trending belt extending from about 1 to 6 miles northwest of the settlement of Oatman (fig. 49) and in the following claims and locations:

Mag group	Sec. 8, T. 19 N., R. 20 W.
Whitehouse group	Secs. 17, 18, 20, T. 19 N., R. 20 W.
Midnight group	Sec. 8, T. 19 N., R. 20 W.
Pioneer claim	Sec. 16, T. 19 N., R. 20 W.
Moss Wash group	Sec. 25, T. 20 N., R. 21 W.

Table 28 lists chemical analyses of brucite-bearing material from these deposits. From the analyses it is apparent that the deposits contain considerable amounts of calcite ($CaCO_3$) and dolomite ($CaMg(CO_3)_2$, or magnesite, in addition to brucite. Campbell reported the material from the North Star claim to be an impure limestone, and that from the Pioneer claim to be a magnesium marl containing little brucite.

The brucite deposits are layers, as much as 30 feet thick, resting on the Alcyone Trachyte, the oldest unit of the sequence of middle and upper Tertiary volcanic rocks. They generally are overlain by Oatman Andesite, but at several places the brucite layers appear to be within the andesite. Lausen (1931, p. 41–42) discussed alteration of the Alcyone Trachyte, without recognizing the presence of brucite. Evidently he considered the white brucite layers to be kaolinized or serpentinized volcanic rock resulting from fumarolic activity in the newly formed volcanic flows.

The brucite layers show diverse attitudes ranging from near horizontal to dips as high as 70 degrees, but parallel to the enclosing volcanic rocks. The principal deposits of the district, at the Mag claims in the Times Gulch area, trend north and dip as much as 70° E.

TABLE 28.—*Chemical analysis of brucite-bearing material, Oatman district, Arizona*

[Analyses from Ian Campbell, unpublished data, 1944]

Location	Sample type	Drill-core interval (feet)	Composition (weight percent)					
			MgO	CaO	Insolubles	R_2O_3	Ignition loss	
Mag claims (hole No. 1)	Drill core	0.0- 3.0	49.41	8.90	8.86	2.12	29.50	
Do.	do.	3.0- 7.1	56.17	3.70	4.23	1.19	33.59	
Do.	do.	7.1-11.7	60.75	2.30	3.90	.27	33.15	
Do.	do.	11.7-13.5	64.95	.60	2.18	.45	32.78	
Do.	do.	13.5-16.6	59.82	6.90	1.45	1.34	29.65	
Do.	do.	16.6-23.0	67.99	2.30	4.00	1.22	29.90	
Do.	do.	23.0-29.0	50.79	6.00	10.53	3.91	28.84	
					SiO_2	$Al_2O_3+Fe_2O_3$	CO_2	H_2O (+ 105°C)
Whitehouse claims	Grab	---------	47.70	9.40	1.17	1.11	22.30	15.83
Do.	do.	---------	18.57	29.29	16.83	3.08	27.32	4.30
Do.	do.	---------	18.10	31.55	16.67	4.08	23.16	4.22
Midnight claims	do.	---------	23.90	19.73	30.62	7.98	14.24	3.08
Do.	do.	---------	36.90	16.46	8.65	.93	29.04	6.04
Do.	do.	---------	36.62	7.82	36.21	.74	11.69	5.08
Do.	do.	---------	20.47	22.69	21.89	2.14	29.53	2.12
North Star claim	do.	---------	36.89	10.18	1.08	.25	47.92	.16
Pioneer claim	do.	---------	3.86	19.78	48.30	9.22	13.35	1.54
Hoss Wash claims	do.	---------	35.60	12.91	4.00	.37	24.92	21.68
Do.	do.	---------	24.30	25.78	13.22	4.18	29.64	1.21

Fresh brucite ranges from serpentine green to lighter shades of gray green to light gray and almost white. The brucite is cryptocrystalline and dense, breaking with a subconchoidal fracture. The weathered surface is coated with powdery hydromagnesite and is a brilliant white. Weathered surfaces are pitted and cavernous.

Some of the massive brucite layers are as much as 4 or 5 feet thick but most abundant is a thinly laminated material of alternating bands of contrasting shades of green, gray, yellow, and white. This laminated material resembles marl, but it is commonly high-grade brucite.

The grade of brucite-bearing material varies considerably, from place to place, as shown in table 28. The highest-grade and thickest material was encountered in diamond-drill holes in the Mag claims in Times Gulch, about 3 miles northwest of Oatman. Some core segments were nearly pure brucite (MgO 69.12 percent). Deposits in other claim areas are generally thinner and lower in grade than those in Times Gulch.

Campbell estimated that about 40,000 tons of brucite-bearing material was present in the Mag group claims. None of the other claim areas contains deposits of comparable size or grade.

The brucite deposits in the Oatman district are too small and too low in grade to be mined now or in the foreseeable future.

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CLAY

(By Sam H. Patterson, U.S. Geological Survey, Beltsville, Md.)

INTRODUCTION

Clay, when considered as a mineral resource, includes many different types of fine-grained minerals and rocks. The most common use of the term "clay" is for a natural, earthy, fine-grained material which develops plasticity when mixed with a limited amount of water. The term is also used in referring to a definite group of silicate minerals most of which are aluminous, to grain or particle sizes (either

less than 2 or less than 4 microns), and it is also applied to some fine-grained rocks which do not become plastic when wet. Clay resources include such diverse materials as bentonite consisting chiefly of one clay mineral, miscellaneous clays and shales composed of mixtures of clay and nonclay minerals, and the muds used for adobe which may be any of several different types of soil and surficial earthy materials and may contain only minor quantities of clay minerals. Also included in this section is a brief discussion of pyrophyllite, and diopside is mentioned. Neither mineral, as they occur in Arizona, can be considered a clay in the strict sense, but diopside is used in ceramics and, therefore, related to clay with respect to use; and pyrophyllite occurs in clay in other states, and its possible uses are the same as those for which certain types of clay are now produced.

Clays have been mined in Arizona for many centuries and for many purposes. Arizona Indians dug clay for pottery from about A.D. 1000 (Wilson, 1962, p. 100) and were using a red claylike material from near Del Rio (Bartlett, 1939), which is similar to the Minnesota catlinite used for pipestone. They also were making crude adobe block and using earthy materials for mortar prior to the arrival of the Spanish settlers. Adobe was the most common building material under the Spanish influence and for decades following the Gadsden Purchase in 1853, and it is still used for new construction, particularly in rural areas. Brick was made at several places in Arizona in the late 1800's, and by 1915 miscellaneous clay was dug for this purpose at Benson, Douglas, and Naco, Cochise County; Williams and Flagstaff, Coconino County; Alhambra and Tempe, Maricopa County; Snowflake, Navajo County; Tucson, Pima County; Florence, Pinal County; Nogales, Santa Cruz County; and Mayer and Prescott, Yavapai County (Willis, 1915, p. 6). Clay used for brick has also been dug north of Safford, Graham County, and east of Clarkdale, Yavapai County (S. B. Keith, written commun., 1967). In 1949, six brick plants were operating in Arizona, of which three plants were located in Tucson, two in Phoenix, and one at Eager (Wilson and Roseveare, 1949, p. 15). In 1967 the Grabe Brick Co. and the Tucson Pressed Brick Co. were making brick at Tucson, the Phoenix Brick Yard and Wallapai Brick and Clay Products Co. were active at Phoenix, and the Grabe Brick Co. was constructing a plant southeast of Tucson.

Bentonite was first mined in Arizona in 1925 when a carload from the Cheto deposits near Sanders was shipped to New York for use in beauty preparations (Wilson and Roseveare, 1949, p. 15). It has since been mined at three other localities and used for several purposes. Some of the purposes for which bentonite is used include the decolorizing of mineral and edible oils and for other purposes for which it can be classed as bleaching clay or fuller's earth. Though not all bleaching clays and fuller's earths are bentonitic, all those produced in Arizona are bentonite, and the terms "bleaching clay" and "fuller's earth" will not be used for classes of clay in this report.

Fireclay has been mined at a few localities and used mainly in refractory linings of converters in copper smelters and for making light-colored brick. Fireclay is also used in making tile and pots. For the latter use, it can be classified as pottery clay; however, pottery clay includes a wide variety of earthy materials used by the Indians in making artistic objects, principally for sale to tourists.

The suitability of clays for various uses is controlled by physical and chemical properties which are related to the mineral composition. Most clay minerals are chiefly hydrous aluminum silicates, but they commonly contain iron, magnesium, potassium, sodium, calcium, and other ions. The clay minerals that are most common in Arizona include illite, montmorillonite, and mixed-layer minerals; kaolinite, halloysite, sepiolite, and other clay minerals are common locally. All clays contain nonclay mineral impurities; and quartz, cristobalite, feldspar, titanium minerals, carbonate minerals, and mica are common in many clays; and gypsum and organic matter are abundant in others. The value of clays for most uses varies directly with the purity of the clay mineral present; however, for some products nonclay minerals or organic matter having certain properties are important. Physical properties of clays, one or more of which make them suitable for different uses, include plasticity, bonding strength, color, vitrification range, deformation with drying and firing, resistance to high temperatures, gelation, wall-building properties, viscosity of slurries, swelling capacity, ion-exchange capacity, adsorbent properties, and so on. The chemical composition, mineral structure, methods of identification, and testing of various clays for different uses have been summarized by Murray (1960). Books by Grim (1953, 1962) contain detailed information on these subjects, and a report by Klinefelter and Hamlin (1957) outlines many of the laboratory procedures used in evaluating clays.

Production

The total value of miscellaneous clays and shale produced in the State from 1894 through 1961 was $1,725,000, and the fired products made from them during this period were valued at about $11 million (Wilson, 1962, p. 108). During the years 1962 through 1965, the total miscellaneous clay produced in Arizona amounted to 599,000 tons valued at $764,000 (Larson, 1963, p. 102 and 1964, p. 100; Larson and Biggs, 1965, p. 106; Larson and Henkes, 1967, p. 88). During this period, the highest yearly production was attained in 1964 when 168,000 tons valued at $213,000 was produced. In that year, the populous neighboring state of California produced over 3.6 million tons of clay valued at more than $8 million.

The total value of bentonite produced in Arizona from 1925 through 1961 was $24.5 million (Wilson, 1962, p. 108); figures for more recent years have not been released. This total value for the bentonite produced, chiefly from the Sanders-Cheto district, is clearly more than twice the value of all other clays, exclusive of adobe, and the totals for the other clays are for a period approximately twice that of the bentonite mining. Also, most of the bentonite produced has been shipped to distant markets, and most other clays have been used for products consumed locally.

Adobe

Adobe consists of a mixture of clayey earthy materials, straw, and water, which can be formed into blocks and when sun dried becomes hard and durable. The material used in adobe consists of various surficial fine-grained unconsolidated rocks, alluvium, soil, and lake depos-

its, some of which is calcareous or rich in alkali. The chief requirement for adobe is that sufficient clay-size particles be present to form a workable material when wet, and some adobe contains much more sand and silt-size particles than it does clay. Also, too much clay of certain types causes undesirable warping and cracking with drying, and is unsuitable for use in adobe. Adobe dwellings have a reputation of being cool in summer and warm in winter, because they have exceptionally thick walls, and the heat transfer of this material is less than that of other types of building materials. Methods of building construction using adobe have been described by Miller (1949) and Neubauer (1955), and attractive buildings are made from adobe.

A building product consisting of irregular adobe or mud blocks that have been fired or burned has been shipped into Arizona from Mexico in recent years. Fired adobe is used chiefly in construction of homes and other small buildings in Tucson and elsewhere in the State.

Cement and asphalt-bonded adobe have been used on a small scale in some southwestern states. Low cost adobe blocks stabilized with cement have been used in home construction at Sacaton, Ariz. (Wilson, 1963, p. 28), but the author knows of no use of asphalt-bonded adobe in the State.

Bentonite

Bentonite is a clay that has altered from volcanic ash or tuff, and it is ordinarily composed chiefly of montmorillonite. One kind of bentonite known as "swelling," "Wyoming," or "sodium" type has very high swelling capacity, extremely fine particle size, and other properties that make it valuable for use in drilling mud; as a bonding material for foundry sands and pelletizing fine-grained iron ores, where high dry strengths are required; as a relatively impervious lining for reservoirs, irrigation ditches, and stock tanks; and for many other uses. The swelling-type bentonite includes a variety referred to as "hectorite" that contains magnesium and lithium. This type of bentonite is now mined in San Bernardino County, Calif., for use in clarifying wines and other beverages, drilling muds, making preservatives for rope, and for other purposes. A second kind of bentonite called "calcium," "southern," or "nonswelling" type is mineralogically similar to the "swelling" type but has different physical properties and is suitable for different uses. Nonswelling bentonites are ordinarily not as efficient in drilling muds as the swelling type but they are more suitable for bonding materials requiring high green strengths, catalysts used in refining petroleum, bleaching clays, and for other purposes.

Bentonite has been mined in five districts in Arizona (Galbraith and Brennan, 1959, p. 109). Low swelling bentonite has been mined near Sanders and Cheto (fig. 50, No. 1), Apache County, since 1925, and more than 90 percent of the total bentonite that has been produced in the State has been mined in this district. It has been used in making beauty preparations, refining and decolorizing mineral and edible oils, clay-pack filters, coating seeds, DDT powders (Wilson and Roseveare, 1949, p. 15), and for cleansing wool. The principal uses of this clay in recent years have been in making catalysts for refining petroleum and in desiccants. It is shipped to plants in California and Mississippi for processing for catalysts and bleaching clay. A plant processing the bentonite for desiccant use is located at Gallup, N. Mex.

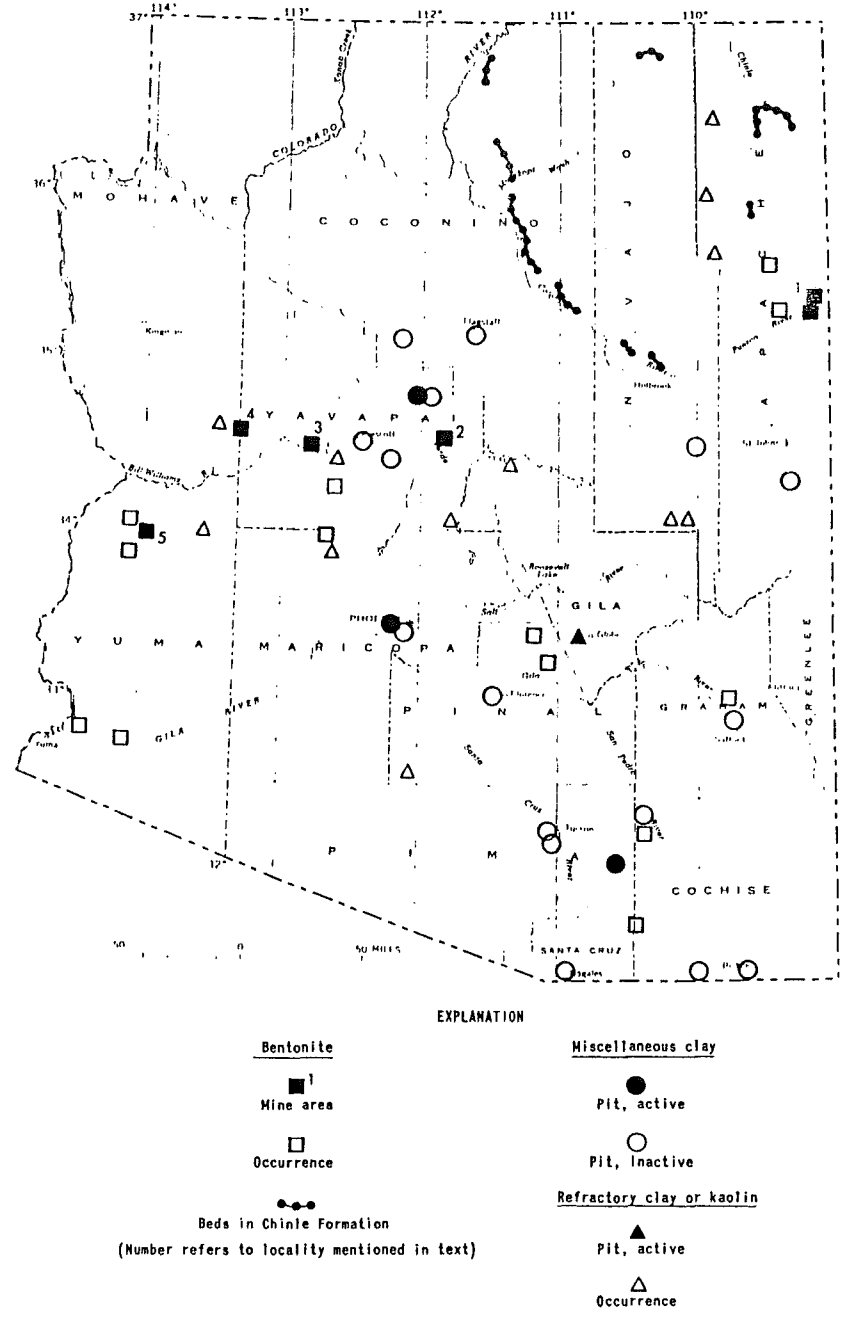

Figure 50.—Bentonite, miscellaneous clay, and refractory clay and kaolin in Arizona.

Bentonite from the Sanders-Cheto district, after processing for use as catalysts and bleaching clay at Los Angeles, Calif., sold for $45 to $165 per ton in 1955, and unprocessed bentonite at the same shipping point was priced at $20 to $25 per ton (Kiersch and Keller, 1955, p. 471). Bentonite has been mined by the Arizona Gypsum Corp. 4 miles southeast of Camp Verde (No. 2), Yavapai County, in recent years for use in bonding ore pellets and in sealing reservoirs, stock ponds, and irrigation ditches (Larson and Henkes, 1967, p. 113). A small quantity of bentonite used for sealing has also been dug from the Lyles deposit (No. 3), 3 miles east of Yava, Yavapai County (Norton, 1965, p. D164). A few hundred tons of bentonite has been mined east of Bouse (No. 5), Yuma County (Wilson and Roseveare, 1949, p. 15). The Bouse bentonite was used in drilling mud, which suggests that it is of the swelling type. Bentonite has also been mined on a small scale by the Udylite Corp. along Burro Creek (No. 4) near the Mohave-Yavapai County boundary, at a point 8 miles due west of Bagdad (Funnell and Wolfe, 1964, p. 65).

The bentonite deposits in the Sanders-Cheto district are in the Bidahochi Formation of Pliocene age. The bentonite occurs in lenses, discontinuous beds, and channel-fill deposits. The bentonite has formed by the alteration of vitric ash of latite composition (Sloane and Guilbert, 1967, p. 1). A few "horses" or moundlike masses of unaltered or partially altered ash or tuff occur within the clay locally. Most of the bentonite mined ranges in thickness from 3 to 5 feet, but in places it is as much as 9 feet thick (Kiersch and Keller, 1955, p. 479). Though underground mining methods have been used in the Sanders-Cheto district, most mining has been by stripping methods. In 1949, the thickness of overburden removed to mine bentonite 6 feet thick was 70 to 85 feet (Wilson and Roseveare, 1949, p. 15). The depletion of clay under thin cover has brought about a less favorable overburden to clay ratio, and in recent years overburden nearly 100 feet thick has been removed in several places.

The bentonite mined near Camp Verde is in the Verde Formation of Tertiary or Quaternary age; the Lyles deposit occurs in lake beds of Cenozoic age; and the deposits along Burro Creek and east of Bouse probably are similar to the Lyles deposit in occurrence. The bentonite along Burro Creek is associated with and developed from rhyolite tuff (Funnell and Wolfe, 1964, p. 65). The origins of the Lyles deposit and those near Camp Verde and east of Bouse haven't been determined, but they may also have been altered from tuffaceous lake beds.

The bentonite in the Sanders-Cheto district is chiefly calcium montmorillonite, and it contains only minor quantities of quartz and feldspar impurities (Sloane and Guilbert, 1967, p. 37). Bentonite in the Lyles deposit consists chiefly of montmorillonite containing magnesium and lithium (Norton, 1965). It, therefore, is probably closely related in mineralogy and chemical composition to the hectorite in California, and it may be found to possess the physical properties that make hectorite valuable. No published information on the type of bentonite in the other deposits that have been mined is available.

In addition to the localities where bentonite has been mined in Arizona, undeveloped deposits occur in several areas (fig. 50). Bentonite is

reported to occur both north and south of Bouse, Yuma County; east of Elgin and 2 miles south of Benton, Cochise County; and 3 miles north of Thatcher, Graham County (Olson and Long, 1957, p. 4). Galbraith and Brennan (1959, p. 109) note bentonite occurs 2 miles northeast of Wickenburg and near Phoenix, Maricopa County; east of the Big Sandy River in southern Mohave County; near Welton, Yuma County; and near Ray and Superior, Pinal County. Bentonite deposits also crop out near Wagoner, Yavapai County, and southwest of Salome, Yuma County (Funnell and Wolfe, 1964, p. 299, 308). The occurrence of extensive deposits of bentonite in the Chinle Formation of Triassic age was first noted by Allen (1930), and this bentonite was later investigated by R. L. Wilson and W. D. Keller (Kiersch, 1955a, p. 21–40). Deposits in the Petrified Forest Member of the Chinle Formation in the Lees Ferry area, Coconino County, have also been described briefly by Phoenix (1963, p. 60).

The resources of bentonite in Arizona are undoubtedly very large, but little is known about the size and grade of individual deposits. The only deposits for which reserve estimates are available are those along Burro Creek, where 1 million tons are thought to be present on claims covering 500 acres (Funnell and Wolfe, 1964, p. 65). The reserves in the Sanders-Cheto district, the State's leading producer, are probably adequate to sustain mining at the present rate for several years. However, reserves in this district are limited, as is indicated by the great thickness of overburden now stripped and the marked thinning of the bed north and northwest of the mines noted by Kiersch and Keller (1955, p. 494). Areas that are favorable for the discovery of valuable bentonite include those where it has been mined and undeveloped deposits are known to occur. Extensive deposits probably occur in the vicinity of Camp Verde, inasmuch as bentonite crops out nearly 5 miles south of the active mine (Twenter and Metzger, 1963, p. 96). Scattered bentonite deposits in the Bidahochi Formation, which contains the bentonite mined in the Sanders-Cheto district, occur in the country north of the district (Kiersch, 1955a, fig. 12), and some of these may be of sufficient size and purity to be mined profitably. Also, bentonitic tuffs are known to be present in recently recognized lake deposits believed to be equivalent to the Bidahochi Formation near Tonalea (Red Lake) Trading Post and Cow Springs (J. C. Wright, oral commun., 1967). This area is approximately 125 miles northwest of the Sanders-Cheto district.

Thick beds of bentonitic material are known to occur in the Chinle Formation at several places, and the total, if it could be estimated, would probably be expressed in billions of tons. Most of this material is so impure that it might be considered a bentonitic shale, and much of it is far from railroads and highways, and, therefore, it has virtually no value. A few tests of the purer beds (Kiersch, 1955a, p. 40), however, indicate that some of the Chinle bentonite does have desirable properties, and valuable deposits may some day be found in this formation.

Refractory Clay and Kaolin

Refractory clay, which is commonly referred to as fireclay, and kaolin are types of clay ordinarily consisting chiefly of kaolinite, $Al_2(Si_2O_5)(OH)_4$. Refractory clay has been mined intermittently on a

small scale in Arizona for a long time. Kaolin probably has been dug at several places, but there is no record of significant production in the State. Refractory clay used for lining converters in copper smelters has been mined in the Copper Queen mine, Bisbee district (Ransome, 1904, p. 17) and the Longfellow mine, Clifton-Morenci district (Willis, 1915, p. 10). Fireclay dug locally is also reported to have been used many years ago at the Old Dominion smelter at Globe (N. P. Peterson, written commun., 1967). A graphitic fireclay, which burned white and was used in converter linings and in making pressed brick, was mined in the Whetstone Mountains near Benson (Willis, 1915, p. 6).

The only fireclay produced in Arizona in recent years (Larson and Henkes, 1967, p. 106) was mined from the Weary Lode No. 2 near Globe. This clay was formed by the alteration of granitic rocks; it occurs along the eastward limb of the Miami fault (N. P. Peterson, written commun., 1967). It is used by the McKusick Mosaic Co. in making tile and art objects, and it also has been mined recently for lining ponds to prevent loss of copper-leaching solutions.

Refractory clay and kaolin occur in several types of rocks in Arizona, and a few deposits have been investigated sufficiently to determine their origins. The deposits in the Morenci district are known to be of hydrothermal origin (S. B. Keith, written commun., 1968), and they may contain the best quality kaolin in the State. The deposits mined in the Copper Queen, Longfellow, and Weary Lode No. 2 mines are in metallic mineral mining districts, and probably are of hydrothermal origin. Other deposits of refractory clay or kaolin that are also presumably of hydrothermal origin occur in the Tombstone and Turquoise districts, Cochise County, and in the wall rock on the upper levels of the El Tiro mine, Pima County (Galbraith and Brennan, 1959, p. 108). A large deposit of refractory material consisting of kaolinite, cristobalite, and quartz, occurring 6 miles north of the Santa Fe Railway's Franconia siding in western Mohave County (Funnell and Wolfe, 1964, p. 82), also may be chiefly a product of volcanic activity and related hydrothermal alteration. Extensive deposits of impure kaolin formed by weathering of aluminous rocks during a Jurassic-Cretaceous interval (Leopold, 1943) occur at several places in northeastern Arizona. Beds in weathered parts of the Cow Springs Sandstone, Westwater Canyon Member of the Morrison Formation, and Mesaverde Group on the Navajo-Hopi Reservations contain 13 to 25.5 percent kaolin (Kiersch, 1955a, p. 73). Other deposits that are probably weathered products of older rocks occur in sandstone and shale of Cretaceous age on the Fort Apache Indian Reservation (Moore, 1967, p. 75–76).

In addition to the deposits previously noted, some of the places where kaolin or refractory clay deposits have been reported to occur in Arizona are as follows. A nonplastic kaolin crops out along the Santa Fe Railroad south of Wickenburg, Maricopa County, and kaolinitic clay was penetrated by wells in the Safford Valley (Olson and Long, 1957, p. 8). A large deposit about 3 miles southeast of Pine, Gila County, was investigated by one company and reportedly it has some valuable properties but contains fine-grained calcite (S. B. Keith, written commun., 1967). Kaolin deposits are also reported to be present near Cave Creek, Maricopa County; 20 miles north of Winslow, Navajo County; in the

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Vekol mines, Pinal County; near Skull Valley and Chalk Mountain, Yavapai County; and southwest of Salome, Yuma County (Funnell and Wolfe, 1964, p. 69–71).

Miscellaneous Clay

Miscellaneous clay includes several types of fine-grained materials used chiefly in Arizona for making brick and other structural clay products, and some is used in portland cement. Most of this material is clay and shale, and it is dug chiefly from sedimentary beds of Tertiary or Quaternary age that were deposited in lakes or local basins. Most of the miscellaneous clay now used in brick is dug near Pantano in eastern Pima County (S. B. Keith, written commun., 1967). The material used is slightly indurated dark gray shale. This shale occurs in a basin about 3 miles long and a mile wide. Some miscellaneous clay used for brick in Phoenix is dug near Tolleson. Both clay and shale are dug from the Verde Formation of Tertiary or Quaternary age north of Clarkdale and used by the Phoenix Cement Co. in making portland cement. Miscellaneous clay in this same formation was the raw material used for brick of which many of the buildings in Clarkdale are constructed.

Only a few clay materials in Arizona have been tested sufficiently to determine whether or not they are suitable for use in lightweight aggregate, a product now made from miscellaneous clays in several other states. Much of the reason for this is that Arizona has adequate resources of natural lightweight aggregate, such as scoria, pumice, volcanic cinder (p. 407), tuff, and perlite (p. 403), so no appreciable demand for artificially bloated clay has developed. The materials that have been tested and may be suitable for use in making lightweight aggregate include the following: (1) a bentonitic bed in the Petrified Forest Member of the Chinle Formation in northeastern Arizona (Kiersch, 1955b, p. 55); (2) sediment deposits in Lake Mead (Gould, 1960, p. 199); (3) clays on the Gila River Indian Reservation, consisting chiefly of illite (Wilson, 1963, p. 28); and (4) miscellaneous clay near Roll, Yuma County (Funnell and Wolfe, 1964, p. 83). The bentonitic clay in the Chinle Formation expands 530 percent when heated to 1,050° C, and after heating at approximately 1,150° C, the Lake Mead sediment ranges in weight from 19 to 24 pounds per cubic foot.

Diopside, $CaMgSi_2O_6$, though not a clay mineral, has been mined on a small scale in Arizona in recent years at the Yellow Flower mine, 20 miles southwest of Aguila, Yuma County (Funnell and Wolfe, 1964, p. 98). This diopside is shipped to California for use in ceramics (Davis, 1967, p. 148), which is the only recorded use of diopside in ceramics, a field ordinarily dominated by clays. It is noted here merely to complete the record of mineral production in Arizona.

Pottery Clay

The only clay mined in Arizona for pottery reported in recent years (Larson and Biggs, 1965, p. 126) is the fireclay used by the McKusick Mosaic Co., Globe. Small quantities of miscellaneous clay are dug at several places and used by the Indians in making artistic pottery pri-

marily for sale to tourists, and a few people active in ceramic hobbies obtain some raw material locally. Several of the refractory clay and kaolin deposits in the State would probably be suitable for use in pottery, if local demands for pottery clay develop.

Pyrophyllite

Pyrophyllite is a hydrous aluminum silicate, $Al_2O_34SiO_2H_2O$, that is now mined in North Carolina and California. It is or has been used in making pencils or crayons, ceramics, refractories, fillers, paints, wallboard, soap, textiles, cosmetics, rubber, battery boxes, welding rod coatings, insecticides, and fireplace hearths. Probably many more uses for it will be found in the future.

According to Galbraith and Brennan (1959, p. 109), pyrophyllite occurs in Arizona near the Alamo crossing of the Bill Williams River and southeast of Yucca, Mohave County; and near Quartzsite and Alamo Springs, 27 miles southeast of Quartzsite; and Bouse, Yuma County. The deposits near Quartzsite occur in schist and are associated with dumortierite (Wilson, 1929). The deposits southeast of Yucca are reported to be large, and those near Alamo Springs are 8 feet wide and extend for 3,000 feet.

Sepiolite (Meerschaum)

Sepiolite is a fibrous hydrous magnesium silicate, which, when occurring in masses, is a lightweight material known as meerschaum (German word for sea-foam). Meerschaum has been used for nearly 200 years in making pipes and other articles for smokers, and small quantities have been used for several other purposes including an absorbent for nitroglycerine. All meerschaum consumed in the United States for many years has been imported from several countries, either in raw form or as finished products. However, a small tonnage of meerschaum was mined in New Mexico in the early 1900's.

Sepiolite occurs in a few places in Arizona as an alteration product of magnesian rocks, and ordinarily it is associated with serpentine or magnesite. Sepiolite has been reported from a locality 42 miles north of Phoenix and 2 miles east of Arizona Highway 69, Maricopa County, and in the Santa Maria River basin west of the McCloud Mountains, Yavapai County (Galbraith and Brennan, 1959, p. 107). The deposits in Yavapai County were prospected by the R. T. Vanderbilt Co., N.Y., but they were found to be too small for commercial production (Kauffman, 1943, p. 512).

Resource Potential and Future Prospects

Only a few generalized inferences can be made about future use of Arizona's clay resources, chiefly because geologic investigations made to date are inadequate for meaningful appraisals. With the exception of bentonite, no large deposits of "high-value" clays are known to occur in the State; however, large areas are still unexplored for clay. Demands for several types of clay for many uses are destined to increase with the population and economic growth and will, no doubt, increase prospecting activity that could lead to the discovery of clay deposits in several parts of Arizona.

The resources of miscellaneous clay suitable for brick and tile and other structural clay products and cement are more than adequate to meet Arizona's needs. Arizona companies will probably continue to rely on their present sources of these materials, but may be forced to seek other deposits as markets develop for new products. The supplies of earthy materials for adobe are virtually inexhaustible, because so many types of fine-grained deposits can be used.

Miscellaneous clays suitable for bloating into lightweight aggregate almost certainly exist in several areas other than those now known, and deposits nearer the population centers may be used for this purpose in the not too distant future. The possible value of the Lake Mead sediment and the bentonitic clay on the Navajo-Hopi Reservations suitable for this purpose is reduced because both are remote from major market areas. The Lake Mead sediment has the advantages of being a renewable deposit and any significant use of it would also serve to reduce the loss of water storage resulting from sediment fill; however, these factors are not likely to offset the costs of shipping a product made from this sediment to distant markets.

The prospects for continued growth of the bentonite industry in Arizona are bright. Though the bentonite resources in the State are now inadequately known and appraised for uses, that large deposits having diverse physical properties exist seems almost a certainty. Demands for bentonite in products for which it is now mined are likely to continue and several new uses may be found. The lithium-bearing bentonite in the Lyles deposit and probably in others, where it is yet to be identified, may be suitable for several "high-value" products, such as those for which California hectorite is now sold. Several new applications of lithium and other types of bentonite are likely to be developed by research on ways of improving products and raw materials in the construction, chemical, petroleum, metallurgical, and other industries.

As no large deposits of high-grade kaolin have been found in Arizona (Wilson and Roseveare, 1949, p. 16), the prospects for major use of this type of clay are limited. Kaolin and refractory clay are known to occur at several places, and sufficient quantities probably exist to fulfill the State's needs for such products as low-heat-duty firebrick of the type used in fireplaces and light-colored facebrick. The possibility that high-grade kaolin, such as that now mined for paper coating in Georgia, does exist in Arizona also cannot be ruled out, and some of the impure kaolin in weathered sandstone and other deposits might be marketable, if a cheap way to beneficiate it could be found.

Other clays in Arizona that would have appreciable value for several uses, if large high-grade deposits are found, include pyrophyllite, sepiolite, and halloysite. The prospects for finding valuable deposits of pyrophyllite are reasonably good, because large deposits of presumably low grade are reported near Yucca and Alamo Springs, and undiscovered high-grade deposits may exist in these and other areas. The prospects for finding large deposits of sepiolite are less favorable, inasmuch as all known deposits are both small and of low grade. Halloysite, a variety of kaolin, is known to occur, in specimen size, in several mines, and large deposits could remain undiscovered or by-

passed by prospectors searching for metallic minerals. Large high-grade halloysite deposits, if found, would have appreciable value for use in making petroleum refining catalysts, a use for which this clay has been mined for several years near Eureka, Utah.

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CORUNDUM

(By D. M. Larrabee, U.S. Geological Survey, Washington, D.C.)

Introduction

Corundum is a very hard natural aluminum oxide having two uses—abrasives and gemstones of precious or semiprecious nature. Emery, another abrasive, is a naturally occurring mixture of corundum, magnetite, and other minerals. Corundum occurs in some igneous and metamorphic rocks, and placer deposits resulting from the disintegration of certain of these rocks have been mined throughout the world. In the United States, such placers are especially well known for minor production of gemstones in North Carolina and Montana.

Domestic corundum has not been mined since World War II, when a negligible amount was produced. The present small domestic demand for natural abrasive corundum is met from production in Africa. Artificial substitutes are harder, more uniform, and ultimately more economic for most uses than the natural product. Gemstones, too, are synthesized, and many are in demand. A small sporadic domestic production of sapphire and ruby semiprecious gemstones has come from North Carolina and Montana. No presently commercial deposits of corundum are known in the Western Hemisphere (Ambrose, 1965, p. 301).

Arizona Occurrences

In Arizona corundum has been reported at an unknown source in northwestern Pinal County. This source may be the deposit in the SE¼ sec. 12, T. 5 S., R. 5 E. that consists of crystalline corundum and associated rutile and quartz. These minerals form irregular masses, as much as several inches in diameter, in felsite dikes that cut granite (Wilson, 1963, p. 19–20). Galbraith and Brennan (1959) reported the presence of red, blue, and white corundum associated with andalusite in a pegmatite dike in the Red Lake area, Mohave County. They also reported corundum from a source rock on the Papago Indian Reservation in Maricopa County. This latter occurrence may be a mistaken location for the one referred to above (R. T. Moore, written commun., 1968).

In general, ultramafic rocks and placers derived from there offer the best sources for prospecting for corundum. Any future production of abrasive quality corundum from the United States, and from Arizona in particular appears practically nil. However, specimens of gem (largely semiprecious) quality might be found in Arizona.

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DIATOMITE

(By H. Wesley Peirce, Arizona Bureau of Mines, Tucson, Ariz.)

Introduction

Diatomite, or diatomaceous earth, is a sedimentary rock composed of a high proportion of the microscopic-sized shells of minute water-dwelling plants, or algae, called diatoms. The frustules, or shells, are siliceous, opallike skeletons containing pores and channelways that give them internal porosity and permeability. There are thousands of species that are distinguished by the frustule characteristics. Diatoms thrive in both ocean and fresh waters that are physically and chemically suited to their growth. In calm waters a constant rain of expired diatoms can result in the accumulation of sedimentary deposits composed of high percentages of their skeletons.

It is estimated that nearly 600,000 short tons of diatomite, valued at over $30 million, was produced in the Western United States in 1966, approximately 80 percent of which came from California while Nevada and Washington produced smaller amounts and Arizona, with one operating property, contributed less than half a percent of the total value. Major uses were for filtration (46 percent), fillers (20 percent), insulation (5 percent), and miscellaneous uses (29 percent) (U.S. Bur. Mines, 1967, p. 469). Hundreds of miscellaneous uses include: absorbents, pesticide carriers, lightweight aggregate, pozzolan, ceramics, floor-sweep, anticaking agents, etc.

Although occurrences of diatomaceous sedimentary rocks in the Western United States are numerous, only selected deposits are exploited. Economic evaluation of the commercial possibilities of any sedimentary sequence containing diatomite is a demanding task that requires the application of technical knowledge. Because of variability of diatomites the suitability of any given deposit for particular uses can be determined only after extensive testing. Diatomite deposits can differ in many ways, including: the distribution of diatom species which control particulate shapes, the nature and distribution of impurities (volcanic ash, sand, silt, clay, chert, carbonates, moisture, and various oxides), and the bulk density, color absorption capacity, etc. Physical setting affects amenability to mining and geographic factors control position with respect to transportation, energy sources, and

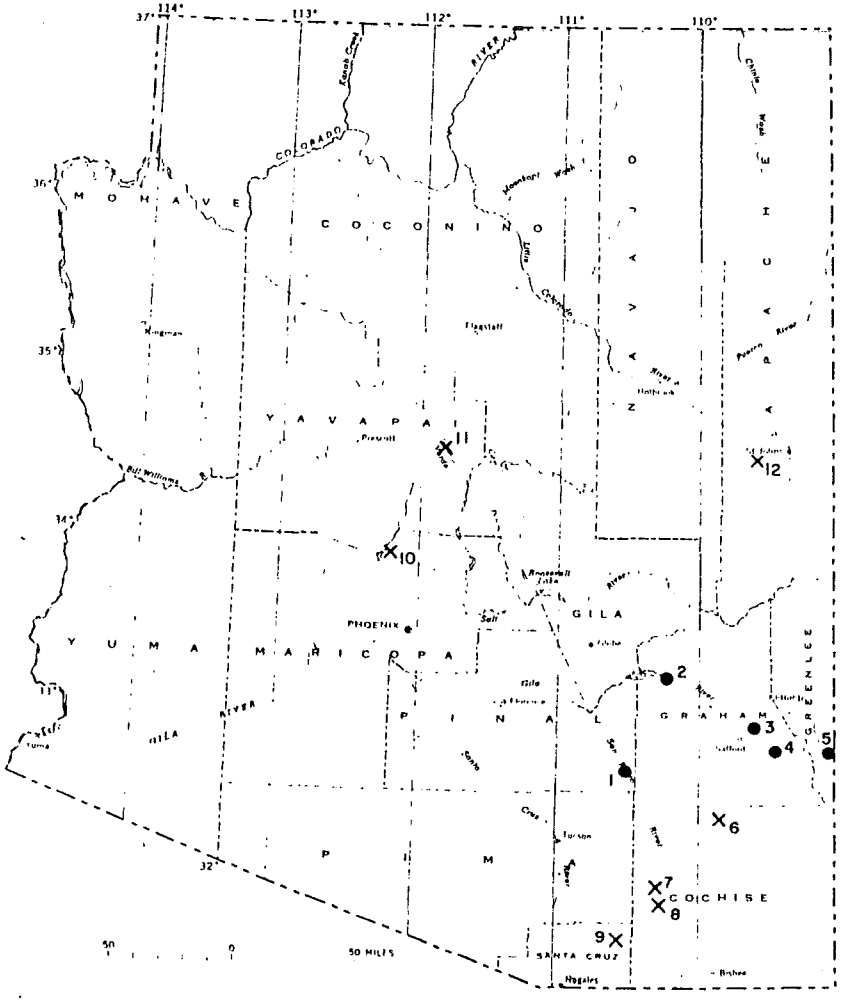
markets. Diatomite is never "pure" so it is necessary to subject crude material to milling processes to remove impurities. Mills, usually designed to produce a variety of commercial products, involve schemes for crushing, grinding, drying, air classifying, packaging, and waste disposal and, in addition, certain higher use products may require calcining or flux-calcining.

Arizona Occurrences

Diatomaceous occurrences in Arizona are associated with sedimentary sequences that accumulated in lacustrine and related environments that, at least locally, prevailed in late Cenozoic time. Concurrent volcanic activity is indicated by the close association between diatomaceous materials and volcanic glass particles (ash). The silica needed for skeletal growth was most likely provided by nearby volcanic activity. All but one of the 12 occurrences shown in figure 51 occur in valleys within the Basin and Range province where they are exposed along canyons and washes tributary to the northwesterly trending main drainage lines.

The Mammoth or White Cliffs occurrence located on the east bank of the San Pedro River in all or parts of secs. 13 and 24, T. 9 S., R. 17 E., and secs. 17–20, 29, and 30, T. 9 S., R. 18 E., in Pinal County (see fig. 51, locality No. 1), is of principal interest because it is the only Arizona deposit with a significant production history. Wilson and Roseveare (1949, p. 18) indicate that production took place in the 1920's, and intermittent production efforts have continued to the present time. Although there is no reliable figure for total cumulative production, the Arizona Bureau of Mines estimates that it is about 15,000 short tons. In 1966, the Arizona Gypsum Corp. produced 1,353 short tons of product that was valued at about $135,000 (Larson and Henkes, 1967, p. 89), and indications are that the output increased in 1967. Crude diatomite was processed in a mill capable of producing 4 to 6 tons per day. Products are made by various combinations of grinding and air separation procedures. Important local uses for diatomite products have been as a carrier for insecticides, an additive to cement, and as an anticaking agent in ammonium nitrate fertilizers.

Blake (1903) called attention to this locality and noted that the white cliffs contained both ash-bearing and diatomaceous sedimentary units. Trischka (1929, p. 13) and Olson and Long (1957, p. 9) have also provided brief preliminary comments about this locality, but a thorough study of the occurrence has not been made. Stratigraphically, Heindl (1963, p. 21) places the diatomaceous sedimentary rocks in the Quiburis Formation of Pliocene and Pleistocene age. Recent preliminary examinations by the Arizona Bureau of Mines indicate that the exposed white to light-colored sedimentary sequence is at least 140 feet thick and that, as pointed out by Blake (1903), the sequence consists only partly of diatomite. Crude diatomite of varying quality is interbedded with mudstones, siltstones, and tuffaceous materials. These strata have been subjected to some faulting and folding and are tilted a few degrees to the northeast and truncated at the top by an erosion surface that cuts out older units to the southwest. Prospecting has been done by examining and sampling natural exposures, trench and tunnel



EXPLANATION

●1 Major occurrence

×6 Minor occurrence

(Numbers refer to localities listed below and referred to in text)

1 Mammoth or White Cliffs	7 Post Ranch
2 San Carlos Reservation	8 Curtiss
3 Solomon	9 Huachuca
4 Whitlock Hills	10 Lake Pleasant
5 Duncan	11 Verde
6 Willcox	12 Concho

FIGURE 51.—Diatomite in Arizona.

exposures, and by developing small quarries which have been opened in several places on the property. However, considering the large size of the area that is underlain by diatomaceous materials, additional detailed exploration will be required before the distribution of the thickness and grade of crude diatomite will be determined with confidence. Also, determination of appropriate uses and potential markets will require a continued study.

The diatomaceous sedimentary rocks of Cenozoic age that crop out on the San Carlos Indian Reservation between Peridot and Bylas along State Highway 70 in Graham County (No. 2) have been generally described by Bromfield and Shride (1956, p. 683) and Long and Olson (1956, p. 14). The strata have been disturbed by faulting and are covered by overburden, the amount generally increasing northward toward the Gila Mountains. Again, it is emphasized that all white material is not diatomite as the diatomaceous units are interbedded with light-buff to white limestone beds. There is no recorded commercial production from this area.

Trischka (1929, p. 13) and Olson and Long (1957, p. 17) report that diatomaceous strata crop out about 10 miles north of Solomon and north of the Gila River in Graham County (No. 3). This occurrence is limited in extent and has not been commercially exploited.

Further to the southeast diatomaceous strata crop out immediately northwest of the Whitlock Hills in secs. 21–23 and 26–28, T. 8 S., R. 28 E., and also in Graham County (No. 4). Knechtel (1938, p. 196), Van Horn (1957), Mathias (1960, p. 13), Olson and Long (1957), p. 19), and Seff (1962) have commented on this occurrence. Seff studied the stratigraphic sequence in detail and suggests that the diatomites contain considerable impurity and that individual diatomaceous units change character laterally. Although there is a relatively large area underlain by strata that contain diatomaceous materials, surface exposures do not offer strong encourgement for the development of high quality crude diatomite. An exploration program involving drilling and trenching would be required to further evaluate the subsurface potential.

Olson and Long (1957, p. 21) and Heindl (1958, p. 233) record the occurrence of diatomaceous strata on the north side of the Gila River just north of Duncan in Greenlee County (No. 5) where light-colored diatomaceous strata crop out in low cliffs. Apparently these materials are not of sufficient quality to stimulate development.

Other occurrences of diatomaceous materials have been reported but details are not known. Although McCrory and O'Haire (1961) show an occurrence of diatomite near Willcox in northern Cochise County (No. 6) information about it is lacking. Gray (1965, p. 128) measured a stratigraphic section on the Post ranch in sec. 27, T. 17 S., R. 20 E., Cochise County (No. 7) that includes a diatomaceous unit 5 feet thick. This unit, according to Gray, has been quarried for lightweight building block and for scouring powder for local use. Trischka (1929, p. 14) reported a deposit near Curtiss, in Cochise County, 3 or 4 miles west of the San Pedro River (No. 8). He characterized the material as being 4 to 8 feet thick and of "excellent quality." Trischka also reports an occurrence of diatomaceous material in the northwestern foothills of the Huachuca Mountains, Santa Cruz County (No. 9). However, he

concludes that the deposit is too "impure" to be considered of "present" (1929) value.

Larson and Biggs (1965, p. 127) reported that a small quantity of diatomite was produced in 1964 from near Lake Pleasant in northern Maricopa County (No. 10). Apparently the occurrence is associated with local exposures of Cenozoic lake beds (Wilson and others, 1957).

Diatomaceous strata have been reported from the Verde Formation which occupies the floor of the Verde Valley in Yavapai County (No. 11 (Olson and Long 1957, p. 25). They report that the diatom-bearing strata crop out south of Camp Verde and are intimately associated with calcium carbonate. Apparently the diatomaceous material is not of desirable quality for development. In the Colorado Plateaus province diatomite is present in remnant exposures of Tertiary strata exposed along Concho Creek south of Concho in Apache County (No. 12). Approximately a 6-foot thickness of diatomite is exposed but it is capped by basaltic rocks that obscure the lateral continuity away from the exposure. Published statements, such as in Wilson (1940, p. 4), have suggested that Blake (1903) reported a separate diatomite locality near Reddington, Pinal County. This was not Blake's intent and the error stems from a misinterpretation of Blake's description of the location of the Mammoth or White Cliffs deposit (No. 1).

Outlook

Diatomite is a potentially valuable mineral resource that is currently being produced in Arizona in a small way. The peculiar and unique properties of diatomite products have been utilized in a multitude of ways by industry. Expansion of diatomite production in Arizona is contingent upon increased industralization, a continuing search for new markets, the development of a wide range of marketable products, and exploration designed to locate and evaluate the best available deposits of crude diatomite. Diatomite-based products are produced in the West and consumed by eastern U.S. industry. Arizona is in a competitively favorable geographic position, but thus far the State's diatomaceous material has not been proven to be able quantitatively or qualitatively to support the large-scale production of a wide range of competitive products. It is likely, however, that Arizona deposits, especially in the Mammoth region, will eventually be subjected to more detailed exploration and evaluation, which could lead to expanded diatomite production.

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FELDSPAR

(By S. B. Keith, Arizona Bureau of Mines, Tucson, Ariz.)

Introduction

The feldspar minerals form a group of anhydrous aluminum silicates of potassium, sodium, and calcium. The potassium feldspars, orthoclase and microcline, have a composition of $KAlSi_3O_8$ but different crystal habits. Sodium may replace as much as half of the potassium in orthoclase and more than half in a type of microcline called "anorthoclase." Both orthoclase and microcline have a vitreous luster, a hardness of 6, and a specific gravity of about 2.57. Colors range from white to shades of gray, yellow, and red. The sodium and calcium feldspars, called plagioclase, form an isomorphic series ranging from albite ($NaAlSi_3O_8$) at one end to anorthite ($CaAl_2Si_2O_8$) at the other. The intermediate members oligoclase, andesine, labradorite, and bytownite, are arbitrarily defined by the proportions of contained albite and anorthite. Potassium usually replaces some sodium near the albite end of the series. Plagioclase feldspars are vitreous to pearly and have a hardness of 6. Their specific gravity ranges from 2.62 for albite to 2.76 for anorthite. They may be colorless, white, gray, or shades of green, yellow or pink. The potassic and sodic feldspars usually contain admixtures of each other and often small amounts of free quartz. Graphic granite is an intimate intergrowth of orthoclase and quartz. Perthite is an irregular intergrowth consisting of alternating bands of albite and microcline.

The feldspars are the most abundant and common minerals in igneous rocks and also in some metamorphic rocks, such as gneiss. The potassium feldspars occur mainly in granite, syenite, and their effusive equivalents. Feldspars may compose as much as 60 percent of the min-

eral content in those rocks. The sodic feldspars are the predominate type in granodiorite, diorite, dacite, and andesite. Basalt, gabbro, anorthosite, and norite characteristically contain the more calcic feldspars. In some rocks, the feldspars are fine grained and intimately intergrown with other rock-forming minerals. In others, some of the feldspars occur as phenocrysts. More rarely, in certain igneous masses and dikes, the feldspar and other minerals attain larger than normal size. Such rocks, called "pegmatites", are a principal source of feldspar.

Aplites are fine-grained, mineralogical equivalents of pegmatites. Alaskite is a term used for crystalline rock consisting mainly of orthoclase and microcline with subordinate quartz. Another mineral family, the feldspathoid group, forms in place of feldspar in certain rocks rich in potassium, sodium or calcium but deficient in silica. The most common mineral of this group, nepheline (Na,K) $AlSiO_4$, along with the potassium and sodium varieties of feldspar, are the most important commercially. They are used with other materials in the manufacture of glass, pottery, enamel, tile and other ceramic products where they promote fusion during firing and impart strength, toughness, and durability to the finished products. Ground feldspar is used also as a mild abrasive in scouring powders, soaps, and sweeping compounds; as a binder and filler in hard abrasive products; and in high-temperature coatings and cements.

Feldspar has been used in the manufacture of vitrified products for many centuries throughout the world. It was mined in the eastern United States before 1800 and was being processed for use in this country by 1850. The feldspar industry has grown quite steadily since that time and its use has increased in a variety of products. Early production was from selected, hand-cobbed, pegmatite material, but with the development of new processing methods, such as flotation and electrostatic separation, good recovery of feldspar from finer-grained and less well-segregated material was made possible. At the same time, technological developments in the uses of feldspar permitted the substitution of nephaline-rich rocks from eastern Canada, feldspar-rich mixtures associated with quartz in aplites and graphic granites, and even fines derived from processing granites. There are some large mining operations by major producers but many small pegmatite operators contribute to the total output. The largest share of the feldspar industry is still centered in the eastern United States, but since feldspar is a relatively low value mineral, and transportation costs limit the distances it can be economically shipped, users on the Pacific Coast depend largely on production from the Rocky Mountain region and California.

Production

In 1966, United States production of crude feldspar was about 686,000 long tons valued at a little over $7 million. Two-thirds of this amount came from flotation concentrates and the balance was obtained about equally from hand-cobbed and from milled feldspar-silica mixtures. Glass and ceramic products consumed 89 percent.

Arizona has had only one consistently productive feldspar operation. G. I. Taylor started shipping crude feldspar in 1923 from a pegmatite deposit on the east side of the Cerbat Mountains, north of Kingman. In 1924, the deposit was sold to the Kingman Feldspar Co. which increased production to several thousand tons per year. The Consolidated Feldspar Corp., subsequently taken over by International Minerals and Chemical Corp., built a grinding and processing mill 1 mile east of Kingman in 1931 and acquired ownership of the mine. Production has been continuous since that time. Arizona's output of feldspar has not been disclosed but Wilson and Roseveare (1949) estimated about 100,000 short tons of crude and, or, ground feldspar, valued at $1,850,000 were sold prior to 1945. Since that time, production has remained remarkably steady and the amount of ground feldspar sold is estimated to be over 250,000 short tons with a value of more than $6 million. The feldspar has gone mainly to California for pottery ware with only minor amounts shipped to the Midwest and foreign markets. Arizona's annual production is less than 2 percent of total U.S. production.

Arizona Deposits

Pegmatites are the only known commercial source of feldspar in Arizona. They occur in many parts of the State but mainly in the older crystalline rocks exposed within an irregular, southeastward curving belt extending from Lake Mead, Mohave County, to Cochise County. Many of the pegmatites within this belt have been studied or prospected but few have warranted development and testing for possible commercial feldspar production.

Table 29 lists and figure 52 shows the location of reported occurrences of feldspar that are considered as possible resources. Tenney (1928, 1930); Hewett, Callaghan, Moore, Nolan, Rubey, and Schaller (1936); Jahns (1952); Heinrich (1960); and Olson and Hinrichs (1960) have noted or described some of the larger feldspar-bearing pegmatite deposits in the northwestern part of this belt. Wilson (1963) described intergrown feldspar and quartz in pegmatites in the Sierra Estrella area of the Gila River Indian Reservation but did not consider the feldspar to be commercially important. Olson and Long (1957) and Tenney (1936) noted occurrences of feldspar in various locations in Gila, Maricopa, and Yavapai Counties and Funnell and Wolfe (1964) cited occurrences in Yavapai County. Larson (1963, p. 117) reported that feldspar-silica mixtures, containing 70 percent feldspar, were mined from the San Antonio mine, near Ajo, western Pima County. No details are given or known on most of these reported feldspar occurrences and many of them may not be of the pegmatite type.

The only deposits that appear to be of commercial interest are the Taylor deposit near Kingman and the ones in the White Picacho district (fig. 52, localities Nos. 1 and 2), which are described below.

The Taylor deposit is in a pegmatite body, which trends northeasterly, is at least 1,500 feet long, and in places is more than 200 feet wide. The pegmatite dips steeply east and has been mined to a depth of about 100 feet without noticeable change. It was intruded into a medium-grained granite that is locally gneissic and porphyritic. A flat-lying di-

TABLE 29.—*Feldspar occurrences in Arizona*

Locality No. in fig. 52	District, mine, or area	Location	Description and remarks	References
1	Taylor mine	Sec. 26, T. 22 N., R. 17 W., Mohave County. 5 mi. N. of Kingman.	See text. Constant producer of feldspar and quartz since 1923.	Heinrich, 1960, p. 5-7; Olson and Hinrichs, 1960, p. 194-196; Ariz. Bur. Mines, file data.
2	White Picacho district	Tps. 6, 7, and 8 N., Rs. 2 and 3 W., Maricopa and Yavapai Counties, E. of Wickenburg.	See text. Partly developed and mined but no commercial sale of feldspar.	Jahns, 1952.
3	Pinal Mts.	Approx. Tps. 1-2 S., Rs. 14-15 E., Gila County. SW. of Globe.	No data. Undeveloped.	Olson and Long, [1957], p. 12-13.
4	Aguila	Approx. T. 7 N., R. 7 W., Maricopa County.	No data. Undeveloped.	Do.
5	Hualpai Mts.	T. 20 N., Rs. 14-15 W., Mohave County. SE. of Kingman on NE. slope of mountains.	Pegmatite dikes in Precambrian granite gneiss. Small amount hand sorted by Consolidated Feldspar Co. and shipped to Los Angeles.	Tenney, 1930, p. 105; Moore, 1936, p. 170.
6	Painted Desert	T. 30 N., R. 22 W., Mohave County. About 4 mi E. of Hoover Dam.	Abundant feldspar in 1-3-ft-thick pegmatite dike in Precambrian granite gneiss. Prospected but no commercial production.	Olson and Hinrichs, 1960, p. 192-193.
7	M and P claims	T. 28 N., R. 17 W., Mohave County. Above Hackberry Wash at base of Garnet Mtn.	Irregular pegmatite, 200 ft long by 60 ft wide, with coarse-grained potassium feldspar, perthite, quartz, muscovite, garnet, biotite, and hematite in Precambrian granite gneiss. Mined for sheet mica, 1943-45. No feldspar production.	Olson and Hinrichs, 1960, p. 193-194.
8	Cerbat Mts.	T. 22 N., R. 17 W., Mohave County. 5 mi. NW. of Kingman on SW. side of mountains.	Feldspar-rich pegmatite dikes in Precambrian granite gneiss. One dike over 225 ft long and 40 ft wide with at least a 40 percent potassium feldspar content. Prospected but not mined.	Olson and Hinrichs, 1960, p. 196.
9	Sierra Estrella area	Secs. 6, 7, and 8, T. 4 S., R. 2 E., Pinal County. In Gila River Indian Reservation.	Intergrown potassium feldspar and quartz with mica in several small pegmatite bodies in Precambrian schist. Largest body about 100 ft long and 40 ft wide. Prospected but not mined.	Wilson, 1963.
10	Silver Christmas mines	T. 12 N., R. 1 E., Yavapai County. Near Mayer.	No data.	Funnell and Wolfe, 1964, p. 300.
11	White Spar	T. 13 N., R. 2 W., Yavapai County on White Spar road S. of Prescott.	No data.	Do.
12	San Antonio mine	T. 13 S., R. 7 W., Pima County. SW. of Ajo.	Pegmatite in Mesozoic granitic intrusive. Produced feldspar-silica mixture with 70 percent feldspar in 1962.	Larson, 1963, p. p. 117.

TABLE 29.—*Feldspar occurrences in Arizona*—Continued

Locality No. in fig. 52	District, mine, or area	Location	Description and remarks	References
13	Rare Metals mine	Sec. 21, T. 17 N., R. 12 W., Yavapai County. On E. side of Big Sandy Wash.	Irregular pegmatite body, 600 ft long by as much as 40 ft wide, in Precambrian granite. Well zoned with marginal microcline masses. No feldspar production.	Heinrich, 1960, p. 12-14.
14	Florence	25 mi NW. of Florence, Pinal County. Possibly on Santan Mtn.	No data.	Olson and Long, [1957], p. 12-13.
15	Cleator	T. 10 N., R. 1 W., Yavapai County. Near Cleator.	No data.	Do.

abase dike, as much as 5 feet thick, cuts across the pegmatite body at moderate depth in the northern part. The contacts between granite and pegmatite are normally quite sharp but some irregular bulges occur along the walls. Mineralogic and textural zoning are clearly defined. The irregular central core, which in places extends to almost the full width of the pegmatite body, is composed of large grayish-white masses of microcline with subordinate gray quartz pods, veins, and stringers. An intermediate thinner wall zone shows medium-grained, commonly streaked or gneissoidal, aggregates of gray quartz, grayish-white feldspar, some biotite and locally muscovite, garnet, magnetite, allanite, and graphic granite. This zone also is cut by quartz veinlets. The outer thin border zone consists of fine-grained, white, aplitic quartz and feldspar. The predominant feldspar is microcline, which is selectively mined and hand-cobbed to yield a high quality product that is exceptionally low in iron, and free of quartz and other impurities.

Jahns (1952) has described in detail the numerous pegmatites that occur principally in a curving belt 10 miles long by ½ to 3 miles wide in the White Picacho district (see fig. 52). These pegmatites form dikes, sills, pods, and generally lenticular masses of various sizes, some as much as 1,000 feet long. The wall rocks are mainly Precambrian schist and granite with the schist favored for the best developed pegmatites. Contacts are highly irregular and mostly discordant to the schistosity, but the walls are well defined. Three general types of pegmatites are present. The most abundant are simple pegmatites consisting of quartz, potash feldspar, subordinate plagioclase, and muscovite mineral assemblages with graphic granite and minor accessory minerals. The second type contains segregations a very coarse-grained quartz and potash feldspar and a varied assortment of accessory minerals. The third type contains concentrations of lithium minerals. Almost all the pegmatites comprise two or more zones. The potash feldspar is mainly microcline, and to a large extent, is perthitic. Quartz commonly is present in a graphiclike orientation. In some pegmatites, coarse perthite masses totaling as much as 80 long tons are known. Many of the pegmatites have been explored and partly developed and, reportedly, several large lots of feldspar have been hand cobbed for testing. However, there is no recorded commercial production.

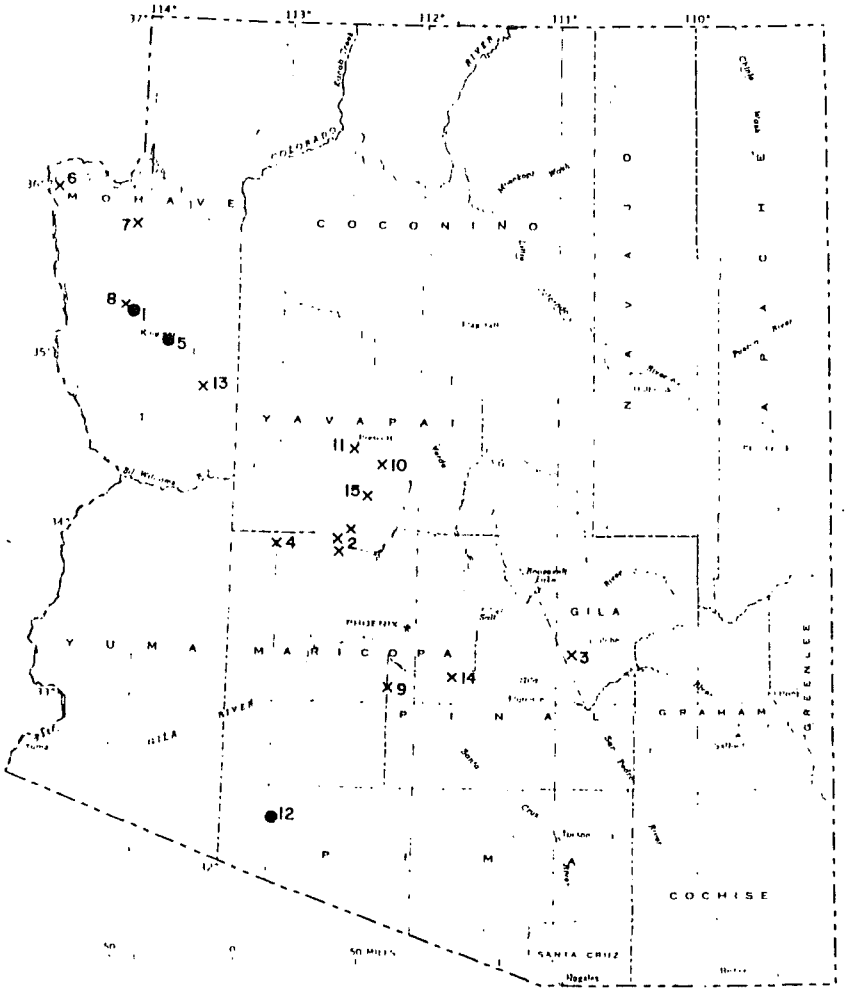

FIGURE 52.—Feldspar in Arizona.

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RESOURCES

The commercial reserves and resources of potash and sodium feldspar in Arizona are estimated to total several hundred thousand long tons and are considered adequate to supply the present-scale demands for many years. Future of feldspar production in the State will depend largely on the rate of growth of the Pacific Coast market and on the development of industrial uses within the State.

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FLUORSPAR

(By R. E. Van Alstine, U.S. Geological Survey, Washington, D.C., and R. T. Moore, Arizona Bureau of Mines, Tucson, Ariz.)

INTRODUCTION

Fluorspar is the commercial name generally applied to the mineral fluorite (CaF_2) and is the principal ore mineral of the very important industrial element, fluorine. The mineral commonly occurs as crystals or in cleavable masses but also is found in massive form and as fine to coarse granular material. Fluorite has a specific gravity of 3.18 and displays a wide variety of colors, ranging from colorless and white to shades of green, yellow, brown, blue, and purple.

As a source of fluorine, fluorspar is important in the manufacture of hydrofluoric acid which, in turn, finds a large market in the chemical industry and in the production of fluorides used in the electrolytic reduction of alumina to aluminum metal. The second greatest use of fluorspar is as a flux in steelmaking. Appreciable quantities also are used in the production of ceramic materials, in enameling metal utensils, and in the manufacture of opalescent glass.

Production and Sources of Supply

The United States for many years has been the major user of fluorspar in the world and in 1966 consumed more than one million tons, about 32 percent of the world production (U.S. Bur. Mines, 1967, p. 475). Prior to 1952 domestic production supplied more than half of our needs, but since then imports, principally from Mexico, have exceeded domestic output; in 1966, imports equaled nearly 83 percent of the United States consumption. About 80 percent of the United States production has come from vein and replacement deposits in Mississippian sedimentary rocks in the Illinois-Kentucky district.

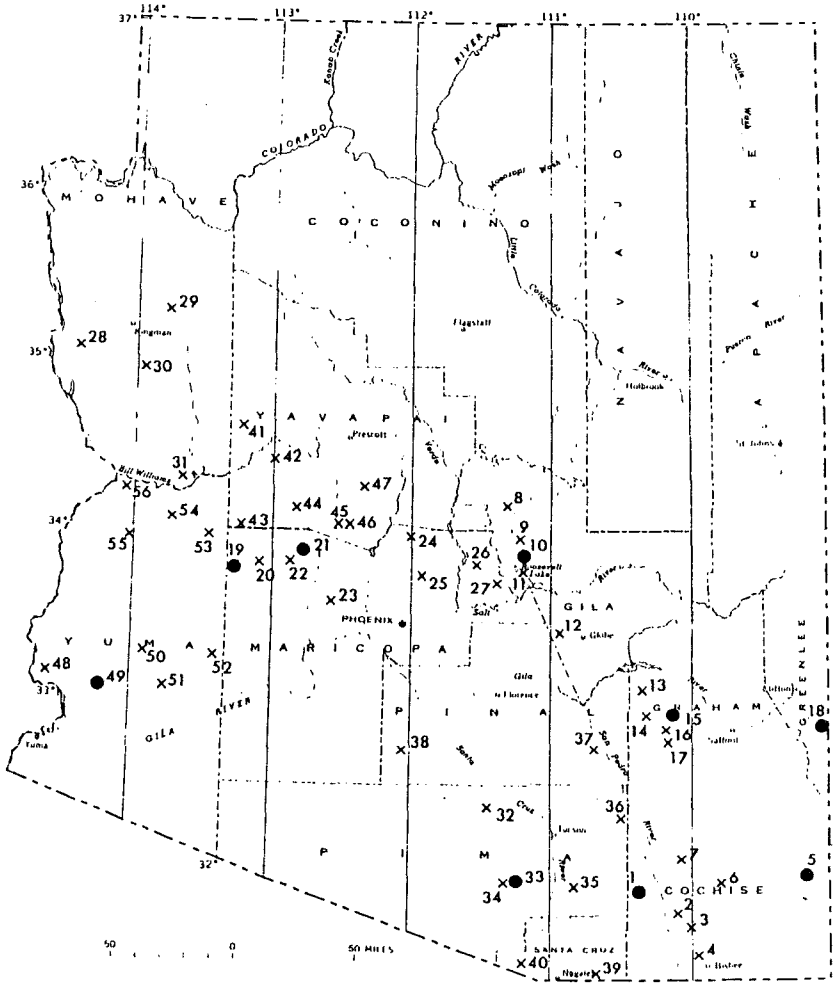
The known fluorspar deposits of Arizona are widely scattered in the southern half of the State, as shown in figure 53. Fifty-six fluorspar localities are indicated, including some mineralogic occurrences representing types productive elsewhere, and brief descriptions of most of them are given in table 30. Production came from the nine centers shown by the separate symbol on the locality map.

Fluorspar was first produced in Arizona in 1902, and the total output through 1967 has amounted to about 21,500 short tons having an estimated value of about $600,000. During 34 years of this 66-year period no fluorspar shipments were made in Arizona. In 1902–17 the entire fluorspar production of Arizona, 1,152 tons valued at $11,747, came from the Castle Dome district (No. 49, fig. 53) as a byproduct of lead mining (Wilson, 1950a, p. 2). Fluorspar mining began in the Duncan district (No. 18) and in the Sierrita Mountains (No. 33) in 1918; however, output was small through 1920 and ceased during 1921–35. Production from the Duncan district was resumed in 1936 and continued until the end of 1944; during this period this district yielded about 6,500 tons valued at $124,000. Some production came also from the Sierrita Mountains shortly after 1939 and from the Vulture Mountains (No. 21) and Harquahala Mountains (No. 19) after 1942. From 1946 through 1952 shipments were largely from the Lone Star mine (No. 1). Also, during the 1940's a small amount of production came from the Paradise area in the Chiricahua Mountains (No. 5). In 1952 some production again came from the Duncan district, and in 1953 the largest amount (1,951 tons) of fluorspar produced in Arizona in a single year was shipped from mines in the Duncan and Castle Dome districts and from the Spar mine (No. 15). In 1958 small shipments of fluorspar were made from the Packard claims (No. 10) and the Harquahala Mountains; in 1967 about 10 tons came from the Lone Star mine.

Fluorspar from the Castle Dome district was shipped mostly to Riverside, Calif., for use as a flux in making cement clinker and for potash recovery in cement manufacture (Wilson, 1950a, p. 11). Ore from the Duncan district went largely to flotation mills at Lordsburg and Deming, N. Mex., for the production of acid-grade fluorspar. Metallurgical-grade fluorspar from the Lone Star mine was used in steel plants at Pittsburgh, Penn., Chicago, Ill., and Fontana, Calif.

Summary of Principal Deposits

The principal fluorspar deposits of Arizona are mainly epithermal veins that fill fissures and brecciated zones along faults. At some deposits the fluorspar partly replaced earlier vein minerals and the wall



EXPLANATION

×7 Prospect or occurrence

●10 Productive district, area, or mine

(Numbers refer to localities cited in text and table 30)

Figure 53.—Fluorspar in Arizona.

TABLE 30.—*Known fluorspar occurrences in Arizona*

Locality No. in fig. 53	County and locality name	Manner of occurrence	References
	Cochise		
1	Whetstone Mts., Lone Star mine	Coarse-grained, banded, greenish fluorspar and dense, vuggy quartz in vein in Precambrian schist. Ore shoots, averaging 2-1/2 feet thick and as much as 25 feet long and 30 feet deep, contain more than 85 percent CaF_2. Arizona's most productive fluorspar mine.	Wilson, 1950a, p. 9-10.
2	Tombstone district, Empire mine	Green and purple fluorite locally abundant in silicified areas in limestone associated with lead; commonly cements brecciated and fractured novaculite.	Butler and others, 1938, p. 56, 105.
3	Government Draw	As small, purple crystals in quartz veins in limestone.	Galbraith and Brennan, 1959, p. 43.
4	Capt Fluorspar property	No data.	Arizona Dept. Mineral Resources, 1964; Stipp and others, 1967.
5	Chiricahua Mts., Paradise area	Crystals and massive material in quartz veins. Minor production in 1940's.	Galbraith and Brennan, 1959, p. 43.
6	Fluorine Hill deposit	Narrow carbonate vein with fluorite and uranophane or autunite in silicified rhyolite.	Granger and Raup, 1962, p. A3.
7	Little Dragoon Mts., Cochise (Johnson) district	In quartz veins in quartz monzonite associated with beryl, tungsten, copper, zinc, and lead.	Warner and others, 1959, p. 99; Cooper and Silver, 1964, p. 142.
	Gila		
8	Payson district, Ox Bow mine	As veinlets associated with epidote, gold, and silver in a fissure vein in hornblende diorite.	Lausen and Wilson, 1925, p. 78.
9	Quartz Ledge prospect	No data.	Arizona Dept. Mineral Resources, 1964.
10	Tonto Basin, Packard claims	Medium-grained, white to purple fluorite and quartz gangue in lenses in an east-trending, steeply dipping vein in granite. Examined and sampled by U. S. Bur. Mines; lenses averaging 2.8 feet thick contain about 72 percent CaF_2 and 20 percent SiO_2. Minor production in 1958.	Cummings, 1946.
11	Conway prospect	No data.	Arizona Dept. Mineral Resources, 1964.
12	Castle Dome copper mine	Fluorite, barite, and quartz crystals along fractures and vugs in Mesozoic (?) quartz monzonite with chalcopyrite and other sulfide minerals.	Peterson and others, 1951, p. 93.
	Graham		
13	Stanley Butte district	Veins of quartz, barite, fluorite with copper, lead, and silver minerals in latite or andesite breccia at Silver Spar prospect. Veins of barite, fluorite, and calcite in trachyte at Barium King claims.	Ross, 1925, p. 109; Stewart and Pfister, 1960, p. 25-28.
14	Aravaipa district, Grand Reef mine, and Landsman group	Veins of quartz, fluorite, galena, sphalerite, pyrite, chalcopyrite, and argentite in rhyolite porphyry and limestone; contact metamorphic deposits in limestone with fluorite, barite, calcite, quartz, silicates, and sulfide minerals.	Ross, 1925, p. 61-63, 66; Wilson, 1950b, p. 62.

TABLE 30.—*Known fluorspar occurrences in Arizona*—Continued

Locality No. in fig. 53	County and locality name	Manner of occurrence	References
	Graham--Continued		
15	Spar property	No data; reported 145 tons shipped to flotation mill in Deming, N. Mex., in 1953.	Mining World, 1953.
16	Edith 1 and 2 property	No data.	Arizona Dept. Mineral Resources, 1964.
17	Clark district, Marcotte claims	Veins of barite, fluorite, and calcite with gold and silver in volcanic agglomerate.	Stewart and Pfister, 1960, p. 19-24.
	Greenlee		
18	Duncan (Steeple Rock) district	Medium- to coarse-grained, colorless or green fluorite, as lenses in veins of dense, massive to banded quartz cutting Tertiary rhyolite, andesite, and basalt. Ore shoots, averaging 3-4 feet thick, 50 feet long, and 50 feet high, contain about 65 percent CaF_2 and 25-30 percent SiO_2. Arizona's most productive fluorspar district.	Wilson, 1950a, p. 8-9; Trace, 1947.
	Maricopa		
19	Harquahala Mts., Snowball, Princess Ann, and White Rock deposits	Veins of fluorite, calcite, barite, and quartz in gneiss, schist, limestone, volcanic conglomerate, and basalt. Examined and sampled by U. S. Bur. Mines; trench samples across breccia zone indicate maximum grade and width of 4 feet of 72 percent CaF_2 and 12 feet of 36 percent CaF_2 at Snowball deposit. Small production in 1958.	Denton and Kumke, 1949; Stewart and Pfister, 1960, p. 37-40.
20	Big Horn Mts., Valley View mine of Aguila district	Veins of fluorite, barite, black calcite, chalcedony, and manganese oxides in andesite flow.	Hewett, 1964, p. 1450.
21	Vulture Mts.	As lenses in veins associated with pegmatite and andesite porphyry dikes in rhyolite and basalt. Small production in early 1940's.	Wilson, 1950a, p. 6; unpub. data, U. S. Geol. Survey.
22	San Domingo district, Texas Queen property	No data.	Arizona Dept. Mineral Resources, 1964.
23	White Tank Mts.	No data.	Schrader and others, 1917, p. 23.
24	Cave Creek district, Amethyst property	No data.	Arizona Dept. Mineral Resources, 1964.
25	Pinnacle Peak area	Fluorite in the white quartz quarry on Pinnacle Peak, east of Paradise Valley.	Galbraith and Brennan, 1959, p. 43.
26	Granite Mtn., Muskhog claims	Fluorspar vein 1-4 feet thick in granite.	McCrory and O'Haire, 1961; unpub. data, U. S. Geol. Survey.
27	Four Peaks area, Adventure property	No data.	Arizona Dept. Mineral Resources, 1964.

TABLE 30.—*Known fluorspar occurrences in Arizona*—Continued

Locality No. in fig. 53	County and locality name	Manner of occurrence	References
	Mohave		
28	Oatman district	As pale green and purple crystalline material in quartz veins. In some places associated with gold. Apparently not abundant in the district.	Lausen, 1931, p. 62; Ransome, 1923, p. 33.
29	Hackberry area	No data.	McCrory and O'Haire, 1961.
30	Boriana mine	Fluorite in tungsten-bearing quartz veins in granitic rocks; fluorite forms veinlets and nearly 5 percent of some veins.	Hobbs, 1944, p. 254.
31	Artillery Mts., Red Hills prospect	Radioactive breccia of Artillery Formation, probably Eocene, mineralized with barite, fluorite, and secondary copper minerals.	Lasky and Webber, 1949, p. 33; Granger and Raup, 1962, p. A22.
	Pima		
32	Silver Bell Mts.	Abundant with silver-lead near the Mammoth mine, and with barite and galena in limestone at several other properties.	Galbraith and Brennan, 1959, p. 43.
33	Sierrita Mts., Neptune, Fluxore properties	White, purple, and green fluorite, calcite, quartz, and barite veins in schist, granite, and aplite. Fluorspar shoots are 2-5 feet thick and perhaps 25 feet long and 25 feet deep. Production small and intermittent.	Wilson, 1950a, p. 11; Allen and Butler, 1921, p. 7.
34	Black Dike deposit	Fluorite, pyrite, chalcopyrite, magnetite, pitchblende, and manganese oxide occur at contact of gneissic granite and basalt (?) dike where the zone is altered to garnet, chlorite, and epidote.	Granger and Raup, 1962, p. A25-A29.
35	Helvetia area	Fluorite and quartz in fissure veins carrying argentiferous galena, minor copper-bearing minerals, and some gold; chiefly in granite.	Schrader, 1915, p. 98.
36	Sure Fire No. 1 claim	Schist and gneissic granite contain veinlets of quartz, calcite, fluorite, uranophane, and autunite.	Granger and Raup, 1962, p. A34-A35.
	Pinal		
37	Mammoth mine	Microscopic crystals in veins, associated with lead, zinc, and copper sulfides, pyrite, quartz, and barite; in rhyolite and quartz monzonite.	Creasey, 1950, p. 79; 1967, p. 81.
38	Vekol Mts.	No data.	McCrory and O'Haire, 1961; Stipp and others, 1967.
	Santa Cruz		
39	Patagonia Mts., Alta mine	Reddish fluorite with quartz as a gangue in veins carrying argentiferous galena, embolite, and pyrargyrite; veins in quartz diorite and rhyolite.	Schrader, 1915, p. 272.
40	Annie Laurie claims	Calcite and quartz veins in granite, containing fluorite, sphalerite, galena, chalcopyrite, pyrite, and uraninite.	Granger and Raup, 1962, p. A39-A42.
	Yavapai		
41	Bagdad area	White and purple fluorite associated with bismutite in Precambrian pegmatite dikes and quartz veins; fluorite as alteration of Precambrian granite and in quartz-wolframite-beryl veins.	Anderson and others, 1955, p. 21; Warner and others, 1959, p. 107.

TABLE 30.—*Known fluorspar occurrences in Arizona*—Continued

Locality No. in fig. 53	County and locality name	Manner of occurrence	References
	Yavapai—Continued		
42	McCloud Mts., near Leviathan mine	No data.	Galbraith and Brennan, 1959, p. 44.
43	Hatton (Harris) mine	Veins of barite, black calcite, fluorite, manganese oxides, pyrite, galena, and chalcopyrite in sandstone.	Farnham and Stewart, 1958, p. 57-59; Hewett, 1964, p. 1449.
44	Congress Junction area	Fluorite crystals in pegmatite dikes.	Galbraith and Brennan, 1959, p. 44.
45	Abe Lincoln mine	Veins along contacts of basalt and trachyte porphyry dikes in gneiss and schist; veins contain quartz, calcite, fluorite, sanidine, chalcopyrite, chalcocite, pyrite, and secondary uranium minerals.	Granger and Raup, 1962, p. A44-A46.
46	Swallow mine	Fluorite as gangue constituent in vein containing oxidized copper ores, specularite, quartz, and calcite.	Lindgren, 1926, p. 185.
47	Springfield shaft	Purple fluorite with quartz, chalcopyrite, and pyrite in gash veins in quartz diorite.	Lindgren, 1926, p. 165.
	Yuma		
48	Trigo Mts., Silver district	Fluorite as vein material with quartz, calcite, barite, galena, and wulfenite, and as crystalline to dense coatings on quartz; veins in andesite, rhyolite, and schist.	Wilson, 1933, p. 55; Stewart and Pfister, 1960, p. 88-89.
49	Castle Dome district	Green, purple, and rose-colored fluorite associated with calcite, barite, quartz, galena, and wulfenite in veins in diorite porphyry and Cretaceous shale. Veins generally less than 5 feet thick and locally containing 40-60 percent CaF_2. Fluorspar recovered as a byproduct of lead-silver mining.	Wilson, 1933, p. 83; Burchard, 1933, p. 4-5.
50	Kofa Mts., near King of Arizona mine	Fluorite, calcite, galena vein in monzonite porphyry dike near contact with Precambrian schist.	Jones, 1916, p. 164 and pl. 5.
51	Neversweat district, Notthusch mine	Veins of barite, fluorite, black calcite, gypsum, and argentiferous galena in schist next to rhyolitic to andesitic intrusive bodies.	Stewart and Pfister, 1960, p. 84-87.
52	Clanton Wall area, Yellow Breast prospect	Green fluorite, galena, and wulfenite in quartz vein in schist.	Wilson, 1933, p. 146-147.
53	Ellsworth district, Fluorspar property	No data.	Arizona Dept. Mineral Resources, 1964.
54	Buckskin Mts., Chicago and Mammoth deposits	Fluorite and barite associated with quartz in veins weakly mineralized with chrysocolla; in gneiss and between gneiss and granitic breccia.	Bancroft, 1911, p. 121-122.
55	Bouse (Plomosa) district	Veins of barite, fluorite, calcite, and quartz in volcanic agglomerate; ore from Red Chief deposit, 13-47 percent CaF_2, yields fluorspar and barite products in flotation tests.	Stewart and Pfister, 1960, p. 59-77; Bloom and others, 1963.
56	Planet area	No data.	McCrory and O'Haire, 1961; Stipp and others, 1967.

rocks next to the mineralized faults; however, no large replacement bodies of fluorspar are known in Arizona.

Nearly half of the fluorspar deposits for which geologic information is available are in coarse-grained intrusive rocks of various ages; the host rocks at the other deposits are about equally divided between sedimentary rocks, volcanic rocks, and metamorphic rocks (see table 30). The host rocks at the centers of fluorspar production, however, are chiefly schist and volcanic rocks.

At nine of the localities shown the deposits consist predominantly of fluorite; quartz and calcite are the chief gangue minerals. Galena or barite have been of commercial interest at 14 other localities. An investigation of 75 barite deposits of Arizona (Stewart and Pfister, 1960) showed that about half contain fluorite and range from less than 1 percent CaF_2 to 48.6 percent CaF_2; the eight deposits with analyses showing a CaF_2 content greater than 10 percent are in fluorspar localities indicated in figure 53. Many of the other fluorspar localities in Arizona are deposits that have been worked at some time for copper, manganese, tungsten, or gold. At six of the localities the fluorspar is associated with uranium minerals.

Wilson (1950a, p. 7–8) discussed the association of fluorspar with many of the above vein minerals and metals; although the fluorspar deposits are near districts that have been sources of various metals, zonal relations were regarded as indefinite. According to Hewett (1964, p. 1450, 1460, 1467), however, fluorite and barite deposits are found in the lower parts of the Plomosa Mountains (Bouse district, No. 55), below a zone exploited for manganese oxides, and in the Aguila district of Maricopa County (No. 20) they are marginal to a belt of manganese oxide veins. Hewett (1964) suggests that manganese minerals, fluorite, barite, and minor metal sulfides formed during Tertiary time in the higher and cooler zones of the base-metal districts of the southwestern United States.

As shown in the accompanying table, the grade of productive fluorspar deposits in Arizona ranges from less than 50 percent CaF_2 in the lead-fluorspar mines of the Castle Dome district to more than 85 percent CaF_2 in the Lone Star deposit. Large fluorspar deposits of such grades have not been worked in Arizona, however; fluorspar shoots along the mineralized structures described are typically only 2 to 5 feet thick, 25 to 50 feet long, and 25 to 50 feet deep.

Outlook

Additional fluorspar deposits may be found in Arizona when economic conditions in the domestic fluorspar industry favor further exploration. Exploration probably would be directed most profitably to the known centers of fluorspar mineralization and around the margins of metalliferous deposits, especially lead and manganese deposits. Hewett (1964, p. 1470) recommends drilling manganese oxide veins in the southwestern United States 500 to 1,000 feet below existing workings to explore for barite, fluorite, precious metals, and base-metal sulfide deposits that may have formed at successively lower depths. Attention also should be given to mixed barite-fluorspar deposits (Stewart and Pfister, 1960), for a metallurgical study of ore from the

Bouse district, containing about 39 percent barite and 31 percent fluorspar, has shown that barite and fluorspar products can be made successfully by flotation (Bloom and others, 1963).

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GEM MATERIALS

(By H. Wesley Peirce, Arizona Bureau of Mines, Tucson, Ariz.)

Introduction

As used here, "gem materials" include all of the rock and mineral substances that owe their value to a natural beauty and attractiveness or in which these qualities can be enhanced by tumbling, cutting and polishing, faceting, etc. The qualities of durability, rarity of form and design, color, and perfection all influence their value and use. Arizona gem materials are limited to the so-called semiprecious varieties as none of the precious stones (diamond, sapphire, ruby, and emerald) are known to exist in exploitable form. Although Arizona is estimated to have produced $120,000 worth of gem materials in 1966 (Larson and Henkes, 1967, p. 89), the output is of minor significance. The esthetic and recreational values that are derived from their pursuit, however, are significant. It is well known that the activity of amateur collectors, many of whom collect, cut, and polish materials and manufacture jewelry as a hobby or a small business, is a principal feature of Arizona's production of gem materials.

Gem materials occur in all of Arizona's 14 counties where the distribution of each gem substance is controlled by the distribution and extent of a particular geologic environment. For instance, gem materials found among the copper minerals (turquoise, chrysocolla, and shattuckite) are limited to the relatively localized sites of copper mineralization, whereas, certain quartz family minerals (agate, chalcedony, jasper, etc.), because of their association with common rocks, are more widely distributed. An appreciation for the geologic environment of a given region can lead to a determination of the probable types of gem materials to be found there.

Arizona Gem Materials

Arizona's best known gem materials are: silicified wood, chalcedony, agate, jasper, amethyst, and clear quartz crystal among the quartz family; turquoise, chysocolla, malachite, and shattuckite among the copper minerals; peridot; pyrope garnet; marekanite (Apache tears); and onyx marble. Figure 54 shows the distribution of the

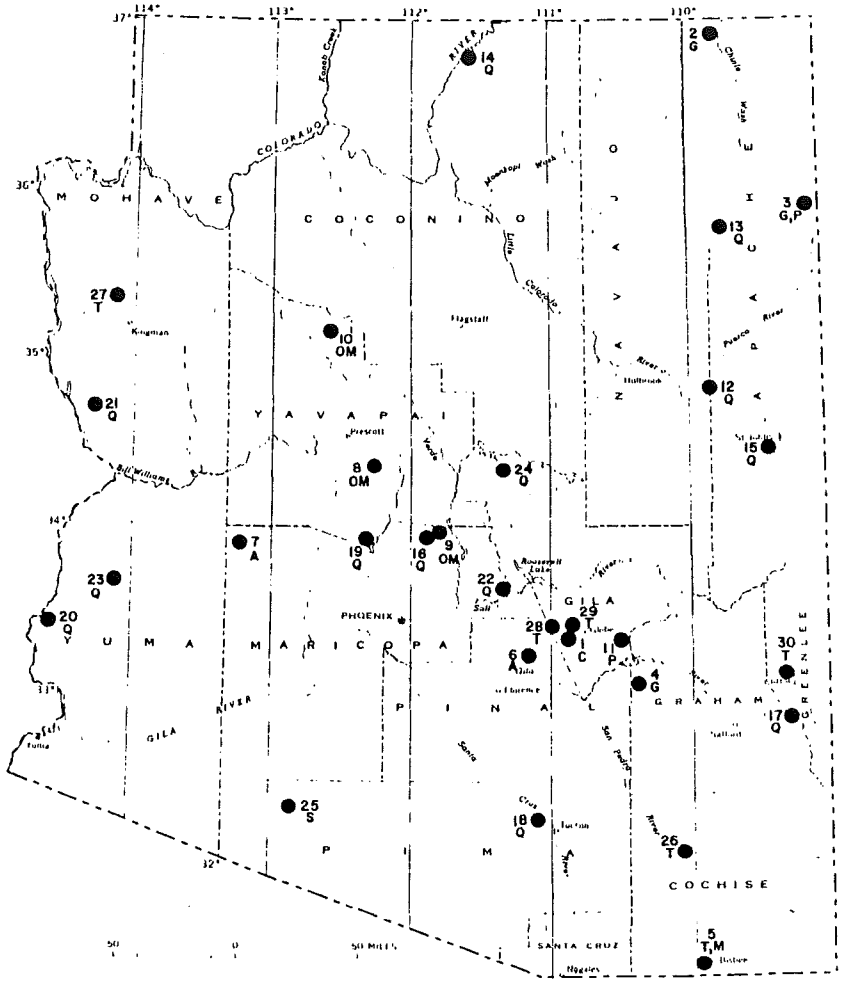

Figure 54.—Gem materials in Arizona.

principal occurrences of gem materials in Arizona. Only a few of the better known localities of the most common occurrences, such as some of the quartz family types, are shown. Each of these materials is described below in alphabetical order.

CHRYSOCOLLA

Chrysocolla, composed of copper, silica, and water, is a green to blue substance commonly mistaken for turquoise. It is found in the upper or oxidized parts of many of Arizona's copper deposits. Because of a variable copper-silica ratio chrysocolla may not be a definite mineral species. Technically it may be more correct to consider it a mineral gel. In relatively rare cases, however, the proportion of silica is high enough that the hardness, color, and transparency render the material of gem quality. Material of this nature from the Live Oak mine (see fig. 54, locality No. 1) in the Globe-Miami district of Gila County is highly prized, exceptional material having sold for as much as $100 per pound (Switzer and Thomson, 1955, p. 434).

GARNET

The garnet group consists principally of the six subspecies, grossularite, pyrope, almandite, spessartite, andradite, and uvarovite. All are silicates but with different combinations of aluminum, magnesium, iron, manganese, calcium, and chromium. When transparent, of pleasing color, and relatively flawless, garnet is used as a semiprecious gemstone. Arizona is well known for pyrope ("Arizona ruby") occurrences on the Navajo Indian Reservation in Apache County. In addition, andradite from the Stanley Butte area of Graham County has been described as gem quality (Sinkankas, 1959, p. 291).

Arizona's most noted garnet locality is on Garnet Ridge (fig. 54, No. 2) about 5 miles west of Mexican Water just south of the Utah boundary. Beautiful fragments of pyrope, derived from the weathering of rocks brought to the surface by igneous activity, are abundant (Gregory, 1916, p. 224). Garnets that will cut good gems over 3 carats in weight are scarce, but those that will cut gems ranging from 1 to 2 carats are plentiful, and stones of less than 1 carat are abundant (Sterrett, 1909, p. 826). Pyrope also occurs with peridot at Buell Park (fig. 54, No. 3), 10 miles north of Fort Defiance on the Navajo Reservation, where the individual garnets are smaller in average size than at Garnet Ridge but of good quality.

North of Stanley Butte, on the south slope of Quartzite Mountain in Graham County (No. 4), about 10 miles southeast of Coolidge Dam, andradite garnet is abundant. It occurs with other silicate minerals in a zone of metamorphosed Paleozoic limestone near a granitic instrusive of Laramide age. Some of the garnets have been tumbled into attractive chatoyant baroque gems and some have been faceted (Sinkankas, 1959, p. 291).

In addition to the few known occurrences of gem garnet in Arizona there are numerous localities of common garnet (Galbraith and Brennan, 1959, p. 94). Although common garnet is mined and processed in the northeastern United States for use as abrasives, Arizona common garnet, for economic reasons, has not been considered suitable for commercial recovery.

MALACHITE

Malachite, a green copper carbonate, is common in the oxidized parts of many copper deposits. Most occurrences are not valued as gem material. Those, however, at the Copper Queen mine (No. 5) at Bisbee, in Cochise County, have been noted as one of the outstanding American localities of material suitable for cutting and polishing into decorative items. Large and thick masses of material have been recovered of which a notable example is displayed at the American Museum of Natural History in New York City (Sinkankas, 1959, p. 535).

MAREKANITE (APACHE TEAR)

The popular name for marekanite is "Apache tear." The "tears" are globules of structurally homogenous dark glass that occur in perlitic volcanic rocks. They are abundant in the perlite just west of Superior (No. 6) in Pinal County, where, for a small fee, they can be collected by the pound. After being tumbled and polished they are sold as pendants or used in assorted silver jewelry. Production statistics are not available, but it is probable that hundreds, if not thousands, of pounds are collected each year. In addition to the principal occurrence near Superior, marekanite can be collected a short distance south of Aguila (No. 7) in Maricopa County.

ONYX MARBLE

Onyx marble, sometimes called "Mexican onyx," is composed of banded calcite precipitated from spring waters. Impurities such as iron oxides add color, which, when added to intricate design, may result in material suitable for fabrication into a wide variety of decorative uses. An extensive deposit, exploited periodically since the 1920's, occurs by State Highway 69 at Mayer (No. 8) in Yavapai County. Deposits near Cave Creek (No. 9) in Maricopa County and 10 miles southwest of Ashfork (No. 10) in Yavapai County, have also been worked.

PERIDOT

Peridot is the greenish-yellow gem variety of the green mineral olivine, a silicate of magnesium and iron. In Arizona peridot occurs in two principal localities, at Peridot Mesa (No. 11) about 2½ miles southwest of San Carlos, Gila County, and with pyrope in and around Buell Park (No. 3), Apache County. Peridot Mesa has been described as the most productive peridot locality in North America (Sinkankas, 1959, p. 205). There, peridots were eroded from basaltic rocks and are gathered by local Indians who take them to collectors and stonecutters in Globe or to local traders (Bromfield and Shride, 1956, p. 686). The Buell Park occurrence is associated with a plug-shaped complex of ultramafic volcanic rocks of Cenozoic age that have been eroded and weathered to release a large volume of peridots to the local soil (Gregory, 1917, p. 146). At one time ant hills contained a high percentage of small peridot grains (Sterrett, 1909, p. 834) and later, according to Allen and Balk (1954, p. 23) ants were still actively transporting peridot grains. Production data are incomplete, but in 1963 Arizona produced about 1,500 pounds of peridot valued at $4,000 (Petkof, 1964, p. 538), an average of about $3 a pound.

QUARTZ

Quartz, the most common mineral in the earth's crust, is composed of silicon dioxide, or silica. Quartz varieties, originating in a multitude of geologic environments, can be divided into two major categories: (1) coarsely crystalline and (2) finely crystalline varieties. The first category includes all varieties whose fundamental unit, crystal, or grain, is visible to the unaided eye and the second category includes all varieties whose fundamental unit can be perceived only with magnification (Frondel, 1962, p. 170).

The finely crystalline category includes silicified wood, agate, and jasper, the most abundant as well as the most popular gem materials in Arizona; the coarsely crystalline category is less abundant, of which amethyst is the most notable variety.

Silicified wood, which generally is associated with sedimentary rocks of the Chinle Formation (Triassic), is the most widely publicized and collected gem material in Arizona. According to Sinkankas (1959, p. 368), the Petrified Forest National Park, embracing parts of both Navajo and Apache Counties, contains the most colorful examples of silicified logs in existence (No. 12). Because the host Chinle Formation is widespread and is exposed over a considerable area of northeastern Arizona, silicified wood also is widespread, as at Beautiful Valley (No. 13) near Nazlini on the Navajo Reservation in central Apache County, and near Lees Ferry (No. 14) along the Colorado River in northern Coconino County. There are no figures on the amount of material removed each year, but it must amount to many tons and be worth many thousands of dollars. In addition to the "in place" sources of silicified wood, "out of place" sources, such as gravels, derived in part by erosion and accumulation of the more resistant materials from the Chinle Formation, provide excellent sources of silicified wood and other finely crystalline varieties of quartz. The Tertiary gravels that cap the higher surfaces in the vicinity of St. Johns (No. 15), in Apache County, are productive of colorful material.

In addition to their occurrence in sedimentary rocks, finely crystalline varieties of quartz, such as agate, jasper, and chalcedony may be found in volcanic rocks. Much of the popular literature directed at "rock hounds" emphasizes localities either in or close to mountains in the Basin and Range province that contain basaltic to andesitic igneous rocks. In these, gem materials may occur as geodes, vug linings, or fracture fillings. Gravel deposits derived, at least in part, from such rocks are choice collecting localities because the material is loose and accessible. Of the many localities known in which finely crystalline quartz (other than silicified wood) occurs, only a selected few are shown in figure 54. An orbicular jasper deposit (No. 16) along Camp Creek about 18 miles north of Cave Creek, in Maricopa County, is reputed by Sinkankas (1959, p. 375) to be one of the finest in the world. Agate and other forms of chalcedony occur in the Peloncillo Mountains near Highway 666 between Safford and Clifton (No. 17) near the Graham-Greenlee County line; in the andesitic volcanics at the northern end of the Tucson Mountains (No. 18) in Pima County; near Castle Hot Springs (No. 19) at the southern tip of Yavapai County; in gravels near the Colorado River north of Cibola (No. 20) in Yuma County; and in gravels between Topock and Oatman (No. 21) in Mohave

County. For more information on localities see Ransom (1955) and Johnson (1959).

Although coarsely crystalline quartz is abundant, gem quality material is scarce in Arizona. Amethyst continues to be taken from a mine in the Four Peaks area (No. 22) of the Mazatzal Mountains, Maricopa County, and is found in vugs or druses in the silicified wood of the Petrified Forest region. Rock crystal (clear quartz crystal) has been collected at Crystal Peak (No. 23) 10 miles southeast of Quartzsite in the Plomosa Mountains, Yuma County (Sinkankas, 1959, p. 375). The Diamond Rim (No. 24) just north of the highway between Payson and Kohl's Ranch, in Gila County, owes its name to the abundant clear quartz crystals associated there with the Martin Formation (Devonian).

SHATTUCKITE

Shattuckite, a hydrous copper silicate, is a scarce mineral found in the oxidized parts of a few copper deposits. Its deep blue color is attractive and in its massive form it is much sought after for lapidary (decorative) uses. The New Cornelia open-pit mine (No. 25) at Ajo, in Pima County, is a notable locality for this mineral. A polished mass from this locality is on display at the American Museum of Natural History (Sinkankas, 1959, p. 536).

TURQUOISE

Turquoise, also frequently found in the oxidized or upper parts of copper deposits, is an amorphous basic hydrous phosphate of copper and aluminum. Its color, so important in determining quality, ranges from greenish gray to sky blue, the latter being the most sought after. The principal sources in Arizona are in the Turquoise district of Cochise County, Wallapai district of Mohave County, Globe-Miami district of Gila County, and the Morenci district of Greenlee County.

The mining of turquoise in Arizona has been carried on for at least the last 5,000 years, for records indicate exploitation in pre-Colombian time. Arizona production in the early 1960's, ranked first in the United States, and in 1962 totaled about 11,500 pounds valued at about $17,000 (Hartwell and Brett, 1963, p. 586).

In the Turquoise district the principal deposits, which were rediscovered in 1890, occur on the west flank of Turquoise Ridge (No. 26) three-fourths of a mile west of Courtland. Turquoise occurs as stringers and nuggets in both Bolsa Quartzite (Cambrian) and in a granite that intrudes the quartzite. In the late 1920's one occurrence yielded 80 pounds of material valued at $8,000 to $9,000, an average of about $100 per pound (Sinkankas, 1959, p. 220). Overall production is not known but amounts to thousands of pounds.

The most extensive prehistoric turquoise workings in Arizona are in the Wallapai mining district on the southwestern side of the Cerbat Mountains, 15 miles northwest of Kingman. Modern production dates from about 1883. The turquoise occurs in several deposits in and around Ithaca Peak (No. 27), the site of Duval Corp.'s open-pit copper mine. Turquoise occurs as seams, masses, and veins in altered and mineralized granitic rock. It is estimated that lessees in 1967 will produce about 20,000 pounds of chalk (soft, light-colored inferior quality

turquoise that requires special treatment) and 1,000 pounds of gem material (Dean Lynch, oral commun., 1968).

The Globe-Miami district is another important copper producing area noted for the occurrence of turquoise (Peterson, 1962, p. 76). Turquoise has been produced from the oxidized part of the now abandoned Castle Dome opencut mine (No. 28), and it occurs similarly at the currently operating Copper Cities open-pit mine (also called the Sleeping Beauty mine) (No. 29). Production records are incomplete but thousands of pounds of turquoise-bearing material probably have been recovered from the district.

Turquoise is also produced by a lessee from the Morenci open-pit mine (No. 20) operated by the Phelps Dodge Corp. It is estimated that thousands of pounds of turquoise are produced per year.

Some excellent turquoise has come from Bisbee (No. 5) but apparently the material has been depleted (K. J. Coke, written commun., 1967).

Outlook

Arizona has and will continue to provide its share of the wealth, beauty, and recreation associated with the world of gem materials. Certain materials of limited occurrence and accessibility to the general public will continue to be the most valuable, monetarily. Other materials of less monetary value, but which are widespread in occurence, abundant, and generally accessible to the public will continue to be of great esthetic value. Arizona is endowed with wide open spaces that will continue to stimulate the pursuit, collection, and enjoyment of these gem materials by the public. New deposits to be found in both old and new localities, coupled with established collecting sites, will provide Arizona with a continuing supply of this valuable resource.

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GRANITIC ROCKS

(By S. B. Keith, Arizona Bureau of Mines, Tucson, Ariz.)

Introduction

The term "granitic rock" as used here applies only to those rocks resembling granite in appearance and composition, i.e., light-colored, medium- to coarse-grained, igneous or metamorphic rocks composed essentially of feldspars and quartz. Included are granite, grandiorite, quartz monzonite, quartz diorite and quartz porphyry as well as syenite (the silica-deficient equivalent of granite) and light-colored gneiss. Gneiss is a medium- to coarse-grained metamorphic rock in which layers or segregations of granular minerals alternate with layers of schistose minerals. It is commonly granitic in composition and formed by recrystallization of igneous or sedimentary rocks because of heat and pressure within the earth's crust. Some dark-colored, fine-grained rocks are referred to commercially as "black granite"; such rocks are discussed under "Basalt and related rocks" (p. 315).

Granitic rocks are widespread in the United States, occur in a wide variety of colors and textures, and have been used extensively as dimension stone, and as crushed and broken stone. The granitic rocks of Arizona are exposed mainly in the Basin and Range province, but only a relatively few occurrences are of suitable quality or are so located that they can be considered feasible for commercial exploitation.

For dimension stone, granitic rocks must break into large solid blocks and the rock must be even grained, uniformly textured, and have an attractive textural design and color. Nearly all granitic rocks are jointed or have planes of weakness, called "rift" or "grain," along which the rock breaks or can be split most easily. The spacing of the joints and rift or grain determine the size of the block that can be extracted and how the block can be further split into the required sizes and shapes. If the planes of weakness are closely spaced, the rock is suitable only for crushed and broken stone. The presence of irregular segregations of dark minerals; the occurrence of dikes, streaks, veins, or bands in the rock; and the inclusion of minerals or substances that can cause staining or deterioration are detrimental in dimension or decorative stone. Durability under conditions of weathering and abrasion is commonly an important requirement. The major use for dimensional granitic rock, namely, rough or finished building stone, paving blocks, curbing, and monuments, have decreased in recent years because of the growing use of less expensive concrete and composition stone. However, polished and unpolished large and thin slabs still are in demand for special decorative exterior and interior wall facings in public and private buildings and for memorial stone. The value of granitic dimension stone sold or used by producers in the United States in 1966 averaged about $54 per short ton, and ranged from $4.60 for rubble to $192 for dressed monumental stone (U.S. Bur. Mines, 1967, p. 578).

For use as crushed and broken stone, granitic rocks should be hard, tough, dense, resistant to weathering and abrasion, chemically inert and capable of being broken into equidimensional, blocky shapes. Most granitic rocks make a high-quality crushed stone. However, weathered and coarsely porphyritic granitic rock tend to disintegrate more rapidly than fresh and equigranular rock. Sheeted rock breaks into slabs and "flats" that are undesirable. Micaceous granitic rocks are generally undesirable and rocks that have undergone chemical alteration from mineralizing solutions may be weak, soft, and chemically active. The major use of crushed and broken granitic rock is for concrete aggregate and roadstone. Lesser amounts are used for riprap, railroad ballast, stone sand, poultry grit, fill, roofing gravel, and other miscellaneous purposes. The average value of crushed and broken granitic rock, sold or used by producers in the United States in 1966, was $1.45 per short ton and ranged from $0.52 per ton for fill to more than $9 per ton for poultry grit (U.S. Bur. Mines, 1967, p. 584).

Production, Use, and Sources of Supply

Granitic rocks have been used in the United States since earliest colonial times, particularly in the eastern part of the country. The production of granitic rock for dimension stone in 1966 totaled 626,000 short tons with a value of about $33.8 million, and was mostly used as rough and dressed monumental stone, dressed architectural stone for building, and as curbing and flagging. An unspecified amount of "black granite" is included in those figures. In comparison for the same year, more than 65 million short tons of crushed and broken granitic rock, with a value of about $94.7 million, was reported sold or used by producers, 84 percent having been used as concrete aggregate and roadstone (U.S. Bur. Mines, 1967, p. 578, 584).

There was no reported production of granitic rock in Arizona in 1966, but since 1900, producers in the State have used or sold about 15,000 short tons of dimension and more than 4 million short tons of crushed and broken granitic stone. All dimension stone was produced prior to 1931. Burchard (1914, p. 1339) reported that gneissic granite quarried about 7 miles south of Phoenix, Maricopa County, may have been used in the first story of the State Capitol building. Large residual boulders of granitic rock were quarried from a deposit 1½ to 2 miles northwest of Prescott and the dressed stone used in building the Yavapai County Courthouse and other buildings in Prescott in the 1910's (Burchard, 1914, p. 1339; Wilson and Roseveare, 1949, p. 47). Also it was noted that, "The ABC Granite Company . . . operated a quarry in Pinal County, 20 miles west of Casa Grande," and that "Some granite was quarried a few years ago from the Harcuvar Mountains, about 6 miles northwest of Salome in [Yuma County]" (Wilson and Roseveare, 1949, p. 47). Some quarrying of granitic rocks for dimension stone undoubtedly also occurred in other localities. Kiersch (1955, p. 33, 35) noted past production from an isolated granite occurrence near Hunter's Point, Apache County, and Townsend (1962, p. 31–32) reported some production from north of Morenci, Greenlee County. In general, however, the granitic rocks of Arizona are either unsuitable or too distant from markets to be competitive as dimension stone.

Irregular and sporadic amounts of crushed and broken granitic rocks have been used and sold by producers in Arizona since about 1910, mainly for concrete aggregate, roadstone, and railroad ballast. The highest annual production, in 1964, was 817,000 short tons valued at $1.2 million. Burchard (1914, p. 1339) reported granite quarry operations about 2 miles east of Dome, Yuma County, and Wilson (1963) stated that two old granite quarries in the Gila River Indian Reservation, Pinal County, furnished stone for railroad ballast. The production of this type of stone depends largely on the quality and availability of a supply close to place of use and on its ability to compete commercially with other suitable rock types. Thus, granitic stone operations within the State generally are small and designed for short-term local use.

Granitic rocks occur in considerable quantities throughout the southwestern half of Arizona as indicated in figure 55. They can be subdivided into two main age groups; Precambrian, and Mesozoic and Cenozoic "granitic" rocks. The Precambrian granitic intrusive and granite gneiss bodies crop out in a wide band that extends from the northwest to southeast corners of the State. The character and quality of this stone is highly variable but in a few localities, such as south of Phoenix and northwest of Prescott, dimensional stone has been produced and rock suitable for crushed and broken stone has been found at many places. The Mesozoic granitic rocks crop out mainly in Cochise and Yuma Counties. Some granitic gneiss has been quarried near Yuma for dimension stone, and elsewhere some has been used locally as roadstone. Total production has been small and mostly for governmental agencies. Laramide (Cretaceous-early Tertiary age) granitic intrusives and gneisses are scattered throughout much of the Basin and Range province and consist of batholiths and stocks, or metamorphic masses associated with the intrusives. Most of the larger bodies of granitic rocks of this age group crop out in Pima and Santa Cruz Counties and many have closely associated hydrothermal mineral deposits and thus show considerable alteration which may make them unsuitable as commercial stone. The youngest granitic intrusions are of Tertiary age and they occur mainly in Cochise County. Some of this granite such as that in the Dragoon Mountains, may be exploitable (Townsend 1962).

Outlook

Granitic rocks will continue to be a valuable Arizona resource, particularly as a source of crushed and broken stone for concrete aggregate and roadstone. This material will be utilized as a substitute for the diminishing supplies of good and readily available sand and gravel near the population centers of the State. High-quality dimension granitic rock is scarce in Arizona and extensive studies of the physical and mineralogic character and the economic aspects of development, quarrying, preparation, transportation, and use are needed to encourage greater exploitation.

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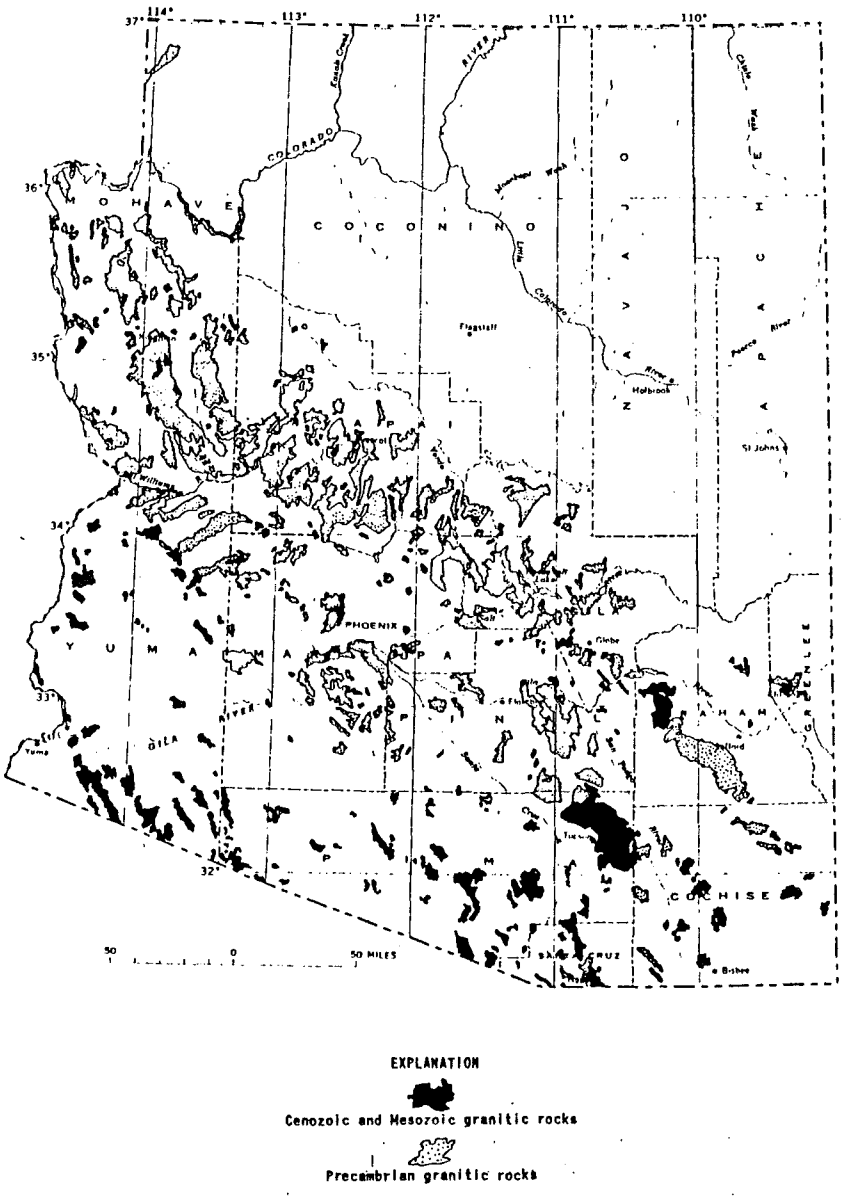

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GUANO, NITRATE, AND PHOSPHATE

(By S. B. Keith, Arizona Bureau of Mines, Tucson, Ariz.)

Introduction

Arizona does not appear to have appreciable resources of nitrates and phosphates. Bat guano, which contains both these commodities, has been exploited to a limited extent in the State and noncommercial occurrences of nitrate and phosphate have been reported. Nitrates and phosphates are essential to plant and animal life and although Arizona is apparently deficient in commercial deposits of these commodities, their occurrence and possibility of occurrence in the State are discussed briefly.

Guano

"Guano" is a term applied to deposits of the excrement of sea fowls, bats, or other animal life found where dry climatic conditions exist along sea coasts, such as bird guano along the west coast of South America, or bat guano in caves or caverns. When comparatively fresh, guano is a dry powdery mixture of organic nitrates, phosphates, and carbonates with lime, ammonia, and other compounds in which calcium phosphate, ammonium urate, oxalic acid and uric acid predominate. After deposition, the more volatile and soluble compounds are slowly eliminated and the deposit solidifies with the formation of new hydrous phosphates, nitrates, and oxalates. The high content of phosphates and nitrogenous matter make guano a high quality fertilizer. Bird guano has been mined extensively from islands along the coast of Peru and limited amounts of bat guano have been exploited throughout the world. World reserves and resources of guano are insignificant with respect to other sources of phosphate and nitrate and production of guano is insignificant in the world market.

The only guano deposits of any commercial interest in Arizona are those formed in caves and caverns from bat excrement. Since the caves and caverns frequented by bats are usually limited in size and the deposition of any sizable amount of guano requires a long period of time, the tonnage in most deposits does not exceed a few hundred tons. Bromfield and Shride (1956, p. 687) reported several bat guano deposits in caves on the San Carlos Indian Reservation. One of these, about 10 miles northeast of San Carlos along the San Carlos River, yielded about 63 short tons, valued at $15 a ton, in 1933–34. The U.S.

Bureau of Mines (1959a, p. 126; 1959b, p. 112) reported production of bat guano from Bat Cave in the south rim of the Grand Canyon, 60 miles north of Kingman, Mohave County. The tonnages extracted and the value were not disclosed but appreciable amounts were shipped to Kingman for packaging and distribution as a soil conditioner and fertilizer. A guaranteed analysis of the prepared commercial product shows:

	Percent
Nitrogen:	
Nitric	2.00
Ammonic	1.65
Organic	5.35
Total	9.00
Phosphoric acid (available)	3.25
Potash (water soluble)	1.57

The bat guano resources of Arizona might total several thousand tons but few, if any, of the individual deposits contain sufficient tonnage to be of commercial interest.

Nitrates

Nitrates are compounds of nitrogen with oxygen and other elements. The most common natural nitrates are those with sodium ($NaNO_3$) and potassium (KNO_3). Nitrogen, a colorless, odorless, and generally inert gaseous element, makes up 78 percent of the volume of common air and is required for all forms of life. For commercial and industrial use, the most important nitrogen-containing compounds are those based on ammonia (NH_3). Nitrogen compounds, mainly the nitrates, are used mostly in fertilizers but the largest single industrial use is for explosives.

The reserves and resources of nitrogen in the atmosphere, coal deposits and nitrate deposits are sufficient to supply the world for all time. Atmospheric nitrogen is the major source and is used to produce dilute nitric acid, calcium cyanamide or ammonia from which other nitrogenous products can be made. Ammonia or ammonia compounds are recovered from the gas resulting from the coking of coal. The only large commercial deposits of natural nitrates are the extensive deposits in northern Chile which are estimated to contain as much as 1 billion short tons (U.S. Bur. Mines, 1968, p. 105). There is no shortage of nitrogen in the world from which to make nitrogen compounds, and any deficiency is caused by a lack of production capacity.

The total nitrogen content of synthetic ammonia and natural nitrate consumed in the United States in 1966 was 8.9 million short tons of which only about 388,000 short tons, valued at $44 per ton, was natural nitrate imported from Chile (U.S. Bur. Mines, 1968, p. 104). The U.S. production of natural nitrate was negligible as are the U.S. resources which are mainly in bat guano.

Extremely small occurrences of natural nitrate, additional to guano, have been found in Arizona in several localities; these originated largely from the leaching of guano or other organic deposits. The nitrates occur as superficial encrustations, in seams in rock caverns or in protected rock walls. Mansfield and Boardman (1932, p. 15–21) reviewed these occurrences in many parts of the State but none are considered to be of commercial interest. The numerous playas and basins in Arizona appear to have extremely low nitrate contents as determined from the numerous analyses of cores, cuttings, and water samples from drill holes. Nitrogen is found with carbon dioxide and helium gas in wells in northeastern Arizona (Picard, 1960) but it is considered a waste product (see "Other associated gases," p. 83). Arizona apparently has no resources of natural nitrate, except guano, but could produce nitrogen and its products from the the atmosphere or from natural gas if it became economically feasible.

Phosphate

Phosphate is a compound of phosphorus, an active element not found in a free state in nature but combined with oxygen and other elements in many minerals. The major primary occurrence is as fluorapatite $(CaF)Ca_4(PO_4)_3$ disseminated in igneous rocks. Weathering of such rocks releases the phosphorus to be carried away by water, eventually into the oceans where carbonate fluorapatite phosphate minerals are precipitated through biological and chemical activity. Such precipitation appears to be possible only under certain favorable marine conditions including a restricted basin and a reducing environment in which large amounts of organic material are preserved. These marine phosphate deposits, which are the most important commercial sources, are composed of nodular phosphates, residual weathered phosphatic limestones, and consolidated and unconsolidated phosphatic sediments. The world's major commercial reserves are in Florida, Tennessee and the western phosphate field of Idaho, Montana, Utah, and Wyoming in the United States; in Morocco; in the U.S.S.R.; in Tunisia; and in Algeria. Smaller reserves and minor deposits occur in many other countries and some of these sources are also being exploited. Some apatite-rich igneous and metamorphic rocks have been mined for phosphate but such production is small and such sources are economically unfavorable. There is no shortage of phosphate to meet world or U.S. needs. The United States produced 39 million short tons of marketable phosphate rock and apparently consumed 27 million short tons in 1966 (U.S. Bur. Mines, 1967, p. 527). Most of the difference was exported.

Marine sedimentary conditions in Arizona during the geologic past evidently were not favorable for phosphate deposition. Trace to a few tenths of a percent phosphate have been detected in Permian and some other Paleozoic marine shales and fossiliferous limestones but there is no evidence that either original depositon or weathering has produced any concentrations that could be considered of economic interest. Apatite crystals have been noted in some igneous rocks of the State (Galbraith and Brennan, 1959, p. 72) but not in commercial amounts.

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GYPSUM AND ANHYDRITE

(By S. B. Keith, Arizona Bureau of Mines, Tucson, Ariz.)

Introduction

Gypsum, or hydrous calcium sulfate ($CaSO_4.2H_2O$), normally occurs as a soft, compact, granular rock interbedded with limestone, shale, dolomite, clay, and salts. It also occurs in a fine-grained, massive, and sometimes translucent form called alabaster; as selenite, a well-crystallized variety that may be split into clear, inflexible, transparent sheets; as satin spar, a silky, fibrous type; and as gypsite, an earthy mixture of gypsum crystals, clay, and silt. Gypsum may be colorless, white, gray or hues of red, yellow, or brown. It has a hardness of 1.5 to 2 (can be scratched by the fingernail) and a specific gravity of 2.32. When pure, gypsum contains 32.5 percent lime (CaO), 46.6 percent sulfur trioxide (SO_3) and 20.9 percent water (H_2O). To be considered commercial, a gypsum deposit should contain not less than 80 percent gypsum and, for many purposes, not less than 90 percent. Gypsite with as low as 50 percent gypsum may be used for some agricultural purposes.

Anhydrite ($CaSO_4$) contains 41.19 percent CaO and 58.81 percent SO_3. Its hardness is 3 to 3½ (harder than the fingernail) and the specific gravity is 2.89. Anhydrite is usually white or light gray, or pale hues of blue or red. Normally it is translucent.

Bedded deposits of gypsum and anhydrite result from the precipitation of calcium sulfate from marine or other saline waters through evaporation and concentration of salts within more or less restricted basins. The deposits of calcium sulfate may be a few inches or hundreds of feet in thickness, and may extend from a few to many square miles in area. Most geologists agree that calcium sulfate was originally deposited as anhydrite and altered to gypsum by hydration. In any event, most gypsum deposits become anhydrite at depth. In humid regions, gypsum may extend as far as 1,000 feet below the surface; in semiarid and arid regions this depth is generally about 30 feet and some isolated crystals or layers of anhydrite occur within gypsum beds at the surface. Gypsum beds are often thickened in the crests of anticlines and thinned on the flanks, due to flowage to points of least stress. Gypsum and anhydrite, usually in minor amounts, are found also in altered carbonate rocks and in hydrothermal and oxidized sulfide ore deposits where sulfuric acid-bearing waters have been active.

Uncalcined gypsum is an important ingredient that functions as a retarder of the setting time of portland cement; for this purpose 3 to 6 percent by weight of gypsum is mixed with the cement clinker

in the final grinding stage of cement manufacture. Appreciable quantities of gypsum and gypsite, called "land plaster," are used in agriculture in some areas of the United States where calcium and sulfur are required or deemed beneficial as a soil additive. Anhydrite is used to supply sulfur to such crops as peanuts. In Arizona, along with other areas in the Southwest, land plaster has been used extensively to break down the sodium content of "black alkali" soils that result from the excessive accumulation of this element, particularly from irrigation waters. The calcium from gypsum replaces the sodium adsorbed on clays so that it can be leached away by heavy irrigation (Fuller, 1962; Fuller and Ray, 1963). Alabaster has been used in sculpture and decorative objects and large plates of transparent selenite were used as a substitute for glass in windows by early settlers.

Plaster of paris, gypsum calcined at temperatures of 250° to 400° F., is an important construction material. In calcining, three-fourths of the water content is driven off, leaving a hemihydrate ($2CaSO_4.H_2O$) which, when mixed with water, forms an easily worked plaster that recrystallizes to gypsum. The plaster can be used for direct application or it can be molded between sheets of heavy paper or other similar materials to form gypsum board (also called sheetrock or plasterboard). Calcined gypsum is used also in making molds for industrial machines, tools, and other objects; in crayons and chalk; in various insulation materials; in medical, surgical, and dental plasters and bandages; in briquetting granular materials; as a filler in paints, textiles, and papers; and as a chemical agent in brewing, making calcium sulfide, and manufacturing glass. When calcined at 900°–1,000° F., gypsum converts to anhydrite, called "dead-burned gypsum" which, like natural anhydrite, is used as a desiccator and dehydrator and in the manufacture of Keene's cement. In Europe and Asia anhydrite is used in the manufacture of ammonium sulfate and sulfuric acid.

The United States is the world's largest producer and consumer of gypsum; in 1966, domestic production was about 9.6 million short tons, valued at about $35.7 million. In addition, about 5.5 million short tons were imported to supply a large part of the requirements along the coastal regions of the country (U.S. Bur. Mines, 1967).

History and Production

The occurrence of gypsum in Arizona was noted as early as 1873 by Gilbert (1875, p. 160–161) and the occurrence of gypsum and selenite were noted by Reagan (1903) and Blake (1904). Gypsum has been produced commercially in Arizona since about 1880 but it did not become an important mineral commodity until the mid-1950's when the local demands for its use in cement, in construction, and in agriculture required a marked increase in production. Figure 56 illustrates the annual tonnage of gypsum produced in Arizona from 1900 to 1966. The sharp rises and falls in recent years mainly reflect the fluctuations and economic status of Arizona's construction industry. The apparent consumption of gypsum in the manufacture of portland cement is shown also to emphasize its importance in gypsum production. The

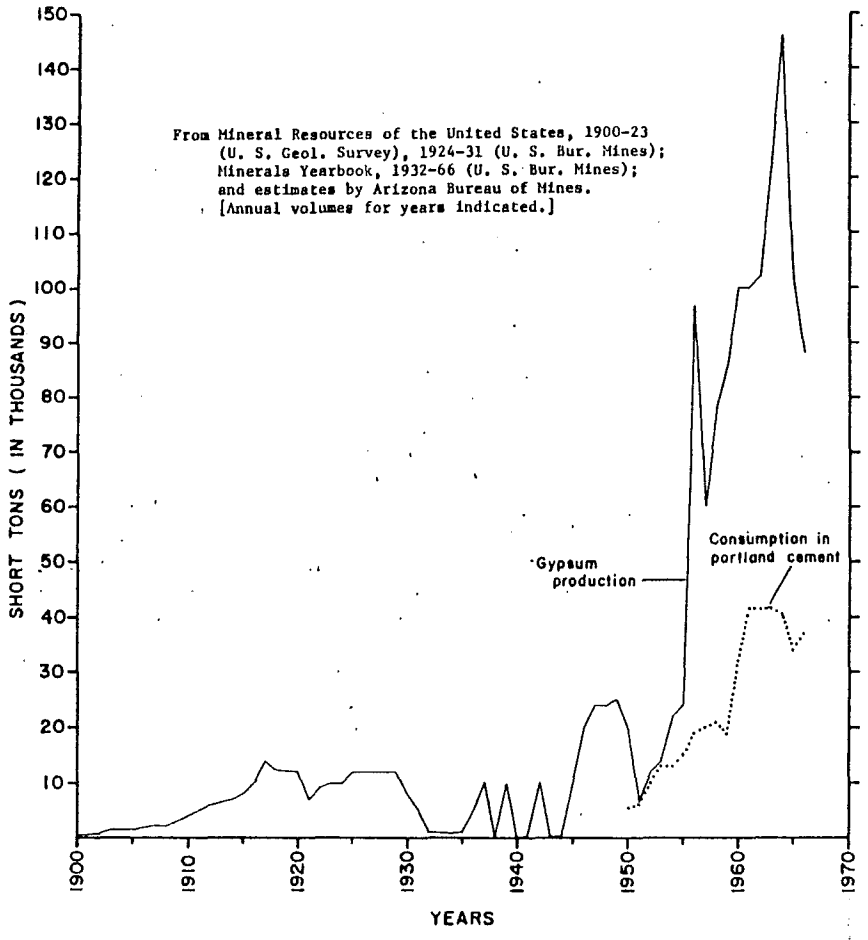

FIGURE 56.—Annual tonnage of gypsum produced in Arizona, 1900–66.

average dollar value per ton of raw gypsum produced in Arizona has not always followed the national average and has fluctuated widely, depending on the quality, major use, and local demand. Until recent years production has been very irregular.

The first reported production of gypsum in Arizona was from a small deposit in the western foothills of the Santa Catalina Mountains north of Tucson. The gypsum was calcined for plaster, some of which was used in interior decorations of a cathedral in Tucson (Blake, 1904). Between 1909 and 1914, gypsum was mined from surface beds west of Winslow along the Coconino-Navajo County line and the raw product was shipped to California for cement additive and agricultural uses (Stone, 1920). From 1908 to about 1932, gypsum and gypsite were mined intermittently from the surface east of Douglas in Cochise County. The products were calcined to produce plaster and used also in the manufacture of gypsum blocks for local building construction

(Stone, 1920). In 1945 surface mining began in the San Pedro Valley gypsum deposits in eastern Pinal County. Since that time, these deposits have provided the major share of Arizona's production, being used in the cement plant at Rillito in Pima County, calcined in Phoenix for plaster and gypsum board, and sold as "land plaster." Gypsum for agricultural use first was mined from surface deposits near Camp Verde, Yavapai County in 1957. Since 1959 this source also has supplied the gypsum for the cement plant at Clarkdale. Relatively small and intermittent production has come from other deposits in the State, mostly for agricultural use.

Arizona Gypsum and Anhydrite Deposits

Table 31 lists the principal gypsum mines and occurrences in Arizona and figure 57 shows their location. The active and inactive mines in 1966 are noted. Reported occurrences of anhydrite, except in deep drill holes, are rare and are of no economic significance. Logs of deep drill holes in the Willcox area of Cochise County, the Salt River Valley area west of Phoenix in Maricopa County, the Hualapai Valley area north of Kingman in Mohave County, and the Supai Basin area in east-central Arizona, show gypsum and anhydrite beds at depths ranging from a few hundred to 2,000 feet. At these depths they are not exploitable but they mark gypsiferous zones that may be traced to outcrops and thus can be of economic interest.

Three general times of gypsum-anhydrite deposition are recognized in Arizona: late Paleozoic, early Mesozoic, and Cenozoic. The earliest deposition occurred principally during the Permian Period when the gypsum beds in the Empire (fig. 57, locality No. 14), southern Whetstone (No. 42), Sierrita (No. 17), and Santa Rita Mountains (No. 16) of southeastern Arizona; the Harquahala deposit (No. 5) in Yuma County; those in the Holbrook Basin (No. 41) of east-central Arizona, and the reported occurrences in the red beds of the Toroweap Formation and the Kaibab Limestone in northern Arizona (Nos. 9, 33, 34, 35, 36, and 37) were deposited. The second period of deposition was during Triassic time when gypsum was deposited with nonmarine and marine sediments of the Moenkopi Formation in northern Arizona (Nos. 8, 29, 30, 31, and 38). The gypsum associated with undifferentiated sedimentary and metamorphic rocks at the Blue Moon deposit (No. 25) in Yuma County may be related to this period. The third and youngest period of deposition was during Cenozoic time in the Basin and Range province. These deposits are mainly continental, having been formed in lakes and playas in the basin areas which were being filled principally with alluvium, limestone, volcanic debris and, locally, evaporites. The gypsum beds are scattered irregularly within the basin sediments; some have been exposed by erosion but most are buried and are only known from drill-hole samples and logs. The San Pedro Valley deposits (Nos. 1, 2, 3, 18, and 19) in eastern Pinal County are the largest and best exposed deposits of this period. Also of this period is the gypsum in the Verde Formation (Nos. 4, 27, 28) in eastern Yavapai County. Other Cenozoic gypsum deposits shown in figure 57 and listed in table 31 are occurrences of more geologic than apparent economic interest.

TABLE 31.—*Gypsum mines and occurrences in Arizona*

Locality No. in fig. 57	Locality or mine name	Location	Description	Remarks	References
1	National Gypsum	Secs. 26 and 35, T. 6 S., R. 16 E., Pinal County. On E. side of San Pedro Valley, 6-7 mi S. of Winkelman.	Zone at least 100 ft thick in some localities, containing a series of 1-8-ft-thick, massive, white to grayish white, granular to microcrystalline, flat-lying gypsum beds separated by thin layers of calcareous and gypsiferous shale and silt. Occur in Cenozoic lake sediments in Gila Group. May be areally extensive. Exposed near surface where mined, but buried to S. and E. and eroded away to W. and N. except in isolated resual hills. Grade varies but mostly +90 percent or more gypsum. Reserves and resources not estimated but probably in multimillion-ton range.	Bench mining in open pit. Raw gypsum shipped to company calcining and gypsum board plant in Phoenix; some sold for agricultural use. Active in 1966.	Blake, 1904, p. 100-101; Stone, 1920, p. 54-56; Ariz. Bur. Mines file data.
2	Arizona Gypsum	Secs. 25, 26, 34, and 35, T. 6 S., R. 16 E., Pinal County. On E. side of San Pedro Valley, 7-1/2 mi S. of Winkelman.	do.	Shallow open-pit mining. Ground raw gypsum sold to Ariz. Portland Cement Co. at Rillito, Pima County, and also sold for agricultural use. Active in 1966.	Do.
3	Garcia Gypsum	Secs. 10 and 14, T. 7 S., R. 16 E., Pinal County. On E. side of San Pedro Valley, 8-1/2 mi N. of Mammoth.	do.	Surface mining. Raw gypsum sold for agricultural use. Active in 1966.	Do.
4	Arizona Gypsum (Larson quarry)	Sec. 11. T. 13 N., R. 5 E., Yavapai County. On E. side of Verde Valley, 4-1/2 mi SE. of Camp Verde.	Gypsiferous zone, possibly as much as 100 ft thick locally, containing a series of nearly pure, white, massive, microcrystalline and granular, flat-lying gypsum beds in interbedded mudstone and volcanic ash of the mudstone facies of the Verde Fm. of Cenozoic age. Extent of lake bed deposit probably covers several square miles. Reserves and resources estimated in millions of tons mostly 90 percent or more gypsum.	Surface mining. Ground raw gypsum sold to Phoenix Cement Corp. at Clarkdale, and sold for agricultural use. Active in 1966.	Twenter and Metzger, 1963, p. 53, 91, 102; Ariz. Bur. Mines file data.

TABLE 31.—*Gypsum mines and occurences in Arizona*—Continued

Locality No. in fig. 57	Locality or mine name	Location	Description	Remarks	References
5	Harquahala gypsum	SW. part of T. 5 N., R. 11 W., Yuma County. On S. side Harquahala Mts. about 7 mi SE. of Wenden.	An irregular, lensing, white, crystalline bed of gypsum, 1-12 ft thick, in folded Permian (?) limestone and shale. Thickened by flowage in anticlinal crest. Grade probably about 90 percent gypsum. Reserves and resources probably small.	Underground mining. Raw gypsum sold for agricultural use. Active in 1966.	Ariz. Bur. Mines file data.
6	Alamo Springs area	Secs. 3 and 4, T. 13 S., R. 14 E., Pima County. In SW. foothills of Santa Catalina Mts., 8 mi NE. of Tucson.	Several 1- 2-1/2-ft-thick massive, light brown to white gypsum beds separated by clay partings in Cenozoic clay, shale and sandstone. Probably in small lake bed. Grade of gypsum fair to good but reserves and resources believed to be small.	Earliest recorded production in Ariz. (1880's); calcined for plaster in Tucson. Inactive in 1966.	Blake, 1904, p. 100-101; Stone, 1920, p. 52-54; Galbraith, 1949.
7	Douglas area	Secs. 2 and 11-15, T. 24 S., R. 28 E., and secs. 2 and 11, T. 23 S., R. 28 E., Cochise County. About 5 mi E. and 8-1/2 mi NE. of Douglas.	Up to 6-ft-thick, irregular, lenses of light buff to white gypsum and gypsite at surface overlying Cenozoic clay and shale. Deposited in lake of unknown extent. Grade of gypsum reported to be 91-95 percent; apparently largely mined out.	Surface mining by Ariz. Gypsum Plaster Co., Douglas Block and Plaster Co., and G. O. Bohannon, about 1908-32. Largely calcined for plaster and use in gypsum blocks. Inactive in 1966.	Stone, 1920, p. 49-51; Galbraith, 1949.
8	Winslow area	Secs. 15, 16, and 21, T. 19 N., R. 15 E., Coconino and Navajo Counties. About 3 mi W. of Winslow.	Extensive, irregular, 1/2-4-ft-thick bed of flat-lying, almost alabasterlike gypsum on surface Deposit underlain by shale of Moenkopi Formation of Triassic age. Grade and amount of resources unknown.	Mined by Acme Cement Plaster Co. and Navajo Gypsum and Fertilizer Co., about 1909-14. Shipped to Calif. for cement, plaster, and agricultural use. Inactive in 1966.	Stone, 1920, p. 51-52.
9	Mokiah Wash area	T. 40 N., R. 12 W., Mohave County. N. of Wolf Hole.	Gypsum lenses in Permian red beds between massive limestones of Kaibab and Toroweap Fms. Grade and amount of resources not determined.	Intermittent open-pit mining by Sam Bowman. Raw gypsum sold for agricultural use. Inactive in 1966.	Larson and Biggs, 1965, p. 128. Ariz. Bur. Mines file data.
10	Turkey Creek	T. 18 S., R. 28 E., Cochise County. Along Turkey Creek in Sulphur Spring Valley.	Probably in local outcrop of Cenozoic lake bed deposit. No information on extent or grade.	Undeveloped.	Ariz. Bur. Mines, 1965.

TABLE 31.—*Gypsum mines and occurrences in Arizona*—Continued

Locality No. in fig. 57	Locality or mine name	Location	Description	Remarks	References
11	Turkey Creek Ridge	Sec. 4, T. 18 S., R. 26 E., Cochise County. In Sulphur Spring Valley.	Crystalline and fibrous, white to reddish gypsum, in beds up to 6-1/2 ft thick, in crudely bedded Cenozoic sediments. Grade probably low and extent unknown; generally very gritty.	Undeveloped.	Coats and Cushman, 1955, p. 18.
12	Land	Sec. 19, T. 18 S., R. 21 E., Cochise County. 1 mi E. of Land.	Up to 10-ft-thick bed of gypsum interbedded with clay in Cenozoic caliche, sandstone, and gravel; under thick overburden. Grade and extent unknown.	Undeveloped. Thick overburden limits exploitation.	Stone, 1920, p. 49-51.
13	Benson	Secs. 21 and 22, T. 17 S., R. 20 E., Cochise County. 2 mi S. of Benson.	Gypsum lenses and aggregates of small, platy selenite crystals in red clay under outcrops of coarse Cenozoic sandstone. Grade probably poor and extent limited.	Undeveloped.	Do.
14	Empire Mts.	Secs. 19, 28, 30, and 32, T. 17 S., R. 17 E.; secs. 4 and 8, T. 18 S., R. 17 E., Pima County.	Three zones of irregular, lensing gypsum beds, 16-60 ft thick and 1-2 mi long in Permian marl, shale, and limestone above Naco Fm. Large resources of high-grade gypsum.	Undeveloped. Difficult access and steep dip limits exploitation possibilities.	Stone, 1920, p. 52-54; Galbraith, 1949.
15	Vail	T. 16 S., R. 16 E., Pima County.	Gypsum and gypsite lenses in Cenozoic sediments. Grade, thickness, and extent unknown.	Undeveloped.	Galbraith, 1949.
16	Santa Rita Mts.	Secs. 13 and 14, T. 18 S., R. 15 E., Pima County. Near Helvetia.	Two areas contain faulted gypsum beds, 50-60 ft thick and 600-1,800 ft long, in Permian marl, shale, and limestone above Naco Fm. Reportedly good grade but limited extent.	Undeveloped. Difficult access and steep dip limits exploitation possibilities.	Do.
17	San Xavier--Mineral hill	Sec. 2, T. 17 S., R. 12 E., Pima County. On NE. side of Sierrita Mts.	Gypsum lenses, up to 60 ft thick and 1,500-2,000 ft long in Permian limestone outliers. Fair to good grade but limited extent.	Undeveloped.	Do.
18	Reddington	Sec. 26, T. 10 S., R. 18 E., Pinal County. On E. side of San Pedro Valley, 6 mi N. of Reddington.	Thick beds of gypsum in high bluff of sediments of Gila Group (Cenozoic). Grade and extent unknown.	Undeveloped. Thick overburden probably limits exploitation.	Stone, 1920, p. 54-56.
19	Winkelman	Secs. 2 and 11, T. 5 S., R. 16 E., Pinal County, 3-1/2 mi NE. of Winkelman.	Almost pure gypsum and a little calcite apparently within andesite flows. Grade and extent unknown.	Undeveloped.	Ross, 1925, p. 48.
20	Clifton-Morenci	T. 4 S., R. 29 E., Greenlee County.	Gypsum replacement of limestone associated with oxidized sulfide deposits.	Not a commercial source.	Lindgren, 1905, p. 120.

TABLE 31.—*Gypsum mines and occurrences in Arizona*—Continued

Locality No. in fig. 57	Locality or mine name	Location	Description	Remarks	References
21	San Carlos	Sec. 16, T. 1 S., R. 18 E., Gila County, 3 mi W. of San Carlos in San Carlos Indian Reservation.	Three to five, white, granular gypsum beds, 2-10 ft thick, in 100-150-ft-thick exposure of Cenozoic mudstone, siltstone and sandstone. Gypsum includes seams and pockets of clay; deposit covered by variable thicknesses of overburden. Grade fair to good. Gypsum beds may extend through 9-acre area and contain 100,000 tons of available gypsum.	Mined on a small scale for local use.	Bromfield and Shride, 1956, p. 681-683.
22	Black Gap	T. 7 and 8 S., R. 5 W., Maricopa County, 15 mi S. of Gila Bend on NW. slope of Sauceda Mts.	Gypsum with associated celestite, (strontium sulfate) interbedded in tuffs in 40-50-ft-thick zone in Cenozoic sandstones and conglomerates. Outcrop extends about 1 mi. Probably low grade.	Examined as source of strontium.	Phalen, 1914, p. 131-133; Moore, 1936, p. 154.
23	Holiday	T. 7 N., R. 6 E., Maricopa County, by Verde River.	Probably in Cenozoic lake bed deposit. Grade and extent unknown.	Undeveloped.	Ariz. Dept. Mineral Resources, 1963.
24	Cave Creek	Approx. secs. 21 and 28, T. 8 N., R. 6 E., Maricopa County. Near Horseshoe Dam.	do.	do.	Do.
25	Blue Moon	Secs. 25 and 26, T. 6 N., R. 17 W., Yuma County. 10 mi SW. of Bouse near Hudersback mine in Plomosa Mts.	Gypsum bed, several feet thick, exposed for several hundred feet in Permian limestone. Grade and extent unknown.	Few tons sold for local agricultural use.	Bancroft, 1911, p. 91-92; Ariz. Dept. Mineral Resources, 1963.
26	Adams	Approx. T. 14 N., R. 13 W., Mohave County. Near Wickieup in Big Sandy R. Valley.	Probably local Cenozoic lake bed deposit. Grade and extent unknown.	Undeveloped.	Ariz. Dept. Mineral Resources, 1963.
27	Wingfield	Approx. sec. 22, T. 13 N., R. 5 E., Yavapai County. S. of Camp Verde.	Probably in Verde Fm (Cenozoic) lake bed associated with other salines in mudstone.	do.	Do.
28	Camp Verde	Approx. T. 14 N., R. 6 E., Yavapai County. 6 mi E. of Camp Verde.	Gypsum beds probably in lake-beds of Verde Formation (Cenozoic).	do.	McCrory and O'Haire, 1965.
29	Snowflake	T. 13 N., Rs. 21-22 E., Navajo County, near Snowflake.	Probably local lake bed gypsum deposit in Moenkopi Fm. of Triassic age.	Reported developed and possibly exploited in early 1900's.	Stone, 1920, p. 51-52.

TABLE 31.—*Gypsum mines and occurrences in Arizona*—Continued

Locality No. in fig. 57	Locality or mine name	Location	Description	Remarks	References
30	Woodruff	T. 16 N., R. 22 E., Navajo County.	Probably local lake bed gypsum deposit in Moenkopi Fm. of Triassic age.	Possibly mined on small scale in early 1900's.	Stone, 1920, p. 51-52.
31	Black Falls	Secs. 32 and 33, T. 26 N. R. 11 E., Coconino County. On E. bank Little Colorado River, SE. of Black Falls Ford.	Irregular gypsum lenses, locally 4 ft thick, that crop out under area 14,500 by 4,500 ft, in Moenkopi Fm. of Triassic age. Gypsum beds overlie thin gypsite bed and are covered by overburden of variable thickness. Estimated reserves 362,500 tons that average 97.5 percent gypsum.	Undeveloped.	Anthony and others, 1955, p. 78-83.
32	Detrital Wash	T. 30 N., R. 20 W., Mohave County.	Gypsum lenses in Muddy Creek Fm. of Tertiary(?) age.	do.	Longwell, 1928, p. 93-96.
33	Hack Canyon	T. 36 N., R. 4 W., Mohave County.	Gypsum beds in red beds associated with Kaibab and Toroweap Fms., of Permian age. Lenses of gypsum, 1-4 ft thick, extend over wide areas; gypsum also occurs in limestone breccias. Gypsum ranges from fine grained, hard and white to coarse grained, sugary, soft and massive; locally contains abundant quartz sand.	do.	Stone, 1920, p. 51; McKee, 1938, p. 17-22, 35, 50-51, 121-126; Withington, 1962, p. 2.
34	Toroweap Canyon	T. 36 N., R. 7 W., Mohave County.	do.	do.	Do.
35	Antelope Wash	T. 38 N., R. 5 W., Mohave County.	do.	do.	Do.
36	Wolf Hole	T. 39 N., R. 12 W., Mohave County.	do.	do.	Do.
37	Hurricane Cliff	T. 40 N., R. 10 W., Mohave County.	do.	do.	Do.
38	Black Rock Springs	T. 39 N., R. 12 W., Mohave County.	Gypsum lenses in Moenkopi Fm. of Triassic age.	do.	Withington, 1962, p. 2.
39	Rock Canyon	T. 41 N., R. 12 W., Mohave County.	do.	do.	Do.
40	Beaver Dam	Approx. secs. 3 and 4, T. 41 N., R. 14 W., Mohave County.	Gypsum lenses at top of Callville Limestone of Late Pennsylvanian age.	Mined intermittently for agricultural use.	Moore, R. T., written commun., 1967.

TABLE 31.—*Gypsum mines and occurrences in Arizona*—Continued

Locality No. in fig. 57	Locality or mine name	Location	Description	Remarks	References
41	Fort Apache Reservation	Tps. 6-9 N., Rs. 20-22 E., Gila and Navajo Counties.	Gypsum and gypsiferous beds, 1-40 ft thick, associated with red clastics and siltstone in upper and lower parts of Supai Fm. of Permian age. Exposed in various localities along southern edge of Permian Holbrook Basin.	Undeveloped.	Peirce and Gerrard, 1966; Moore, 1967.
42	Southern Whetstone Mts.	Secs. 32 and 33, T. 19 S., R. 19 E., Secs. 4, 5, 9, 10, and 15, T. 20 S., R. 19 E., Cochise County.	Local gypsiferous zone and gypsum beds interbedded with siltstone and dolomite, in sequence 200-400 ft thick, and associated with Epitaph Dolomite of Naco Group of Permian age. About 19 million ton reserve of more than 80 percent gypsum estimated.	do.	Graybeal, 1962.

RESOURCE OUTLOOK

Both reserves and resources of gypsum in Arizona are extensive although detailed exploration data on which to make definitive estimates are lacking. Certainly reserves and resources are sufficient to supply Arizona's requirements for the foreseeable future. Gypsum and gypsum products are readily and economically available in most parts of the United States and there is strong market competition between producers. Gypsum products are bulky and heavy and transportation costs limit most shipments to local markets. The average value of raw gypsum in Arizona in 1966 was $5.25 per short ton but the value actually received by the producer from sales varied considerably with the quality of the product, the amount of processing required, the end use and transportation costs. The present and future production of gypsum apparently depends on the local markets within the State and to a large extent on the economic status of the construction industry but the ample reserves and resources of gypsum in Arizona may be called upon in the future to supply the requirements of southern California.

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