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ARIZONA NONMETALLICS

A Summary of Past Production and Present Operations

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TABLE OF CONTENTS

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INTRODUCTION

The nonmetallic mineral resources of Arizona are attracting increased attention because of their possible utilization in future industrial expansion of the Pacific Coast region and the Southwest.

Production of nonmetallics in Arizona has been small compared with that of metals. Of the $3,500,000,000 value of all minerals produced in the State prior to 1944, nonmetallics constituted possibly $48,000,000 or about 1⅓ per cent.

Development and mining of nonmetallics have been handicapped by costs of transportation to the industrial centers that offer steady markets. Because of their natural abundance, most nonmetallics are relatively low priced. The potential value of a deposit depends largely upon its location in reference to transportation, its adaptability to low-cost mining, and its quality and tonnage.

Most of the nonmetallics mined in Arizona have been used locally, but some find their chief markets outside the State.

There is room for much research upon the geology, methods of beneficiation, and possible new uses[1] for Arizona's minerals.

SCOPE OF REPORT

This review of past and present operations is based largely upon information obtained during visits by the writer to the deposits and plants. Definitions of minerals, their chief commercial uses, general specifications, prices, and data of occurrence in the State are incidentally included, preliminary to more detailed reports which the Arizona Bureau of Mines plans to issue.

Although this report has been designed for both the layman and the engineer, the specifications of some minerals, such as Iceland spar, optical fluorite, and strategic quartz, are necessarily somewhat technical. The Arizona Bureau of Mines is prepared to assist interested parties in determining whether or not Arizona samples meet the stated specifications.

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[1]References are listed numerically at end of this report.

No attempt is made to include names of buyers. Lists of potential purchasers, which are particularly subject to change at this time, may be obtained from the Arizona Bureau of Mines.

As stated in the Engineering and Mining Journal *Metal and Mineral Markets,* price quotations can serve only as a general guide. The market value of a particular nonmetallic mineral can be ascertained only by direct negotiations between buyers and sellers.

PRODUCTION

Incomplete production data were obtained from the following sources: annual reports of the U.S. Geological Survey prior to 1900; Mineral Resources of the United States, published by the U.S. Geological Survey, 1882-1923, and by the U.S. Bureau of Mines, 1924-31; and U.S. Bureau of Mines Minerals Yearbooks and releases, 1932-43. Unfortunately these publications do not give the figures for each nonmetallic for every year. Consequently many of the production figures listed in this report are designated as estimates.

VALUE OF PRODUCTION

Sand and gravel, 1917-43	$10,600,000[a]
Stone, 1889-1943	10,000,000[b]
Lime, 1894-1943	9,100,000[c]
Clay products, 1894-1943	7,500,000[d]
Asbestos, 1914-43	4,000,000[e]
Clay (raw), 1918-43	2,175,000[f]
Feldspar, 1923-43	1,500,000[g]
Sodium sulfate	865,000[h]
Coal	700,000[h]
Cement	505,000[i]
Gypsum	500,000[h]
Precious and semiprecious stones, 1900-1921	300,000[j]
Fluorspar, 1902-43	125,000[k]
Barite, 1929-38	30,000[h]
Total	$47,900,000

[a]1919, 1923, 1925, 1935 estimated; [b]1890-94, 1909, 1921, 1943 estimated; [c]1900, 1902, 1922 estimated; [d]1932-34, 1942-43 estimated; [e]1922, 1925-28, 1931-35, 1941-43 estimated; [f]approximately 300,000 tons at $7.25 per ton, including freight; [g]approximately 100,000 tons; [h]roughly estimated; [i]388,452 barrels; [j]1900-1906 estimated, no figures since 1921; [k]1939-43 estimated.

ABRASIVES (NATURAL)

Definition

A natural abrasive is any mineral or rock capable of abrasive, grinding, or polishing action.

Uses

Abrasives are used in every household and by almost every industry. During recent years manufactured or artificial abrasives have largely replaced natural abrasives for many purposes, especially for grinding metals.

Abrasive materials are used in natural, crushed, shaped, or bonded forms. Among the more common products are abrasive paper or cloth, grinding wheels, whetstones, grinding compounds, sand-blasting sand, cutting mediums, tube-mill pebbles and liners, polishes, cleaners, and soaps.

Detailed lists of the various uses and specifications for natural abrasives are given in the literature.[2]

Abrasive materials in Arizona

Little attempt has been made to exploit natural abrasives in Arizona. As a rule, adequate supplies of such materials have been obtainable from places less distant than Arizona from the large industrial centers.

Some of the natural abrasives known to occur in the State are as follows:

Corundum. Aluminum oxide. Gray, brown, red, blue, to nearly white. Transparent to nearly opaque. Hardness 9 (next to diamond, the hardest mineral known). Gravity 3.95 to 4.1. Crystalline to granular and massive. Occurs chiefly in basic rocks and also in other rocks devoid of free quartz. Recent quotations for corundum range from $8.75 to 70 cents per pound. Practically all the natural corundum used in the United States during recent years has been imported from South Africa. Specimens from northwestern Pinal County have been submitted to the Arizona Bureau of Mines, but the exact location, extent, and ownership of the deposit are not known.

Garnet. A complex silicate. Commonly red, brown, green, or yellow. Hardness 6 to 7.5, gravity 3.15 to 4.3. Crystalline to granular and massive. Occurs in metamorphic and igneous rocks.

The efficiency of garnet as an abrasive depends upon both its hardness and its quality of breaking down into particles with numerous sharp edges. A new use for garnet is in nonskid deck covering on ships.

The most abundant Arizona varieties[3] are andradite and grossularite which occur in contact-metamorphic zones. No serious attempt has been made to use or experiment with Arizona garnet for abrasive purposes. Although the grossularite (hardness of about 6) and andradite (hardness of 7) varieties are regarded as too soft for standard abrasive cloth or paper,[2] they might be adaptable for special abrasive uses.

Siliceous abrasive materials. Quartz,* quartzite, sandstone, chert, silica, sand,* mica schist, novaculite, siliceous shale, volcanic ash,* pumice,* perlite,* and diatomaceous earth* are plentiful in Arizona. For abrasive purposes some of them have found

*Described in this report. See index.

small local use, but most have had a low market value that would not warrant their transportation to outside industrial centers.

Nonsiliceous soft abrasives. Clay,* feldspar,* talc,* pyrophyllite,* manganese oxide, and river silt are available in Arizona, but few attempts have been made to use them for commercial abrasives or polishes.

ALUNITE

Definition

Alunite is a hydrous sulfate of aluminum and potassium, with sodium replacing the potassium in some deposits. Generally white, light brown, or pinkish. Compact, fibrous, finely granular, or crystalline. Hardness 3.5 to 4, gravity 2.58 to 2.8.

Uses

Domestic industries at present do not consume much alunite. During World War I it was mined in the West for manufacture of potassium sulfate. During the present emergency it has been of interest as a possible source of alumina through the Kalunite[4] process, and of alum for the manufacture of paper. Some alunite has been used directly as fertilizer.

Arizona occurrences

Alunite veins occur in schistose dacite at Sugarloaf Butte, 5 miles west of Quartzsite, Yuma County. This deposit has been known since 1929, when samples of the material were identified by the Arizona Bureau of Mines. It has been prospected only to a limited extent. As described,[5] its alunite is of the sodic variety, which could be treated by the Kalunite process only after mixing with high-potash alunite or potassium sulfate.

It was recently announced[6] that the U.S. Geological Survey had identified platinum in alunite and associated schist from Sugarloaf Butte. Investigation by the Arizona Bureau of Mines and College of Mines, however, did not confirm the statement as to noteworthy quantities of platinum in this deposit.

The only other notable alunite deposit known in Arizona is at the 3R mine, 5 miles south of Patagonia, Santa Cruz County. It consists of veins and replacements of potash alunite in porphyry.[7]

No commercial production of alunite has been made in Arizona.

ASBESTOS

Definition

The general trade name of asbestos applies to fibrous serpentine (chrysotile) and fibrous amphibole (anthophyllite, tremolite, actinolite, crocidolite, and amosite).

Chrysotile is a hydrous silicate of magnesium. Color commonly white, light gray, light yellow, greenish, or brownish. Hardness

2.5 to 3, gravity 2.22. Fresh, high-grade fibers are soft, extremely fine, and tough. Harsh fiber is prickly and relatively brittle.

Anthophyllite is essentially a silicate of iron and magnesium. Color brownish-gray or greenish. Hardness 5.5 to 6, gravity 2.85 to 3.2. Fibers generally brittle.

Tremolite is a silicate of calcium and magnesium. Color white to dark gray. Hardness 5 to 6, gravity 2.9 to 3.4. Fiber somewhat harsh and generally brittle.

Actinolite is a silicate of calcium, magnesium, and iron. Color greenish. Hardness 5 to 6, gravity 2.9 to 3.4. Brittle.

Crocidolite and amosite are complex silicates that are not known to occur in Arizona.

Uses

Chrysotile is the most useful asbestos. Its highest grades No. 1 and No. 2 are used for spinning yarn and thread to make brake linings, clutch facings, fireproof or heat-repelling cloth, and electrical insulation. Shorter or less flexible fiber is used extensively in manufacture of heat-insulating material, paper, millboard, shingles, roofing, plaster, paving, pipe, tile, magnesia block, certain plastics, asbestos cement, molded brake lining, and fillers in paints and greases. There seems to be no satisfactory substitute for chrysotile in brake lining and clutch facings. Because of its low iron content, Arizona chrysotile is superior for electrical insulation.

Anthophyllite is used chiefly in insulation, cement, plaster, and paint.

Tremolite and actinolite are used mainly for filtering acids and to a limited extent for insulation, cements, and arc welding.

Arizona occurrences

Arizona chrysotile asbestos occurs with serpentine in dolomitic limestone, near diabase intrusives. The most important commercial deposits are in central Gila County, and some in the Grand Canyon have been worked to a small extent. The Arizona deposits were described by the Arizona Bureau of Mines in 1928.[8] Recently the U.S. Geological Survey studied occurrences in Gila County, and the U.S. Bureau of Mines conducted some exploration of them.

No notable deposits of anthophyllite are known in Arizona. Tremolite and actinolite have been found in many contact deposits but not in sufficient tonnage and grade to encourage production for existing markets.

Arizona chrysotile asbestos industry

Production from 1914-43 is estimated as approximately 17,000 tons, valued at $4,000,000.

During recent years the principal producers and potential producers have been as follows:

Johns-Manville Products Co., Frank Knuckey, Supt., Box 1943, Globe. Mill of 150 tons daily capacity and mine at Chrysotile, Arizona.
Arizona Chrysotile Asbestos Co., Box 328, Globe. Mill of 100 tons daily capacity at Regal mine.
Phillips Asbestos Co., Guy Phillips, Box 662, Globe. Mill of 45 tons daily capacity at mine.
Southwest Asbestos Co., Globe, Arizona. Old Canadian mine. Mill of 700 tons per month capacity under construction at Globe.
Sloan Creek, Pueblo, and Miami groups, Roger Q. Kyle, Globe. Mill of 60 tons daily capacity in Globe.
Reynolds Falls and White Tail groups, Arthur Enders, lessee, Box 362, Globe.
Rock House group, Earl Pearce, Young, Arizona.
Fiber King and Victory groups, John A. Bacon, lessee, Roosevelt.
Buckhorn and associated groups, Roy Wilson, Young.
Lucky Strike, T. C. Coughlin, 2039 N. 15th St., Phoenix.
McIntyre, Dr. A. J. McIntyre, 203 Luhrs Bldg., Phoenix.
Maxwell group, George Wright, Globe.

Asbestos production in Arizona has been retarded by relatively high costs of mining and transportation under average demand and market value. Present wartime conditions have not stimulated the local industry. Although production during 1941 more than doubled the 1940 yield of 1,197 tons, it fell back to approximately the 1940 level during 1942[9] and 1943. Since late 1937 the maximum prices quoted for Canadian Crude No. 1 have remained constant. Other grades advanced slightly in April, 1942, and remained unchanged through 1943. Present prices per ton, based on Canadian or Vermont schedules, are quoted[10] as follows:

Crude No. 1 (more than ¾ inch long)	$650-750
Crude No. 2 (5/16 to ¾ inch)	$165-385
Spinning fibers (5/16 inch or more)	$124-233
Sheet fibers	$124-146.50
Shingle stock (1/32 to 5/16 inch)	$ 62.50-85
Paper stock (up to 1/32 inch)	$ 44-49
Cement stock	$ 28.50-33

Future industrialization of the West should stimulate the demand for asbestos, and Arizona is the only notable producer of chrysotile asbestos in the West.

BARITE

Definition

Barite (barytes, heavy spar, or tiff) is barium sulfate. White unless colored by impurities. Crystalline to massive. Hardness 2.5 to 3. Gravity about 4.5, one of the heaviest nonmetallic minerals.

Uses

The principal use for barite is in heavy muds for rotary oil-well drilling. It is also used in manufacture of glass; paints, particularly lithophone (barium sulfate with zinc sulfide); plastics; white rubber; paper, linoleum; oilcloth; certain textiles and leather; heavy cements; various chemicals; barium carbonate for casehardening of steel and for preventing efflorescence in brick; green signal flares; and certain explosives.

Specifications

The specifications on commercial barite are high. For oil-well muds it must have a gravity of at least 4.3. Most other uses demand a barium sulfate content of 93 to 95 per cent or over, with not more than 1 per cent ferric oxide.

Prices

Because of its abundance and widespread occurrence, barite is low priced. Quotations reached a peak of $9.39 in 1920, averaged $6.22 during 1942, and recently[10] were $8.25 to $8.50 (per ton f.o.b. mine shipping points).

Arizona occurrences

Barite occurs as a gangue in veins of metallic minerals at numerous places in Arizona. In some veins it forms bodies of commercial size and grade, associated chiefly with calcite and more or less free of other minerals.

The total barite production of Arizona has been relatively small. Figures are available only for 1931-32 when the output was 3,410 tons, valued at $23,171.

A large part of the production was from the Christman property in the Goldfield Mountains, east of Phoenix. It was actively worked several years ago but has since been idle.

The Renner deposit[11] north of Mohawk, Yuma County, produced nine carloads during 1929-30.

The Ernest Hall property in Cottonwood Pass, near Salome, Yuma County, is reported to have yielded several carloads during 1938.

Small shipments are reported to have been made from other deposits for which data are not available.

Excepting a small amount in 1943, no barite is known to have been mined in Arizona during recent years.

CEMENT (PORTLAND)

Definition

Portland cement[12] is an artificial chemical product containing 60 to 65 per cent lime, 20 to 25 per cent silica, and 5 to 12 per cent iron oxide and alumina. It is manufactured by heating the proper combination of finely ground raw materials to a temperature of some 2,700 degrees F., followed by addition of gypsum to control the setting rate and further fine grinding.

Raw materials

The principal raw materials commonly used for manufacture of Portland cement are limestone, clay or shale, and gypsum.

Approximately 225 tons of limestone, 75 tons of clay or shale, and 5 tons of gypsum are required for each 1,000 barrels (188 tons) of Portland cement.[12]

Under standard specifications, the limestone should contain less than 6 or 8 per cent magnesium carbonate; very little flint, chert, or nonalumina silicates; and less than 1 to 1.5 per cent sulfur. During recent years some large cement plants have employed froth flotation to beneficiate their limestone.

The clay or shale should be relatively free from gravel or sand, and its alumina and iron oxide together should equal approximately one third of its silica.

In some cases other raw materials are suitable. For instance, the Southwestern Portland Cement Company, at Victorville, California, has successfully used limestone containing lime silicates, together with weathered granite and schist as a source of extra silica and alumina.[13] During 1943 approximately 2,000 tons of hematite (iron oxide) tailings from Swansea, northern Yuma County, are reported to have been shipped to a California cement plant.

Fuels and power

Coal, oil, or natural gas serve for fuels in cement manufacture. During 1941 the Portland cement industry of the United States generated 47 per cent of its electric-power requirements and used an average of 22.2 kilowatt-hours per barrel of cement produced.[14]

Prices

The average factory prices of Portland cement in the United States during the past several years have been near $1.50 per barrel (376 lbs.).

Location of plants

As stated by Bowles and Balser,[14] "Raw materials for manufacture of Portland cement are so plentiful and widely distributed that other factors, such as markets and transportation facilities, are usually the principal elements that control selection of plant location. Most of the plants are contiguous to populous industrial centers. Concentrations of plants on the Pacific Coast are due partly to the requirements of growing industrialization areas and partly to the extensive demands of great reclamation projects." A plant in the Las Vegas, Nevada, area was under construction in 1941.

Arizona consumption of cement

During the twenty-year period 1923-42, shipments of Portland cement into Arizona totaled 10,636,018 barrels.[15] The amount for 1942 (1,379,825 barrels) was unusually large because of wartime construction; the annual average for the nineteen years prior to 1942 was 487,220 barrels.

Cement industry in Arizona

The only important production of Portland cement in Arizona was by the U.S. Reclamation Service, which established a plant near Roosevelt in 1905. A total of 388,452 barrels of cement was manufactured at this Government plant for the Roosevelt Dam project.[16] After completion of the dam, the plant was removed.

Abundant resources of raw materials suitable for manufacture of Portland cement occur in Arizona, although as a rule they have not been found ideally situated with respect to population or industrial centers.

In addition to the average annual consumption of cement in Arizona, the proposed development of Colorado River and further irrigation projects would seem to warrant a local cement plant. Some of the large cement companies hold limestone tracts in the State, and various interests have been investigating the problems of locating postwar plants in both northern and southern Arizona.

CLAY [17, 20]

GENERAL FEATURES

Definition

Clay is a fine-grained earthy substance that becomes more or less plastic when wet. It consists primarily of one or more minerals of the kaolin, montmorillonite, or illite groups. Various impurities, such as iron oxide, quartz, feldspar, manganese oxide, and organic matter, may be present.

Most of the clay minerals are hydrous silicates of aluminum, although some members of the montmorillonite group contain iron, magnesium, or calcium.

Types

The principal commercial types of clay are kaolin or china clay, ball clay, slip clay, fire clay, bentonite, and fuller's earth.

Kaolin is a white-firing clay consisting essentially of minerals of the kaolinite group.

Ball clay is a highly plastic, strong, tough, refractory clay that fires to ivory, buff, or white.

Slip clay resembles ball clay but contains a high percentage of iron and manganese which causes it to melt at relatively low temperatures.

Fire clay generally is not fusible below approximately 3,000 degrees F.

Bentonite is composed mainly of minerals of the montmorillonite group, formed by decomposition of igneous rocks, particularly volcanic ash. It is commonly characterized by pearly or waxy luster, slippery surfaces, and a capacity to absorb, with swelling, many times its own volume of water.

Fuller's earth is any natural clay that, without previous chemical treatment or activation, may be used commercially for filtering, bleaching, or decolorizing oils and other liquids.

Uses

Clays are used mainly for ceramic, filler, bonding, and adsorptive or bleaching purposes and as a source of alumina in cement manufacture.

The ceramic or fired products include common brick, tile, pipe, and various structural, refractory, decorative, and household materials. Many products are made of mixtures of different clays with other minerals. Detailed classifications of clays according to ceramic uses may be found in the literature.[17]

Use of clay for inert fillers depends essentially upon its fineness of grain, freedom from grit, color, and low cost. Various types are extensively employed in manufacture of paper, cardboard, certain textiles, rubber, linoleum, oilcloth, paint, wall coatings, putty, fertilizers, polishes, soaps, crayons, cosmetics, dental powders, insecticides, and plastics.

Strong clays find use as binders in synthetic molding sands, abrasives, plastics, cements, and road material. Fire clay or ball clay and bentonite seem to be the best for such purposes.

Clays with marked adsorptive or bleaching properties are used extensively in processing and refining of vegetable and mineral oils. Naturally adsorptive clay (fuller's earth) is less efficient than bentonitic clay that has been activated by chemical or physical treatment. Activated bentonite has become particularly important during recent years for use (reportedly as a catalyst) in manufacture of high-octane gasoline.

Bentonite has been found to be very serviceable for stopping leaks in dams, ditches, and other engineering works; for sealing oil wells against water and for thickening drilling muds; as an admixture in concrete; in making synthetic foundry sand; as a spreader in horticultural sprays; for clarifying turbid waters and sewage; as a cleaning agent; and for special cosmetics and drugs. More complete lists of its uses are given in the literature.[18]

CLAY INDUSTRIES IN ARIZONA

Clay products

Since very early days, considerable Indian and Mexican pottery and adobe brick have been made in Arizona, but their total value is not known. The leading clay industry in the State is manufacture of fired products, chiefly brick for local use. The reported value of these products made commercially in Arizona from 1894 to 1943, inclusive, was approximately $7,500,000.

The following brick plants in Arizona are listed.[19]

De Vry Brick Yard, Tucson.
Grabe Brick Company, Tucson.

Long Brick and Mortar Company, Phoenix.
Phoenix Brick Yard, Phoenix.
Day Sampson, Eager.
Sheffield Brick and Lime Company, Phoenix.
Wallapai Brick and Clay Products Co., Phoenix.

Bentonite

In Arizona bentonitic clay occurs at many places, but deposits of it have been mined only in the vicinity of Chambers, Cheto, and Sanders, Apache County.[20] The principal operations have been by C. A. McCarrell and C. E. Gurley, lessees, and the Filtrol Corporation. According to Mr. McCarrell, production started in 1925 when a car of the bentonite was shipped to New York for beauty clay. Up to June, 1944, approximately 300,000 tons have been shipped for various purposes mainly to the Filtrol Corporation in Los Angeles. Part of the material was from underground mines near Chambers, but during the current labor shortage it has come from open-pit operations southeast of Sanders or south of Cheto. Production during June, 1944, was at the rate of about 4,000 tons per month. Nearly all of it was used in manufacture of high-octane gasoline. The value of the clay (f.o.b. Sanders) is $2.50 per ton.[21] Freight rates to Los Angeles, which amount to about $4.77 per ton, hamper production.

Recently the College of Agriculture of the University of Arizona and others have been investigating possibilities of bentonite for lining irrigation ditches and sealing cracks in dams. Apparently considerable bentonite might be used for such purposes, provided the material with a swelling capacity of three or four times its initial volume could be obtained at sufficiently low cost.

FUTURE POSSIBILITIES OF ARIZONA CLAY INDUSTRIES

Clay products

The manufacture of brick for local use obviously will continue as long as the product is in demand. Tile and other fired clay products that are shipped into Arizona for structural and household purposes might be made locally, provided the proper clays were known to be available.

Raw clays

High-grade bentonite should continue to find a ready market in California, in keeping with demand by oil-refining industries.

Utilization of other Arizona raw clays depends upon freight rates and various additional economic factors.

Much field and laboratory research work must be done on Arizona clays before their future commercial possibilities can be adequately outlined.

Arizona clay as a possible source of aluminum

During recent years the possibility of extracting aluminum from clay has attracted much interest, and processes have been extensively investigated by the U.S. Bureau of Mines, private corporations, and others.

Clay deposits differ considerably in alumina content and in their percentage of extractable alumina.[22] For the various processes that have been announced,[4, 22, 23] clays containing less than 35 per cent Al_2O_3 (alumina) are not regarded as immediately promising economic sources of aluminum. However, as summarized by Archibald and Jackson,[23] "The lowest grade of clay that could be utilized commercially has not been established, and would vary with mining costs, freight and power rates, fuel costs, and other economic factors, as well as the amenability of the clay to beneficiation and the cost thereof."

The kaolinite group of clay minerals appears to be the most promising, as it contains about 39 per cent Al_2O_3 (alumina). The other two groups of clay minerals, montmorillonite and illite, are of considerably less interest as sources of aluminum, as their total alumina content and percentage of extractable alumina are low. Illite has about 12 per cent of soluble alumina, and montmorillonite about 5 or 6 per cent.

Although relatively impure kaolinite occurs extensively in Arizona, no large deposits of the high-grade material have been found. Deposits of montmorillonite in various degrees of purity are fairly abundant.

The possibility of recovering aluminum from clays and other aluminous raw materials that occur in Arizona is not yet clear. It depends upon satisfactory demonstration of suitable processes on a commercial scale and upon favorable economic factors.

COAL

Deposits

Notable deposits of bituminous or subbituminous coal occur in the Black Mesa, Pinedale, and Deer Creek areas of Arizona.

During 1926-34, the recorded production of coal in the State was 59,423 tons, valued at about $268,000; this output was almost all, if not entirely, from the Black Mesa. Figures for other years are not available.

Black Mesa

The Black Mesa coal field is in northeastern Arizona, in the Hopi and Navajo Indian reservations, 30 to 115 miles north of the Santa Fe Railway. The area has been estimated to contain at least eight billion tons of mineable coal.[24] It is believed to be somewhat higher in fixed carbon, but slightly lower in calorific value, than Gallup coal.[24] It evidently belongs on or about the dividing line between bituminous and subbituminous and is rather high in ash. Tests made by the U.S. Bureau of Mines indicate that the product from part of the area at least would not be satisfactory for making coke.[25]

For many years coal to supply the needs of local Indian agencies, schools, missions, and trading posts has been mined from several mines in the Black Mesa field. The Casey, or New Mexico and Arizona Land Company mine at Montezuma's Chair, 30 miles north of Winslow, has furnished coal to Winslow and vicinity. In November, 1941, this mine was producing about 20 tons per week.

Pinedale area

The Pinedale coal area is west of Showlow, principally in T. 10 and 11 N., R. 18 and 19 E. Comparatively little development work has been done on these deposits. Part of the coal is of low grade, but one of the beds shows 2 to 3 feet of very good subbituminous coal.[26] A little production for local use has been reported.

Deer Creek area

The Deer Creek coal field occupies an area of about 30 square miles in eastern Pinal County, south of the Mescal Mountains. It has been estimated to contain about 30,050,000 tons of available coal, part of which may be of coking quality.[27] Considerable prospecting has been done in this area since 1881 and a little coal produced.

Future possibilities of Arizona coal

As stated by A. C. Rubel[28] in 1915, "There is a possibility that this hitherto neglected part of the State's resources will some day prove itself of great value." With the eventual depletion of other sources of fuel, Arizona's coal may be used to produce gas or synthetic liquid fuels.

DIATOMACEOUS EARTH

Definition and origin

Diatomaceous earth is also known as diatomite, kieselguhr, or tripolite, and by various trade names of its industrial products. It is a siliceous material made up largely of skeletons of diatoms. When pure it resembles white chalk but is harsher to the touch. Impurities such as clay, iron oxides, and organic material may affect its color. The lump material ranges in weight from 28 to 60 pounds per cubic foot, and the dry loose powder from 7 to 16 pounds. It does not effervesce in acids. The best method of identification is to place a small amount of the powdered material in a drop of water upon a piece of glass and examine it with a high-power microscope, which reveals any diatom skeletons present.

Diatoms are tiny, generally microscopic, plants. Diatom skeleton fossils composed of silica accumulate in favorable places to form deposits of diatomaceous earth. Each skeleton is a hollow complex cell, which fact accounts for the high porosity of diatomaceous earth. More than eight thousand different varieties of diatoms have been classified. As a rule the varieties of diatoms and the amount of impurities present determine the industrial uses to which the material may be put.

Diatomaceous earth is employed principally for filtration mediums, particularly in manufacture or processing of sugar, beer, wine, fruit juices, and vegetable and animal oils; heat and cold insulation; admixture in light-weight concrete, roofing tile, and brick; filler in battery boxes; absorbent in chemical and explosive manufacture; soundproofing and fireproofing; polishes and abrasives; refractories; and poultry litter. It may be used also in paper manufacture, as an ingredient of paint, a general light-weight inert filler, an absorbent in fertilizer, and for amending soils.

Diatomaceous earth from the fresh-water, or lake, deposits, in which diatoms of the small type predominate, is best suited for polishes, fillers, admixtures, and insulation products. If the larger elongated and disc forms of diatoms are abundant, the material may be used for filtering purposes.[29]

Prices

Diatomaceous earth has a rather broad price range, depending upon its type, the amount of impurities present, and processing. Recent quotations[10] per ton f.o.b. Nevada mines are: crude dried, $7; 98- to 100-mesh, $20; low-temperature insulation, $19; high temperature, $30; fine abrasive, 2 cents per pound. It is frequent practice for the seller to submit standard samples.

Arizona occurrences

Extensive deposits of diatomaceous earth have been found at various places in the San Pedro Valley and the upper Gila Valley. Their principal impurities are volcanic ash, clay, and sand.

The M. Hererras property, 9 miles south of Mammoth, was worked in a small way at intervals for a few years after 1920. The product was sold mostly for insulation in building construction in southern Arizona.

During 1940-41 the Arizite Products Corporation worked the Hererras property by open-cut and underground methods. The material was milled near Mammoth in an air-flotation plant of 30 tons' daily capacity. The operation closed down, reportedly because costs of mining, milling, and freight were high in comparison with the market value.

FELDSPAR

Definition

The feldspars form a series of minerals grading from potassium-aluminum silicate (orthoclase or microcline) through sodium-aluminum silicate (albite) to calcium-aluminum silicate (anorthite). Commercial feldspar is an intergrowth of two or more species, generally orthoclase or microcline and albite. Commonly white to pink, also brown, red, gray, or green. Crystalline. Hardness 6 to 6.5, gravity 2.56 to 2.76. Melting point 2,030 to 2,789 degrees F. Commonly associated minerals include quartz, muscovite (white mica), biotite (black mica), garnet, and tourmaline.

Feldspar is a constituent of most igneous rocks, but large and fairly pure segregations of it occur only in pegmatites. "Aplite," a granular feldspar rock free from dark minerals, has been mined in the eastern United States during recent years for glass manufacture.

Uses

Most of the feldspar produced goes into manufacture of glass, pottery, and enamel. It is used also for making artificial teeth; soaps, cleansers, and sweeping compounds; abrasives; miscellaneous fillers; welding-rod coating; fire-brick cement; concrete aggregate; stucco; roofing granules; and poultry grit. A wartime use is for extinguishing magnesium incendiary bombs.

For fired or fused products, the most objectionable impurity is iron, commonly present in garnet, biotite, or tourmaline.

Prices[31]

Per ton in Los Angeles area, ground feldspar, $19 to $20; crude, $8 to $10. Prices at mines range from $2.90 to $3.60.

Arizona occurrences

The only Arizona feldspar deposits that have been worked commercially are 6 miles northeast of Kingman, Mohave County. These deposits consist of high-potash feldspar in pegmatite and are mined by open-pit methods. Production began about 1923. Only crude feldspar was shipped until late 1931 when the present operator, the Consolidated Feldspar Corporation of Trenton, N. J., established a grinding mill at Kingman. About 1935 the mill was equipped with a magnetic separator for removing iron. In 1944 the production of feldspar was at a rate of about 850 tons per month.[32] A few hundred tons per year are sent to York, Pennsylvania, for dental purposes, and most of the remainder is shipped to the Pacific Coast. Some by-product silica is sold. The total production of feldspar from the Kingman area during 1924-44 is estimated to have been approximately 100,000 tons.[33]

FLUORSPAR

Definition

Fluorspar or fluorite is calcium fluoride. Commonly white, gray, green, or purple; rarely red, pink, orange, yellow, blue, brown, or black. Transparent to translucent. Hardness 4, gravity

3.01 to 3.25 (about 10 cubic feet per ton). Crystalline to granular and massive. Some varieties are phosphorescent, and some fluorescent. Common impurities are calcite, quartz, barite, and metallic sulfides or oxides.

Uses

The largest use of fluorspar is for flux in manufacture of steel. The aluminum industry and various other metallurgical processes require it for flux.

The second largest use is for manufacture of hydrofluoric acid. This acid is important in making artificial cryolite (sodium aluminum fluoride) for metallurgy of aluminum; manufacture of refrigerating mediums; refining and plating of metals; processing of high-octane gasoline and synthetic rubber; and for etching.

The third largest consumer is the ceramics industry, where fluorite is employed in manufacture of glass, enamel, and facings for brick.

A small amount is in demand for optical purposes. Numerous miscellaneous uses are listed in the literature.[9, 34, 52]

Specifications[34]

"Gravel" fluorspar for metallurgical flux generally is less than 1 inch in diameter with not more than 15 per cent fines. The standard grade contains not less than 85 per cent CaF_2 (calcium fluoride), not more than 5 per cent silica, and not more than 0.3 per cent sulfur, although some dealers accept material containing as low as 60 per cent CaF_2.

Acid fluorspar should contain not less than 98 per cent CaF_2, not more than 1 per cent each of silica and calcium carbonate, and practically no lead, zinc, iron, or barite. It is sold as lump or ground 80- to 100-mesh.

Glass and enamel fluorspar generally contains at least 95 per cent CaF_2, with not more than 3 per cent silica, 1 per cent calcium carbonate, and 0.12 per cent ferric oxide. Lead, zinc, and sulfur are objectionable. It is ground to 100-mesh or finer.

Prices

Recent quotations per ton are as follows:[10] washed gravel fluorspar, 85 per cent CaF_2 and not over 5 per cent silica, $33 f.o.b. Illinois and Kentucky mines; acid fluorspar, $37; ground fluorspar, 95 to 98 per cent CaF_2 and not over 2.5 per cent silica, $39 f.o.b. Illinois mines. Prices recently offered to Arizona producers generally have not exceeded $17 to $20 per ton, f.o.b. mine shipping points, for standard-grade gravel spar. Some buyers pay on the basis of effective CaF_2 content, which is determined by deducting 2.5 times the silica content from the CaF_2 content.

Arizona fluorspar mining

In Arizona[3] fluorspar is a fairly common gangue of mineral veins, but commercial bodies of it have been found in comparatively few districts.

The total value of fluorspar mined in Arizona prior to 1944 is estimated at approximately $125,000. The recorded production from 1902 through 1938 amounted to 4,010 tons, valued at about $54,800. Figures for the yield since 1938 are not available.*

Prior to 1918 the entire output, 1,152 tons valued at $11,747, came from the Castle Dome district in Yuma County as a by-product of lead mining.[34] Beginning with 1918, deposits containing principally fluorspar were opened. Since that time most of Arizona's fluorspar production has come from the Duncan area in Greenlee County. Some has been mined from the Sierrita Mountains in Pima County and the Wickenburg and Aguila areas in Maricopa County.

The principal recent producers have been as follows:

- Lucky claims—E. F. Sanders, Lordsburg, New Mexico.
- Fourth of July—R. T. Ellis, Duncan, Arizona.
- Daniels Camp—R. T. Ellis, Duncan.
- Jumbo claims—G. W. Fiske, Aguila, and D. L. Salomon, Wickenburg.
- Big Spar and other claims—J. A. Campbell, Prescott, and Wm. Daniell, Wickenburg.
- Fluxore and other claims—N. A. Gonzales, E. O. Hall, and E. J. Frielinger, Tucson.

Much of the Duncan output was beneficiated in custom flotation plants, principally by the General Chemical Company, at Deming, N. M.; the Indian Metals Company, at Lordsburg, N. M.; and the Southwest Mineral Company, near Duncan, Arizona.

In the Wickenburg and Sierrita areas, the fluorspar has been shipped after hand sorting and screening.

The by-product fluorspar shipped from the Castle Dome district prior to 1920 was recovered by hand sorting, jigging, and dry concentration. Since 1942, the Arizona Lead Company has milled a large tonnage of lead-fluorspar ore from this district without attempting to recover the fluorspar. According to Mr. George I. Holmes, Manager of the company, some 50 tons per week of metallurgical-grade fluorspar could be recovered, but the prices offered for it up to July, 1944, did not warrant installation of the necessary concentration units.

Present wartime conditions have stimulated the search for fluorspar in Arizona by Government agencies and others. The future outlook, particularly for small or low-grade deposits distant from markets, depends upon prices more favorable in reference to costs of production and transportation.

GRAPHITE

Definition

Graphite, also called black lead or plumbago, is crystalline carbon. Dark gray to black. Opaque. Hardness 1 to 2, gravity 2.1. Highly refractory to acids and heat. Good conductor of heat and electricity. Commercial graphite ranges from about 30 to 95 per cent carbon, with impurities chiefly of silica and alumina.

Commercial graphite is classified as crystalline or flake and "amorphous." The "amorphous" variety is actually crystalline but fine grained. Manufactured or "artificial" graphite is relatively fine grained.

Uses[35]

The possible uses for graphite depend upon its carbon content, the amount and kind of its impurities, and its physical properties. Flake graphite is used for crucibles, certain refractories, lubricants, and prevention of boiler scale. Amorphous graphite and small flake of relatively low carbon content are employed in foundry facings. Impure graphite may be used in manufacture of paint. Amorphous graphite mixed with clay is the principal constituent of lead pencils. Amorphous graphite is also used in stove polish, shoe polish, dry batteries, fertilizers, and waterproofing of various articles.

Prices

According to recent quotations,[10] crude amorphous graphite sells for $14 to $30 per ton, f.o.b. New York, and flake graphite for 3 cents to 16 cents per pound. Mexican amorphous graphite[35] containing 85 per cent carbon is sold for $10 to $15 per ton f.o.b. mines.

Arizona graphite

Veins of relatively impure graphite and graphitic shale occur in the Dos Cabezas and Chiricahua mountains, Cochise County. Vein graphite is reported to have been found in the Cerbat Mountains, near Kingman. No commercial production has been made from these deposits. Their future possibilities seem to be uncertain. As summarized by Gwinn,[35] "The majority of graphite buyers in the United States are reluctant to experiment with domestic grades, having long been accustomed to standard foreign material." He adds, "American graphite deposits are characteristically low grade. They constitute an abundant source of potential supply but have proved relatively costly to work."

GYPSUM[36]

Definition

Gypsum is a hydrous calcium sulfate. Most deposits of it contain impurities such as clay, silica, iron oxide, and calcium carbonate. Material with 90 per cent or more of hydrous calcium sulfate is satisfactory for most uses, and standard specifications state that material shall not be considered gypsum if it contains less than 64.5 per cent.

There are several varieties of gypsum, but most commercial occurrences are either rock gypsum or gypsite. Rock gypsum is opaque, granular, massive, and interbedded with sedimentary rocks. Gypsite consists of abundant small gypsum crystals scattered through clay or sandy loam, forming up to 90 per cent of the mass.

Pure gypsum ranges from dull to glistening white and is soft enough to be scratched by the fingernail.

Preparation

Gypsum is prepared for the market by crushing, grinding, and calcining in kettles or rotary kilns.

Uses

Gypsum, not less than 83 per cent pure and crushed to pass through a half-inch screen, is used as a retarder in the manufacture of Portland cement. Ground gypsum finds uses as filler in paint, paper, and cloth, and in manufacture of insecticides, certain chemicals, and fertilizer compounds. Uncalcined gypsum is also used to treat alkali soils, as land plaster or fertilizer. It has a very beneficial effect on some crops, especially clover and other leguminous plants. Experiments by the U.S. Department of Agriculture show that gypsum has given remarkable increase in the yield of cotton.

Calcined gypsum forms the basis of most plasters and is extensively marketed as wallboard, plasterboard, insulating board, partition block, and tile. It is also used in filtering and in dehydration of oil; nonferrous foundry work; self-sealing liners for bullet-proof gasoline tanks; and glass manufacture.

During 1942 the average mill value for agricultural gypsum in California was $1.91 per ton.

Arizona occurrences[37]

Gypsum deposits are widely distributed throughout Arizona, but only a few of them have been developed because of small demand for gypsum products within the market area. Many of the known occurrences are unsuitable because of location, small extent, degree of purity, or other factors. As the crude material is of low value, only deposits favorable for low-cost mining are of economic importance.

The principal known occurrences are 5 miles east of Douglas, Cochise County; near Winslow, Navajo County; 8 miles north of Tucson, and in the Empire, Santa Rita, and Sierrita mountains, Pima County; near Feldman and Redington, Pinal County; south of Bouse, northern Yuma County; and in northwestern Mohave County.

Some production for local use came from the Tucson area prior to 1904.

Mining of the Douglas gypsite began about 1908. Until after 1934 this deposit was the source of raw material for the Arizona Gypsum Plaster Company, at Douglas, the largest gypsum pro ducer in the State. Subsequently this company obtained its raw material from Texas but closed down in December, 1942. During 1918-21 another plant at Douglas made gypsum products from a gypsite deposit near that of the Arizona Gypsum Plaster Company.[37]

Two gypsum quarries near Winslow, Navajo County, were worked from about 1909[38] to 1914. Part of their crude gypsum was used at the cement plant at Riverside, California; part was calcined at Los Angeles, and another part was shipped to California for use as land plaster.

The total gypsum production of Arizona has not been published. Figures are available only for 1918, 1921-22, and 1933-34, which amount to 30,363 tons, valued at $204,010.

Local postwar demands will probably justify operation of a plaster plant in the State. Whether its raw material will be mined locally or brought in from outside depends upon availability of this material at low cost. Many of the known gypsum deposits have not been developed sufficiently to indicate their size and grade.

Considerable gypsum will be required for agricultural uses in Arizona, especially for correction of black alkali land and for correction of crumb structure in heavy adobe soils.

Other possible buyers of crude gypsum are cement manufacturers, who could haul the material on otherwise empty trucks returning to their plants from construction-job deliveries.

LIME

Definitions[39]

Lime (quicklime) is essentially calcium oxide or calcium oxide with a smaller amount of magnesium oxide. Hydrated or slaked lime is chiefly calcium hydroxide or a mixture of calcium hydroxide, magnesium oxide, and magnesium hydroxide. Limes are classified as follows:[40]

High-calcium lime, containing not less than 90 per cent calcium oxide and 0 to 5 per cent magnesium oxide.

Low-magnesium lime, containing 5 to 25 per cent magnesium oxide.

Dolomitic or high-magnesium lime, containing 25 to 45 per cent magnesia.

Lime is made[12] by calcination or "burning" of limestone, marble, or dolomite to temperatures of 1,350 to 1,700 degrees F. Theoretically, 100 pounds of pure limestone will make 56 pounds of lime. Thus original impurities, chiefly silica, alumina, iron, sulfur, gypsum, and alkali salts, are virtually doubled in the lime. Commercial lime generally contains not more than 5 per cent total impurities.

Hydraulic lime, made by calcination of limestone with clay, will set under water.

Uses

Lime is used extensively in the chemical, manufacturing, building, and agricultural industries.

Practically every chemical process in industry requires lime. It is employed as a flux in manufacture of steel; a reagent in flotation and cyanidation; in Bayer aluminum manufacture; water treatment; and manufacture of refractory brick, sand-lime brick, paper, synthetic rubber, glass, leather, carbide, cyanimide, sodium hydroxide, ammonia, sugar, glycerin, soap, lubricants, paint, varnish, bleaches, polishes, and certain plastics.

Its principal uses for building are in mortar, plaster, masonry cement, concrete, and artificial stone.

In agriculture lime is important for fertilizer, insecticides, fungicides, and disinfectants.

Specifications required for various uses are discussed in the literature.[12, 39, 40]

Lime industry in Arizona

Lime is used in Arizona mainly for flotation and cyanidation, building construction, and agriculture. The recorded production of lime in the State for 1894-1943 amounted to approximately 1,044,000 tons, valued at $9,100,000. It has been manufactured chiefly in Yavapai, Coconino, Gila, Cochise, and Pima counties. Since 1907 from two to five plants have operated, and several smaller kilns have run intermittently.

In Yavapai County the principal producers have been the Grand Canyon Lime and Cement Company, which for many years has operated kilns at Nelson, on the Santa Fe railway west of Seligman; the Puntenney Lime Company, which operated for a long period prior to about 1928 at Puntenney, north of Prescott; and the Storey Lime Company, which operated for a short period after about 1928 at Perkinsville.

In Coconino County lime was produced near Flagstaff prior to 1913.[41]

In Gila County lime has been made in a plant 4 miles northwest of Globe, chiefly for flotation plants of the Globe-Miami district.

The largest lime producer in southern Arizona is the Paul Lime Plant, at Paul Spur, west of Douglas. This plant started manufacture of lime about 1918 and now has a reported capacity of 110 to 115 tons per day. Raw materials are quarried locally, except the stone for plastic building lime, which is obtained from a marble deposit near Dragoon. Besides lime, this plant normally turns out slag wool, building blocks, stock food, silica, and limestone flux.

In Pima County a lime plant at Tucson was operated after about 1931 by the New Process Lime Company and during 1941-42 by the Arizona Lime Company.

Present wartime conditions have hampered the industry with shortages of labor and equipment, high general costs, and lime prices.

Future possibilities for lime manufacture in Arizona appear to be good. Ample reserves of limestone occur favorably situated with respect to transportation facilities. Aside from local consumption, Arizona lime may be shipped to outside industrial centers in so far as freight costs will permit. During the past fifteen years 592,500 tons of lime were produced in Arizona, 11,100 tons were shipped in, and 215,000 tons were shipped out of the State.

LITHIUM

Minerals

The principal lithium minerals of commercial importance are spodumene, amblygonite, and lepidolite. Less important are triphylite and zinnwaldite.

Spodumene is lithium aluminum silicate. Dull gray to greenish white. Hardness 6.5 to 7, gravity 3.17. Contains 4 to 8 per cent lithium oxide. Occurs in pegmatites.

Amblygonite is a fluophosphate of lithium and aluminum. Commonly resembles white feldspar. Contains 8 to 9 per cent lithium oxide. Occurs in pegmatites.

Lepidolite is a lithia mica. White, gray, pink, purple, or blue. Contains 2 to 4 per cent lithium oxide. Occurs in pegmatites.

Triphylite is an iron-lithium phosphate. Gray to brown. Hardness 5, gravity 3.5. Contains 2 to 6 per cent lithium oxide. Occurs in pegmatites.

Zinnwaldite is a lithium mica. Brown, yellow, or gray. Contains 2 to 3 per cent lithium oxide. Occurs in veins and greisens.

Uses

Lithium and its compounds are used[42] in manufacture of glass and ceramics, for certain alloys and metallurgical processing, for removing oxygen from heat-treatment furnaces, for fluxes for welding aluminum; in various chemicals, in storage batteries, air conditioning, optical lenses, luminous paints, airplane greases to withstand great changes in temperature, dental cements, photography, insecticides, and pyrotechnics; and for transporting hydrogen, removing nitrogen from helium, delustering fabrics, preserving meat, and treating citrus fruits.

Prices

Recent quotations[10] for some lithium ores per ton f.o.b. mines are as follows: amblygonite, $40 to $50; lepidolite, $24 to $25; spodumene, $30.

Arizona occurrences

The only lithium minerals known to occur in Arizona are lepidolite in the Bagdad area of Yavapai County, and zinnwaldite in the Duquesne area of Santa Cruz County. Further prospecting for lithium minerals in pegmatites seems to be justified.

MANGANESE

Uses

Most of the manganese consumed goes into manufacture of steel, alloy steels, and various nonferrous alloys. Manganese is also used in manufacture of dry batteries; various chemicals and disinfectants; coloring agents in dyes, cloth, glass, pottery, and brick; decolorizers for glass; and driers in paints. In the sulfate form it has found increasing importance as fertilizer, particularly for citrus and vegetables, although the tonnage so used is not large.[43]

Prices

During the present emergency, manganese ore has been purchased by the Government through the Metals Reserve Company. Details as to current specifications and prices may be obtained from this company. Prices for manganese normally are not high; Arizona's production of 369 tons in 1940 was valued at $4,940 or an average of $13.39 per ton.[14]

Arizona deposits

The principal deposits of manganese in Arizona are described in the literature.[44] During recent years they have been investigated by Government agencies, and the U.S. Bureau of Mines is now examining the deposits of manganese-silver ores.

Profitable manganese mining operations in Arizona normally are handicapped by freight costs and specifications which are difficult to meet at prevailing metal prices.

The concentration of Arizona manganese ores is difficult, and methods to produce a satisfactory grade of concentrate at prevailing market prices have not been successful.

Considerable research is now being conducted by the U.S. Bureau of Mines, looking forward to the production of manganese for future emergencies and determining the possibilities for postwar production. This work involves treatment of Arizona refractory manganese-silver ores. The Arizona Bureau of Mines is co-operating in this research. The final results should be of considerable interest to the Arizona mining industry.

MICA

Principal minerals

Mica is the group name of several aluminum silicate minerals characterized by bright luster and a capacity for being split into exceedingly thin parallel sheets or flakes that are tough and elastic. The most useful mica mineral is muscovite, and the term mica generally refers to this variety unless otherwise specified.

The principal mica minerals in Arizona[3] are muscovite, sericite, biotite, and vermiculite.

MUSCOVITE AND SERICITE[45, 46]

Definition

Muscovite mica, sometimes called isinglass, is a hydrous silicate of aluminum and potassium. Hardness 2 to 2.5, gravity 2.76 to 3. Luster bright. Colorless, gray, brown, greenish, or yellowish and more or less transparent. Crystals of the mineral may range in size from microscopic to 5 feet in diameter. In places certain other minerals, particularly iron oxide, garnet, rutile, tourmaline, and biotite, occur intergrown with the muscovite and limit its industrial usefulness.

Sericite is regarded as a fine scaly, silky variety of muscovite.

Geologic occurrence

Muscovite occurs abundantly in schist, gneiss, and granitic rocks, but generally so intermingled with other minerals as to be of no economic importance. All the sheet mica of commerce comes from pegmatite, which is a rock composed essentially of feldspar, quartz, and mica, and characterized by very coarse, irregular crystallization. Pegmatite containing albite feldspar and hydrothermally altered is considered a promising place to prospect for muscovite.

Sericite results from hydrothermal alteration of feldspar minerals in schist, gneiss, and granitic and porphyry rocks.

Uses

Muscovite is used in the form of sheets and as scrap for making ground mica. Sericite is used as ground mica.

More than 90 per cent of the sheet mica produced goes into electrical equipment for various insulating purposes. It is also used for stove and furnace windows, lamps, lanterns, goggles, gas masks, sound diaphragms, and ornamentation.

Ground mica is employed in manufacture of wallpaper, molded electric insulation, paint, rubber, plastics, roofing, stucco, lubricants, foundry facings, Christmas-tree snow, and insulators of heat and sound. Its further potential use is enormous.[47]

Specifications[48]

The grade of muscovite depends upon the size, quality, and preparation of the sheets into which it can be split. Standard sheet yields rectangles 1½ by 2 inches or larger. Smaller sizes down to about 1 inch square ordinarily are classed as punch, or splittings, although during the present emergency sizes 1 inch square have been classed as sheet. Spotted or stained mica is generally less desirable than clear, transparent varieties. Sizes under 1 inch or material that is ruled, rumpled, or flawed can be classed only as scrap or grinding mica.

As stated by Tyler,[48] "The small mica miner can scarcely hope to know how to appraise the value of his product, and ordinarily his appraisal would not be accepted by large buyers, who know exactly what they want."

Prices

During 1930-40, muscovite mica prices tended to improve, with prices of the larger and better grades increasing less rapidly than those of the lower grades.[14] In 1936-38, the average for waste or scrap mica was $12.44 per short ton at the mines, but some sold for as low as $6. Ground mica ranged from about $12 per ton for by-product or low-grade dry-ground, to over $100 per ton for clean wet-ground.

During the present emergency, military requirements have greatly increased demand for the better grades. In December, 1942, a nonprofit organization, the Colonial Mica Corporation, 141 Broadway, New York 6, N. Y., was designated by the U.S. Government as the sole buyer of domestic strategic mica.[49] Normal considerations of price have been disregarded; in order to encourage domestic output, this corporation has given much advice and assistance to prospective mica producers and is paying prices for domestic mica which result in an average loss to the Government of about $4.50 per pound. Quotations effective from August 7, 1944, through December 31, 1944, are as follows: fully trimmed sheet mica, No. 1 and No. 2 quality, 1½ by 2 inches and larger, $8.00 per pound; 1 inch square to 1½ by 2 inches, $6.00 per pound; punch mica, 40 cents per pound; prices subject to discount for substandard quality.

Arizona deposits

Muscovite and sericite occur abundantly and widely distributed in Arizona, but few of the deposits have been found to be of commercial grade except as possible sources of scrap mica for grinding.

Most of the larger sheet mica known in the State has been flawed by earth movements or contains impurities. Some commercial sheet material has recently been produced at the Mica Giant property, south of Kingman.

During recent years the N. D. Hightower property in the Estrella Mountains of Maricopa County, north of Enid station, is reported to have produced a little trimmed sheet, some scrap, and notable quantities of ground mica.

A small production, chiefly of scrap grade, is reported to have been made from the Bradshaw Mountains, between Cleator and Crown King; from properties near Morristown; and from the Berrier property in Peeples Valley, south of Prescott. Considerable scrap mica is reported to occur in northwestern Mohave County, north of Lake Mead.

An extensive deposit of sericite south of Buckeye, Maricopa County, was prospected a few years ago. Although this material seems to require comparatively little milling or grading, it has been exploited only in a small way.

Punch and scrap or grinding mica might be produced at many places if prices and transportation rates were more favorable. As stated by Houk,[48] "Mica mining, particularly if conducted by inexperienced operators, involves great financial risk, owing to the irregularity of the borders of the pegmatites and the erratic distribution of the mica."

BIOTITE

General statement

Biotite or black mica is the commonest mica mineral. In sheet form it is of little industrial use. In fine flake or powder form it is utilized as a coating or filler in roofing and in some rubber and structural materials.

Because of its relatively low market value, no biotite has been mined in Arizona.

VERMICULITE[50]

Definition

Vermiculite minerals are micaceous silicates of widely varying composition, derived chiefly by hydrothermal alteration of biotite and other micas. Of the numerous vermiculites that have been defined, jeffersite (a hydrous magnesium aluminum iron silicate) is probably the most commonly known.

Vermiculite is dark brown or yellowish-brown to green, with a dull luster. It retains most of the original capacity of its parent mica to cleave or split into very thin, parallel leaves. Because of its water content, which amounts to 20 per cent for some varieties, the mineral when heated expands into wormlike forms and becomes lighter in color. The raw material weighs about 100 pounds per cubic foot, but heat treatment may expand it more than sixteen fold, with a proportionate reduction in weight per cubic foot.

Uses

The usefulness of vermiculite depends upon its response to heat treatment, whereby the crude mineral separates, with swelling, into very thin flakes of silvery to golden color. This flaky product, commonly known as "Zonolite" or "Tung Ash," is an effective light-weight fireproof insulator against heat, cold, and sound; for such purposes it may be packed loose or mixed as an aggregate. The loose material is used in walls and roofs of buildings; refrigerators; ovens; furnaces; thermal jugs; life preservers; shells and bombs; and imitation sandstorms for motion pictures. It is employed as an aggregate in various light-weight refractory and acoustical products, such as plasters, bricks, cements, concrete, composition roofing, and high-temperature gaskets. It is also used in ornamental stucco and wallpaper. It is reported to be a highly effective ingredient for greases and paints.

Since early 1938, considerable progress has been made in utilization of smaller-sized flakes.

Treatment

Milling of vermiculite generally consists of little more than crushing, drying, screening, cleaning, and sizing.

In order to save on freight rates, heat treatment or expansion of crude vermiculite is generally done at industrial centers where the product is marketed. It is exfoliated at temperatures of 1,600 to 2,000 degrees F. for four to eight seconds.

Prices

Recent quotations[10] for screened crude vermiculite, f.o.b. mines, range from $9.50 to $12 per ton.

Arizona occurrences

Vermiculite occurs intermingled with other rock-forming minerals in many altered intrusives, particularly dark basic rocks, but such deposits are generally below commercial grade.

Comparatively little is known of the vermiculite deposits that may occur in Arizona, but large deposits of relatively high grade seem to be rare. Samples of the mineral have been sent to the Arizona Bureau of Mines from Kingman, Wickenburg, Prescott, Phoenix, Yuma, Bouse, and Douglas.

In the Hualpai Mountains, a deposit occurs 15 miles southwest of Kingman. During 1940 the Micro-Cell Insulation Company began development of this ground and installation of a pilot mill to prepare raw vermiculite for shipment to California, but this project did not reach the production stage.

Until more is known regarding the vermiculite deposits in Arizona, their possible future exploitation cannot be predicted.

MINERAL WOOL[51]

Definition

Mineral wool (rock wool, slag wool, glass wool, glass silk, and silicate cotton) is a manufactured product composed of very fine silicate fibers.

Uses

Mineral wool is used chiefly for insulation against heat and sound and to some extent for filtering acid liquids. Each fiber of the wool contains numerous minute air pockets which retard transfer of heat. It is used for insulation in homes, buildings, plant equipment, roofing, refrigerators, ovens, automobiles, railway cars, airplanes, tanks, and ships.

Manufacture

Mineral wool commonly is manufactured by melting the raw materials and fiberizing the melt by means of a high-pressure steam or air jet, followed by cleaning and fabrication.

A wide variety of raw materials, containing the requisite amounts of lime or lime and magnesia together with alumina and silica, may serve for making mineral wool. Those most commonly utilized are siliceous limestone, or dolomite; calcareous shale, or clay; slag; soda-lime glass; and ceramic plant refuse. Suitable mixtures may be compounded of various materials and fluxes. Some of the processes are covered by patents, as listed by Thoenen.[51]

Specifications and prices

The specifications of mineral wool vary somewhat according to use. They generally emphasize chemical composition, softness, heat conductivity, and freedom from unfiberized particles. Prices during 1942 per short ton in car lots, f.o.b. plant, were $30 for loose mineral wool and $45 for granulated wool.[51]

Arizona mineral wool industry

Since 1941 the Paul Lime Plant, west of Douglas, has been manufacturing mineral wool, and in July, 1944, was producing it at the rate of about 400 tons per month. The raw materials used are principally Douglas smelter slag, locally mined silica, and coke.

Materials suitable for making mineral wool are available at many places throughout Arizona. Mineral wool is expensive to ship long distances, as usually not more than 12 tons of it can be loaded in a freight car. Because of transportation costs, the future of the industry in Arizona probably will depend largely upon local needs. There is room for much research in regard to the raw materials and methods of manufacture to meet more exacting specifications.

NITRATES[49, 52]

Nitrates have been found at several places in Arizona, and their discovery from time to time has occasioned considerable local interest. The occurrences thus far known are of the guano, covern, and playa types.

A small tonnage of guano has been mined from caves and old mine workings for use in fertilizer.

The most common occurrence of nitrate throughout the Southwest is in rock caverns where it has accumulated as superficial incrustations and seams. Probably guano was the original source of this nitrate. Although considerable prospecting has been done on several deposits of this type, none of them has been found to be of important commercial extent.

A little nitrate occasionally has been found associated with clay and silt in playas or dry lakes, but the best of these deposits known in the Southwest have not been workable.[52]

OIL

Many attempts have been made to find oil in Arizona. More than forty wells have been drilled in various parts of the State to prospect for oil or to seek information that might assist in its discovery, but none of them has resulted in production.

Recently notable exploration has been carried on in the St. Johns and Holbrook areas. During 1943-44 the Argo Oil Corporation drilled a hole 15 miles northeast of St. Johns for the purpose of investigating a possible westward continuation of New Mexico Pennsylvanian beds. At about the same time the Union Oil Company of California and the Continental Oil Company jointly drilled the Holbrook anticline, about 25 miles southwest of Holbrook, for the purpose of obtaining geologic information. This work has been discontinued, at least for the present.

Explorations prior to 1931 and the possibilities as understood at that time are summarized[53] in Arizona Bureau of Mines Bulletin No. 130.

OPTICAL CALCITE AND FLUORITE

ICELAND SPAR[54]

Definition

Iceland spar is transparent crystalline calcite, calcium carbonate. Hardness 3, gravity 2.7. Shiny luster. Cleavable into rhombohedral fragments which have the property of doubly refracting and polarizing light.

Uses

Prisms made of Iceland spar are required in polarizing microscopes; in colorimeters to standardize colors; in saccharimeters to determine sugar in solutions; in photometers to measure intensity of light; in spectrographs; and in various other optical equipment. The material has found a highly important wartime use in gunsights, and the need for it during the present emergency has been critical, although the recent development of a synthetic substitute is reported to have eased demand.

Specifications

Iceland spar must be clear and transparent, free from cracks and rainbow colors, and untwinned except for basal twinning. Small inclusions are allowable in some cases. If in the form of rhombs, they must be at least 1½ inches on each edge. Care must be exercised in mining and handling the material to avoid fracturing.

Prices

Prices for Iceland spar vary according to quality. The reported price for usable material is about $10 per pound and for especially good crystals, about $40 per pound.

Arizona occurrences

Samples of fairly good Iceland spar have been submitted to the Arizona Bureau of Mines from several localities in the State. These occurrences have been investigated recently by agencies seeking the material for wartime use. So far as known, Iceland spar of optical grade is not abundant in Arizona.

OPTICAL FLUORITE[54]

Definition

Optical fluorite is crystalline fluorspar.* It must be clear, colorless or almost colorless, free from flaws or inclusions, untwinned, and without anamalous double refraction. It is cleavable into eight-sided forms, but it tends to fracture with curved surfaces rather than with the perfect cleavages characteristic of ordinary fluorite. As fluorite is fragile, the optical material must be mined and handled with care.

Uses

The principal use of optical fluorite is for correcting aberration in lenses and lens systems. Some is employed in spectrographs for ultra-violet work and in telescopes to regulate color.

Prices

During the past several years the price of optical fluorite has ranged from $1 to $10 or more per pound, depending upon quality as determined by the buyers.

PERLITE

Definition

Perlite is a glassy siliceous volcanic rock characterized by concentric, shelly texture. It contains 3 or 4 per cent of combined water. When heated to a proper temperature it loses 3 or 4 per cent of its weight and increases several times in volume. The expanded product is light colored and porous and readily absorbs considerable moisture. Commercially, the term perlite usually refers to the expanded material.

Preparation and properties

The properties and possible utilization of perlite began to receive serious attention about 1941 when L. L. Boyer conducted some experiments on crude perlite from near Superior, Arizona.

*Fluorspar is described on page 19.

In 1941, tests on perlite from an Arizona locality were made by E. H. Crabtree, Jr., of the Arizona Bureau of Mines. This investigation showed that when the crude perlite is crushed through ¼ inch and heated to a temperature of 1,650 degrees F., a loss in weight of 3.8 per cent takes place. At the same time the volume of the sample increases 623 per cent. When the expanded perlite is introduced into a bath of water the finished product floats on the surface, and foreign material sinks. Tests indicated that the finished perlite conducted heat more slowly than rock wool in the temperature range between 50 and 131 degrees F. Between 86 and 122 degrees F. it apparently was better than ground asbestos; above 122 degrees, the asbestos appeared to be the better. From 89.6 to 136.4 degrees, perlite was better than vermiculite. From 86 to 109.4 degrees it was better than ground cork; above this range up to 127.4 degrees the cork had greater resistance. The perlite was greatly superior to air in its resistance to heat conduction.

The weight per cubic foot of the expanded perlite was found to range from 5.63 to 12.6 pounds. Expanded perlite is reported to be a good nonconductor of electricity.

Uses

Expanded perlite has been used in Arizona for bulk insulation in buildings, light-weight insulating and acoustical plaster, light-weight concrete for heat insulation, chicken litter, and as an absorbent for fertilizer. Some suggested possible uses are for insulating and acoustical wallboard, wet-type air coolers, abrasives and soaps, paint fillers, filtering mediums, molding or foundry sand, as filler in plastics, and for high-temperature (up to 1,000 degrees F.) industrial insulation.

Arizona perlite industry

Perlite has been mined from the Superior area by L. L. Boyer (Rt. 10, Box 191, Phoenix, Arizona) and associates and processed in a small plant at Phoenix. Some is reported to have been mined from near Haviland, Mohave County, and shipped to Los Angeles for experimental processing, by the Perlite Production Company (Myron J. Glauber, 704 S. Spring St., Los Angeles, California, agent).

As costs of production and processing perlite are reported to be relatively low, the future of the industry in Arizona depends largely upon the useful properties of the material as compared with competitive materials.

PIGMENTS (NATURAL)[55]

Definitions and uses

Natural pigments are minerals that, without chemical synthesis, may be utilized to impart color, body, or hiding power.

Pigments are distinguished from fillers mainly on the basis of their opacity or hiding power and color. Thus ground mica, vermiculite, jarosite, talc, certain clays, amorphous silica, diatomite, perlite, barite, ground limestone, and chalk usually are classed as fillers rather than pigments.

Natural pigments are employed mainly in paint, stucco, cement, mortar, plaster, oilcloth, linoleum, rubber, and various plastics. Military uses require great quantities of paint for equipment and inexpensive mineral pigments for camouflage.

Varieties

The list of natural pigments includes iron oxides, manganese oxides, carbon (chiefly graphite), and various other minerals and rocks composed of colored minerals.

Red iron oxide pigment, largely hematite, contains 60 per cent or more ferric oxide. In some cases material containing down to 5 or 10 per cent ferric oxide is employed for mixing with other red pigments.

Brown iron oxide pigment, mainly limonitic material, contains more than 65 per cent ferric oxide.

Raw umbers contain 25 to 50 per cent ferric oxide and 8 to 23 per cent manganese oxide. Umbers grade into siennas with decreasing manganese content.

Raw siennas contain limonite together with hydrous iron silicate, and their ferric oxide content is 40 to 75 per cent. With decreasing iron content, siennas grade into ochers.

Ocher, composed of limonite together with clay, contains 17 to 60 per cent ferric oxide.

Black natural pigments include impure graphite, graphitic shale, manganese oxide, powdered coal, and asphaltum.

Specifications

The allowable particle size of natural pigments ranges from colloidal or very minute to about 200-mesh. Detailed specifications concerning size, color, opacity, hardness, gravity, composition, and absorption are given in the literature.[55]

Prices

Natural pigments are priced according to quality, supply, and demand. Various refined natural domestic iron oxides during 1941 ranged from 1 to 4 cents per pound.[55] Recent quotations for domestic earth iron oxide are 2½ to 3¾ cents per pound.[10] Red to yellow iron oxide with clay occurring near Farmington, New Mexico, has been treated and sold locally for paint at 6 to 25 cents per pound.[56]

Possibilities for Arizona pigments

So far as known, little or no commercial production of natural pigments has been attempted in Arizona. Costs of preparation and freight, together with a lack of knowledge regarding the specifications, markets, and raw materials, have been the principal obstacles. Ample deposits of iron oxide, manganese oxide, and impure graphite occur in Arizona, but their adaptability for future pigment industries may be known only after extensive field and laboratory research.

PRECIOUS AND SEMIPRECIOUS STONES

History and production

Mining and cutting of precious and semiprecious stones in Arizona have never constituted more than a small industry. It was started by the Indians and subsequently has been carried on mainly by individuals as a side line or hobby. The production reported for 1907-21[57] was valued at $228,366; figures for other years are not available. During that period the annual value ranged from $46,667 in 1909 when Arizona ranked third, to $4,878 in 1916 when Arizona ranked sixth, in value of precious and semiprecious stone production in the United States.

Apparent exhaustion of the surface or near-surface deposits, together with changes in style trends and employment conditions, has curtailed output during recent years.

Varieties

The principal varieties of precious and semiprecious stones which have been produced in Arizona are as follows:[3]

Turquoise	Obsidian
Petrified wood (chalcedony, jasper)	Quartz
Oxidized copper minerals	Amethyst
Garnet	Chrysoprase
Peridot	Agate
Mexican onyx	Dumortierite
Opal	Catlinite
Tourmaline	

Turquoise was one of the first[58] gems dug out by Indians in Arizona, and it has been mined more extensively than any other precious or semiprecious stone in the State. The mineral was found principally near Mineral Park,[59] in Mohave County, and Courtland,[60] in Cochise County, but production during recent years has amounted to little. According to B. S. Butler, some turquoise was obtained from the Castle Dome open-pit copper mine, west of Miami, during the past year.

For many years varicolored petrified wood, chiefly from the vicinity of the Petrified Forest in Apache and Navajo counties, has been polished and sold for semiprecious stones and ornaments. The products have ranged in size from stickpins to table tops. In addition to their occurrence as petrified wood, chalcedony and jasper of various colors are found at many places.

Large quantities of azurite, malachite, and chrysocolla from the oxidized copper ore bodies in Arizona have been cut into semiprecious stones. With exhaustion of the shallower ore bodies, the better material has become relatively scarce.

Red pyrope garnet, sometimes called "Arizona ruby," is gathered by Navajo Indians from Garnet Ridge and Buell Park, in Apache County. Most of the stones are either small or imperfect, but selected specimens are much in demand.[61]

Gem peridot (olivine) occurs associated with the garnet of Apache County and west of San Carlos (formerly Rice) in Gila County.[62] Both these localities have yielded considerable material. Peridots ranging up to 1½ ounces in weight have been found at the Rice deposit.[63]

Mexican onyx or onyx marble is used extensively for polished ornaments. Its occurrences in Arizona are mentioned on page 46.

Common opal of various colors, black tourmaline, and black obsidian occur at many places in Arizona and have been extensively utilized as semiprecious stones.

Clear, transparent quartz is relatively abundant. Rose quartz has been reported from a locality 40 miles northeast of Kingman in Mohave County. A little amethyst has been produced from Four Peaks in Maricopa County, and it occurs also in Mohave and Santa Cruz counties. Blue and blue-green chrysoprase (copper-stained chalcedony) were found in the Keystone and Live Oak mines, Miami district. Agate or banded chalcedony occurs as petrified wood and as nodules in lavas and limestones at various places.

Deep-blue dumortierite resembling lapis lazuli occurs as boulders in gravels along the Colorado River 30 miles north of Yuma.

Catlinite (pipestone) is found east of Del Rio, Yavapai County.

Diamonds have been found in Arizona only as tiny black inclusions in some of the Canyon Diablo meteorites. The great diamond swindle of 1870 was based upon an alleged discovery of diamonds, rubies, sapphires, emeralds, amethysts, garnets, and spinels, all in a single deposit. According to Farish[64] the site was near Ft. Defiance, Arizona, but T. A. Rickard[64] places it in Colorado. This fraud was exposed in 1872 when a U.S. Government geologist, Clarence King, found that the ground had been salted.

QUARTZ

Definition

Quartz is silicon dioxide. Colorless to various colors. Transparent to opaque. Crystalline to massive. Hardness 7. Gravity 2.65 to 2.66. Quartz, in crystals, veins, sand, gravel, sandstone, quartzite, and many igneous rocks, comprises about 59 per cent of the earth's crust.

Uses

Because of its physical and chemical properties, quartz finds wide and varied use[65] in industry. Sand, gravel, stone, and silica are discussed elsewhere in this report.

Rock-crystal quartz is used[31] chiefly for radio oscillators and filters, telephone resonators, optical lenses and prisms, instruments to measure pressure in gun barrels and engines, depth sounders, direction finders, periscopes, gun sights, and various precision instruments. For such purposes the material is regarded as strategic and critical, although recent advances in methods of preparation and utilization have greatly augmented the amount of strategic quartz available.

Crystals unsuited for sound equipment and optical purposes are employed in the manufacture of fused quartz glass.

Specifications

For sound equipment each quartz crystal must be perfectly transparent inside and clear except for a possible light smoky color. A large portion of each crystal should be free from specks, bubbles, lines, cracks, or flaws. The crystal must be untwinned, as determined by laboratory tests. The minimum weight required for each crystal was reduced in March, 1943, to 50 grams (slightly less than 2 ounces).

For optical use, quartz must be water clear and free from any coloration, bubbles, or flaws. Ordinarily crystals weighing less than ¼ pound are not acceptable, and larger ones are preferred.

Prices

Reported prices, depending upon quality, range from $4 to more than $36 per pound for usable material.

Optical quartz ordinarily is priced nominally at about $2 per pound.[65]

For fusing, quartz crystals of all sizes are quoted[10] at $100 to $150 per ton.

Arizona occurrences

Quartz crystals of strategic and optical grades are rare in the United States, and Brazil is the principal source of the material. Promising samples have been submitted to the Arizona Bureau of Mines from a few Arizona localities, but investigation of these occurrences has failed to find the material in important commercial quantities.

Quartz crystals of fusing grade occur at many places[3] in the State, but the known deposits have not appeared to be of sufficient size to encourage exploitation.

REFRACTORIES

GENERAL FEATURES

Definition

Refractories are commonly defined[66] as materials able to withstand slow heating to 1,500 degrees C. (2,732 degrees F.) without obvious signs of fusion; also they must resist chemical action, spalling, wear, and other physical failure under conditions of use.

Varieties

The list of refractory raw materials includes fire clay, silica, alumina, magnesite, dolomite, chrome, spinel, andalusite, sillimanite, kyanite, dumortierite, graphite, and miscellaneous minerals and rocks.

Uses

Refractories are used principally for furnace linings in the iron, steel, and smelting industries; in coke ovens, steam boilers, gas producers, incinerators, cement kilns, lime kilns, glass works, and oil refineries; and in manufacture of chemicals, paper, salt, sugar, ceramics, and other products.

The specifications[66, 68] required for various uses are somewhat technical and beyond the scope of this report.

REFRACTORIES IN ARIZONA

Silica

Fine lump or crushed quartz and quartzite of high silica content have been employed extensively in Arizona smelters for lining furnaces and converters. Data as to the amount and value of silica produced in Arizona are not available. During the past several years the Paul Lime Plant west of Douglas has produced finely ground quartzite for reverberatory-furnace lining. In 1943-44 Arthur Enders (Box 362, Globe, Arizona) mined a few thousand tons of silica from the Dixie claims, 40 miles northeast of Phoenix; this material sold for $3.80 per ton, f.o.b. Phoenix.[67]

Magnesite[68]

The magnesium carbonate, magnesite, is white, grayish-white, yellow, or brown, with shiny luster. Hardness 3.5 to 4.5, gravity 3 to 3.12. Granular to massive. Pure magnesite contains 47.6 per cent magnesia (mangnesium oxide) and is commonly associated with brucite (magnesium hydroxide).

For refractories, magnesite is dead-burned to magnesia (magnesium oxide). Dead-burned brucite is also used for refractories.

For most other purposes magnesite is converted to caustic-calcined magnesia. The largest use of caustic-calcined magnesia is for manufacture of magnesium metal. It is also employed in making oxychloride cement for use in stucco, wallboard, flooring, and rubber; catalysts in manufacture of synthetic rubber and rayon; fertilizer; and magnesium chemicals. The principal magnesite deposits known in Arizona were discovered west of Oatman, Mohave County, about 1943. They consist of veins of magnesite, brucite, and serpentine cutting volcanic rocks. Such veins on claims held by Robert Martin, J. H. McCarthy, and G. F. Mosier, of Oatman, have been prospected to a limited extent. The Martin deposit was diamond drilled by Basic Refractories, of Lunning, Nevada, but no commercial magnesite has been produced in the area.

Dolomite

Dolomite is calcium-magnesium carbonate which, if pure, contains 45.7 per cent magnesium carbonate or 21.8 per cent magnesia (magnesium oxide). It most commonly occurs as beds resembling limestone within formations broadly classed as limestones.

Dolomite has limited use as a cheap refractory, either in deadburned or raw condition. Some progress recently has been made in processing dolomite refractories by converting the lime present into a stablized calcium silicate.[69]

Dolomite is a source of magnesia, magnesium carbonate for heat insulation, and magnesium metal. Other uses are as flux; in manufacture of paper, plaster, stucco, dolomitic lime, and mineral wool; for neutralizing acid water; and as poultry grit and fertilizer. Crushed dolomitic lime rock is priced in the Los Angeles area[31] at $3.75 to $4.00 per ton in car lots, bulk.

Portions of several limestone formations in Arizona have long been known to be dolomitic over extensive areas. Because of the interest in dolomite as a source of magnesium, the Arizona Bureau of Mines in 1942 made a preliminary investigation of dolomite deposits in Arizona[70] and later co-operated with the U.S. Geological Survey in a more detailed examination. Particular consideration was given the areas most favorably situated with respect to ample electric power and transportation facilities. Large tonnages containing from 39.07 to 45.06 per cent magnesium carbonate were found. However, since the large plant of Basic Magnesium, Inc., near Las Vegas, Nevada, is favorably situated with respect to extensive reserves of magnesite and dolomite in Nevada,[13] there is currently little interest in Arizona dolomite as a source of magnesium.

Aluminum silicates[71]

Andalusite, kyanite, and sillimanite are aluminum silicates with different physical properties. Dumortierite is an aluminum silicate containing boron. When properly processed, these minerals form high-grade refractories that are used extensively in the glass industry, various fireboxes, electrical porcelain, spark-plug cores, and special porcelain ware. As recently quoted,[10] crude kyanite sells for $19 per ton, f.o.b. point of shipment. Material very low in iron commands a premium.

Andalusite, kyanite, sillimanite, and dumortierite occur at various places in Arizona,[3, 72] but most of the deposits have not been found to be of commercial size and grade. Several years ago Nels Anderson (Box 672, Peoria, Arizona) shipped about 38 tons of kyanite from Squaw Peak, north of Phoenix.

SALT

Definition and uses

Common salt is sodium chloride. As the mineral halite or rock salt it forms crystalline to granular masses and incrustations. In solution it occurs in the sea, in many lakes, and in cavities or pore spaces of rocks.

Aside from being required in the diet of human beings and livestock, the largest use of salt is for manufacture of sodium chemicals and chlorine. Large tonnages of salt are required to produce chlorine for manufacture of magnesium. Salt is extensively employed in packing and preserving of numerous articles, in various industrial and metallurgical processes, as a refrigerant, and in fertilizers. Sodium and chlorine are used in manufacture of high-octane gasoline, synthetic rubber, dyes, and smokeless powder. Chlorine has numerous other uses.

Arizona occurrences

A small tonnage of rock salt has been mined from the Camp Verde sodium sulfate deposit in Yavapai County and sold to local stockmen.

Salt occurs in the Salt River and as incrustations in the Salt River Valley, particularly at the Salt Banks 35 miles northeast of Globe. The principal source of this material is saline springs.[8]

Salt is found more or less dispersed in various playa or lake beds, as, for example, in the Virgin River Valley of northwestern Mohave County, but these deposits as a rule are far below commercial grade.

SAND AND GRAVEL

Definition

Sand and gravel, the unconsolidated granular materials resulting from natural disintegration of rocks, are distinguished on the basis of grain size. Wentworth's classification[73] by diameters in inches is as follows: sand, 1/400 to 1/12; granule gravel, 1/12 to 1/6; pebble gravel, 1/6 to 2½; cobble gravel, 2½ to 10; boulder gravel, 10 or more.

Commercial varieties and uses[49, 74]

Foundry (molding and core) sands are high in silica and contain sufficient clay to bind the grains together. Fire or furnace sand, used for lining furnaces, generally contains more than 80 per cent silica and some bonding material. Glass sand is high in silica with generally less than 1 per cent iron oxide. Sand for filtering water must consist of fairly uniform rounded to angular grains that resist disintegration in water. Sand for abrasive, grinding, polishing, and sandblasting purposes should be hard and of a grain size that depends upon the particular use. Engine sand, poured on rails to promote traction, is typically of clean silica ranging from 20- to 80-mesh in size.

More than 90 per cent of the sand and gravel produced goes into construction of buildings, pavements, railway ballast, and aircraft runways.

Specifications for various uses are outlined in the literature.[74]

Arizona sand and gravel industry

Sand and gravel lead Arizona's nonmetallics in production with a total recorded yield from 1917 to 1943, inclusive, of approximately 19,350,000 tons, valued at $10,600,000. Production in 1942 was distributed as follows:[49]

Type	Tons	Value
Building sand	160,558	$ 145,316
Paving sand	94,782	80,758
Abrasive sand	275	212
Engine sand	21,995	20,567
Ballast sand	5,269	4,635
Other sand	1,260	1,600
Total sand	284,139	253,088
Building gravel	202,719	206,284
Paving gravel	1,105,730	725,773
Ballast gravel	11,710	5,881
Other gravel	7,055	2,577
Total gravel	1,327,214	940,515
Grand total	1,611,353	$1,193,603

Small tonnages of filter sand and other sands have been produced.

Arizona has vast resources of sand and gravel, but the low value per ton of these materials, shown by the production figures, has limited the industry chiefly to local market areas.

The principal recent producers of sand and gravel in Arizona are listed as follows:

Arizona Sand and Rock Co., Box 1522, Phoenix.
Arrow Head Products, Box 166, Tucson.
Carr Bros. Products Co., Rt. 12, Phoenix.
Coolidge Sand and Rock Co., Coolidge.
Daley Corp., Box 1590, Phoenix.
Hassayampa Sand and Rock Co., Wickenburg.
Oswald Bros., 366 E. 58th St., Los Angeles, Calif.
Prescott Sand and Rock Co., Prescott.
San Xavier Rock and Sand Co., W. 25th St., Tucson.
Tucson Ready Mix Concrete Co., S. Granite Ave., Tucson.
Tucson Rock and Sand Co., Inc., N. Bonita, Tucson.
Union Rock and Material Co., Rt. 5, Phoenix.
W. E. Hall Construction Co., Box 289, Phoenix.

SODIUM SULFATE

Minerals

The sodium sulfate minerals found in Arizona are thenardite, mirabilite, and glauberite.

Thenardite is anhydrous sodium sulfate. White to brownish, yellowish, or grayish. Glassy. Hardness 2.7, gravity 2.68, soluble in water. Alters to mirabilite.

Mirabilite is hydrous sodium sulfate. White. Hardness 1.5 to 2, gravity 1.48. Resembles granular ice when fresh. Melts above 91 degrees F.

Glauberite is sodium-calcium sulfate. Generally pale yellow to gray. Hardness 2.5 to 3, gravity 2.7-2.85. Commonly forms fine crystals.

Uses

Sodium sulfate enters into manufacture of Kraft paper pulp, glass, ceramics, dyes, rayon, sodium chemicals, stock feeds, medicines, and freezing mixtures. It is also used in antimony recovery.

Prices

During 1942 crude anhydrous sodium sulfate (salt cake) sold for about $15 per ton[49] at points of consumption. The natural product must compete with synthetic salt cake, an abundant by-product from manufacture of hydrochloric acid.

Arizona sodium sulfate

The only known commercial occurrence of sodium sulfate in Arizona is near Camp Verde, Yavapai County. This deposit[75] consists of thenardite associated with mirabilite, glauberite, halite (rock salt), and gypsum in clay. It was worked during 1920-26 by Western Chemical Company, which treated the material in a washing plant. In 1927 Sodium Products Corporation modified the plant and worked the deposit at a loss. Production was suspended during most of 1928-29 because of competition from German synthetic salt cake. Operations were carried on after 1929 by the Arizona Chemical Company, but the project was closed down at the end of 1933 when overall costs of production and transportation rendered it unprofitable under existing market prices.

No figures as to the amount or value of sodium sulfate produced from the Camp Verde deposit are available. According to Tyler[75] the product during the last years of operation rarely brought more than $6 per ton (f.o.b. railway at Clemenceau). Most of it was shipped to lower Mississippi Valley points at an average freight cost of about $12 per ton.

Future exploitation of this apparently large deposit would seem to depend upon more efficient mining and milling, together with lower transportation costs and favorable markets. Its position in a future Pacific Coast market will be subject to competition from other western deposits and synthetic salt cake.

STONE

TYPES AND USES

Commercial stone is broadly classified as dimension stone, slate, and crushed stone.

Dimension stone includes rock blocks, slabs, or rubble for use in construction of buildings, walls, pavements, curbs, flagging, and ornaments.

Among the slab slate products are roofing, flooring, electrical switchboards, billiard and laboratory tables, sinks, mantles, hearths, grave vaults, blackboards, hand slates, and flagstones.

Crushed stone is used for concrete, road material, railroad ballast, sewage filtration, and roofing granules. Broken rock for riprap is generally classed as crushed stone. Crushed limestone and marble are employed for smelter flux, rock-dusting in coal mines, and fillers; in manufacture of cement, lime, fertilizer, sugar, and rock wool; and in chemical industries. Pulverized slate is used for fillers, fuse covers, pigments, abrasives, and substitute fuller's earth.

The specifications of stone for various uses are beyond the scope of this report and are outlined in the literature.[76]

DIMENSION STONE IN ARIZONA

Production

Since early days dimension stone has been quarried in Arizona. The recorded production of this material during 1889-1915 was valued at approximately $2,431,000; data for other years are not available.

Sandstone

Sandstone and some quartzite have been quarried for local construction at many places in Arizona. Much of the material was used in railway bridges. Commercial shipments of sandstone have been made chiefly from Coconino, Navajo, and Yavapai counties.

Moenkopi red sandstone from near Flagstaff and Winslow has been used extensively in northern Arizona and also shipped to other cities; the Flagstaff stone, for example, entered into construction of Federal buildings at Los Angeles and Sacramento, California.[77]

Coconino sandstone of various colors is quarried near Ash Fork, Seligman, and Drake for building, flagging, and polished decorative construction. Since about 1930 this stone has become popular, especially in southern California. Production during some years was at a rate of 500 to 1,000 tons per month and valued at $2.50 to $8 per ton, f.o.b. shipping points. The output has been curtailed somewhat by wartime conditions. Principal producers have been H. Swanback, S. Watson, H. H. Gray, F. Maddock, W. C. Clingman, and C. Caruthers, of Ash Fork; G. T. Felty, Hollywood, California; and T. J. Jones, Seligman.

Granite

Granitic rock for building and monumental purposes has been quarried in several Arizona localities, chiefly near Prescott, Phoenix, Casa Grande, and Salome.

The granite from near Prescott was used in construction of the Yavapai County Court House (1916) and other buildings in Yavapai County.

Gneissoid granite has been quarried from a locality 7 miles south of Phoenix. A similar granite was used in the first story of the State Capitol.

The A B C Granite Company has operated a quarry in Pinal County, 20 miles west of Casa Grande.

Some granite was quarried a few years ago from the Harcuvar Mountains, about 6 miles northwest of Salome.

Tuff

Volcanic tuff, commonly known as "tufa," is a popular building stone in the Southwest because of its light weight and the ease with which it may be shaped. It has been quarried principally near Kirkland in Yavapai County, San Carlos in Gila County, Douglas, Tucson, Phoenix, Flagstaff, and Kingman. The Kirkland tuff was used in upper stories of the State Capitol.

Marble

Marble was quarried many years ago in the northeastern part of the Chiricahua Mountains,[78] Cochise County. Some of it is reported to have been used in New York and Denver.

Black marble marked with yellowish and white stringers occurs northwest of Manzoro, Cochise County. Some of it is reported to have been used for ornamental purposes in the Jackson County, Missouri, Court House, and for sculpturing in the Nelson Art Gallery, Kansas City, Missouri.

Onyx marble

Onyx marble or Mexican onyx is travertine-like calcite of various colors, mainly brownish or greenish. It has been mined for decorative and novelty purposes chiefly from Mayer in Yavapai County and upper Cave Creek in Maricopa County. A little is reported to have been produced near Winona and south of Canyon Diablo, Coconino County, and from near Greaterville in Pima County. Recently B. Bonner, of Flagstaff, is reported to have shipped onyx from a locality in Yavapai County 18 miles southwest of Ash Fork.

The Mayer deposit was worked intermittently prior to about 1933 by the Yavapai Onyx Mining Corporation. The Cave Creek deposit was worked prior to 1940 by the Arizona Onyx Mfg. Company, 415 S. First St., Phoenix.

Future of the industry

Arizona has large resources of excellent dimension stone of various types, texture, color, and composition. Many of the deposits are not favorably situated with respect to transportation facilities, but several are near railways or highways.

Changes in architectural trends have affected demand for dimension stone, but there is room for expansion of the local industry to compete with the building stone that is shipped into the State.

SLATE IN ARIZONA

Slate occurs in many of the schist areas of Arizona, as in the Phoenix, Estrella, Mazatzal, and Sierra Ancha mountains. A sample from the Phoenix Mountains was considered by Dale[76] to be of commercial quality. Because of the small local demand, low market value, and transportation costs, none has been produced commercially in the State.

CRUSHED STONE IN ARIZONA

Of the approximately $10,000,000 value of all commercial stone that has been produced in Arizona, crushed stone constituted the major portion. Most of it has been used for concrete, road material, railroad ballast, and smelter flux. Generally it is quarried as near as possible to consuming centers. A small tonnage of crushed limestone has been shipped from Arizona to beet-sugar refineries.

The total stone production of Arizona in 1942 was 227,220 tons,[49] valued at $219,231, of which 23,680 tons was limestone smelter flux, valued at $14,298. Most of the producers of sand and gravel also produce crushed rock.

STRONTIUM

Mineral

The only strontium mineral found in Arizona is celestite, strontium sulfate. White to bluish or reddish. Hardness 3 to 3.5, gravity 3.96. Fibrous to granular.

Uses

Celestite is employed in manufacture of signal flares, tracer bullets, and strontium chemicals. The ground mineral is used in place of barite for oil-well drilling muds and for purification of caustic soda in rayon manufacture.

Prices

Celestite, containing 92 per cent strontium sulfate and finely powdered, is quoted[10] at $45 per ton. Its peacetime average price was $12 to $15 per ton.

Arizona occurrences

Celestite deposits occur in Maricopa County, 15 miles south of Gila Bend and 15 miles southeast of Aguila. The latter deposit, held by Milton Ray, of Aguila, is reported to be large.[13]

Future possibilities

Normal consumption of celestite is small, and ordinarily domestic producers cannot compete with the imported material.

TALC AND PYROPHYLLITE

Definitions

Talc is a hydrous magnesium silicate, and pyrophyllite is a hydrous aluminum silicate. Both minerals are soft (hardness of 1), white or light colored, and greasy to the touch; generally they cannot be distinguished without chemical analysis. Several commercial talcs contain various silicate impurities,[79] and soapstone is massive low-grade talc.

Uses

For many purposes talc and pyrophyllite are equally useful. They are important in the ceramic industry, especially for white ware and wall tile, where their use depends upon chemical composition. Talc is employed in manufacture of certain refractories, electrical insulators, and heat retainers. Talc and pyrophyllite are used in paints, rubber, paper, roofing, plasters, asbestos goods, linoleum, oilcloth, plastics, ropes, insecticides, lubricants, polishes, cosmetics, foundry facings, and crayons.

Prices

Current prices for talc and pyrophyllite range from $4.25 to $43 per ton, depending upon grade and preparation.

Arizona occurrences

Talc is found at several places in Arizona, but not in known large amounts. Pyrophyllite occurs chiefly near Quartzsite[72] and at other localities in northern Yuma County, but little development of the deposits has been undertaken.

TITANIUM

Minerals

Titanium occurs in several minerals of which comparatively few are commercially important.

Rutile is titanium oxide. The pure mineral contains 59.95 per cent titanium, but iron and silica are generally present as impurities. Hardness 6 to 6.5, gravity 4.18 to 4.25. Brown, red, to black. Crystalline to massive.

Ilmenite is a ferrous titanate of variable composition. Hardness 5.5 to 6, gravity 4.5 to 5. Iron black. Generally massive.

Titaniferous magnetite is magnetic iron oxide containing 3 or more per cent titanium as ilmenite.

Uses

Titanium is used mainly in pigments, alloys in iron and steel manufacture, various nonferrous alloys, and welding-rod coatings. It is also employed in ceramics, dyes, arc lamps, electrical insulators, fertilizer, fireworks, smoke-screen compounds, special cements, glass manufacture, and various titanium chemicals.

Prices

Nominal quotations[10] for ilmenite, 60 per cent titanium oxide, are $28 to $30 per ton, f.o.b. Atlantic seaboard; rutile, minimum 94 per cent concentrate, 8 to 10 cents per pound.

Arizona occurrences

Titaniferous magnetite occurs in gabbro west of Bagdad, Yavapai County. Some of this material is reported[80] to contain 15 per cent titanium oxide, but the bodies have not been regarded as of commercial size.

Other titanium minerals[3] have been found in Arizona, but generally as accessory minerals rather than as commercial deposits.

VOLCANIC ASH (PUMICE)

Definitions

Pumice is a highly cellular, generally siliceous lava. Pumicite consists of finely divided pumice or glassy volcanic particles, also called volcanic ash, dust, or tuff. Much pumicite is finer than 200-mesh.

Uses

Small-sized or granular pumice is used increasingly as a lightweight concrete aggregate and acoustical plaster. The largest use for ground pumice and pumicite is for abrasives, soaps, and cleansers. Some is employed as a filler in paints, for filtration, in manufacture of vinegar, in chemical plants, for flux, and in ceramics.

Prices

Powdered pumice is quoted[10] at 2½ to 4½ cents, and lump at 5 to 7½ cents per pound, f.o.b. New York or Chicago. These prices, however, apply only to select material; the pumice and pumicite sold or used by producers in the United States during 1942 had an average value of $5.58 per ton.[49]

Arizona occurrences

Pumice and pumicite are plentiful in Arizona, but their low market value and cost of transportation have limited them chiefly to local uses. Volcanic cinders have been employed extensively in northern Arizona for highway and railroad construction. According to Moore,[81] commercial deposits of pumice are worked near Bouse, Yuma County.

ZEOLITES

Definition and uses

Natural zeolites are hydrous silicates of aluminum with chiefly sodium and calcium. Also greensand, which is largely glauconite, a hydrous silicate of iron and potassium, is known to the trade as "zeolite."

Natural zeolites, particularly glauconite, are used[82] chiefly for water softeners in competition with artificial zeolites. Greensand was employed extensively in the eastern United States as fertilizer, but this use has diminished since the latter part of the nineteenth century; it is, however, regarded as a potential source of potash.[82]

Arizona occurrences

The principal zeolite deposits found in Arizona are near Wikieup, Mohave County. There a friable green sandstone consists largely of fine-grained analcite (a sodium aluminum zeolite) coated with thin films of glauconite.[83] So far as known, the possible industrial utilization of these deposits has not been investigated.

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INDEX