Technical Paper 155 Mineral Technology 19

DEPARTMENT OF THE INTERIOR

FRANKLIN K. LANE, SECRETARY

BUREAU OF MINES

VAN. H. MANNING, DIRECTOR

GYPSUM PRODUCTS

THEIR PREPARATION AND USES

BY

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Geologist, U. S. Geological Survey

[In cooperation with the United States Geological Survey]

WASHINGTON

GOVERNMENT PRINTING OFFICE

1917

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First edition. July, 1917.

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PREFACE.

This paper has been prepared by R. W. Stone, of the United States Geological Survey, from information collected by him in the course of a comprehensive investigation of the gypsum deposits in the United States for the Geological Survey. The distribution of the deposits, their extent, their stratigraphic relations, and the conditions under which they formed will be described in a Survey bulletin. This report discusses the methods of mining or quarrying gypsum, the equipment and operation of plants for reducing the crude rock to commercial plaster, and the various forms in which gypsum products are marketed.

Although a minor industry, the manufacture of gypsum possesses decided importance. In 1915 the total amount of calcined plaster produced in this country amounted to 1,613,720 short tons, valued at $5,946,018, and the total value of all gypsum products was approximately $7,000,000. Sixty-eight plants were engaged in the production of gypsum and the manufacture of gypsum products, and these plants represented a capital investment of probably not less than $20,000,000.

In view of the greater attention being given to fire resistance and other desirable features of construction, the use of gypsum products in buildings is bound to increase. Also, as manufacturing industries become more varied and refined, the use of gypsum products for other purposes than in buildings will become larger. For these reasons this paper is printed by the Bureau of Mines in the hope that it will aid the development and utilization of one of the country's mineral resources and will thereby promote the advancement of the general welfare.

VAN. H. MANNING.

GYPSUM PRODUCTS; THEIR PREPARATION AND USES.

By R. W. STONE,
Geologist, United States Geological Survey.

INTRODUCTION.

In response to requests from the public, received by bureaus of the Department of the Interior, for information about the method of making gypsum plaster, the writer has prepared the general description given in this paper, which is based on various published reports, including the bulletin on gypsum and salt in Oklahoma, by the Oklahoma Geological Survey,[a] the volume on gypsum in Canada by the Mines Branch, Department of Mines, Canada,[b] and on the writer's knowledge of the subject from observation in gypsum quarries, mines, and mills. Furthermore, the manuscript received in June, 1916, careful reading and criticism by engineers of the largest producers of gypsum products in the United States, by the manager of a company operating in several States, and by the president of a small gypsum company. Therefore, the information presented may be considered up to date and in accordance with general practice. The paper is published by the Bureau of Mines as one of a series of reports on mineral technology.

Practice varies in different gypsum mills, according to the experience of operators in getting desired results, the kind of machinery used, and the volume of business. Calcination is completed in some plants in 60 to 75 minutes; in others the gypsum is cooked slowly for 3 or 4 hours. When gypsum is dried before going to the kettle, calcination is completed in much less time than if preliminary drying is omitted. Of course, more time is required for making second-settle than for first-settle plaster. Some operators believe high temperature for a short time gives the best results, whereas others maintain that a lower temperature for a longer period gives more even and thorough calcination. In either case the result seems to be the same. Methods and machines are being improved as the technology

[a] Snider, L. C., The gypsum and salt of Oklahoma: Oklahoma Geol. Survey Bull. 11, 1913, 214 pp.

[b] Cole, L. H., Gypsum in Canada: Canada Dept. Mines Bull. 245, 1913, 256 pp.

of the industry is better understood, so the description given will not fit all cases exactly and in a short time may be obsolete in some details. The writer believes the time is near when calcination by continuous passage through a revolving calciner will be more common, and looks for calcination by electricity in some plants in the future where electric heat is cheaper than coal.

ACKNOWLEDGMENT.

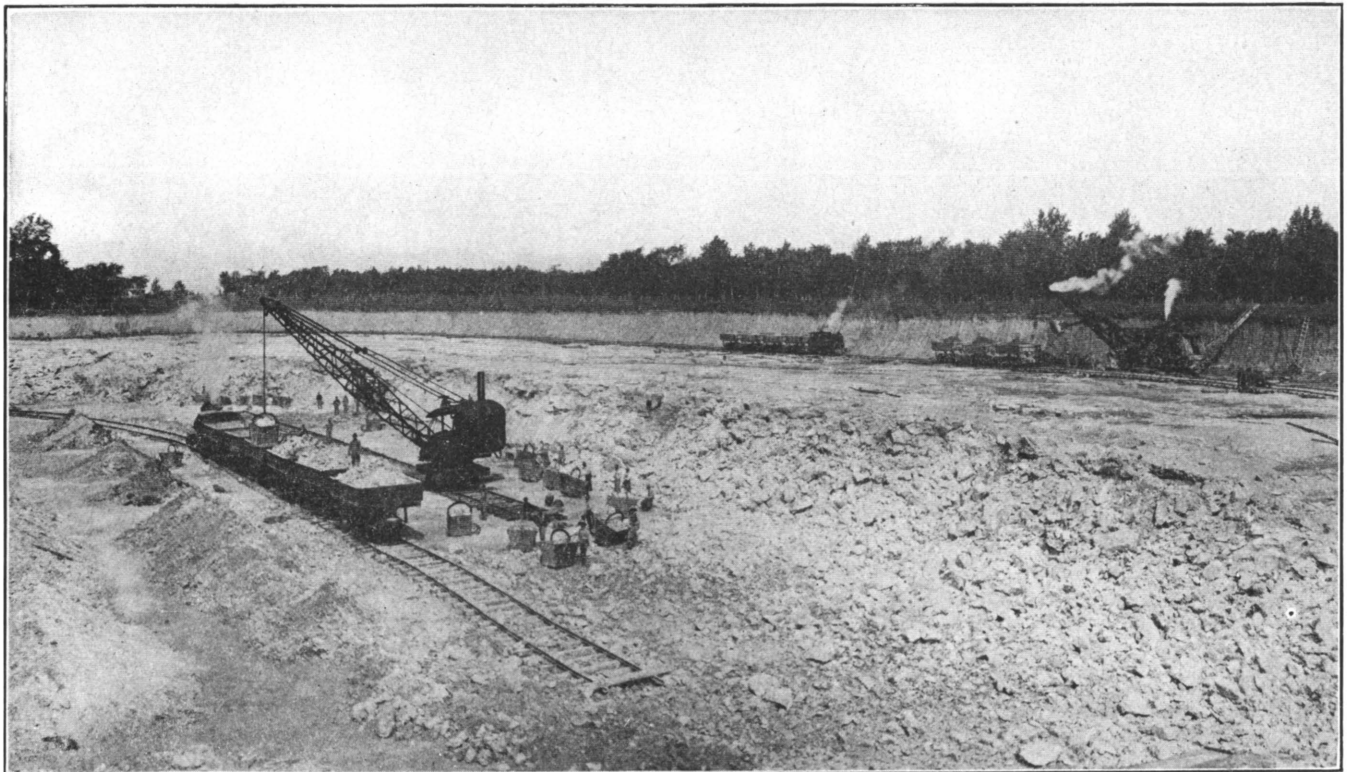
The writer acknowledges his indebtedness to the officials and employees of gypsum companies from New York and Virginia to Arizona and California, who freely gave him information and permitted access to mines and mills. The illustrations in this report are from official photographs by members of the United States Geological Survey, from photographs provided by gypsum companies, and from catalogues of manufacturers of machinery for use in gypsum mills. For obvious reasons the names of companies and manufacturers have been omitted, although the indebtedness of the writer is thereby increased. Pictures of machines have been selected for their illustrative value and not from any preference for the particular type or make of machine.

MINING.

Procuring the crude material is the first step in the manufacture of gypsum products. The methods employed depend naturally on the character of the deposits, but are very simple. If a gypsum deposit has any overburden, the feasibility of removing this determines in part whether or not the deposit may be worked by open-pit or underground mining. A hard rock cover above the gypsum permits underground mining only, but where the overburden is soft, unconsolidated, and of no great thickness, the practice is to strip and then remove the gypsum by quarrying. (See Pl. I.)

Stripping is done by hand, by horse scrapers, and by steam shovel. In hand stripping, men shovel the overburden into wagons for haulage to a dump. This method is employed only where the area to be uncovered is small and the overburden is thin. In some places the material removed may be shoveled directly into a worked-out pit. Where the stripping is on a larger scale, horse scrapers may be used. The surface cover may be broken up by plow or disk harrow and removed to the waste pile by drag or wheel scraper. In still larger undertakings and where the cover of waste is thick, the steam shovel does effective and economical work. If a steam shovel is used, a track is generally laid so that the shovel loads directly into cars.

Gypsite or gypsum earth always lies close to the surface and may have little or no overburden. Deposits of this sort are worked in South Dakota, Oklahoma, Wyoming, Texas, New Mexico, Arizona,



METHOD OF QUARRYING GYPSUM, ALABASTER, MICH. STRIPPING IN BACKGROUND, LOADING IN CENTER, AND FRESHLY BLASTED ROCK IN RIGHT FOREGROUND.

and California by shoveling directly into wagons or tram cars in some places without the necessity of first being loosened, or are dug with horse scrapers. (See Pl. II, *A*.) At some places gypsite is dried by breaking it with a disk, and is stored under sheds for use in wet weather because it is pulverized and is worked easier when dry. Steam shovels could be used for digging gypsite, but are not required for the small and temporary operations involved. Many gypsite deposits are so small that they may be worked out in a short time, and then the plant must be moved to a new deposit or the new supply hauled a longer distance.

Rock gypsum is either quarried or mined, depending on the thickness and character of the cover. Quarrying has many advantages and is the method used wherever possible. The advantages over underground mining include cheaper operating costs, easier handling and supervision, easier selection of material, complete recovery, and in some places better working conditions.

Quarrying practice has not resulted in systematic exploitation save in a few places. The openings for the most part are irregular, having been carried back from the outcrop to the limit of stripping or safe recovery and along the outcrop for a greater or less distance. In places, after an open quarry has been extended as far as may be without too much loss of safety or economy, it is abandoned and a new opening made a short distance farther along the outcrop. In other places, where the thickness of the overburden is moderate, single quarries are of large size. Rock gypsum is broken from the ledge by blasting with low-power explosives. If the face is high enough it is broken down by caving. Holes are drilled in the lower part of the ledge with a one-man auger or hand-power drill and blasted with light charges. Black powder is used where there is no moisture, but as a rule low-grade dynamite (18 to 20 per cent nitroglycerin) is used for blasting and for breaking the large chunks. The blocks of gypsum thus brought down and broken with explosives and with wedges and sledge hammers to a size convenient for handling are loaded into wagons or small cars for hauling to the mill or loading platform. (See Pl. II, *B*.) In hand loading there is opportunity to sort out inferior material.

Where the overburden becomes too thick for quarrying, recovery may be continued at the same place by mining. This requires that a large part of the gypsum bed be left as pillars to support the roof. When, after a number of years of work, the underground passages have become very extensive, it may be cheaper to sink a shaft to the bed than to continue long tram hauls to the outcrop.

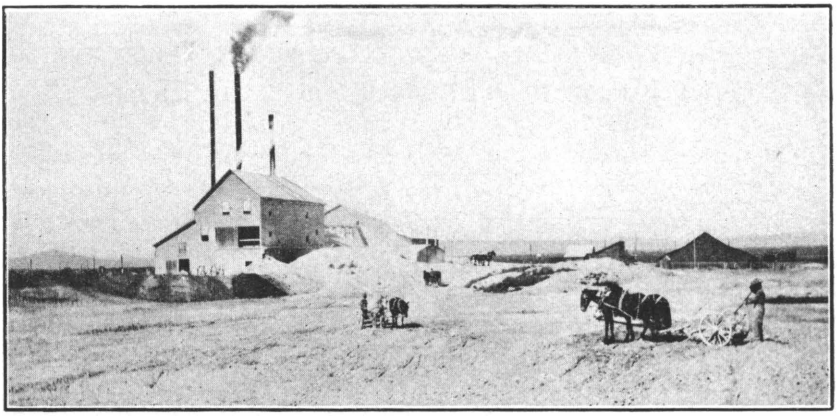
Mining is the method of extraction used where the overburden is excessive or consists of consolidated rock. (See Pl. II, *C*.) The underground methods are similar to the room-and-pillar system used in coal mines. Main haulage ways are driven and rooms laid off from them, pillars being left between the rooms to support the roof. Where the rock overlying a thick gypsum bed is easily broken or is unconsolidated, the upper part of the bed is left to support the roof. The room-and-pillar system is the simplest and most practical method of underground recovery of a flat-lying bed, but it entails the loss of a considerable part of the deposit. The pillars usually are composed of good gypsum and constitute about 25 per cent of the bed. Where gypsum is not left as a roof, and where pillars can be drawn and the surface allowed to cave, a bed may be completely mined out, but commonly not more than three-quarters of a deposit is recovered by underground mining.

In mining, as in quarrying, gypsum is broken from the bed by making holes in it with hand or power augers or drills and breaking it out with an explosive. (See Pl. III, *A*.) Tracks are laid to the working faces and the broken gypsum is loaded directly into cars which are moved by hand or by mule to the main haulage way, where they are made up into trains and hauled to the surface or to the foot of a shaft by mule, by cable, or by electric locomotive.

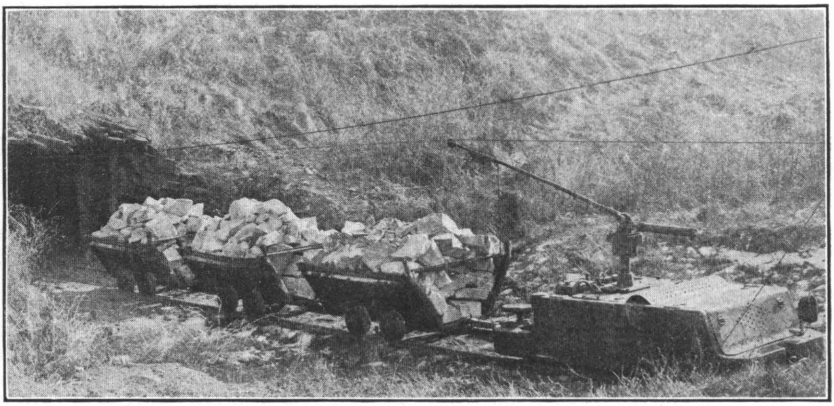
When different parts of the bed vary in composition, the purer rock may be sent to the mill for plaster and the impure gypsum, separated by hand sorting, may be utilized for land plaster. Preparing gypsum for land plaster consists only of crushing, drying, and grinding. For making other gypsum products the rock goes through these operations: Crushing, drying, grinding, calcining, screening, regrinding, and mixing. The order in which these operations are performed differs in practice. In Europe it is customary to calcine the lump gypsum, crushing and pulverizing it afterwards at a much less expense of energy, for calcination shatters it decidedly. The product, however, is not so evenly calcined as when the rock is crushed first. The European method of calcining is by the use of ovens rather than kettles, and is better adapted to lump gypsum. The usual practice in Canada and the United States is to crush and grind the rock before calcining.

CRUSHING.

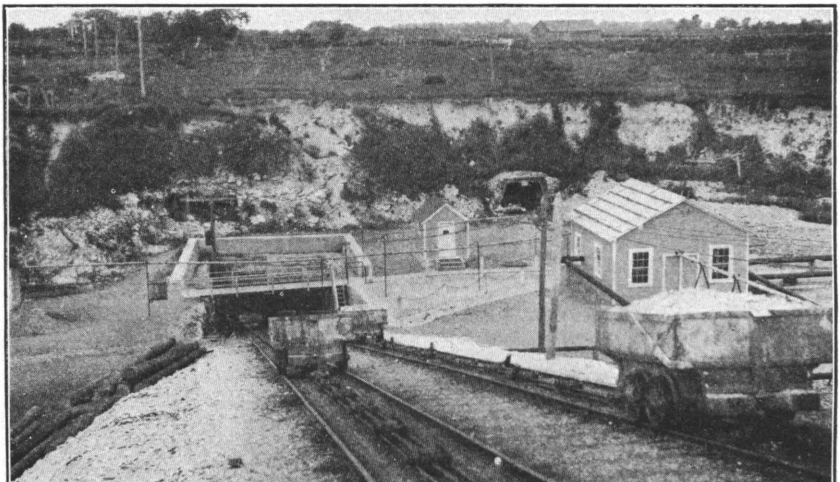
Rock gypsum is delivered to the mill in blocks no larger than one man can handle, and is dumped into a bin or chute or on a platform from which it is fed directly into a large heavy jaw crusher or "nipper" (fig. 1), as the machines are known to the gypsum trade, or into a rotary crusher. There are various forms of jaw crushers, but commonly one part of the machine is stationary with a corrugated face of chilled iron against which works a similar but movable face, or jaw, with a V-shaped opening between. The movable plate



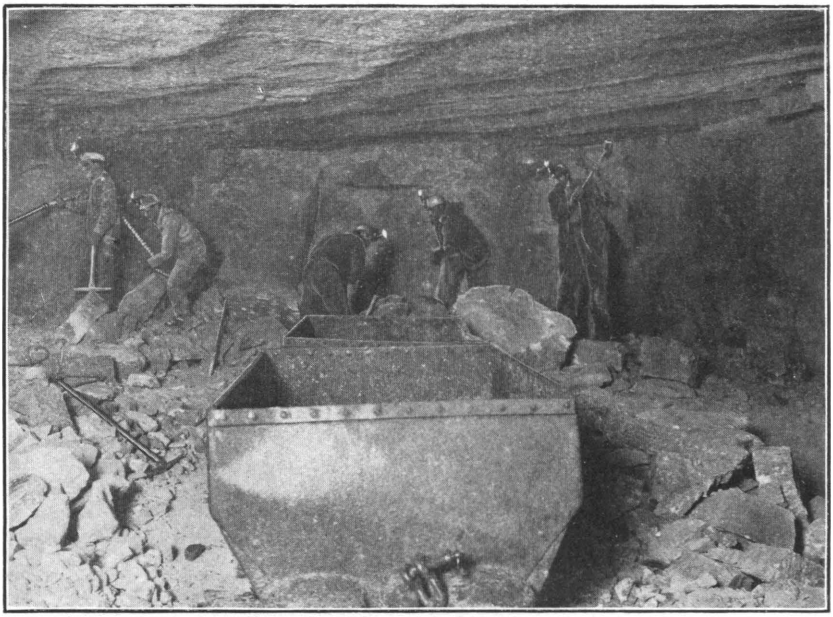
A. DIGGING GYPSITE WITH HORSE SCRAPERS, LARAMIE, WYO.



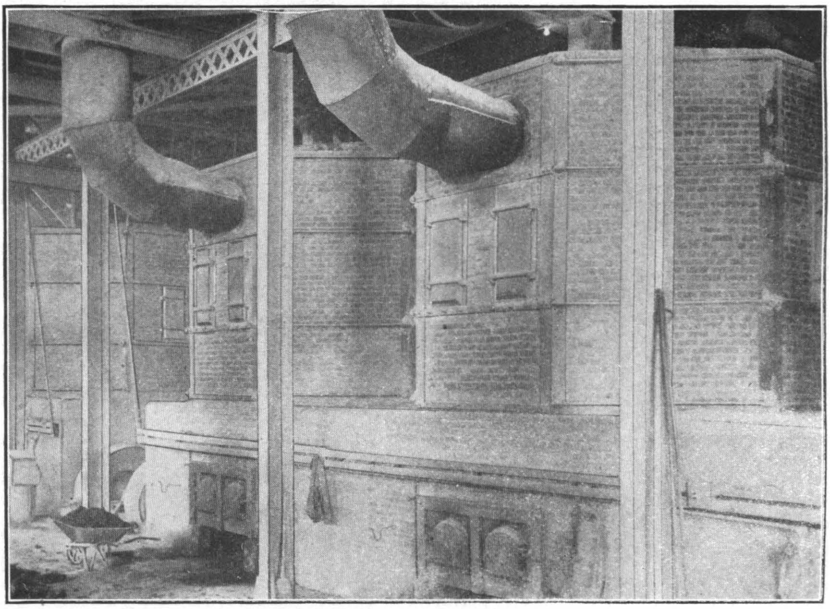
B. ROCK GYPSUM AS IT COMES FROM THE MINE OR QUARRY.



C. MINE AT GYPSUM, OHIO. OLD QUARRIES AND ENTRIES ON BED NEAR SURFACE, AND SLOPE TO MINE ON LOWER BED.



A. MINING GYPSUM, FORT DODGE, IOWA. SHOWS FAIRLY EVEN ROOF, THICKNESS OF PART OF GYPSUM BED BEING WORKED, AUGERS USED FOR MAKING BLAST HOLES, AND STEEL TRAMCARS.



B. CALCINING KETTLES.

is moved alternately forward and back by an eccentric on the shaft. These nippers, or jaw crushers, are made in different sizes, the rock opening varying from 15 by 22 inches to 36 by 48 inches; they weigh several tons and require 1 to 75 horsepower. The rock is broken to somewhat less than the size of a man's fist, the opening at the bottom of the jaws being 2 inches. The capacity of a nipper, in tons per hour, and the power required to operate it vary with the condition of the rock, dry gypsum being crushed more easily than wet. At some mills the preliminary crushing is done in a rotary or gyratory crusher of large size, described below.

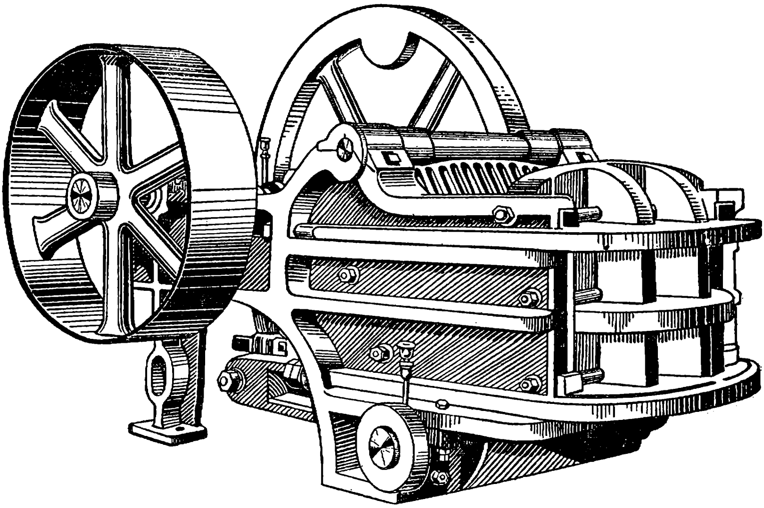


FIGURE 1.—Jaw crusher.

Where the quantity of rock handled is large and the lumps vary considerably in size, economy in power is gained by running the crude rock dumped from the mine car over a grizzly, or set of parallel iron bars to sort out the material less than 3 inches in size, and by feeding the undersize directly to the second crusher.

From the first crusher the broken rock slides directly into the hopper of a rotary crusher or "cracker" (fig. 2) installed below. The common type of rotary crusher is shaped like an hourglass and resembles a coffee mill. Within a conical shell having a corrugated inner surface revolves a shaft with a corrugated iron shoe. This mill is easily and quickly adjusted for fine or coarse grinding. The ordinary reduction is to fragments that will pass a 1½-inch ring. These rotary crushers weigh from 1 to 7 tons and require from 1 to 35 horsepower, and the largest size takes pieces up to 14 inches in diameter.

To arrest pieces of iron or steel mixed accidentally with the gypsum in mining and to prevent their clogging or damaging the machinery, a magnet is placed on the plate over which the broken rock slides from the nipper to the cracker, or is suspended over a belt conveyor carrying the "gravel" away from the cracker. In the latter position the magnet does not protect the cracker, but it makes a surer recovery of metal.

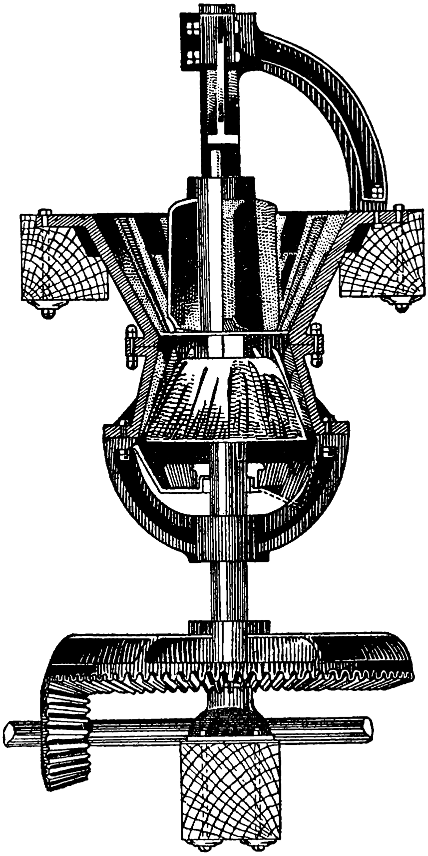


FIGURE 2.—Rotary crusher.

DRYING.

From the cracker the finely crushed rock or "gravel" is usually carried by belt conveyor to a drier. The drier is a large slightly inclined, rotating cylinder. Crushed rock is fed into the upper end of the drier and hot gases are forced into the lower end. The surface moisture taken from the rock as it passes through is carried off by an exhaust fan. The dry rock discharged has a temperature of about 150° F., and is elevated to a storage bin at the top of the crusher building. A mixture of coke and coal is used commonly for heating the drier, in order to avoid staining the rock with smoke.

GRINDING.

From the bin at the top of the building the "gravel" is fed by gravity through chutes to the pulverizers. The type of pulverizer used is not uniform, there being four that are giving service—burr mills, emery mills, disintegrators, and roller mills.

BURR MILLS.

A burrstone mill consists of two rough, siliceous stone disks; one of these is stationary and the other revolves concentrically against it. The stones are set either horizontal or vertical. Radiating grooves are cut into the grinding surface of each stone, and must be recut when the surfaces are worn smooth, which is about once a fortnight. Extra stones are kept on hand that time may not be lost during redressing. The vertical mills grind faster but not as uniformly fine as the horizontal mills. Burr mills reduce the partly crushed rock to 60 mesh, or a size that will pass through a screen having 60 holes to the linear inch. The capacity of the mills varies but will average 30 tons of 60 mesh in 24 hours. The mills are driven at speeds ranging up to 650 revolutions per minute. After the first grinding, the material may be screened and reground so that 85 per cent will pass a 100-mesh screen.

EMERY MILLS.

Built on the same plan, but with different material for grinders, emery mills are an improvement on burrstone mills. The grinders have a center of burrstone surrounded by concentric rings of grooved emery blocks. The whole is surrounded by an iron band and the loose blocks outside the burrstone core are cast in metal. This type of stone was devised to remedy the wearing away of the outer part of the burrstone more rapidly than the center.

DISINTEGRATORS.

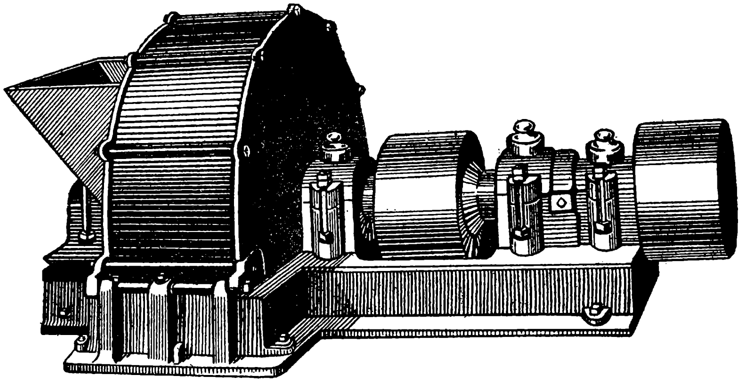
A machine especially adapted to pulverizing soft rock such as gypsum has come into extensive use in gypsum mills. It consists of two circular plates revolving concentrically in opposite directions on a horizontal axis. Each plate is armed with a double circle of short iron bars attached at right angles and so placed that they interlock with those of the other plate, thus forming a circular cage made of four concentric rows of posts. (See fig. 3.) The gypsum gravel fed into the center of the cage drops against the first set of iron bars. The impact with these bars breaks the gypsum, and it passes between them to be struck at once by the second set of bars moving in the opposite direction. By the time the outer set of bars is passed, the rock is reduced to powder. Speed regulates the fineness.

Disintegrators vary from 30 to 50 inches in diameter, from 3,000 to 15,000 pounds in weight, require 6 to 45 horsepower, and have a capacity of 8 to 75 tons in 10 hours.

ROLLER MILLS.

A method of producing a fine uniform product by grinding and air separation used in a number of gypsum plants is known as the Raymond system. Grinding is done by suspended rollers, and all working parts are inclosed in a tight metal case. At the top of the main shaft, which is vertical, is a rigidly attached spider that rotates with the shaft. To the spider arms the roller journals are pivotally suspended by trunnions fastened in the top and carried in bearings in the spider.

The speed of the machine regulates the pressure the cast-iron rollers exert on the grinding surface, which is a bull ring made of high-carbon steel. A steel plow ahead of each roller throws a



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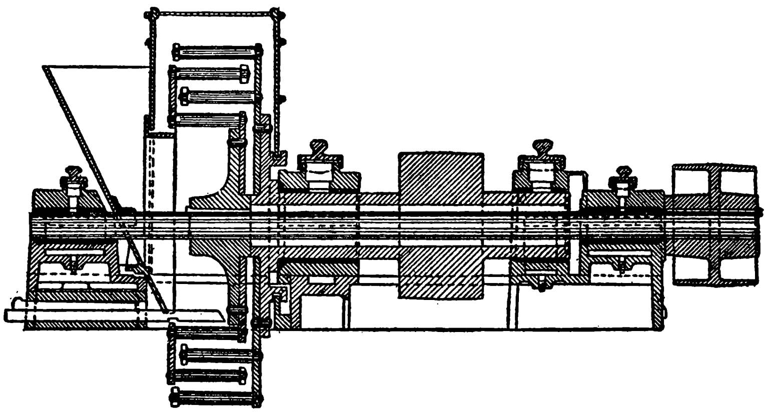


B

FIGURE 3.—Disintegrator.

stream of material between the face of the roller and the bull ring. A fan driven by electric motor makes an air current that carries away pulverized material. Selective separation of the ground rock is regulated by the speed of the fan. The air current also delivers the pulverized material to the bins above the calciners, whereas from other types of pulverizers the pulverized gypsum is raised by elevators, usually the bucket-belt conveyor type, to storage bins.

CALCINING.

From storage bins the ground gypsum flows by gravity to the calciners, the common type being stationary kettles. Rotary continuous-process kilns are used at three mills in the United States.

When powdered gypsum is heated with a rising temperature, part of the water of crystallization is driven out of the mass, and the steam thus formed, assisted by constant mechanical agitation, causes the fine particles to float upward and to become violently disturbed as if boiling. This vigorous "boiling" begins at a temperature of about 230° F. and continues until about 270° F. is reached; then boiling ceases, and the whole mass settles down to 10 to 14 per cent less than the original volume. This comparatively quiet condition is called the first settle and means that most of the gypsum particles are dehydrated to the first stable chemical combination of the half-hydrate. With continued increase of heat, the partly calcined gypsum again gives off water in the form of steam and boils more violently than before. This continues until the second settle is reached, when the mass quiets down. At this stage all of the gypsum has been dehydrated to the half-hydrate, and some of it has been reduced to soluble anhydrite. The loss from the original volume is now 15 to 18 per cent.

Calcination is stopped before or after the second settle, depending on the character of product wanted. In making wall plaster the common practice is to stop calcination after the first settle at temperatures ranging from 310° to 350° F. For bedding plate glass, and for purposes requiring a denser and stronger casting, calcining is continued to the second settle.

The calcined product is plaster of Paris, commonly called stucco in the trade, and distinguished as first and second settle stucco, according to the degree of calcination. When calcining is completed the plaster is dumped into fireproof cooling bins. The total loss in weight is about 20 per cent, including water removed and losses from escaping dust throughout the process.

Gypsum has been calcined in various ways in the United States. There are several pioneer methods. At present commercial calcining is done in kettles, rotary kilns, stationary kilns, and baffle-plate furnace.

PIONEER METHODS.

In the infancy of the industry on this continent, gypsum was "cooked" in caldrons and stirred by hand. These caldrons had a capacity of only a few barrels and were heated with wood fires. The massive gypsum was broken with sledges to small size, and may have been ground before calcining. A pioneer in southern Utah told the writer that 40 years ago gypsum plaster was made there in molasses pans. Large blocks from the quarry were broken with sledges and run through a horizontal burr mill which reduced the gypsum to the size of acorns and corn. It was then cooked in a large, shallow, rectangular sheet-iron molasses or sorghum pan, with constant stirring by hand. The plaster was drawn after the first settle. It is presumed that the material was reground after calcining.

At one place in Utah in recent years ranchers have made gypsum plaster by burning the rock in a rough stone kiln over a wood fire. It is assumed that the rock was cooked in lumps and crushed or ground in a portable mill after calcination.

Plaster of Paris is sometimes needed in small quantities for taxidermy or making a mold for casting metal. It can be made by baking any form of gypsum in the oven of a cookstove or by heating in a pot over a fire. Gypsum crystals that are common in many areas in the Western States are used for this purpose. The crystals are easily pulverized by hand after calcining.

KETTLE PROCESS.

In the United States and Canada the kettle process of calcining gypsum is used almost exclusively. It is not economical of heat and it requires strong horsepower to agitate the powdered mass, but it is easily watched by the operator and produces a well calcined plaster.

Kettles made by four different manufacturers in the United States vary in minor details only.

The kettle itself is a hollow cylinder of $\frac{3}{8}$-inch boiler plate, having a diameter of 8 to 14 feet and a depth of 6 to 10 feet. (See fig. 4.) It usually has a convex bottom made as a single casting from iron with a low coefficient of expansion, or of one piece of pressed steel. Some manufacturers make a bottom plate $\frac{5}{8}$ to $\frac{7}{8}$ inches thick; others give it a thickness of $\frac{5}{8}$ inch at the edge, increasing to 4 inches at the crown of the arch. As the single-piece bottoms are liable to crack, some kettles have sectional bottoms. Sectional bottoms are not wholly successful, however, for there is great difficulty in getting new sections to fit with the old because of the uneven expansion of the different sections under the intense heat. The kettle and the bottom plate rest on an iron flanged ring which rests on the masonry foundation surrounding the fire box. The bottom plate and ring are firmly cemented to the kettle.

The masonry fire box incloses a fire grate measuring 2 by 3, 3 by 4, or 4 by 5 feet, which is set 6 or 7 feet below the kettle bottom. The masonry continues upward and surrounds the kettle. (See Pl. III, *B*, p. 12.) This shell of brick is 15 to 17 inches thick with an air space between it and the kettle. Formerly the air space was made 7 inches wide, but later practice is to make it 12 to 16 inches, in order to give freer circulation of heat and permit easy cleaning. Two or four flues about 14 inches in diameter extend horizontally through the kettle. Thus the heat applied to the bottom of the kettle also

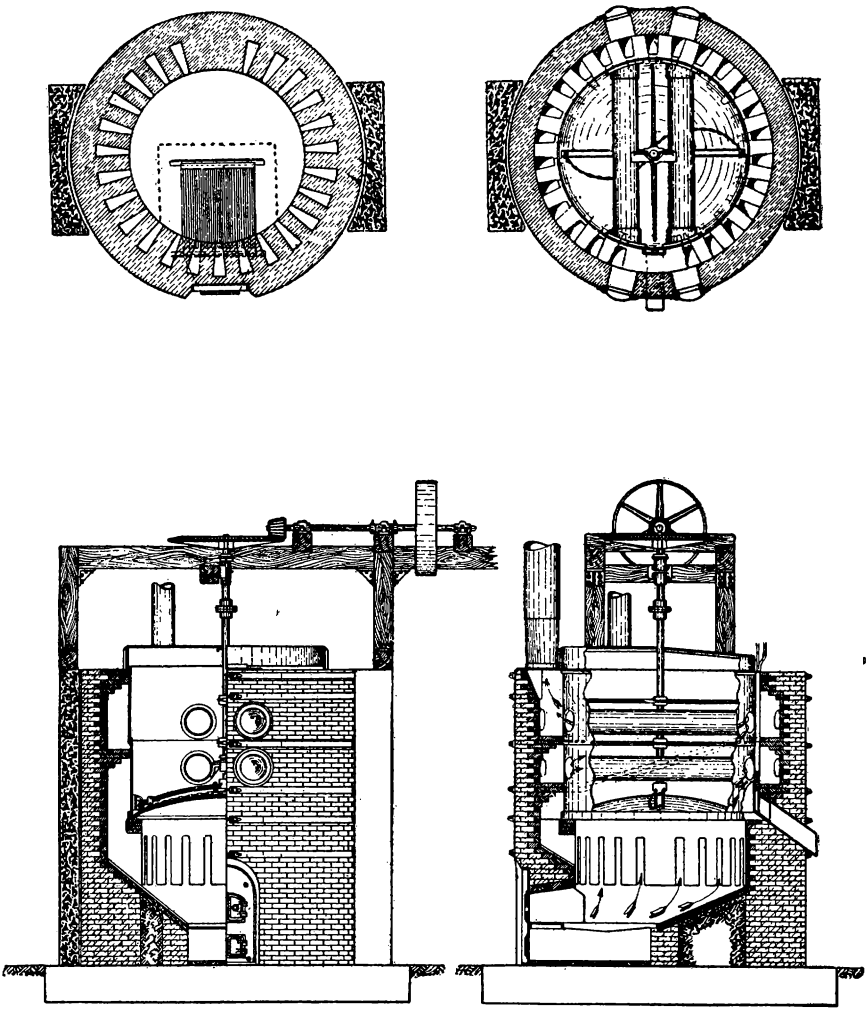


FIGURE 4.—Four-flue calcining kettle.

circulates around and through it before passing up the stack. In order to prevent burning the gypsum is kept constantly in motion by an agitator. This consists of a gear-driven vertical shaft about 4 inches in diameter, to the bottom of which is attached a curved cross arm bearing a series of stirring paddles. Revolving the agitator tends to move the gypsum toward the shaft. Another cross-arm paddle is attached above the flues. The agitator revolves at the rate of 15 revolutions a minute and requires 10 to 25 horsepower, depending on the size of the kettle and weight of the charge. A sheet-iron lid with loading doors covers the kettle. Figure 5 shows a cross section of a one-kettle gypsum mill.

Kettles vary in capacity from 2 to 20 tons a charge, and require for their setting, depending on the size, from 2,000 to 7,000 fire

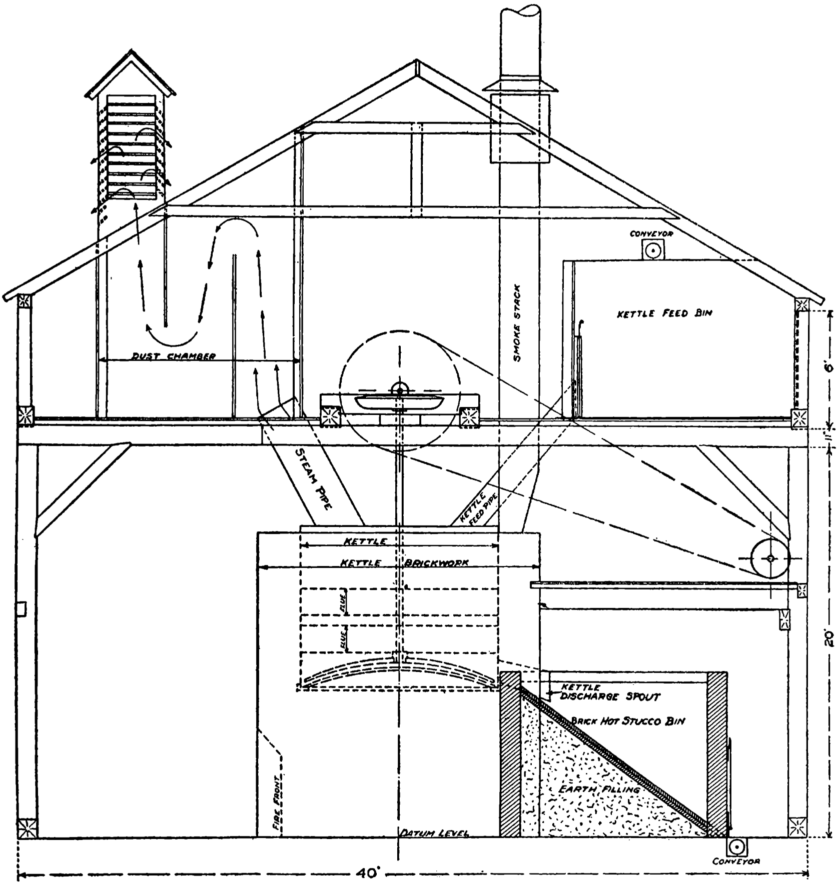


FIGURE 5.—Cross section of one-kettle gypsum mill.

bricks for the lower part, and 10,000 to 23,000 common brick for the part above the fire pit. The weight of kettle and fixtures is 3 to 10 tons.

In 1916, gypsum was calcined in the United States by 55 plants using coal, 13 using oil, and 2 using wood.

The gypsum, whether ground rock gypsum or ground gypsite, is fed slowly from the bin above through a loading door in the cover.

Filling a 14-ton kettle requires 15 to 50 minutes if the gypsum is dry; longer if it is damp. This is done with the kettle heated to 212° F. The temperature is raised gradually and at 230° F. the mass begins to boil. Note of the heat changes is made by a long tubular thermometer fastened to the kettle, or by an automatic recording thermometer. Expert calciners tell by the appearance of the mass how far calcination has progressed. The time required for cooking a charge varies with skillful firing and forced draft; first-settle stucco may be calcined in 60 minutes. At some plants, when everything works smoothly, a kettle will run twelve charges in 12 hours, or one charge in 1 hour. Other plants require longer, even 3 to 5 hours to a charge. When calcining is complete a slide at the bottom of the kettle is opened and the plaster falls through a chute and is carried by a screw conveyor to the cooling bin.

Advantages claimed for the kettle process are speed, opportunity to watch the cooking, and uniform calcination. Calcination may be completed in less than two hours; the operator can see just what stage has been reached and can dump the contents of the kettle at any stage or degree of heat desired. Furthermore, as the rock is pulverized before entering the kettle, all particles are calcined alike.

ROTARY CONTINUOUS PROCESS.

Three plants in the United States calcine gypsum by the rotary continuous process, or, as it is commonly called in this country, the Cummer process, named from the maker of the machinery. The Cummer rotary calciner (fig. 6) consists essentially of a slowly revolving cylinder slightly inclined from horizontal. The rock to be treated passes downward and is calcined by hot gases moving in the opposite direction. The cylinder, which is 30 feet or more in length and 5 feet in diameter, is supported on roller bearings and at its ends by extended trunnions. It is driven by a heavy geared wheel at one end. The cylinder is inclosed at its sides and top by a brick wall and at the ends by metal plates (see Pl. IV). An extension of the brick wall beyond the higher end forms a furnace. A series of brick air chambers with perforated tops is built on the floor beneath the cylinder. About 2 feet above these chambers and just below the cylinder there is a perforated arch. A suction fan connected with the higher end of the cylinder makes a draft which draws most of the hot gases from the furnace through the long horizontal chamber beneath the arch to the lower end of the calcining chamber and thence up through it. Cool air admitted through the perforated tops of the air chambers is mixed with the gases to give a regular and proper degree of heat. The perforated arch admits some of the mixed air and hot gas directly to the calcining chamber. Heat enters this chamber through a series of traps in the shell. These traps extend in a spiral the whole length of the cylinder and are so hooded on the inside as to prevent escape of the rock. The gypsum, which is crushed to $\frac{3}{4}$-inch ring and not pulverized as for calcining in kettles, is fed from a hopper into the upper end of the cylinder.

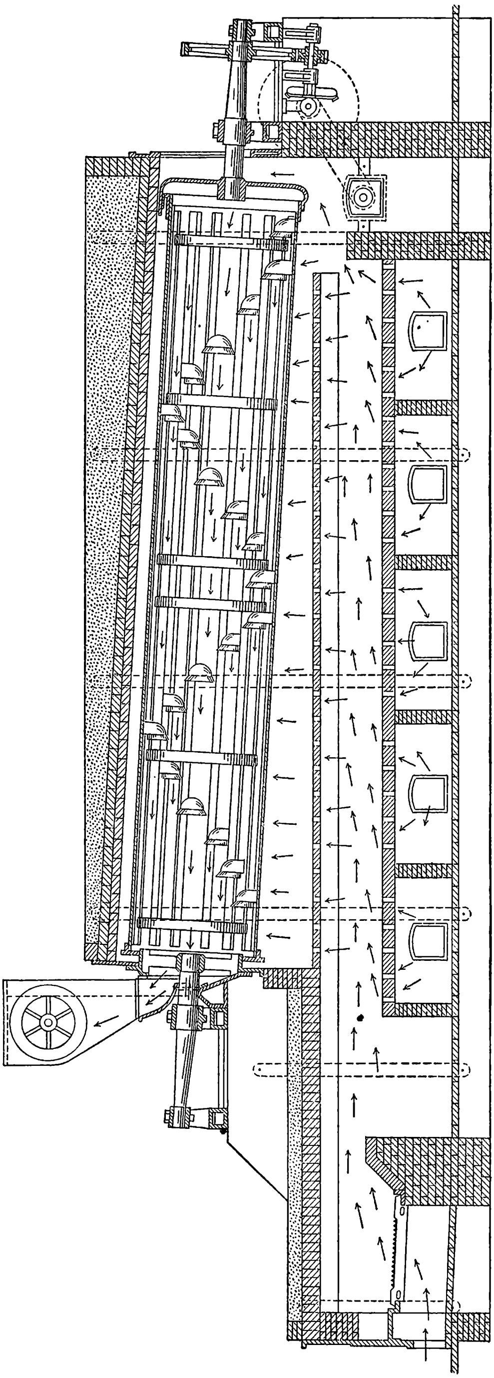
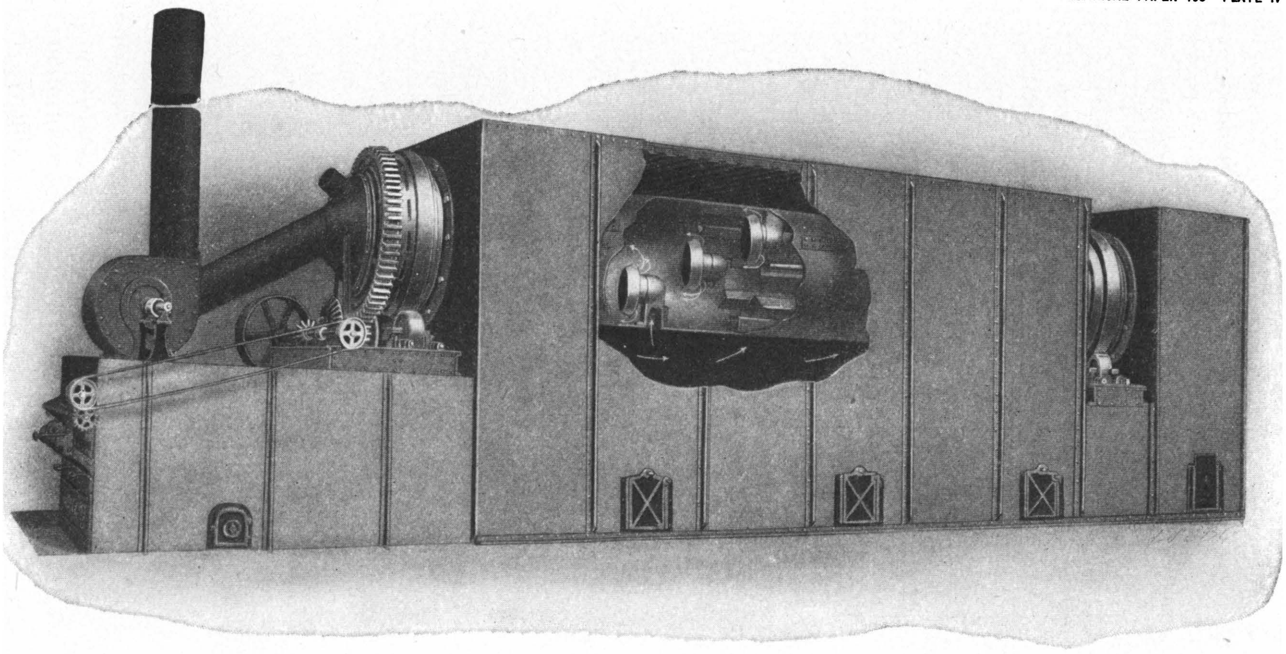


FIGURE 6.—Cummer calciner, side elevation.

Longitudinal shelves or lifting blades inside the cylinder and running its entire length keep the gypsum constantly cascading. About 10 minutes is required for passage through the calciner. A recording thermometer in the discharge spout registers the temperature of the gypsum as it leaves the calciner. By watching the dial of this thermometer the operator endeavors to keep the rock uniformly heated. The furnace is stoked automatically, and the operator regulates the heat by the dampers admitting air to the mixing chamber.

Another essential feature of the Cummer continuous process (fig. 7) is the cooling bins, of which there are four. Gypsum passing through the calciner, which is kept at a temperature of 400 to



ROTARY CALCINER.

600° F., is not wholly cooked when discharged, but is still steaming. To complete the process four brick-lined bins are provided for each cylinder. A screw conveyor discharges the hot gypsum into these bins, where it remains about 36 hours. Outside air being excluded and the lining being made of nonabsorbing brick, calcination goes on in the bin by the heat of the material, equalizing itself throughout the mass. Free moisture, not driven off in the cylinder, together with more of the water of crystallization, is removed by the cooking in the bin. Thus any small variation in the amount of calcination

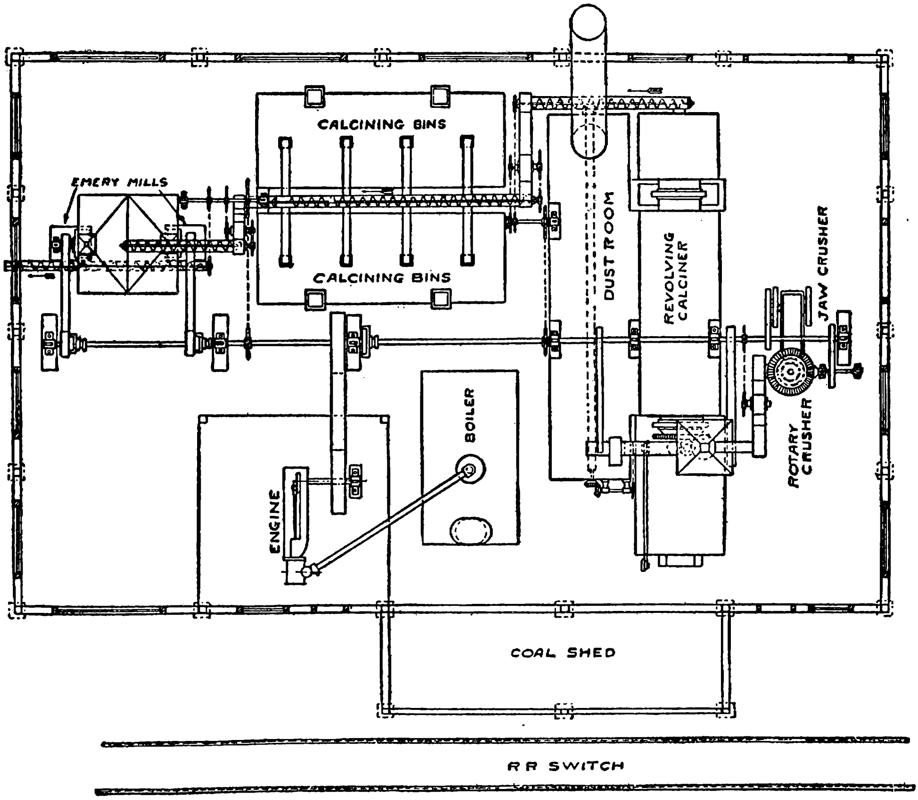


FIGURE 7.—Plan for Cummer-process gypsum mill.

within the cylinder during the day's run is equalized. The use of four bins makes the process continuous, for while one is being filled calcination is being completed in the second and third and the fourth is being emptied.

In 1917 a gypsum company that previously used kettles only put into operation two rotary calciners, each 70 feet long, such as are used in making Portland cement. The increased time that the gypsum is exposed to heat in the calciner completes the cooking and makes unnecessary the bins described above as essential to the Cummer process. A saving in power is brought about by much less being required to turn the rotary calciner than to drive the stirring arms in large kettles and by the rock not being pulverized until after it is calcined.

Gypsum dust fed into the cylinder or made there by cascading the rock from the longitudinal shelves is calcined by the high temperature and drawn out the upper end of the cylinder by the suction fan. It is deposited in a dust chamber, where it is collected by a hopper bottom and used for the fine grades of plasters, such as dental and molding plaster.

STATIONARY KILNS.

At a few places in the United States stationary kilns are used for calcining gypsum. There are various forms of such kilns, but the one commonly used in the gypsum industry is a low dome with a flat floor, resting on a low cylindrical base. The base has several doors, each opening into a separate furnace. The tops of the compartments make the floor of the single calcining chamber in the dome. The kiln is about 30 feet in diameter, 16 feet high, and built of brick. It is very similar in shape to a beehive coke oven, but is of the down-draft type. The heat from the fires, which may be of coal, oil, or wood, is conducted first to the top of the kiln chamber by means of flues on the inner wall of the kiln and then down through the gypsum. The heat is carried off through flues in the bottom of the kiln by an underground conduit to the stack, which may serve several kilns.

Rock gypsum in lumps several inches in diameter is placed in the calcining chamber and cooked at a white heat for three days. After calcining the lumps are crushed, ground, screened, and pulverized. This type of kiln is used for making Keenes cement.

BAFFLE-PLATE FURNACE.

In 1915, near Almogordo, N. Mex., gypsum sand accumulated in dunes was calcined in a baffle-plate furnace, a stack with overlapping, sloping shelves. Material dumped on the top shelf slides from it to the second shelf, which is on the opposite side of the stack and slopes in the opposite direction. From there it slides to the third shelf and so on down to the bottom shelf, which may discharge outside of the stack. The rate of movement is regulated by the slope of the shelves, and heat is commonly supplied by a wood fire at the bottom of the stack. It is questioned whether a uniformly calcined product can be made by this process with a reasonable expenditure of energy. The main difficulty would seem to be the maintenance of a proper degree of heat.

REGRINDING AND SCREENING.

Calcined gypsum made by the kettle process is finely pulverized before calcining, and after cooling is passed through screens to remove foreign material and any lumps formed during the process. Various types of screens are employed, including the rotary and shaking types and the inertia classifier. A machine in common use called the Newaygo screen consists of a highly inclined screen tightly enveloped in metal sheeting to prevent escape of dust, and jarred by many small hammers automatically tripped on the upper surface of the cover. The material passing the screens is conveyed to storage bins and the oversize is reground in one of the types of pulverizer previously described, usually a small burr mill.

Gypsum calcined by the Cummer process is not ground fine until after calcining. After removal from the calcining and cooling bins it is pulverized in burr or other mills, screened as described above, and the oversize reground. After grinding and screening, the material is conveyed to storage bins in the upper part of the mixing end of the mill.

The result of all these operations is a finely pulverized calcined rock called plaster of Paris or stucco. The plaster will consist of calcium sulphate plus a small residue of water, the amount of water depending on the degree of calcination. The ideal composition of plaster of Paris is represented by the formula $CaSO_4 . \frac{1}{2}H_2O$, which calls for 93.8 per cent of calcium sulphate and 6.2 per cent of water. High-grade plaster of Paris approaches these percentages and finds special uses, but most gypsum plasters contain an appreciable proportion of impurities, due to clay, lime, and other foreign matter in the raw material.

MIXING.

Plaster of Paris when mixed with water will set or harden. This is the principal characteristic that gives gypsum its economic importance. Unless setting can be controlled, the length of time required for the initial set determines the adaptability of plaster to various uses. Pure plaster of Paris of normal (80 to 90 per cent passing 100 mesh) fineness starts to set in six to ten minutes. Impure plaster may require an hour to harden. Therefore in preparing gypsum plaster for the market retarders or accelerators are added to fit it for special uses.

From storage bins the cool calcined plaster is drawn by gravity through chutes to the hopper of a mixing machine (fig. 8). This machine, usually installed on the first or shipping floor of the mill, consists of three parts—at the top a hopper opening in the floor above, in the middle a mixing chamber in which are paddles revolving in opposite directions, and below this a sacking chamber with several chutes for filling a number of sacks or bags simultaneously. A mixer has a capacity of 1,000 to 2,400 pounds per charge. When the charge of plaster has been run into the hopper the proper quantity of accelerator or retarder and hair, wood fiber, or sand is added. The operator pulls a lever that empties the charge into the mixing chamber. The stirring paddles cause movements in opposite direc-

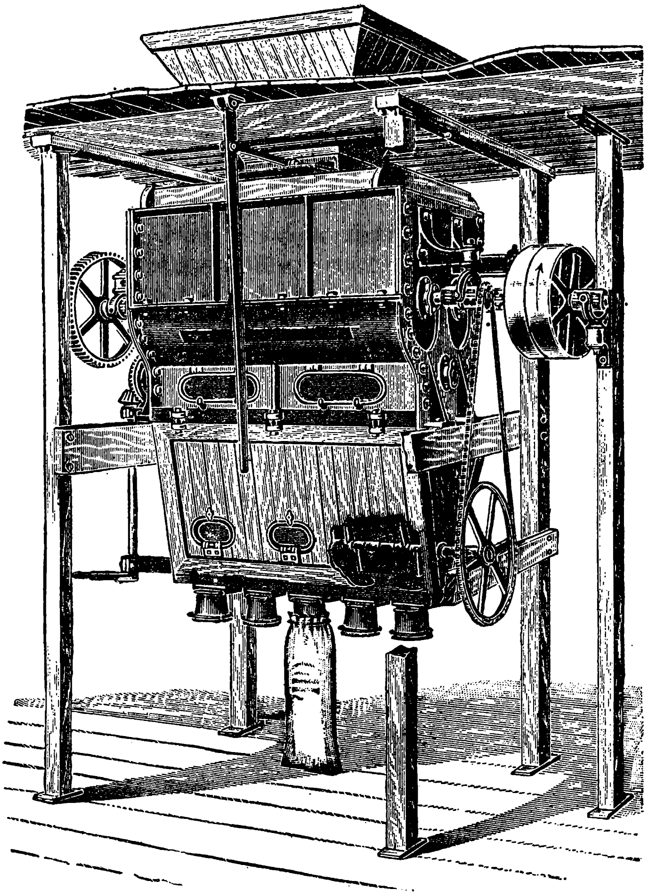


FIGURE 8.—Mixing machine.

tions, and the mix is completed in two to four minutes. During mixing the hopper is recharged by a man on the floor above, so that the operation is practically continuous. The sackers adjust bags to the discharge chutes and empty the plaster from the mixing chamber into the sacking chamber, where it is kept from clogging by an agitator. At some plants sacking is done by a device that automatically weighs the plaster and stops the discharge. Sacks may be fastened at the neck by hand with a simple wiring device, or they may be furnished to the sackers securely fastened at the neck and be filled through a valve in the bottom which closes tight when the filled sack is upended.

MATERIALS ADDED TO THE CALCINED GYPSUM.

In order to control the time of setting, or give strength or volume, various materials are added to the calcined plaster. These materials are called retarders, accelerators, and fillers, and are added to the cool ground plaster in the hopper of the mixing machine.

RETARDERS.

Plaster of Paris sets so quickly that for some uses, in order to insure sufficient time for mixing and placing in position, a retarder must be added. Several materials, most of them organic, are or may be used for this purpose, such as glue, glycerin, flour, blood, and sugar. The retarder commonly used in the United States and Canada is manufactured from low grades of hair, caustic soda, and lime. Caustic soda is used to reduce the hair to glue, and lime is used as a drier of the glue solution. Formerly most of the retarder used in this country was made from slaughterhouse tankage.

The action of these retarders seems to be mechanical; that is, they hinder crystallization of the plaster by decreasing its solubility and thus prolonging the period of hydration. Plaster made from gypsite is less pure, containing organic matter that acts as retarder, and therefore sets slower and requires the addition of less retarder. Practically all gypsum wall plaster is retarded so that when mixed with two parts of sand by weight it will set in about two hours. The quantity of retarder added to a ton of plaster is a trade secret with each manufacturer, but is said to vary from 2 to 15 pounds a ton, depending on the kind of retarder used and the time of set desired.

ACCELERATORS.

For some special purposes, as in dental work, a very quick set is desired. This is accomplished by adding alum or other inorganic salt to the fine white plaster. The time of setting can thus be reduced from six to three minutes. The set of a slow-setting plaster made from gypsite is sometimes accelerated by the addition of salts, including common salt. Common salt, however, takes up moisture and may result in rusting metal lath. Plaster of Paris that has been stirred constantly while setting, then dried and reground, is used as accelerator, as also may be any gypsum plaster that has set and been reground.

FILLERS.

In the making of gypsum wall plaster it is customary to add various materials, including sand, cut wood fiber, hydrated lime, and hair, so that the finished product as furnished to the trade needs only the addition of water to be ready for use. Hair used by gypsum mills is either cattle or goat hair and comes compressed in large bales. It is loosened or picked to pieces by machine so that it will be evenly distributed through the plaster by the mixer. The presence of hair in mortar has a beneficial effect in holding wet plaster together and thus preventing waste behind the lathing in the keys of the base or scratch coat. Its presence is necessary, therefore, only in this coat. How much it strengthens the set plaster may be surmised from the fact that only 3 to 5 pounds of hair are used to a ton of plaster. Sisal, or manila fiber, is used in place of hair by some manufacturers. Wood fiber is made from any nonstaining wood, such as cottonwood, basswood, etc., in a machine especially designed for the purpose. Wood fiber toughens plaster and lightens the weight. Wood fiber plaster is used where local sand is unsuitable and also where light weight, sound deadening, and heat insulation are desired. Wood fiber as used in plaster and in plaster blocks has no injurious effect on the fire-resisting quality, because, each fiber being thoroughly embedded in plaster, the wood only chars in case of fire exposure. The quantity of cut wood fiber used varies according to the quality of the plaster and the practice of the mill, but is generally about 20 to 50 pounds of fiber to a ton of plaster.

Sand is added to some plasters at the mill to meet the convenience of the trade. Mill mixing gives precision to the mixture and provides a consumer who lacks proper sand with a plaster that needs only the addition of water to be ready for use. Sand is dried at the mill before mixing in some such way as elevating by bucket conveyor and spilling into the top of a tall vertical stack or cylinder lined with baffle plates and heated by a fire at the base. The sand cascades from shelf to shelf as it falls through the drier and is carried from the bottom to storage bins in the mixing mill. The rotary drier is used for the same purpose, the sand passing through the heated rotating cylinder being lifted by angle irons and falling repeatedly through a current of hot air.

STORAGE.

Gypsum plaster is packed, stored, and shipped in barrels (gross weight 250 and 320 pounds), jute and cotton sacks (100 pounds), and paper bags (80 pounds).

Storage must be in warehouses where the humidity is low. Packages usually carry printed directions regarding use of the plaster.

There are many brands, some manufacturers having 50 or more. The same grade or brand of plaster may be given several different names, to indicate the mill in which made.

ARRANGEMENT OF PLASTER MILLS.

Gypsum mills are arranged in several ways. At some plants all operations are conducted under one roof; at others each department is in a separate building (see Pl. V). The most compact type of mill is a nearly square building with all departments under one roof. Another type is a single building, narrow and several hundred feet long, with crushers at one end and warehouse at the other end. A number of the larger mills house the departments in separate buildings connected by overhead inclosed bridges or simply by conveyor tubes. These buildings may inclose (1) power plant; (2) crushing, drying, and grinding plant; (3) calcining; (4) screening, regrinding, mixing, and sacking; (5) plaster board; (6) tile and block plant.

In general the rock is received at that end of the mill where the crusher and the power plant are situated; the grinding and calcining department is in the middle of the building; and the mixing, sacking, and storage rooms are in the other end. Figure 9 shows the plan and cross section of a four-kettle gypsum mill.

Local conditions cause considerable variations in the details of arrangement. In some mills the crusher is on the ground floor at the end of the mill nearest the quarry, and the cracker is in an excavation directly below the crusher. (See Pl. VI.) In other mills, especially those at a lower elevation than the quarry, the crusher is on the second floor and the cracker is below it on the first floor. This arrangement is used by a number of mills using rock from underground mines. The kettles, hot pit, power plant, sacking and storage rooms are also on the ground floor. The second floor is occupied by the tops of the kettles, by the burr mills for grinding and regrinding, and by the charging hopper of the mixing machine. Storage bins for the burr mills, kettles, and mixer occupy the third floor. The making of plaster board and gypsum blocks or tile may be done in a separate building.

COST OF GYPSUM MINE AND MILL.

Several factors make considerable variation in the cost of a gypsum mill of given capacity. These include type of mill, availability and kind of building material, labor conditions, and transportation facilities. With each mill there must be mine development and equipment, including drills, tracks, cars, motive power, and office equipment.

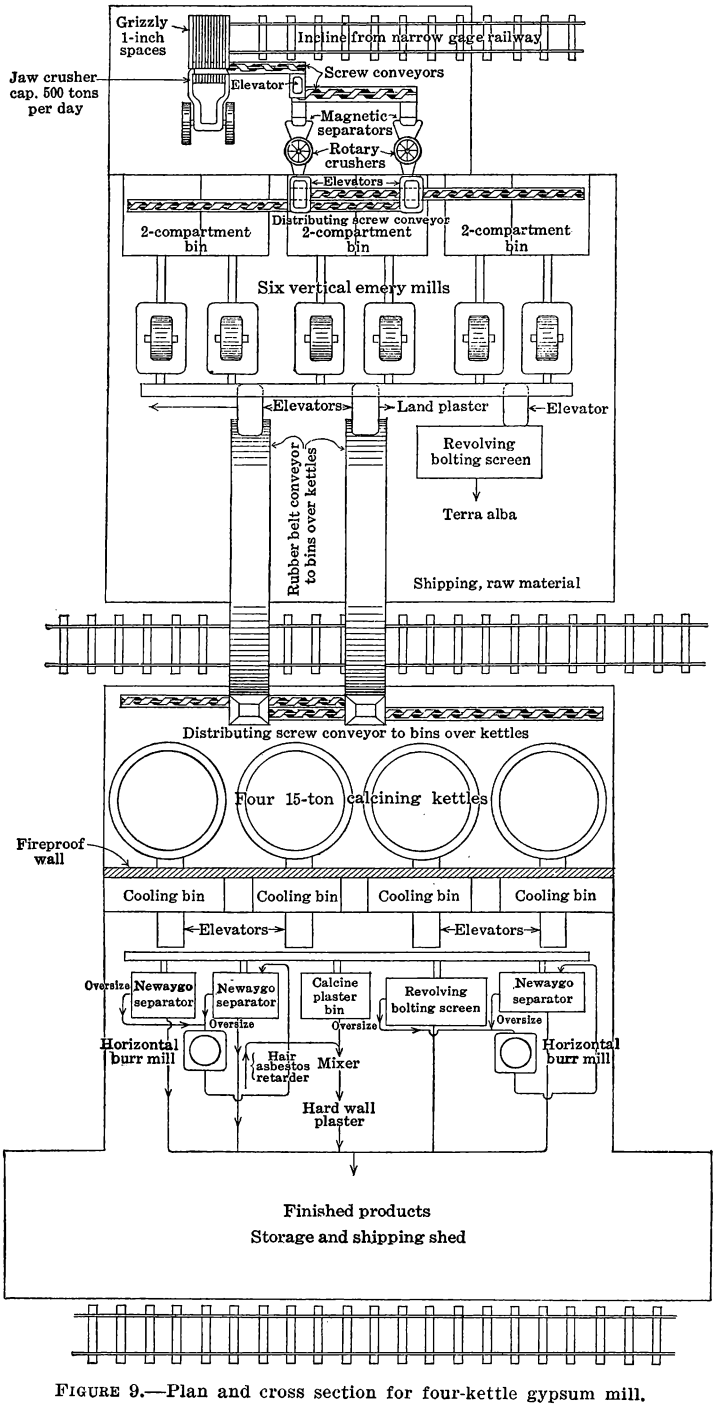
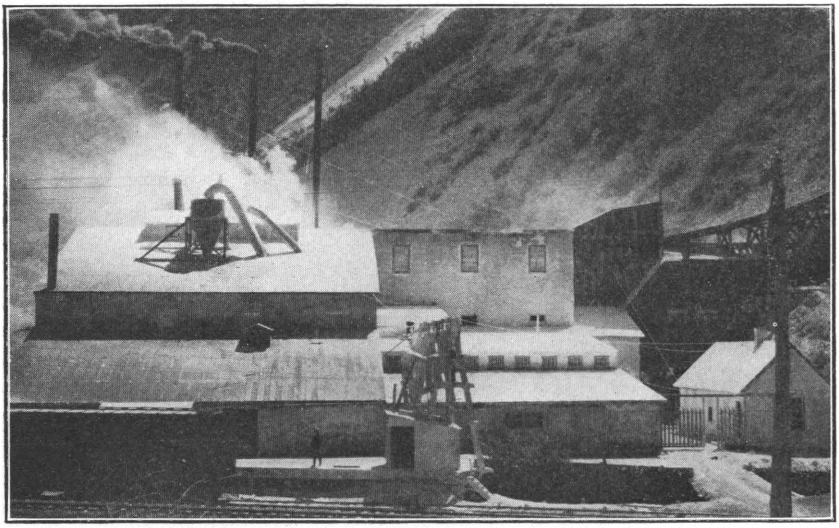
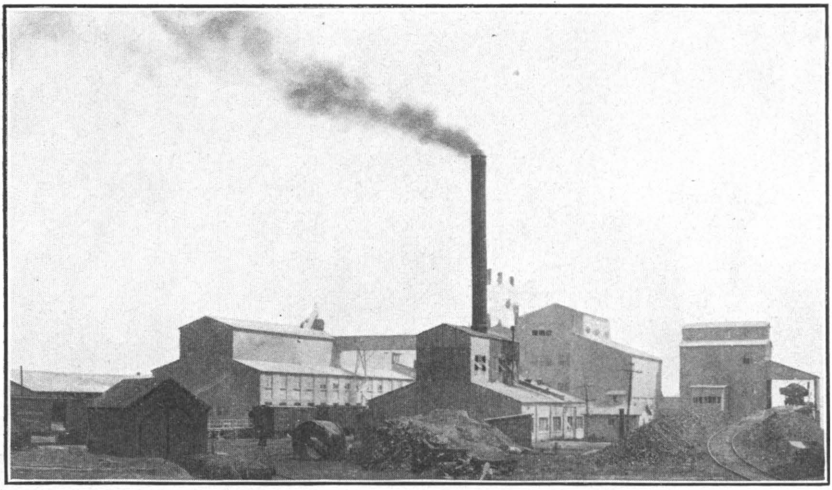


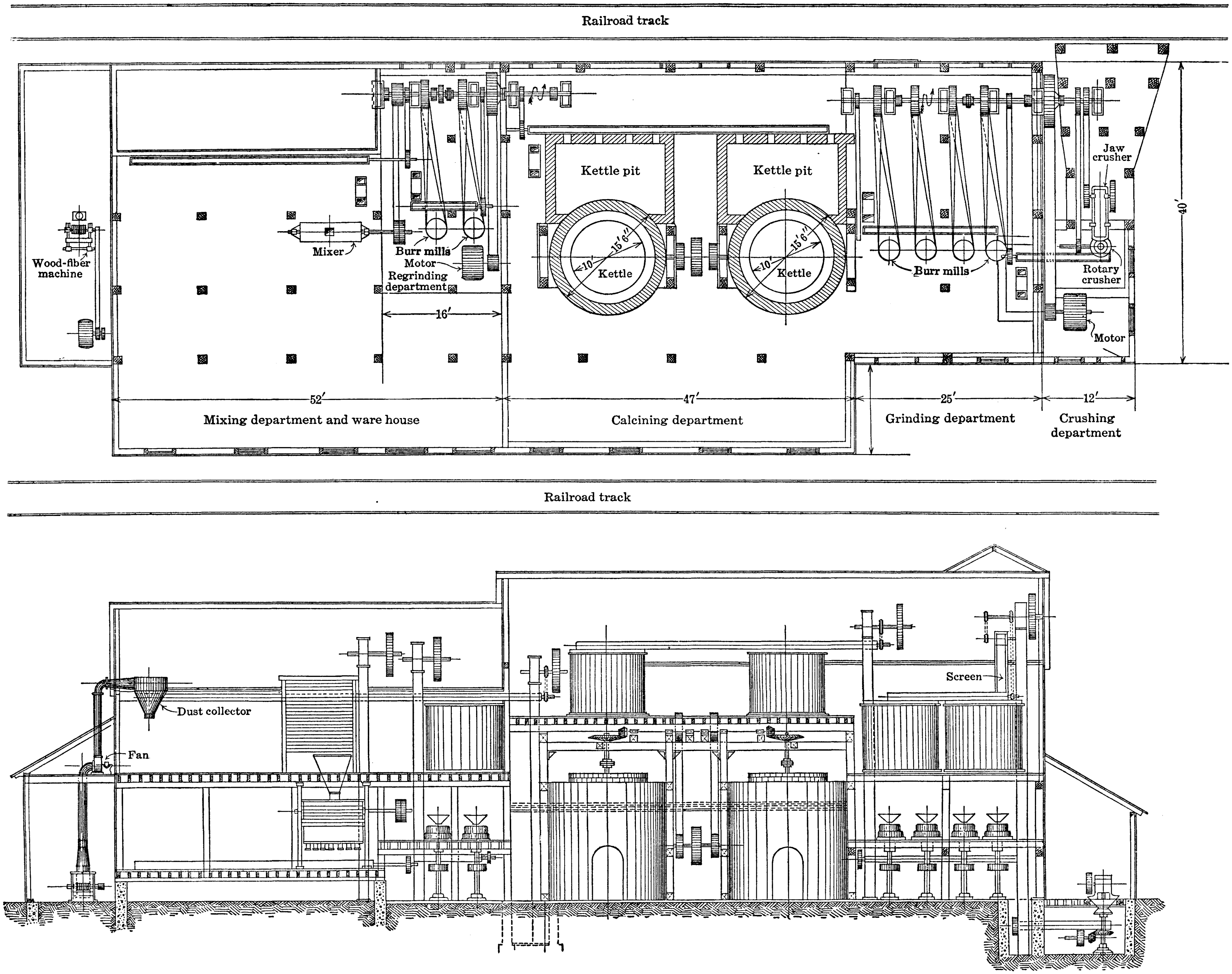
FIGURE 9.—Plan and cross section for four-kettle gypsum mill.



A. GYPSUM PLASTER MILL, NEPHI, UTAH. COMPACT TYPE, ALL UNDER ONE ROOF. RAW MATERIAL ENTERS FROM HILLSIDE TRAM, FINISHED PRODUCT LEAVES LOADING PLATFORM IN FOREGROUND.



B. GYPSUM PLASTER MILL, ALABASTER, MICH. SHOWS POWER PLANT IN CENTER, CRUSHING PLANT AT RIGHT, CALCINING PLANT WITH SEVERAL SMOKESTACKS, AND MIXING PLANT AND WAREHOUSE AT LEFT.



PLAN AND CROSS SECTION FOR TWO-KETTLE GYPSUM MILL.

Estimates of approximate cost of plaster mills, wood construction, including necessary mills, kettles, conveyors, building, and bins complete, with necessary mine development and equipment, are as follows:

Capacity 25 tons in 24 hours, 60-horsepower steam plant____	$15,000 to $25,000
Capacity 100 tons in 24 hours, 150-horsepower steam plant__	$50,000 to $75,000

A mill of steel construction, fireproof throughout, having a capacity of 200 tons in 24 hours and requiring a 300-horsepower plant will cost, complete, with mine development and equipment, $125,000 to $150,000.

COST OF PRODUCING AND MARKETING GYPSUM PLASTER.

When asked, in June, 1916, how much it costs to produce and sell a ton of calcined gypsum, one of the large gypsum companies replied, "It varies from $2.50 to $4 or more a ton." In reply to the same question another company which has mills in several States said, "It varies from about $2.75 a ton for a big mill running at full capacity to about $4 a ton for a smaller mill working less advantageously." These figures are for plaster of Paris or stucco, in 1915, and not for gypsum wall plaster ready for use. The statements were verified by cost sheets shown to the writer by each company. In 1916 and 1917 the costs were much higher.

For the information of those who are not familiar with the gypsum business some explanation of the wide variation in cost is desirable. The cost varies in different localities, and at the same mill in different months, because of differences in labor conditions, capacity of plant, tonnage produced, fluctuations in demand, and other vital factors. It should be borne in mind that the output during the winter is always small, because of the general decrease in building operations. It is said that no gypsum company does business at a profit in January and February, and it is certain that some show a loss in those months. Very little if any money is made by gypsum producers in December and March. Expenses continue during the winter months and make the cost of production high for that part of the year.

Costs may be divided, for the purposes of this discussion, under the following heads: Mining, milling, shrinkage, fuel, repair and supplies, and overhead charges.

MINING.

Mining costs include labor, explosives, haulage to mill, pumping water from mine, royalty, and equivalent items. There is a wide range in the cost of mining. Quarrying costs less than underground mining. The company that obtains its rock gypsum from an open cut and delivers it by gravity to the mill is at less initial expense than the company that mines underground, hoists the rock to the surface, and pumps a million or more gallons of water daily to keep the mine from flooding. Gypsite is dug at small expense with horse scrapers, but it is expensive to calcine.

MILLING.

Milling includes labor and power for crushing, drying, grinding, calcining, and sacking. Variations in output cause large fluctuations in these costs. A mill running at full capacity can make plaster at a lower cost per ton than a mill that is idle part of the time. Full capacity can not be maintained throughout the year because of shortage of orders in the winter months, delays due to repairs, and other uncontrollable conditions. Gypsite costs more to calcine than rock gypsum because more power is needed to agitate in the kettle and cooking takes nearly twice as long, thereby requiring more fuel.

SHRINKAGE.

Shrinkage from quarry to warehouse is heavy, amounting to about 20 per cent. One hundred tons of rock make only 80 tons of plaster. This shrinkage is due to free moisture in the rock driven off in drying, water of crystallization removed in calcining, dust floated off with steam from the kettles, and loss from bucket, belt, and screw conveyors in the mill.

FUEL.

The fuel cost covers only the fuel used in drying and calcining. It does not include fuel used for power, which is figured in milling costs. The cost of fuel per ton of plaster varies not only with the initial cost of this item, but with the condition of the rock, which affects the amount of heat required for calcining, and it varies with the skill of the firemen.

REPAIRS AND SUPPLIES.

Repairs and supplies include necessary alterations to machines and buildings, waste, lubricant, sacks, and other items. Variation in this item as between different companies, is accounted for in part at least by differences in accounting methods.

OVERHEAD CHARGES.

Overhead charges, which include administration and selling, are about 25 per cent of the whole cost, but vary considerably. The season of the year affects demand, the volume of sales and consequently selling costs; so do the reputation of a company and the popularity of its brands of plaster. For the first few years, or until its reputation is established and a demand is created for its products, a new company may have selling costs 50 to 100 per cent greater than any given below.

COSTS.

In presenting the figures given below the writer points out that averages may be misleading, but he hopes that they may prove suggestive at least. The figures given by each company are based on costs at mills in several different States. Neither of the companies that furnished the figures in the following table knew what the other had given. One company assumed an average cost of $3 per ton and divided that into its component parts on a basis of the percentage of each item to the whole cost. The other company followed the opposite plan, giving maximum and minimum costs of various operations and thus arriving at the total cost per ton. The figures in the third column of the table were furnished by a separate company and are not based on figures in the other two columns.

Cost of producing and selling calcined gypsum or stucco in 1915.

Item.	Minimum.	Maximum.	Average.
Mining	$0.52	$1.10	$0.65
Milling	.80	1.25	.85
Shrinkage	.13	.22	.15
Fuel	.25	.35	.50
Repairs and supplies	.30	.40	.25
Overhead	.95	1.25	.60
Total cost per ton	2.95	4.57	3.00

These figures are for the year 1915 and for plaster of Paris or stucco only. Cement plaster (see p. 41) costs 50 to 75 cents more a ton for fiber, retarder, package, fasteners, tags, etc. On account of the demands of labor for higher wages and the increased cost of all supplies entering into the manufacture of gypsum plaster, the cost in 1916 and subsequent years may be 20 to 35 per cent higher than these figures.

A third company, which has only one quarry and mill, but produces with exceptional economy, because of long experience and unusually advantageous conditions, has furnished the figures given below. Probably no other company now operating in the United States can produce gypsum plaster as cheaply, so the figures are given not as representative costs for the guidance of those who may be considering the manufacture of gypsum plaster, but as an example of the way the costs of an old-established company may vary within 12 months.

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Variation in cost of producing and selling calcined gypsum or stucco.

Item.	May, 1914.	March,1915.
Mining	$0.30	$0.39
Milling	.36	.38
Fuel	.16	.22
Repairs and supplies	.56	1.07
Overhead	.40	1.37
Total cost per ton	1.78	3.43

This company's low cost of mining results from a combination of quarrying and underground work and the moving of rock to the mill by gravity. Milling costs are low, because power is furnished by a turbine driven by privately owned water power. The item for repairs in March is high because of unusual rebuilding, and the overhead charges were excessive by reason of the small tonnage produced. The company reports that for the years 1911–1915 the average cost of producing a ton of unfibered, unretarded calcined plaster was $2.64.

In concluding this discussion of costs it may be asserted with some assurance that probably as much money has been lost in ill-advised ventures in the gypsum industry as has been made in it during the past 20 years.

GYPSUM PRODUCTS AND THEIR USES.

Gypsum is marketed in both the raw and the calcined condition. (See fig. 10.)

The quantity that is calcined is about four times as great as that sold without calcining, and the ratio is likely to increase with the expansion of the industry.

UNCALCINED, GROUND GYPSUM.

Gypsum that has been crushed or pulverized, but not cooked, is used principally for retarder in Portland cement, for land plaster, and in paints. It goes under various names, that sold for fertilizer being called land plaster, and that which is very fine and white being called terra alba.

RETARDER IN PORTLAND CEMENT.

About 400,000 tons of raw gypsum is used annually in the United States as an ingredient in Portland cement. Pure Portland cement sets in a few minutes, so that the addition of a substance to delay setting is usually necessary. Gypsum is used as the retarder. Either raw or calcined gypsum may be used, and cement manufacturers naturally employ the cheaper raw material. As the retarding effect is

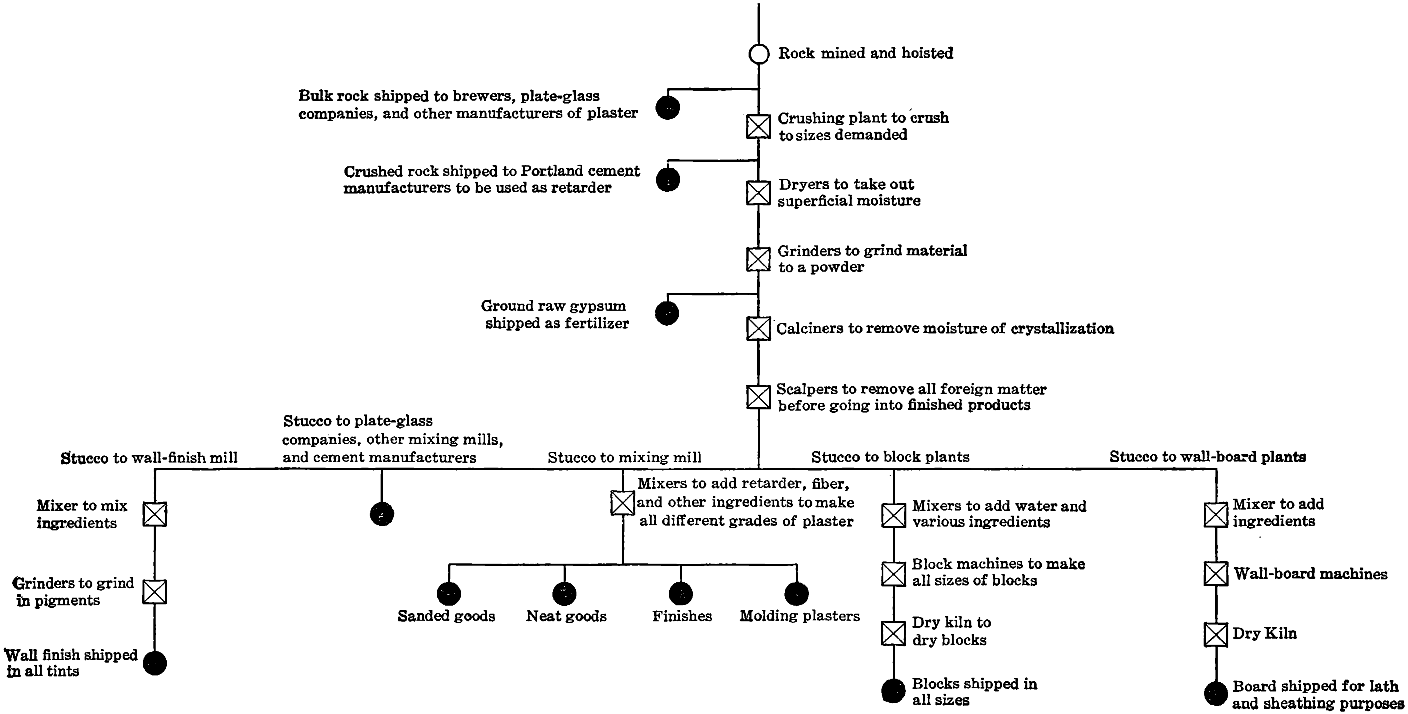


FIGURE 10.—Flow sheet of gypsum products plant.

due to the sulphur trioxide, a like result is produced by a smaller quantity of calcined than of raw gypsum. The cost of raw gypsum is only little more than one-half that of calcined gypsum, so the former is preferred. Raw gypsum crushed to about one-half inch ring is added in proportions of 2 to 2½ per cent to the cement clinker as it comes from the roaster and before it is ground. If calcined gypsum is used, it is added to the ground cement. Contracts for gypsum by cement mills are usually based on a minimum percentage of sulphur trioxide in the gypsum.

BASE FOR PORTLAND CEMENT.

Patents have been issued covering processes that employ gypsum as a substitute for limestone in Portland cement, with the idea of saving the sulphur content of the gypsum as a by-product. The sulphur trioxide driven off could be utilized in making sulphuric acid. Either a technologic or an economic difficulty must be overcome, for no commercial attempts to apply the process have been made. Probably the difficulty is that of cost, for calcium derived from gypsum doubtless would cost more than limestone, and the sulphur would probably be obtained as hydrogen sulphide.

LAND PLASTER OR FERTILIZER.

One of the first uses, and for many years the principal use, of gypsum in this country was as land plaster. The output of other gypsum products has far outstripped it, however, and the quantity of raw gypsum now used annually for land plaster, about 50,000 tons, is only a small percentage of the whole product. Raw ground gypsum applied to some soils as a fertilizer has a very beneficial effect on some crops, especially clover and other legumes. The action of gypsum as a fertilizer is indirect and not as a food for plants. It is supposed to act on the double silicate of magnesia and potash in the soil, freeing magnesia and potash for plant food. The necessary elements must first be present in the soil to obtain any beneficial result. In other words, the application of gypsum to some soils would be ill advised.

Land plaster, some authorities claim, tends to make nonporous clay soils more pervious to water and to make sandy soils less so. Another characteristic of ground gypsum is that it has an affinity for water and will draw moisture from the atmosphere. This quality is a great factor in keeping moisture in the soil and is of value to the farmer in starting grain and grass crops, as it holds moisture where the roots of the small plants most need it. The application of ground gypsum or land plaster in a dry, hot season will in many cases draw the necessary moisture from the atmosphere to save a crop from being damaged by drought. It is commonly used in the cultivation of peanuts to insure a crop.

Raw gypsum, or land plaster, if applied freely on manure piles and stable floors, acts as an absorbent that retains the ammonia which is the valuable product of the barnyard and manure heap. Three or four pounds of powdered gypsum per animal per day scattered on the stable litter will unite with the nitrogen of the manure to form ammonium sulphate. In this form the ammonia is easily available as plant food; it is not given off into the air nor is it readily washed from the manure heap by rain, but is saved until the manure is spread on the land. The claim is made that the gypsum seems to cause the potash and phosphates to be retained in the manure, and that the gypsum itself has no bad effect on the soil, as it is probably converted in part, at least, to lime carbonate in the manure.

Land plaster may be applied to the soil by drilling or may be sowed broadcast. When applied in this manner it should be used at the rate of 200 to 500 pounds per acre.

Land plaster is employed to neutralize the black alkali that forms in many of the soils of arid regions.

CRAYONS.

The common blackboard or school crayon known as chalk is made of finely pulverized, uncalcined gypsum. Ingredients added to the gypsum include a binder, and for colored crayons a pigment. The mixture is molded into the required shape under pressure.

SULPHURIC ACID.

Patents have been issued covering the extraction of sulphuric acid from gypsum, but commercial success has not been attained. Among the schemes may be mentioned (1) passing steam over red-hot gypsum, it being supposed that SO_2, O, and SO_3 would be liberated, leaving CaO behind; (2) passing HCl gas through a red-hot mixture of gypsum and coal, forming $CaCl_2$, CO, H_2S, and S; and (3) subjecting molten gypsum to an electric current and an excess of free oxygen, thus forming sulphuric dioxide, which could be conveyed into lead chambers and converted into sulphuric acid in the usual way.

FLUX.

Gypsum is added as flux to galena concentrate in the Carmichael-Bradford blast-roasting process of reducing lead ore, a process patented in the United States in 1902, but used only at a smelter in New South Wales. Gypsum is used as flux in the concentration of lead-copper matte in reverberatory furnaces in Germany. In the smelting of certain nickel ores in New Caledonia, gypsum furnishes the sulphur necessary for collecting the metal into a matte and also acts as a base to counteract and slag the siliceous gangue. The use of calcined gypsum in copper smelting is mentioned on page 40.

BREWING.

Ground gypsum is sometimes added to the water used for brewing, as it increases the solubility of the albuminous matter in the malt.

TERRA ALBA.

Terra alba is very white rock gypsum ground to pass a 200-mesh screen. It is the same as fine white land plaster. The whitest gypsum is used for making terra alba, alabaster from New Brunswick being an example. Lumps of this rock are scrubbed and rinsed with water, dried, ground, and bolted through silk. Terra alba is used principally as a filler in paper and paint.

MINOR USES.

Finely ground very white raw gypsum is sometimes used as a filler for cotton cloth; and it is used in nearly all the finer grade papers, especially in writing and printing papers. Its function is to close up the pores and enable the paper to take a better finish. Other uses to which raw gypsum is put are as a base for paint, for mixing with Paris green or other insecticide, as a drug, and in chemical work. It has been used as an adulterant in flour, sugar, baking powder, etc. Mixed with a pure grade of wheat flour it makes what is known as Corine flour, used to dust molds for metal castings in foundries.

RAW GYPSUM, UNGROUND.

Large quantities of fine-grained semitranslucent rock gypsum or alabaster quarried in large blocks are used in Europe by sculptors for statuary and other forms of decoration.

At a few places in the arid regions of the southwestern United States gypsum has been quarried in blocks and used for the walls of buildings. Under favorable climatic conditions such walls may remain secure for many years. At a few places in this same region, gypsum is used successfully as road material.

CALCINED GYPSUM.

Gypsum partly dehydrated, or calcined, and pulverized is called plaster of Paris or stucco. Calcined gypsum as it comes from the pulverizers is put to many uses, and by the addition of other substances to control the time of setting and plasticity, its range of usefulness is greatly increased. Calcined gypsum to which no foreign substance has been added, either before or after calcining, is employed in many ways, the more important of which are mentioned here.

USED WITH ADDITION OF WATER ONLY.

PLATE-GLASS BEDS.

Thousands of tons of calcined gypsum are used annually in the plate-glass industry for bedding the glass during the grinding and polishing process. The plaster must be finely pulverized and free from grit, so that it will not scratch the surface of the glass imbedded in it. The rough plate of heavy glass ready for polishing is placed on a circular table, which has been covered with plaster of Paris. The plate settles in the paste, which, as it sets, makes a firm support and frees the glass from strain. Polish having been given to one side, the plaster is broken away from the edges, the plate removed, the table cleaned, and a fresh bed of plaster laid. The plate is then replaced, polished side down, and the other side is polished. For this second bedding only fresh plaster is used. In some glass factories the set plaster scraped from the table is recalcined and mixed with fresh plaster to make the bed for the rough side.

POTTERY AND TERRA COTTA MOLDS.

Manufacturers of pottery and architectural terra cotta use large quantities of plaster of Paris in making molds for their designs. Such molds are especially suitable, because their porosity permits proper absorption of moisture from the clay. They have strength with light weight, are easily made, and not expensive.

STATUARY AND OTHER ART WORK.

The familiar and abundant small pieces of statuary, busts, panels, etc., which can be bought at prices ranging from a fraction of a dollar up, are made of plaster of Paris, as are also the large replicas of Greek statuary and architecture commonly seen in art museums. Reproductions of modeling done in clay or other material are made by first taking a negative mold from the original in plaster of Paris. Relief maps and models for various scientific purposes are so made, and will serve to illustrate the process. A relief map is first built up and modeled in clay or some other plastic material. It is surrounded by a frame, coated with linseed or other oil, and covered with a thin paste made of plaster of Paris and water. When the plaster has set, it is removed from the model and the face of the mold is coated with shellac or some other nonabsorbent material. A reproduction of the original can then be made by oiling the mold and filling it with plaster. A tendency on the part of plaster of Paris to expand as it sets insures reproduction of the finest details in the mold. Many casts can be made from a single mold.

COPPER SMELTING.

Gypsum plaster is used at some copper smelters as a binder for concentrates and flue dust. It is mixed with the flue dust and sacked. The plaster sets, making the contents of the sack a solid block, which is sent to the furnace for recovering the values originally carried away in the flue dust.

MOLDS FOR RUBBER STAMPS.

On account of the fact that it will take and preserve sharp imprints, plaster of Paris is used in the making of rubber stamps. The letters to be reproduced are set in type and impressed in plaster, making a mold into which the melted rubber is poured.

FOUNDRY MOLDS.

Metal casting requires that the mold be porous as well as rigid and resistent to fusion. By reason of its porosity plaster of Paris is adapted for making molds for babbitt and other special castings.

SURGICAL CASTS AND ORTHOPEDIC BANDAGES.

Plaster of Paris is employed by surgeons for casts around broken limbs, etc., a special use that does not employ a large quantity of plaster annually, but for which there is no equally available and suitable substitute. The qualities that make the plaster valuable are that it is plastic, sets quickly, and makes a strong support. Furthermore, the cast is a nonconductor of heat, and is not affected by moisture.

Plaster of Paris is applied in orthopedic surgery by means of bandages. Open-mesh bandages of various widths are passed through a tray containing dry orthopedic plaster, which is made of fine and coarse particles to insure uniform filling of the meshes. This plaster is mixed over and through the bandage, which is then wound tight in advance of use. Before use the rolls are soaked in water for about two minutes; then the surgeon unrolls the plaster bandage and winds it firmly about the fractured, sprained, or deformed part, intermixing additional wet plaster where necessary. The result is a close knit, tough, strong splint.

MISCELLANEOUS USES.

Plaster of Paris is used in making the heads on parlor matches; is made into blocks on which hats are shaped; and gold, silver, and precious stones are set in it to be engraved or polished. Relief decorating for walls and ceilings, including moldings, cornices, and artistic designs in sprays, lattice, and spot work are made in this material. In taxidermy, for finishing the surface over which the skin is to be drawn, and in paleontology, for supplying missing parts and for imbedding fragile fossils so that they can be transported, plaster of Paris has its special uses. Another important use is in dentistry for making casts and models of jaws and teeth (see also p. 46). In making furnace and steam-pipe covering, asbestos packing, and gaskets, gypsum plaster is used.

USE WITH ADDITION OF OTHER MATERIAL.

GYPSUM PLASTERS.

The principal use of calcined gypsum, amounting to one and one-half million tons annually, is as wall plaster. Gypsum wall plasters are used in the ordinary manner for covering walls and ceilings, being spread on metal and wood lath, plaster board, and tile, on plaster previously spread for a base coat or directly upon concrete and other masonry surfaces. They are used also for decorative moldings, friezes, and panels. As gypsum plaster is a poor conductor of heat and cold, it is used as an insulating medium by being poured in plastic form into spaces provided in the construction of cold-storage buildings, for fire protection of steel frames of buildings by pouring it into forms surrounding the member to be covered, and for fire-stopping hollow spaces in combustible construction. All gypsum wall plasters, besides being wet with water, have other materials added to the calcined gypsum, either before sacking or just before wetting for use. These so-called "patent" plasters, of which there are many brands, may be classed in a general way in three groups: Gypsum cement plasters, wood fiber plasters, and prepared plasters.

Cement plaster.—Cement plaster is made of calcined gypsum, hair, retarder, and fillers that add "slip" or working qualities to the material. Cement plaster is neat and requires the addition of two to three parts of sand to make it workable. It is commonly used for the base coat.

Wood-fiber plaster.—Wood-fiber plaster differs from cement plaster in composition and use. Cut wood fiber is used instead of hair for binder, and as the plaster is designed for use generally without sand ingredients are added to overcome stickiness; in cement plaster the added sand takes care of this. Wood-fiber plaster is popular in localities where good sand is not obtainable economically and also for purposes that make lightness, toughness, and insulating qualities desirable.

Prepared or sanded plaster.—Prepared or sanded plaster is identical with the cement plaster described above, except that sand is added at the mill rather than at the place of use. The use of sanded plaster is not economical where freight rates amount to more than the value of the sand, as each ton of prepared plaster contains two parts, more or less, of sand to one of plaster. The advantages are uniformity and also elimination, when directions are followed, of the possibility of oversanding.

In addition, may be mentioned gypsum finishing plaster, to use with lime putty. Such a plaster is calcined gypsum, with or without retarder. Other finishing plasters are prepared to be used without lime putty.

Staff.—Staff is a gypsum plaster used in large quantity for the exterior surface of the temporary buildings of exhibitions. It is made of plaster of Paris toughened and reinforced with manila or other fiber. Sometimes in making staff a little cement, glycerin, and dextrin are added, the different compositions fitting the material for different uses, such as broad, flat surfaces of buildings; massive statuary; or for casting smaller art objects and decorative panels bearing finer details.

Gypsum plaster is used as mortar in setting gypsum tile, for setting and backing up marble construction and glazed-tile side walls, and for making artificial stone for decorative purposes. It is also used in the manufacture of certain modern building materials, including plaster board, tile for various purposes, and screeds.

GYPSUM PLASTER BOARD.

Gypsum plaster boards are thin sheets of gypsum plaster with a fibrous binding material, tough paper or wool felt, to give necessary strength and toughness. One type of plaster board in common use consists of four alternate layers of wool felt with three intermediate layers of gypsum. Other boards contain but two layers of felt or paper with a gypsum layer between, the nailing strength or toughness being obtained by mixing fine-cut wood fiber or similar material with the plaster. Two-ply wall board used as a substitute for lath and plaster is increasingly in demand for some types of construction.

Gypsum plaster board is made at only a few places in the United States. The machines are not on the market and are built by the companies using them. There are two kinds, the long, fast running, and the short, slow running. In both machines the method of making the board is the same, the difference being in the way opportunity is provided for the plaster to set before reaching the delivery end of the machine. A plaster-board machine is a belt conveyor onto which are fed alternately sheets of paper or wool felt and streams of gypsum plaster. The conveyor belt, which is about 3 feet wide, receives first a sheet of wool felt or tough paper fed continuously from a large roll. On this is spread a layer of wet gypsum plaster. These, with a second sheet of binding material from a roll suspended above, are fed between rollers that squeeze the plaster back and allow only a given thickness to pass between them. In making three and four ply board this operation is repeated the necessary number of times. The gypsum plaster is fed automatically onto a concave belt conveyor, wet with warm water, and stirred by mechanical stirrers, so that it spills onto the binding material in a steady stream. In some factories the plaster is mixed on the main belt by hand.

Long machines have a total length of 600 to 800 feet; short ones, of 20 to 80 feet. At a place in the long machine where the plaster begins to set the moving board is scored by a perforating device, so that at the delivery end it can be broken off readily; at the delivery end of the short machine there is a traveling circular saw or a knife which cuts the moving board off square.

The boards as delivered from the machine are damp and the plaster is not wholly set. They are loaded on trucks that pass slowly through a drying room, or each board is set in a light wooden frame hung on a slow-moving belt that carries it through a drier. The finished boards are stored in warehouses, as they must be kept dry.

In order to meet the joist and stud spacing of standard construction, plaster boards are usually 32 by 36 inches (8 square feet) and are made ¼, ⅜, and ½ inch in thickness. The thinnest board (¼ inch) weighs about 1½ pounds per square foot, while the thickest (½ inch) weighs about 2½ pounds per square foot. In special cases, plaster boards are made to a total thickness of 1 inch, and on special orders may be made any rectangular shape desired that is less than the standard size, 32 by 36 inches. A panel board recently put on the market is 32 by 72 inches and ⅜ inch thick.

The wool felt or paper binding material forming the outside of the plaster boards gives an excellent bonding surface for gypsum plaster. Minute needle crystals of gypsum formed as the plaster sets penetrate the binding material and interlace with it and the plaster forming the board, making a very strong bond.

Plaster boards are used in place of wood and metal lath where high fire-resistive construction is required and in fireproof or fully protected building construction. In the latter case the plaster boards are secured to metal studs, hangers, or fireproof construction with metal clips.

Plaster boards not to be plastered are used for sound deadening by being laid between rough and finished floors; as sheathing boards by being nailed to the studding and behind the clapboards; as outside sheathing and waterproofed before application of outside stucco covering; as insulation and fire resistance under wood shingles, in air ducts, and in dumb-waiter shafts and nailed to joists in basement and to rafters in attic ceilings.

GYPSUM TILE, DOMES, AND SCREEDS.

Gypsum tile are made for partitions, floors, roofs, and furring. They are lighter than clay tiles; are straight and true; can be cut by a handsaw; are fire and sound resistant, nonconductors of heat and cold; and, on account of light weight and large size, can be laid rapidly.

The method of making gypsum tile adopted at the inception of the industry was by hand with a very simple outfit. A wet rubber mat was placed flat on a bench and surrounded by a solid wooden frame in which was inserted lengthwise two or three iron pipes. The operator then mixed a batch of plaster, wood fiber, and warm water in a tub and filled the mold or molds with it. By the time a second set of molds was in place the plaster had set so that the iron pipes or cores could be driven out, the frame removed, and the tile set aside to dry.

This method soon gave way to the use of hand trucks and several men working in pairs, each pair having only one duty to perform. On the trucks are sheet-iron frames with partitions set in grooves so spaced as to make molds for 6 to 10 tile standing on edge. Tapered wooden cores are placed in each mold. As the truck passes under the delivery spout of a hopper in which the plaster is mixed, the molds are filled and leveled off. When the plaster has set the truck is placed between two parts of a machine that loosens the cores so that they can be drawn by hand. The frame of the mold is then knocked off and the tile separated by means of the metal dividing plates. While the tile are being removed from the truck the molds are cleaned.

As the demand for standard gypsum tile has increased, a machine that does all of these things mechanically and faster and requires fewer men is being used. This machine may be described as a continuous belt of molds all of the same size, which are filled automatically with plaster from a mechanical mixer. The metal cores are inserted and pulled from the molds by a groove which approaches and recedes from the main belt and in which the heads of the tapered metal cores travel. Three men are required, one to level the plaster in the freshly filled molds, one to remove set tile from the machine, and one to grease the withdrawn cores. Finished tile are stored either in a warehouse or out of doors. As mentioned above, the tile are designed for various and special uses.

Partition tile.—Partition tile, solid or hollow, are 12 by 30 and $16\frac{1}{2}$ by 28 inches and $1\frac{1}{2}$ to 12 inches thick. (See Pl. VII.) These tile, laid with gypsum plaster, are used in the highest grade of fireproof building for dividing and corridor partitions, elevator and stairway inclosures, and dumb-waiter shafts. They are light in weight, can be laid very rapidly, can be cut with a handsaw, and when plastered with gypsum make partitions that resist high temperature. Plaster is applied directly to the tile, thereby making what is virtually a monolithic wall of gypsum.

Floor domes.—Gypsum floor domes are hollow boxes or tiles of reinforced gypsum plaster, used as a filler between concrete joist construction. These domes are 19 inches wide and 24 inches long, 7, 9, 11, and 13 inches high, and weigh 24, 27, 30, and 33 pounds per linear foot. Such domes save dead weight in construction and provide a smooth, all-gypsum ceiling for plastering. They are cast from molds and are therefore alike in size and shape and fit perfectly. The end pieces are cast as an integral part of the whole and serve not only to strengthen the dome but to prevent concrete being wasted by running inside if a dome is displaced during construction.

Roof tile.—Gypsum roof tile commonly are made 24 and 30 inches long, 12 inches wide, and 3 inches thick, and are laid between supporting subpurlin **T** irons. Others measure 16 by 26 inches. Gypsum roof tile, reinforced and made from especially dense gypsum, are made to span 4 to 10 feet and to rest on the main roof purlins. These tile are $4\frac{1}{2}$ inches thick, 15 to 18 inches wide, and of biscuit pattern, or beamed construction. All gypsum roof tile weigh 13 to 20 pounds per square foot, depending on the length of the span. As gypsum is a poor conductor of heat and cold, the temperature of the inner side of the roofing slab is nearly the same as that of the space it covers; and therefore the tile sweat less than other materials. For this reason the tile are desirable in cold-storage warehouses, laundries, and many other structures. The low heat conductivity of gypsum is an especially valuable quality in a roof deck also, because it effects a saving in heating requirements.

Floor and roof filler.—Another method of using gypsum is that of pouring gypsum plaster mixed with shavings into forms set in place on the job. The result is a light, monolithic filler of excellent nonconductive properties. This filler is used in place of cinders for floor bases to be surfaced with other material, and for the same purpose in roof decks.

Furring tile.—Gypsum furring tile are of the same character and general dimensions as the partition tile, are hollow or solid, and 2 inches thick. They are fastened to the wall by nailing and are used for sound absorption and soundproofing, fire protection, insulation from heat or cold, and damp-proofing.

Floor screeds.—Gypsum floor screeds are used as a nailing sleeper for floors. They are 2 by 3 inches and 8 feet long, weighing 2 pounds per linear foot. They consist of a wood core or nailing strip embedded in hard gypsum plaster. The advantage in their use is that they are fireproof, can be laid on a rough surface, cemented in place and leveled up quickly with mortar, and they will not buckle or rot.

BUILDING BLOCKS.

In an arid climate molded blocks of gypsum plaster can be used for exterior construction. They are so used in Bighorn Basin, Wyo., and at Douglas, Ariz. The blocks are made of uniform size, hollow, and with smooth sides except the face to be exposed, which may be smooth or molded to represent rough-dressed stone. Buildings in which molded gypsum blocks form the walls are shown in an accompanying illustration. (See Pl. VIII, *A*.) Warehouses, garages, and other simple structures in Douglas, Ariz., are built of hollow gypsum blocks 8 by 12 by 24 inches. (See Pl. VIII, *B*.) At Douglas gypsum-block structures are estimated to cost one-quarter less than brick buildings of the same design. On account of the size of the blocks the walls can be laid faster, and less skillful labor can be used.

DENTAL PLASTER.

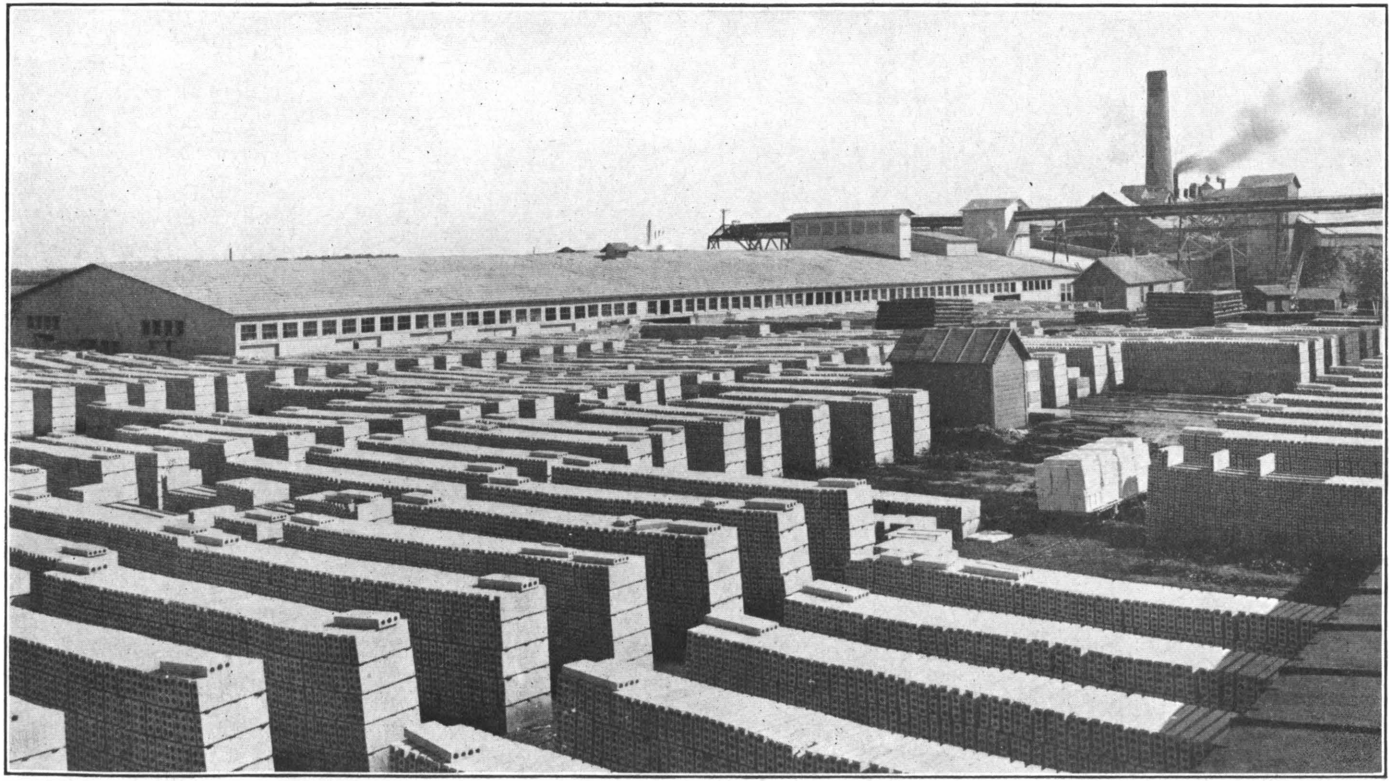
Plaster of Paris for dental use is prepared in several grades. An extremely fine-grained plaster of Paris to which an accelerator has been added, is used by dentists in taking impressions of the mouth. This is known as impression plaster. Quick set and reproduction of fine details are the qualities demanded in such work. The fines from the last screening of the reground calcined gypsum is used for this plaster. Plaster for making dental casts and models is not so fine grain as the finest impression plaster, and sets slower and harder.

GYPSUM PAINT.

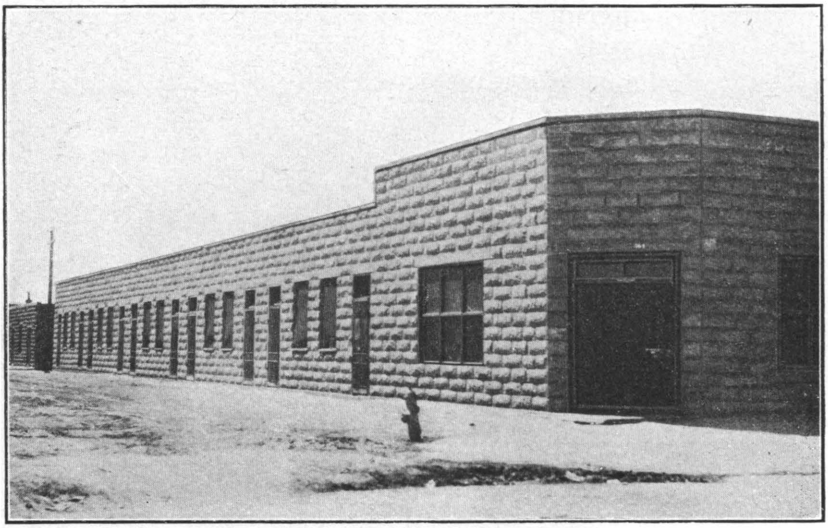
Plaster of Paris is used extensively as a whiting or whitewash paint. With the addition of coloring material and glue to pure white calcined gypsum a variety of wall tints is produced. This material is sold in 2½, 5 pound, and larger packages, and needs only the addition of water to be ready for use. Gypsum paint can be applied to plaster, wood, burlap, and other material.

KEENES CEMENT.

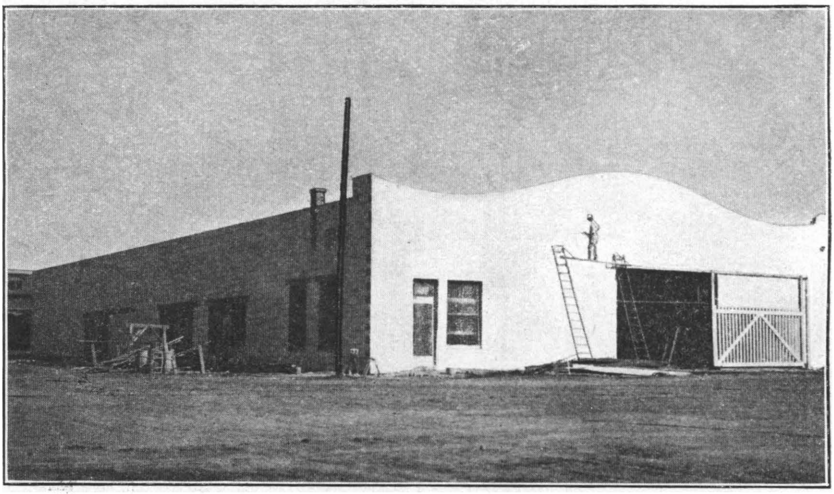
A hard-finish wall plaster which is manufactured at a number of gypsum mills in the United States is known as Keenes cement. It



GYPSUM PARTITION BLOCK OR TILE STORED AT MILL READY FOR SHIPMENT.



A. ROUGH-FACED, HOLLOW GYPSUM PLASTER BLOCKS USED IN BUILDINGS, DOUGLAS, ARIZ.



B. SMOOTH-FACED, HOLLOW GYPSUM PLASTER BLOCKS USED IN WAREHOUSE, DOUGLAS, ARIZ.

differs from ordinary gypsum wall plasters in method of manufacture, time of setting, and superior hardness. Keenes cement is slower in setting than ordinary gypsum plaster, but when set it is much harder.

It is the practice in Great Britain[a] to burn gypsum at a low temperature so as to convert it into the hydrate ($2CaSO_4.H_2O$); to soak the lumps in a solution of alum, aluminum sulphate, or borax; and to recalcine them at about 500° C. (932° F.). On grinding, they give Keenes cement. Other writers state that gypsum in small lumps is calcined in small vertical kilns which are similar to limekilns, but so constructed that only the gaseous products of combustion come into contact with the gypsum to be burned and contamination with the ash of the fuel is avoided. The gypsum is brought to a red heat, after which it is treated with a 10 per cent solution of alum and allowed to dry.[b] It is again calcined, this time to a dull red heat, for 6 to 8 hours. When cool it is ground to flour. It is found that borax alone gives as good results as a solution of borax and cream of tartar or of alum, and that the time of setting is retarded by using a stronger solution.[c] If to 1 part of saturated solution of borax be added 12 parts of water and the lump plaster soaked in this bath, the set takes place in about 15 minutes; but if only 8 parts of water be used, the cement takes an hour to set.

The descriptions given above apply to methods of making true Keenes cement. The manufacturers in the United States are secretive as to the process employed, and the writer has been informed that only one company uses the original method. It is reported that most of the producers of so-called Keenes cement in this country calcine lump gypsum in stationary kilns, grind it to a very fine powder, and add a small amount of powdered borax and other chemicals. The mixture is not recalcined and is marketed as American Keenes cement.

THE GYPSUM INDUSTRY.

Gypsum has been quarried and used in the United States for a little more than a century. The advancing tide of population found and first used the easternmost deposits, those in central New York; then those in Virginia, Michigan, Ohio, and Iowa were utilized. Gypsum was discovered in New York as early as 1792, and a stock company was organized in 1808 to quarry the rock for land plaster, but not until 1892 was the first production of plaster in New York reported. The utilization of Virginia gypsum for land plaster was advocated in 1835. About 1840 the deposits near Grand Rapids, Mich., were discovered, and before 1850 gypsum was being obtained near Sandusky, Ohio. Iowa began to produce gypsum in 1872 and

[a] Cement: Encyclopedia Britannica, 11th ed., vol. 5, p. 658.
[b] Eckel, E. C., Cements, limes, and plasters, 1st ed., 1905, p. 77.
[c] Redgrave, G. R., and Spackman, Calcareous cements, 2d ed., 1905, p. 273.

California in 1875. In 1895 the production of 265,503 tons of crude gypsum was reported from 13 States, and in 1915, 18 States and Alaska were yielding quantities of crude gypsum varying from a few thousand tons in some of the States to more than one-half million tons in New York.

There were 68 gypsum mills in the United States in 1915. The most rapid development of the industry was between 1898 and 1903, when the increase in production was more than 350 per cent. During this period gypsum wall plaster began to be used extensively. The use of gypsum for this purpose has rapidly increased, and the value of the output of the industry has grown from $750,000 in 1898 to approximately $7,000,000 in 1915. The largest producers are the United States Gypsum Co., Chicago, Ill., which has 22 mills in 12 States; Acme Cement Plaster Co., St. Louis, Mo., with 12 mills in 9 States; and the American Cement Plaster Co., Chicago, Ill., operating 7 mills in 6 States.

Two gypsum products of recent development, plaster board and gypsum tile, are adding impetus to fire-resistant or protective construction and seem to augur an appreciable increase in the output of gypsum products.

The following table, compiled by the United States Geological Survey, shows the development of the industry:

Crude gypsum mined in the United States, 1880–1915.

	Short tons.		Short tons.		Short tons.
1880	90,000	1892	256,259	1904	940,917
1881	85,000	1893	253,615	1905	1,043,202
1882	100,000	1894	239,312	1906	1,540,585
1883	90,000	1895	265,503	1907	1,751,748
1884	90,000	1896	224,254	1908	1,721,829
1885	90,405	1897	288,982	1909	2,252,785
1886	95,250	1898	291,638	1910	2,379,057
1887	95,000	1899	486,235	1911	2,323,970
1888	110,000	1900	594,462	1912	2,500,757
1889	267,769	1901	633,791	1913	2,599,508
1890	182,995	1902	816,478	1914	2,476,465
1891	208,126	1903	1,041,704	1915	2,447,611

PRODUCING LOCALITIES.

Gypsum was calcined in 1915 and 1916 at plants in the following places (see Pl. IX):

Arizona: Douglas.
California: Amboy, Los Angeles.
Colorado: Loveland, Portland.
Iowa: Fort Dodge.
Kansas: Blue Rapids, Medicine Lodge.
Michigan: Alabaster, Grand Rapids, Grandville.
Montana: Great Falls, Hanover.
Nevada: Arden, Mound House.
New Mexico: Acme, Alamogordo, Oriental.
New York: Akron, Garbutt, Oakfield, Wheatland.
Ohio: Castalia, Gypsum, Port Clinton.
Oklahoma: Acme, Eldorado, Okeene, Primm, Southard.
Oregon: Gypsum.
South Dakota: Black Hawk, Rapid City.
Texas: Acme, Plasterco.
Utah: Nephi, Sigurd.
Virginia: North Holston, Plasterco.
Washington: Tacoma (using Alaska gypsum).
Wyoming: Basin, Greybull, Kane, Laramie, Red Buttes.

Scales

100 0 100 200 300 400 500 600 Miles

100 0 100 200 300 400 500 600 Kilometers

Base map by U S. Geological Survey

SITUATION OF GYPSUM MILLS USING LOCAL GYPSUM

Gypsum from Nova Scotia was calcined in 1915 at Brooklyn, New Brighton, Newburgh, and New York City in New York State, and at Chester in Pennsylvania.

Six plants reported the manufacture of Keenes cement, and 12 plants reported making gypsum block, tile, or board.

PRODUCTION BY STATES.

The following table summarizes the gypsum industry in 1915 as reported by the United States Geological Survey:

Gypsum marketed in the United States, 1915, by States and uses.

State.	Number of mills reporting.	Total quantity mined (short tons).	Sold without calcining.				Sold as calcined plaster.		Total value.
			Ground for land plaster.		For Portland cement, paint, bedding plate glass, and other purposes.				
			Quantity (short tons).	Value.	Quantity (short tons).	Value.	Quantity (short tons).	Value.	
Alaska, Arizona, Colorado, Illinois,[a] Minnesota,[a] Montana, Nevada, New Mexico, Oregon, South Dakota, Virginia, Washington,[a] Wisconsin [a]	16	319,164	25,089	$52,596	49,025	$108,746	215,492	$1,073,957	$1,235,299
California	3	32,559	(c)	(c)	(c)	(c)	c 29,060	c 113,863	113,863
Iowa	5	495,860	12,086	11,422	59,823	48,508	335,057	1,218,198	1,278,128
Kansas	4	60,919	(b)	(b)	b 17,332	b 14,887	40,634	235,127	250,014
Michigan	8	389,791	(b)	(b)	b 69,572	b 63,236	245,484	623,073	686,309
New York	11	540,914	9,262	17,463	175,255	251,004	293,870	999,239	1,267,706
Ohio	4	259,036	4,030	6,485	5,131	6,485	217,811	759,550	772,520
Oklahoma	5	110,790	(b)	(b)	b 17,580	b 15,784	73,348	278,446	294,230
Texas	5	176,306	(c)	(c)	(c)	(c)	c 148,138	c 519,879	519,879
Utah	3	23,445	(c)	(c)	(c)	(c)	c 20,541	c 75,835	75,835
Wyoming	5	38,827	......	......	......	......	25,749	103,110	103,110
	69	2,447,611	69,256	122,714	406,393	528,161	1,613,720	5,946,018	6,596,893

a No crude gypsum produced in the State.
b Some land plaster included with gypsum sold for Portland cement, etc.
c Some crude gypsum included with calcined plaster.

The sum of the quantity sold without calcining and sold as calcined plaster does not equal the total quantity mined, principally because there is a loss of about 20 per cent by weight in calcining.

PRODUCTION BY USES.

The quantity and value of gypsum marketed for various purposes are shown in the following table:

Gypsum marketed in the United States, 1911–1915, by uses.

Year.	Sold without calcining.														
	For Portland cement.			As land plaster.			For paint material.			For other purposes.			Total.		
	Quantity (short tons).	Value.	Average price per ton.	Quantity (short tons).	Value.	Average price per ton.	Quantity (short tons).	Value.	Average price per ton.	Quantity (short tons).	Value.	Average price per ton.	Quantity (short tons).	Value.	Average price per ton.
1911	327,953	$484,373	$1.48	52,880	$97,573	$1.85	(a)	(a)	....	[a]6,647	$7,533	$1.13	387,480	$589,479	$1.52
1912	382,952	509,400	1.33	53,065	107,058	2.02	(a)	(a)	....	[a]5,591	7,064	1.26	441,608	623,522	1.41
1913	408,221	600,913	1.47	54,815	95,953	1.75	(a)	(a)	....	[a]100	200	2.00	463,136	697,066	1.51
1914	[b]390,742	[b]549,083	1.41	52,945	97,716	1.85	(b)	(b)	....	....	....	....	443,687	646,799	1.46
1915	[b]406,393	[b]528,161	1.30	69,256	122,714	1.77	(b)	(b)	....	....	....	....	475,649	650,875	1.37

Year.	Sold calcined.														
	As plaster of Paris, wall plaster, Keenes cement, etc.			For dental plaster.			To glass factories.			For Portland cement and other purposes.			Total.		
	Quantity (short tons).	Value.	Average price per ton.	Quantity (short tons).	Value.	Average price per ton.	Quantity (short tons).	Value.	Average price per ton.	Quantity (short tons).	Value.	Average price per ton.	Quantity (short tons).	Value.	Average price per ton.
1911	1,523,263	$5,678,453	$3.73	413	$2,612	$6.32	33,472	$80,220	$2.40	41,270	$111,271	$2.70	1,598,418	$5,872,556	$3.67
1912	1,678,417	5,805,999	3.46	[c]3,190	15,564	4.88	24,159	52,741	2.18	25,908	66,082	2.55	1,731,674	5,940,386	3.43
1913	1,680,157	5,858,785	3.49	861	4,168	4.84	10,942	21,797	1.99	81,889	193,006	2.36	1,773,849	6,077,756	3.43
1914	1,565,937	6,038,777	3.86	641	3,374	5.26	(d)	(d)	....	[d]89,488	207,039	2.31	1,656,066	6,249,190	3.77
1915	1,520,308	5,776,826	3.80	534	2,376	4.45	11,861	26,620	2.25	81,017	140,196	1.73	1,613,720	5,946,018	3.68

[a] Paint material included under "For other purposes."
[b] Small quantity of paint material included with gypsum sold for Portland cement.
[c] Includes some casting plaster.
[d] Calcined gypsum sold to glass factories included under "For Portland cement and other purposes."

IMPORTS.

Gypsum imported into the United States comes almost wholly from Nova Scotia and New Brunswick and enters the ports of the New England and North Atlantic States, over one-half of it entering the port of New York. The value of imports from 1889 to 1898 averaged about one-third of the value of domestic production, but since 1899 the proportionate value of imports has become very small and seems to be steadily decreasing. It amounted to less than one-twelfth of the value of the domestic production in 1913, a little more than one-sixteenth in 1914, and somewhat more than one-seventeenth in 1915.

Gypsum imported and entered for consumption in the United States, 1911–1915.[a]

Year.	Unground.		Ground or calcined.		Value of manufactured plaster of Paris.	Total value.
	Quantity (short tons).	Value.	Quantity (short tons).	Value.		
1911	389,874	$413,119	388	$3,353	$34,334	$450,806
1912	412,697	430,183	3,702	19,709	38,589	488,481
1913	447,383	473,594	4,542	31,277	52,051	556,922
1914	369,214	392,118	3,559	27,931	24,792	444,841
1915	336,856	356,791	5,749	22,873	10,095	389,759

[a] Figures compiled from records of the Bureau of Foreign and Domestic Commerce, Department of Commerce.

GYPSUM AND GYPSITE IN THE UNITED STATES.

The following pages concerning the occurrence of gypsum in the various States have been extracted verbatim from Federal and State reports and other sources, or rewritten by the present writer to suit the needs of this report.

ALASKA.

The only extensive gypsum deposit known in southeastern Alaska is operated by the Pacific Coast Gypsum Co. and is situated in the eastern part of Chichagof Island, about a mile from Iyoukeen Cove. At the surface the deposit is covered by gravel except near the shaft house, and no footwall nor hanging wall has been encountered in the mine workings which are reported to measure probably 1 mile, Gravel-filled solution channels extend below the 160-foot level. One channel has been tunneled for 35 feet without being cut through. Thin dikes of basaltic rock cut the gypsum beds, and a vein of anhydrite ranging in thickness from 6 inches to more than 10 feet has been encountered in the lower workings. This anhydrite is much harder to drill than the inclosing gypsum, and it is left in the mine. The gypsum is generally of a light bluish-gray color, although some is white, and occurs in massive beds, which dip 30°–60° NE. The main body of gypsum is extremely pure.

Adjoining on the east the claims now being worked for gypsum by the Pacific Coast Gypsum Co. and extending to the shore of Chatham Strait are other claims which have been located on reported deposits of gypsum.

ARIZONA.

Gypsum occurs at several localities in this State, the following being noteworthy: Cochise and Pinal counties, in the low hills along the course of San Pedro River, at Land, near Redington, and at Feldman; Mohave County, extensive beds of rock gypsum in Virgin Valley; Navajo County, rock gypsum has been quarried at Winslow and shipped to Los Angeles, Cal., for calcining; Pima County, in the foothills of the Santa Catalina Mountains north of Tucson, and in the Empire Mountains southeast of Tucson. The gypsum deposits in the Empire Mountains are reported to be in two beds, each about 50 feet thick. Gypsite is dug at Douglas and used at the only plaster mill in the State.

ARKANSAS.

Gypsum is found in Pike and Howard Counties. The thickest exposure is in Plaster Bluff, 65 feet above Little Missouri River. A single bed ranging from 10 to 14 feet in thickness is pure saccharoidal gypsum, with some thin seams of satin spar, and as much as 3 feet of interbedded clay in its lower part. The thickest layer of gypsum is at the top of the bed and measures 4 feet. Gypsum not exceeding 3 feet thick is found as far west as Messers Creek in Howard County. In Arkansas the occurrence of gypsum is so restricted that the gypsum has practically no commercial value, although it could be produced in a small way for purely local use.

CALIFORNIA.

Gypsum is found throughout nearly all the coast ranges, particularly south of San Francisco Bay, in the foothills of the Great Valley, in the valleys of southern California, and in the Palen and Maria Mountains. Deposits are known to occur in the counties of Fresno, Ventura, Kings, Monterey, Kern, San Luis Obispo, Santa Barbara, Los Angeles, San Bernardino, Riverside, and Orange. They are generally shallow and of the variety known as gypsite, although there are some extensive exposures of rock gypsum, as at Tecopa and in the Palen and Maria Mountains.

Gypsum has been quarried in Fresno County, at Coalinga and Mendota; Kern County near Fellows, Mohave, McKittrick, and Bakersfield; Los Angeles County at Palmdale and Castaic; Monterey County, King City; Riverside County, Corona; San Bernardino County, Amboy; and Ventura County, Fillmore.

In 1915 gypsum was ground for wall plaster or land plaster at three mills in California, one at Amboy and two at Los Angeles.

COLORADO.

Gypsum-bearing localities in Colorado occur at intervals from the northern to the southern border of the State along the eastern foothills of the Rocky Mountains and also near Arkansas River in Custer County, on Gunnison River in Delta and Montrose Counties, along Grand and Eagle Rivers in Eagle County, and along Frying Pan Creek in Eagle and Pitkin Counties. The gypsum varies in thickness up to 30 feet; much of it is good quality; and the supply may well be regarded as very great. Beds have also been prospected on Bear Creek, near Morrison, and 8 miles southeast of Morrison on Deer Creek. Quarries have been worked in the past at Ruedi, near Perry Park, and at the Garden of the Gods, near Colorado City. In 1915 gypsum was quarried at Wildes Spur near Loveland, near Coaldale, and at Stone City. Two mills were operated, one at Wildes Spur, 5 miles west of Loveland, and one at Portland.

FLORIDA.

A deposit of soft gypsum, probably gypsite, occurs 6 miles west of Panasoffkee, Sumter County, in a low-lying area known as Bear Island. The gypsum is 6 to 7 feet thick and contains bowlders of impure limestone. It is not used.

IDAHO.

Gypsum occurs in Washington County, Idaho, in the bluffs overlooking Snake River about 10 miles northeast of Huntington, Oreg., which is the nearest town. Short tunnels and prospect pits have shown that the material consists of lenticular masses of rock gypsum banded with grayish and greenish material, possibly chloritic. The thickness of gypsum ranges from 6 to 30 feet or more. A branch of the Oregon Short Line passes down the Oregon side of Snake River within 2,000 feet of the gypsum outcrop. The deposits apparently correspond to those on the Oregon side of Snake River a few miles farther south.

IOWA.

Gypsum in Iowa is confined mainly to a single area of 60 to 70 square miles near Fort Dodge, Webster County. It occurs in one bed, which varies from 10 to 25 feet in thickness. The bed is practically horizontal and at least 40 square miles of it may be regarded as available for use. The average thickness of the gypsum suitable for plaster is 10 feet, and the yield per acre of a bed of this thickness is 30,000 tons. Except immediately along Des Moines River and its tributaries, the bed is covered by a mantle of glacial drift 60 to 80 feet in thickness.

The first gypsum mill in Webster County was erected in 1872. Operators formerly stripped off the drift and quarried the gypsum along the river, but now the bed is reached by shafts back on the prairie. The Iowa gypsum is extensively worked, 5 plaster mills being in operation in Webster County in 1915.

Gypsum associated with anhydrite occurs more than 500 feet below the surface at Centerville, Appanoose County. A recent attempt to develop the deposit has been abandoned and the shaft is flooded.

KANSAS.

The area in which gypsum is found in Kansas is an irregular belt extending northeast and southwest across the State. It is naturally divided into three districts, which, from the important centers of manufacture, may be named the northern or Blue Rapids area, in Marshall County; the central or Gypsum City area, in Dickinson and Saline Counties; and the southern or Medicine Lodge area, in Barber and Comanche Counties. A number of small intermediate areas have been developed, which connect the three main areas more or less closely. The beds in the southern area are the continuation of the gypsum hills of Oklahoma.

Both rock gypsum and gypsite or gypsum earth occur in extensive deposits. The rock-gypsum beds are so vast as to be almost inexhaustible, and only those favorably situated with respect to transportation are developed. Near Blue Rapids the bed is 8 to 9 feet thick; near Gypsum City, 5 to 14 feet; at Dillon 18 feet; and in the Medicine Lodge area beds vary from 3 to 20 feet thick. Some of the rock gypsum is suited to the manufacture of fine grades of plaster of Paris.

Gypsite is found in low, swampy ground in central Kansas in deposits several acres in extent and up to 18 feet deep. It is particularly adapted to wall and cement plasters, but many of the gypsite deposits have been exhausted. The first gypsum mill in Kansas was erected at Blue Rapids in 1872. Four mills were operated in Kansas in 1915, 3 at Blue Rapids, and 1 at Medicine Lodge. The last-named plant produces Keenes cement.

LOUISIANA.

Thick beds of gypsum have been encountered in deep drill holes at St. Charles, Calcasieu Parish, associated with sulphur, and at Pine Prairie, St. Landry Parish. Gypsum also occurs at Rayburn's salt work, Bienville Parish.

MICHIGAN.

Rock gypsum was known to the Indians and fur traders and had been used for making plaster before the first gypsum mill was erected in 1841. This mill was on Plaster Creek between Grandville and Grand Rapids and in one of the areas that produces to this day.

The principal gypsum areas are: (1) In the vicinity of Grand Rapids near the western side of the Lower Peninsula, and (2) at Alabaster, north of Saginaw Bay on Lake Huron. The deposits occur in a formation which outcrops around the interior coal basin. At Grand Rapids there is an upper ledge 6 feet thick separated by 1 foot of shale from a lower ledge 12 feet thick; about 40 feet below the latter bed there is a 20-foot bed of gypsum and a few feet above this thick bed another deposit several feet thick, making four beds which have been utilized. Several thinner beds are not used. At Granville, 5 miles southwest, two ledges 11 and 14 feet thick are separated by 4 feet of limestone. The gypsum is very pure and is taken from quarries and underground workings.

At Alabaster an extensive exposure of gypsum 23 feet thick has been worked back from its original outcrop on the shore of Lake Huron for more than a quarter of a mile, the quarry now being very large. A 10-foot bowlder-clay cover is stripped and the rock is blasted from a horseshoe-shaped face. The bottom of the quarry is about 15 feet above the lake level. Several thin beds underlie the quarry within a depth of 90 feet. Gypsum has been found in a number of wells in northern Arenac County and southeast Ogemaw County; in Mackinac County, near Point Aux Chenes, 7 miles west of St. Ignace, and in the vicinity of St. Martins Bay. Eight plants were operated in 1915 in Michigan, 7 being near Grand Rapids and 1 at Alabaster.

MONTANA.

Rock gypsum deposits occur in the eastern foothills of the main Rocky Mountain Range in Cascade, Carbon, Fergus, and other counties of Montana. There are several beds of gypsum ranging from a few feet to as much as 30 feet in thickness. They occur intercalated with red and green shales and limestones. There are extensive deposits around the Big Snowy Mountains and also a few miles southeast of Bridger. Mills were formerly located at Armington, Bridger, and Great Falls, but their operation has been discontinued. A claim has been developed at Limespur, Jefferson County, for supplying gypsum to the Portland cement plant at Trident. Gypsum deposits at Hanover and Heath, in Fergus County, were being developed in 1916. In many places the undeveloped gypsum beds are within 5 miles of railroads. The supply far exceeds any demand that can be expected in many years.

NEVADA.

The best-known gypsum deposits of this State are in the northwestern part, near Mound House and Lovelock, and in the southern part, in Clark and Lincoln counties. In Esmeralda County there are large bodies near Hawthorne, and an extensive bed is exposed at the Ludwig mine in the Yerington district, Lyon County.

The gypsum near Mound House, on the east flank of the Virginia Mountains, forms a thick bed that stands nearly vertical. Its greatest width is 350 feet. The main deposit is cut off abruptly at one end by diorite and pinches out in the other direction in a few hundred yards.

The deposit at Lovelock is pure white or grayish-white rock gypsum. At the point of broadest exposure the gypsum is folded into an anticline and its measurement is difficult, but probably it nowhere exceeds 200 feet. At another place in the vicinity the gypsum is 130 feet thick. The outcrop is about half a mile long and is terminated by faults.

Pure white coarsely crystalline rock gypsum at the Ludwig mine in Lyon County seems to have a total length of 4,000 feet and maximum width of 200 feet.

Extensive deposits of rock gypsum in beds and lenticular masses occur in southern Nevada near Galt, Moapa, Las Vegas, and Arden. The beds range in thickness from a few feet up to 80 feet. The most extensive development in southern Nevada is at Arden.

Gypsum plaster mills were operating in Nevada in 1915 at Mound House, Reno, and Arden.

NEW MEXICO.

The "Red Beds," which contain rock gypsum in many places, underlie large areas in New Mexico. The largest area is in eastern New Mexico, principally in the valley of the Pecos, but it connects with the area entering the State along Canadian River from northern Texas, Oklahoma, and Kansas. The central division of the "Red Beds" area is drained by the Rio Grande and its tributaries, and there is also an area in western New Mexico in the region of the Zuni Mountains. Along the western base of Sierra Nacimiento in Sandoval County there are immense beds of massive gypsum. At Gallina the gypsum bed is over 40 feet thick, at Senorita it measures 54 feet, and at San Miguel copper mine the total thickness of massive white gypsum in a single bed is 60 feet. A bed of practically pure gypsum of this thickness extending for miles would be considered a practically inexhaustible resource, but at the head of a tributary to Rio Salado, about 3 miles southeast of Ojo del Espiritu Santo, the gypsum bed reaches a maximum thickness of about 100 feet. In addition to the areas of bedded gypsum there are accumulations of white gypsum sands in Otero County. These sands form dunes which cover an area of about 270 miles. The highest dunes are about 50 feet. A small deposit of gypsum sands occurs about 10 miles north of Torrance near Pinoswells, Torrance County. Development of the vast resources of gypsum has been retarded by the limited markets and the long distances that the raw or manufactured materials must be transported. Many of the gypsum deposits lack railroad facilities. Plaster mills have been operated at Acme, Chaves County, at Ancho, Lincoln County, and at Oriental, Eddy County. Gypsum was quarried for use in Portland cement at El Rito.

NEW YORK.

The gypsum in New York State occurs as rock gypsum interbedded with shales and shaly limestones. Several gypsum beds, separated by shale, usually occur in any given section. They are lenticular in shape, but of such horizontal extent that in any given quarry they are usually of practically uniform thickness. Those that are worked are 4 to 10 feet thick, but at Fayetteville a 30-foot bed is exposed. Underground mines furnish most of the gypsum in the western part of the State, but the heavier beds outcropping near Syracuse are quarried. The area in which the gypsum-bearing formations are found extends more than 150 miles through the central part of the State, the workable portion of the belt including parts of Madison, Onondaga, Cayuga, Ontario, Genesee, Monroe, Livingston, and Erie counties. The center of the industry is now in the western part of the State, and whereas the output was formerly marketed largely as raw gypsum, principally for agricultural purposes, it is now converted mainly into wall plasters, plaster board, and gypsum tile or partition blocks in plants operated in connection with the mines.

Large quantities of crude gypsum are shipped to Portland cement mills in New York and Pennsylvania. Although the annual production is more than 500,000 tons, the exhaustion of the New York gypsum deposit can not be foreseen, as an area 150 miles long and 10 to 20 miles wide is underlain by at least 4 feet of rock gypsum.

Gypsum was quarried in 1915 at Union Springs, Cayuga County; Akron, Erie County; Oakfield, Genesee County; Caledonia, Livingston County; Garbutt, Monroe County; Jamesville and Fayetteville, Onondaga County. Eleven mills reported production of gypsum in either the raw or the calcined condition in New York State in 1915. Gypsum was calcined at Akron, Garbutt, Oakfield, and Wheatland.

OHIO.

The gypsum deposits prospected or developed consist of beds of rock gypsum in the northwestern part of the State. Some of the deposits are exposed close to the level of Sandusky Bay, and have been known since the first settlements were made on its northern shore. Approximately 1,000 acres in Portage Township, Ottawa County, has been proved, by drilling, to be underlain by one or more workable beds of gypsum. Formerly a 7-foot bed near the surface was quarried, but now lower beds 11 and 14 feet thick are mined through shafts and slopes. The deepest mine is less than 100 feet. Considerable water is encountered in the workings and pumps are used. Four plants were operated in Ohio in 1916, three being in the area north of Sandusky Bay, near Port Clinton. On the south shore of the bay, about 2½ miles northwest of Castalia, another area of workable gypsum has been developed. The gypsum is white and gray, massive, and some is granular.

OKLAHOMA.

The gypsum in Oklahoma may be considered as occurring in four regions: (1) The Kay County region; (2) the main line of gypsum hills, extending from Canadian County northwest through Kingfisher, Blaine, Major, Woodward, Woods, and Harper counties to the Kansas line; (3) the second gypsum hills, parallel with the main gypsum hills, and from 50 to 70 miles farther southwest, which extend from the Keechi Hills, in southeastern Caddo County, northwestward through Washita, Custer, Dewey, and Ellis counties; and (4) the southwestern region, occupying part of Greer, Jackson, Harmon, and Beckham counties. The deposits in Kay County consist of soft, earthy gypsum, or gypsite. In the other three regions rock gypsum predominates, although there are numerous localities where gypsite occurs in workable bodies. In the main line of gypsum hills are three distinguishable beds of gypsum that extend many miles. These vary from 4 to 30 feet in thickness, and one bed more than 50 feet thick of massive white gypsum, with only one parting 5 to 7 feet thick, has been found. In the second line of hills the gypsum beds are more irregular and are very thin in the northwestern and the southeastern portions of the area, but localities are known where 60 feet of massive gypsum is exposed.

The southwestern region contains beds of rock gypsum that maintain a fairly constant thickness of 18 to 20 feet for many miles. The reserves of rock gypsum in Oklahoma are enormous, but the gypsite deposits adjacent to railways are limited. Materials for plaster are obtained from open quarries rather than from mines. The supply for wall plaster has been largely from gypsite deposits which are comparatively soon worked out. New deposits are, however, being discovered from time to time. Some ledges of rock gypsum are being quarried, but gypsite, so long as it lasts, will probably be used for wall plaster because it costs less to quarry, and because much of it contains nearly, if not exactly, the right proportions of silica and other impurities to make a good wall plaster when calcined, and therefore does not require the addition of much retarder. Gypsite that is unusually impure or that contains considerable surface soil may be brought up to the requisite standard by the addition of rock gypsum.

Five plants produced gypsum, including that ground for land plaster, for wall plaster, and for plaster of Paris in Oklahoma in 1915 as follows: One each at Acme, Eldorado, Okeene, Primm, and Southard.

OREGON.

Gypsum occurs in Oregon in two localities. One is on the eastern border of the State near the middle point of the boundary line on a ridge between Burnt River and Snake River at Gypsum, about 6 miles north of Huntington. The gypsum occcurs here as elongated lenses, in places 10 to 40 feet thick, interstratified with limestones and shales with a few intercalated strata of volcanic tuffs. The gypsum is in part white and crystalline, but contains in places thin strata and films of greenish chloritic mineral. It is worked at present by quarrying. The rock is carried to the calcining plant on Snake River by means of an aerial cableway 6,100 feet long. The weight of loaded buckets on the cableway develops 50 horsepower for operating an air compressor and pneumatic tools at the quarry. The kettles are fired with oil.

Another deposit of gypsum occurs in Crook County, 30 miles east of the town of Bend. It is reported that this material is in part gypsite and that it has been used as fertilizer.

SOUTH DAKOTA.

An elliptical outcrop of the "Red Beds" surrounds the high ridges and plateaus of the central portion of the Black Hills. The hook-shaped outcrop zone in South Dakota is over 140 miles long and has an average width of 3 miles, except in a few districts where the rocks dip deeply and it is much narrower. The formation consists mainly of red, sandy shale, with included beds of gypsum at various horizons, some of which are continuous for long distances and others are of local occurrence. The thickness of the deposits varies greatly, but in some districts over 30 feet of pure white gypsum occur, and nearly throughout the outcrop of the formation the deposits are of sufficient thickness and extent to have commercial value. A bed at Hot Springs is 33½ feet thick, and north of Edgemont a 25-foot bed is continuous for many miles. The average thickness about Rapid is 10 feet. The gypsum beds are convenient of access from Hot Springs, Rapid, Spearfish, and Edgemont. Plaster mills were formerly operated at Hot Springs, Rapid, Black Hawk, and Sturgis, but have been destroyed by fire. New mills were built in 1916 at Piedmont and Black Hawk.

TEXAS.

The largest area in Texas containing deposits of gypsum lies east of the foot of the Llano Estacado, in northern Texas. The beds have an approximately northeast strike and extend from Red River to the Colorado in an irregular line, the sinuosities of which are produced by the valleys of the eastward-flowing streams. This belt, which is nearly 200 miles long, is a continuation of the deposits in Oklahoma and contains beds of massive, pure, white gypsum 6, 9, 11, 20, and 34 feet thick.

In Culberson County, to the east of the Guadalupe Mountains, there is an area of gypsum which extends beyond the border of the State northward into New Mexico. It lies north of the Texas & Pacific Railway and west of Pecos River. In a few localities this great plain of gypsum is overlain by beds of later limestone and conglomerate. The gypsum is conspicuously exposed along the course of Delaware Creek, a stream rising in the foothills of the Guadalupe Mountains and flowing eastward into the Pecos.

In the Malone Mountains, in El Paso County, there is a third area which contains noteworthy deposits of rock gypsum. This locality has the advantage of being situated near the Southern Pacific Railroad. Extensive deposits of good alabaster in beds up to 4 feet thick are reported at Kiowa Peak in the northwestern corner of Stonewall County. The only area exploited for gypsum at present is in northern Texas. Four plants, 3 at Acme and 1 at Plasterco, were engaged in the manufacture of plaster in 1915. Keenes cement is made at one of these plants.

UTAH.

The more important known deposits in Utah occur in the central and southern portions of the State. They are all of the rock-gypsum type, except the one near Fillmore, which is composed of selenite crystals and gypsum sand blown from dry lakes into dunes. Important localities are as follows: (1) Iron County, where an enormous bed of pure white gypsum 200 feet thick outcrops for several miles south of Kanarraville to the county line. (2) Emery and Wayne Counties, along the west side of the San Rafael Swell, where gypsum beds 4 to 50 feet thick are continuous for many miles. The area contains within 2 miles of the outcrop about ten billion tons of good rock gypsum. (3) Juab County, deposits near Nephi and Levan. The Nephi gypsum deposit forms the entire mass of a prominent spur at the entrance to Salt Creek Valley. The quarry face, all in gypsum, is 250 to 350 feet wide and 500 feet high. (4) Sanpete and Sevier Counties, from Mayfield to Sigurd, beds from 10 to 50 feet thick. (5) Kane County, extensive deposits near Kanab. (6) Washington County, a bed of pure massive gypsum 160 to 200 feet thick outcrops for many miles across the northeast corner of the county. (7) Millard

County, vast deposit at White Mountain near Fillmore. Mounds and dunes of gypsum sand and crystals, which constitute this deposit, are estimated to contain 450,000 tons. (8) Grand County, between Grand River and the La Sal Mountains.

In 1916 three mills produced plaster in Utah—one at Nephi and two at Sigurd. Keenes cement is made in both localities. Most of the deposits are so far from a railroad and market that there is no demand for their exploitation.

VIRGINIA.

All the workable gypsum deposits of Virginia occur in Washington and Smyth Counties in the valley of the North Fork of Holston River. The area within which the known deposits are located is a narrow belt 16 miles in length, extending from a short distance southwest of Saltville to a point about 3 miles west of Chatham Hill post office.

The material occurs as rock gypsum intimately associated with salt deposits and interbedded with shale and shaly limestone. The gypsum-bearing shales outcrop around a syncline, and the dip of the gypsum beds is so high as to require mining except at the surface. The bodies of gypsum are large masses and lenses interbedded with red and gray clays. The beds of gypsum average 30 feet in thickness at the localities at which they are now worked. The rocks of the district dip at a high angle, usually between 25° and 45°, so that drillers of certain wells in the gypsum have reported great thicknesses of gypsum erroneously, because they did not consider inclination of the deposits.

In 1916 two plaster mills were in operation, one at North Holston and one at Plasterco.

WYOMING.

The gypsum deposits of economic importance in Wyoming occur in the "Red Beds," which consist largely of red sandstone and shale. The areas where gypsum deposits are known to occur are the Rawlins uplift, Freezeout Hills, Grand Canyon of the Platte, Black Hills, and Laramie, Medicine Bow, Shirley, Seminoe, Ferris, Rattlesnake, Bighorn, Absaroka, and Wind River mountains. In all there are over 800 miles of the gypsum-bearing formation exposed, and throughout this extent there are generally present beds of gypsum ranging from 5 to 20 feet thick, and in places reaching thicknesses of 30 to 70 feet. The material is generally found to be excellent. Besides the rock gypsum, there are secondary surficial deposits of gypsite, which occur in depressions below the gypsum outcrops.

Five mills produced plaster in Wyoming in 1916. Two of them at Laramie utilized gypsite as raw material and one at Red Butte, 10 miles south of Laramie, worked rock gypsum and gypsite. Operators in Bighorn Basin at Basin and Greybull used rock gypsum.

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