DEPARTMENT OF COMMERCE

BUREAU OF STANDARDS

George K. Burgess, Director

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ABSTRACT

In 1904 the value of crude and calcined gypsum produced in the United States was $2,750,000, with a tonnage of less than 1,000,000. In 1923 the value had increased to approximately $35,000,000 and the tonnage to over 4,750,000.[1] It is not, therefore, surprising that the bureau has received increasingly numerous inquiries as to various phases of the technology of gypsum manufacture. These requests have become of such volume as to warrant a publication covering the subject.

A description is given of mines, quarries, and pits from which the raw material is obtained, together with methods of working. Types of calciners in use are described and approximate figures concerning the efficiency of each are given. The processes through which the material passes, with the machinery employed, are described and discussed.

There are also included in the paper brief descriptions of the processes, apparatus, and method of manufacture of gypsum wall and plaster board and gypsum tile. In order to obtain first-hand information several representative mills were visited and a description of each is included in an Appendix.

CONTENTS

*Prepared by J. M. Porter, associate chemical engineer, Bureau of Standards, in charge of section on gypsum, lime, and sand-lime brick.

[1] Mineral Resources of the United States, 1923, Pt. II, Department of the Interior, United States Geological Survey.

I. INTRODUCTION

In spite of the increasing use of gypsum products there is very little information which is readily available as to their manufacture. To obtain the necessary data for a paper covering such a subject it was thought advisable that a study of the processes in use in the United States be made. It was deemed both impracticable and unnecessary to attempt a study of each of the many plants in the country, but to confine the survey to a few of the plants located at the larger gypsum deposits. Twenty-six mills in various parts of the United States were selected and visited. A general description of these mills is given as an Appendix to this paper.

The field work was undertaken with a view of obtaining complete information about the process of manufacture involved in the production of calcined gypsum and gypsum products—of noting the methods of mining or quarrying and crushing; of selecting typical samples of the raw material for analysis; of observing the methods of calcination, temperatures, and duration of calcination; of sampling the calcined product; of following this through the process of grinding, screening, and packing; and, finally, of observing the methods of manufacture of products made from calcined gypsum.

It is the object of this paper to correlate and compare the equipment used and the processes followed in the various mills visited.

Acknowledgment is hereby made to the officers of the many companies whose mills were visited; to W. E. Emley, under whose supervision the work was carried out and who contributed the description of the mills in New York State; to The Gypsum Industries for their hearty cooperation; to the chemistry division of the bureau for analytical work by A. W. Epperson and R. B. Rudy; and to the equipment manufacturers who contributed cuts, drawings, and photographs of apparatus.

II. GENERAL DISCUSSION

From a tonnage of less than 1,000,000 in 1904, with a value of $2,784,000, the production of crude and calcined gypsum in the United States has increased so rapidly that in 1923 the tonnage was in excess of 4,750,000, with a value of approximately $35,000,000. The major uses, with the tonnage of gypsum used in each, in 1923, are given in Table 1.

TABLE 1.—*Gypsum in 1923, by uses*

	Short tons		Short tons
Calcined:		Calcined—Continued.	
Calcined gypsum	476, 596	Keene's cement	23, 273
Neat plaster	1, 536, 077	Structural gypsum products	374, 111
Sanded plaster	178, 016	Raw:	
Mixed plaster	208, 271	Portland cement, paint, etc	821, 816
Plaster of Paris, molding, etc	155, 295	Agricultural purposes	25, 426

The calcination of gypsum can be defined as the process of converting gypsum into dehydrated gypsum through the agency of heat. It is one of the oldest chemical processes of which we have record. The improvements which have been made in comparatively recent years have been the result of economic conditions which have brought about progress in the manufacturing processes along rational lines.

1. RAW MATERIALS

Gypsum has been defined by the American Society for Testing Materials to be a material which contains not less than 64.5 per cent, by weight, of calcium sulphate combined in crystalline form with two molecules of water.[2] From such a definition it follows that there can be many forms of material from either a physical or chemical viewpoint which would be included within the scope of the definition. Such is the case.

(a) ROCK GYPSUM

The raw material used in the manufacture of gypsum products in the majority of mills is rock gypsum. The quality suitable for calcination varies within wide limits in its physical and chemical composition, as the analyses of the samples collected and compiled in Table 2 show. These analyses were made at the Bureau of Standards under the direction of F. W. Smither, chemist, and A. W. Epperson, assistant chemist, unless otherwise noted.

TABLE 2.—*Analyses of rock gypsum*

Locality	Calcium oxide (CaO)	Sulphur trioxide (SO_3)	Gypsum ($CaSO_4 \cdot 2H_2O$) (A. S. T. M.)	Combined water (H_2O)	Silica and insoluble (SiO_2, etc.)
Centerville, Iowa	32. 60	44. 40	89. 00	18. 90	1. 74
Medicine Lodge, Kans	33. 16	45. 75	96. 00	20. 05	. 43
Fort Dodge, Iowa	32. 34	45. 40	90. 80	19. 00	2. 60
Port Clinton, Ohio	32. 90	41. 87	74. 20	15. 54	1. 63
Acme, Tex	32. 04	45. 82	93. 80	19. 62	. 16
Ideal, Okla	32. 66	46. 44	96. 00	20. 12	. 10
Grand Rapids, Mich.[1]	32. 94	44. 70	89. 50	19. 00	1. 28
Garbutt, N. Y.[1]	31. 36	33. 74	70. 80	15. 14	. 16
Oakfield, N. Y.[1]	30. 76	43. 78	83. 70	17. 53	. 40
Plasterco, Va.[1]	31. 51	46. 72	74. 50	15. 60	. 75
Nephi, Utah [1]	32. 20	45. 80	98. 00	20. 85	1. 08
Nova Scotia, Canada [2]			97. 80	20. 43	. 11
Alabaster, Mich.[2]			99. 50	20. 96	. 05
New Brunswick, Canada [2]	32. 37	46. 18	99. 00	20. 94	. 10

[1] From Gypsum Deposits of the United States, by R. W. Stone, United States Geol. Survey Bull. No. 697.
[2] From Gypsum, by F. W. Wilder, Iowa Geological Survey, 28.

As stated above, material to be classed as gypsum in accordance with specifications of the American Society for Testing Materials must contain at least 64.5 per cent calcium sulphate, combined in crystalline form with two molecules of water. It is believed that this is generally true of rock gypsum and except for use in the manufacture of Keene's cement and calcined gypsum for the finish coat work of plaster, rock of this composition is entirely satisfactory. However, for the purposes above mentioned, the percentage of impurities permitted is probably too liberal. Even for these products small percentages of the usual impurities are not objectionable if they do not affect the color of the finished material.

The most objectionable feature of the inert and insoluble impurities is that they are diluents. This bureau is at present engaged

[2] Standard Specifications for Gypsum, C22-25, of the A. S. T. M.

in a study of the effects of small amounts of silica, iron oxide, etc., during calcination upon the resulting product. While the work is far from complete and definite statements can hardly be made, the following indications have been noted:[3] (1) The higher the gypsum content the stronger the resulting plaster. (2) The presence of calcium carbonate increases the amount of water necessary to bring the finished plaster to a given consistency. Calcium carbonate also decreases the plasticity and sand-carrying capacity of the plaster. (3) Clay or shale in small amounts have no deleterious effects and may increase the plasticity and sand-carrying capacity of the plaster. (4) Iron oxide if not in sufficient quantity to give "off-color" material acts only as a diluent. (5) Silica in small amounts acts as a diluent and has no marked deleterious effect upon the finished plaster. (6) All soluble salts are objectionable in that they render the setting time hard to control and are always a possible source of efflorescence.

The physical properties of the gypsum rock do not play an important function except in the manufacture of Keene's cement when compact lumps of a suitable size are desirable. These properties need be given only little consideration, however, as all the rock gypsum mined in the United States has the compactness and hardness necessary for the manufacture of this product when the color requirement is met.

There is usually associated with gypsum an anhydrous form of gypsum, anhydrite, having the formula $CaSO_4$, which is not suited for the manufacture of gypsum products. Inasmuch as this material is easily detected by its greater hardness it offers no difficulties and is not worked unless for a particular reason.

(*b*) GYPSITE

Gypsite is exceeded only by rock gypsum in quantity utilized as a raw material in gypsum products. The low requirement of calcium sulphate in the definition of gypsum of the American Society for Testing Materials was made so as to include this material.

Analyses of gypsite from various localities are given in Table 3.

Table 3

Locality	Calcium oxide (CaO)	Sulphur trioxide (SO_3)	Combined water (H_2O)	Silica and insoluble (SiO_2, etc.)	Gypsum ($CaSO_4 \cdot 2H_2O$) (A.S.T.M.)
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Acme, Okla	26.10	32.00	13.96	22.43	66.70
Hamlin, Tex	33.56	42.25	17.64	3.22	84.50
Acme, Tex	28.30	34.12	15.48	14.65	73.40

[3] "The effect of composition on some properties of gypsum plaster," F. C. Welch, Rock Products, **27**, No. 23, p. 27.

The use of gypsite for the manufacture of plaster is limited to the southwestern States, inasmuch as it is in this locality only that the raw material is found. It is marketed as "brown" plaster, and even though the amount of cementitious material is sometimes low the quality of the plaster is entirely satisfactory. However, it should be noted that the specifications of the A. S. T. M. are so broad as to govern the quality of gypsite which may be utilized, it having been found by experience that if less than 64.5 per cent of gypsum is present the finished plaster will be soft and weak.

(c) SYNTHETIC GYPSUM

"Synthetic gypsum" is a term which has been applied to a material which has recently entered the gypsum field. It is usually the by-product of fertilizer and other plants engaged in the manufacture of phosphoric acid from phosphate rock or calcium phosphate. Calcium sulphate is obtained in a finely divided state containing small quantities of phosphoric acid and organic materials.

An analysis of a typical specimen of calcined synthetic gypsum gave the following results:

	Per cent
Calcined gypsum ($CaSO_4 \cdot \frac{1}{2}H_2O$)	58. 7
Calcium sulphate ($CaSO_4$)	37. 2
Phosphoric acid	1. 0
Total	96. 9

From the nature of the synthetic gypsum it is obvious that the phosphoric acid content must always be given consideration. The presence of this material is apt to give trouble for several reasons. It will affect the time of set, efflorescence is possible, and it will attack either the wire lath or the reinforcing if used in structural gypsum products. However, if methods are employed whereby the phosphoric acid is eliminated such gypsum is entirely suitable for the manufacture of gypsum products.

2. GENERAL DISCUSSION OF PROCESS

After the rock is brought down from the mine or quarry face it is necessary that it be further reduced. The first operation may take place in the mine, at the quarry, or at the mills. From the primary crusher the rock goes to the secondary, which is usually fed by gravity. From the secondary crusher the rock is conveyed to either a bin, a storage pile, or directly to the dryer. After passing through the dryer the rock is screened, the fine material going to the kettle bins and the coarse to grinders. When the material has passed through this process it is ready for calcination. However, if a rotary calciner is employed the rock from the dryer without further reduction may be calcined. After having been calcined the treatment of the material may differ slightly, depending upon the method employed for calcination. If the usual type of kettle is used, the hot calcined gypsum is discharged into the hot pit. This is a bin which is located in the rear of the kettle and has for its purpose the cooling, aerating, and blending of the hot calcined gypsum. If a rotary calciner is employed, the hot pit is likely to be very little used, inasmuch as rotary coolers, to a large extent, serve the same purpose. From the hot pit the material is conveyed to storage bins.

Where a rotary calciner is used the burnt rock passes through a cooler and then to pulverizers before reaching the storage bins.

The material from the storage bins may be or may not be further reduced before going to the mixing hoppers, where the retarder and lime or clay are added. The product is then finished except for the mixing and bagging.

From the nature of gypsite it is obvious that when it is the raw material several of the operations enumerated are not always necessary. This is especially true of the crushing and drying.

3. CALCINATION

For the calcination of gypsum two conditions must be met: (1) The raw material must be heated to such a temperature that under the conditions dehydration occurs, and (2) the water liberated by the dehydration must be removed. When the gypsum is heated the first reaction which occurs may be expressed as follows:

$$2(CaSO_4 \cdot 2H_2O) + \text{heat} = 2CaSO_4 \cdot H_2O + 3H_2O$$

The product of the reaction $2CaSO_4 \cdot H_2O$, usually expressed, $CaSO_4 \cdot \frac{1}{2}H_2O$, is known as "the hemihydrate," "first settle stucco," or "calcined gypsum." It is the basis of the great majority of gypsum products. Much work has been done to determine the temperature at which the above reaction occurs, and it is fairly well established that in saturated air with a pressure of one atmosphere gypsum changes to the hemihydrate, $CaSO_4 \cdot \frac{1}{2}H_2O$, at 107° C. (192.6° F.). However, under other conditions the gypsum will lose its water of crystallization at much lower temperatures.[4] The reaction is reversible; that is, the products which result unless separated will reunite with the formation of gypsum, $CaSO_4 \cdot 2H_2O$. It is therefore obvious that the water must be removed.

The temperature at which the remainder of the water of crystallization is removed and setting properties retained is a subject upon which much work has been done but still remains a matter of

[4] Calderon, Bol. Real Soc. Esp. Hist. Nat., **11**, 756; 1911.

discussion.[5] The reaction by which this occurs can be expressed by the equation

$$2CaSO_4 \cdot H_2O = 2CaSO_4 + 2H_2O.$$

The consensus of opinion, however, is that several products which have different properties result. Rohland [6] classifies these as follows: (*a*) $CaSO_4$, which is formed between 130 and 525° C., commonly known as "soluble anhydrite" or "second settle stucco," does not set by itself, but takes up water rapidly to form the "hemihydrate"; (*b*) $CaSO_4$, known as "flooring plaster," formed slightly above 525° C., and which takes up water extremely slowly, finally setting hard; (*c*) $CaSO_4$, formed at 600° C. and above, a "dead burned" form which has no capacity for setting within a reasonable time. As would, therefore, be expected, the material in a calcining kettle or rotary kiln while consisting mainly of calcined gypsum contains also appreciable quantities of "soluble anhydrite," "flooring plaster," and "dead burned" gypsum. However, because of the avidity of "soluble anhydrite" for water the least exposure to the air is sufficient for its hydration.

Upon reaching the dehydration temperature gypsum has lost some or all of its water of crystallization, and in the laboratory it is immaterial whether this temperature be reached quickly or slowly. In the production of plaster, however, the characteristics of the finished material are decidedly different whether calcined rapidly or slowly. Winterbottom [7] has shown that the longer the period of calcination the slower the setting of the plaster obtained. This same investigator [7] has also shown that the size of particles has a material influence on the heat required for calcination, a longer calcination period being necessary for large particles than for smaller ones of the same composition.

In practice, much higher temperatures than theoretically necessary are employed for calcination, from 300° F. (149° C.) to 350° F. (176.5° C.) being common practice where kettles are used, the temperature being measured near the top of the batch. Under these conditions there is little doubt that mixed with the hemihydrate there are other products of calcination and possibly appreciable amounts of raw gypsum. The high temperatures used in the industry have not been wholly due to lack of realization that to produce the hemihydrate a much lower temperature could be used, but have been found necessary for volume production. Furthermore, it has

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[5] Vant Hoff, Z. Krypt. Mineralog., **54**, 200; 1914; Z. Phys. Chem., **45**, 257; 1903; **26**, 727; 1907; Keene, L. H., Jour. Phys. Chem., **701**; 1916; Le Chatelier, Acad. des Scien., Compt. Rend.; 1883.

[6] Jour. Soc. Ind., pp. 906 and 1244; 1903.

[7] Winterbottom, D. C., Plaster of Paris and gypsum, Bull. No. 7., Dept. of Chem. of S. Australia, p. 109, 1917.

been thought that a plaster which has better sand-carrying qualities than one calcined at a lower temperature results. Sight seems to have been lost, however, of the fact that the keeping quality of the plaster is dependent upon the amount of material present which upon aging does not undergo a change, and high temperatures in calcination are conducive to the formation of products which upon exposure change their composition and physical characteristics. It would, therefore, seem that if the calcination could be controlled so as to result in the formation only of calcined gypsum a more nearly uniform material would be obtained with a higher efficiency of the calcination process.

4. CHEMICAL AND PHYSICAL PROPERTIES OF CALCINED GYPSUM

Calcined gypsum when pure may be said to contain 55.2 per cent sulphur trioxide, 38.6 per cent calcium oxide, and 6.2 per cent water. It has the chemical formula $CaSO_4 \cdot \frac{1}{2}H_2O$, indicating that it is calcium sulphate combined with one-half molecule of water of crystallization. The article of commerce, however, may and usually does vary widely in composition from the chemically pure compound. Inasmuch as the rock or gypsite from which the calcined gypsum is made may contain limestone, iron oxide, clay, or silica it is to be expected that these materials will be found in the calcined gypsum. Other substances, including hydrated lime, talc, asbestos, etc., which are added to improve the working qualities, will also be found in the commercial product.

The color of calcined gypsum, while depending somewhat on the color of the raw material, is always lighter and varies from nearly white to gray.

The most valuable property of calcined gypsum is its ability to combine with water, resulting in a hard, dense mass of gypsum. It is not within the scope of this paper to go into the mechanism of the setting of gypsum, inasmuch as it is a subject which, after many years of study by numerous investigators, is still a much mooted question. Two explanations have been advanced. The oldest and most generally accepted is that it is a process of recrystallization; that is, the calcined gypsum is dissolved in the mixing water, when the concentration reaches a certain degree gypsum crystallizes out, more calcined material going into solution. This process continues until the available water is used up. The other explanation which is advanced by not a few chemists is that the process is crystallization from the colloidal state; that is, the calcined gypsum unites with the mixing water with the formation of a colloid which in time changes to crystalline gypsum. Regardless of how the formation of gypsum occurs from calcined gypsum, the fact that it may be controlled at will is the property which has given to gypsum its present place in the building industry.

5. KEENE'S CEMENT

In the usual nomenclature "calcined gypsum is used to indicate material which retains a part of the water of crystallization present in gypsum, or, as in the case of soluble anhydrite, a material which on exposure readily takes up water with the formation of the hemihydrate. However, if gypsum is heated to a temperature of approximately 1,832° F. (1,000° C.) a completely dehydrated product is obtained which when accelerated to set in 24 to 48 hours is marketed as Keene's cement.

Inasmuch as the process employed in the manufacture of Keene's cement, both in the burning and the accelerating, differs quite widely from plant to plant, it is possible to make only a few statements which may be accepted as applying in all cases. These may be summarized briefly, as follows: As nearly white and compact a rock as possible is required, the gypsum is burned at a temperature of about 1,000° C. and in lump form, the accelerator is a salt which is added either before burning or after burning and grinding.

As it is usually used on the surface it is desirable that the rock from which Keene's cement is manufactured be as nearly white as possible, for unless the color is satisfactory a material of no commercial value results. If the rock is not compact it will not prove suitable for burning because of the process employed, which is burning in a shaft, rotary kiln, or a beehive oven.

The accelerator originally employed in the manufacture of Keene's cement was alum. It was added to the rock after burning. The practice at present is not uniform. However, salts other than alum are used with success, including potassium sulphate, borax, and aluminum sulphate.

If during the setting of Keene's cement it is troweled, a surface can be obtained which is harder and more dense than can be obtained with calcined gypsum. It can be further polished to a very high finish. One of the major uses of Keene's cement is in the production of artificial marble, travertine, etc.

III. PROCESS OF MANUFACTURE OF CALCINED GYPSUM

1. MINES

As rock gypsum usually occurs in nearly horizontal beds, the mining problems encountered are not difficult. The customary room and pillar system is employed in a large majority of mines. The pillars are left standing until the time when the work in a given section is to be abandoned, when they are withdrawn. The size of the pillars is dependent on the overburden to be carried. The compressive strength of the rock is assumed as 1,000 lbs./in.^{2} and the size of pillars computed from the amount of overburden.

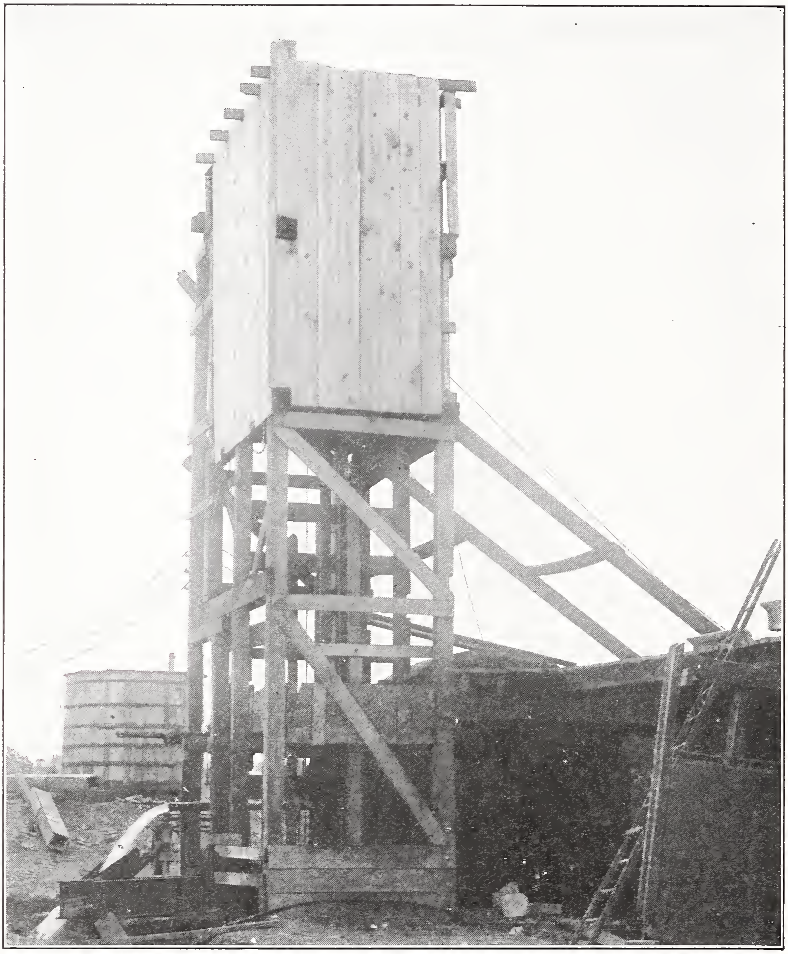

FIG. 1.—*Tipple and mine shaft, Centerville Gypsum Co., Centerville, Iowa*

Note flow of water from mine

It is the practice where the face is in excess of 20 feet to work the vein in ledges of 9 or 10 feet. Experience has shown that it is not good economy to attempt the working of a vein whose face is less than 4 feet.

Due to the comparative solubility and softness of gypsum, it is to be expected that water passages from either the surface or a water-carrying sand would penetrate into the mine. This is universally true.

The most economical method of handling water in a mine is by drainage into a "sump" and then elevation to the surface by a pump. The size and number of pumping units necessary depend upon the quantity of water to be disposed of.

(a) DRILLING

The very nature of gypsum rock has made drilling a comparatively easy and inexpensive process. Until recently all drilling was done with hand augers of 1½ to 2 inches in diameter. At present electric and air drills or augers have replaced these. The usual procedure is to drill the holes horizontally to a depth of from 8 to 12 feet. Spacing in a vertical direction is from 1 to 3 feet, depending on the degree of fineness to which it is desired to shatter the rock. The holes are bored at angles in such a manner that a wedge-shaped volume is displaced.

(b) BLASTING

There are two general methods in use in the blasting of rock gypsum, depending upon the desired condition of the rock after the blast, namely, whether it is desired to shatter the rock into as small pieces as possible or to bring the rock down in large pieces. The difference in operating to obtain the different results depends upon the number and position of the holes and the kind of explosive used. The more finely the rock is to be shattered the closer the holes should be to each other and the more powerful must be the explosive. The method whereby large pieces are brought down requires less explosive for the initial blast, but in order to be handled, further reduction is necessary, requiring more drilling and blasting, probably to such an extent that for completion more labor and explosives are needed than in the method in which the rock is shattered. However, practice favors the double blasting method because of the large production of the desired fine material.

In the blasting of a material which runs so nearly uniform in hardness the selection of an explosive depends primarily on the method of blasting which is to be employed. Experience has shown that a 20 per cent dynamite is satisfactory in all cases except where the rock of the deposit is unusually hard and dense. Then a higher percentage dynamite must be used to obtain the same results

(c) SORTING AND LOADING

After the rock has been blasted loose and thrown down to the mine floor the larger pieces are broken up by dynamite, by a method termed "pop shooting." Holes are drilled into the lumps and charged with the explosive, a method in opposition to one formerly employed, in which the explosive was laid on top of the rock and covered with mud, termed "mud capping." The latter method has been abandoned except in isolated cases. The rock is broken still smaller by sledging until it is reduced sufficiently to be handled by hand. It is then loaded into the mine cars and transported out of the mine. Loading is done by hand so that the rock may be sorted. Sorting is necessary in most mines, as the rock may contain large percentages of material not suited for calcination. Such materials which are discarded include anhydrite, flint, shale, limestone, and salt.

2. QUARRIES

Twenty years ago practically all gypsum was quarried. This method of obtaining the raw material has diminished until at present the number of mines greatly exceeds the number of quarries. However, a few quarries are still active, and in certain localities it is the only feasible method of winning the gypsum.

(*a*) STRIPPING

When gypsum is quarried, there is always a certain amount of material overlying the gypsum which has to be removed. The removal of this overburden is called stripping. Unless the bed of gypsum lies in a parallel plane with reference to the surface, the thickness of the overburden will be uneven. Several methods of stripping are in practice, depending more or less on the thickness of the overburden to be removed. If the overburden is only a few feet in thickness, it is removed by either plow and scraper or by hand digging and carts. If the thickness is greater, a more economical method is by shovel, either electric or steam. The method employed in stripping is also dependent somewhat on the nature of the overburden.

(*b*) DRILLING

After the overburden is removed holes are drilled in the rock preparatory to blasting. This is done by hand augers or electric or air drills. The holes are usually 1½ or 2 inches in diameter and may be vertical or vertical and horizontal. They are from 8 to 12 feet deep and spaced with reference to the type of explosive used and the degree of fineness desired in the blasted rock. The vertical holes are usually 6 to 10 feet back of the working face.

(*c*) BLASTING, SORTING, AND LOADING

The same considerations which apply to blasting, sorting, and loading in mine work are applicable to quarry work.

3. PITS

In the southwestern fields many deposits of gypsite are worked. This is a material formed by the disintegration of gypsum rock. It usually occurs near the surface in beds of 1 inch to 20 feet or more in thickness. It is a clay-like material and as such is easily worked.

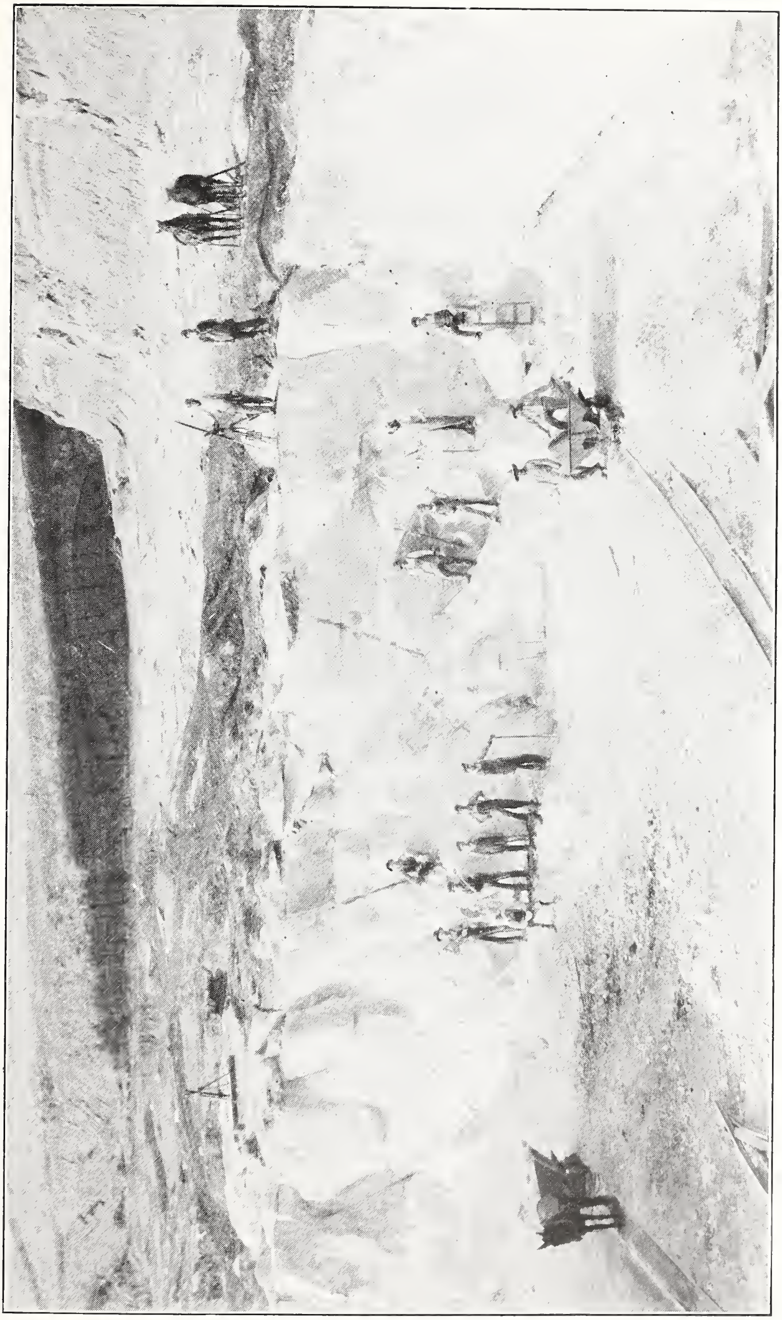

Fig. 2.—*Gypsum quarry, Kling, Kans.*
Best Bros. Keene's Cement Co., Medicine Lodge, Kans.

(*a*) STRIPPING

The gypsite deposit is usually overlain with a layer of variable thickness of clay or soil. This is removed by stripping with plow and wheeled scrapers if less than 4 feet in thickness. Overburdens more than 4 feet have not proved economical to remove except in isolated cases where an exceptionally heavy deposit is exposed by removal of the overburden.

(*b*) LOADING

In working a gypsite deposit loading is usually accomplished by hauling the plowed gypsite by wheeled scrappers to cars in which it is transported to the mill. Where the deposit is of sufficient thick-

Fig. 3.—*Method of collecting gypsite after plowing*

Certain-teed Products Corporation, Acme, Tex.

ness shovels, electric or steam, may be used economically to load the cars.

(*c*) SORTING

There is usually no sorting done at the pit. The material is screened at the mill to remove substances not suitable for calcination. A somewhat similar process, though not sorting, is necessary in the pit, however, for the production of a good plaster in order that seams and plugs of clay or marl, which frequently occur in gypsite deposits, be not sent to the mill. Such material is easily discernible by either the color or texture and is not worked.

4. METHODS OF TRANSPORTATION

(*a*) MINES

The method of transporting the rock from the face of the mine to the entrance is essentially the same in all workings. The rock is loaded by hand into narrow-gauge cars of a capacity of from 1 to 5 tons. These are drawn to the entrance by mules or horses or are assembled into trains of from 8 to 12 cars, the trains being hauled to the entrance by electric locomotives. The choice of the two methods used in the mine are based upon the length of haul. If short, there is no objection to the use of mules or horses. As the workings are extended the face becomes too far removed for economical work in this manner. It is then that electrification becomes an economical necessity.

The transportation from the mine entrance to the mill offers no difficulties except in isolated cases, as it is customary to erect the mill either over or in close proximity to the mine entrance. At one mill which was visited the mine entrance was one-half mile from the mill. Transportation to the mill was by aerial tramway.

(*b*) QUARRIES

Where quarries are worked the varieties of transportation to the mills are almost as numerous as the quarries. This is to be expected, since the method must be varied to comply with the particular conditions at each mill, such as the distance of the quarry from the mill, shape of the quarry, location of crushers with reference to the quarry, and the tonnage to be handled. The methods used include cars drawn by horses or mules, cable or locomotive, and cars or buckets transported by aerial tramway. It is frequently the custom to use two or more of these methods in combination.

The horse or mule and cart has an advantage over the other means of transportation in that it can follow the working face of the quarry no matter how the face shifts. If the distance to the mill is not too great, this means of transportation may be used. The method is very slow, however, and is not to be recommended when a considerable tonnage must be moved.

Tramcars have the disadvantage of requiring tracks. These tracks must be extended and shifted to keep up with the working face, and they must be moved every time a blast is made. If the quarry is less than one-half mile from the mill and located above the mill, an economical method of transportation is by hauling the cars to the crest of the hill by either animals or cable and lowering to the mill by gravity, the empties being returned by a donkey engine or electric hoist and cable.

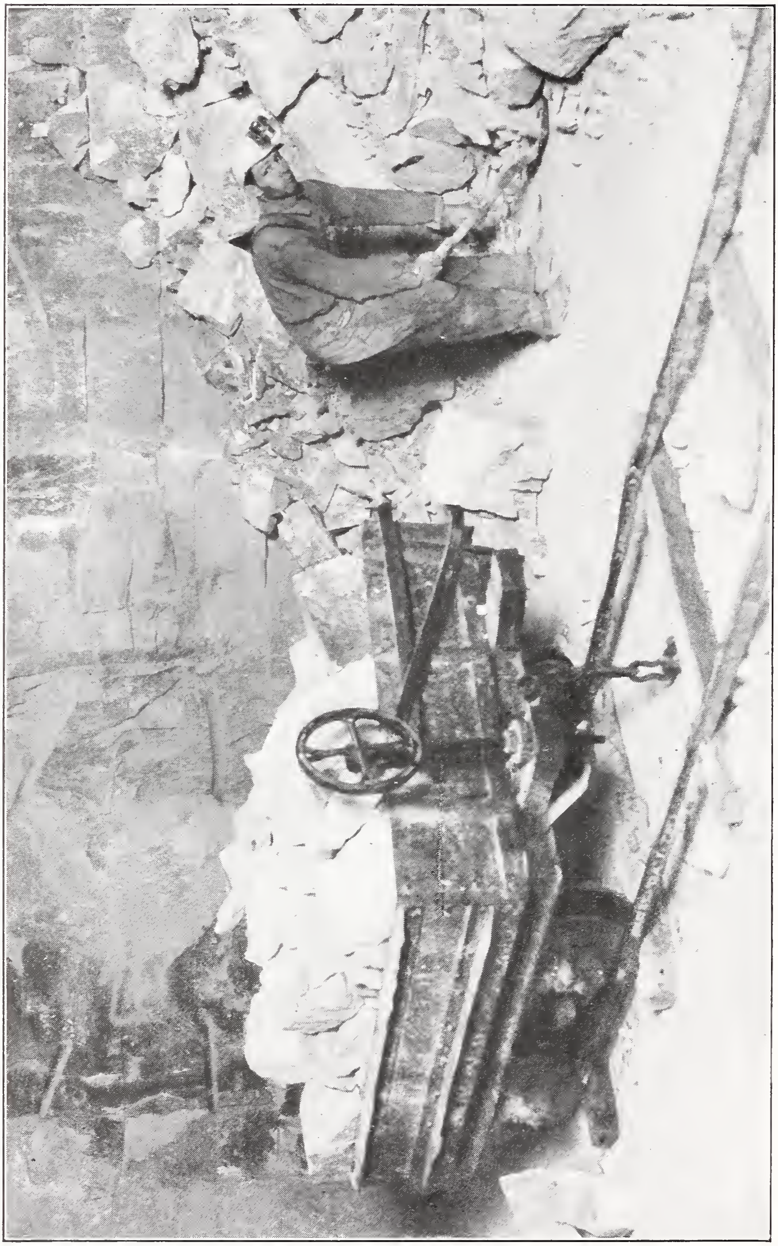

Fig. 4.—*Interior of gypsum mine*
The Universal Gypsum Co., Fort Dodge, Iowa

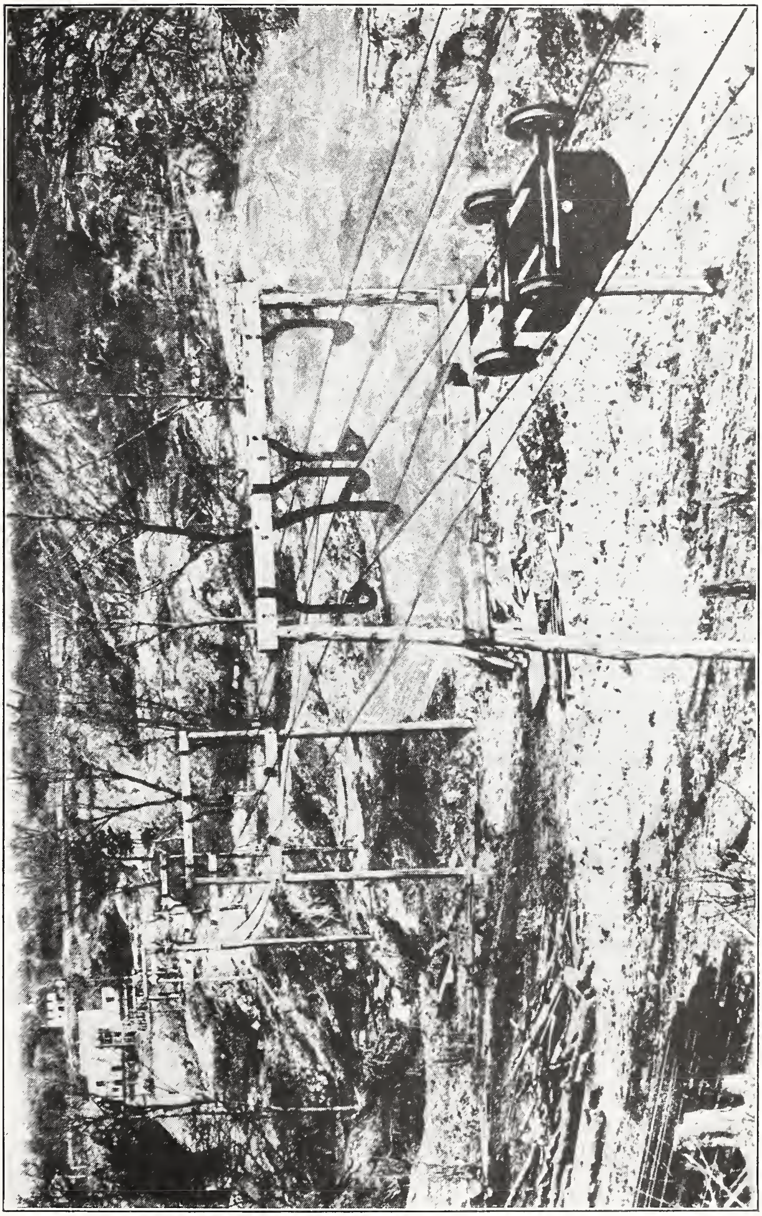

FIG. 5.—*Aerail tramway*
The Universal Gypsum Co., Fort Dodge, Iowa

Experience seems to indicate that the construction and upkeep of an aerial tramway are higher than for the other methods of transportation. Moreover, it is not adaptable to the changing face of the quarry, so that some other means must be relied upon to take the rock to it. Such tramways may be necessary, however, in some instances, as when the rock must be carried over a hill too steep for locomotive or animals or over a railroad track, river, or ravine.

(c) PITS

Transportation methods at mills working gypsite deposits are more or less uniform, as the conditions encountered are essentially the same in all cases. If the distance which the raw material is to be moved is

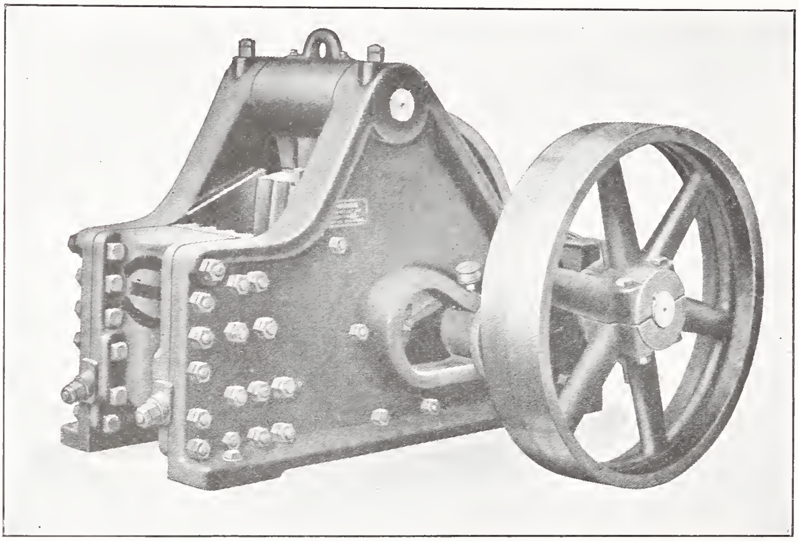

FIG. 6.—*Type of jaw crusher used extensively for primary crushing*

comparatively short, horse or tractor drawn wheeled scrapers may be used satisfactorily. As the deposit is worked and the distance becomes greater it is better to lay tracks and haul cars loaded by the scrapers to the mill by locomotive.

5. METHODS AND DEGREE OF CRUSHING

The crushing operation at a gypsum mill consists essentially of two stages, the first in which a jaw, gyratory, or roll crusher is employed, and the second in which a pot or roll crusher or a hammer mill is used. The jaw, gyratory, or roll crusher receives the rock as it is discharged from the cars, reduces it to 3 inches or less, and delivers by gravity into the secondary crusher. The size of the jaw crusher or gyratory must be of sufficient capacity to take care of the tonnage demanded by the mill. In the 17 mills where the primary crushers were noted

9 used gyratories, 6 jaw crushers, and 2 rolls. All three types were giving entirely satisfactory results. However, a criticism often made of gyratories and roll crushers is that they tend to "gum up;" that is, the material builds up on the metal at the places where pressure is applied. This objection is not substantiated, however, if the equipment is amply large to take care of the amount fed into it. A type of jaw crusher commonly used is shown in Figure 6.

The pot crushers are very much like large coffee mills in operation. Their function is to reduce the 3-inch rock from the nipper or gyratory to three-fourths inch and less. Within a corrugated shell made in the form of an hourglass are two corrugated cones, the upper one coarse ribbed and the lower one with fine corrugations to match those on the sides of the shell within which it revolves. The crusher may be driven from above or below by a bevel gear. The principal advantage in having the gears located above the crusher is to obviate as much as possible trouble from dust, which is always a matter of concern. If the gears are located below the crusher, there is the added possibility of trouble from fines, which at times leak through at this point in appreciable quantities. A crusher of this type is shown in Figure 9. In the mills visited 12 used pot crushers for this operation, 4 hammer mills, and 2 Edison rolls. Few hammer mills are used because of the

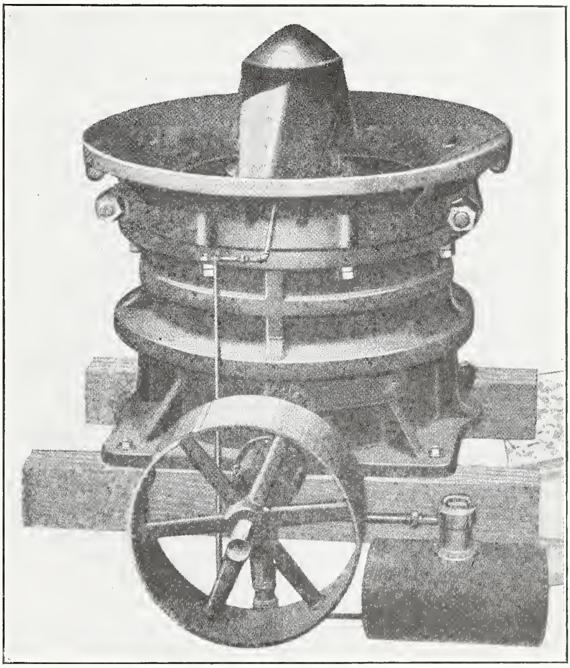

FIG. 7.—*Gyratory crusher used for primary reduction*

belief that the angular particles produced by such mills do not give the finished product the desired working qualities which it is thought that the rounded particles resulting from pot crushing do. It is hardly possible that this objection carries much weight when a hammer mill is employed at this stage of the refinement process. Furthermore, the large capacity and low power requirement of such mills more than compensate for any criticism of this nature.

Further reduction of the raw rock is accomplished in buhr, emery, hammer, roller, or tube mills. Of the mills visited 9 employed buhr mills. 6 roller mills, 4 hammer mills, and 7 combinations of two or more types of mills

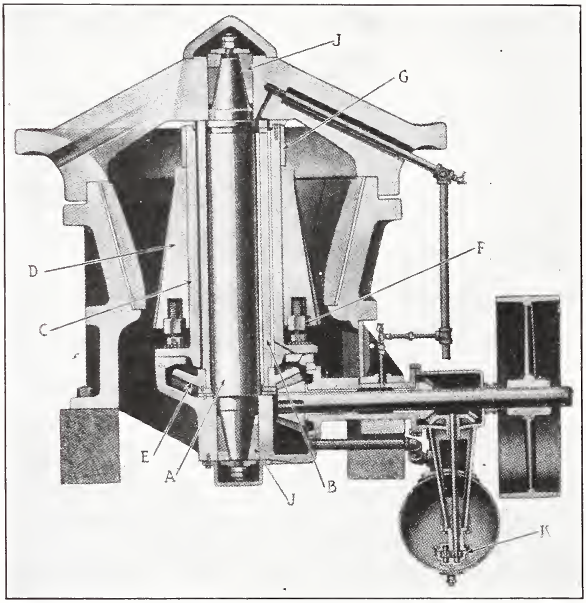

Fig 8.—*Sectional view of gyratory crusher*

A, Rigid central shaft; *B*, sleeve eccentric; *C*, flanged head liner; *D*, crushing head; *E*, gear; *F*, jack-screws; *G*, split distance ring; *J*, expansible taper bushings, *K*, oil pump

As the name indicates, the effective means of disintegration employed by the buhr mill are buhrstones. Two such stones circular in shape are mounted in such a manner that one is stationary while the other revolves concentrically against it. Several grooves are cut in the grinding surface of each stone. In the center of the stone through which the material is fed is a hole 8, 9, or 10 inches in diameter. The first cost of buhr mills is low, which is in their favor, but their upkeep is high, as it is necessary to dress the stones quite frequently, a work requiring skilled workmen if a uniformly fine product is to be secured. Moreover, the power consumption of buhr mills is high when exceedingly fine grinding is desired. The sizes usually employed have diameters of from 24 to 42 inches.

A mill acting on the same principle as a buhr mill, except that the buhrstones are replaced by emery stones, is a recent modification. They may be obtained in the same sizes as buhr mills and in two types—the vertical and horizontal. In these mills blocks of emery are set in a base of cement. The emery being much harder than the buhrstones, mills of this type do not require the attention that the buhrs do.

Disintegrators of the hammer mill type have been used to a limited extent for many years in the gypsum industry. The rock is finely reduced by means of rapidly rotating hammers, striking by centrifugal force. The capacity of this type of mill is high, the first cost not excessive, and the power consumption low.

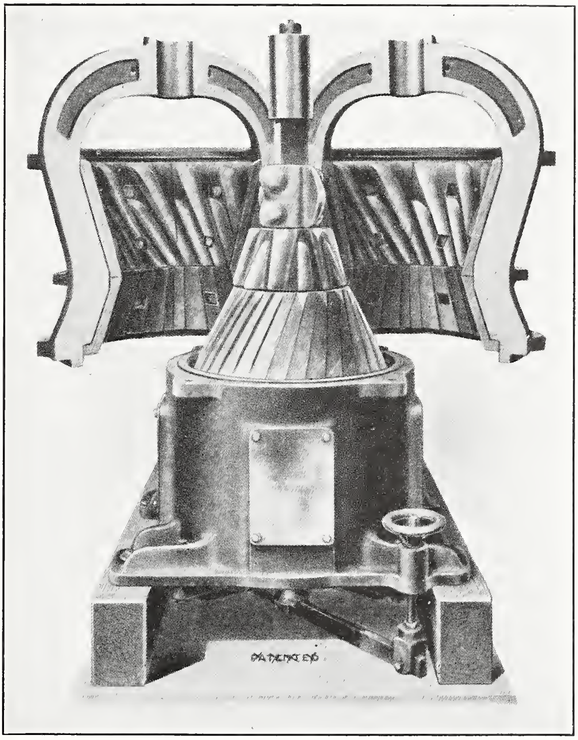

FIG. 9.—"*Pot crusher*"
Used for secondary reduction

Within the last few years the tendency in the gypsum industry has been toward finer grinding. Consequently, two types of disintegrators are at present used in an attempt to achieve this result. They are the roller and tube mill. Both are especially advantageous where the rock to be ground contains silica, flint, or cherty material, which is exceedingly deleterious to buhr or emery stones. The essential principle involved in roller mills is that crushing is done by rollers. Separation of the fine particles is accomplished by air. The air stream is created by a large fan, and simple adjustments of the fan are all that is necessary to change the size of the particles removed. In standard roller mills one horsepower per ton of gypsum ground each 24 hours is required, the rock being reduced to such a degree that 90 per cent will pass a No. 100 screen.[8]

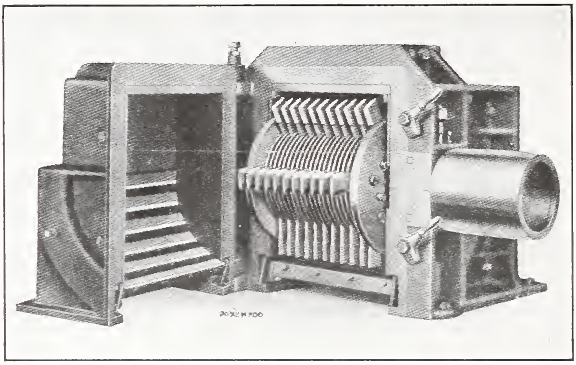

FIG. 10.—*Hammer mill*

The type of roller mill extensively used in the gypsum industry has four or five heavy rolls suspended from a central shaft. When the shaft is rotated, the rolls by centrifugal force are pressed against a broad steel ring. The raw rock is mechanically fed into the machine.

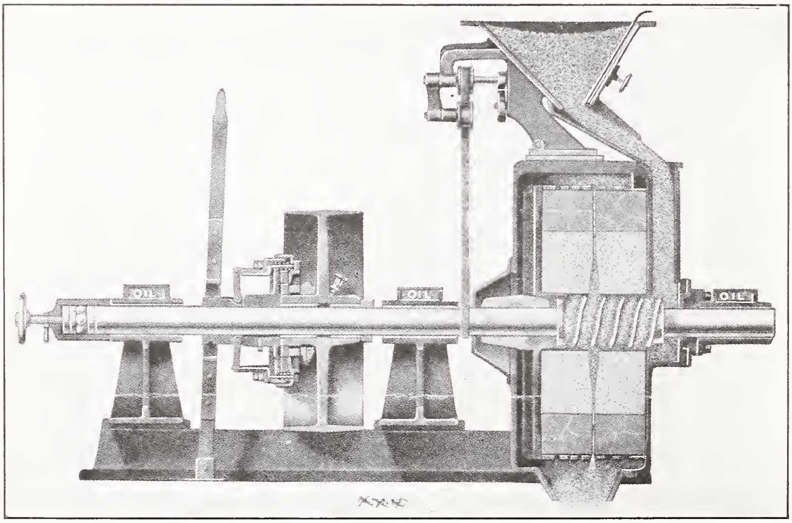

FIG. 11.—*Sectional view of vertical emery mill*

Properly arranged blades keep it crowded against the ring, so that it is forced between the rolls and the ring. The fines are carried to a collector by a strong air stream produced by a fan. In the collector the coarse material is separated and returned to the mill for further grinding. Such a type mill is shown in Figure 15.

[8] Iowa Geological Survey, 28, p. 219; 1917–18.

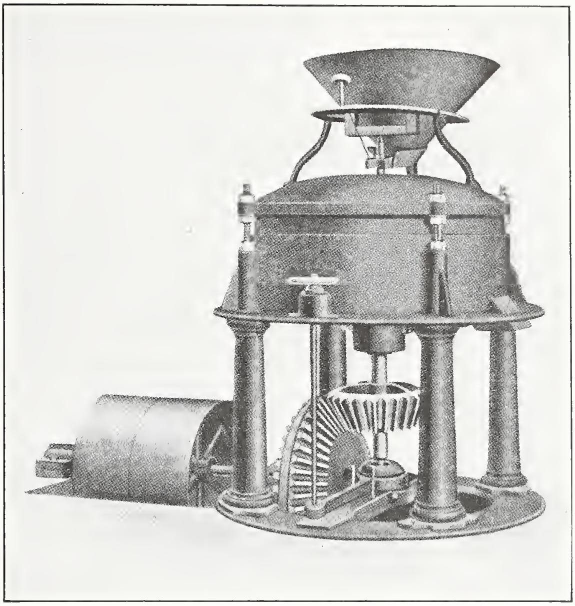

Fig. 12.—*Gear-driven buhr mill*

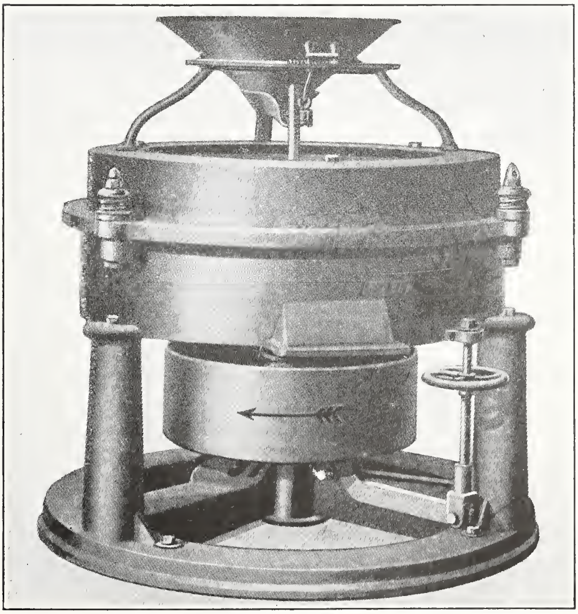

Fig. 13.—*Horizontal emery mill*

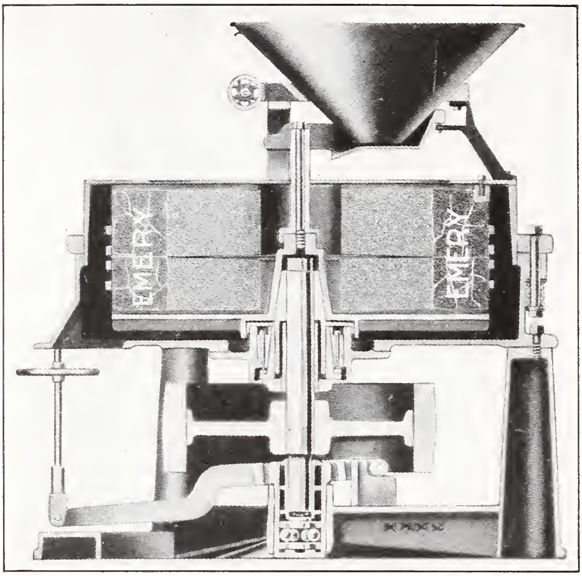

FIG. 14.—*Sectional view of horizontal emery mill*

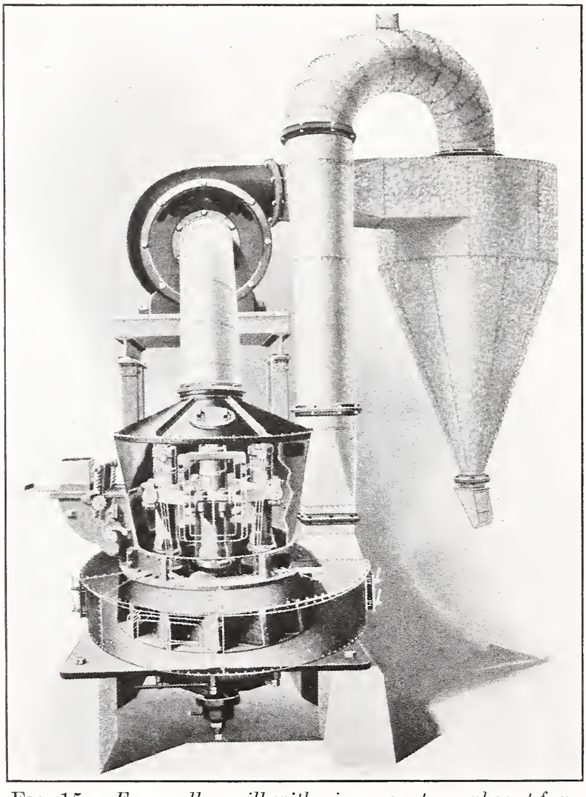

FIG. 15.—*Four roller mill with air separator, exhaust fan, dust collector, and piping*

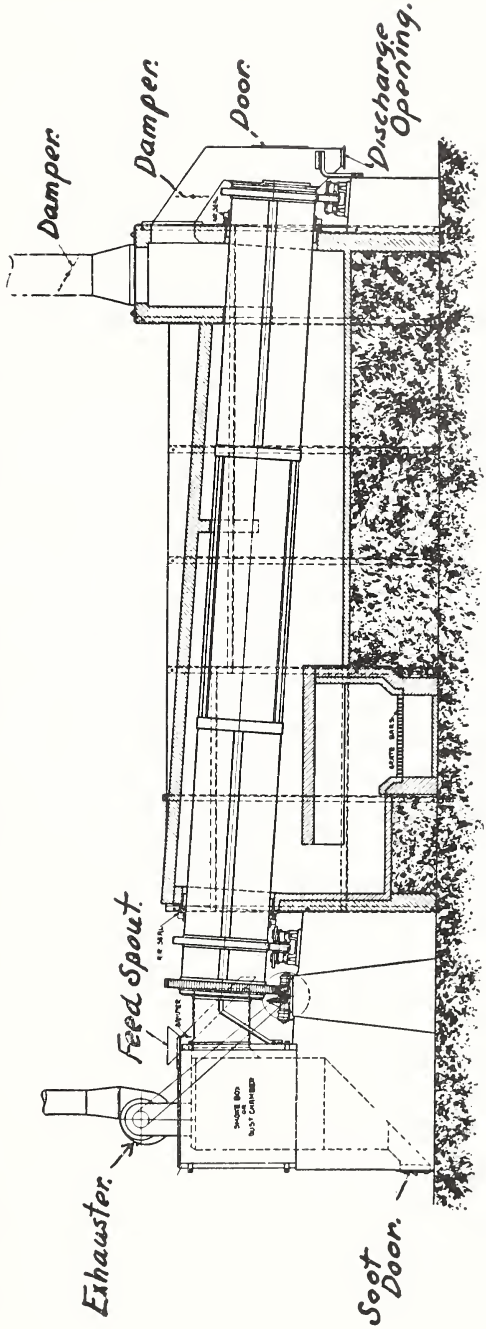

FIG. 16.—*Diagram illustrating set-up of rotary dryer*

Tube mills are a still more recent innovation in the gypsum industry. They have come as a response to the plaster contractors, who have demanded an easy working material with high sand-carrying capacity. Tube mill grinding partially meets these demands. Mills of various sizes and types are used. The degree of fineness desired governs the amount and size of balls used. One and one-half inch polished steel balls have proven satisfactory in many installations. Many difficulties have been overcome in plants where tube mill grinding has been applied to calcined material, not the least of which is a tendency of the gypsum to "ball" or "gum up" the mill and bagging machinery. When this condition occurs, two methods have proved satisfactory in overcoming the difficulties. The first is accurate control of the feed. A mill may satisfactorily grind a specific amount of calcined gypsum; if this amount be diminished, "gumming" occurs. When the mill can not be uniformly fed a small amount of finely divided silica fed in with the calcined gypsum will eliminate "gumming." However, the silica added acts as an inert material, reducing the sand-carrying capacity of the plaster.

Inasmuch as fine grinding is done either before or after calcination, it is not possible to make a statement as to where each type of equipment is customarily employed. Obviously, the primary and secondary crushing is upon the raw rock. Hammer, emery, buhr, and roller mills are usually employed, though not always, before calcination. In the mills visited where tube mills were used they were employed after calcination in all cases except one.

6. SCREENING

An essential feature of all gypsum mills is the screening of the material at various stages of refinement in order to obtain as nearly uniform a product as possible. In every case the gypsum is passed over at least one set of screens before going to the packers, and not infrequently two or three sets.

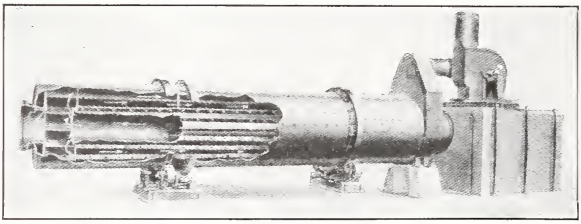

Fig. 17.—*Type dryer used in many gypsum mills for driving off moisture in the raw rock*

Diagram shows flow of gases

Where rock gypsum is the raw material it is common practice to have a ¼ or ⅜ inch screen so located that the rock from the crushers must pass over it. This procedure is always followed in mills equipped with driers, the coarse rock going to the driers, the fines to bins for grinding. Various types of screens are used at this stage of the grading, including grids, reels, or shaker screens.

Where a gypsite deposit is worked, the preliminary screening operation is omitted, the gypsite going directly to the kettles from the pit without any treatment.

After the gypsum rock has been dried and crushed it is screened before calcination in order that as nearly a uniformly graded material as possible be sent to the kettles. In some mills screening before calcination is the only fine grading operation employed. The mesh of screen used at this stage of refinement depends upon whether or not further screening after calcination is to be done. If not, a 35-mesh screen elevated at an angle of from 30 to 35° gives satisfactory grading. If further screening follows in the treatment, a screen with larger openings may be used

The tendency to the production of a finer and more nearly uniform product has led to the installation of screens after calcination in many mills. The mesh here employed is from 30 to 35, elevated at an angle.

Whether the fine screening be done before or after calcination, or both, the vibrating or hammer type screen has been found satisfactory. A screen of this type is illustrated in Figure 18.

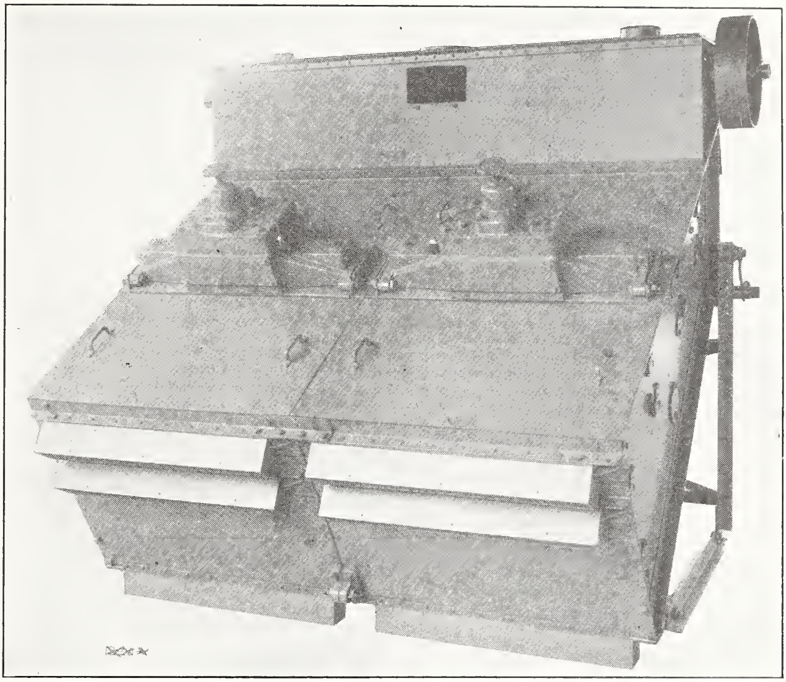

Fig. 18.—*Six-foot, two-surface, electric, vibrating screen, inclosed, with screw feed distributor*

7. TEMPERATURE AND DURATION OF CALCINATION

When gypsum is heated under atmospheric pressure in saturated vapor to a temperature of 107° C. (225° F.), it loses three-fourths of its water of crystallization, becoming calcined gypsum.[9] Further heating under the same conditions results in the formation of an anhydrous calcium sulphate, termed "soluble anhydrite." These are the two major constituents of material calcined in kettles. The proportions of each present depends upon the temperature and duration of calcination.

[9] Glasenapp, Jour. Soc. Chem. Ind., p. 858; 1908.

In practice it is customary to calcine at temperatures higher than theoretically necessary. Two reasons may be given for this: (1) In order that the contents of either kettle or rotary be raised to a sufficiently high temperature throughout the mass (of a certainty the material is heated higher than necessary for "calcined gypsum"), (2) the belief that a limited amount of "soluble anhydrite" materially improves the quality of the plaster. This material is obtained by heating to a temperature in excess of 107° C.

The time necessary for proper calcination is variable, depending upon several factors, including condition of raw product, size of unit, fuel used, temperature of drawing, method employed in calcination, and rapidity of removal of water. If the time of calcination is increased, the time of set is also increased.[10]

The temperature at which gypsum is calcined materially affects some of its properties, especially the time of set. Results of work in the laboratory of the Bureau of Standards which have not been published entirely corroborate Winterbottom's results that calcination at higher tempreatures causes the prolongation of the time of set. However, the prolongation of the time of set may be attributed to more nearly complete calcination rather than to the formation of "soluble anhydrite," as proposed by Winterbottom.

8. DETAILED DESCRIPTION OF CALCINING UNITS

(*a*) KETTLES

Until quite recently practically all of the gypsum calcined in the United States was the product of especially constructed vertical cylinders, termed by the industry "kettles." One of these is illustrated in Figure 19.

(1) Size and Capacity.—The usual diameter of kettles is 8, 10, or 12 feet, with a depth of 8 or 10 feet. With these dimensions the kettles hold from 8 to 15 tons of raw material.

(2) Bottoms, Tops, Flues.—The shell is cylindrical in shape and of steel three-eighths to three-fourths inch in thickness. The bottom of a kettle is a segment of the surface of a sphere, concave, its maximum height being from 6 to 12 inches. The bottom is either solid or sectional and made of cast iron or steel. A sectional bottom is one that is made up of pieces. Bottoms of 6 pieces are quite common and those of even 15 not unusual. The triangular pieces are bolted together. The thickness of the bottom is from 1 to 3 inches. The use of the sectional bottom has been brought about in an effort to increase the life of the bottom by elimination of cracking, which has always proved a source of trouble. It seems to have served its purpose.

[10] Winterbottom, D. C., Gypsum and plaster of Paris, Bull. No. 7, Dept. of Chem. of South Australia, p. 109; 1917.

The top of a kettle is sheet iron with openings for the agitators, thermometers, and dust spouts, besides the doors through which the process of calcination is observed. Each kettle is usually equipped with four flues, 6 to 8 inches in diameter. In gypsite kettles the flues are horizontal, and "in a line" and about 18 inches from the bottom of the kettle. In mills using rock gypsum the flues are horizontal, and two are about 18 inches from the bottom and two

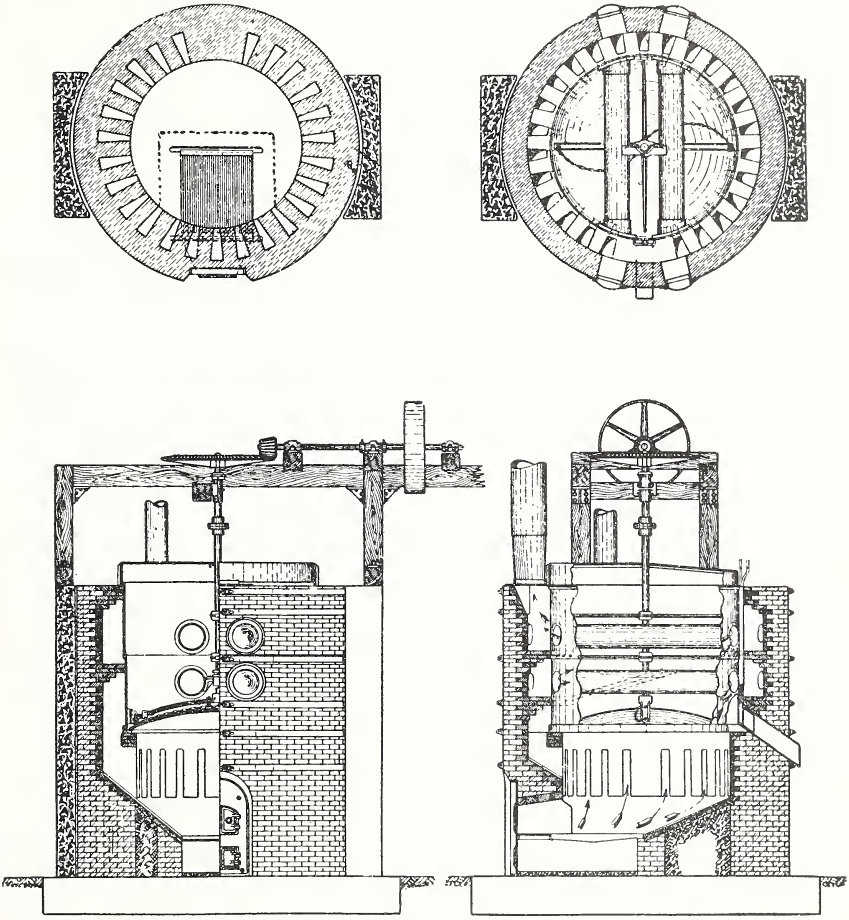

FIG. 19.—*Diagram illustrating calcining kettle and setting*

12 to 14 inches above these and at right angles. Fire brick is used to inclose the shell of the kettle and is usually from 6 to 14 inches from the shell itself. A "lip ring" is used to support the kettle, care being taken to protect the "ring" from the direct heat of the fire box.

The distance from fire door to the rear of the combustion chamber is about 12 feet. The grates occupy the front 6 feet. The kettle is so designed as to distribute the heat on the sides and through the flues in such a manner that excessive heating of the bottom is more or less eliminated. Ports are provided below the brickwork protecting the "lip ring" from the heat and gases, allowing the gases to pass out into the space at the sides of the kettle, thence into the flues. The flues and ports are not in a line, and baffles of fire brick between the shell and outer wall direct the gases over the lower portion of the kettle before allowing them to pass through the flues and out of the stack.

Where kettles are employed it is not customary to use a forced draft, the stacks being built of sufficient height to give the necessary draft. As considerable combustion takes place in the space between the kettle and side walls as well as in the flues, provision must be made for this in the design of the kettle stacks. While no actual figures are obtainable on the efficiency of combustion in kettle calcining, observation of the smoke issuing from the stacks shows that there is a considerable loss in incomplete combustion which indicates that in this method of calcination there is room for improvement.

To prevent excessive heating of material on the bottom, sides, and flues, and under heating of material not near the heating surface, each kettle is equipped with mechanical agitators. The agitators consist of two sweeps to which chains are attached, one dragging the bottom and a second just above the flues. The sweeps are attached to a shaft that is pivoted in the kettle bottom and driven by a bevel gear above the kettle. It is to the effectiveness of the agitators that the length of service of the bottom of a kettle is due. However, the greater portion of the agitation of the mass is due to the ebullition of gypsum when the water of crystallization is driven off.

In the calcination of gypsite it is customary to use scrapers on the sides of the kettle as well as the bottom, on account of its dampness giving rise to excessive sticking.

(*b*) ROTARY CALCINERS

In an effort to obtain a continuous method of calcination there have been tried in recent years several types of rotary calciners. Only one, however, the rotary kiln, has proved satisfactory.

(1) Size and Capacity.—The rotary kilns in use are in reality a modified type of the kilns which have for years been used in the cement industry. They consist, essentially, of an inclined cylindrical tube of steel which is rotated on an axis by a gear located on the exterior; usually at about the quarter point of the kiln. The length of the kiln may be anywhere from 70 to 110 feet with a diameter of about 6 feet. The crushed rock is fed into one end by gravity from a bucket elevator or screw conveyer and drops out of the opposite end into a screw conveyer or a bucket elevator where it is cooled

and aerated. The capacity of this type kiln is from 10 to 20 tons of calcined gypsum per hour, depending upon the size and speed of operation, etc. This type of calciner is operated using crushed rock of from one-fourth inch diameter to 1 inch. If smaller than one-fourth inch stone is used, the fine material which is carried out by the draft is caught in dust collectors and is mixed with the material in the supply bins. However, the calcination of large pieces of rock, such as are necessary in this type of operation, demands close control of the final grinding and mixing in order that a uniform product be produced.

(c) HEAT REQUIRED FOR CALCINATION

An attempt was made to obtain data relative to the fuel consumed in the process of calcination. However, in many mills a record of

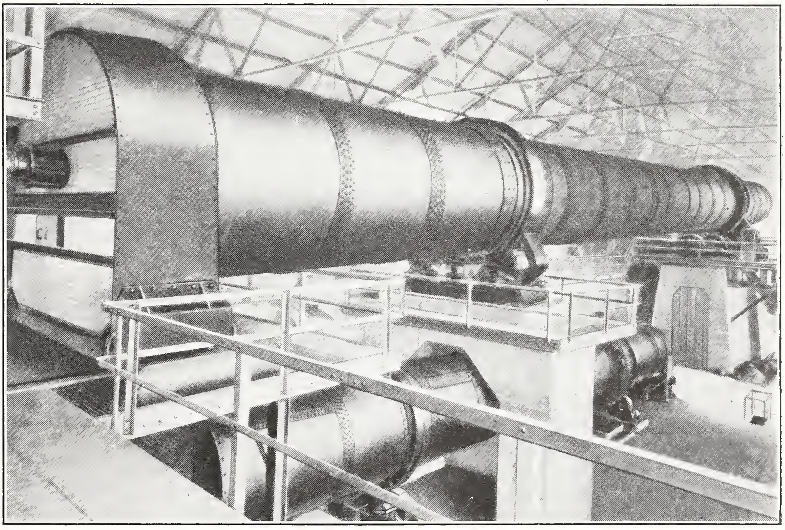

Fig. 20.—*Rotary kiln (100 by 5 feet) with rotary cooler (73 by 7 feet) showing firing hood*

the fuel for power is not separated in any way from that used in calcination, so the figures given below are only approximate at the best.

Process	Fuel	Drawing temperature	Pounds of fuel per ton of gypsum	B. t. u. used per pound of gypsum
Kettle	Oil	400° F. (204° C.)	107	1,015
Do	do	330° F. (165° C.)	33	317
Do	Coal	330° F. (165° C.)	67	397
Do	do	356° F. (180° C.)	79	473
Do	do	330° F. (165° C.)	75	459
Do	do	305° F. (152° C.)	72	430
Rotary	do	550° F. (288° C.)	103	620
Do	do	450° F. (232° C.)	84	505

The calculation of the theoretical amount of heat required for calcination, based upon a 100 per cent gypsum, with an initial temperature of 68° F. (20° C.) and a calcination temperature of 356° F. (180° C.), may be of interest.

Since the specific heat of gypsum is 0.259[11] the heat necessary to raise its temperature from 20° C. (68° F.) to 180° C. (356° F.) is $0.259 \times 160 = 41.4$ calories per gram.

The heat absorbed in the decomposition of gypsum, $CaSO_4 \cdot 2H_2O$, to the compound $CaSO_4 \cdot \frac{1}{2}H_2O$ and liquid water is 3,921 calories per gram molecule of $CaSO_4 \cdot 2H_2O$.[12] This is equivalent to 22.8 calories per gram.

One gram of $CaSO_4 \cdot 2H_2O$ on decomposition liberates 0.157 gram of water. The heat necessary to vaporize this amount of water at 180° C. (356° F.) requires $0.157 \times 480.6 = 75.4$ calories. The heat actually required to calcine gypsum at 180° C. (356° F.) is the sum of these three items, namely, $41.4 + 22.8 + 75.4 = 139.6$ calories per gram. This is equivalent to 252 B. t. u. per pound.

While it is realized that there are some discrepancies in the above calculations, these may be attributed to the fact that the necessary data have not been developed. However, it is believed that the computation is sufficiently accurate for all practical purposes. It must be appreciated that in practice this amount of heat, together with a quantity lost through the walls, in furnace gases, and in heating the kettle itself must be taken into account. However, a study of the table indicates that there is much room for improvement in kiln or kettle design to realize a higher efficiency in calcination.

9. METHOD OF OPERATING CALCINERS

(a) KETTLE FIRING PROCESS

Where kettles are used for calcining the choice of fuel is governed by economic conditions. In the Southwest oil is usually near and coal quite distant, while in other localities the reverse is true. When oil is used, it is in conjunction with compressed air or high-pressure steam. If coal is the fuel, it is desirable that a free burning grade giving a long flame and plenty of gas for combustion about the sides and in the flues be used.

Because of the easy control of the heat, oil makes an excellent fuel. This control is to be desired especially when the kettle is being charged or discharged. Under no conditions should drafts be allowed to strike a hot kettle bottom, as the strains set up will most certainly result in cracking.

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[11] Landolt-Bornstein, "Tabellen," Julius Springer, Berlin, 1912.

[12] Vant Hoff, Armstrong, Hinrichsen, Weigert and Just, Zeit. f. phys. Chem. **45**, 290; 1903.

(b) ROTARY PROCESS

Firing of rotary calciners is usually by compressed air and pulverized coal, though in localities where fuel oil is easily available it is used instead of coal. Figures which were obtainable indicated that the fuel consumption of a rotary kiln installation varies from 70 to 125 pounds of coal per ton of calcined gypsum produced. Control of operation of a rotary kiln is by the use of a pyrometer embedded in the stream of material leaving the kiln. The temperature at this point is maintained at from 450° F. in some mills to 550° F. in others.

(c) HOT PITS

When calcination in a kettle is complete the kettle is discharged through a wicket into the hot pit. This is usually of concrete or steel with a steeply sloping side, so that the calcined gypsum will flow freely into a screw conveyer at the lower side of the pit. In the more modern mills a flue connects the hot pit with the outside

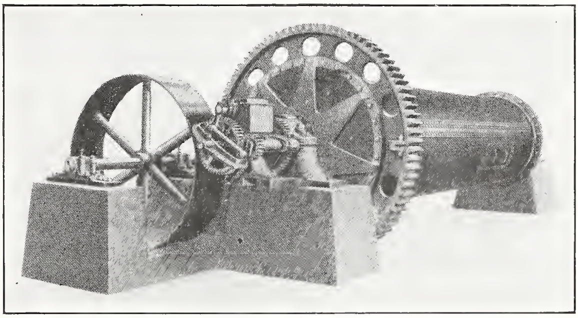

FIG. 21.—*Type of "ball mill" used in regrinding*

Equipped with single swing feeder

to allow the escape of steam, preventing its condensation in the pit. As any uncalcined or set gypsum in the hot pit results in plaster of uneven set it is imperative that a securely fitting cover be over the hot pit, together with a tight wicket gate from the kettle.

10. REGRINDING

When calcining is carried out in a rotary calciner it is always necessary that the final disintegration be done after the calcination on account of the size of rock which is calcined. In many kettle mills further reduction is also done after calcination. Similar types of disintegrators may be used as described in the part of this paper dealing with "methods of crushing."

However, the tendency in recent years has been to carry the fineness to a greater degree than may be obtained economically by the use of the type of disintegrators previously described. The advantages to be gained by extreme fineness include improved working and keeping qualities.

A type of regrinder which has come into use with the demand for finely ground calcined gypsum is the tube mill. This apparatus consists, essentially, of a rotating steel cylinder in which the grinding is done by means of steel balls. The size of the tube mill employed varies within wide ranges—from 22 feet in length by 4 feet in diameter to 4 feet in length and 4 feet in diameter having been noted. By this treatment it is entirely possible to produce a product such that 100 per cent of it passes a No. 100 screen and 98 per cent a No. 200 screen.

11. SCREENS AND AIR SEPARATORS

In all gypsum mills screening is usual at at least one point before the finished product is ready for bagging. If a mill uses gypsum

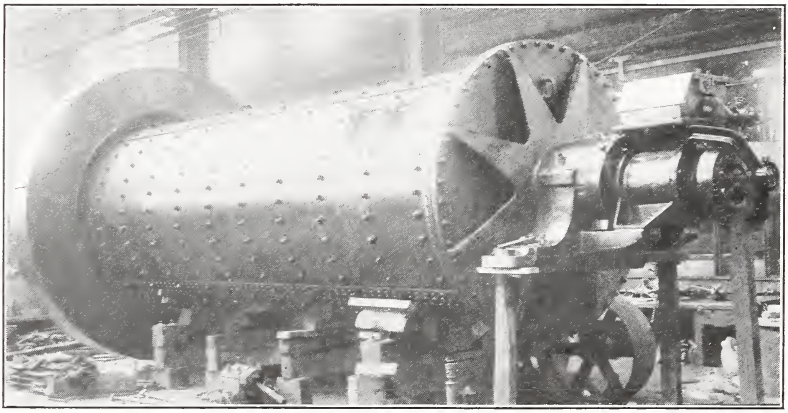

Fig. 22.—*"Ball mill" used for regrinding*

it may be only necessary to separate the large lumps before calcining. In this case the screen would probably be of ¼-inch mesh. However, the usual practice demands more than one screening operation, in many instances as many as three, at the following locations: Before drying, before calcination, after calcination.

After the rock has been ground and is ready for calcination, or after calcination, it has been found that vibrating screens of the Jeffrey, Sturtevant, or Newaygo type are most satisfactory. These all consist, essentially, of a frame upon which the wires are stretched and elevated at an angle. They are vibrated by either shaking or knocking, which causes the material to slide down across the screen. For use in the gypsum industry the size is usually of about 30 meshes per inch and the angle of elevation from 30 to 40°. They are always covered so as to confine the dust as much as possible. Rotary screens of fine mesh have not proven successful for operation on gypsum on account of the tendency of such screens to clog.

In recent years the demand for a fine, uniformly graded product has brought into the gypsum industry various types of roller mills with air separators. This type of installation yields large quantities of fine material and is of particular value where the character of the stone is such as to render grinding by buhr and emery stones uneconomical. In roller mills the grinding or crushing is accomplished by rollers, the fine material being removed by a current of air produced by a fan. The air carrying the finer particles is discharged into a chamber where because of the reduced velocity the fine material is deposited.

There are many excellent features of roller mills which can not be overlooked, the major one being the ease of control of the size of particle desired. The only adjustment necessary for change of size being a change in the fan speed. They are also practically dust proof, a feature which is to be desired. However, provision must be made for the operation of the fan at a uniform speed, which produces the size particle desired.

12. ELEVATORS, CONVEYERS, BINS, MIXERS, AND PACKERS

In every gypsum mill there are numerous occasions in which the material must be moved vertically. In practically all cases the use of elevators is resorted to. The type almost exclusively employed is the common bucket type. If the material to be moved is finely ground, it is customary to inclose the elevator in a tight box to prevent leakage of dust.

Where the material is to be transported horizontally two types of conveyers are in general use, depending, primarily, upon the character of the material to be moved. If crushed or calcined gypsum, the most convenient type is the screw conveyer. It is easily covered to do away with dust and offers besides an excellent opportunity for more thorough mixing and cooling if from the hot pits. In the handling of raw gypsite, however, the screw conveyer is not feasible, as it will clog and not handle the damp material. For use under such conditions the belt conveyer has proven entirely satisfactory.

Ample storage bins are a necessity in any gypsum mill. For the storage of raw rock there are no specific requirements which demand attention. They should, of course, be of ample size, easily emptied, and in a convenient location. On the other hand, bins for the storage of the calcined gypsum demand that certain conditions be given consideration. They should be so constructed as to keep the calcined gypsum absolutely dry. Unless protected against the passage of moisture, bins of concrete should not be in contact with the ground. Sheet-metal bins with sloping sides have proved the most satisfactory for the storage of calcined gypsum.

Fig. 23.—*Weighing hoppers*

Centerville Gypsum Co., Centerville, Iowa

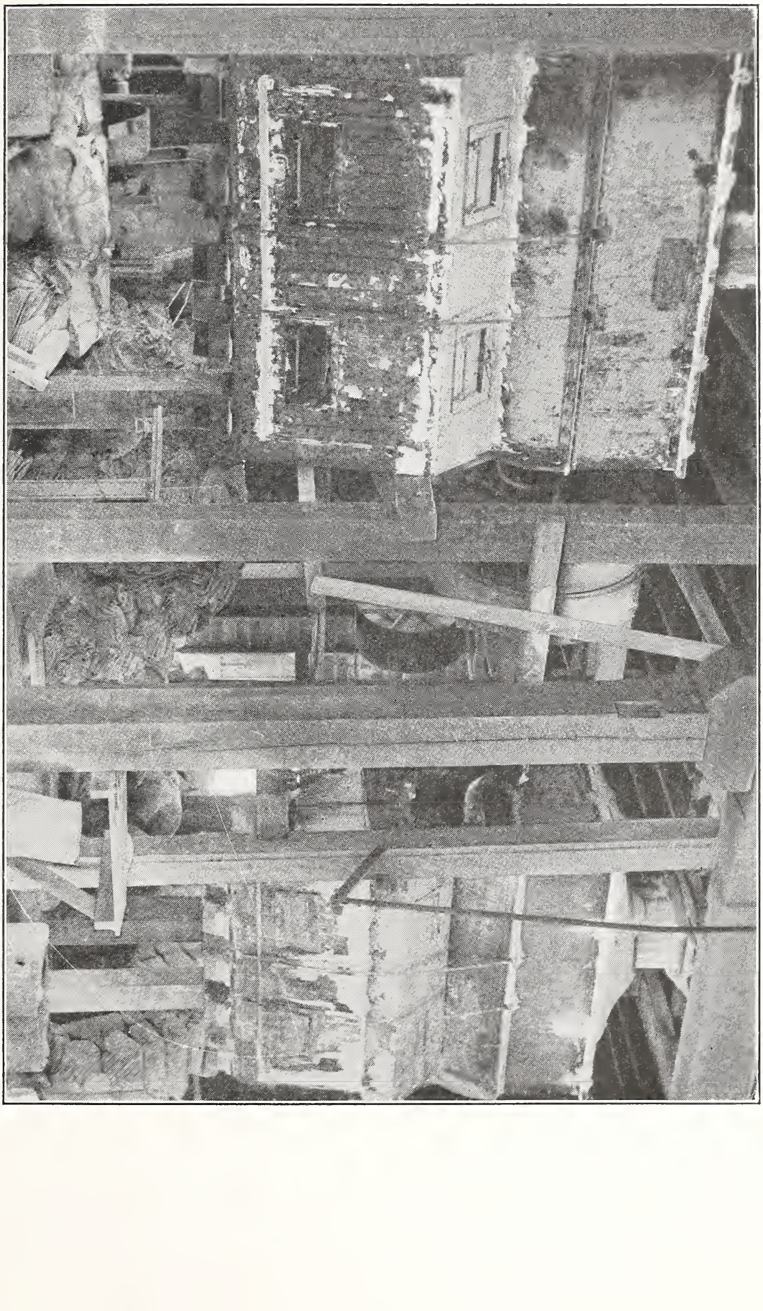

Fig. 24.—*Mixers and hand packers*
Centerville Gypsum Co., Centerville, Iowa

From the storage bins it is the practice to run the calcined gypsum into a weighing hopper, where various materials to control the set improve the working qualities, etc., are added before going to the mixers. The capacity of the mixers is usually 1 ton, though in some cases 2-ton mixers are employed. The mixing is done by a series of blades attached to a revolving shaft.

After mixing the plaster is discharged into the packer, which may be of the hand or automatic type. Here it is bagged into either paper or jute bags of 80 or 100 pounds net, respectively. Seven automatic baggers and six hand baggers were noted in the mills visited, while in one mill both automatic and hand baggers were used.

The automatic bagging machine of the Bates type was found to be used in a great majority of the mills visited. It is with a few modifications the same as that used in the Portland cement industry, and a detailed description does not appear necessary. The major advantages of an automatic bagger over hand bagging are economy, speed, and elimination of the dust nuisance.

13. ADMIXTURES

In the weighing hopper above the mixer various ingredients are added to the calcined gypsum to alter its physical condition. These materials serve two major purposes—first, the retardation of the gypsum so as to give a setting time within practical limits, and second, to improve the working quality of the plaster without sacrificing any of the properties to be expected of an interior wall surface. For the first purpose "commercial" retarder, a product of hair, lime, and soda ash in exceedingly small quantities is used, approximately 0.2 per cent retarding the set two hours. To improve the working quality many materials in various quantities are used, some of which are hydrated lime, clay, talc, and asbestos. Other materials, such as hair, wood fiber, or sisal are added to increase the resistance of the plaster to cracking and to prevent "droppings" during application. Many mills are taking advantage of a process for improving the plasticity of gypsum discovered by W. E. Emley, of this bureau, to decrease the amount of admixtures formerly used. The process consists, essentially, of fine grinding of the calcined material.

The following shows the amount of admixtures, within wide limits, added per ton of calcined gypsum:

	Pounds
"Retarder"	4
Lime	10
Clay	160–400
Hair (goat)	4–6
Wood fiber	30–40
Talc	400
Asbestos	3
Ground silica	320–500
Sisal	1–2

It is, of course, understood that all of these ingredients are never added to one mix but in various combinations for different class plasters.

Flow Sheet for Rock Gypsum Mill

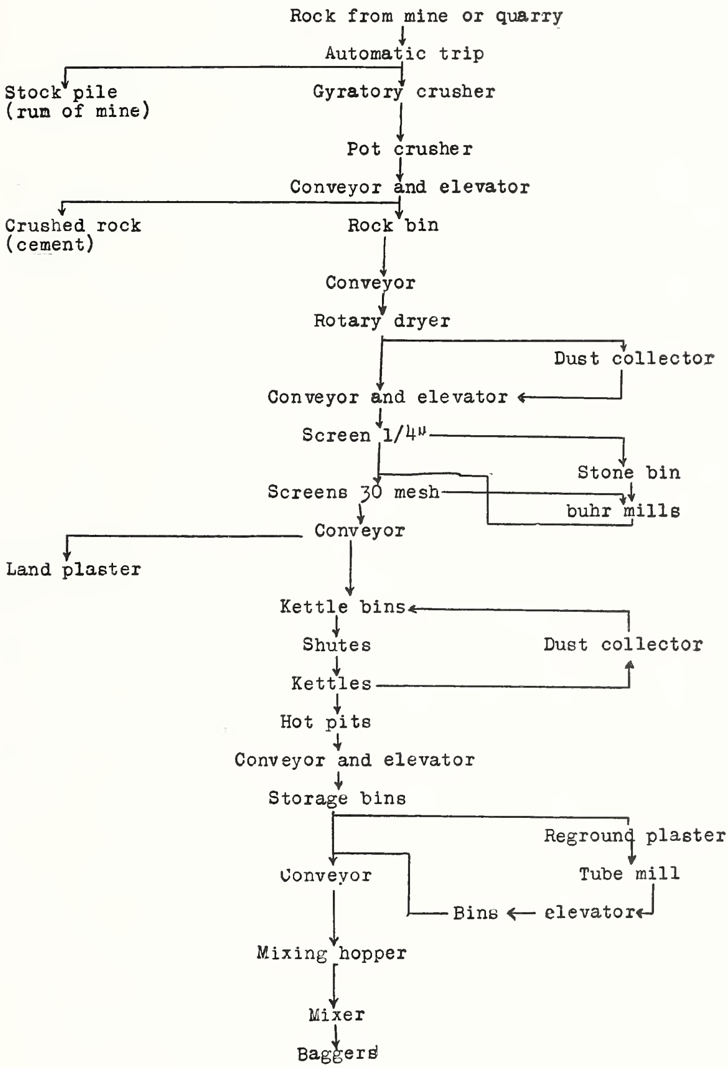

FIG. 25

The mill receives the hair fiber in bales. Before use it is necessary that it be shredded. This is accomplished with a machine known as the "hair picker," which consists of a central disk with projecting teeth which is revolved near a disk of similar construction which is stationary. The tightly-matted hair from the bales is thrown into an opening near the center of the revolving disk and is frayed between the teeth of the two disks until thrown out by centrifugal force, completely disintegrated, through an opening in the cover of the inclosing case.

Wood fiber is either bought or manufactured at the mill. The process of manufacture of this material is not so simple and requires from 20 to 30 horsepower to operate. The log is first cut to the proper

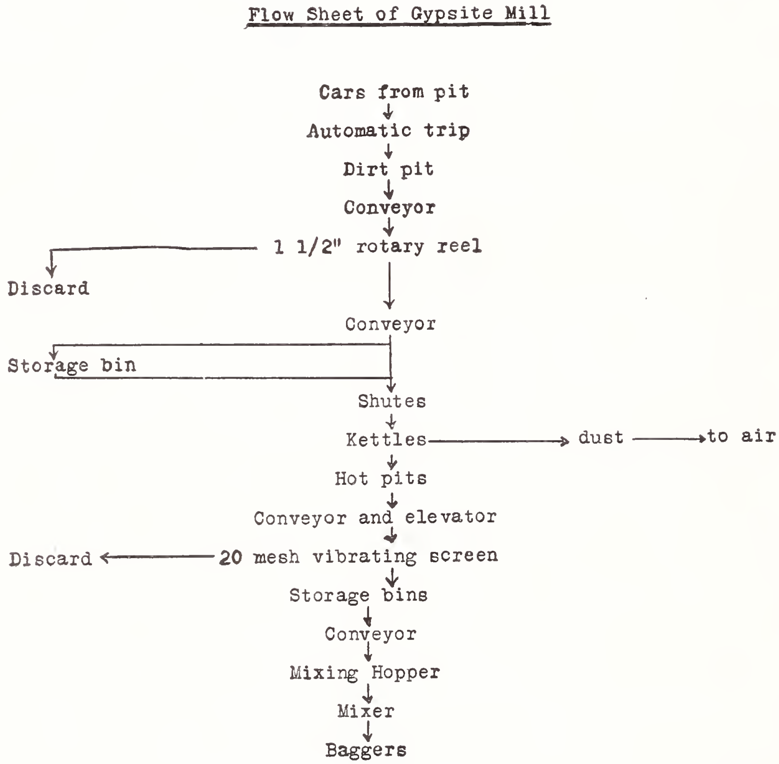

FIG. 26

length and barked. It is then rotated and forced with an even pressure against revolving saw-toothed disks. As the diameter of the log decreases its speed of rotation is increased by means of a cone drive in order to keep the length of fiber as nearly uniform as possible. A fan is usually employed to convey the fiber from the shredder to a fire and moisture-proof storage bin. For the best operation of such a machine it is desirable that the wood be not completely dry. There are other types of shredders in use, but the one described is the type most generally employed. On account of its use it is necessary that the wood employed shall be nonstaining. It has been found that bass, willow, poplar, and buckeye meet the requirements quite satisfactorily.

IV. PROCESS OF MANUFACTURE OF GYPSUM WALL AND PLASTER BOARD

Gypsum plaster boards are sheets or slabs composed of one or more layers of gypsum with or without fiber, reinforced on the surfaces with a covering made from fibrous material. Their major use is as a backing for plaster. Gypsum wall boards are building units which without the addition of plaster furnish to interior walls or ceilings a surface which may or may not be further decorated. The usual width of gypsum plaster board is 32 inches and wall board 48 inches; thickness, three-eighths inch; length of plaster board, 36 inches; of wall board, from 4 to 12 feet.

As the process of manufacture for both types of board is essentially the same, they will not be described separately. However, since wall board is used as a finished surface it is necessary in the manufacture that the surface and thickness be more nearly uniform than with plaster board, as in the latter case such discrepancies will be covered with plaster.

1. INGREDIENTS

The surface of plaster board or wall board is a fibrous material resembling somewhat a high-grade blotting paper, though not quite so absorbent. The nature of the surfacing material is necessarily porous in order that the gypsum core will adhere properly. In the case of wall board the surface which is to be exposed is sized and is generally a better grade than that used on the unexposed side or on plaster board.

The core in plaster and wall board is the same, and until recently all manufacturers used a core composed of calcined gypsum to which had been added not more than 10 per cent, by weight, of sawdust or other fibrous material. There has recently been developed, however, a mix to be used in the manufacture of plaster and wall board composed of calcined gypsum and starch. Upon the addition of hot water the starch grains swell, giving a board which has all the properties of the older type but not so heavy.

2. MAKING OF THE BOARD

The board mill of a gypsum plant is usually housed separately from the calcining mill and is treated as a separate department. While it was noted that the process of mixing differed slightly from mill to mill it does not seem justifiable to go into the details of each process. A typical example will be given, and it should be borne in mind that while in the process cited the mix is made dry, in many mills it is wet, and that other such minor changes may also be expected. The calcined gypsum is delivered by conveyer from the calcining mill directly into the supply bin located above the feed bin. As desired the calcined gypsum is fed from the feed bin to a belt conveyer. This conveyer discharges to the mixing belt, where the fiber and water are added and thorough mixing obtained by means of agitators. The agitators are belt driven and are located slightly above the belt carrying the mix. The mixing belt discharges to the board machine's feed belt, which, in turn, delivers the wet mix to a moving sheet of paper. The paper feeding the machine is under a slight tension as it comes under the feed belt. Before reaching the feed belt the edges of the paper are folded.

After the wet mix is discharged to the paper an oscillating arm moves agitators over the width of the sheet, uniformly distributing the mix. Upon passing the agitators the other layer of paper is applied and the completion of edges effected. The sheet then passes under a roll which is set to give a board of the desired thickness. The next operation is to press the board to the exact size desired and to eliminate any nonuniformities. This is accomplished by another set of rolls.

In some mills it is the practice to cut the board into the desired lengths after passing this stage; in others it is not done until the gypsum is set. Regardless of where the cutting is done the board travels along for a sufficient distance to allow the gypsum to set. It then goes to the drier.

3. DRYING

The drying of plaster and wall board is usually effected by steam radiators, though in some mills direct heat is obtained by coke burning. In the latter method a higher degree of control is necessary in order that the temperature be kept below the point at which calcination of the gypsum would occur. A very effective method of drying is to force air, by means of blowers, over steam coils.

V. PROCESS OF MANUFACTURE OF GYPSUM TILE

1. GENERAL

Under the term "gypsum tile" may be included several types of tile, block, or slabs consisting, essentially, of gypsum used in construction. However, as a large majority of the material sold under this designation is used in the construction of nonbearing interior partitions, only this class of tile will be given consideration. Nevertheless, it should be borne in mind that the types not described include a number of structural units made of gypsum which are rapidly increasing in use and demanding annually a large tonnage of calcined material. Some phases of this type of material will be considered briefly in Section VI.

Gypsum partition tile is a building unit used for nonbearing construction in the interior of buildings. It is rectangular in shape, being 30 by 12 inches measured on the face and may be either solid or cored. In thickness the tile may be 2, 2½, 3, 4, 5, 6, or 8 inches. The 2-inch solid and 3 and 4 inch cored, are the sizes usually preferred. The core spaces may be either circular, elliptical, or rectangular in shape, the usual shape being circular.

2. INGREDIENTS

Gypsum tile consists of gypsum with or without an aggregate. In practice it is customary to use as an aggregate 3 per cent or less of a nonstaining wood fiber. The remainder is usually first settle calcined gypsum. In the process of mixing it is desirable to have a comparatively thin mix, necessitating the use of a considerable amount of mixing water.

3. TILE MAKING

All gypsum tile is manufactured by casting. There are essentially three operations necessary, namely, mixing, casting, and drying. Until quite recently all tile were hand cast. At present this method is rapidly disappearing with the advent of several types of tile-making machines. These may be appropriately grouped into two classes—the belt and the circular.

Tile which are made by hand are cast on rubber mats, inclosed in a framework of a height equal to the thickness of the tile. Tapered wooden or metal plugs pass through the frame in the long direction, forming the cores of the tile. The framework and cores are so arranged that they may be easily removed from the set tile. The calcined gypsum containing wood fiber is mixed to the consistency of a thin sirup and poured into the assembled framework. After the tile has set it is removed, loaded upon trucks, and dried. While machine-made tile may be more rapidly manufactured they are in no way superior to hand-made tile.

The manufacture of gypsum tile by machinery is a continuous process, the calcined gypsum, wood fiber, and water being mixed in a tank before casting of the tile on the moving machine. The wet mix is allowed to flow into the molds carried on a continuous belt in the belt process or a revolving table in the rotary tile machine. The tile so cast are carried along the belt or around the table until set, when the mold is automatically removed and the core-forming units withdrawn. They are then passed to a belt conveyer or loaded by hand upon a truck and transported to the dryer. The mold is reassembled either automatically or by hand and passes again under the wet mix container. The tile are prevented from adhering to the molds by a thin film of oil which is sprayed or brushed upon the molds immediately before the casting operation.

Especial precaution is necessary, in casting tile by machines in which the fiber and calcined gypsum are mixed first, to see that the wood fiber shall be thoroughly dry, as otherwise trouble will be encountered in the wet mix setting in the mixing tank. This is caused by the formation of set gypsum in the dry mix from the water

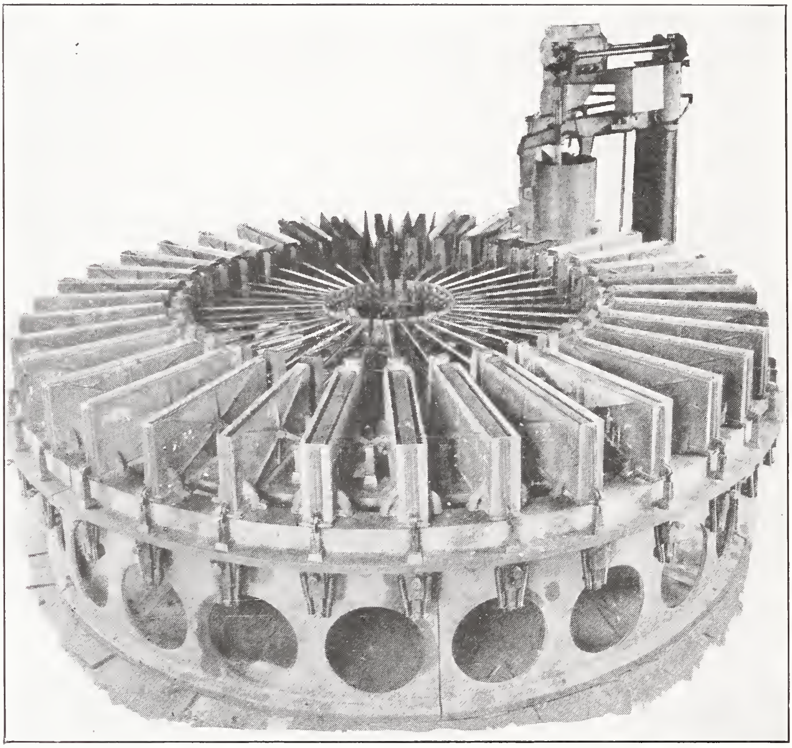

FIG. 27.—*Rotary type gypsum tile machine*

Set up for casting several sizes of tile

contained in wet fiber. As calcined gypsum does not usually set quickly enough it is necessary to add to the wet mix a small amount of ground tile or raw gypsum to hasten the setting.

4. DRYING

Gypsum tile are dried either by allowing them to stand in the open or by heat in a dryer or kiln. The dryers consist of long sheds which are heated either by air, steam coils, or direct heat from a coke-burning furnace. One ingenious installation noted was the use of the flue gases in the kettle mill to heat the air going into the dryer.

No matter which type drying is employed fans or blowers are generally used to circulate the air.

VI. OTHER USES OF CALCINED GYPSUM

The uses of calcined gypsum other than for plaster, plaster board, wall board, tile, and Keene's cement are many and include those in which only a few pounds are demanded annually to others which use an appreciable tonnage. Brief descriptions will be given of a few of these uses, together with the method of preparation of the calcined gypsum.

1. POURED-IN-PLACE CONSTRUCTION

The use of gypsum in the construction of floors, roofs, etc., in which the mix is made on the job is increasing each year. The calcined gypsum used is the normal first settle material. Before using it is mixed with wood chips, cinders, or similar aggregate. It is then poured into the forms containing the reinforcing in the manner of concrete. Several types of this kind of construction are employed. However, the Keystone and another system in which gypsum plaster boards are an integral part of the construction, serving as forms which are left in place and may be plastered upon, are those most used.

2. PRECAST REINFORCED TILE

As the name indicates, this type of material is cast at the mill and shipped as separate units. They are made in a variety of sizes and shapes and contain besides the gypsum and aggregate, reinforcement, usually welded galvanized wire. Its major uses are the construction of roofs and as a filler in floors. Many merits are claimed by the manufacturers of precast reinforced tile, some of which are low thermal conductivity, fire resistance, lightness, elasticity, rapidity of construction, and economy.

3. RETARDER FOR PORTLAND CEMENT

While it is the usual custom to add ground gypsum rock to Portland cement clinker as a retarder, there are some cement mills which prefer to use calcined gypsum. As the active constituent of either gypsum or calcined gypsum for this purpose is thought to be SO_3, it is readily seen that if calcined gypsum is used an appreciably smaller quantity is necessary. However, the much greater cost of calcined gypsum makes it more expensive even though less material is used, and probably the only reason it is ever employed for this purpose is because the cement manufacturer believes a better product results.

4. BEDDING OF PLATE GLASS

Each year the plate glass mills of the country use many tons of calcined gypsum in which to bed the plate glass preparatory to polishing. The calcined gypsum demanded for this purpose must be free from grit. This requirement is met by the gypsum manufacturer by elimination of impurities or by fine grinding.

5. POTTERY MOLDS

Calcined gypsum is used in the pottery trade in the manufacture of molds. It is desirable that pitting of the mold be retarded, that they absorb the moisture from the slip, and that they have sufficient strength. Both first and second settle gypsum are sold for this purpose.

6. CRAYONS OR CHALK

Blackboard crayons are sometimes made, by casting, from calcined gypsum.

7. COLD-WATER PAINTS

Calcined gypsum, to which has been added pigments, is sold for interior decoration. All that is necessary for the production of a paint is the addition of water.

8. INSULATION

Much calcined gypsum each year goes into the production of insulating materials used as a covering for pipes and boilers and as a filler between the walls of safes and filing cabinets. For these uses calcined gypsum is mixed with asbestos or with limestone, aluminum sulphate, and glue. The latter mix gives a porous, cellular product.

9. SURGICAL USES

Calcined gypsum is used in surgery as the familiar "plaster cast" to hold broken bones in place while they knit and as orthopedic bandages. In the latter use open-mesh bandages are impregnated with finely ground calcined gypsum and then rolled until ready for use, when the roll is soaked in water, unrolled, and wrapped around the broken limb. Upon setting of the gypsum a strong, rigid splint is formed.

10. MOVING PICTURES

The moving-picture industry annually consumes many thousands of tons of calcined gypsum in the erection of "sets." The gypsum for this purpose is mixed with excelsior and is known as "staff." The same material is used on the surfaces of large temporary buildings, striking examples being the Chicago and St. Louis fairs.

11. SCAGLIOLA

When Keene's cement is colored and used as imitation marble for columns, wainscoting, etc., it is known as Scagliola. No especial process is used in the manufacture of the Keene's cement for this purpose. The effects obtained are due more to the workmanship than any particular property of the gypsum.

12. DENTAL PLASTER

In the making of casts in dental work calcined gypsum with an especial retardation is employed, it being desirable that sufficient time is permitted for the mixing and molding and that then the plaster shall quickly set. Success has been obtained by the use of sodium-ammonium-hydrogen phosphate as a retarder.

13. MOLDING PLASTER

Calcined gypsum, to which has been added hemp fiber, is used in making the plaster decorations with which ceiling and walls are sometimes embellished. Another type of molding in which calcined gypsum finds extensive use is in the casting of Babbit and other metals.

14. MISCELLANEOUS

There are many minor uses of calcined gypsum, among which might be mentioned match heads, preparation of casts and protecting fossil remains during removal to museums, briquetting of coal, manufacture of corncob pipes, as a dehydrating agent, in the casting of rubber stamps, as a filler in paper manufacture, as a setting for gold, silver, and stones for engraving and polishing, and in numerous toilet articles, such as facial powder, dental powder, etc.

VII. APPENDIX

1. DESCRIPTION OF GYPSUM PLANTS IN TEXAS, OKLAHOMA, KANSAS, IOWA, MICHIGAN, AND OHIO

In order to obtain first-hand information of the processes in use 26 gypsum mills where various methods of treatment were employed and which were located in the States of Texas, Oklahoma, Kansas, Iowa, Michigan, Ohio, and New York were visited in the spring of 1924. The methods of working the mine, quarry, or bed of gypsite, treatment of raw material both before entering the mill and in the mill, were studied in detail. The process employed in the manufacture of structural gypsum products was also observed in any mill where such products were made. The part of this paper following is the description of these plants, together with analyses of the gypsum or gypsite worked, and in some cases of the calcined material.

For uniformity of description the following arrangement has been followed wherever practicable:

1. Name of company, location of mill, and transportation facilities.

2. Mine, quarry, or bed; (*a*) geology of deposit; (*b*) raw material—physical properties and chemical analyses; (*c*) mine, quarry, or bed—location, extent of deposit, condition; (*d*) operation—shaft, open quarry, pit, drilling, blasting, sorting, and transportation; (*c*) amount of raw material delivered to mill per unit of time.

3. Mill: (*a*) Primary crushing—method, equipment; (*b*) secondary crushing—method, equipment, fuel used, amount of fuel per ton of material, temperature in drier, temperature of product; (*d*) screening before calcination—size, type, and number of screens; (*c*) calcination—method, equipment, temperature of drawing, time of calcination, fuel, etc.; (*f*) treatment after calcination—cooling—size of cooling unit, method of operation, temperature drop; grinding—method, equipment; screening—size, type, and number of screens; (*g*) bagging—equipment; (*h*) control—where samples are taken, number, tests to which subjected; (*i*) tonnage—how distributed.

4. Structural gypsum products: (*a*) Kind of gypsum used; (*b*) equipment employed; (*c*) products; (*d*) capacity and distribution.

(*a*) TEXAS CEMENT PLASTER CO., HAMLIN, TEX.

The mill of the Texas Cement Plaster Co. is located at Plasterco, Jones County, Tex., 6 miles southwest of the town of Hamlin. At Plasterco Junction a spur runs to the plant from the main line of the K. C., M. & O. Ry., and the major portion of the material is shipped out over this, although there is also a spur from the mill to the A. & S. Ry. 1 mile to the north of the mill.

The following discussion is from United States Geological Survey Bulletin No. 697, Gypsum Deposits of the United States, by R. W. Stone and others, and the reader is referred to that publication for a more complete description of the gypsum deposits of Texas.

"Three gypsum-bearing areas occur in Texas, namely: (1) In north central Texas from the Red River, southwestward 150 miles to the Colorado River; (2) in Hudspeth and Culberson Counties, in Gypsum Plain and Malone Mountains; and (3) in southeast Texas. The three gypsum mills operating in the State and including that of the Texas Cement Plaster Co. are located in the area of the Red

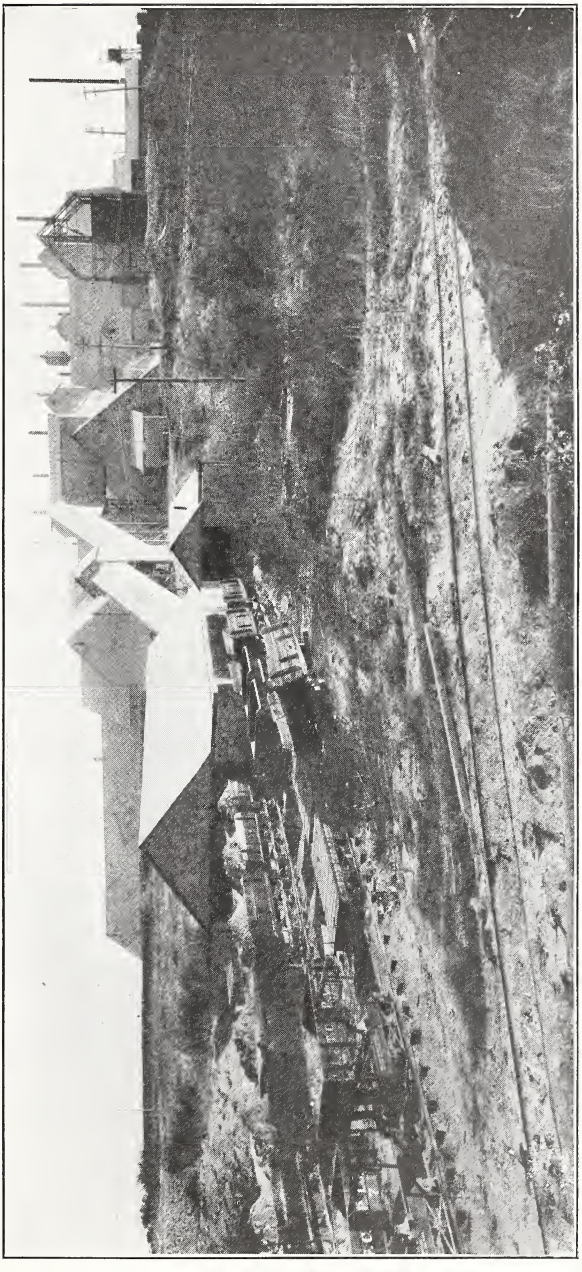

Fig. 28.—*Mill of the Texas Cement Plaster Co., Plasterco, Tex.*

River-Colorado River deposit. The gypsum beds of this deposit are Permian and are a continuation of the Greer formation. However, the Greer formation, which overlies the Woodward formation in Oklahoma, can be traced far into Texas in continuous outcrop. In many places along the range of the Gyp Hills, which lie as a rule just west of the K. C., M. & O. Ry., gypsite has been noted and the three operating mills utilize this material to a great extent."

At Plasterco the gypsite deposit is only 8 to 12 inches below the surface and is in a fairly dry condition. The color is good, but there seems to be an exceedingly large number of calcareous nodules and streaks of dark clay distributed throughout the deposit.

The following is an analysis of a representative sample taken by the writer and analyzed at the Bureau of Standards laboratory:

	Per cent
Gypsum ($CaSO_4 \cdot 2H_2O$)	84. 5
Calcium carbonate ($CaCO_3$)	7. 0
SiO_2,Al_2O_3,Fe_2O_3, clay, etc. (by difference)	8. 5

The bed of gypsite worked by this company is 10 to 24 feet in thickness and extends over the total of 400 acres owned by the company. As the deposit is in a fairly dry condition it can be worked satisfactorily with electric shovels. The shovels empty into 5-cubic-yard side-dump, narrow-gauge cars. These are pulled in trains to the mill, a distance of one-fourth mile by a Shaw-Walker gas locomotive. When working on one 9-hour shift, about 750 tons of material can be excavated.

Upon arrival at the mill the cars are discharged into a concrete pit 12 by 4 by 6 feet, from which the gypsite is conveyed to an open Jeffrey mill by a shovel conveyer.

The Jeffrey mill breaks up the larger lumps and delivers to a 2-foot rubber belt, set at an angle of 30°, which runs for a distance of 125 feet where the material is delivered to a revolving squirrel cage screen with openings of 1½ inches in diameter. The material not passing through the openings is discarded as unsuitable for plaster. That passing through the openings is delivered to another 2-foot belt, which carries it up an incline and into the storage bins. These bins are of sufficient capacity to take care of the needs of the kettles should the weather for six days prohibit working of the pit.

Openings in the floor of the storage bin allow the material to drop upon a belt which delivers to an elevator. The elevator delivers to a belt delivering into a spout, which directs the material to either the three center kettles or to one of two belts delivering to the three kettles on either side of the center three.

The kettles are nine in number, 8 by 10 feet, with a capacity of 10 tons of raw gypsite. The only feature in which they differ from the ordinary gypsum kettles is in bottom design, the bottoms being composed of sections of sheet steel riveted to the side shell. Each kettle has four flues in a line. A thermometer is located in the top of each kettle and extends 12 inches into the gypsite. The kettles are "pulled" at 400° F., three and one-half hours being necessary for calcination. The fuel used is oil which is mixed with steam or compressed air. Seventeen gallons of oil are used per ton of calcined gypsite.

The kettles are emptied into a hot pit from which the stucco is delivered to a bucket elevator by means of a 9-inch screw conveyer. The elevator delivers to a screw conveyer which in turn delivers to 20-mesh Sturtevant vibrating screens. The material retained on the screens is discarded. That passing is carried by screw conveyer to bins of 8,000 tons capacity from which the calcined gypsite is carried by screw conveyer to 1-ton weighing hoppers located above Broughton mixers. Into the hoppers the hair or wood fiber and retarder are added. From the mixers the material passes by gravity to the baggers. The bagging is done by hand.

When running at full capacity, the power consumed is 7,500 kilowatt hours per day. This is the largest mill in operation using gypsite exclusively as raw material.

(b) CERTAIN-TEED PRODUCTS CORPORATION, ACME, TEX.

The Acme (Tex.) mills of the Certain-teed Products Corporation are located in Hardeman County, 6½ miles northwest of Quanah, Tex. Shipping facilities are exceptionally good, as spurs from the Q. A. & P., F. W. & D. C., and the Frisco railways run to the shipping room of the mills.

"At this location the gypsum is exposed in nearly horizontal ledges along a narrow creek. It is closely associated with dolomite and occurs here in two beds, the lower one nearly 22 feet thick and lying 19 feet below a 10-foot bed. The rocks exposed at the surface in this vicinity belong to the Clear Fork formation of the Permian series." [13]

This company at this location works both gypsite and rock-gypsum deposits. Analyses of typical samples of the gypsite and gypsum submitted by the writer to the laboratories of the Bureau of Standards are as follows:

	Per cent
Gypsite:	
Gypsum ($CaSO_4 \cdot 2H_2O$)	73. 0
Calcium carbonate ($CaCO_3$)	7. 9
SiO_2, Al_2O_3, Fe_2O_3, etc. (by difference)	19. 1
Gypsum:	
Gypsum ($CaSO_4 \cdot 2H_2O$)	93. 8
Calcium carbonate ($CaCO_3$)	. 1
SiO_2, Fe_2O_3, Al_2O_3, etc. (by difference)	6. 1

The deposit of gypsite at this mill has been worked for a considerable time, and in consequence all of the material lying close to the mill has been worked out until at present the workings are located about one-fourth mile southwest of the mill.

The overburden in this vicinity varies in thickness from practically none to 5 and 6 feet. When the overburden is in excess of 18 inches, the deposit is not economically workable. The thickness of the bed varies in a like manner. The present company has holdings on 7,000 acres of land in the vicinity of the mill, all of which, by borings, indicate workable deposits of either gypsite or rock gypsum with the exception of the draws and creek gullies.

The top soil is plowed and removed by scrapers. The gypsite is then plowed and conveyed by wheeled scrapers to a loading platform, where it is automatically emptied into a bin. From this bin the gypsite is elevated and deposited in standard size coal cars by means of a drag-chain conveyer. The plow and scrapers are pulled by Fordson tractors, and the conveyer is operated by a Fordson engine. When the cars reach the mill, they are discharged into the "dirt pit," from which the gypsite is carried by an 18-inch Balata belt to a bucket elevator delivering into spouts which lead to the kettles. The kettles are eight in number, six 10 feet in diameter and two 8 feet in diameter; all are equipped with the usual drag on bottom of kettles and agitators over the flues. The flues are four in number and located in a line. The bottoms are solid. The kettles are drawn at 350° F., and the time necessary for calcination is usually three and one-half hours, depending somewhat upon the condition of the gypsite. The fuel used is oil and compressed air. The consumption is 11 gallons of oil per ton of calcined gypsite. Each kettle is equipped with a thermometer embedded 18 inches into the gypsite.

The kettles are discharged into a hot pit through gates, from which the material is conveyed by a screw conveyer to a bucket elevator, which in turn delivers to a

[13] Bulletin No. 697, Gypsum Deposits of the United States, by R. W. Stone and others, United States Geological Survey.

bin of 1,500 tons' capacity. A screw conveyer delivers from this bin to an elevator which carries the stucco to a battery of Acme type screens. This battery is composed of three screens, of four sections each, elevated at 45°. The material passing the screens is carried by screw conveyer to a bin above the weighing hoppers and baggers. That retained on the screens is passed over a one-fourth-inch screen, the oversize being discarded. The material passing this screen is put through a 40-inch horizontal buhr mill and then goes to the bins containing the fines from the Acme screens.

Screw conveyers deliver from the bin to the weighing hoppers, where the wood fiber or hair and retarder are added. These hoppers are located above one-half ton Broughton mixers, and delivery to the mixers is by gravity. From the mixers the finished plaster is dropped to the Bates bagging machines.

This company also has a mill adjacent to the gypsite mill which uses gypsum rock as the raw material. The rock is mined. The entrance to the mine is at

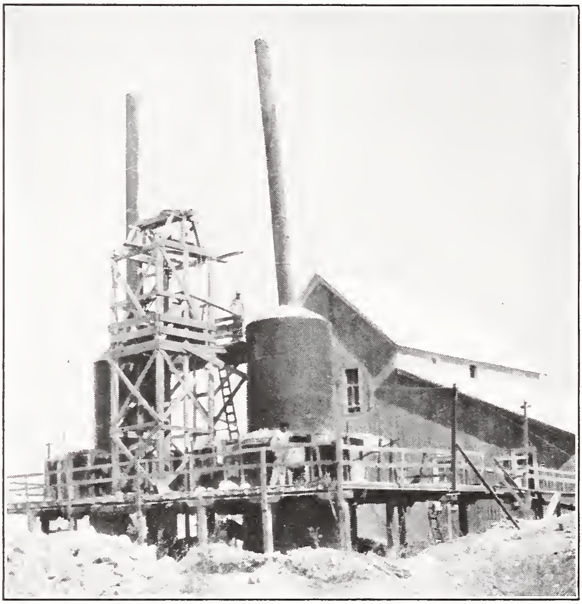

Fig. 29.—*Keene's cement mill of the Certain-teed Products Corporation, Acme, Tex.*

the south end of the mill and is by a 50-foot shaft. The vein of gypsum is approximately 10 feet in thickness and of good color, especially the upper part. The roof of the mine is dolomitic limestone, the floor gypsum, as only a 9-foot face is worked. As the working of the mine has been in progress for a comparatively short time, the area worked is relatively small.

The usual room and pillar method of excavation is employed. Drilling is done with electric drills and blasting with 20 per cent dynamite. The mine is lighted with electricity. After the rock has been brought down it is hand sorted, the large white pieces being separated from the others. Transportation from the mine is in hand-loaded, 3,500-pound end-dump, horse-drawn cars. The cars are elevated to the surface, the white rock going to the Keene's cement mill, and the remainder to the rock plaster mill. One hundred tons of rock per day are usually brought to the surface. Twenty-five tons of this go into the manufacture of Keene's cement.

The rock going to the plaster mill is discharged from the mine cars into an Ersham nipper, which delivers directly to an Ersham pot crusher. The material from the pot crusher is all three-eighths inch and under. The pot crusher delivers to a bucket elevator which delivers to a one-fourth-inch screen. The rock here separated is run into separate bins. The material one-fourth-inch and over is fed from the bin into a 25 by 6 foot cylindrical, coke fired drier, kept at a temperature of 100° C. The rock requires about 16 minutes to pass through the drier, after which it is elevated into the bin containing the fines from the screen. From this bin a Raymond mill is fed by gravity. The fines from the Raymond mill are delivered to a bin from which by means of a screw conveyer and chutes they are fed into the kettles. The kettles for this mill are two in number, 8 inches in diameter, fired with oil and steam. They are "pulled" at 305° F., requiring about two and one-half hours to reach this temperature. The flues are in a line, each kettle being equipped with four.

The flow of the material after calcination and the equipment used is essentially the same as for the gypsite mill. The only exception is that instead of all the mixers being Broughton this mill has one ½-ton Day mixer. A mill at this locality manufactures all of the Keene's cement this company produces.

The best colored rock from the mine, in large lumps, is loaded from the mine cars into wheelbarrows which are elevated to the top of the kilns, charging of the kilns being done by hand.

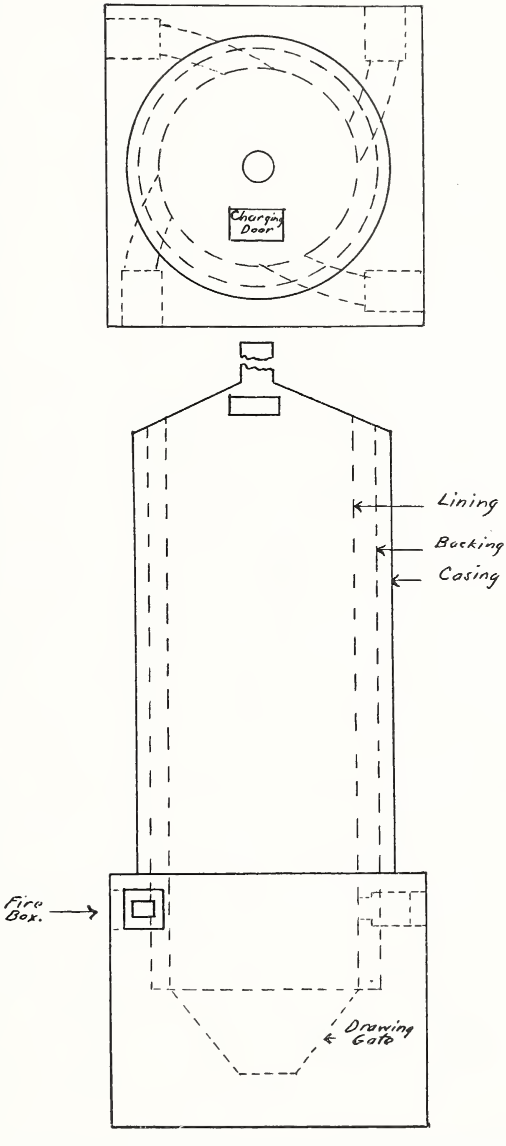

Fig. 30.—*Line drawing of the Keene's cement kilns of the Certain-teed Products Corporation, Acme, Tex.*

The kilns are two in number with inside dimensions approximately 6 by 15 feet. The bottom of each kiln has a gate opening feeding the burnt rock to a 12-inch drag chain conveyer which delivers into a mill building. At the base of the kiln and about 3 feet above the gate there are in each kiln four fireboxes, one at each corner, and located as shown by the sketch. Firing is done with Arkansas semianthracite coal. About 5 feet above the fireboxes in the shell of the kilns are located peepholes. When the rock as viewed through the peepholes, reaches a cherry red, the gate in the bottom of the kiln is opened and some of the rock discharged on to a chain conveyer. To keep the kiln full, more rock is added in the top.

Upon entering the mill the chain conveyer discharges the burnt rock into a pot crusher. From the crusher, by elevator, delivery of the material is made to a bin located above a 24-inch horizontal buhr mill. The rock is fed to the buhr mill by gravity. The buhr delivers to an elevator which delivers to a screw conveyer which in turn discharges the finely ground material into a bin over a weighing hopper located above a ½-ton Day mixer and a Bates automatic bagger. It is in the hopper that the accelerator for hastening the set of the cement is added.

When running one 9-hour shift per day this mill produces from 12 to 15 tons of Keene's cement with a fuel consumption for the kilns of 4 tons of coal. There has recently been installed at this mill equipment for the manufacture of gypsum tile.

From the stock bin in the "rock" mill a screw conveyer has been installed which delivers to a bin located over an automatic weighing hopper, feeding the tile machines. Into this hopper sufficient calcined gypsum, together with enough water and the necessary fiber for sixteen 3-inch tile is delivered. When sufficiently mixed, the wet material is released by hand into the molds underneath contained on a small car. After the tile have set the car moves forward, releasing the core forming units. The tile are then removed from the molds and loaded into other cars by hand, which are rolled into the drier. The tile remain in the drier for at least 12 hours. The temperature in the drier is maintained at 160° F. by circulating air which has been pulled through the flues of the gypsite mill and forced through an oil-fired heating unit. Circulation is maintained by a 36-inch fan located between the flues of the gypsite mill and the heating unit.

The equipment included five Acme type tile machines capable of turning out 10,000 square feet of 3-inch tile per day. Besides the calcined material manufactured at this plant 22,000 tons of raw rock are sold annually to cement manufacturers.

Power for the operation of the three mills and the tile machine was obtained from three 225-horsepower type A Diesel engines.

(c) CERTAIN-TEED PRODUCTS CORPORATION, ACME, OKLA.

This mill of the Certain-teed Products Corporation is located 4 miles northwest of the Rush Springs, Okla., station of the Chicago, Rock Island & Pacific Railway. A spur runs from the main line to the mill.

A gypsite deposit is the source of raw material. The following from Bulletin No. 697, United States Geological Survey, "Gypsum Deposits of the United States," by R. W. Stone and others, describes the geology of gypsum deposits occurring in Oklahoma.

"The gypsums of Oklahoma form a part of the great series of rocks which are generally known as the 'red beds.' The greater portion of the 'red beds' in Oklahoma are of Permian age, and all of the gypsums occur in rocks of that age. The gypsum deposits are contained in the Blaine and Greer formations. For convenience of discussion the gypsum deposits in Oklahoma are considered to occur in three areas—(1) the main line of gypsum hills, along Cimarron River, in the northwest portion of the State; (2) the second line of gypsum hills, in the west-central portion; and (3) the southwestern gypsum hills, in the extreme southwestern portion."

The Acme and Cement mills of the Certain-teed Products Corporation are located in the second area.

"Although generally spoken of as a line of hills, the gypsum outcrops of this area do not form a single prominent escarpment, as the outcrop of the Blaine formation does, but rather a series of low, rounded knolls and ridges. The gypsum beds are present in the lower part of the Greer formation. The rocks of this formation are principally soft clay shales, with some soft sandstones and lenticular masses of gypsum. Some of the lenses of gypsum are of considerable extent and thickness, but there are no well defined beds which can be traced for many miles like those in the Blaine formation."

The gypsite deposits at Acme cover more than 50 acres and have an average thickness of about 8 feet.

The composition of the deposit is shown by the following analysis:

	Per cent
Gypsum ($CaSO_4 \cdot 2H_2O$)	66. 7
Calcium carbonate ($CaCO_3$)	6. 6
SiO_2, Al_2O_3, Fe_2O_3, etc. (by difference)	26. 7

The pit from which the gypsite is obtained at present is located 1 mile northwest of the mill. A light overburden of 12 inches is removed by plows and scrapers, leaving exposed a 4-foot bed of gypsite. The deposit is very wet even in dry seasons. To facilitate handling and to shorten the time of calcination, it is usually piled upon high ground and allowed to drain and dry somewhat before going to the mill. At the pit the material is loaded by scrapers into 10-ton, narrow-gauge, bottom-dump cars. These are hauled to the mill by gas locomotives. The cars are discharged upon an 18-inch Balata belt which delivers to an elevator. The elevator discharges into a chute with a gate arranged in such a manner that the gypsite may be delivered into the kettles direct or to the storage bin. Material is drawn from the storage bin by means of a belt, elevated, and delivered to the kettles.

The mill is equipped with two 12-foot kettles, each having four flues in line. Both recording and nonrecording thermometers dip into the gypsite in each kettle. The fuel used is oil and compressed air, both at 45 lbs./in.^{2} About 20 barrels of oil are used per 9-hour day. Each kettle has a capacity of 12 tons and is "pulled" at 330° F. The duration of calcination is three and one-half hours.

From the kettles the stucco goes into the hot pits located directly behind the kettles. By means of a screw conveyer and elevator the material from the hot pit is delivered to one of two 4-section Acme vibrating screens set at an angle of 45°.

The material passing the screens is carried by screw conveyer and discharged into the stock bin above the hoppers. Oversize material goes to a Jeffrey mill by conveyer and from the Jeffrey mill into the stock bin.

The hoppers are all of ½-ton size, and into them are added the hair or wood fiber and retarder. From the hoppers the mix is discharged by hand and delivered by gravity to ½-ton Broughton mixers. After going through the mixers the material is bagged by Bates automatic baggers and is trucked to either the warehouse or into cars for shipment. Power for the mill is supplied by one 175-horsepower type A Diesel engine. The capacity of the mill is 160 tons of finished plaster per day.

(*d*) CERTAIN-TEED PRODUCTS CORPORATION, CEMENT, OKLA.

At Grady's switch, 2 miles south of Cement, Grady County, Okla., on the Frisco Railway, is located a gypsum rock quarry operated by the Certain-teed Products Corporation and under supervision of the Acme (Okla.) mill.

A geological discussion of the deposit is given in Bulletin 697, Gypsum Deposits of the United States, of the United States Geological Survey. The vein of rock at this point is 40 feet thick and is worked in 20-foot faces by open quarry. After the material is brought down it is loaded into narrow-gauge cars, transported to the crushing mill, where it is first put through a nipper and then a pot crusher. From the crusher the rock is loaded into the railway cars by means of a bucket elevator.

(*e*) OKLAHOMA PORTLAND CEMENT CO., IDEAL, OKLA.

The Oklahoma Portland Cement Co. owns and operates a gypsum mill at Ideal, Blaine County, Okla., a station on the Chicago, Rock Island & Pacific Railway, 3 miles west of the town of Darrow, Okla. The post office is Homestead, Okla. The office of the company is Oklahoma City, Okla.

The gypsum deposit worked lies in the main line of gypsum hills (see p. 56). These hills are produced by the outcrop of the Blaine formation, which consists of three beds of gypsum separated by red shales. Of the three beds the lowest one is known as the Ferguson gypsum member, the middle as the Medicine Lodge gypsum member, and the uppermost as the Shimer gypsum member.[14]

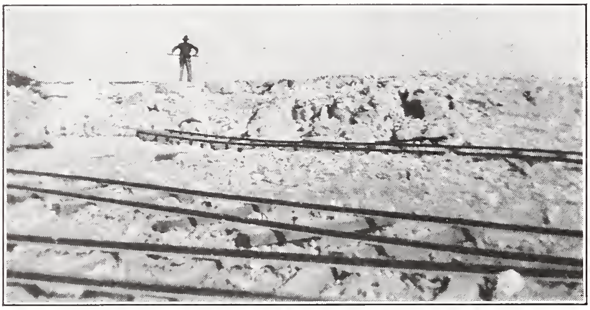

FIG. 31.—*Gypsum quarry of the Oklahoma Portland Cement Co., Ideal, Okla.*

The analysis of rock from the quarry is as follows:

	Per cent
Gypsum ($CaSO_4 \cdot 2H_2O$)	96. 0
Calcium carbonate ($CaCO_3$)	. 3
SiO_2, Al_2O_3, Fe_2O_3, etc. (by difference)	3. 7

Gypsum rock, the raw material, is obtained from an open quarry about 1,000 feet northwest of the mill. The seam varies in thickness from 4 to 5 feet and carries an overburden of soil of from 1 to 3 feet which is removed by plowing and scrapers. As the quarry is located on the top of a hill, there is little chance for hindrance of the operation from water even though it were encountered.

After the rock is brought down it is loaded into 2-ton, side-dump cars. The cars are drawn to the crest of the hill by means of mules. At the crest of the hill they are attached to a cable of a drum hoist and lowered down an incline to the mill. Here the rock is passed through an Ersham nipper, reducing the material to 3 inches and under. The nipper is directly over and feeds into a rotary crusher which reduces to three-fourths inch. The material from the crusher is elevated by bucket elevator and discharged to an 18-inch belt conveyer. From the belt the crushed rock passes over a one-half-inch grid screen. The oversize from the screen is deflected to a chute leading to a bin from which it is elevated into cars and shipped to the company's cement plant at Ada, Okla.

[14] Gypsum Deposits of the United States, by R. W. Stone and others, Bull. 697, U. S. Geol. Survey.

The fines from the grid go into a 9-inch screw conveyer which delivers to the stock bin. From this bin, as required, the material passes through one of two 36-inch horizontal buhr mills. After passing through the buhrs the ground rock is carried by conveyer and elevator to the bins above the kettles.

The mill is equipped with two 10-foot kettles, having four flues each. Two of the flues are 18 inches above the other two and at right angles. Thermometers are located in the top of each kettle and extend about 12 inches into the gypsum. The kettles are fired by coal, "pulled" at either 345 or 505° F., depending upon the product desired, and require from three to three and one-half hours for calcination per batch with a fuel consumption for second settle stucco of from 2,700 to 2,800 pounds of coal.

The raw rock is fed to the kettles by gravity and is discharged from the kettles to the hot pit in the rear of the kettles. From the hot pit the calcined gypsum is carried by screw and elevator and delivered to a 35-mesh vibrating screen. Material passing the screens is carried to the bins in the packing house. That not passing is put through one of two 36-inch buhrs and then goes to the packing-house bins. The packing-house bins are located over the weighing

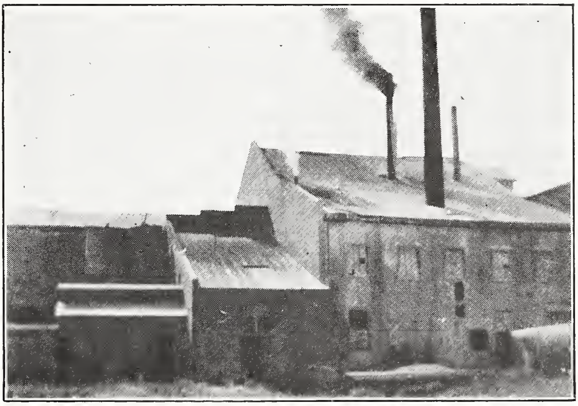

FIG. 32.—*Gypsum mill of the Oklahoma Portland Cement Co., Ideal, Okla.*

hoppers (one 1 ton and one one-half ton) which deliver to Broughton mixers. It is in the hoppers that accelerator or retarder is added. The baggers are located under the mixers. All bagging is done by hand.

In the usual 9-hour day the production of finished product is about 100 tons. The plant manufactures only molding plaster, plaster of Paris, and a small amount of orthopedic plaster. Second settle stucco is used in all except one grade of molding (No. 1), which is first settle.

Power is obtained from a 350-horsepower Corliss engine, which drives a 180-kilowatt generator. This is sufficient, as power records show that under present conditions the power consumption is never over 140 horsepower.

(*f*) BEST BROS. KEENE'S CEMENT CO., MEDICINE LODGE, KANS.

Best Bros. Keene's Cement Co.'s plant is located on the Santa Fe Railway at Medicine Lodge, Barber County, Kans. The gypsum rock deposit from which the raw material is obtained is located 20 miles west of Medicine Lodge, at Kling. An open quarry is worked.

"The gypsum of this area is massive and the lower portion of the stratum is very compact, while the upper portion is sugary in texture.

"The easternmost occurrence of gypsum in this area is 6 miles southwest of Medicine Lodge, in an isolated range of hills 3 miles long, which is separated by a narrow valley from a second hill 1 mile in length. The valleys of East Cedar and West Cedar Creeks, 2 miles wide, separate these hills from the next series, in which the gypsum plateau is continuous to the west. Medicine Lodge River cuts out the gypsum in a valley 6 or 7 miles wide. The northern limit of the gypsum can not be determined from observations, as it is covered with Tertiary deposits. Salt Fork and Sandy Creek cut out broad valleys to the south, and the streams in the eastern portion of Comanche County have removed much of the gypsum, but it is continuous over the great portion of western Barber and eastern Comanche Counties." [15]

Analysis of rock as made at the bureau is as follows:

	Per cent
Gypsum ($CaSO_4 \cdot 2H_2O$)	96. 0
Calcium carbonate ($CaCO_3$)	2. 0
SiO_2, Al_2O_3, Fe_2O_3, etc. (by difference)	2. 0

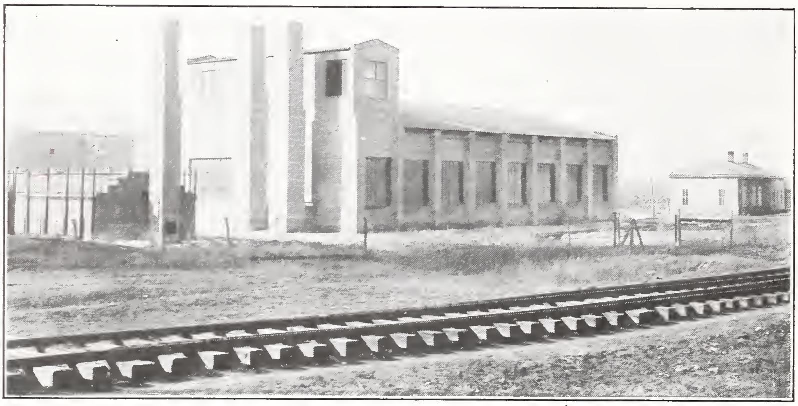

FIG. 33.—*Partial view of the mill of the Best Bros. Keene's Cement Co., Medicine Lodge, Kans.*

At the quarry the rock is loaded by hand into 1½-ton bottom-dump cars and transported 1½ miles to the reducing plant. The reducing plant consists of a nipper and pot crusher. The material coming from the crusher is all one-fourth inch or less. After going through the crusher the rock is loaded into one-half-ton cars and by an aerial tramway is carried 1¼ miles and loaded into hopper-bottomed railway cars. These cars are covered with tarpaulins to exclude cinders and dirt and are shipped over the Santa Fe Railway to the mill at Medicine Lodge.

The "run of crusher" rock as received at the mill is transported by an 18-inch belt conveyer to a bin in the mill building. From this bin the material is carried by screw and elevator and delivered to the kilns.

There are two rotary kilns, 110 by 8 feet, fired by steam and oil at 35 pounds pressure, maintaining a temperature in the kilns of 1,800° F. The speed of the kilns is such that the rock is exposed to the heat, for approximately five hours. From the kilns the hot rock drops into cooling cylinders, 60 by 6 feet, open to the air. The coolers discharge the burnt rock into a screw conveyer,

[15] Gypsum Deposits of the United States, by R. W. Stone and others, Bull. 697, United States Geol. Survey.

thence by belt and another screw it is delivered to a bin in the mixing or packing house.

From the bin in the packing house there are two courses through which the rock may be put, depending on the product desired. If the usual Keene's cement is desired, the burnt rock is elevated and delivered to one of two 36-inch vertical buhr mills and thence to another bin over the weighing hoppers and baggers. If one of many special products is desired, the course of the material from the packing-house bin is to one of two Raymond mills and then to another bin located above other weighing hoppers and baggers. The hoppers in both cases are one-half ton and deliver directly to half-ton Broughton mixers above hand baggers. The normal output for a nine-hour day is 100 tons of finished product. Power is supplied for the Medicine Lodge mill by three 125-horsepower Corliss engines, which drive all the machinery from a main driving shaft.

(*g*) CENTERVILLE GYPSUM CO., CENTERVILLE, IOWA

The mill of the Centerville Gypsum Co. is located at Centerville, Iowa, on the C., B. & Q. Ry. Rock is obtained from a mine, the floor of which is 550 feet below the surface at the shaft opening. This deposit of gypsum was discovered in 1910 by the Scandinavian Coal Co. while prospecting for coal. The extent of this field is not known, and because of its depth the presence or not of the gypsum must be determined entirely by drilling. The geology of the deposit is discussed fully in volume 28 (Iowa Geological Survey), Gypsum, by F. A. Wilder. This authority states that the gypsum of this deposit seems to have been originally anhydrite, part of which has altered to gypsum. Further, that the anhydrite was in turn derived from limestone by the action of sulphurous waters.

Analysis of a sample taken by the writer from the mine and analyzed at the Bureau of Standards laboratory is as follows:

	Per cent
Gypsum ($CaSO_4 \cdot 2H_2O$)	89. 0
Calcium carbonate ($CaCO_3$)	2. 7
SiO_2, Al_2O_3, Fe_2O_3, etc. (by difference)	8. 3

The seam of rock which is being worked is 6 feet in thickness and slopes slightly to the west. Anhydrite is encountered to some extent; usually in large plugs easily identified and not worked. The gypsum is overlaid and underlaid with dolomitic limestone. While considerable water is encountered, it is drained to an underground stream and consequently offers little trouble.

The mine is worked by the usual room and pillar system. The rock is brought down with 20 per cent dynamite, loaded into half-ton end-dump cars, and transported to the shaft by horses. The shaft has two cages which are operated by a steam hoist. When the cars reach the surface, the material is inspected and any anhydrite or limestone discarded. The cars are discharged into an Ersham nipper which reduces to 2½ inches and under. The nipper delivers by gravity to an Ersham pot crusher, where the rock is reduced further, so that all the material is one-fourth inch or less. From the crusher the rock is conveyed by screw and elevator and discharged into a bin directly over a Raymond mill. The Raymond mill is fed by gravity from the bin and the rock is reduced to such a fineness that 75 per cent passes a 200-mesh screen. This fine material from the Raymond mill is carried by screw conveyer to two bins above the kettles.

The mill is equipped with two 10-foot standard Ersham kettles fitted with small dust collectors. There are four flues to each kettle, two above two and the sets at right angles. The kettles are coal fired, "pulled" at 330° F. for first settle stucco and 420° F. for second settle stucco. First settle stucco requires one and one-fourth hours with a fuel consumption of 1,100 pounds of coal.

When the kettles are "pulled" the calcined gypsum flows into the hot pit behind the kettles, from which it is carried by screw and elevator to the packing bins. These bins are located above ½-ton weighing hoppers, and it is into these hoppers that the wood-fiber or hair and retarder are introduced. The hoppers deliver to the ½-ton Ersham mixers, which in turn deliver to four spout hand baggers.

Power for the operation of a main drive shaft is obtained from a motor connected to the city lines. The power consumption was not obtainable. This company also manufactures a small number of gypsum tile. They are made entirely by hand methods and average about 200 tile per day.

The production of raw rock is from 80 to 90 tons per day. One-half of this is sold to cement manufacturers for use as retarder.

Products of the mill using first settle stucco besides the tile are hair-fibered plaster, wood-fibered plaster, neat plaster, and molding plaster. Second settle stucco is used for dental plaster. This company manufactures the new gypsum insulating material "Insulex," the composition of which is limestone, aluminum

FIG. 34.—*Mill of the Centerville Gypsum Co., Centerville, Iowa*

sulphate, glue, and calcined gypsum. According to the patent under which it is made,[16] the aluminum sulphate in the presence of water reacts with the limestone to form carbon dioxide. This results in a very porous mass which is strengthened by the glue coating on the inside of the pores. From the very nature of the product the claims made for it as an insulating material seem justified.

(*h*) CARDIFF GYPSUM PLASTER CO., FORT DODGE, IOWA

The first gypsum mill west of the Mississippi was located at Fort Dodge over 50 years ago. The oldest mill operating in that area at present is that of the Cardiff Gypsum Plaster Co., which was named after the Cardiff giant and erected in 1895. It is located 4½ miles southeast of the city on the Ft. D.–D. M. & S., I. C., and C. G. N. Rys., and is the easternmost development.

The deposit of gypsum from which this mill and all the others in the Fort Dodge area obtain their raw material has been studied thoroughly with respect to the geology of the deposit, and most complete discussion of this nature is given in volume 28, Iowa Geological Survey, Gypsum, by F. A. Wilder.

[16] United States Patent No. 1230085.

"The deposit at Fort Dodge seems to be in a trough or basin. The gypsum beds lie unconformably in strata of Pennsylvanian and Mississippian age, and the basin is completely surrounded by these older rocks. The gypsum and its closely related rocks in this area have yielded few fossils, so that there is little paleontologic evidence of the age of this deposit. The Permian in Kansas, Oklahoma, and Texas is highly gypsiferous, including some thick pure deposits, and is so highly colored as to be known as the "red beds." The Fort Dodge gypsum is related to a pink formation, not red. Furthermore, in Kansas there is no unconformity between the Permian and the underlying coal measures. There is, therefore, no definite evidence for correlating these beds with the Permian 300 miles west, although there is some color of resemblance. The age of the Fort Dodge gypsum is therefore unknown, but is believed to be Permian.[17]

The mine is 60 feet below the surface at the shaft entrance, is electrically lighted, and has a one cage shaft. The vein worked by this company contains close to 10 feet of workable gypsum, is overlaid with glacial drift and underlaid with sand. An analysis of the gypsum is given below:

	Per cent
Gypsum ($CaSO_4 \cdot 2H_2O$)	90. 8
Calcium carbonate ($CaCO_3$)	1. 0
SiO_2, Al_2O_3, Fe_2O_3, etc. (by difference)	8. 2

The mine is worked by the room and pillar system, hand augers being used for drilling; 40 per cent dynamite for shooting. Considerable water is encountered and necessitates the continuous operation of seven pumps delivering two 4-inch streams to the surface. One hundred and ten tons of rock per 8-hour day is the usual production.

After the rock is brought down it is loaded into 2,400-pound end-dump cars which are transported to the shaft by horses. Upon reaching the mill the cars are run over scales and emptied into a 5-foot gyratory crusher. From the gyratory the crushed rock is fed to an 18-inch belt, which delivers it to an elevator discharging into a 1,500-ton bin. Four openings in the bin feed an 18-inch belt, which in turn delivers to a screw conveyer which deposits the rock into another bin over a pot crusher. The pot crusher is fed by gravity from the bin, and after passing through the crusher the rock is carried by belt and elevator to a bin over five 36-inch horizontal carborundum mills. The mills are fed by gravity from the bin and deliver to a 9-inch screw conveyer which, together with an elevator and belt conveyer, discharge the material into a bin located above three 10-foot kettles. Filling of the kettles is by gravity from the bin above.

The kettles have four flues in a line, are equipped with dust collectors, have sectional bottoms, 5-foot thermometers in the top, and are pulled at 120° C. Two hours are necessary to reach the desired temperature. Coal is used for fuel, 6 to 7 tons being consumed per 100 tons of calcined gypsum.

When the kettles are "drawn" the calcined gypsum flows into a hot pit behind the kettles, from which it is carried by screw, elevator, and belt conveyers to bins above two 36-inch horizontal buhr mills. The material is fed to the buhrs by gravity, is carried away by screw, elevator, and belt conveyers and delivered to a bin above two ½-ton mixing hoppers. Into the hoppers is put the hair or wood-fiber, retarder, clay or lime which is to be incorporated in the plaster. The hoppers are fed by spouts and deliver to ½-ton Broughton mixers which are located above the baggers on the floor below. Bagging is done by hand. One hundred tons is the usual production per day.

[17] Gypsum Deposits of the United States, by R. W. Stone and others, Bull. 697, United States Geol. Survey.

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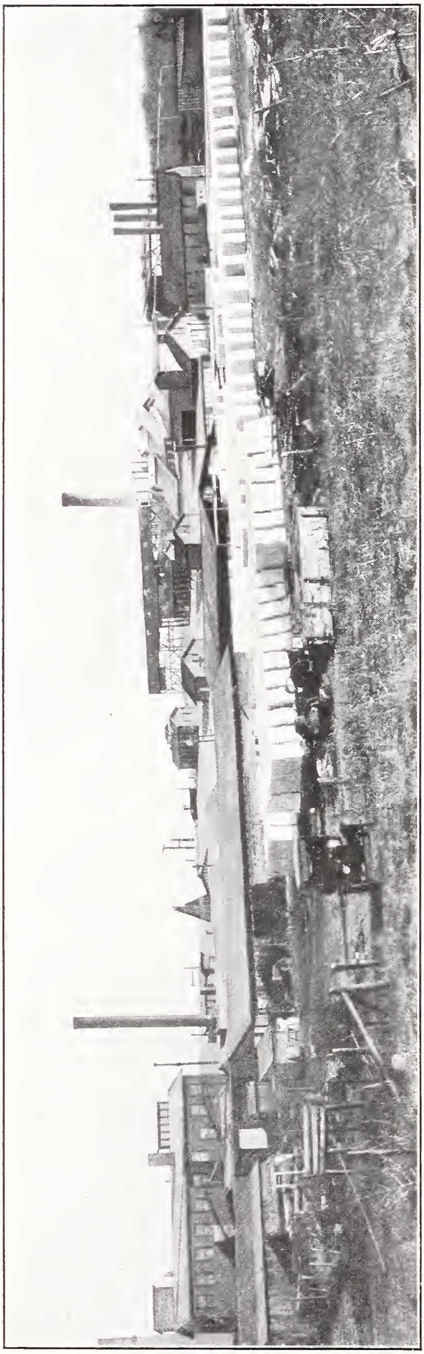

Fig. 35.—*Plymouth mill of the Universal Gypsum Co., Fort Dodge, Iowa*

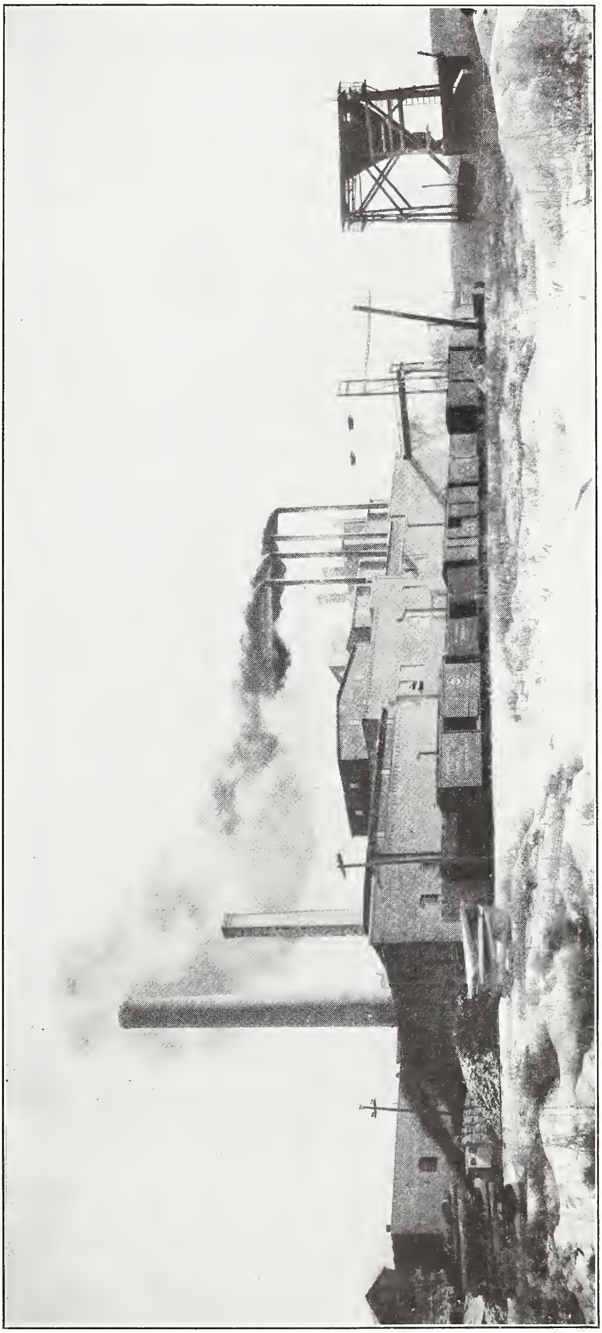

Fig. 36.—*Iowana mill of the Universal Gypsum Co., Fort Dodge, Iowa*

The mill is operated entirely by electricity even to the mine hoist, current being obtained from the city lines. Two hundred horsepower is the normal consumption.

While the major portion of rock mined goes into prepared plasters a considerable quantity is sold each year as crude rock to cement manufacturers. Several brand names are used, the ones best identified with the company are Cardiff and Kallolite.

(*i*) UNIVERSAL GYPSUM CO., FORT DODGE, IOWA

The Universal Gypsum Co. operates two mills in the Fort Dodge area—the Plymouth and the Iowana. The Plymouth mill is located upon the C. G. W. and the Ft. D.—D. M. & S. Rys. the Iowana upon the M. & St. L. Ry.

The rock for both mills is obtained from a drift mine on the west side of the Des Moines River. The geology of the deposit is given in Bulletin 697, Gypsum Deposits of the United States, of the United States Geological Survey, and volume 28, Iowa Geological Survey, Gypsum, by F. A. Wilder.

The vein varies in thickness from 11 to 30 feet, dipping only slightly. Entrance is on the side of a hill, the present working face being about 1¼ miles from the entrance. The overburden is glacial drift and at the deepest point in the mine is about 90 feet.

The mine is worked by the usual room and pillar method. It is electrically lighted throughout. Very little water has to be handled and never in sufficient quantity to hinder the work. When necessary, it is delivered to the surface by pumps. Drilling is done by electric drills, and for shooting 15 per cent dynamite is used.

After the rock is brought down it is loaded by hand into 1½-ton side-dump cars. These are assembled by mules into trains of from 8 to 12 cars and are hauled out of the mine by a 10-ton electric locomotive. When working an 8-hour day the production of rock normally runs about 600 tons.

The primary crushing of the rock is done at a reducing plant located at the mine entrance. As the cars are brought from the mine they are discharged into a No. 7 Tel-Smith gyratory. This reduces all of the rock to 3 inches or less. Upon coming from the gyratory the rock is elevated and passed over a 2-inch screen, the fines being delivered by a chute into the tramcars going to the Iowana mill. The oversize passes down to a pot crusher reducing to 1 inch or less. From the pot crusher it is again elevated to a bin delivering to the tramcars for the Plymouth mill.

The Iowana mill is directly across the river from the mine, a distance of one-half mile. The Plymouth mill is also on the opposite side of the river but 1¾ miles from the mine. Transportation to both mills from the crushing plant is by aerial tramway, each tramcar carrying 1,000 pounds of rock.

The process of refinement and equipment at each mill is essentially the same. A detailed description will be given of the Plymouth mill, and any difference in treatment or equipment at the Iowana mill will be noted.

When the tramcars arrive at the mill they are automatically discharged by a trip, the crushed rock falling into a bin. From this bin the rock is carried by an elevator and delivered to a revolving, coke-fired 30 by 5 foot cylindrical drier. The rock comes from the drier at a temperature of 180° F., is elevated to a bin above a Williams hammer mill, to which it is fed by gravity. A screw conveyer and elevator carry the ground rock from the Williams mill and deliver it upon a Tyler hammer screen set at 34°. The tailings from the screen are either returned to the Williams mill or are conveyed by screw to cars outside the mill and sold as retarder for cement. The fines from the screens are conveyed to bins above the kettles. Each kettle is fed from the bin by gravity through two square chutes, 4 inches on a side.

Each mill is equipped with four 10-foot kettles having four flues each, the flues being all in a line. Each kettle is equipped with two 18-inch vapor pipes leading to dust collectors. The kettles at the Plymouth mill have 15-section bottoms, those at the Iowana various types. The kettles are "pulled" at 325° F., requiring two hours to reach this temperature. Firing is done with coal with a consumption of 1,500 pounds per kettle.

When "pulled," the calcined gypsum from the kettles flows into the hot pit in the rear of the kettles, from which it is conveyed in the Plymouth mill by screw and elevator to either a 400-ton storage bin or to bins above four Sturtevant vertical buhr mills, two 42 inches in diameter and two 36 inches in diameter, fed by gravity from the bins. At the Iowana mill the regrinding is done in two 22 by 4 foot tube mills containing 11 tons each of 2-inch casehardened special balls. By this method plastic gypsum is made, the process having been discovered by W. E. Emley, of the United States Bureau of Standards.

The material coming from the regrinders is carried by screw and elevator to bins above weighing hoppers. The stucco is fed by screw conveyer from the bins into the weighing hoppers, and it is into these hoppers that the hair or wood fiber, retarder, etc., are added. The material is fed by gravity from the hoppers into the mixers directly underneath and by the same means to the baggers. All bagging is done by Bates automatic baggers.

There are two features of operation employed at these mills which offer an interesting basis for comparisons. Both mills operate by electricity. The Plymouth uses the group method, in which several appliances are operated from one motor. The Iowana uses the individual drive method, in which each appliance has its separate motor. The total power necessary for running the two mills, the mine, and the tramway is normally 2,000 horsepower.

Retarder is manufactured from hair, lime, and soda ash at the Plymouth mill and is shipped to all the other mills of this company from Fort Dodge. Wood fiber and chips for tile and block are also made at this mill.

At the time of the writer's visit this company was erecting a wall board and plaster board mill of the same type as that of the Gypsolite Products Corporation, Batavia, N. Y., which is described fully on page 78.

About 4,000 square feet of gypsum tile are manufactured per day at the Plymouth mill. Mixing, casting, etc., is done by hand. Drying is accomplished by storage in the air.

(*j*) WASEM PLASTER CO., FORT DODGE, IOWA

The mill of the Wasem Plaster Co. is located 3 miles southeast of Fort Dodge, in the center of the gypsum deposit, on the Ft. D.—D. M. & S., and I. C. Rys.

Rock is obtained from a mine in the Fort Dodge deposit, the floor of which is located 60 feet below the surface at the shaft. The geology of this deposit is discussed fully in volume 28, Iowa Geological Survey, Gypsum, by F. H. Wilder, and in Bulletin 697, Gypsum Deposits of the United States, of the United States Geological Survey.

The mine is worked by the usual room and pillar method. It is lighted by electricity throughout. The seam varies in thickness from 10 to 30 feet, though a working face of 10 feet is maintained. There is considerable water to be disposed of, it being delivered to the surface by pumps through several 4-inch pipes.

Drilling is done with electric drills, the rock being brought down with 15 per cent dynamite. The shot rock is loaded into 2-ton side-dump cars, which are assembled into trains by mules and transported to the primary crusher by electric locomotives.

The primary crushing is done in the mine at the foot of the shaft. The mine cars are discharged into a 6-foot gyratory, which reduces all the material to 3 inches and less. After passing through the gyratory the rock is elevated to a bin on the surface from which a pot crusher at the foot of the shaft is fed through a chute by gravity. This reduces the rock to three-fourths inch and less. From this crusher the rock is carried by elevator and screw and discharged into the drier. The drier is of the cylindrical, revolving type, 40 by 5 feet, coke fired. The rock comes from the drier, at a temperature of 150° F., passes under an electric magnet to remove any spikes, etc., which may be present, and drops into a screw conveyer. By means of this screw, an elevator, and another screw conveyer the dried rock is delivered to a double 8-mesh and 35-mesh screen. The material passing the 35-mesh is carried by screw directly to the kettle bins. That retained on the screens is discharged by chute to a bin over six horizontal buhr mills, 42 inches in diameter, which are fed by gravity from the bin. After passing through the buhrs the rock is carried by screw and elevator to a series of eleven 35-mesh Tyler vibrating screens. The oversize is returned to the buhrs for further grinding. The fines from the screens are carried by screw conveyer and discharged into metal kettle bins. Screw conveyers deliver from these bins to chutes leading to the kettles.

The mill is equipped with 10-foot (four flues in a line) coal-fired kettles, four in number. Dust collectors are located over each kettle. The kettles are drawn at 325° F. and require two hours to reach this temperature. Twelve hundred pounds of coal are burned per kettle.

The calcined gypsum is discharged from the kettles into the hot pit in the rear of the kettles. From the hot pit the "stucco" is moved by two screw conveyers and an elevator into the warehouse bins. These are located over three ½-ton weighing hoppers which deliver by gravity to ½-ton Broughton mixers. In the hoppers are added the retarder, clay, etc. The mixers deliver by gravity to the baggers. The bagging equipment consists of two hand baggers and one Bates automatic bagger.

Electric power obtained from the city line is used throughout. All units are equipped with individual motors. The capacity of the mill is about 200 tons of finished plaster per day. A considerable quantity of raw rock is sold to cement manufacturers. This company is at present erecting a tile mill in which it is hoped to be able to produce 2,000 square feet per day. The casting is to be done by hand.

(*k*) GRAND RAPIDS PLASTER CO., GRAND RAPIDS, MICH.

The Grand Rapids Plaster Co. operates three mills in the Grand Rapids area. Eagle mills Nos. 1 and 2, on the southwest boundary of the city, and Grandville mill at Grandville, 3½ miles southwest of the city. At the time of the writer's visit to Grand Rapids the Grandville mill was not operating, and consequently was not visited.

The two Eagle mills are located on the N. Y. C. Ry., over which all the material shipped is transported. The geology of the deposit of rock from which these two mills and all of those in the Grand Rapids area are supplied is discussed fully in a paper by G. P. Grimsly, "The Gypsum of Michigan," published by the Michigan Geological Survey, vol. 9, pt. 2; 1904.

The following from Bulletin 697, United States Geological Survey, Gypsum Deposits of the United States, by R. W. Stone and others, indicates the character and occurrence of the deposits in this area:

"The gypsum of Michigan belongs to the massive rock variety and occurs in lenticular deposits embedded in shale and shaley limestones. In some places the beds of gypsum are very numerous. The beds range in thickness from a fraction of an inch to 25 feet or more. The thinner beds are generally small in area, but some of the thicker ones have been traced over large areas. The easily mined deposits of gypsum in Michigan are practically inexhaustible. In addition, less easily accessible deposits underlie an area hundreds and probably thousands of square miles in extent.

"The rock gypsum is generally very pure. Commonly its color is white or reddish, but the upper portions of some beds which lie near the surface are stained yellow by iron oxide and are more or less mixed with clay, sand, and gravel. The texture in most places is finely to coarsely crystalline."

The two Eagle mills obtain their rock from a drift mine with openings at each mill. The top stratum of gypsum, 10 feet in thickness, is worked. This stratum of gypsum while containing some salt and flint has less of these impurities than the other strata of the deposit. The gypsum is overlaid with shale and merges with a flint on the bottom. The analysis of a typical sample is as follows:

	Per cent
Gypsum ($CaSO_4 \cdot 2H_2O$)	89. 5
Calcium carbonate ($CaCO_3$)	2. 9
SiO_2, Al_2O_3, Fe_2O_3, etc. (by difference)	7. 6

The mine is worked by the usual room and pillar method, the pillars being removed as the workings are abandoned. The mine is equipped with electric lights, and drilling is done by electric drills. The rock is brought down with 17 per cent dynamite, loaded by hand into 6½-ton side-dump cars, the cars being pulled to the mine entrance by horses. No sorting of the rock going to mill No. 1 is done. In the rock for mill No. 2 a certain percentage of the overlying shale is included in the rock, it having been found that the shale materially improves the working quality of the finished plaster.

(1) Eagle Mill No. 1.—Upon arrival at the mine entrance the mine cars are brought up an incline by means of a cable and discharged into a Tel-Smith gyratory which reduces all to 3 inches or less. The gyratory feeds by gravity into two Butterworth and Lowe pot crushers driven by a 25-horsepower motor. After passing through the crushers the rock is carried by belt conveyer and delivered to the leaching tanks. These are seven concrete bins, 30 by 12 by 16 feet. Their purpose is to dissolve out the soluble salts which occur in the rock. They are filled with rock and then flooded with water several times. Loading from the tanks to a drag conveyer is done by means of either a clamshell, electric excavator, or a digger as used in ditch work.

The rock from the leaching tanks or from the rock bin goes through one of two 38 by 6 feet Ruggles-Coles driers, fired with either coke or a mixture of coke and coal. The fuel consumption is from 3 to 3½ tons per day. Each drier is equipped with fans for forced draft, the fans being located at the discharge end of the drier. The fine stuff is blown up to cyclone collectors on the roof of the mill. From the driers the material is put through a Jeffrey mill and then through screens. The screens are the four-section, 30-mesh, Newaygo-Sturtevant type. The fines from the screens go directly to the kettle bins. The material retained on the screens goes to a stone bin, from which it is fed to a 36-inch horizontal buhr mill. From the buhrs it is again passed over the screens.

The kettle bins are located directly over the kettles, and the material is fed into the kettles by gravity.

The mill is equipped with four 8-foot kettles with solid steel bottoms. The company has been conducting quite a bit of experimental work upon the relative value of flues with regard to size, number, etc., and consequently the kettles have flues of various types and numbers. The kettles are fired by coal, "drawn" at 356° F. for first settle stucco and at 398° F. for second settle, two hours being required to reach 356° F. Besides the usual type thermometer the kettles are equipped with recording thermometers. The fuel consumption per kettle is 1,120 pounds of coal.

The kettles are discharged into the hot pit in the rear of the kettles, from which the hot calcined gypsum is carried by screw conveyer and passed through a cooler. The cooler is essentially a hollow cylinder 22 feet by 5 inches rotating in a water bath. Its capacity is 20 tons per hour, the temperature of the material being reduced from 340 to 170° F., aerating occurring at the same time.

From the cooler the calcined gypsum is carried by screw and elevator and deposited in the storage bins. The material is conveyed by screw and elevator from the storage bins and discharged into the weighing hoppers, where the retarder, etc., are added before the batch is discharged by gravity into 1-ton Broughton double mixers. The mixers are located over the baggers, which are of the hand-operated, four-spout type.

(2) Eagle Mill No. 2.—The rock is elevated from the mine to the mill in a similar manner as at mill No. 1. The mine cars are discharged into a Simons gyratory which delivers to two Butterworth and Lowe pot crushers. From the pot crushers the rock is carried by conveyer and elevator and deposited in the rock bin. A screw conveyer delivers the rock from this bin to a Ruggles-Coles drier similar to that in mill No. 1. The dust trap at this mill for the drier is a large brick chamber.

After passing through the drier the rock is carried by conveyer and elevator and delivered to a ¼-inch rock reel. The coarse material from this reel goes to the stone bin. The fines are passed over a four-section, 30-mesh, Newaygo-Sturtevant screen. The coarse from these screens also goes to the stone bin. The fines are conveyed by screw to the kettle bins. The rock from the stone bin is reduced in one of three tube mills. One double feed single discharge, 6 by 4 foot mill, containing 16,000 pounds of steel spherical balls, one double feed, single discharge, 50 inch by 4 foot mill, containing 6,000 pounds of balls and one single feed, single discharge 6 by 4 foot mill, containing 8,000 pounds of balls. After having passed through a tube mill the material is passed over 30-mesh screens.

From the kettle bins to the baggers the equipment and flow of the material is identical with that described for mill No. 1 and it does not appear necessary to again detail the process. In both mills individual drive by electric motors is used exclusively, power being obtained from the city lines; 672 kilowatts is the average power consumption for both mills and the mine. This company manufactures only wall plasters (all varieties) and plaster for plate-glass bedding. The total production is about 400 tons per day.

(*l*) MICHIGAN GYPSUM CO., GRAND RAPIDS, MICH.

The mill of the Michigan Gypsum Co. is located on the south side of the Grand River, within the city limits of Grand Rapids, on the P. M. and N. Y. C. Rys.

The geology of the deposit from which this company obtains its raw rock has been studied quite thoroughly and a report upon it made by G. P. Grimsley, The Gypsum of Michigan, Michigan Geological Survey, volume 9, part 2; 1904.

A vein 12 feet in thickness is worked by the usual room and pillar method. The floor of the mine is 90 feet below the surface. It is lighted throughout with electricity. The drilling is done with electric drills. The rock is brought down with a low percentage dynamite. The shot rock is loaded into side-dump cars by hand, after which cars are pulled to the base of the shaft by mules. The primary crushing is done in the mine. The mine cars are discharged into a Monarch nipper which reduces all to 3 inches and less. The nipper feeds a bucket elevator which carries the crushed rock to the surface, depositing it on a 22-inch belt. This belt delivers to a 200-ton rock bin. Directly under the rock bin, so that they may be fed by gravity, are located a Jeffrey mill and a Butterworth and

Lowe pot crusher. The Jeffrey mill handles the rock, except in rush periods when the crusher is also operated.

After passing through the Jeffrey or pot crusher the rock is elevated to a bin from which it goes through one of three courses: (1) To the cars for use in cement manufacture, (2) to a large storage pile, or (3) by gravity to a Kent Maxecon mill for further reduction. The discharge from the Kent mill feeds into a bucket elevator which deposits the ground rock in the kettle bins. These bins are located above the kettles and the rock is fed through spouts by gravity into the kettles.

The kettle equipment of the mill consists of two 10 by 12 foot, 15-ton capacity, four-flue kettles. The flues are two sets of two each above each other and at right angles. The bottoms are solid steel. The kettles are drawn at 350° F., two and three-fourths hours being required to reach this temperature. Firing is done by coal with a consumption of 1,700 pounds per kettle.

When the kettles are drawn the calcined gypsum flows into the hot pit in the rear of the kettles. From the hot pit the stucco is carried by screw and elevator to the stock bin. From the stock bin the material goes to either the tube mill for regrinding or by elevator and screw to the packing house, depending on the product desired. The material to the tube mill is delivered by gravity from a bin above. The tube mill is 22 by 5½ feet, contains 5 tons of 1¼-inch steel balls, and has a capacity of 6 tons per hour. It is of Allis-Chalmers manufacture. After passing through the tube mill the reground material is conveyed by elevator and screw and discharged into the packing-house bins. These bins are above two ½-ton weighing hoppers, the stucco being fed into the hoppers by gravity. The materials to control the time of set and improve the working qualities of the plaster are added by hand into the hoppers. The hoppers discharge by gravity into two ½-ton Broughton mixers above Bates automatic bagging machines. This company manufactures only wall plasters. Its capacity is about 100 tons of finished product per day. The mill is operated under the unit drive motor system. Power is obtained from the city lines. About 425 horsepower is the usual load.

(*m*) AMERICAN GYPSUM CO.'S MIXING PLANT, DETROIT, MICH.

The American Gypsum Co., of Port Clinton, Ohio, operates a mixing plant for the preparation of wall plasters in Detroit. The calcined gypsum is shipped from the Port Clinton mill and sand is obtained from deposits on the Detroit River. The stucco arrives in cars, is transported by belt and elevator, and discharged into supply tanks above the mixing hoppers. The sand is unloaded from the barges to the dock. A crane picks it up from the dock, deposits it in a hopper-bottom box, which delivers to an 18-inch belt discharging into the supply bin. From the supply bin the sand is carried by an 18-inch rubber belt and fed into the drier. The drier is of the revolving type, 40 by 5 feet, using coke for fuel. It has a capacity of 13 tons per hour. No estimate can be made of the fuel consumption, as it varies with the condition of the sand. From the drier the sand is carried by elevator and discharged to three shaker screens arranged one above the other and each of different mesh. The coarse from the screens is fed by spout into a 2½-foot rotary screen with three-eighths-inch openings. The oversize from this screen is discarded. The fines from it are sold to manufacturers of roofing paper. The fines from the shaker screens are fed into three supply tanks, from which it is taken in the correct proportions and elevated to storage bins above the mixing hoppers. From the sand bin and stucco bin the material is delivered by gravity to the hoppers, where the retarder etc., are added. The hoppers discharge by gravity into mixers which in turn feed the baggers. The bagging equipment consists of three hand baggers—one of the three-spout type and two of the one-spout type. All the units are driven by separate motors, approximately 125 horsepower being required for the operation of the plant.

(*n*) AMERICAN GYPSUM CO., PORT CLINTON, OHIO

The mill of the American Gypsum Co. is located 2½ miles east of Port Clinton, on the south side of the Lake Shore division of the New York Central Railway. A shaft at the mill goes down to three strata of Monroe gypsum, one at 42, one at 44, and one at 65 feet below the surface. The thickness of the veins varies from 4 feet in the center vein to 12 feet in the lowest vein.

The geology of the Monroe formation has been the subject of much study by numerous geologists. A comprehensive report upon this formation is given by Orton in the Ohio Geological Survey Report of 1888, and also by Bounocker in Bulletin 697 of the United States Geological Survey, Gypsum Deposits of the United States.

"Gypsum deposits underlie a broad area in Ohio, but in development has been restricted to one Silurian formation, the Monroe, which consists primarily of dolomitic limestone with interbedded layers of sandstone and in places gypsum." [18]

Analysis of a representative sample, collected by the writer and analyzed at the laboratory of the Bureau of Standards, is as follows:

	Per cent
Gypsum ($CaSO_4 \cdot 2H_2O$)	74. 2
Calcium carbonate ($CaCO_3$)	6. 4
SiO_2, Fe_2O_3, Al_2O_3, etc. (by difference)	19. 4

The mine is worked by continuous room and pillar methods, is lighted throughout by electricity, and is comparatively dry. Some little water is encountered, but not in sufficient quantity to hinder the working. Drilling is done with electric drills. The rock is brought down by a low per cent dynamite, loaded into side-dump cars by hand, and transported by electric locomotive to the gyratory crusher at the foot of the shaft on the first level.

The mine cars are discharged into a Tel-Smith gyratory which reduces to 3 inches or less. The rock from the gyratory is elevated to the surface and deposited in either the storage bins or the stock pile. As needed the rock is brought in from the stock pile to the storage bin by a belt conveyer and elevator. The storage bin discharges upon two 18-inch belt conveyers, the rock being moved by these to two elevators discharging into two driers. The driers are of the cylindrical rotating type, 52 by 6 feet, coke fired. After passing through the driers the rock is elevated and goes through one of three Williams mills. From the Williams mills it is passed over one of two 8-section, 36-mesh knocker screens. The fines from the screens are carried by screw to the kettle bins. The coarse is delivered by a 24-inch belt to four Raymond mills, after which it is carried by screw to the kettle bins, from which the kettles are fed by gravity.

The kettle equipment consists of four 10 by 12 foot, 16-ton capacity, two or four flue, cast-iron, sectional bottomed, kettles. They are drawn at 330° F., one and one-fourth hours being necessary to reach this temperature. The fuel used is coal, 850 pounds consumption per kettle.

The flow of the material from the kettles may follow one of two courses, depending on whether or not tube mill regrinding is to be done. If not, the treatment is as follows: When the kettles are drawn, the stucco flows into the hot pit in the rear of the kettles from which it is elevated by bucket elevator and discharged upon 60-mesh knocker screens, 32 in number, elevated at an angle of 45°. The coarse from these screens goes to the tube mills. The fines

[18] Gypsum Deposits of the United States, by R. W. Stone and others. Bull. 697, U. S. Geol. Survey, p. 218.

go to the stock bins, then to the mixing hoppers, where the retarder, hair, etc., are added. These hoppers are all 1-ton capacity and deliver by gravity to five 1-ton mixers located over the baggers. The bagging equipment consists of two Bates automatic baggers and three hand baggers of the four-spout type.

If the calcined gypsum is to be further reduced in the tube mills, it goes through the following treatment: From the hot pit it is carried by elevator, screw, and two 18-inch belts to bins above the tube mills to which it is fed by gravity. There are two tube mills of the cylindrical rotating type, 22 by 6 feet, containing 14 tons of 1¼-inch steel balls. From the tube mills the material is carried by elevator and screw conveyers and discharged into bins above the hoppers, after which it goes to the mixers and baggers. This company manufactures quite an amount of ready sanded plaster, and possibly it would be of interest to follow through the treatment of the sand.

The sand is carried from the stock pile and delivered into a bin by means of a locomotive crane. From this bin it is conveyed by a 24-inch belt conveyer to a

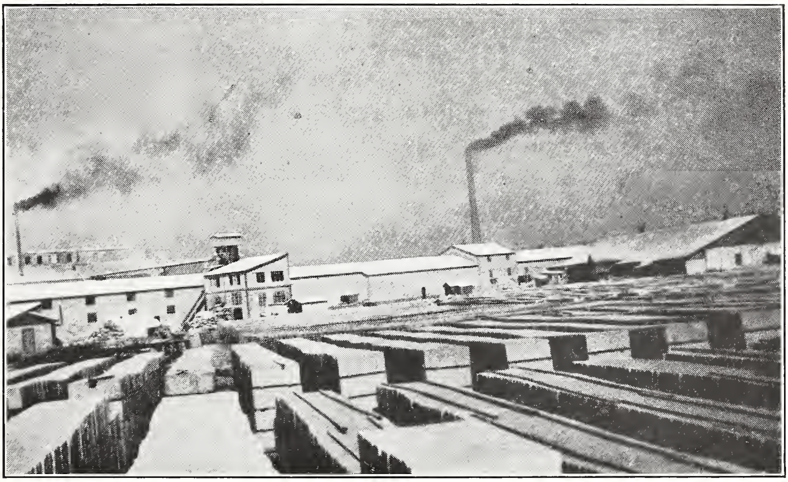

Fig. 37.—*Mill and stock pile of the American Gypsum Co., Port Clinton, Ohio*

40 by 5 foot coke-fired drier. The drier discharges into a cooling bin from which the sand is elevated and graded by passing over knocker screens of three sizes. The coarse from these screens is discarded. After passing through the screens the sand is conveyed by an 18-inch belt and discharged into bins above the mixing hoppers. This company also manufactures wall board, plaster board, and gypsum tile. Fire destroyed the board mill and tile mill early in 1924, but new mills were in the process of erection in March, 1924.

A temporary tile machine was operating during the writer's visit. It consisted of a bin of calcined gypsum which fed by gravity a rubber belt passing through water, discharging upon another belt where the fiber and accelerator were added and discharged into the molds, which after the tile had set were removed by hand. The tile was allowed to dry in a shed. The accelerator used is broken block which has been dried and ground. In the new tile mill there will be two automatic tile machines, one of the Her-born type and one of the Chicago type. The board mill under construction will have a capacity of 150,000 square feet per day. Power for the operation of the mill and mine is obtained from two steam engines, total capacity 750 horsepower, which drive electric generators.

2. DESCRIPTION OF GYPSUM PLANTS IN NEW YORK

Gypsum is produced in New York State in two distinct localities. In the western field a bed of gypsum from 6 to 12 feet thick extends from a short distance southwest of Rochester to a short distance east of Buffalo. This bed dips slightly toward the west, the depth of the mines being about 40 feet at the eastern end to 80 feet at the western end. The deposit is being mined at numerous places, all of which lie in approximately a straight east and west line, running from Akron on the west through Oakfield, Garbutt, to Wheatland on the east. All of these plants ship on the west shore branch of the New York Central Railway; the plants at Garbutt also having connections with the Pennsylvania and the B. R. & P.

The plants operating on this deposit at present are in the order named from west to east: The American Cement Plaster Co. and Nobles Gypsum Co., at Akron; the Phoenix Gypsum Co., Oakfield Gypsum Products Corporation, Niagara Gypsum Co., the United States Gypsum Co., at Oakfield; the Empire Gypsum Co. at Garbutt; and the Ebsary Gypsum Co. at Wheatland. All of these plants mine their gypsum and all except the Phoenix calcine it. The Phoenix Co. produces crushed rock only. In addition, there is a board plant of the Gypsolite Products Co. at Batavia which buys gypsum from the Niagara Gypsum Co. and makes wall board only; a plant of the Standard Gypsum Board Co. at Garbutt, which buys gypsum from the Empire Gypsum Co. and makes plaster board only; and a gypsum block plant of the Ebsary Co., which buys gypsum from the Empire Co. and is located at Garbutt.

In the eastern part of the State the raw material is brought by boat from Canada, mostly Nova Scotia, but some from New Brunswick. The plants operating here are therefore all located so as to provide for water shipment. Around New York Harbor are the plants of the Rock Plaster Manufacturing Co. on Manhattan Island, the Newark Plaster Co. at Newark, N. J., also the Connecticut Adamant Co. at New Haven, the Higginson Manufacturing Co. a little way up the Hudson River at Newburgh, and the United States Gypsum Co. on Staten Island. These plants all make calcined gypsum, and most of them make board, block, and other products, all from the Canadian raw material.

(a) OAKFIELD GYPSUM PRODUCTS CORPORATION, OAKFIELD, N. Y.

This is a new plant owned jointly by the owners of the Paragon Plaster & Supply Co., which consists of three builders supply dealers located in Syracuse, Utica, and Scranton. Oakfield is about 6 miles north of Batavia, in Genesee County, N. Y. The plant is about 2 miles west of Oakfield. The mine is about 75 feet deep. The rock is elevated in end-dump cars holding about 2 tons each, which are tripped automatically at the top of the elevator and discharged into an Allis-Chalmers gyratory crusher, which reduces the material to 2 inches. It is then elevated to a ¾-inch screen, the tailings going through a Traylor roll crusher and back to the screen. The ¾-inch material passing through the screen is elevated to storage bins. From the bottoms of these bins it is taken by drag conveyer, delivered by belt conveyer and bucket elevator to a rotary kiln. The kiln is 70 feet long by 6 feet inside diameter. It is fired with pulverized coal and compressed air. It will produce 10 tons of calcined material per hour, using 123 pounds of coal per ton of material. By means of a recording pyrometer, placed in the material as it flows from the kiln, the temperature is maintained at 550° F. From the calciner the material goes to a Williams mill, which reduces it to quarter inch, and then to storage bins. It is then fed to a tube mill 22 feet long by 6 feet in diameter, containing 13 tons of balls. It is then screened through a 14-mesh sieve and stored in bins over the mixers and baggers. Most of the material is shipped as calcined gypsum to be mixed at the plants of the builders' supply dealers above specified. Equipment is provided, however, for mixing wall plaster complete at this mill.

The power consumed is all electric from Niagara Falls and the load is maintained approximately uniform at 200 kilowatts. The tube-mill grinding seems to be rather severe. It has been found that in making sanded plaster the quantity of clay and lime which were formerly added can be greatly reduced if not eliminated and still have a better working material than used to be the case. This tube-mill product, however, is too sticky to make a good wood fiber plaster. Preparations have, therefore, been made to pass the material through a second Williams mill, where most of the grinding will be done, and use the tube mill merely to finish the grinding.

(b) NIAGARA GYPSUM CO., OAKFIELD, N. Y.

This plant is about a quarter of a mile east of the Oakfield plant. The mine is about 79 feet below the surface, the stone is elevated in 2-ton wooden end-dump cars and delivered to a Pennsylvania jaw crusher, which reduces it to 2 inches. It is then put through a Traylor roll crusher which reduces it to three-fourths inch. From this it is fed to the rotary kilns. There are two kilns 110 feet long by 6 feet in diameter, having a normal capacity of about 20 tons per hour each. They are fired with pulverized coal and compressed air, using about 100 pounds of coal per ton of calcined gypsum. The temperature shown by the pyrometer embedded in the material leaving the kiln is 450° F. After leaving the kiln the material goes to a storage bin, from which it passes through one of four pulverizers. It then goes to another storage bin over the mixers and baggers. This plant is equipped with a rotary block machine in which the ingredients are mixed in a small mixer which is mounted over the block molds. These molds are carried on a horizontal table which revolves slowly. At a certain point the cores are removed by hand, at another point the forms are removed, then the blocks are taken off, the forms and cores replaced, and, as the mold completes its circuit, it gets another charge from the hopper.

The molds are constructed in gangs of 4, there being about 10 such gangs on the table. All of the work except the mixing of the plaster and the filling of of the molds is done by hand. The blocks when taken from the table are stacked in cars and are dried in steam-heated driers overnight. This equipment is capable of making 700 blocks in 10 hours. The blocks are cast flat.

There is also a machine for making wall board. The ingredients for this are mixed in a small hopper, similar to a dough mixer, each batch requiring about 30 seconds. This discharges to a belt conveyer which feeds the material to the board machine. Paper from a roll is fed on to a belt conveyer, the plaster mixture is fed on top of this paper; paper from another roll is fed on top of the plaster, and the whole is then passed under a fixed roller which regulates the thickness. The sides of the lower sheet are turned up and folded over mechanically to make a square edge. The board travels along this conveyer for 30 feet, when it is cut into the desired lengths by means of a circular saw which travels across the board. The boards are then picked up by another belt conveyer which runs at a somewhat higher speed than the first one, so that the individual boards are separated from each other. This conveyer is 260 feet long. By the time the board has reached the end of this conveyer the plaster has set but is not dry. By means of mechanically-operated rollers the boards are then transferred to a drier. This is a belt conveyer of about the same length and parallel to the other but running at a much slower speed.

The drier is built in six tiers to give the same capacity as the more rapidly moving belt. This drier is heated with steam coils at a temperature of 240° F. It is also provided with good ventilation by means of an electric blower. It

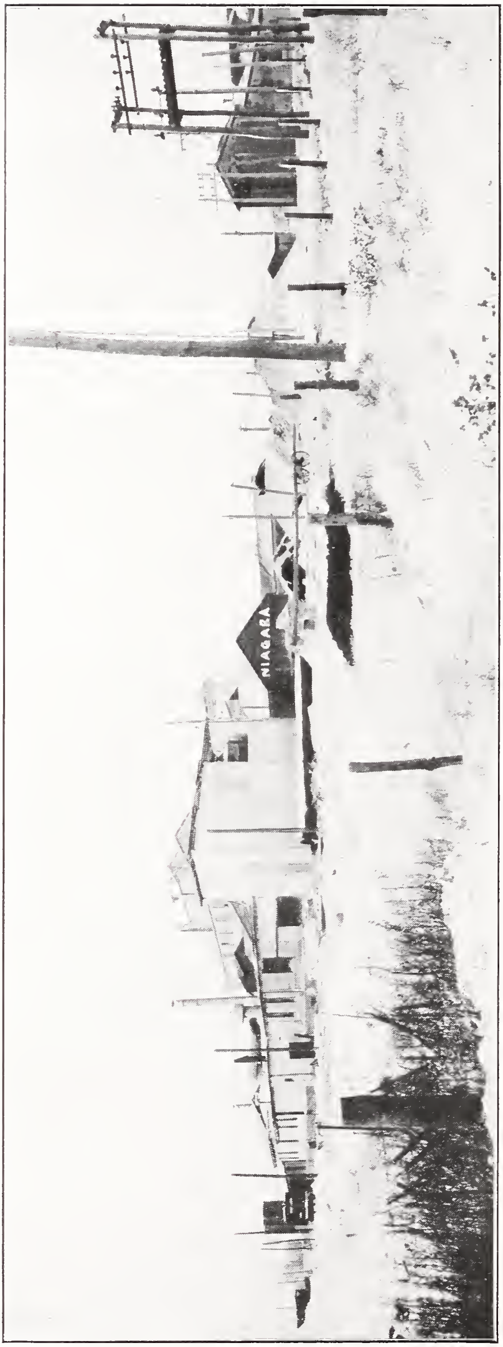

FIG. 38.—*Mill of the Niagara Gypsum Co., Oakfield, N. Y.*

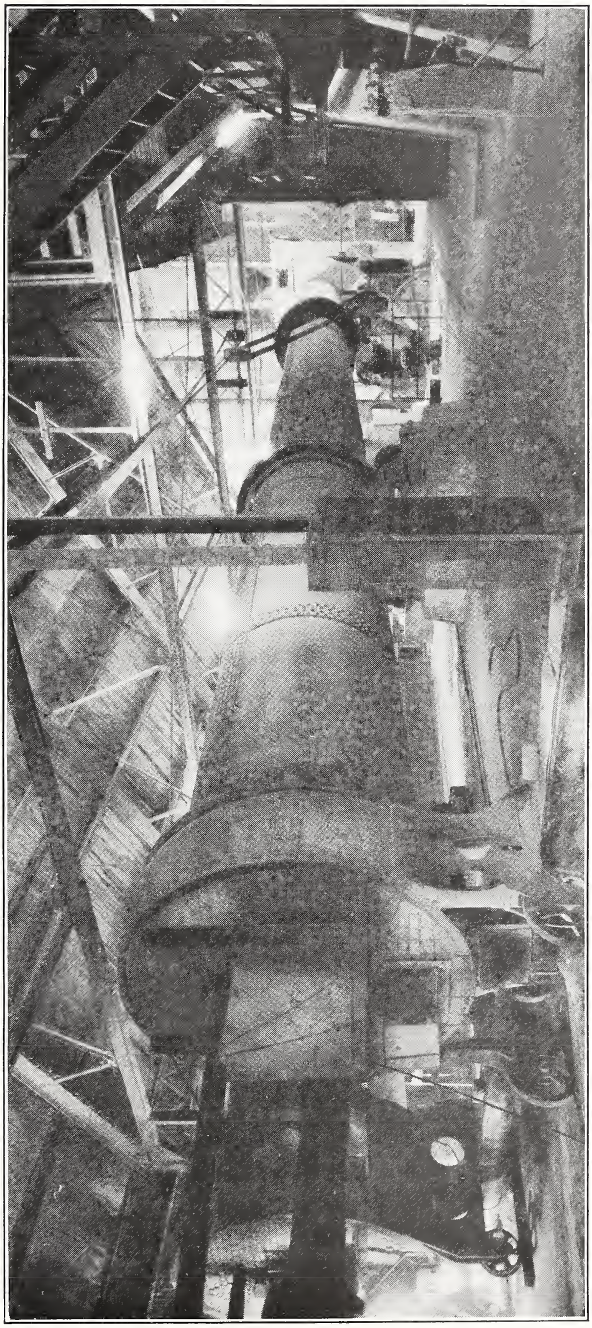

FIG. 39.—*Rotary kilns of the Niagara Gypsum Co., Oakfield, N. Y.*

takes a board about one hour to pass through this drier and come out a finished product. This equipment is capable of making 10,000 square feet of wall board in 24 hours. This plant uses 1,025 horsepower of electricity, and the driers for the block and board plants use 250 horsepower of steam.

(c) THE GYPSOLITE PRODUCTS CORPORATION, BATAVIA, N. Y.[19]

This plant is located in the outskirts of Batavia and has shipping facilities over the main line of the New York Central. It makes wall board only, buying the calcined gypsum from the Niagara Gypsum Co. at Oakfield. This is hauled 6 miles by truck. The ingredients are mixed in two small batch mixes, alternately. No fiber is used in this board. The calcined gypsum is mixed with hot water and starch. The mixers discharge to the small belt conveyer which feeds to the paper on the board machine. This machine consists of a belt conveyer about 300 feet long with no breaks. After about 50 feet in the open the conveyer travels through a steam-heated drier. It is cut into lengths on the same belt by means of an equipment much like a press for cutting steel. This can be set automatically to cut any desired length.

The belt conveyer discharges the boards to a series of rollers which can be turned about the horizontal axis parallel to the direction of motion of the board to discharge the board to a wooden pallet carried by two men. These men transfer the board to a rack, where it is suspended from an overhead trolley by wooden cleats. Each rack will hold about 20 boards. These are placed in a steam-heated drier overnight. This plant can make 40,000 square feet in 10 hours.

(d) NOBLES GYPSUM CO., AKRON, N. Y.[19]

This plant is located about 3 miles east of Akron, 18 miles from Batavia, on the west shore branch of the New York Central. The mine is about a mile and a half from the calcining plant, the stone being hauled to the plant in small cars drawn by a gasoline locomotive. The crushing is done at the mine, so that the material delivered to the plant is about 2 inches and smaller. It is stocked out doors with a clamshell tractor and is fed as needed by means of a screw conveyer to the rotary kilns. There are two of these, 110 feet long and 6 feet in diameter. They produce normally about 20 tons per hour, discharging the material at a temperature of 450° F. They are fired with powdered coal and compressed air. From the calciner the material goes to a Jeffrey mill, which reduces it to one-quarter inch. It is then fed to a wind-swept tube mill made by Kennedy & Van Swan, of New York. This is 8 feet in diameter by 12 feet long and contains 8 tons of balls. The current of air through this mill is maintained by a 100-horsepower fan. There are two settling chambers connected in series. This mill can easily take care of the product of both of the kilns. The material from this mill is discharged into a screw conveyer which takes it to the storage bins over the baggers and mixers.

(e) EMPIRE GYPSUM CO., GARBUTT, N. Y.

This plant is at Garbutt, which is on the Pennsylvania and B. R. & P. Railroads 16 miles west of Rochester. The mine is about 40 feet below ground. Stone is hauled out in cars holding about 2 tons each, which are drawn in trains by an electric locomotive. They are hauled from the entrance of the mine to the plant, about 100 yards, by cable and discharged into a gyratory crusher which reduces the rock to 2 inches. This material then goes through a Williams mill, which reduces it to one-quarter inch, and finally through one of four buhr mills. It is then elevated to a storage bin over the kettles. There are four kettles, each

[19] This plant is now owned and operated by the Universal Gypsum Co., Chicago, Ill.

10 feet in diameter, with solid pressed steel bottoms. Each kettle holds about 9½ tons of calcined material. They are emptied when the temperature reaches 330° F., which takes about 1 hour and 20 minutes. It takes about one-half ton of coal per kettle. The material is discharged from the kettles into a screw conveyer, which mixes and aerates the material as well as conveys it to a storage bin. From this bin it is fed directly to the mixers and baggers. This mill is capable of producing 300 tons of calcined gypsum per day. It uses about 500 kilowatts of electric power.

(*f*) STANDARD GYPSUM BOARD CO., GARBUTT, N. Y.

This company operates a plant for the manufacture of plaster board, which is located immediately alongside of the plant of the Empire Gypsum Co. Calcined gypsum is delivered by screw conveyer from the Empire Gypsum Co. to this plant. From the storage bin it is fed through a small mixer, where the necessary fiber and accelerator are added. The dry material is discharged to a short belt conveyer which runs under a sprinkler through which the water is added. The material is then mixed by rotating fingers on this same belt and is finally discharged on a sheet of paper on the board machine. This machine is about 300 feet long, all in one piece. After about 50 feet the board is cut into lengths by a perforating punch. When the board reaches the end of the machine it has set sufficiently hard to be handled and is stacked on small cars holding about 100 boards each. These are wheeled into steam-heated driers which are ventilated with hot air, the boards being dried overnight. This plant is capable of making about 25,000 square feet of board per day.

(*g*) EBSARY BLOCK PLANT, GARBUTT, N. Y.

This plant is located across the railroad tracks from the Empire Gypsum Co. Calcined gypsum is furnished to the plant by a screw conveyer. From the storage bin the material goes to a small mixer where the fiber and water are added. This discharges in a continuous stream into molds which are carried on an endless belt about 100 feet long. The cores are cut in two in the middle, and each end extending outside of the molds is carried by a track. About halfway down the length of the belt these tracks diverge from the central line, thereby automatically pulling the cores out of the blocks. By the time the blocks have reached the far end of the belt they are set sufficiently hard to be handled. The empty molds returning underneath have the cores automatically replaced in the same way in which they were withdrawn. The linings of the molds and the cores are made of aluminum. The entire interior of the mold is sprayed with hot oil just before it is filled. This machine is capable of making about 2,500 blocks in 10 hours. The blocks taken from the machine are stacked on cars holding about 25 each and are stored outdoors to remove most of the moisture. Drying is then completed in a steam-heated drier overnight. This machine has recently been installed, and the old hand process has not yet been completely abandoned, so that the plant is using about 20 tons of calcined gypsum per day.

(*h*) EBSARY GYPSUM CO., WHEATLAND, N. Y.

The plant of this company is located at Wheatland, about 1½ miles east of Garbutt. The mine is about 40 feet under ground, the stone being brought out in end-dump wooden cars holding about 2 tons each. These cars are hauled by cable up an incline, where they discharge into a gyratory crusher which reduces the material to about 2 inches. This is then put through a gyratory cracker which reduces it to about one-fourth inch, then through a direct heated rotary drier. Finally it is passed through one of four ring mills and delivered to the storage bins over the kettles. There are four of these kettles, holding a little over 9 tons each. They are discharged at a temperature of 305° F., which requires about 1 hour and 10 minutes. About 85 pounds of coal is required per ton of calcined material. The material from the kettles goes to a storage bin from which it is passed through a tube mill 20 feet long by 6 feet in diameter, holding 8 tons of balls. The feed of this mill is automatically regulated, so that the material passes through it in five minutes, the product, therefore, being quite uniform. From here the calcined gypsum is delivered to the storage bins over the mixers and baggers.

(*i*) HIGGINSON MANUFACTURING CO., NEWBURGH, N. Y.

This plant is located in the city of Newburgh, having 1,000 feet frontage on the Hudson River, with the west shore branch of the New York Central running along the other side. The stone is brought in by boat, mostly from Nova Scotia. It is transferred from the ocean vessels to barges in New York Harbor, which are towed up the river to the docks of the company. It is unloaded from these barges by bucket elevators, discharging into small cars, which run on elevated tracks into the plant. These cars are dumped over the stock pile, which is very large to provide enough material to keep the plant in operation all winter. Two grades of stone are used—a very pure white gypsum in large pieces only, which is purchased from the Albert Manufacturing Co., of Hillsboro, New Brunswick; the other run-of-mine gypsum from the Windsor Quarries Co., at Nova Scotia. The New Brunswick material is used almost entirely for making ground raw gypsum, although one or two kettles a year are calcined. This material is first scrubbed by hand, then dried, ground through two gyratory crushers in series, and finally through a battery of buhr mills. This battery consists of three sets of three mills each, the three mills of each set being arranged so that the material coming from one mill is screened, the tailings sent to the second mill, etc.

For the finest grade of material the screens are made of silk bolting cloth, passing a product finer than 150-mesh. The Nova Scotia gypsum goes through the same process up to the screening. This is screened on 40-mesh wire. The material passing this screening goes to a storage bin over the kettles. There are three kettles, 9 feet in diameter, holding about 5 tons each. They are drawn at 305° F. It takes about 200 pounds of coal per ton of calcined plaster. The material coming from the kettles is carried by screw conveyer to the storage bins over the mixers and baggers. This plant maintains its own cooper shop, a great deal of its product being shipped in barrels. They also operate a plant for manufacturing whiting from imported English chalk. They are just preparing to put in a block plant.

(*j*) ROCK PLASTER MANUFACTURING CO., NEW YORK, N. Y.

The plant of this company is located at One hundred and fiftieth Street and East River, on Manhattan Island. It has two docks on East River capable of accommodating ocean freighters and has trackage on the New York Central. The raw material is brought in by boat, some of the finished product is shipped out by boat to local points in New York Harbor, but nearly all of it is shipped out by truck for local delivery. This company operates its own quarries in Nova Scotia. The rock is crushed at the quarry to about 2 inches and smaller. It is brought by barge to the company's dock, unloaded by means of a clamshell delivering to a small car running into the plant on an overhead track. This car discharges to the stock pile, which must be very large to enable the plant to operate all winter. From the stock pile the material is picked up by an electric shovel and delivered to a small gasoline car. This takes it to a gyratory crusher, which is set in the floor of the stock pile. This breaks it to three-fourths inch. It is then carried by screw conveyer to a Williams mill and finally a series of buhr mills and screens, so that it is all reduced to pass 40-mesh. It is then delivered to the bins over the kettles. There are four kettles holding 9½ tons each. These are dumped at a temperature of 285° F., which requires about 2 hours and 20 minutes.

This company also has a small board machine for making plaster board. The material for this machine is mixed by hand in tubs holding about 300 pounds each. The machine is only 50 feet long, ending at the point where the boards are cut into lengths. They are received on wooden pallets, piled up on the floor until they have hardened so that they can be handled, stacked on small cars, and dried in a steam-heated drier overnight.

The blocks are made entirely by hand. The iron molds in gangs of three are set up on rubber mat bases. The materials are mixed by hand in tubs, poured into these molds, and allowed to harden. The blocks are then removed, stacked on cars, and put into a steam drier for overnight. Besides the men mixing the material and hauling away the blocks there are four men, each of whom has charge of four tables, and on each table there are four gangs of molds, so that each man has just time to go around from one mold to the next and get back to the starting place about the time the material in the first mold has set. This equipment is capable of turning out about 900 blocks in 10 hours. The plant uses about 550 horsepower for power plus 250 horsepower for the driers.

WASHINGTON, November 7, 1924.