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MANUFACTURE OF LIME

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Fig. 8.—*Map Showing Location of Plants Visited*

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ILLUSTRATIONS

I. INTRODUCTION

Difficulty having been experienced in specifying the lime suited for use in making mortar and wall plaster and for hydrated lime in terms other than those of trade names, it was desired if possible to secure such knowledge relative to the product of the various limekilns of the United States as would indicate either by their source or by investigations of the chemical and physical properties of the resulting product, which kind of lime would be most efficient and economical for each particular use.

In spite of the common use of lime, exact information regarding its properties in the slaked and unslaked conditions is surprisingly scarce. This is illustrated by the fact that specifications covering the quality demanded for the various uses of lime in the arts are either lacking or are based upon erroneous conceptions. To obtain the proper viewpoint in the study of this product and in the investigations evidently made necessary by the lack of authentic data, it was felt that a first-hand acquaintance with the manufacture of lime was essential. In this way only could the factors affecting the quality of lime during burning and that of the hydrated product during commercial slaking processes be followed with full appreciation of the practical difficulties.

It was deemed both impracticable and unnecessary to attempt to study the quarrying and lime-burning processes at a large number of plants, of which there are several hundred in the country.[1]

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[1] According to the report of the division of mineral statistics of the Geological Survey for the year 1910 the total lime production in that year amounted to 3 481 780 short tons, valued at $13 894 962. The average price per ton was $3.99 and the number of lime burners reported in operation was 1125. Lime production was reported from 43 States, the quality and value of the output of Pennsylvania ranking first, followed by Ohio, Wisconsin, Maine, and Missouri.

It was therefore decided that two or three typical plants should be visited on each separate geologic lime-bearing deposit. Nineteen typical plants, distributed through various portions of the United States, were selected and visited. A general description of these 19 plants is given in the appendix to this paper.

The field inquiry was conducted with a view of obtaining complete information about the process of lime manufacture; of noting the methods of quarrying and crushing; of selecting typical samples of the limestone which were forwarded to the laboratory for analysis and study; of observing methods of burning, temperatures and duration of burning, and of sampling the resulting lime; and, finally, of following this through the process of hydrating and of sampling the resulting product. All samples were sealed and forwarded to the laboratory for further investigation and test.

It was planned that the subject of lime and its products should be considered first from the manufacturing and industrial standpoint, and, second, from the experimental standpoint, based upon laboratory investigations. A program was outlined for the guidance of this inquiry, with a view to determining some of the more salient problems, among which are *the temperatures of burning as affecting the quality of the resulting lime; the effect of duration of burning upon the character of lime; the characteristics of mortar made from quick and from hydrated lime; the conditions under which crystalline and amorphous forms of calcium hydrate are produced in reference to the manufacture of dry hydrate; the devising of a convenient test to determine plasticity; the study of the physical composition of dolomite and the condition of magnesia in hydrated lime; under what conditions magnesia combines with water to form hydrate; and studies of the decomposition temperatures of calcite, magnesite, and dolomite.*

It is the object of this paper to correlate and compare the equipments of the various plants and processes, with special reference to economy of operation and quality of the finished product. The results of some laboratory work have been included in the discussion, in order to throw more light on some of the points. The comparative heat efficiency attained by the use of different methods of creating the draft was deemed of sufficient importance to warrant an investigation. This was carried out by running heat balances at 6 typical plants (4 of which are among the original 19), and the results are included in this paper.

Acknowledgment is hereby made to the National Lime Manufacturers' Association for their substantial aid in this work. The president, William E. Carson, and those members whose plants were visited, deserve special recognition for their active cooperation. This work was carried on under the supervision of A. V. Bleininger, ceramic chemist, and many of his ideas have been incorporated in this paper.

II. GENERAL DISCUSSION

A. QUALITY OF STONE

The art of lime burning dates back to earliest antiquity, and until recently comparatively little improvement has been made in the process. The numerous changes which have been introduced in the past few years are due to economic conditions, which have forced progress in the art along rational lines.

The art of burning lime may be defined as the process of converting limestone into lime through the agency of heat. The term *limestone* is used to describe a class of rocks varying in composition from pure calcium carbonate to a mixture of 54.35 per cent calcium carbonate with 45.65 per cent magnesium carbonate.[2] Any gradation between these limits may be found, and all limestones contain more or less impurities. In the same way, lime may vary from pure calcium oxide to a mixture of calcium and magnesium oxides in the corresponding proportions. The accompanying impurities may or may not be removed. Consequently, the problem of burning lime is merely one of removing the carbon dioxide from the stone by means of heat. When the stone is raised to a sufficiently high temperature and kept there for a sufficient length of time, the carbonates are dissociated and the carbon dioxide is given off as gas.

The quality of limestone suitable for burning may vary, both chemically and physically, within rather wide limits. The chemical analyses of samples of stone collected are given in Table 1.

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[2] According to definition of the National Lime Manufacturers' Association.

They were made under the direction of Mr. P. H. Bates, chemist, and Mr. A. J. Phillips, assistant chemist, of the Bureau of Standards.

The chemical composition of a lime depends on that of the stone from which it was made. Consequently, only those limestones may be used from which a marketable lime can be produced. It must be remembered that on account of the loss of about half the weight of the stone as carbon dioxide during the burning the proportion of every other constituent of the stone will be nearly doubled in the lime. The composition which a lime should have for any given purpose is a much mooted question, but a few generalizations may be given.

TABLE 1

Analyses of Limestones

Company and location	Designation of stone	Silica (SiO_2)	Alumina (Al_2O_3)	Iron (Fe_2O_3)	Calcium carbonate ($CaCO_3$)	Magnesium carbonate ($MgCO_3$)	Total
		Per ct.	Per ct.	Per ct.	Per ct.	Per ct.	Per ct.
Rockland-Rockport Lime Co., Rockland, Me.	Soft	1.29	0.15	0.35	95.91	2.27	99.97
	Rockport	2.41	.22	.40	85.18	11.72	99.93
Farnam-Chesire Lime Co., Cheshire, Mass.	([a])	.44	.08	.20	98.05	1.30	100.07
Connecticut Lime Co., Canaan, Conn.	([a])	.34	.19	.28	58.20	41.16	100.17
New Jersey Lime Co., Hamburg, N. J.	McAfee	.85	.06	.20	96.70	2.04	99.85
	Hamburg	1.21	.41	.45	95.70	2.25	100.02
Chas. Warner Co., Cedar Hollow, Pa.	West end south quarry.	.81	.56	.47	54.68	43.66	100.17
	East end south quarry.	.91	.09	.30	63.02	35.78	100.10
	North quarry [b]	2.27	.51	.40	53.16	43.89	100.23
	Whiteland	.94	.15	.45	54.09	44.58	100.21
Lowell M. Palmer Co., York, Pa.	White	.53	.04	.05	99.21	.74	100.57
	Blue	.14	.02	.10	98.73	1.01	100.00
	Calico	.27	.07	.30	86.43	12.98	100.05
American Lime & Stone Co., Bellefonte, Pa.	Quarry No. 13.	1.41	.25	.40	96.36	1.55	99.97
Thomasville Stone & Lime Co., Thomasville, Pa.	([a])	.15	.10	.15	99.02	.57	99.99
Riverton Lime Co., Riverton, Va.	Slaty	.42	.07	.32	97.20	2.02	100.03
	Oily	.36	.07	.22	96.07	3.26	99.98
	([a])	.46	.06	.20	89.20	10.14	100.06
E. Dillon's Sons, Indian Rock, Va.	Lower quarry	.28	.16	.20	98.50	.78	99.92
	Upper quarry	.80	.10	.35	97.05	1.72	100.02
	Fertilizer [c]	1.05	.40	.55	96.21	1.76	99.97

[a] Average of stone burned for lime.

[b] Not burned for lime.

[c] Burned for fertilizer only.

TABLE 1—Continued.

Analyses of Limestones—Continued.

Company and location.	Designation of stone.	Silica (SiO_2)	Alumina (Al_2O_3)	Iron (Fe_2O_3)	Calcium carbonate ($CaCO_3$)	Magnesium carbonate ($MgCO_3$)	Total.
		Per ct.	Per ct.	Per ct.	Per ct.	Per ct.	Per ct.
Tennessee Marble Lime Co., Knoxville, Tenn.	Main quarry..	.16	.13	.06	98.93	.76	100.04
	Other quarries	.23	.08	.20	93.25	1.26	100.02
	Luttrell.......	0.65	0.05	0.30	84.50	14.53	100.03
Lagarde Lime & Stone Co., Lagarde, Ala.	(a)............	1.64	.33	.31	94.39	3.42	100.09
Ash Grove White Lime & Portland Cement Co., Ash Grove, Mo.	(a)............	.10	....	.05	99.05	.88	100.08
Glencoe Lime & Cement Co., Glencoe, Mo.	Gray..........	.32	.13	.30	98.29	1.05	100.09
	Blue..........	.21	.05	.15	98.89	.67	99.98
	Brown........	.26	.02	.20	98.84	.65	99.97
	White [b].......	1.35	.53	.40	94.89	3.05	100.22
Marblehead Lime Co., Marblehead, Ill.	(a)............	.21	.04	.10	98.45	1.28	100.08
Sheboygan Lime Works, Sheboygan, Wis.	(a)............	.55	.24	.40	55.09	43.91	100.19
Union Lime Co., High Cliff, Wis..	(a)............	1.12	.06	.40	54.82	43.79	100.19
White Marble Lime Co., Manistique, Mich.	Manistique [b]..	1.92	.03	.30	54.04	43.81	100.10
	Blaney........	1.23	.19	.50	94.38	3.74	100.04
	Marblehead..	.56	.05	.20	55.00	44.31	100.12
	Indian Dam..	1.04	.05	.25	54.25	44.52	100.51
Woodville White Lime Co., Woodville, Ohio.	(a)............	.34	.02	.15	56.79	42.92	100.22

[a] Average of stone burned for lime.

[b] Not burned for lime.

The demand of the trade would indicate that the amount of impurities (silica and oxides of iron and aluminum) permissible in a finishing lime is very small—certainly not over 5 per cent (2½ per cent in the stone). Especially should the proportion of iron be very low on account of its tendency to color the lime red or yellow. The value of lime in chemical industries depends on the amount of the active constituent. Therefore, the impurities act merely as diluents, and for many purposes their presence in rather large amounts is not harmful. This same reasoning applies also to lime used for fertilizer. For building purposes it is probable that a small proportion of impurities improves the quality of the lime. This Bureau has attempted to study the effects of various impurities on the properties of lime, and while the results are not sufficiently complete to warrant definite statements the following general conclusions may be drawn: The presence of small amounts of silica tends to decrease the plasticity, sand-carrying capacity, and yield of a lime, but has no apparent effect on its hardness or strength. The same may be said of iron, except that large amounts (25 per cent) show a marked increase in both strength and hardness. Alumina increases all of the factors above mentioned and also improves the color, so that its presence even in large amounts is very desirable. On the contrary, gypsum shows detrimental effects, even when only 1 per cent is present. Kaolin seems to act in a manner similar to silica and iron.

The majority of consumers seem to prefer a magnesian to a high calcium lime for finishing purposes, although both kinds are used. These conditions are reversed in the demand for building lime. In the chemical industries the proportions of calcium and magnesium depend entirely on the particular use of the lime, but most industries demand a high calcium product.

Calcium and magnesium oxides play important but distinct parts as fertilizers. The amount of either permissible in a lime to be used for this purpose depends on the condition of the soil and the kind of crop, and must be varied to suit each particular case.

Thus it is seen that the presence of a rather large amount of impurities in the stone is permissible, except where a finishing lime or a particular grade of chemical lime is to be made. The ratio of calcium to magnesium desired depends largely on what the market in the particular locality is. When the lime is sold for chemical purposes this ratio will generally be specified.

The chemical composition of the stone influences the cost of burning. Experience has shown that it generally requires less heat and a lower temperature to burn a magnesian than a high calcium stone. The greater the proportion of impurities, the more easily is the lime overburned, and therefore too large an amount of these constituents will cause a diminution of the capacity of the kiln. It is possible that the proportion of silica may be high enough to form the dicalcium silicate ($2CaO.SiO_2$). This substance when cooled slowly assumes allotropic forms. Thus, at 675° C (1247° F) it changes from the β to the γ modification, with a marked increase in volume.[3] This causes the lime to fall to pieces, a phenomenon commonly known as "fire slaking."

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[3] A. L. Day and E. S. Shepherd: The Lime-Silica Series of Minerals, J. Am. Chem. Soc., p. 1089, 1906.

From the chemical analyses of the samples of stone collected it will be seen that the amount of lime varies from 29.77 per cent to 55.56 per cent, and of magnesia from 0.31 per cent to 21.23 per cent, but that the total quantity of combined carbonates in any stone is never much less than 97 per cent. The silica is occasionally somewhat over 2 per cent without injury to the stone for lime burning, but the alumina and oxide of iron are generally under one-half of 1 per cent. It must be remembered, however, that this investigation did not cover the entire field, and there are limes being produced in which the proportion of impurities is so high that they are practically cements.

So far as its physical properties are concerned, any kind of limestone is suitable for burning. These properties do, however, influence the cost of production to a noticeable extent. Experience has shown that fine-grained, dense stone can be burned at a lower temperature and with less heat than one which is coarsely crystalline and porous. Coarsely crystalline stones, especially if very pure, are apt to fall to pieces in the kiln, thus reducing the production of lump lime. The same occurrence is sometimes noticed when a porous stone is used, although in this case it is probably due to the rapid expulsion of water from the pores. On the other hand, laboratory work done by this Bureau indicates that "all naturally porous stones lost their carbon dioxide at a lower temperature, 900° C (1652° F), than the denser materials." [4] Why these laboratory results are contradicted in practice is a subject for future investigation, and is probably dependent upon the size of the pieces of stone, the quantity of material used, and similar factors.

Whether a limestone is porous or not, its water content is of importance, for this water must be evaporated, with the consequent loss of heat and lowering of kiln efficiency. Moreover, some of the water, in chemical composition with the clayey impurities of the stone, will probably not be given off until the stone has reached a red heat. This will require the stone to remain in the burning zone for a longer time, and may therefore reduce the kiln capacity to some extent.

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[4] Bleininger and Emley: Burning Temperature of Limestone, Trans. Natl. Lime Mnfrs. Assoc., p. 77, 1911.

B. BURNING

There are three factors essential to the process of lime burning: (1) The stone must be heated to the temperature of dissociation of the carbonates; (2) this temperature must be maintained for a certain length of time; (3) the carbon dioxide evolved must be removed.

Many experiments have been made to determine the temperature of dissociation of calcium carbonate. The best and most recent work done on this subject is probably that by Johnston,[5] who established the dissociation temperature at 898° C (1648° F). The corresponding temperature for magnesium carbonate is generally given as 550° C (1022° F). These figures are for a pressure of one atmosphere of carbon dioxide, a condition probably never attained in practice. There is some doubt, however, as to whether magnesium carbonate exists in limestone as such, or whether it is combined with calcium carbonate to form the double salt dolomite. If the latter be true, the dolomite may have a different dissociation temperature, which has not been determined.

After this temperature has been reached, it must be maintained for some time in order to transfer the required amount of heat to the stone. Johnston, quoting from Thomsen, gives the heat of dissociation of calcium carbonate as 42 900 calories per gram molecule at 27° C (81° F). Assuming a rate of variation of this factor with the temperature, he calculates the figure to be 38 500 calories at 827° C (1521° F). Since the heat of dissociation of calcium carbonate at the temperature ordinarily used in practice has never been determined, it can not be stated that the figures given are scientifically accurate, and the same inaccuracy of our knowledge is true with regard to magnesium carbonate. In the discussion of the heat efficiency of limekilns, we have assumed these figures to be 772 Btu per pound for calcium carbonate, and 464.3 Btu per pound for magnesium carbonate, admitting that these figures are not accurate, but claiming in their defense that they are probably sufficiently near the truth for practical purposes.

The physical properties of the stone undoubtedly have some influence on the amount of heat required and the time in

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[5] Johnston: Thermal Dissociation of $CaCO_3$, J. Amer. Chem. Soc., p. 938, 1910.

which this heat can be transferred at any given temperature. Thus, it will take longer to burn a large piece of stone than a smaller one. A fine-grained, dense stone will conduct the heat more readily than one which is coarsely crystalline and porous. Practical experience seems to point to the fact that the crystals themselves require more heat to dissociate them than the amorphous stone. The time required to transfer a given amount of heat, roughly speaking, varies inversely with the temperature difference. Therefore, it has been found economical to use as high a temperature as possible in order to reduce the time required for burning. The upper limit of the temperature is determined by the phenomenon of "overburning." Overburned lime can be recognized by its yellow color and the extreme length of time it takes to slake. These properties are probably caused by a chemical combination of the lime with the impurities (especially with the silica and silicates) contained in it. That this is the case is indicated by the fact that it has been found practically impossible to overburn some limes which are exceptionally pure. Lime may be overburned by being heated for too long a time as well as at too high a temperature. In general, it is better to underburn than overburn the lime, for the unburned stone may be put back into the kiln while the overburned lime is useless. Moreover, the properties of overburning seem to assert themselves gradually, so that the best lime is obtained by using the minimum amount of heat.

To summarize: A certain quantity of heat must be supplied to dissociate the carbonates in the stone. The quantity varies with the chemical and physical properties of the stone. In supplying this heat it is optional to use either a high temperature for a short time or a lower temperature for a longer time. The temperature used must be higher than 898° C (1648° F) if the decomposition is to take place at atmospheric pressure. The more nearly the amount of heat used approaches the minimum required the better will be the quality of the lime.

It is well known that the chemical reaction involved in burning lime is reversible. That is, calcium carbonate may be decomposed into calcium oxide and carbon dioxide, or these substances may recombine to form calcium carbonate. The factor which determines the way the reaction shall go is the pressure of the carbon dioxide.[6] If this gas is removed as formed so that its partial pressure is kept below that given for the temperature by Johnston's equation, the reaction will continue in the direction to form lime. But if the gas is allowed to accumulate until its pressure becomes higher than this, the reaction will be reversed and will give rise to the phenomenon known technically as "recarbonating." Therefore, the prompt removal of the gas is an essential operation in lime burning.

C. CHEMICAL AND PHYSICAL PROPERTIES OF LIME

Lime, chemically speaking, is the oxide of calcium, but the commercial article may differ very widely from this composition. It may contain anywhere from 0 to 44 per cent of magnesium oxide, and generally contains more or less impurities, such as silica and oxides of iron and aluminum. When properly burned and fresh from the kiln, it should contain no water and less than one-half of 1 per cent of carbon dioxide. If the impurities added by the combination between the lime and the brick lining of the kiln be neglected, the composition of any lime will be the same as that of the stone from which it was burned, minus the carbon dioxide.

The lime will generally retain the same form as the stone, but the porosity is increased very greatly. The color of lime is nearly white, but may have a gray, pink, or yellow tinge, depending upon the impurities present. Stones in which crystals are apparent frequently retain the same structure after calcination.

When lime is slaked the calcium oxide combines with water to form calcium hydroxide. The impurities may be present in chemical combination with the calcium oxide, in which event they also may take up some water. The manufacturers of hydrated lime judge from the gain in weight of their product that magnesium oxide when burned at the temperature of an ordinary limekiln hydrates very slowly, if at all. Nine samples of dolomitic hydrates analyzed by this Bureau showed an average content of 30.92 per cent magnesium oxide and 2.29 per cent magnesium hydroxide. This peculiarity has been made the subject of scientific research,[7]

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[6] Bleininger: Trans. Am. Ceramic Soc., 9, p. 454: 1907.

[7] Campbell, On the influence of the temperature of burning on the rate of hydration of magnesium oxide, J. Ind. and Eng. Chem, 1, p. 665.

the conclusions from which are that magnesium oxide will combine with water with reasonable rapidity only when it has been burned at some temperature below 1100° C. (This is somewhat lower than the temperature of an ordinary limekiln.)

The hydration of calcium oxide generates heat. Since a large part of the magnesium oxide does not hydrate, it acts merely as an inert substance which must be heated by the calcium oxide. Therefore, other things being equal, the less magnesium oxide present in a lime, the more quickly will it slake and the greater will be the amount of heat generated.

The porosity of the lime plays a very important part here, however. Thus, the more porous the lime the more quickly can the water penetrate it, and hence the chemical combination will take place more readily. Indeed, in some cases the porosity seems to be of more importance than the chemical composition; that is, a very porous dolomitic lime may slake more quickly than a dense lime with a much higher content of calcium oxide.

If lime is underburned the calcium carbonate left in it acts as inert matter. Overburned lime exhibits the same phenomenon, although in this case it is probably due to a diminution of the quantity of active calcium oxide present. At the higher temperatures this material combines with the impurities, and hence is not free to take part in the reaction of slaking.

The appearance of underburned lime varies with that of the stone, and can be distinguished only by one who has had practice with the particular lime in question. Overburned lime is generally yellow or black in color and can be readily separated from good lime.

When lime is exposed to the air it absorbs carbon dioxide and water and "air slakes." This reaction takes place in two more or less distinct stages, first, the absorption of water, and second, the displacement of the water by carbon dioxide. Since these reactions are slow, it is possible to obtain lime which has air slaked to almost any degree, and this has led to a great confusion in the literature in regard to the properties of air-slaked lime. For instance, at one stage of the process (when the water has been absorbed and has not been displaced to any extent) the product is similar in composition to "water-slaked" or hydrated lime. In order to avoid such confusion, this Bureau has decided to designate as air-slaked lime only that product in which the process has been completed; that is, air-slaked lime is chemically similar to limestone. Any intermediate product will be designated as partially air slaked.

The absorption of water during the process of air slaking involves a large increase in volume, and therefore the lumps fall to pieces. This fact gave rise to the demand for "lump lime," the consumer being of the opinion that all fine lime is air slaked. There are several grades of limestone which fall to pieces in the kiln. The stone may be so soft that it is broken up by the abrasion; it may have its pores filled with water, which when heated shatters the stone; or its component crystals may be bound together by organic matter which is consumed in the kiln. Stones like these are being burned, and in some cases over 50 per cent of the output of the kiln is fine stuff. Such fine lime is as good for all purposes as lump lime, and it is easier to handle and will keep better. This is obvious from the consideration that the top layer of a pile of fine lime will air slake, and the crust of inert material so formed will prevent access of the air to the quicklime underneath. The old prejudice against fine lime is rapidly losing ground, as is shown by the fact that some manufacturers are putting crushed lime on the market. The better keeping qualities of this product are being taken advantage of by some firms, who ship the fine lime in open gondola cars.

The weight of a lump of lime is about 55 per cent of the weight of the stone from which it was burned. Owing to the fact that the lime is in lumps the weight of it which any given volume will contain varies very widely. Thus, a barrel of lime contains from 150 to 350 pounds net in different localities, and a bushel from 32 to 88 pounds. Therefore, these measures, while quite commonly used in the trade, have little significance when estimating the output of a kiln. For this reason the writer has adopted the short ton as the unit to be used when comparing kiln capacities.

D. HYDRATED LIME

Hydrated lime is a product recently put on the market to take the place of lump lime. As its name indicates, it is lime which has already been hydrated; that is, the chemical combination with water has already taken place. It is a fine, dry, white powder which is shipped in paper or burlap bags and which may be used for any purpose instead of lump lime.

The keeping qualities of hydrated lime have been the subject of a great deal of discussion. The original statement which was generally accepted was that hydrated lime would keep indefinitely. Going on this assumption, samples were tested in their ordinary commercial packages. The average of 11 samples so received showed a content of 3.77 per cent carbon dioxide, and one of them contained 10.09 per cent. These figures correspond, respectively, to 8.57 per cent and 22.93 per cent of calcium carbonate or inert material which had presumably been introduced by air slaking in transit. In order to investigate this matter a sample of lime was ground, mixed thoroughly, and screened through a 60-mesh sieve. It was then divided into two parts, one of which was slaked with an excess of water, dried in an atmosphere free from carbon dioxide, ground and screened through a 60-mesh sieve. The two samples (one of quicklime and one of hydrated lime, prepared from the same material and having the same fineness) were exposed to the action of the air under the same conditions and were analyzed for carbon dioxide at frequent intervals. The results are as follows:

Age of sample (days)	Per cent carbon dioxide	
	Quicklime	Hydrated lime
1	0.93	3.14
4	1.68	6.38
6	3.23	7.45
7	3.87	10.34
8	4.02	10.73
10	8.73	11.25

These figures seem to prove that hydrated lime will not keep any better than quicklime of the same fineness. The fineness is important, however, for the same reason which was cited in the case of lump lime versus ground lime: An impervious coating of air-slaked lime will form on the top of a pile of hydrated lime and prevent access of the air to the interior of the pile.

The chief advantages to the consumer of hydrated lime are as follows: It can be handled more easily on account of its being in powder form. It will keep better than lump lime for the reasons just noted. It does not require slaking, but must merely be soaked in water to prepare it for use. This saves time and labor and eliminates any danger of loss of lime due to unskilled slaking. Any unburned or overburned lime which has passed the sorter will not hydrate and can be screened out of the finished product. Hence, hydrated lime should contain less refuse than lump lime. On the other hand, hydrated lime contains 15 to 25 per cent of water, on which the consumer must pay the freight.

Manufacturers reap several advantages from the operation of a hydrate mill. It gives them a product which can be stored, so that in case the orders for lump lime decrease unexpectedly the lime can be hydrated and stored and the kilns need not be shut down. There are several grades of stone in use which burn either to a dark-colored lime or one which falls to pieces in the kiln. Such lime can not be marketed in the lump, but will give a good quality of hydrate.

A very convenient method for testing hydrated lime is to determine its content of carbon dioxide. If properly made and stored, the amount of carbon dioxide should be less than 1 per cent. Another method which might prove of value as a practical comparative test depends upon the density of the material: Pure calcium hydrate has a lower specific gravity than any other material which may be present in hydrated lime except water. Of 19 samples of commercial hydrated lime tested by this Bureau, 8 samples of good high calcium hydrate showed densities between 2.15 and 2.24; 7 samples of dolomitic hydrates showed densities greater than 2.38; the other 4 samples showed densities between 2.34 and 2.38. Two of these were high calcium hydrates containing unusually large amounts of silica, one was a high calcium hydrate with a large amount of unhydrated (quick) lime, and the fourth was a dolomitic hydrate in which the magnesia was hydrated (because of an unusually low-burning temperature used in the preparation of the lime).

III. PROCESS AND ECONOMY OF MANUFACTURE

In discussing the process and economy of manufacture the apparatus and methods observed at various plants will be compared with a view to ascertaining, first, the influence of each method on the economy of operation and the quantity and quality of product, and second, the most suitable apparatus for each particular step in the process.

The discussion will cover in detail the quarries, kilns, combustion of fuels, and the manufacture of hydrated lime, with reference to the character of the product.

A. QUARRIES

On account of the extreme variations of limestone deposits it is impossible to formulate any definite rules for quarrying which will apply to all of them. However, a few generalities may be stated.

Thus it is usually true that the quality of the stone throughout the same bed (within a small area) will be more nearly uniform than that from different beds. It is therefore advisable when opening a quarry to follow either the dip or the strike of the beds rather than to cut across them.

If a quarry can be so located that its floor is above the tops of the kilns, the cost of hoisting stone can be eliminated. Where this is not possible, it would seem best to maintain the floor at about the drainage level. From a given area this will render available the maximum quantity of stone which can be obtained without pumping. In some cases the value of real estate is sufficiently high to warrant quarrying stone below drainage level, even though a considerable quantity of water must be pumped. An economical method of handling the water is to drain it into a "water hole" or "sump" and raise it to the surface by means of a bucket elevator.

Experience seems to indicate that the cost of labor and explosives will be less if the quarry can be worked with a vertical rather than a horizontal face and that a vertical face can be worked to best advantage when about 20 feet high. If it is much higher than this, especially designed methods of quarrying must be employed, or the cost of explosives will be increased. Faces higher than 20 feet can be worked in "benches" or sections, each of which is about the height required.

1. STRIPPING

Stripping is the name technically applied by quarrymen to the material which covers a deposit of stone. It may consist of almost any kind of material, but the substances generally met with in the lime industry are clay, gravel, and impure or weathered limestone. The clay or gravel may be of commercial value, and the impure or weathered limestone is generally marketable as ballast or for road material. However, stone to be used for lime manufacture should be quarried where the stripping is as little as possible. The impure limestone, and more especially the clay, is apt to be mixed with the stone for burning, and may impair the quality of the lime.

If the beds of stone are nearly horizontal and are covered by clay or gravel of uniform thickness, the stripping may be done by hand digging and hauling in carts, by the use of the plow and scraper, or by means of the steam shovel, depending on the thickness of the overburden. If the beds are horizontal but the country is hilly, it is evident that the thickness of the stripping will vary with the height of the hill. Clay from such a formation can be washed away by hydraulic pressure where a sufficient volume of water is available and drainage is possible. Sometimes, however, this method ceases to be economical, and underground mining of the limestone must be practiced.

A method of mining seen in operation consists of driving horizontal entrances 18 feet high by 50 feet wide into the face of a quarry, leaving enough stone intact to form a roof and the necessary supporting pillars. In a mine of this type the stone is inclosed on five sides, instead of four as in a quarry. Consequently the cost of labor and explosives is much higher than in an open quarry.

In some localities the beds of stone have been steeply tilted and the outcrop either broken off or eroded. The stripping in such a formation is apt to occur in pockets, which may extend down to some distance between the beds. Wherever there are many pockets of considerable size a steam shovel may be employed to advantage.

2. DRILLING

After the stripping has been removed holes are drilled in the stone preparatory to blasting. This is generally accomplished by means of a common bar drill, operated by steam, compressed air, or electricity. At 16 of the 18 plants visited the holes are drilled vertically. At one of the others both vertical and horizontal holes are used, and at the plant where the stone is mined vertical holes are impracticable. The holes are from 1½ to 2 inches in diameter by from 10 to 26 feet deep, depending upon the available depth of stone. Vertical holes are drilled in a row from 4 to 8 feet back of the working face of the quarry and from 5 to 15 feet apart. The distance between holes is governed by the hardness and bedding of the stone and by the fineness to which it is desired to shatter it.

Of the quarries visited the drilling is done in 10 by compressed air, in 1 by electricity, and in 7 by steam.

Compressed air is very well suited for this purpose. The air compressor may be installed in the central power plant, since there is very little loss during the transmission to the quarry. The air may be carried by a 4 or 6 inch pipe, from which it can be distributed to the drills by 1-inch leads. It is generally compressed to 90 pounds pressure.

Electricity has many economical advantages over compressed air. The loss of power during transmission is less. The current may be used for other purposes besides drilling. Less power will be wasted. Time will be saved, because in moving a drill from place to place, it is necessary merely to connect another length of wire instead of being obliged to cut and fit pipe. When a blast is made pipes are apt to be covered up or damaged while wires can easily be moved out of the way. The electric drill seen in operation consisted merely of an ordinary bar drill operated by a small electric motor which is supported on the tripod of the drill.

On the other hand, steam would seem to be the least economical power for drills. If the quarry is at a distance from the kilns, steam can not be generated economically in a central power plant on account of the high cost of transmission; therefore a boiler for this especial purpose must be maintained at the quarry. This entails extra labor and handling of fuel, and even then the loss of power in the pipes leading to the drills is apt to be very large.

3. BLASTING

It is the general practice in quarrying stone for lime burning to blast it loose. Blasting also serves the purpose of breaking the stone to pieces small enough to be put into the kiln. There are two methods of blasting in common use, based on these two purposes—that is, by one method the stone is merely loosened and thrown down into the quarry in blocks; by the other it is shattered to pieces small enough for immediate use. The difference in operating by these methods is in the number and position of the holes and the kind of explosive used. The more finely the stone is to be shattered the closer must the holes be to each other and to the working face, and the more powerful must be the explosive.

The former method requires less explosive for the first blast, but the large stones thrown down must be drilled and blasted separately, so that this method probably requires in the end more labor and explosive than the second. On the other hand, the second method produces a great deal more fine stuff than the first. However, this is no great objection if a crusher is provided to take care of it. These considerations seem to favor the second method of blasting.

The selection of the explosive to be used depends on the nature of the stone and the method of blasting desired. For a very soft stone, or where the stone is to be taken out in large pieces, a large amount of a weak explosive, such as black powder, would answer the purpose. If the stone is hard, or if it is desired to shatter it, 40 per cent dynamite is the explosive in general use.

It is often the practice to "spring" the holes before blasting. This is done by charging them with black powder, not in sufficient amount to loosen the rock. When this is set off it springs or enlarges the ends of the holes into chambers, thus giving room for a larger charge of explosive for the regular blast. Since more explosive may be used in each hole, it follows that a smaller number of holes are required to blast out a given mass of rock.

That is, the method of springing the holes saves drilling, but costs more for explosives. It is, therefore, probably more economical for hard rock but less so for soft rock than the ordinary method of blasting.

4. SORTING AND LOADING

After the stone has been blasted loose and thrown down into the quarry the larger blocks are broken up with dynamite. This is generally placed in holes drilled in the blocks, but may simply be laid on the top of the stone and covered with mud. The former method is called "pop shooting" and the latter "mud capping." Pop shooting requires more labor and power than mud capping, but saves so much in the cost of dynamite that the latter method has been abandoned except in quarries where steam drills are used.

The stone is then broken still smaller by sledging, until it is reduced to the size necessary for charging into the kilns. It is then loaded into the car, cart, or wheelbarrow, which takes it out of the quarry. This loading is generally done by hand so as to give an opportunity for sorting the stone.

Limestone must be sorted in order that only the proper quality and size of stone may be put into the kiln. The quality of stone required for burning has already been described. A quarry should be so located and operated as to give as little unsuitable stone as possible. If some "bad" stone must be quarried with the good, its appearance should form a clear indication of its character, otherwise it can not be sorted out, and a poor quality of lime may result. If the lime is to be used for finishing purposes, particular attention must be paid to sorting the stone, since any great amount of clay adhering to the surface of an otherwise good stone is apt to cause pitting on the wall.

The size of the stone to be used depends on two considerations: A hard, dense stone may be used in smaller sizes than one which is soft and has a tendency to fall to pieces in the kiln. If the draft is normally rather low, large stone should be used, or the draft may be choked below its economical limit. It is the general custom to use anything from a "one-man" stone (a stone as large as one man can readily handle) down to about 4 inches in diameter. On account of more nearly uniform draft it would probably give greater kiln efficiency if the stone were sorted more nearly to the size required by the kiln, but this is hardly economical unless a good market for crushed stone is at hand, so that good use may be made of the smaller sizes.

B. METHODS OF TRANSPORTATION

The methods in use for taking the stone from the quarry to the kilns are numerous. This is to be expected, since the method must be varied to suit the particular conditions of each plant, such as the distance between the quarry and kilns, the shape of the quarry, the elevation from the quarry floor to the top of the kilns, and the amount of stone to be handled. An enumeration of the methods used includes wheelbarrows, carts drawn by horse, cars drawn by horse, cable, or locomotive, and cars or buckets transported by aerial cables, and skips hoisted by derricks. It is frequently the custom to use two or more of these methods in combination.

The transportation of stone may be considered as being carried out in three stages: (1) Taking the stone out of the quarry, (2) taking it from the quarry to the kilns, (3) elevating it to the top of the kilns.

The wheelbarrow has the advantage over all other vehicles except the cart, in that its direction of action is unlimited; that is, it can follow the constantly shifting working face of the quarry. However, taking stone out in a wheelbarrow is a very slow and laborious process, and is certainly not to be recommended, even where the quantity of stone to be moved is very small. Wheelbarrows are generally out of the question when it comes to transporting the stone to the kilns. They are sometimes used for elevating stone to the top of the kilns, but only where the charging doors are too small to admit a whole carload.

The horse and cart has the same unlimited action in the quarry as the wheelbarrow. If the distance to the kiln is not too great, this vehicle may be used for the transportation, and there are instances where the elevation is sufficiently low, so that the horse can haul the stone to the top of the kilns. The method is very slow, however, and is not to be recommended where any considerable amount of stone must be moved.

Tramcars labor under 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 kilns are very near the quarry, it is the custom to slope the quarry floor, so that the cars can be taken to one point by gravity. Here a cable is hooked on, and they are drawn up an incline to the top of the kilns. If the kilns are over one-half mile from the quarry, it is generally considered economical to use a locomotive for the transportation. If the distance is too short to warrant this but too long for a cable, animal power may be used. Generally, it will be found impossible, on account of the grade, for either locomotive or horse to take the stone to the top of the kilns. They deliver it at the foot of an incline, where a cable is attached to pull it up to the top.

The consensus of opinion seems to be that the construction and repair costs of aerial cables are higher than for other methods of transportation. Moreover, they are not adaptable to the changing face of the quarry, so that some other means must be relied on to take the stone to them. They may be necessary in some instances, however, as when the stone must be carried over a hill too steep for a locomotive or horse, or over a railroad track.

If the quarry is very deep, sometimes the only possible way to get stone out is by hoisting it. It may be loaded on skips and pulled up by derricks, which load it on cars for transportation to the kilns.

Since the method of transportation must be varied to suit local conditions, it is not surprising that each quarry visited was equipped with a different method of handling the stone.

C. METHOD AND TIME OF CHARGING

When stone is brought to a kiln by horse and cart the method of dumping it in needs no explanation.

There are two types of cars in general use, the bottom-dump and side-dump cars. They are usually built of iron and hold 2 or 3 tons of stone. In the former type the bottom consists of two plates so hinged that when released they will swing downward and allow the stone to fall into the kiln. Side-dump cars are built V-shaped in cross section, so that they are top-heavy when full of stone and must be fastened to the trucks on both sides. When dumping the fastening on one side is released and the car permitted to roll over toward the other side. It must be righted again by hand. An interesting device in this connection is the automatic car. The fastening of this is tripped by an upright piece bolted to the track, the car rolls over and discharges its load, and is righted again by springs attached to the trucks.

Some of the kilns visited are charged either by wheelbarrows or by hand. These methods are very slow and laborious, but are used apparently because the design of the kiln makes it impossible to use any other.

It is a well-known fact that when a carload of stone is dumped into a kiln the larger pieces will stay where they strike while the smaller ones will roll away. Thus, when side-dump cars are used much difficulty is experienced because the stone in one side of the kiln is larger than that in the other. This can be overcome by using bottom-dump cars, which discharge in the center of the kiln; the fine stones roll to the outer edges and tend to check the draft, which is normally greatest there.

The buckets or cars brought to a kiln by an aerial cable are dumped by being lowered till they catch on a horizontal tripping device over the kiln and are upset.

Kilns which are built without hoppers should, of course, be filled after each draw. Kilns with hoppers are generally filled once a day, or twice if the quarry and hoisting apparatus have sufficient capacity.

Lime burning is a continuous process. It is generally impracticable to store more than two days' supply of stone in the hopper of a kiln, and it is most economical to run the kiln at full capacity. Thus a steady and reliable stone supply is necessary. Arrangements should be made whereby the kilns will be filled at least once every day.

D. DETAILED DESCRIPTION OF KILNS

Practically all of the lime produced in this country to-day is burned in some form of kiln. What is known as the shaft kiln is used almost universally, although a few attempts have been made to adapt the rotary kiln, so well known in the cement industry. The rotary kiln, while it has many advantages over the shaft type, has the one great disadvantage that the stone must be crushed to a fine size. Therefore the product is not salable as lump lime, and can be used only for hydration. The manufacture of hydrated lime is a comparatively new industry, and until it is more fully developed the use of the rotary kiln in the lime industry will be limited.

This paper deals only with shaft kilns, of which there are a great many varieties. In general, a shaft kiln resembles a short, wide stack, of either square, round, or elliptical cross section. It consists of a casing of steel or stone which is lined with refractory material. The long, vertical chamber formed by this lining may be divided into three compartments by imaginary horizontal planes. The top compartment, called the hopper, is used for storing and preheating the stone. Its sides slope in so that the stone may slide down into the middle compartment, the shaft. This shaft is the place where the lime is burned. It may be of either square, round, or elliptical cross section, independently of the outside of the kiln. Generally the sides of the shaft are vertical, although in some cases they slope outward. In this latter method of construction it is customary to omit the hopper. At the bottom of the shaft the third compartment (the cooler) is used for storing the lime after it is burned. The top of the cooler must, of course, have the same cross section as the shaft. The sides are drawn in to form a slide leading to the drawing door. A hole in the side or bottom of the cooler is closed by a door or by sheets of iron which swing on a pivot and are known as shears. The lime is removed through this opening. The fuel used in burning the lime is consumed in the fire boxes usually arranged on two sides of the kiln. They are very similar to the common fire boxes in use under boilers. Each kiln has two or more, which are set in openings through the casing and lining into the lower part of the shaft. In this paper the level of the grates in the fire box will be considered the bottom of the shaft, it being assumed that lime is not burned below this point. When gas is used as the fuel, the fire box is a mere port through which the gas pipe is led into the kiln. In either case the draft caused by the combustion of the fuel draws the flame up through the shaft in direct contact with the lime and stone and the gases formed pass out the top of the hopper.

To increase this natural draft a stack is sometimes placed on top of the kiln. Forced or induced draft, or a combination of both, is also in common use. The forced draft is generally created by blowing steam through the grates into the fire box; the induced, by drawing the gas out through the top with a fan. These two methods may be combined, or the gas which is drawn from the top may be forced back through the grates, according to the Eldred process. These methods of increasing the draft have in some cases necessitated closing the top of the kiln. Hence, a charging door must be supplied through which the stone can be dumped. The various parts of the kiln are shown in Fig. 1.

There are many considerations which limit the practical size of a kiln. Chief of these is probably the market which the kiln has to supply. Lime is a perishable article, hence any cessation in the demand necessitates a curtailment of the supply. If the market demands a definite supply of lime for a continuous period, a kiln can be built large enough to supply that demand. Generally, however, it is safer to build a number of small kilns, so that in case the demand falls off it will not be necessary to close down the entire plant. Recently the custom has been introduced in a few plants to run the kilns at full capacity and hydrate what lime can not be used immediately; for hydrate may be stored. The cross section of the shaft is limited by the distance the heat can be made to penetrate toward the center. The total height of the kiln above the grates is limited by the conditions of the draft. If natural draft is used, the gases must leave the top of the kilns hot enough to produce the draft. That is, the kiln must not be too high, or the stone will absorb too much heat from the gases. With any form of induced draft the kiln should be just high enough so that the gases leave approximately at the temperature of the external air. If the kiln is lower than this, the heat carried off by the gases is simply wasted; if higher, the added amount of stone causes unnecessary work for the fan.

Although there are numerous designs of limekilns, they may be divided, for the sake of classification, into four types, according to the outline of their shafts. These types are illustrated by Figs. 1, 2, 3, and 4.

The drawings are not to be considered as of actual kilns, although there are kilns which are very similar to each of these types, but differ in some detail. These diagrams are intended to be merely composite designs, showing the more important points of variation.

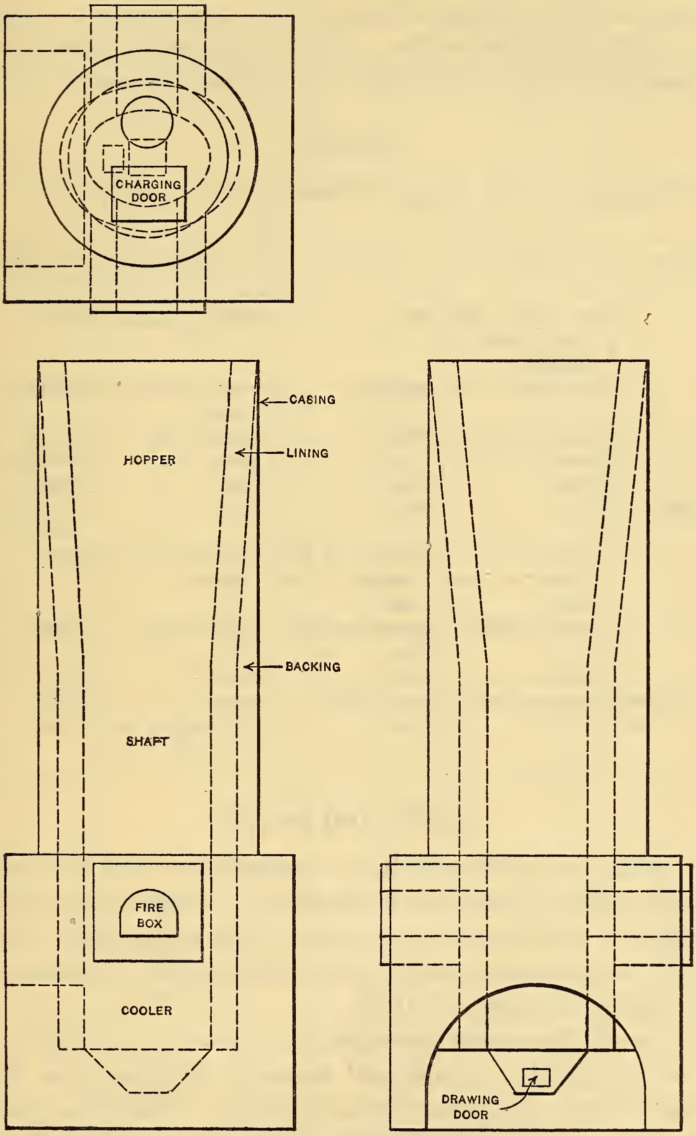

Fig. 1.—*Round Kiln with Shaft Drawn in*

It is of course understood that the component parts of these designs perform the same functions. The dimensions used in the drawings are the averages taken from the kilns investigated. Table 2 calls attention to the variations shown by these designs. Each component part of the kiln will now be discussed in detail.

TABLE 2

Variations in Kiln design (Shown by Figs 1, 2, 3, and 4)

Part of kiln	Figure 1	Figure 2	Figure 3	Figure 4
Casing	Part steel, part stone, brick, or concrete.	Stone	Steel	Steel.
Lining	Fire brick	Fire brick	Two grades of fire brick.	Fire brick.
Backing	Steel section backed	None	Has backing	None.
Stack	None	do	None	Has stack.
Top	Closed	Open	Open	Stack,
Charging door	Flat	None	None	In side of conical piece.
Hopper	Circular at top, elliptical at bottom.	Square at top, rectangular at bottom.	Circular at top and bottom.	None.
Shaft	Straight, elliptical	Straight, rectangular.	Straight, circular	Conical.
Cooler	Unlined	Lined	Unlined	Unlined.
Means of drawing	Door under center	Door at side	Shears	Shears.
Number of fire boxes.	Two	Four	Four eyes for producer gas.	Three.

1. CASING AND BACKING

The casing, or outside shell, in conjunction with the backing, has three distinct functions to perform. It must carry part of the weight of the kiln, it must protect the lining from excessive changes in temperature, and it must minimize the amount of heat lost by conduction and radiation.

The size of the casing depends, of course, on the size of the kiln. With regard to shape and material, they may be divided into four classes: (1) Square stone casings. (These are generally built one stone (9½ inches) thick at the top, extending straight down on the outside, and following the contour of the hopper-shaft, and cooler on the inside. They are illustrated by Fig. 2.)

(2) Round steel casings as shown in Fig. 3. (This is made of sections of steel plate, rolled to shape and bolted together. Instead of being circular in cross section, these casings are sometimes elliptical.) (3) Conical steel casings. (This variation of (2),

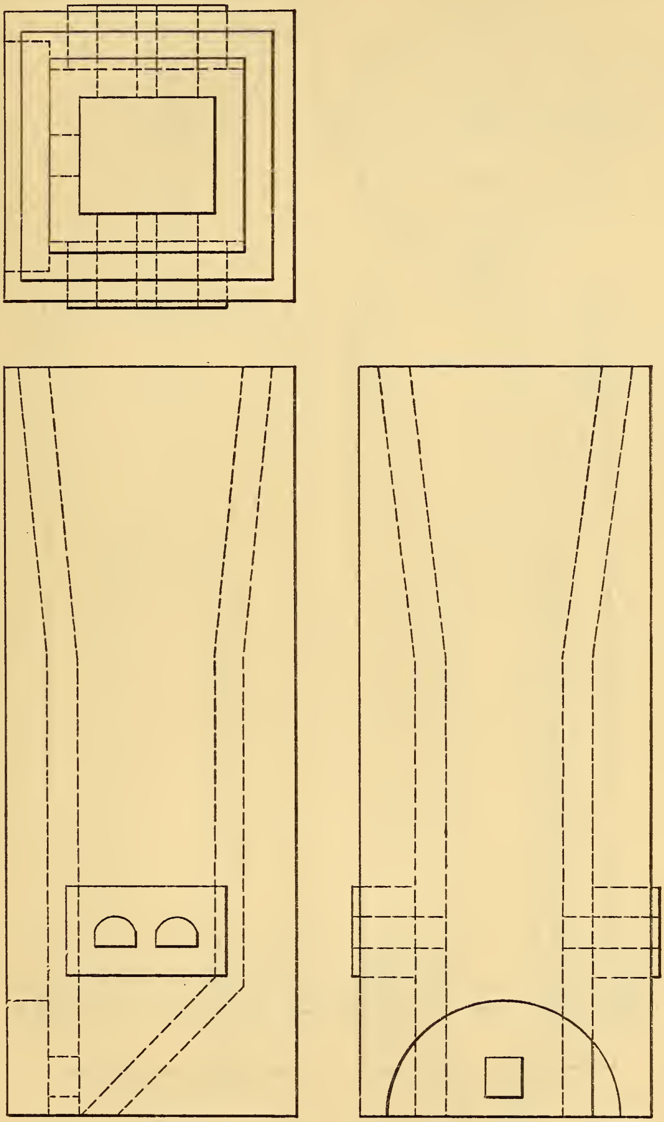

Fig. 2.—*Square Kiln with Straight Shaft*

shown in Fig. 4, is common enough to warrant considering it as a separate class.) (4) A combination of steel with stone or other material. (In this case a cubical structure large enough to inclose the fire boxes is built of stone, brick, or concrete, and

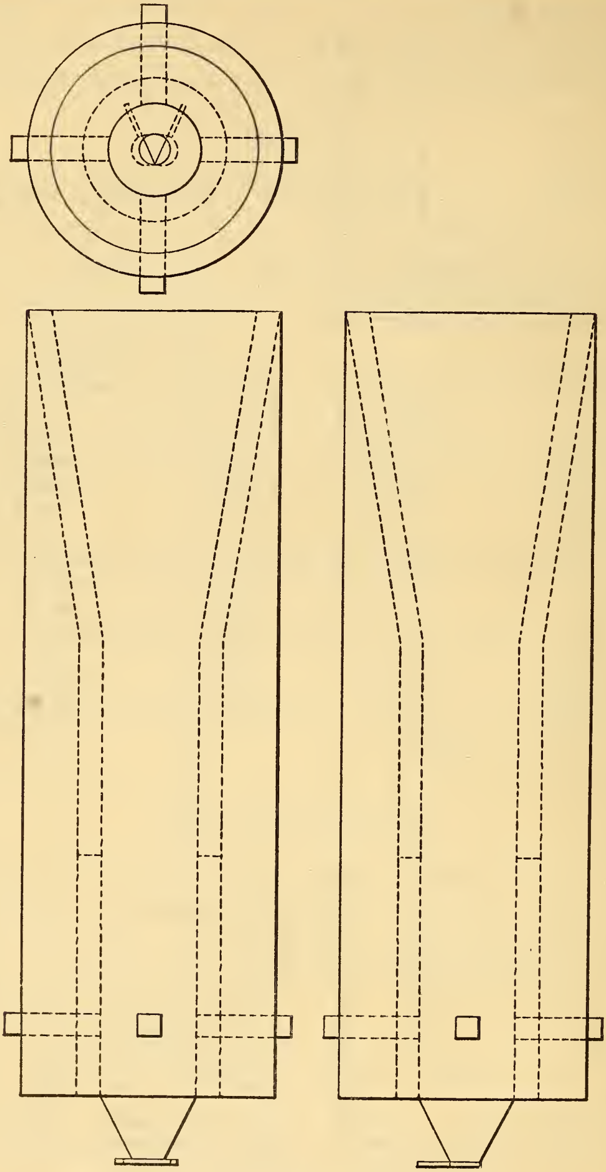

Fig. 3.—*Round Kiln with Straight Shaft*

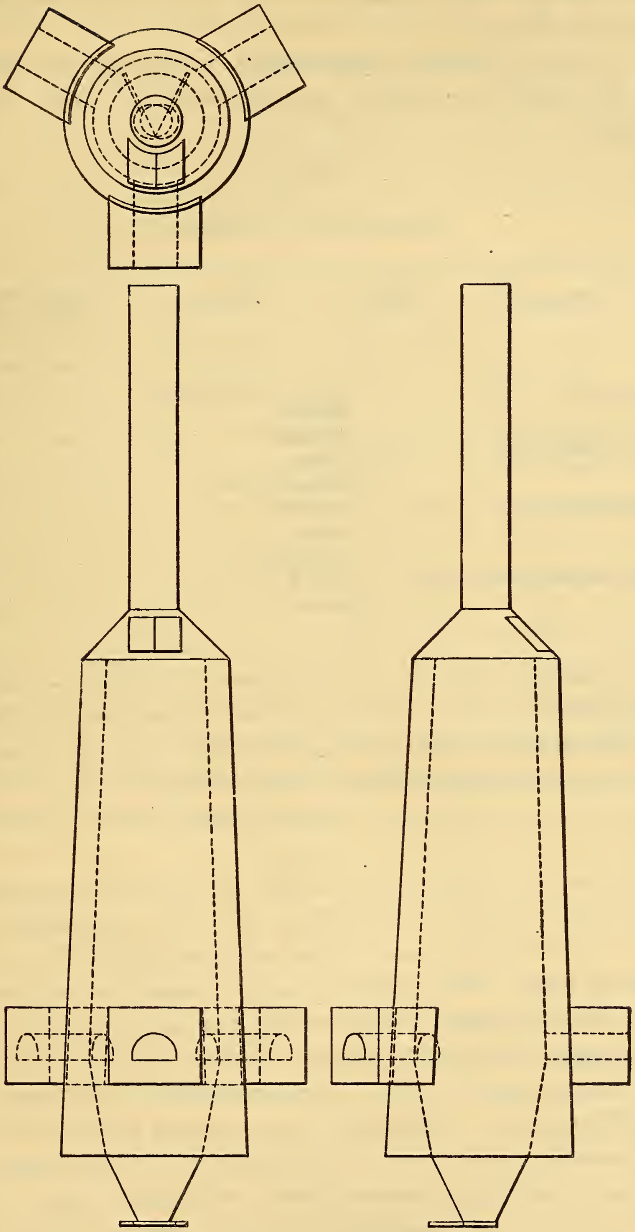

Fig. 4.—*Round Kiln with Flaring Shaft*

the steel casing is built upon it. This method of construction is illustrated by Fig. 1.)

Table 3 shows how the above classes of casings are distributed among the kilns investigated together with the more important dimensions.

TABLE 3

Dimensions of Casings

Class	Description	Kilns	Dimension	Maximum	Minimum	Average
				Ft. in.	Ft. in.	Ft. in.
1	Square, stone	17	Length of side, external	17	10 6	13 6
			Height	42	29	36 5
2	Round, straight, steel	103	Diameter	20 6	6	10 2
			Height	69	16	32 9
3	Round, conical, steel	15	Diameter at top	8	6	7 6
			Diameter at fire	10 6	8 6	9 4
			Height	43	19	36 7
4	Round, steel and stone, straight	25	Diameter at top	16 6	7	12
			Side of square at fire	18 6	15 6	17 6
			Height	43	23	37 5

With regard to the first requirements of casings—supporting the weight of the kiln—steel is probably more satisfactory than stone. The strain is practically all lateral, and the steel plates can give to some extent without losing strength, while if the stone is pushed out (as is often the case), it must be tied together with iron rods.

The loss of heat suffered by a kiln is due to two causes, conduction and radiation. The heat lost by conduction varies inversely with the thickness of the wall and depends on the kind of material used. The material used should be as porous as possible. For example, recent work has shown that a 12-inch wall of porous fire brick will not conduct as much heat as an 18-inch wall of hard brick. The conductivity of ashes is still less than fire brick. Therefore, steel casings backed with ashes will theoretically offer greater resistance to the passage of heat than casings built of comparatively dense limestone. For an example to show the magnitude of the losses involved, assume that a kiln is 15 feet in external diameter and 40 feet high. The shaft is circular, 6 feet in diameter, and is lined with 18 inches of fire brick. The space between the casing and the lining is filled with ashes. The difference in temperature between the inside and outside of the kiln is 1200° C (2192° F) at the bottom and zero at the top. The conductivities of fire brick and ashes may be taken as 1.37 and 0.64 large calories, respectively, per hour per square meter of surface per 1 meter of thickness per 1° C difference of temperature.[8]

If the coal has a heating value of 3276 large calories (13 000 Btu) per pound, the total loss by conduction through the casing will approximate 200 pounds of coal per day.

The other factor, radiation, is also of importance, and the same conclusion holds, i. e., the use of as porous a material as possible. The more and the smaller the air cavities the substance contains the better it is for the purpose in view. However, this must not be carried to the extent of advocating the use of large air spaces within the kiln walls. Although air is an effective nonconductor of heat, it presents no obstacle to the *radiation* of heat, which passes through it as would light. Since the rate of radiation is proportional to the fourth power of the difference in temperature between the hotter and colder bodies, it is readily seen that the heat radiated across the air space may easily become a significant factor. While air spaces in a wall may do for slight temperature differences and low initial temperatures, these conditions do not exits in a limekiln.

Dense substances, like limestone, conduct heat too readily; large air spaces permit the heat to be transferred by radiation; so that theoretically the best insulation will be obtained by the use of some porous material, such as ashes.

The same reasoning which has been used in regard to the heat lost by conduction and radiation naturally applies also to the protection of the lining from excessive changes in temperature.

From the above considerations it will be seen that steel, with a sufficient backing of some porous material, should fulfill the requirements of a casing better than stone. Moreover, it is probably cheaper if the cost of labor is taken into consideration.

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[8] Wologdine and Queneau: Electroch. Met. Ind., 7, pp. 383–389, 433–436, 1909.

The casings built partly of each material are compromises. The stone is used to inclose the hottest part of the kiln, and the steel where the chance for loss by conduction is not so great.

2. LININGS

The lining of the kiln is very important wherever lime is burned by the continuous process, and practically all the lime produced in the United States is so burned. In this process the stone is continually charged in at the top of the kiln and the lime drawn out at the bottom. Therefore, to repair the lining, the lime must be drawn and the kiln allowed to cool down. This is very expensive, involving a loss of time, labor, heat, lime, and stone. For this reason the material used for the lining should be such as will minimize the frequency of repairs.

In shape the lining forms the sides of the hopper, shaft, and sometimes of the cooler; hence its dimensions will be discussed under these heads. It is commonly the custom to maintain the same thickness of lining throughout the kiln. If fire brick is used, two courses are generally considered sufficient. Other materials may vary in thickness from 9 to 18 inches.

In the burning zone (the fire boxes and lower part of the shaft) the material must resist a high temperature, and also the chemical action of the stone. Table 4 shows the way these requirements have been met at the plants visited.

TABLE 4

Materials used in lining Kilns

Burning zone		Upper part	
Material	Kilns	Material	Kilns
Fire brick	124	Fire brick (same grade as in burning zone)	46
Sandstone	21	Fire brick (different grade)	49
Mica schist	15	Paving brick	24
		Granite	11
		Sandstone	30

The temperature in the burning zone probably seldom exceeds 1400° C (2552° F), a temperature which many grades of fire brick are able to withstand. The main difficulty seems to be caused by the chemical action of the lime. At the temperature attained the lime unites with some constituents of the brick to form compounds which fuse with comparative ease. In this respect practical results have shown that calcium oxide is much more corrosive than magnesia. The manufacturers consulted seem to think it impossible to obtain a fire brick which will withstand the fluxing action of a high calcium lime for an economical length of time (one year), although several grades have been used very successfully with magnesian limes. There is, however, the possibility of obtaining brick of ample resisting power by the use of highly aluminous materials containing a sufficient amount of "grog."[9] There is no reason why such brick can not be made, and, though they would command a high price, it would be economical to use them. A high-grade fire brick of this kind would be superior to magnesite brick, since the latter, though very refractory and unaffected by the action of lime, is quite friable and subject to loss by abrasion at the temperatures involved.

The apparent failure of fire brick to meet the demands has led to the experiments with mica schist and sandstone. Each of these materials has given satisfaction, but it may be more expensive than fire brick.

In connection with the manufacture of a brick for lining limekilns, the following analysis of the sandstone used by the Tennessee Marble Lime Co. may be of interest. This analysis was made by the Union Mining Co. (makers of the Mount Savage fire brick) in 1908.

	Per cent
Loss on ignition	0. 86
Silica (SiO_2)	96. 36
Titanic acid (TiO_2)	. 14
Alumina (Al_2O_3)	. 95
Ferric oxide (Fe_2O_3)	. 55
Manganous oxide (MnO)	. 34
Calcium oxide (CaO)	. 38
Magnesium oxide (MgO)	. 22
Sodium oxide (Na_2O)	. 20
	100. 00

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[9] Small pieces of broken brick.

For the upper part of the linings the problem is much simpler. At first it was the custom to use the same grade of fire brick throughout the kiln, but it has been found that a brick sufficiently refractory to give good results in the burning zone is too soft to stand the abrasion in the upper part of the kiln. Hence, a number of kilns are lined with two grades of fire brick. Where granite and sandstone are used the materials are generally found on the premises. They are well able to stand the wear, but would probably be too expensive to cut and put on the market. Of the five materials mentioned in Table 4, paving brick is believed to be the best for the upper part of the lining. It is able to withstand the heat, is made especially for resistnace to abrasion, and is probably cheaper than fire brick or cut stone.

3. TOPS OF KILNS, STACKS, AND CHARGING DOORS

There are three methods in common use for constructing the tops of kilns. Of the 160 kilns reported in this paper 85 have open tops, 22 have closed tops, and 53 are surmounted by stacks. Obviously a discussion of the open top is not necessary.

Closed tops are constructed of flat steel plates, bolted to the casings. They are used in connection with some system of induced draft, and, therefore, should be kept practically air-tight, so that the fan which removes the gas need not handle any unnecessary air. Closed tops must be provided with two openings, one through which the gas is removed, and another for the charging door. This door is generally about 3 feet wide by 5 feet long, and should be large enough to permit dumping a carload (2 or 3 tons) of stone in at one time. It may be either hinged or sliding, but care should be taken to see that it is closed air-tight after each charging. It is a good practice to seal it shut with lime paste.

The stacks used are of the ordinary round steel variety common in boiler practice. They are generally connected to the casings by short conical sections of steel. The charging door is cut in the side of this section, as shown in Fig. 4, and herein lies the greatest objection to the use of stacks. For, unless the kiln is of rather large diameter, it is impossible to make the door of sufficient size and place it in such a position that a carload (2 or 3 tons) of stone can be dumped through it at one time. Of the 53 kilns with stacks only 22 are large enough for this purpose. To four of the others the stone is taken in wheelbarrows, the doors being sufficiently large to admit this smaller amount. The charging of 11 other kilns is done by hand. In order to eliminate this expensive method of charging, the conical section has been omitted from the remaining 16 kilns. The stacks of these project from flat tops which are similar to those used in the closed top construction, and hence the charging doors offer no difficulty.

The dimensions of the stacks in use are as follows:

Diameter—maximum, 48 inches; minimum, 22 inches; average, 35 inches. Height—maximum, 40 feet; minimum, 10 feet; average, 23 feet 5 inches.

The principal reason for placing a stack on a kiln is to increase the draft, which assists in preventing the "recarbonating" of the lime. As explained in the section on burning, lime will become recarbonated whenever the partial pressure of the carbon dioxide rises above the figure given by Johnston's equation. Practice has shown that in open-top kilns a strong wind will sometimes blow the gas back into the kiln, thus forcing the products of combustion down into the cooler and causing a momentary increase in the pressure of the carbon dioxide and the consequent recarbonation of the lime. Stacks are effective in preventing this.

For whichever purpose the stack is to be used it must be large enough to deliver the gas without throttling. A stack not sufficiently large for this purpose is worse than no stack at all. The volume of gas to be delivered may be calculated from the analyses of the stone and fuel and the amount of each used. Assuming that the gas evolved from the stone is 47.69 per cent by weight [10], that the combustion of 1 pound of the fuel will generate 17 pounds of gas,[11] and that the velocity of the gas shall be 787 feet per minute,[12] thus by substituting factors generally known by lime manufacturers in the equations for chimney design,[12] the following approximate formulas have been derived:

$$D = 0.0847\sqrt{\frac{ct\,(r + 18.65)}{r}}$$

$$h = \frac{68\,dt}{t - 538}$$

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[10] Calculated for pure dolomite, since this will give the maximum amount of gas.

[11] Calculated for gas coal, allowing 50 per cent excess air.

[12] Christie: Chimney Design, p. 30.

where D = diameter of stack in inches

c = capacity of kiln in tons of lime per 24 hours

t = temperature of escaping gases + 460°

$r = \text{fuel ratio} = \dfrac{\text{pounds lime burned}}{\text{pounds coal used}}$

d = draft in inches of water

h = height of stack in feet

The manner in which the stack is connected to the kiln is of great importance. It is a well-known fact that a right-angled bend offers great resistance to the passage of gas. Consequently, when the top is built flat the draft created by the stack may be entirely nullified by the two changes in direction which the gas is forced to take. Moreover, the eddy currents set up by these bends may force the gas back into the kiln, with the attendant recarbonation. Both of these considerations point to the advisability of using a conical section for connecting the stack to the kiln.

4. HOPPERS

The hopper, or upper part of a kiln, is designed as a place where the stone can be stored and at the same time preheated by the waste gases from the kiln. It is advisable to have storage room for an extra supply of stone, in order that the kiln may be independent of failures of machinery, inclemencies of weather, and the numerous other factors which may interfere with the regular operation of the quarry. A hopper constructed as the upper section of the kiln will save one handling of the stone, and should add sufficiently to the preheating space to increase the efficiency of the kiln.

Hoppers are built in the form of truncated cones or pyramids. The larger base is at the top of the kiln, and from this the sides slope in until the cross section becomes that of the shaft. The cross section of the upper base is not limited by either size or shape, except that it must be small enough to give the sides a rather steep slope. Otherwise the stone is apt to arch over and will not slide down into the shaft. The height of the shaft and hopper together has already been discussed, but just where the division between the two shall take place is entirely arbitrary. Table 5 gives the forms and dimensions of the hoppers of 107 kilns.

TABLE 5

Forms and Dimensions of Hoppers

	Form	Dimension	Kilns	Maximum	Minimum	Average
				Ft. in.	Ft. in.	Ft. in.
Upper base	Square	Side of square	21	14	8 6	10 8
	Circular	Diameter	86	19	7	9 9
Lower base	Rectangular	Larger dimension	34	8	6	7 2
		Smaller dimension		7	5	6 3
	Elliptical	Larger dimension	73	16	5 10	6 11
		Smaller dimension		7 6	4 10	5 5
Height			107	37	5	15 6

It is generally agreed that stone sufficient to supply the kiln for 48 hours is enough to keep on hand. If, for example, a kiln produces 10 tons of lime per day, its hopper should hold at least 27½ cubic yards of stone. Hence, in designing a hopper the volume and the form and size of the lower base are fixed. The other dimensions may be varied at will, provided that the sides are sufficiently steep and the height is considered in connection with that of the shaft. The volume of the hopper may be calculated from the formula:

$$v = \frac{1}{3} h \left(a_1 + a_2 + \sqrt{a_1 a_2}\right)$$

where v = volume of hopper.
h = height of hopper.
a_1 = area of upper base.
a_2 = area of lower base.

5. SHAFTS

The shaft is that part of the kiln in which the actual burning of the lime takes place. As the stone passes down through the shaft it is gradually heated until the temperature of calcination is reached, usually about 8 feet above the grates. Therefore, the upper part of the shaft serves as a preheating chamber, and the lower part is known as the burning zone.

The size and shape of the shaft depend very largely on the method by which the kiln is to be operated, hence a discussion of the methods in use will be advisable at this point.

E. METHODS OF OPERATING KILNS

There are two methods in common use for operating limekilns, which are known as the "following" and the "sticking" processes. By either process only a part of the lime is taken out at a time, since enough must remain to fill the cooler and so keep the unburned stone above the grate level. The "following" method is very simple. When the lime is drawn from the bottom of the kiln the remaining lime and stone slide down and fill up the space, as would naturally be expected. The difficulty with the process lies in the fact that the stone will not burn evenly. Owing to the tendency of the flame and hot gasses to pass up the side of the shaft, rather than to go into the center, the mass of unburned stone always extends down farther in the center than at the sides, as shown in Fig. 5 A. It is obvious that if the stone falls down evenly, the unburned portion in the center must be brought below the grate level before the burned lime at the sides can be removed from the burning zone. It is the custom to draw out enough lime so that the lowest part of the stone will reach to about the grate level, and then take a chance on overburning the lime in front of the fires. A kiln, after being drawn by this method is shown in Fig. 5 B.

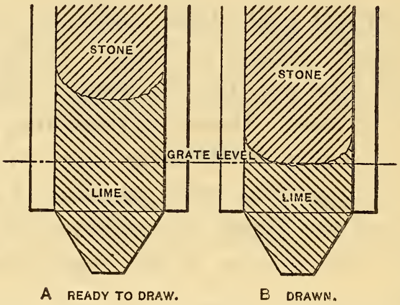

Fig. 5.—*Vertical Sections of Shaft, Showing Method of Operation of "Following" Process*

The difficulty just explained may be oviated by the use of the "sticking" process. In this the kiln is generally chilled by omitting to fire and leaving the fire doors open for from 20 minutes to 1 hour before drawing. This chilling causes a contraction of the lining, and also a solidification of the fused compounds resulting from the action of the lime on the lining. When the lime is drawn from the cooler these two processes acting together prevent the stone from following, and cause it to "stick" or "hang," as shown in Fig. 6 B. After drawing, the lime is knocked down by bars inserted through the fire boxes, and finally the whole mass is caused to fall by knocking the supporting pillar of lime away. The stages of the operation are shown in Fig. 6. By this method the lime can all be removed from the burning zone and an even layer of fresh stone is presented to the fire. It has great disadvantages, however. It requires altogether from one-half to one and one-half hours to complete the drawing, during which time no lime is burned, labor is expended, and the kiln is cooling down. Consequently, it is extravagant of time, labor, and fuel.

It must not be supposed that there is a hard and fast distinction between "following" and "sticking" kilns. In general, it may be said that if the sides of the shaft slope outward, i. e., if the diameter is larger at the fire than at the top of the shaft, the kiln will "follow;" if straight, it will "stick." A skilled fireman can usually operate any kiln by either process, but sometimes kilns designated to "follow" will "stick," and vice versa. "Follow" kilns also have a troublesome habit of "turning over" at times. That is, something will cause a quantity of lime to stick in one part of a kiln, while the stone falls down past it, resulting in a layer of lime above some unburned stone.

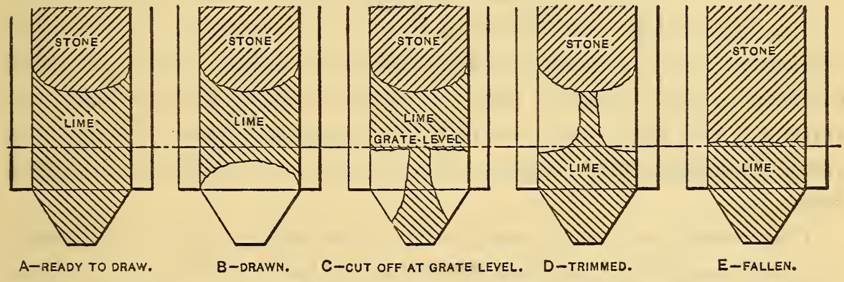

Fig. 6.—*Vertical Sections of Shaft, Showing Method of Operation of "Sticking" Process*

To summarize, it apparently is more expensive to operate a kiln by the "sticking" than by the "following" process. Owing to the danger of obtaining core or overburned or recarbonated lime, the "following" process probably gives a smaller capacity. The "following" process seems to be more economical, but the relative value of the two processes has not been definitely determined.

The above considerations will lead to the decision as to whether the sides of the shaft should be vertical or slope outward. The height must be considered in connection with that of the hopper, as already indicated. It should be added, however, that the burning zone should always be included in the shaft, for the larger dimensions of the hopper offer too many opportunities for the formation of chimneys, which might permit the gas to escape without transferring its heat to the stone.

With regard to cross section, shafts are constructed in three shapes, rectangular, elliptical, and circular. It will be remembered that the economic dimensions of the cross section depend upon the distance to which the heat can be made to penetrate toward the center of the kiln. For this reason, the rectangular and elliptical shafts have their smaller dimensions between the fire boxes. The rectangular shaft is much more easily constructed and repaired than the elliptical, but the corners serve as excellent chimneys for the gases, so that elliptical kilns should be more efficient. The circular shaft is also readily constructed and repaired, but obviously the elliptical form will give a larger area (and therefore great capacity) with the same distance between fires.

This reasoning would lead to the conclusion that the ellipse is the best shape for the cross section of a shaft. However, a circular shaft may give equally good results if provided with three fire boxes.

In Table 6 are given the forms and dimensions of the shafts in the 160 kilns investigated.

TABLE 6

Forms and Dimensions of Shafts

Sides	Cross section	Shape of cross section	Kilns	Dimension	Maximum	Minimum	Average
					Ft. in.	Ft. in.	Ft. in.
Sloping	....	....	25	Height	40	8	24 6
	At top	Circular	25	Diameter	7 6	4 6	5 10
	At fire	......do	25	......do	9 8	6 6	7 8
Straight	....	....	135	Height	29	5	16 1
	At fire	Rectangular	34	Large dimension	8	6	7 2
				Small dimension	7	5	6
		Elliptical	84	Large dimension	16	5 10	7
				Small dimension	7 6	4 6	5 3
		Circular	17	Diameter	6 6	4 6	5 8

1. COOLERS AND DRAWING DOORS

The cooler, as the bottom compartment of the kiln is called, seems to be a necessary adjunct of all shaft kilns. At least every kiln investigated so far is provided with one. As generally constructed it is a pit into which the lime falls from the shaft and from which the lime is removed through an opening at or near the bottom. The sides of the cooler slope in so that the lime can slide down to this opening. The cross section of the cooler must, of course, conform to that of the shaft. The only dimension remaining to be given, therefore, is the height, which was found to be as follows: Maximum, 14 feet; minimum, 4 feet; average, 8 feet 10 inches.

Since it may be assumed that the heat from the fire box never goes below the level of the grates on entering the kiln, it is necessary to keep all unburned stone above this level. The easiest way to do this is to leave enough lime in the kiln to support the stone at the required height. Hence, when a kiln is in operation the cooler is always full of lime.

The term "cooler" seems to be misapplied, judging from the method of construction commonly employed. In 132 kilns the coolers are lined exactly in the same manner as the lower part of the shafts, thus retarding cooling. Five others are lined, but are provided with air ducts, through which cold air is drawn into the ash pits. The other 23 are unlined—merely steel shells, exposed to the cooling effect of the air circulating around them. There is one advantage to be gained by lining the coolers: If, by any chance, some stone should pass through the burning zone without being entirely calcined, the lining of the cooler has enough heat stored up in it to complete the operation. However, the cooler has a function of its own to perform, without being obliged to assume that of the shaft. The cooler should actually cool the lime. If possible the heat so obtained should be utilized. This is best done by providing ducts of some kind in the lining, or pipes inside the cooler, through which the air used in burning the fuel may be drawn and thus preheated. If all of the heat of the lime could be saved in this way, it would be equivalent to about 70 pounds of coal per ton of lime produced.

This saving of heat, however, is very insignificant when compared to the saving of time and labor effected by drawing the lime cold. When a lined cooler is used and the lime comes out hot, it must be dumped on the floor, cooled for several hours, and rehandled. If drawn cold, it can be dumped directly into the car for shipment, thus doing away with the cooling floor and diminishing the work of drawing and handling.

There are three devices in general use for drawing the lime. These are distributed among the kilns examined as follows: "Side-draw doors," 48; "center-draw doors," 19; "shears," 93. In constructing a side-draw door one side of the cooler is built vertical, and the doorway is cut near the bottom of this side. This method has the grave disadvantage that it tends to draw the lime from that side of the kiln under which the door is placed. Consequently, the stone passes through the kiln faster on that side and it is hard to maintain a uniform quality of product. This difficulty has been realized, so side-draw doors are fast becoming obsolete. Center-draw doors are placed near the bottom of one side of a cooler, all of whose sides slope in. Thus, the door is very nearly under the center of the kiln, and the difficulty experienced with side-draw doors is overcome. When shears are used, the opening is in the bottom of a cooler of which all sides slope inward. The opening, therefore, is under the center of the kiln. The shears themselves are two semicircular steel plates of such a size that they will cover the opening when their diameters are brought together. One end of the diameter of each is fastened by a pivot to the cooler. The other end is provided with a handle by which the two plates can be operated somewhat in the manner of ordinary shears.

2. FIRE BOXES

The fire box, or furnace in which the fuel is burned in limekilns, is very similar in purpose and construction to those commonly used under boilers. It consists essentially of a grate surface spanned by an arch of fire brick, closed in front by a door, and opening into the kiln in the rear. There may or may not be a "dead plate" of solid cast iron in front of the grates. In limekiln practice it is customary to construct a "bridge wall" at the inner end of the grates and extending 6 inches or 1 foot above them. A pillar is sometimes put in, extending vertically from the center of the bridge wall to the arch.

The principles of construction of fire boxes have been worked out by experience in boiler practice, and they are in the main applicable to limekilns as well. Of these principles the following may be noted:

The area of the grates should be designed with regard to the quantity and quality of coal to be burned on them and the amount of the draft. It is customary to allow 1 square foot of grate surface for from 12 to 15 pounds of bituminous coal per hour. It is better to make the area too large than too small, for with a high rate of combustion there is some tendency to overburn the lime. In all kilns except those in which the shafts slope outward, to prevent loss of heat by radiation, it is the practice to build the fire boxes inside the casings. Consequently, the depth of the fire box is limited by the thickness of the kiln wall. The arch should be high enough to give plenty of room for the combustion of the gases given off from the coal, and during operation the arch should be kept hot to avoid any possibility of chilling the gases and preventing their ignition.

In order to keep the arch hot the fire door should fit fairly closely. With some grades of coal it seems necessary to admit a little air through the door to insure complete combustion, but the amount should never be large enough to cool the arch. When forced draft is used there is some tendency for the flames to come out through the door, causing high repair cost. This can generally be remedied by proper regulation of the draft. The doors should be wide enough so that all parts of the grates can be reached easily to prevent the occurrence of dead corners at the front of the fire box.

A large dead plate is necessary for burning gas coal when the coking system is used in firing. By this method the fresh coal is put on the dead plate and the gases are distilled off and forced to pass over the fire. When the coal is coked it is pushed back on the grates and a fresh charge put in its place.

The bridge wall is extended above the grate level, so that there will be no danger of pushing ashes back into the kiln, where they might fuse with the lime and impair its quality.

The pillar is intended to support the arch, but is not very successful in performing this function, for it is generally the first part of the kiln to burn out. It does, however, tend to prevent the lime from falling into the fire box by partly closing the opening into the kiln.

Fire boxes for burning wood are similar in every respect to those in which coal is used, except that they are somewhat larger.

The following are the more important dimensions of the fire boxes in the kilns visited:

Dimension	Maximum	Minimum	Average
	Ft. in.	Ft. in.	Ft. in.
Height from grates to top of arch	3 0	1 6	2 4
Depth (including dead plate and bridge wall)	7 9	3 0	4 10
Width	6 0	2 0	3 0
	Sq. ft.	Sq. ft.	Sq. ft.
Area of grates	25	6	11.5

F. METHOD AND TIME OF DRAWING AND SORTING THE LIME

There are some kilns still in use which have side-draw doors located at the ground level, so that the lime must be shoveled out. By far the majority of kilns, however, are built with the draw doors 3 or 4 feet above the floor. Iron barrows are pushed underneath and the lime is merely poked loose and allowed to fall into them.

Barrows or buggies are built in two sizes, to hold about 250 or 1000 pounds, respectively. The smaller size is similar to an ordinary wheelbarrow; the larger has two wheels and is dumped by removing the tailboard. The larger size is to be preferred since by its use a kiln can be drawn in less time.

If the lime is drawn cold, it may be loaded into the freight car immediately. If drawn hot, it must be cooled either by letting it stand in the barrows or by dumping it on the cooling floor. It is always desirable to construct the kiln so that the lime comes out cold, but if this is not practicable, the former method of cooling is the less laborious one.

Lime is sorted either while being drawn or when it is taken up from the cooling floor. The object of sorting is to remove all unburned stone or overburned lime. In some localities, also, the consumer requires that the fine stuff be taken out. This requirement is based on the opinion that the fine lime is air-slaked; a fallacy the untruth of which is rapidly being recognized. If the lime is to be sorted as drawn, the fine stuff can be taken out by grates in the bottom of the cooler. When a cooling floor is used the coarser stuff is generally removed by forking, leaving the fine stuff on the floor. Underburned stone and overburned lime can be distinguished from good lime by appearance. They can be picked out of the barrows while drawing or they may be dumped on the cooling floor with the lime and sorted when cold.

The time at which a kiln should be drawn depends upon the design of the kiln, the method of firing, the personal equation of the fireman, the quality of the stone, and the facilities for drawing. Therefore, an arbitrary interval is usually established between drawings at each plant, and very little experimental proof is at hand to show that the interval selected is the best for the conditions obtaining. Of the 160 kilns visited,

6 are drawn every 1 hour.
3 are drawn every 2 hours.
29 are drawn every 3 hours.
51 are drawn every 4 hours.
53 are drawn every 6 hours.
15 are drawn every 7 hours.
3 are drawn every 8 hours.

After the lime has been completely burned any further heating tends to impair its quality. The conclusion reached from this is that the lime should be kept moving through the kiln and drawn as frequently as possible. On the other hand, every time the drawing door is opened a large amount of cold air rushes into the kiln, causing a loss of heat. At many plants, especially where cooling floors are used, the facilities for drawing are such that it would be impracticable to draw much oftener than every three hours.

It is a well-known fact that every kiln has its individual method of operating, and that the same kiln works differently on different days. Consequently, where competent firemen are available it would perhaps be advisable to let them decide when a kiln should be drawn, just as they are now depended upon to say how much lime shall be taken out.

IV. HEAT UTILIZATION AND EFFICIENCY

A. FUELS

It is hardly within the scope of this paper to discuss the theory of combustion of fuel, so only those points will be noted which are of practical importance to lime manufacturers.

Of the 160 kilns visited, 27 are fired with wood, 104 with coal, 16 with coal and wood mixed, and 13 with producer gas.

Wood has long been recognized as the best fuel with which to burn lime, and is used wherever it can be obtained with any degree of economy. The number of such localities is rapidly growing smaller, so that the problem of using some other fuel is of increaseing importance. Experience has shown that wood gives a larger capacity and a better quality of lime, and requires less care in the operation of the kiln than coal. Therefore, the tendency of experiments with the latter fuel has been to modify the normal coal fire so that it will to some extent resemble the combustion of wood. A wood fire has three characteristics which distinguish it from a coal fire in its adaptability to lime burning. First its flame is longer. This enables the heat to penetrate farther toward the center of the shaft and creates a larger burning zone. Therefore, the capacity of the kiln is greater, and the lime tends to burn more evenly, causing less difficulty in the operation. The amount of water generated by burning wood is much greater than that from coal. The presence of this steam in the products of combustion lowers the temperature required for calcination,[13] and thus lengthens the burning zone and increases the capacity of the kiln. The flame from a wood fire is cooler than that from coal. This, in connection with the effect of the presence of steam, results in less danger of overburning and a better quality of product.

In all kilns where wood is burned natural draft has been found satisfactory.

The easiest way of modifying a coal fire so as to cause it to resemble the combustion of wood is to use a mixture of wood and coal. This works successfully wherever tried, but even the small amount of wood needed is not economically obtainable in many localities.

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[13] S. V. Peppel: Bulletin No. 4, Geological Survey of Ohio, p. 294, 1906.

Many lime manufacturers are, therefore, forced, much against their will, to use coal for their fuel supply. The reasons cited above show why the coal fire should be modified to resemble the wood fire, and it may also be added that in many instances the normal combustion of coal has proven distinctly unsatisfactory for the burning of lime. Experiments on modifying the fire have been mostly confined to different methods of producing the draft.

B. METHODS OF PRODUCING THE DRAFT

The following methods are in use at kilns visited: Natural draft; forced draft, caused by blowing steam under the grates; induced draft, created by a fan which draws the gas from the top of the kiln; and the Eldred process, according to which a fan takes the gas from the top of the kiln and forces as much of it as is required back under the grates. In order to determine the relative efficiencies of these processes a number of heat balances were made. For this purpose six plants were selected, each being typical of one method of burning coal. At each plant observations were made extending over 48 hours, in order to determine those factors which are necessary for the calculation of the fuel efficiency. From the data so obtained heat balances have been constructed which show (1) how much heat was put into the kiln and from what source it was derived; (2) how much of it was actually required and the purposes for which it was used; and (3) the quantity of heat lost and the manner in which it escaped. The "heat efficiency" is the ratio (expressed as per cent) of the heat used to the heat put in. The heat used is taken to include only the amount actually required for the calcination of the stone. Practically sufficient heat must also be supplied to raise the stone to the calcination temperature and to create sufficient draft to remove the gases evolved. Theoretically, however, the stone must be raised to temperature only once, successive charges of stone being heated by the cooling of the lime and gas from the first charge; and no draft is necessary where the pressure at which the reaction takes place is not limited. A less exact but more used method of expressing the heat efficiency is by means of the "fuel ratio." This is the ratio of the pounds of lime produced to the pounds of coal burned. The fuel ratios given have been made a little more accurate by using, not the actual pounds of coal as fired, but the pounds of coal equivalent to the total amount of heat put in. The figures are still of small value for the comparison of different plants, because variations in the stone will cause variations in the quantity of heat required to burn it, and different coals have different heating values. For this reason the "theoretical fuel ratio" has been calculated for each plant, in order to make allowances for the variations in the stone and coal. The plants selected all manufacture high calcium limes, but at the first plant a test was also made on a dolomitic lime for purposes of comparison. The capacity per kiln day depends on many factors, chief of which is the size of kiln. No attempt has been made to compare the capacities of the different plants, but the figures are given with the idea that they may throw some light on the cost of erection of the kiln.[14]

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[14] The following data are used in calculating the heat efficiencies. They are not to be regarded as scientifically accurate, but as approximations close enough for the work in hand:

Heat of combination

Carbon to carbon dioxide, 14 500 Btu per pound.
Carbon monoxide to carbon dioxide 4396 Btu per pound.

Heat of dissociation

Calcium carbonate to calcium oxide and carbon dioxide=772 Btu per pound.
Magnesium carbonate to magnesium oxide and carbon dioxide=464.3 Btu per pound.

Densities of gases at 760-mm pressure and 32° F

	Pounds per cubic foot	Cubic feet per pound		Pounds per cubic foot	Cubic feet per pound
Carbon dioxide	0.1226	8.15	Oxygen	0.0892	11.20
Carbon monoxide	.0780	12.81	Nitrogen	.0783	12.77
Sulphur dioxide	.1788	5.59	Steam (at 212° F)	.0379	26.36

Specific heats

Limestone	0.217	Water vapor	0.48
Lime	.217	Sulphur dioxide	.155
Carbon dioxide	.217	Oxygen	.217
Carbon monoxide	.248	Nitrogen	.244

It must be emphasized that neither the data measured nor the calculations made therefrom are more than approximate. This would be impossible to attain with our present methods of measuring the quantities involved and our knowledge of thermochemistry. It is possible, however, to obtain results sufficiently near the truth to be of practical value, and, while the calculations here given could be made more nearly exact in some cases, no additional information of practical value would be obtained thereby.

C. Results of Kiln Tests.

A preliminary survey of each plant indicated what data it was necessary to obtain in order to calculate the heat balance. One kiln was selected for the investigation which in the opinion of the foreman or superintendent was giving the most satisfactory results. Some of the data, such as the speed of the fan, size of steam nozzle, etc., were constant throughout the test and were determined once for all. Other data, such as the weight of the stone, lime, or coal, were determined at irregular intervals, governed by the time of charging, drawing, or firing. The data which were variable were determined once an hour for 48 hours, and the results were averaged in order to obtain the values used in the calculations.

The temperature of the air was measured by means of a thermometer; all other temperatures by means of a platinum-rhodium thermocouple. The gas analyses were made on the spot with an Orsat-Muencke gas analysis apparatus. The draft was measured by means of a water draft gauge, reading directly to hundredths of an inch. Wherever fans were driven electrically, it was possible to measure the actual power used by means of a wattmeter. In other cases the maker's rating was relied on and was changed to allow for the noted change of speed. Samples of stone, coal, and ash were collected and shipped to Pittsburgh for analysis. The stone was analyzed in the laboratory of this Bureau, under the direction of Mr. P. H. Bates; the coal and ash in the coal laboratory of the Bureau of Mines, under Mr. A. C. Fieldner.

With the exception of plants 1 and 6, the results are believed to give a fair comparison of the different kilns under normal working conditions. The results seem to indicate that plants 2 and 6 were not being run with the maximum efficiency of which their equipment is capable.

1. PLANT 1.—ROTARY KILN, FIRED WITH PRODUCER GAS.

Description of Plant.—The stone is brought from the quarry in cars, from which it is fed by hand into a gyratory crusher, which breaks it to about 1 inch and smaller. A bucket elevator takes it to a storage bin, whence it is delivered by gravity to a plunger which feeds it at a regular rate onto a belt conveyor. This delivers it to a bucket elevator which discharges into the upper end of the kiln. After passing through the kiln the lime drops into a rotary cooler. From this it drops onto a belt conveyor which takes it to a rotary screen. This screen is of about 3/8-inch mesh, and is used to sort out the core. The theory is that any pieces which have not been broken by their passage through the kiln and cooler so that they will go through this screen are not lime, but consist chiefly of granite or other impurities. The tailings of the screen are therefore thrown away. The lime passes through the screen into an automatically dumping bucket. This measures the lime and delivers it to a bucket elevator, which takes it to a storage bin for either hydration or shipment.

The coal is gasified in a Marten's gas producer. This is equipped with a hopper holding about enough coal for two hours' run, which feeds automatically into the producer. The draft is supplied by a steam jet. The pressure of the steam used is indicated by a gauge about 10 feet from the opening. The air for combustion of the gas is taken in through the rotary cooler. It is thus preheated by the waste heat from the lime and meets the gas at the entrance to the kiln.

The gases from the stone and the products of combustion pass from the upper end of the kiln through a dust collector and a water-tube boiler. They then divide into two parts. One part is permitted to escape through the "boiler stack"; the other is drawn through an economizer by a Sturtevant rotary blower and is blown out the "economizer stack."

A small amount of coal is fired directly on the grates of this water-tube boiler. The feed water is drawn from a storage pond by means of a feed-water pump, and is forced through a closed feed-water heater and an economizer before entering the boiler. The steam generated is used to furnish power for the entire plant.

Description of Tests.—This test was divided into two parts. Dolomite was burned during part one and calcite during part two. The plant does not show its maximum or even normal efficiency, because the kiln had just been relined and required to be heated up very slowly. Moreover, the locomotive which hauls the stone from the quarry was out of commission, so that the kiln had to be run below its normal capacity in order to prevent the supply of stone from giving out.

Samples of stone, coal, and ash were collected and shipped to Pittsburgh for analysis. The following readings were taken once an hour for 48 hours: Temperature of boiler feed water, taken by means of a thermometer suspended in the pond at the opening of the intake pipe; boiler pressure, read from the gauge on the boiler; strokes of feed-water pump, counted for five minutes; wheelbarrows of coal fired on the grates of the boiler; temperature of the external air; temperature of stack gases from boiler; temperature of stack gases from the economizer; number of hoppers of coal fed into producer; number of buckets of lime produced, counted for five minutes; pressure of steam blown into producer; analysis of stack gases from the boiler; analysis of stack gases from the economizer.

Analyses of Stone

	Dolomite	Calcite
	Per cent	Per cent
Silica (SiO_2)	0.51	2.95
Alumina (Al_2O_3)	.19	.75
Iron (Fe_2O_3)	.25	.20
Lime (CaO)	31.40	52.26
Magnesia (MgO)	20.86	1.62
Carbon dioxide (CO_2)	46.32	41.54
Water (H_2O)	.38	.61
Total	99.91	99.93
Calcium carbonate ($CaCO_3$)	56.07	93.32
Magnesium carbonate ($MgCO_3$)	43.81	3.40
Total solids, nonvolatile	53.21	57.78

Analyses of Coal

	Producer	Boiler
	Per cent	Per cent
Carbon (C)	77.94	74.55
Hydrogen (H)	5.31	4.98
Nitrogen (N)	1.61	1.45
Oxygen (O)	8.32	6.57
Sulphur (S)	1.19	.65
Ash	5.63	11.80
	100.00	100.00
Heating value (Btu per pound)	13,914	13,230

Combustible in Ash

—	0.29	17.42

Calculations.—The heat put into this kiln is derived from two sources—the coal fired in the producer and the coal fired under the boiler. Part of this is used for the actual burning of the lime, part of it to create the necessary draft, and part of it to produce the power required to run the machinery. Some of it is lost by permitting some of the combustible to escape with the ash of the coal, some of it is carried off by the hot stack gases, and the balance is lost by radiation and conduction. Another source of loss—the heat carried off by the lime as drawn—has been eliminated at this plant by cooling the lime to the temperature of the air before drawing it.

2. PLANT 2.—KILN USING ELDRED PROCESS

Description of Plant.—This plant comprises 10 vertical shaft kilns. The stone is fed into the top, each kiln being filled up once a day. The burned lime is drawn out of the bottom once every four hours. In general, the kilns are supposed to "follow down"; that is, the stone is supposed to feed down by gravity as the lime is drawn out. Sometimes they are "stuck" intentionally, in order to clean them out, and frequently they stick of their own accord. In this event it becomes necessary to knock the lime down by means of bars inserted through the fire boxes. Each kiln has two fire boxes, one on each side, into which coal is fed by hand. The gases produced are drawn from the tops of the kilns and returned according to the Eldred process. For this purpose three fans are used, each being driven by its own electric motor. One fan draws the gas from five kilns and blows it out a stack. Another draws it from the other five, delivers part of it under the grates of all 10, and blows the rest out a stack. The third supplies the air for all 10. Each fire box is thus supplied with a mixture of air and gas, the proportion of each being regulated by means of dampers. This gas is inert so far as combustion is concerned. As it passes through the hot fire it is heated and some of it may be decomposed. When it enters the kiln it is cooled and its constituents recombine. In this way it serves both mechanically and chemically to transfer the heat from the fire box into the kiln. Theoretically, therefore, the use of the Eldred process should lead to higher fuel efficiency and lower repair cost.

Description of Test.—The lime produced is drawn into iron buggies, each of which is weighed before being dumped on the cooling floor. The coal used is wheeled to the kilns in barrows which are filled to 200 pounds net weight from a storage hopper. The power used to run the fans was measured by a professional electrician. The test was conducted on one kiln only, so that the power measured will be divided by 10. The gas is delivered through an 8-inch pipe, and in order to estimate the quantity used its pressure, temperature, and analysis were taken. The data include also the temperature and analysis of the stack gases, the temperature of the air, and the temperature of the lime as drawn. Weight of coal taken each time a fresh lot was wheeled to the kiln. Weight and temperature of lime taken at each draw. Other readings taken once an hour for 48 hours. The pressure of the Eldred gas is the pressure due to its velocity. It was measured by inserting two ¾-inch pipes into the main. Each pipe ended in an elbow, one of which opened in the direction of the flow and the other in the opposite direction. These pipes were attached to the opposite ends of a draft gauge, so that the pressure indicated was the difference of pressure in the two pipes.

Analysis of Stone

	Per cent
Silica (SiO_2)	0.25
Alumina (Al_2O_3)	.03
Iron (Fe_2O_3)	.27
Lime (CaO)	45.77
Magnesia (MgO)	8.81
Carbon dioxide (CO_2)	44.06
Water (H_2O)	.97
	100.16
Calcium carbonate ($CaCO_3$)	81.73
Magnesium carbonate ($MgCO_3$)	18.50
Total solids (lime)	55.13

Analysis of Coal

Carbon (C)	73.10
Hydrogen (H)	4.85
Nitrogen (N)	1.46
Oxygen (O)	7.92
Sulphur (S)	1.32
Ash	11.35

Heating value, Btu per pound = 13 005.
Combustible in ash = 38.81 per cent.

Calculations.—The heat put in is derived from two sources: From the coal fired into the kiln, and the heat equivalent of the power required to run the fans. Some heat is recovered from the gas which is taken from the top of the kiln and delivered under the grates. Part of this heat is used to burn the lime. Part of it is used to create the draft. Some of it is lost by permitting some combustible matter to be removed with the ash of the fuel. Some of it is carried off by the hot lime. Some of it is carried off by the waste gases. The remainder is lost by radiation and conduction.

3. PLANT 3.—KILN USING THE SCHMATOLLA SYSTEM

Description of Plant.—This plant comprises three vertical shaft kilns. The stone is charged in through a door in the top at frequent intervals, the aim being to keep the kiln nearly full all the time. The lime is drawn from the bottom every three or four hours. The kilns generally "follow down," that is, the stone feeds down by gravity as the lime is drawn out. They do "stick" occasionally, but this is not intentional. The coal used is charged from a storage hopper into a Wood gas producer. Each kiln has its own hopper and producer. The draft for the producer is furnished by an electrically driven fan, one fan for the three producers. Water is fed into a compartment on top of the producer where it serves to cool and protect the top. The steam generated is carried into the producer by the air. The air required for combustion of the producer gas is admitted through the bottom of the kiln. It comes up in contact with the hot lime, and meets the gas in the interior of the kiln. The products of combustion are drawn from the top of the kiln by an electrically driven fan, one fan for each kiln.

This plant is said to be run according to the Schmatolla system because of the method of admitting the air used for combustion. The forced draft into the producer and the induced draft from the top of the kilns are at variance with the Schmatolla system as generally understood.

Description of Tests.—The weight of the coal was determined as follows: The dimensions of the hopper being known, its volume can be calculated. The average weight of a cubic foot of coal was actually determined, so that the weight of a hopper full can be calculated. The hopper was filled to the top at the start, and was emptied completely. Coal was then wheeled to the hopper in barrows, the net weight and the number of the barrows being recorded. At the end the distance from the top of the hopper to the top of the coal in the hopper was measured. The weight of the stone can be calculated from the average net weight of a car and the number of cars. The power required to run the fans is taken from figures furnished by the company, which we believe to be reasonably accurate. The power used by the fan supplying air to the producers must be divided by three, because it supplies all three producers. The weight of water fed into the producer was determined by diverting the stream into a bucket for one minute and weighing the amount collected.

Analysis of Stone

	Per cent
Silica (SiO_2)	1.08
Alumina (Al_2O_3)	.50
Lime (CaO)	54.00
Iron (Fe_2O_3)	.19
Magnesia (MgO)	1.13
Carbon dioxide (CO_2)	42.57
Water (H_2O)	.62
	100.09
Calcium carbonate ($CaCO_3$)	96.43
Magnesium carbonate ($MgCO_3$)	2.37
Total solids (lime)	56.90

Analysis of Coal

Carbon (C)	78.22
Hydrogen (H)	5.45
Nitrogen (N)	1.78
Oxygen (O)	7.75
Sulphur (S)	1.13
Ash	5.67

Heating value, Btu per pound=14 004 Btu.
Combustible in ash=9.73 per cent.

Calculations.—The total amount of heat is derived from two sources: From the coal charged into the producer and from the heat equivalent of the power required to run the fans. It is used to burn the lime and to create the draft. Part of it is lost by permitting combustible to be taken out with the ash from the fuel, and by drawing the lime hot. Part of it is carried off by the stack gases, and the remainder is lost by radiation and conduction.

4. PLANT 4.—KILN USING FORCED AND INDUCED DRAFT

Description of Plant.—This plant comprises five vertical shaft kilns. The stone is charged in through a door at the top at frequent intervals so that the kiln is kept nearly full. The lime is drawn out at the bottom every six hours. The kiln is "stuck" intentionally at every draw; that is, the stone does not feed down by gravity as the lime is drawn out, but is made to arch over and support its own weight until it is knocked down with bars. It is claimed that by the use of this method the kiln can be kept in better shape and a better quality of lime can be produced. Each kiln is provided with two fire boxes, into which coal is fired by hand. Steam is admitted under each grate. This acts in a manner similar to the Eldred gas to carry the heat from the fire box into the kiln, and has an additional advantage in that it prevents clinkers from forming on the grate bars. The products of combustion are removed from the top of the kiln by means of a rotary blower, which is directly connected to a steam engine. This blower furnishes the exhaust for all five kilns.

Description of Tests.—Each car of stone charged into the kiln was weighed. The weight of coal was determined by filling a bin with a known weight, using coal from this bin only, and weighing the amount left at the end of the test. The pressure of the steam used was measured by a gauge about 4 feet from the nozzle. The draft (of the exhaust) was measured by means of a draft gauge attached to the main leading from the top of the kiln to the fan. The zero reading was taken each time to correct for variations in temperature.

Analysis of Stone

	Per cent
Silica (SiO_2)	0.32
Alumina (Al_2O_3)	.23
Iron (Fe_2O_3)	.12
Lime (CaO)	54.99
Magnesia (MgO)	.65
Carbon dioxide (CO_2)	43.34
Water (H_2O)	.26
	99.91
Calcium carbonate ($CaCO_3$)	98.20
Magnesium carbonate ($MgCO_3$)	1.37
Total solids (lime)	56.31

Analysis of Coal

Carbon (C)	73.98
Hydrogen (H)	5.19
Nitrogen (N)	1.52
Oxygen (O)	7.64
Sulphur (S)	1.57
Ash	10.10

Heating value, Btu per pound=13 259 Btu.
Combustible in ash, 28.09 per cent.

Calculations.—The heat used in this kiln is derived from three sources: The coal fired into the kiln, the heat equivalent of the power required to run the fan, and the heat required to generate the steam used. This heat is used to burn the lime, and to create the draft. Part of it is lost, due to combustible in the ash. Part of it is carried off by the hot lime, and part of it by the stack gases. The remainder is lost by conduction and radiation.

5. PLANT 5.—KILN USING NATURAL DRAFT

Description of Plant.—This plant consists of six vertical shaft kilns. The stone is charged in at the top, each kiln being filled up immediately after the lime is drawn, day or night. The lime is drawn out at the bottom about every three hours. The kilns are designed and operated so that the stone will follow down by gravity as the lime is drawn out. The kilns will "stick" or arch over occasionally, however, and sometimes they are made to stick intentionally in order to clean them out. The kiln tested is equipped with four fire boxes, located one on each of the four sides. Coal is fired into these by hand. The natural draft is augmented by the use of stacks on top of the kilns.

Description of Test.—The lime was drawn into iron barrows which were wheeled to the scales. Sufficient lime was added or taken off to bring the net weight to a definite figure. The number of barrows was tallied by an automatic counter attached to the scales. A number of barrows of coal of known weight were dumped into an empty bin. The coal used during the test was taken from this bin, and the quantity remaining at the end of the test was wheeled out again and measured.

Analysis of Stone

	Per cent
Silica (SiO_2)	0.15
Alumina (Al_2O_3)	.14
Iron (Fe_2O_3)	.14
Lime (CaO)	55.17
Magnesia (MgO)	.37
Carbon dioxide (CO_2)	43.52
Water (H_2O)	.45
	99.94
Calcium carbonate ($CaCO_3$)	98.52
Magnesium carbonate ($MgCO_3$)	.78
Total solids (lime)	55.97

Analysis of Coal.

	Per cent
Hydrogen	5.07
Carbon	72.72
Nitrogen	1.87
Oxygen	11.11
Sulphur	.88
Ash	8.35
	100.00

Heating value of coal=12 980 Btu per pound.
Combustible in ash=36.05 per cent.

Calculations.—All of the heat used was derived from the coal fired. This heat was used for burning the lime and creating the draft. Part of it was lost, due to combustible in the ash. Part of it was carried off by the lime as drawn. Part of it was carried off by the waste gases, and the balance was lost by radiation and conduction. It is considered that the heat carried off by the waste gases is utilized in creating the draft.

6. PLANT 6.—KILN USING PRODUCER GAS

This plant consists of eight vertical shaft kilns, only three of which were in operation. The stone is charged in at the top at irregular intervals, the kilns being kept fairly well filled. The lime is drawn out at the bottom about every three hours. The stone is supposed to follow down as the lime is drawn out, but it sticks occasionally, and is sometimes made to stick in order that the kiln may be cleaned out. The eight kilns are supplied with fuel by three Duff gas producers, only one being in operation during the test. These producers are located at a considerable distance from the kilns, giving rise to a possibly large loss by radiation from the mains, which may cool the gas to such an extent that it would become difficult to control its combustion. Each producer is run under forced draft, created by means of a steam jet, which draws in the necessary air. The gas enters the kiln through four ports. The air required for combustion is furnished by a blower and is mixed with the gas just as it enters the kiln. All of the air valves were open during the test, so that the fan was supplying sufficient air for eight kilns.

Description of Test.—The figures of the company, covering a period of several years, have led to fairly accurate determinations of the average net weight of a shovelful of coal and a barrow of lime. These factors, therefore, were used in determining the weights of coal and lime, by merely counting the shovels and barrows, respectively. The pressure of the steam blown into the producer was read from a recording gauge. Unfortunately, however, this gauge was about 30 feet from the nozzle, and there were three reductions and three bends between the gauge and the nozzle. The loss of pressure due to this resistance must, therefore, be calculated. A pressure gauge attached close to the nozzle indicated about 65 pounds, but this gauge was known to be inaccurate. However, a calculation of the drop in pressure of steam flowing through this pipe shows that the loss would not be over 1 pound. This may be neglected and the pressure on the nozzle will be taken as that read on the recording gauge.

The temperature of the air was taken inside of the kiln house, which explains why the stack gases were apparently cooler than the air. This test can hardly be considered fair to the plant, because the kind of stone used during the test furnishes only about 5 per cent of the total annual output of the plant. The stone generally used is said to give a larger capacity with the same amount of fuel. The bell of the gas producer burned out during the test and had to be replaced. This necessitated shutting down the plant for a short while and resulted in the loss of one draw of lime.

Analysis of Stone

	Per cent
Silica (SiO_2)	0.13
Alumina (Al_2O_3)	.21
Iron (Fe_2O_3)	.19
Lime (CaO)	51.85
Magnesia (MgO)	3.42
Carbon dioxide (CO_2)	43.88
Water (H_2O)	.28
	99.96
Calcium carbonate ($CaCO_3$)	92.59
Magnesium carbonate ($MgCO_3$)	7.18
Total solids (lime)	55.80

Analysis of Coal

	Per cent
Hydrogen	4.81
Carbon	70.29
Nitrogen	1.27
Oxygen	7.42
Sulphur	1.12
Ash	15.09
	100.00

Heating value of coal=12 461 B t u per pound.
Combustible in ash=44.38 per cent.

Calculations.—The heat put into the system is derived from three sources: From the coal charged into the producer, from the steam blown into the producer, and the heat equivalent of the power required to run the fan. It is used to burn the lime and to create the draft. Part of it is lost due to the combustible in the ash. Part of it is carried off by the hot lime. Part of it is carried off by the stack gases. The remainder is lost by conduction and radiation.

Summary of Heat Balances

Number	1 (using dolomite)		1 (using calcite)		2		3		4		5		6	
Process used	Rotary kiln		Rotary kiln		Eldred process		Schmatolla process		Forced and induced draft		Natural draft		Producer gas	
	Millions of Btu	Per cent	Millions of Btu	Per cent	Millions of Btu	Per cent	Millions of Btu	Per cent	Millions of Btu	Per cent	Millions of Btu	Per cent	Millions of Btu	Per cent
Heat put in:														
1. From coal fired	[17] 209.0 [18] 61.9	100.0	[17] 139.0 [18] 28.6	100.0	146.0	99.9	531.0	99.6	148.0	95.5	208.0	100.0	157.0	99.3
2. From power for fans	0	0	0	0	0.17	0.1	1.9	0.4	0.1	0.1	0	0	.03	0.0
3. From steam blown in	0	0	0	0	0	0	0	0	6.7	4.4	0	0	[17] 1.0	0.7
Heat used:														
4. To burn the lime	101.0	37.2	64.1	38.2	56.0	38.3	288.0	54.0	68.4	44.1	64.3	30.9	55.7	35.3
5. To create the draft	20.6	7.6	14.4	8.6	0.17	0.1	1.9	0.4	6.8	4.4	31.7	15.2	1.1	0.7
6. For power	33.5	12.4	19.8	11.7	0	0	0	0	0	0	0	0	0	0
Heat lost:														
7. By combustible in ash	1.7	0.6	0.8	0.5	11.7	8.0	3.3	0.6	6.4	4.1	10.9	5.2	21.8	13.8
8. By hot lime	0	0	0	0	0.68	0.5	5.4	1.0	12.4	8.0	1.8	0.9	1.55	1.0
9. By stack gases	49.6	18.3	22.0	13.1	35.8	24.5	122.0	22.9	37.3	24.1	3.7	1.8	20.9	13.2
10. By radiation and conduction (by difference)	64.6	23.9	46.9	27.9	41.8	28.6	112.0	21.1	23.7	15.3	95.5	46.0	57.0	36.0
Heat efficiency	....	37.2	....	38.2	....	38.3	....	54.0	....	44.1	....	30.9	....	35.3
Fuel ratio:														
Theoretical	11.4		10.7		9.85		10.45		9.74		9.45		9.25	
Actual	4.27		4.10		3.78		5.65		4.29		2.92		3.27	
Capacity (tons per kiln per day)	31.5		31.5		10.6		53.8		12.6		11.7		10.4	

[17] In producer.

[18] Under boiler.

7. SUMMARY

Attention should be called to the following points: The efficiency is in all cases calculated as the ratio (expressed in per cent) of the heat actually used to burn the lime, divided by the heat put in, from the coal burned, the power to run the fans, and the steam blown in. The power used to run the fans has been calculated as the actual power used by the fans. No allowance has been made for losses in generating or transmitting this power, for these can not fairly be charged against the kiln. The method of calculating the heat balance credits the kiln with all the heat used, but does not consider whether or not the use of it was necessary. For this reason a fair idea of the economy of operation can be obtained only when the efficiency, heat balance, and fuel ratio are considered in conjunction with the working conditions.

With this idea in view it may be profitable to criticise several of the items separately.

Heat in the lime after burning: Some of this is recovered and some is lost (item 8). In plant 4 a large part of this heat is lost because the lime is drawn too hot. Most of it is recovered in other plants—all of it in plant 1. It should be remembered, however, that there is little advantage to be gained by recovering this heat and then losing it in some other way. In plants 2, 5, and 6 it is not even put back into the kiln, but is recovered only to be lost immediately by radiation. It can be used to preheat the air either by taking the air directly through the lime, as in plants 1 and 3, or through pipes surrounding it, as in plant 5.

Heat in the stack gases: Some of this is recovered, some is used before it escapes (items 5 and 6), and some of it is lost (item 9). The only method for the recovery of this heat which was seen in operation consists of introducing some of the waste gases under the grates of the kiln according to the Eldred process (plant 2). This method is not very satisfactory from a standpoint of efficiency, because not all of the gas is used; there is a chance for loss of heat by radiation from the pipes through which the gas is conveyed, and there is no assurance that the heat recovered will be used instead of being lost again. Another method of utilization of this heat is by passing it through a boiler and generating power.

At plant 1 this power is used to operate the kiln and its accompanying crushers, conveyors, etc., so that it is included in the heat used. If, however, the power were used for some purpose not directly connected with the kiln, as would necessarily be the case in the ordinary type of shaft kiln, the recovery of this heat could not be credited to the kiln, but would increase the economy of operation of the plant as a whole. In any event it could have no influence on the fuel ratio. Some of this heat might also be used to create the draft, as in plant 5, and the use of it for this purpose must be credited to the kiln. However, it is evident from the figures that natural draft requires the expenditure of more heat than any kind of mechanical draft. That is, more heat is used for this purpose in plant 5 than is necessary, which accounts in part for the observed low fuel ratio. It should also be noted that when the gas is removed by a fan it makes very little difference in the power required whether the gas is hot or cold, and that therefore any heat carried off by gas removed in this manner must be figured as lost and included in item 9. From the above considerations it is probable that the most efficient method of handling this gas would be to build the kiln high enough so that practically all of the heat of the gas is imparted to the stone before it leaves the kiln, and then draw the gas off by means of a fan. This method would tend to give a high efficiency and also a high fuel ratio.

It will be noted that steam is used to create the draft in plants 1, 3, 4, and 6, and that the heat used for this purpose in each of these plants is greater than in plant 2, where fans alone are used. From the data obtained the pounds of steam used per pound of lime burned may be calculated as follows: Plant 1, 0.21; plant 3, 0.14; plant 4, 0.12; plant 6, 0.02. However, this steam serves other purposes besides creating the draft; it may be used to increase the capacity, lower the repair cost, or reduce the labor by keeping the grate bars free from clinkers. While, therefore, a reduction of the amount of steam used might increase the fuel ratio, it might also decrease the economy of the plant, and care should be taken to note all the effects of any change.

With good capacity and careful firing the loss of heat due to combustible in the ash should be very small; by the use of a good gas producer it should be reduced to a minimum. This seems to be the case in plants 1 and 3. The high figure shown in plant 6 can be accounted for only by assuming that the producer was pushed too hard in order to supply sufficient gas for three kilns.

The heat lost by radiation and conduction may be considered as emanating from three parts of the kiln: The gas main or fire box, the bottom of the kiln where the lime is permitted to cool after being burned, and the shaft of the kiln. A study of the designs of the various kilns shows that the following methods should tend to reduce the amount of heat lost in this manner. The gas main leading from the producer to the kiln should be short (as in plants 1 and 3) or should be insulated. The comparatively poor gas which it is necessary to use for burning lime carries a large part of its energy as sensible heat, and the loss of this heat can be prevented only by introducing the gas into the kiln at the same temperature at which it leaves the producer. Fire boxes will show less loss by radiation when built within the shell of the kiln as in plant 4, rather than externally as in plants 2 and 5. A large part of the heat contained in the lime after it is burned will be lost by radiation before the lime is drawn out of the kiln unless means are supplied by which this heat can be recovered and used, as in plants 1, 3, and 5. Unless the kiln wall is extraordinarily thin, as in plant 1, or the temperature used extraordinarily high, as in plant 5, the loss by radiation from the shaft of the kiln seems to be very small. This can be still further reduced by increasing the diameter of the kiln, as in plant 3.

In conclusion, it must be emphasized that the heat efficiency is only one item of the total plant economy. The cost of labor, the ratio of capacity to investment, and the quality of the product must also be considered. Therefore, merely because the figures show plant 3 to have the highest heat efficiency, would be no reason for stating that it is the most economical plant.

In the light of the facts brought out by the above heat balances, a theoretical discussion of the different methods of producing the draft may not be out of place.

Natural draft, by the use of stacks, can be made sufficient to give good capacity. However, there is grave danger of overburning, for with strong draft the flame may be short and hot.

Conditions may easily arise which will force the products of combustion down into the cooler, thus causing recarbonation. Since there is no means of controlling the pressure of gas over the fire, every time the fire door is opened cold air rushes in, which may cause a loss of heat and may increase the repair cost.

The practice of blowing steam under the grates is obviously one method of introducing the moisture obtained by burning wood. But water content does more than lower the calcination temperature. Part of it is undoubtedly dissociated into its elements while passing through the hot fire. This dissociation takes up heat, which is later given out in the kiln where the elements recombine. Consequently, the use of steam tends to cool the fire and produce a longer flame, both highly desirable objects to lime burners. On account of the cooler fire and lower calcination temperature, the capacity of the kiln may be increased with less danger of overburning than when natural draft is used. The forced draft under the grates permits of regulating the pressure above the fire, and therefore the fire door may be opened without admitting enough air to influence the efficiency or repair cost of the kiln. Forced draft does not, however, prevent the products of combustion from going down into the cooler.

This danger of recarbonating the lime can be eliminated by the use of induced draft. When used alone, however, the characteristics of the fire produced by this type of draft have all the disadvantages of a normal coal fire. Since induced draft is created by a fan, any heat carried off by the waste gasses is a total loss.

In many kilns a combination of forced and induced draft is used with very good results. The induced draft prevents recarbonation of the lime by removing the carbon dioxide as fast as formed. The forced draft by means of the steam jet gives a cooler fire and longer flame, and also permits control of the gas pressure over the fire. Owing to the lower calcination temperature and the greater rapidity of combustion attainable, this method should give the maximum kiln capacity.

Another method of combining the forced and induced draft is according to the Eldred process. The mechanical equipment for operating this process may be designed along various lines, one method being shown in Fig. 7. For maximum economy, the top of the kiln should be closed air tight, and all the gas should be removed by the fan, as in creating induced draft. This fan should

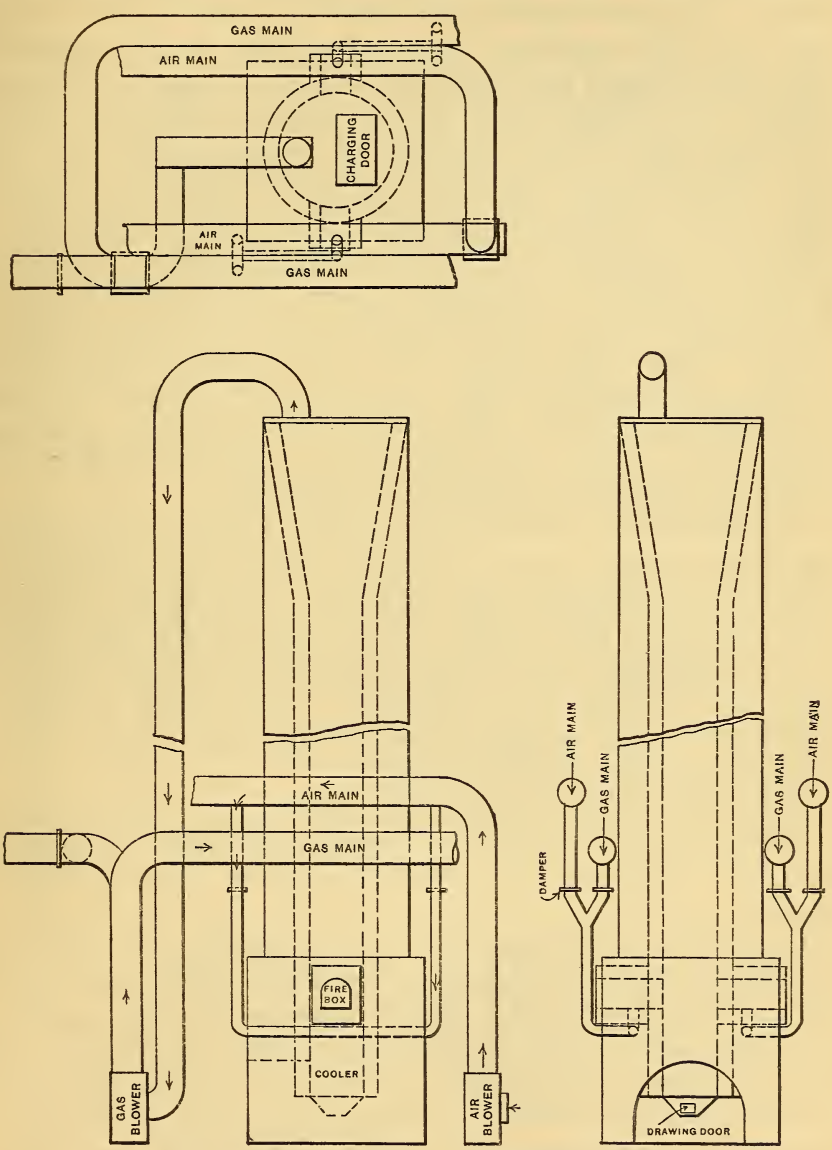

Fig. 7.—*Mechanical Arrangement of Eldred Process*

deliver as much gas as needed under the grates, and should blow the remainder out through a stack. Separate and fairly accurate means of controlling the supply of both air and gas should be provided, and the induced draft created by the fan should be entirely independent of the amount of gas used for the forced draft. As thus installed, many advantages of the combined forced and induced draft may be obtained by using the Eldred process. The induced draft tends to prevent recarbonation and the forced draft permits regulation of the gas pressure over the fire. The fire is kept cool by diluting the air with carbon dioxide taken from the kiln, thus causing a slower rate of combustion. This carbon dioxide also aids by mechanically carrying heat from the fire into the kiln. Moreover, it may act chemically to some extent, since some of it may be reduced to carbon monoxide while passing through the hot fire. This reduction absorbs heat from the fire and liberates it again when the carbon monoxide burns in the kiln, in a manner similar to the action of steam. Carbon dioxide does not serve the same purpose as steam. however, for it does not lower the temperature of calcination.

In comparing the two methods—steam and induced draft versus the Eldred process—it must be noted that they both produce a cool fire by mechanically and chemically transferring the heat from the fire box into the kiln. The former method gives a high rate of combustion and a lower calcination temperature, both of which tend to increase the capacity. Owing to lack of oxygen the Eldred process causes the coal to burn more slowly. This would tend to give a lower capacity.

Of the kilns visited 105 burn coal, and for 31 of these the draft is natural; for 25 it is forced, by blowing steam under the grates; for 14 it is forced and induced; and for 35 the Eldred process is used.

In general it may be said that the best method to be used for creating the draft depends on local conditions, chiefly the kind of stone. Thus, if the stone is difficult to overburn, a high capacity and good quality of lime may be obtained with natural draft. If there is danger of overburning the forced and induced draft will probably give good results. If there is great danger of overburning or if the lime is apt to act as a flux on the lining, the Eldred process may be used to obtain a good quality of product and keep the repair cost within reasonable limits.

D. COMPARISON OF COMBUSTION ECONOMY

1. DIRECT COMBUSTION

There has as yet been no mechanical stoker perfected which can be adapted to limekiln practice, so hand firing must be relied upon exclusively. What is known as the coking system of firing has given very good results wherever tried. By this method the green coal is put on a dead plate just inside the fire door, left there until coked, and then pushed back and replaced by a fresh charge. The gases distilled from the coal must pass between the fire and the arch and meet with a large amount of air coming through the burned coal at the rear of the fire box. Hence, complete combustion is practically assured. Whether this method is used or not, the economical combustion of gas coal requires that the coal be fired frequently and in small amounts. However, this requires more labor than firing larger amounts at longer intervals, and it is a question of local conditions whether or not the saving of coal would pay for the increased labor.

The heat lost in the waste gases may be increased by two means: The admission of excess air, or incomplete combustion of the fuel. Of course, it is impossible to regulate the air to exactly the theoretical amount, and it is always better to have too much than not enough. Incomplete combustion may be caused by not having enough air, or by chilling the gases distilled from the coal below their ignition point. To prevent this latter occurrence, the arch of the fire box must be kept hot, and no more air than necessary should be admitted over the fire. In order to overcome these losses of heat the stack gases should be watched closely. If possible, the firing should be adjusted according to gas analyses. If this is not practicable, their appearance is a fair indication of their composition. If they are perfectly colorless, it is safe to assume that too much air is being admitted; if black and smoky, the combustion will generally be found to be incomplete. The greatest economy seems to be obtained when the gases have a rather dark gray appearance.

When a fire is cleaned it is bad practice to draw it completely, since this admits a large quantity of cold air into the kiln and causes a considerable loss of heat. There is a method in use in boiler practice by which one side of a fire is cleaned at a time. This process could be used to advantage by lime burners.

In the preceding discussion of draft, stress was laid on the fact that with forced draft the pressure of the gas over the fire may be regulated. The idea in this is to use forced draft of just sufficient strength to force the air through the fire, and induced or natural draft of a strength very little more than sufficient to pull it into the kiln. By this means the pressure of the gas over the fire may be made very nearly equal to atmospheric pressure. Therefore when the fire door is opened the quantity of air admitted is very small. However, this method causes a slower rate of combustion and lowers the capacity of the kiln, unless the draft could be increased directly after firing and again checked during firing.

2. GAS PRODUCERS

Instead of modifying the draft to make a coal fire resemble the combustion of wood the coal itself may be modified by converting it into producer gas. The claim for the greater economy of gas producers is based on the lower labor cost and the greater convenience and adaptability of the gas. By adaptability is meant that the fire can be placed where wanted. This is especially important in limekilns, where coal must be burned in external fire boxes, while the gas can be introduced directly into the kiln itself.

All of the producers seen generate mixed gas, consisting of the products of distillation, carbon monoxide, and water gas. Air is blown through the bed of coal by a steam jet. In such producers, the heat of the coal is used up in four ways, namely, the reduction of the carbon dioxide formed to carbon monoxide, the decomposition of the steam, the distillation of the hydrocarbons from the coal, and raising the temperature of the gas. When the gas is burned the hydrogen and carbon monoxide liberate the exact amount of heat taken up by their formation. This, together with the heat generated by combustion of the hydrocarbons, may be called the "potential" heat of the gas. It is evident from the definition that a gas must have practically the same potential heat at the kiln that it had when leaving the producer, but the amount of sensible heat retained depends entirely on the chances for loss by radiation. Therefore, it is imperative to have the producer as near the kiln as possible, and to have all gas mains well insulated. Of course, the higher the proportion of noncombustibles in the gas the greater will be the sensible heat in proportion to the potential heat and the more carefully must loss be guarded against. In limekiln practice it has been found that a rich gas (one high in combustibles) gives too hot a fire with too great danger of overburning the lime. Therefore, a gas with a large proportion of noncombustibles should be used, and care should be taken to prevent the loss of sensible heat. Another reason for keeping the gas hot is to prevent condensation of the hydrocarbons. These have a high heating value, and the loss of even a small amount of them should not be permitted. It is evident that if the gas is kept hot enough to prevent condensation of the hydrocarbons the potential heat is independent of the temperature; also if the gas enters the kiln at the same temperature at which it leaves the producer the loss of sensible heat will be zero. It should be possible, therefore, to design a plant so that the use of a poor gas instead of a rich one should make practically no difference in the efficiency of transmission of heat from producer to kiln.

It is customary to mix the gas with air just as it enters the kiln, thus producing combustion in direct contact with the stone. The gas is blown in by forced draft, and steam is one of the chief products of combustion. These considerations indicate that in a gas-fired kiln it should be possible to force the flame farther toward the center, the burning zone should be longer, and the calcination temperature should be lower. Consequently, the kiln should have a larger capacity and should produce a better quality of lime. For a large plant the labor cost should be less. There is, however, the danger of recarbonation, which occurs wherever forced draft alone is used. Care must be taken not to blow in the gas and air so fast that the products of combustion will have any tendency to go down into the cooler.

Gas producers have one decided advantage over methods of direct firing, as a much cheaper fuel may be used, and while the coal must be low in sulphur to prevent corrosion of the iron, it may be higher in ash and have a lower heating value than the grade of coal economical for direct firing.

Producers may be obtained which are supplied with a device for automatically and continuously feeding the coal and removing the ashes. The fuel bed revolves, so that its depth is kept uniform. Such a producer would cost more to install than the types generally used and would require a small amount of power for its operation. These economic difficulties may be more than counterbalanced by the saving in labor and the production of a uniform quality of gas. This last point is of especial importance to lime manufacturers.

If the plant is properly designed, with especial regard to preventing any loss of heat by radiation, and is run by a competent fireman, so that the gas is not too rich, is not blown in too fast, and is mixed with very nearly the theoretical amount of air, the use of a gas producer should prove at least as economical as any method of direct firing of coal.

V. PROCESS OF MANUFACTURE OF HYDRATED LIME

In the manufacture of hydrated lime the following stages must be considered, starting with the burnt product as it comes from the kilns: *Crushing*, *hydrating*, *screening*, and *packing*.

The object of crushing the product is to produce a larger surface for the action of the water, and, moreover, large lumps would be rather unwieldy in the hydrator.

After crushing, the lime is fed into the hydrator. Here it is mixed with the correct amount of water and agitated till the reaction is complete.

It comes from the hydrator as a fine dry powder, which must be screened to remove any core or overburned lime that would not slake.

From the screens it goes to the storage bins, where, if the capacity is available, it is deemed advisable to let it age for 30 days. Aging is not of particular importance if sufficient care has been used during the hydration.

Finally, it is fed into the packing machine which puts it into bags for shipment

The equipment generally includes two elevators, one to take the lime from the crusher to the bin over the hydrator, and one to take the hydrated lime from the hydrator to the storage bin.

Most mills also include a machine for grinding the tailings from the screens. This material consists of unburned stone, overburned lime, lime which is not completely hydrated, and even pieces of brick and coal ashes. When ground it can be sold for fertilizer, but certainly should never be called hydrated lime.

A. CRUSHING THE LIME

One reason for crushing the lime is that it will lessen the time of slaking and increase the capacity of the hydrator. It is obvious that the less porous a lime is and the more magnesia it contains, the more finely should it be crushed.

Another reason for crushing the lime is that large lumps would be unwieldy in the hydrator. In this the lime and water must be agitated with some form of paddle. By using small pieces of lime a thorough mixture can be obtained more easily, and it is also easier to determine when sufficient water has been added.

A Gates gyratory crusher is generally used for crushing lime. This machine can be obtained in various sizes to suit the requirements of the plant. The size of the crushed lime at most plants is about 1 inch, although in some cases it is crushed as fine as 10 mesh

B. HYDRATORS

The actual slaking of the lime takes place in an apparatus called the hydrator. Theoretically, the only function it has to perform is to mix the lime and water thoroughly and quickly, to prevent burning the lime by local overheating. Just what happens when lime "burns" during slaking is not very well understood. If a lump of lime is given enough water to start hydration but not enough to complete the process, the unslaked portion will "burn" and become practically useless. The phenomenon is probably due to some change in the physical condition of the lime caused by the concentrated heat. It is, therefore, absolutely necessary that sufficient water be added and that it shall be mixed with the lime very thoroughly and quickly

Of the 11 hydrate plants visited, 7 are equipped with Clyde hydrators, 2 with modifications af this machine, and 2 with Kritzer hydrators.

The Clyde and Kritzer hydrators differ essentially in that the former is intermittent and the latter continuous in its operation.

The Clyde hydrator consists of a circular iron pan large enough to hold about 1½ tons of hydrated lime, and capable of revolving horizontally. Suspended in the center of this pan is a fixed shaft with arms radiating from its lower end. These arms carry plows, which scrape the bottom of the pan, and are arranged in a horizontal spiral, so that every part of the pan is touched at least once each revolution. The whole machine is surmounted by a hood and stack to carry the dust out of the building.

In operating a Clyde hydrator, the pan is first started revolving. A definite amount of crushed lime is then fed in, generally from an automatic weighing bin. Then the water is turned on. The amount of water used is sometimes regulated automatically by an overflow tank or some such arrangement, but more often it is left to the discretion of the man in charge. If the man is a good operator, the latter method is probably to be preferred. A large proportion of the water added is given off as steam, and the amount of this generated depends on whether the room is warm or cool, and to what extent the machine has been heated by previous charges. Therefore the quantity of water necessary is not constant and requires supervision. After the water has been added, the pan is kept rotating until hydration is complete. This requires from 6 to 20 minutes, depending on the quality of lime used. The end of the reaction can be readily discerned with practice. The powder becomes very light and appears dry, and the evolution of steam ceases. A central section of the bottom of the pan is then raised and the plows force the product through this opening into the bin below.

The Kritzer hydrator consists of a series of long iron tubes, one above the other, to save space. Within the pipes a screw conveyor is arranged which carries the lime through them. The lime is admitted at one end of the top section of the pipe. As close as possible to the end through which the lime enters a large vertical stack is erected. The water is admitted about two-thirds of the way up this stack, and falls down it, over a series of baffle plates, into the pipe. Here it meets the lime. The two substances are mixed very thoroughly by the screw conveyor, and at the same time are carried through the tube. The conveyor is run at such speed that when the mixture has reached the end of the pipe hydration is complete. In this machine it is impossible to regulate the quantity of water automatically, on account of the constantly increasing temperature (and consequent evaporation) when it is running.

A comparison of the two hydrators seems to result in favor of the Kritzer. First, since the lime and water are admitted in small, constantly flowing streams, a quicker and more thorough mixture is obtained. It is much easier to insure the presence of sufficient water for complete hydration, hence the danger of burning is diminished. The stream of water flowing down the stack absorbs the dust. This dust is a serious nuisance around a hydrating plant and makes the labor problem a difficult one. Besides absorbing the dust, the water also condenses the steam generated, and therefore enters the hydrator hot. It is a matter of common experience that a better quality of slaked lime can be obtained with hot water than with cold.

One of the modifications of the Clyde hydrator is an ingenious adaptation by which a more thorough mixing is accomplished. The pan revolves as in the ordinary machine; the shaft carrying the plows revolves in the opposite direction, and each plow is replaced by a screw propeller, which also revolves on its own axis. The other modification is designed to lessen the danger of burning merely by using a smaller machine and less lime.

In general, magnesian limes hydrate far less quickly than high calcium limes, and there is less danger of "burning." Consequently, the water does not need to be mixed so quickly or so thoroughly, and practice has demonstrated that magnesian limes can be hydrated with good success in a Clyde hydrator. Excellent high-calcium hydrate from very quick-slaking lime is now being made by the Kritzer machine.

The quantity of water to be used in making hydrated lime is a very important factor. As indicated above, it must be varied to suit constantly changing conditions, and considerable experience is required to be able to tell by the appearance of the finished product just when the correct amount has been added. Too much water will cause the product to become pasty and clog the screens. If too little is used the balance will be later absorbed from the air, with the consequent bursting of the bags in which it is stored. As yet no rapid practical means has been devised for determining the quantity of water present in the finished product, so that it must be judged merely by its appearance.

C. SCREENS AND AIR SEPARATORS

The hydration of lime is accompanied by an increase in volume, which causes the lumps to disintegrate. Evidently, anything which does not hydrate will retain its original lump form, and can be separated from hydrated lime by screening.

The Jeffreys screen, which is used in a majority of the plants visited, consists of a wooden frame with wires stretching across the bottom. One end of the screen is higher than the other. The hydrated lime is fed in at the upper end and caused to slide down over the wires by giving the whole machine a shaking motion. The hydrated lime falls through, while the impurities pass on. The wires are set to form a "36 diagonal mesh"—that is, there are 36 spaces between wires per linear inch—and the wires are set diagonally so that the squares formed by their intersections have their diagonals lengthwise of the screen. It has been found that this method of construction produces the same effect as a much finer mesh with the wires set straight. Consequently, heavier wires can be used, with less danger of breaking. The whole apparatus is covered with a canvas top to keep the dust in.

The Newaygo screen is very similar to the Jeffreys. The chief difference is that the frame of the former is of iron, instead of wood. It is claimed that a wooden frame will warp, thus distorting the wires and forming cracks through which dust escapes. For these reasons the iron frame is to be preferred.

Various forms of air separators are coming into use in place of screens. An air separator consists essentially of a rotary fan. The substance to be separated is mixed with the air taken into the fan. When the air is discharged the lighter particles are carried with it, while the heavier ones settle out. The air is blown into a suitable chamber where its velocity is so much reduced that the finer particles are deposited. The same air can be used over again, so that the system can be kept tight and the spreading of dust prevented.

Air separators have several advantages over screens. They are practically dust proof, a factor the importance of which can not be overlooked. A variation of the size of the particles taken out can be made by merely changing the speed of the fan, whereas a screen can be used for one size only. If the hydrated lime contains a little too much water, it is apt to clog the screens. This source of trouble is eliminated when an air separator is used. On the other hand, provision must be made to operate the separator fan at a constant speed which has been found suitable for the desired sizing.

D. ELEVATORS, BINS, AND PACKERS

Two elevators are generally used in a hydrate mill, one to take the lime from the crusher to the hydrator, and one to take the hydrated lime from the hydrator to the screens. If the tailings are ground and rescreened, another elevator is required to take them from the grinding machine to the screens. These elevators are almost exclusively of the bucket type, working within a tight wooden box. Every precaution must be taken to make the box tight, to prevent leakage of dust. A good method of constructing the box is to build it of two thicknesses of matched lumber with a layer of canvas between them.

Where hydrated lime is to be transported horizontally, a screw conveyor is generally used. It is easily kept tight and dust proof, and affords further opportunity for mixing the product.

From the screens the hydrated lime goes directly to the storage bin, where it may be aged or not, depending on the size of the plant. These bins are generally built of wood, and here, also, precautions must be taken to make them dust proof. Hydrated lime, especially if a little moist, is apt to be sticky and will not flow. Hence the bins must have steep sides and rather large openings.

The packer is the machine which takes the product from the bins and packs it in bags. Hydrated lime is shipped in either paper or cloth bags of 40 or 100 pounds capacity, respectively.

Nine of the 11 plants visited use the Urschel-Bates patent valve bagging machine. This machine consists of a long, narrow, horizontal wooden box, in which is revolved a shaft with pins projecting from it. The hydrated lime flows from the bin into the box. The pins convey it along the box and keep it stirred up to prevent its sticking. Along the bottom of the box are several openings, which may be closed by means of a lever and which when open connect with a long muffle-shaped chute. The bag to be filled is connected to the chute and the lever is raised so that the hydrated lime flows in. The bag rests on a scale pan, counterbalanced by a weight. When this weight of hydrate has been admitted, the scale pan drops, and in so doing pulls down the lever, thus closing the opening in the box and stopping the flow of hydrated lime. The Urschel-Bates valve bag is so made that both of its ends resemble the bottom of an ordinary bag. In forming the ends the smaller sides are folded over first and are overlapped by the larger sides. One of the smaller sides is left unfastened and through this opening the muffle-shaped chute is inserted. When the bag has been filled, the pressure of its contents forces the smaller side against the overlapping portions of the larger sides and thus closes the bag. When made of paper, such a bag can not be opened without tearing. If cloth is used, the top is made open in the usual manner and is tied before filling. The bag is then filled through a valve in the bottom.

Hydrated lime is a very fine powder, which will rise up in clouds of dust and permeate the air at every opportunity. On account of its caustic properties it is a very disagreeable substance to breathe. Hence, every precaution must be taken to make all machinery dust proof or the labor problem will become very difficult. The Urschel-Bates valve bag gives much less opportunity for the dust to get out than a bag which is filled while still open and which must be handled and tied after filling.

E. TAILINGS

What to do with the tailings from the screens is a very perplexing question. One manufacturer has found that his tailings consist chiefly of partially hydrated lime. He exposes them to the action of the steam generated in the hydrator and then returns them to the screens. Once a day the conveyor is opened and what little refuse has accumulated is taken out and thrown away.

At another plant the tailings are taken directly from the screens and sold for fertilizer.

All the other plants visited find it necessary to grind the tailings, after which they are put back on the screens and mixed with the material coming from the hydrator. The product so obtained is sometimes sold for fertilizer and sometimes as first quality hydrated lime. This latter practice is certainly to be condemned. It nullifies the most important function of the screens and impairs the quality of an otherwise good product.

The tailings are generally rather soft and in small pieces, so that almost any machine may be used for grinding them. The machines seen in operation were: Jeffreys mill, Kent mill, Fuller-Lehigh mill, Sturtevant rock-emery mill, Sturtevant pulverizer, and Williams crusher.

WASHINGTON, February, 1913.

APPENDIX

DESCRIPTION OF TYPICAL LIME-MANUFACTURING PLANTS

Lime has long been one of our most important building materials, yet a search through the literature seems to indicate that our knowledge of its properties could be materially increased by further investigation. In taking up the study of this subject it was deemed advisable to begin at the beginning; that is, to examine the various processes of manufacture actually in use. For this purpose a tour of inspection was made during the summer of 1909. This included 19 typical lime plants in various parts of the United States. The methods of operation of quarries, kilns, and hydrate mills were studied in detail. The following part of this paper consists of descriptions of these plants, a small amount of data, such as chemical analyses of the products, having been added.

Wherever possible the data has been arranged in the following order:

I. Name of company, location of plant, and transportation facilities.

II. Quarries: (1) Geology of deposit—Age, bedding, strike, and dip. (2) Stone—Physical properties and chemical analyses. (3) Quarry—Location, size of opening, direction of extension, and drainage. (4) Operation—Stripping, drilling, blasting, sledging, sorting, and transportation. (5) Refuse—Equipment and capacity of crushing plants and uses of products.

III. Kilns: (1) Construction—Casings, tops, linings, dimensions, coolers, and fire boxes. (2) Operation—Kind of fuel and method of firing, kind of draft, time of charging and drawing, sticking or following process, temperature and analyses of waste gases, temperature of interior of kiln, temperature of lime as drawn, capacity of kiln, and fuel consumption.

IV. Lime—Drawing, cooling, sorting, uses, and analyses.

V. Hydrate mills—Equipment, uses of product, and analyses.

1. ROCKLAND-ROCKPORT LIME CO., ROCKLAND, ME.

The Rockland-Rockport Lime Co. has operations extending about 6 miles along the coast of Maine, from Thomaston to Camden. The various plants have transportation facilities on the

Fig. 9.—*Quarry of the Rockland Rockport Lime Co.*

Maine Central Railroad, but rely chiefly on their own barge system. This consists of steam tugs and barges, with a complete equipment of docking and loading facilities, including electric trains to take the lime from the kilns to the docks.

A complete description of the stone used may be found in the Rockland Folio (No. 158), Geological Atlas of the United States, United States Geological Survey, 1908. The main deposit extends in a general northeasterly direction from the St. George River at Thomaston to Chickawaukie Pond. There are several more or less parallel outlying exposures on either side of the main deposit. The bedding is generally rather thin and irregular, with prominent jointing planes. The beds dip very steeply 75° to 80°.

The deposit consists chiefly of three kinds of stone, which are known locally as "soft rock," "hard rock," and "Rockport rock." The soft rock is dark gray and coarsely crystalline. This is the best grade of high calcium stone, but some of it is so soft as to cause difficulty by falling to pieces in the kiln. The hard rock is denser and of a dark-blue color. It contains somewhat more impurities and magnesia than the soft rock. The Rockport rock is a coarsely crystalline dark-gray dolomite. Its name is derived from the fact that it is quarried near Rockport. A large part of all grades of stone carries visible amounts of iron pyrites. Sometimes the quantity of this impurity is so high that the rock can not be used for burning lime. The following analyses were made by the United States Geological Survey in 1909:

	Soft rock	Rockport rock
	Per cent	Per cent
Silica (SiO_2)	1.29	2.41
Iron (Fe_2O_3)	.35	.40
Alumina (Al_2O_3)	.15	.22
Calcium carbonate ($CaCO_3$)	95.91	85.18
Magnesium carbonate ($MgCO_3$)	2.27	11.72
Total	99.97	99.93

The main quarry examined, known as the "Nellie Ulmer," and located a short distance west of Rockland, is shown in Fig. 9.

Since the beds of rock are almost vertical, it follows that, in order to work one bed only, the opening must extend either along the strike or down into the ground. Unfortunately, the amount of available stone along the strike is limited. To the south of the present opening the quality of stone in the same bed deteriorates; to the north the bed is covered by a lake. A bed of soft rock is being followed straight down, and smaller quantities of hard rock are taken from the beds on either side of it. The quarry as shown measures about 1000 feet along the strike, 125 feet wide at the top, 40 feet wide at the bottom, and 350 feet deep. The bottom of the quarry is below drainage level, so that pumping is necessary.

Owing to the form of the quarry, there is of course very little stripping to be done. It occasionally becomes necessary to widen the opening at the top in order to prevent the sides from becoming so nearly vertical as to be dangerous, but the amount of stripping is negligible. Holes are drilled in the stone by means of steam drills and the material is blasted out with dynamite and sledged to the size required. The stone is then sorted. The soft rock and hard rock are both used for burning lime, but are burned in separate kilns. The spawls and any stone which contains too much pyrites are discarded. The stone is loaded by hand on wooden skips, which are hoisted by derricks and dumped into cars. These are then taken by a steam locomotive over a railroad to the kilns. This road is so graded that the locomotive is able to deliver the cars on top of the kilns.

The spawls and quarry refuse are used locally to some extent for ballast and road metal, and small quantities have been shipped for furnace flux. There is no crushing plant, however, and most of this material is thrown away.

This company owns more than 80 kilns altogether, but only 44 were in operation at the time of this visit. The most modern of these are the 7 which constitute the Gregory battery at Rockland. These are of the ordinary shaft type, consisting of vertical steel cylinders, lined with fire brick. The tops are left open. The brick lining is capped with two courses of granite, which offers a better resistance to the abrasion of the stone. The inside dimensions of these kilns are: At top, 9 feet square, drawn into a rectangle 7½ by 5 feet at the fire; total height, 44 feet; height from bottom of cooler to grate level, 13 feet. The coolers are also lined with fire brick and are provided with shears through which the lime is drawn. Each kiln is provided with two fire boxes 42 inches wide by 6 feet long by 2½ feet high to the crown of the arch. The grate area is only 4½ feet long, the rest of the fire box being taken up by a dead plate in front and bridge wall in back. A pillar 14 inches square supports the arch at the inner end of the fire box, where it enters the kiln.

The fuel used is either Westmoreland or Fairmont slack. A thick bed is maintained and is replenished whenever the fireman thinks it necessary. A very small amount of steam is blown into the ash pit. This is not enough to create any appreciable forced draft, but serves primarily to keep the grate bars free from clinkers. The air used for combustion is taken in over the fire, the door of the fire box being generally left open for this purpose.

The kilns are filled up with stone twice a day and the lime is drawn out every three hours. For about half an hour before drawing the fire is permitted to die down, which chills the kiln and causes the lime to stick to the sides until it is knocked down by bars inserted through the fire boxes. The fires are cleaned after each draw. The temperature of the stack gases averaged about 200° C, and the interior of the kiln, as measured through the fire box, about 1350° C. The figures furnished by the company indicate that these kilns have a capacity of about 13 tons of lime per kiln day, with a fuel ratio of about 3.5 pounds of lime per pound of coal. This latter figure does not include the heat used in generating the steam blown into the ash pits.

The lime is drawn every three hours in iron buggies and dumped on the floor to cool. When cold it is sorted, the fine stuff being sent to the hydrate mill. Some of the lump lime is shipped in bulk, but most of it is barreled. It is used chiefly for building lime, although some of it is sold for such chemical purposes as water purification, etc. The following analyses were furnished by the company (authority not stated):

	Soft rock	Hard rock	Rockport rock
	Per cent	Per cent	Per cent
Silica (SiO_2)	1. 25	2. 74	0. 93
Iron and alumina (R_2O_3)	. 82	1. 61	1. 31
Lime (CaO)	97. 28	85. 51	69. 00
Magnesia (MgO)	. 64	9. 25	28. 76
Loss (CO_2H_2O)		. 89	
Total	99. 99	100. 00	100. 00

In the hydrate mill the lime is put through a Sturtevant crusher and pulverizer and slaked in a modification of a Clyde hydrator. This machine consists of two small pans operated in series instead of one large one. The advantages claimed for it are that the smaller batches permit a closer regulation of the quantity of water and more thorough mixture of lime and water. These pans discharge automatically into a mixer, which is merely an endless screw conveyor, in which the hydrate is kept moving until ready for use. This permits the material to cool, equalizes the water content of different batches, and provides a continuous feed for the screens. The hydrate, after passing through a Jeffreys screen, is aged in a bin for 30 days, packed by a Wade bagging machine, and sold for agricultural, building, and chemical purposes. The tailings from the screen are passed through the steam of the hydrator and returned to the screen. It is found that this process results in the hydration of almost all of the material. The small amount which will not pass through the screens is removed from the system once a day and thrown away. The hydrate has been analyzed, with the following results:

	Soft rock (analysis furnished by company; authority not stated)	Best grade (analyzed by Bureau of Standards)
	Per cent	Per cent
Silica (SiO_2)	1.08	0.42
Iron (Fe_2O_3) and alumina (Al_2O_3)	.89	.21
Lime (CaO)	73.02	72.25
Magnesia (MgO)	.61	1.47
Water (H_2O)	24.40	24.98
Carbon dioxide (CO_2)		.57
Total	100.00	100.23

2. FARNAM-CHESHIRE LIME CO., CHESHIRE, MASS.

The plant of the Farnam-Cheshire Lime Co. is located on the Boston & Albany Railroad, about 2½ miles from Cheshire, in Berkshire County, Mass. The shipping station, Farnam, is directly across the Boston Reservoir from the kilns, and the quarry is located about a mile farther west.

The topographic map of the Taconic quadrangle, United States Geological Survey, 1900, shows a chain of hills parallel to the Boston Reservoir, running in a northwesterly direction. These contain a deposit of Stockbridge limestone of Cambro-Ordovician age. The beds of stone appear to lie perpendicular to the trend of the hills, striking south 50° east and dipping about 10° toward the northwest. It outcrops on the top and both sides of the hill in which the quarry is located.

The stone is highly metamorphosed and coarsely crystalline. It is found in massive beds, which have been twisted and faulted greatly in smaller areas and which leave prominent jointing planes. Except for a variation in color from pale blue to pure white the deposit seems to be remarkably uniform in quality. Its composition is shown by the following analyses:

	Lathbury & Spackman, Philadelphia, 1908			Dill, Sharon, 1908		U. S. Geological Survey, 1909
	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent
Silica (SiO_2)	0.61	0.08	0.55	0.30	0.60	0.44
Iron (Fe_2O_3)	.42	.13	.15	.10	.38	.20
Alumina (Al_2O_3)						.08
Calcium carbonate ($CaCO_3$)	98.96	99.28	99.46	99.01	98.12	98.05
Magnesium carbonate ($MgCO_3$)	....	....	....	.35	.48	1.30
Total	99.99	99.49	100.16	99.76	99.58	100.07

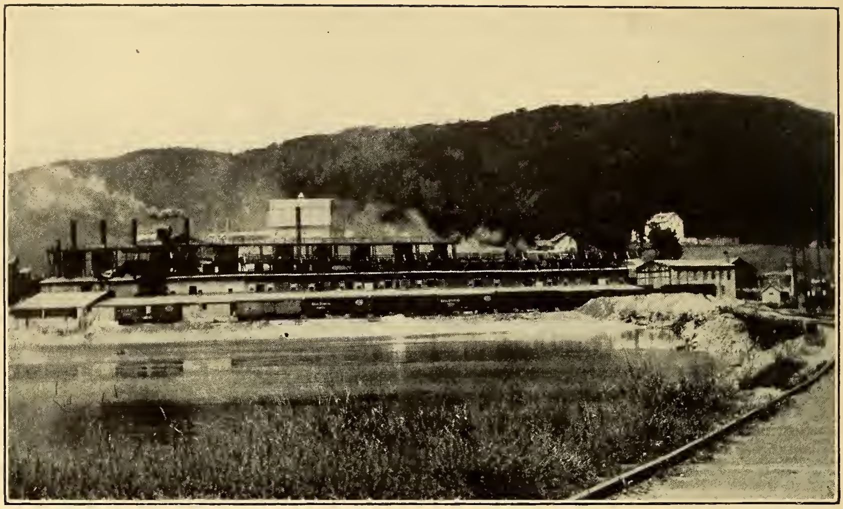

Fig. 10.—*Plant of the Farnam Cheshire Lime Co.*

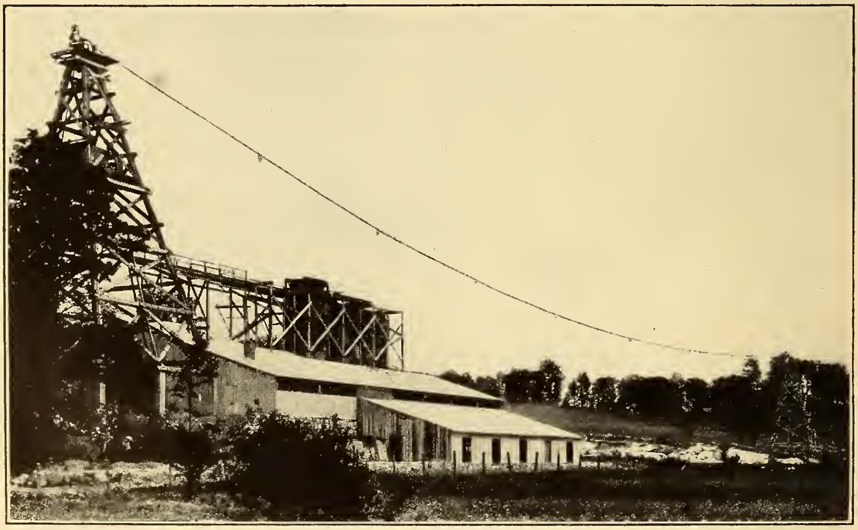

Fig. 11.—*Plant of the Connecticut Lime Co.*

The quarry is located near the summit on the southwestern slope of a hill in such a position that the stone must be carried over the top of the hill to the kilns. The quarry is semicircular in shape, about 1400 feet north and south by 300 feet east and west. The stone is exposed in a face about 35 feet high on the east, but dips below the quarry floor on the west. The deposit has been tested by drilling vertical holes in the quarry floor, and has been found to be uniform for at least 100 feet. The quarry is being extended downward, with the intention, when a sufficient depth has been reached, of tunnelling through the hill toward the kilns, and thus do away with the necessity of hauling the stone over the top of the hill. A small creek runs in close proximity to the present opening and is frequently the cause of drainage troubles. By conducting this water through the tunnel it is planned to develop a valuable water power on the other side of the hill.

When extending the quarry according to the above method no stripping is required. Holes are drilled in the stone by means of compressed air, and it is blasted with dynamite. It is sledged and sorted with regard to size and quality. Any stone showing a black or yellow discoloration from the jointing planes is discarded. The good stone is loaded in carts, which take it to a dump pile at one end of the quarry. Here it is again sorted and picked by hand into buckets, which carry it on an aerial cable to the kilns. The floor of the quarry is 700 feet above the tops of the kilns, so that the weight of the full buckets going down furnishes sufficient motive power to pull up the empty ones. At the lower end the buckets dump the stone into tramcars, which take it to the tops of some of the kilns or into a pile from which it is hauled to the others by means of a horse and cart.

The quarry waste is thrown away, no attempt having been made to market it.

The lime plant, as shown in fig. 10, consists of 14 kilns. This plant is peculiar in that the kilns show so many variations in design. The outside casings of the kilns are all steel, and all are lined with fire brick at the burning zone. The upper part of the lining is of either a different grade of fire brick or of sandstone. The tops of four of the kilns are closed and provided with doors through which the stone is charged and stacks 36 inches in diameter by 20 feet high. The other kilns are left open on top. The linings are either circular or oval at the top, and are drawn in to either ellipses 5½ feet by 6½ feet or to circles 7 feet in diameter at the fires. The height of the kiln is 30 to 32 feet above the grates, with a cooler 7 or 8 feet deep below. These coolers are lined with fire brick in all kilns but one. One kiln is provided with shears, through which the lime is drawn; three have doors in the bottoms of the coolers; and the other ten have doors in the sides of the coolers. Eleven of the kilns are provided with two fire boxes each, one on each side; the other three have four gas ports each, situated 90° apart. The fire boxes are built with a grate surface 3 feet long by 32 to 36 inches wide, an 18-inch dead plate in front, and an arch 30 to 36 inches high.

Three of the kilns burn producer gas, which is supplied by one Wood producer, 10 feet in diameter, under a forced draft caused by a steam pressure of 35 pounds. Two kilns burn coal under forced and induced draft arranged according to the Eldred process. Each kiln is provided with a fan which takes some of the waste gases from the top of the kiln and forces them back under the grates. Two more burn coal with forced and induced draft. The forced draft for these is created by blowing steam under the grates; the induced draft by means of a fan which exhausts the gas from the tops of the kilns. The other kilns burn a mixture of wood and coal under natural draft. The coal used is Westmoreland throughout, nut size for the producer and slack for direct firing.

Stone is charged into the kilns whenever it can be obtained from the quarry—at no definite time intervals. The lime is drawn out every six hours. The fires are run with thick beds and are replenished at the discretion of the fireman. The stone is so soft that it is apt to fall to pieces in the kiln, which causes serious difficulty by choking the draft. This phenomenon is noticed whenever the stone is charged wet, or when the kiln becomes so nearly empty that the stone is heated up very rapidly. The kilns are operated by the sticking process; that is, the lime is made to stick to the sides of the kiln until it is knocked down with bars. The temperature of the waste gases is about 200° to 250° C; of the inside of the kiln, about 1300° C; and the lime is drawn out red hot. The figures of the company show an average capacity of the entire plant of about 10 tons of lime per kiln per day. The fuel ratio of the kilns burning coal only is about 3 pounds of lime per pound of coal; of those burning mixed fuel, about one-third cord of wood and 200 pounds of coal per ton of lime. These figures do not include the heat used to generate the steam or drive the fans used in creating the draft.

The lime is drawn every six hours into iron buggies and dumped on the floor to cool. It is then sorted. The best quality is sold for finishing lime, and any which shows signs of having been smoked or having been in contact with the kiln lining is put in the second grade and sold as building lime. The following analysis of the finishing lime was made by the Bureau of Standards in 1911:

	Per cent
Silica (SiO_2)	0.79
Iron (Fe_2O_3)	.19
Alumina (Al_2O_3)	.22
Lime (CaO)	94.30
Magnesia (MgO)	1.22
Water (H_2O)	2.92
Carbon dioxide (CO_2)	.68
Total	100.32

3. CONNECTICUT LIME CO., CANAAN, CONN.

The plant of the Connecticut Lime Co. is located on the Central of New England Railroad between Canaan and East Canaan, in Litchfield County, Conn.

The topography of this district is shown by the map of the Sheffield Quadrangle, United States Geological Survey, 1897. The ground rises to form a hill on the north bank of Blackberry River. The main body of this hill appears to be limestone, which is folded into gradual undulations with a maximum dip of about 15° and striking north 50° east. On the side of the hill toward the river it is overlain by quartzite and at the summit by mica schist. The stone has been completely metamorphosed and the many prominent fissures in it have been filled by many varieties of minerals, including celestite.

The stone is a coarsely crystalline, pure white dolomite, with the following analysis:

	Connecticut Agricultural Experiment Station	U. S. Geological Survey, 1909
	Per cent	Per cent
Silica (SiO_2)	2.78	0.34
Iron (Fe_2O_3)	.52	.28
Alumina (Al_2O_3)		.19
Calcium carbonate ($CaCO_3$)	53.43	58.20
Magnesium carbonate ($MgCO_3$)	43.27	41.16
Total	100.00	100.17

At one point on the southern slope of the hill a place was discovered where the limestone is not overlain with quartzite. Here the quarry was opened and extended back into the hill. The original quarry yielded stone of some variation in composition, so a new quarry has been opened beside the first one. This new quarry is shaped like a horseshoe, with the opening toward the river. It measures about 105 feet north and south by 90 feet east and west, with a face of stone 10 feet high on the side opposite the opening. It is all above drainage.

The overburden at this particular locality consists of only a small amount of gravel, which is removed by hand and carted away. Holes are drilled in the stone by means of electricity, and it is blasted with dynamite. After sledging, it is sorted for both size and quality. The good stone is loaded by hand into cars, which run by gravity to the opening of the quarry, where they are lifted off their trucks, carried to the kiln, dumped and returned by means of an electrically operated aerial cable.

The spawls and rejected stone are sold for fluxing purposes just as they come from the quarry.

The three kilns are built on a line parallel to the river and directly west of the opening of the quarry. They consist of circular steel shells lined with fire bricks. The tops of two of them are closed with a plate provided with a charging door through which the stone is admitted. The top of the third is left open. The fire-brick linings are capped with limestone for the upper 7 feet. They are circular in shape, 14 feet in diameter, and are drawn into ellipses 5 feet by 7½ feet at the fire boxes. The height is 45 feet above the grates and 10 feet below. The coolers are brick lined and are provided with shears for drawing. Each kiln is provided with two fire boxes, one on each side. These are inclosed in a drum, built around the kiln to give better heat insulation. The grates are 38½ inches deep by 45 inches wide, with a 28-inch dead plate in front. The arch is 38 inches high and is supported by a pillar 13 inches square at the inner end of the fire box.

The stone is charged in whenever it is available—at no definite intervals of time. The lime is drawn out every four hours. The kilns are operated by the sticking process; that is, the lime is caused to stick to the sides of the kilns until it is knocked down with bars. It is drawn from only one side of a kiln at a time, so that it remains in the burning zone for eight hours. The fuel used is Westmoreland slack coal, which is burned under forced and induced draft according to the Eldred process. The waste gases are taken from the top of one kiln (whichever one is closed) and are mixed with a regulated supply of air. The amount of this mixture required for combustion is blown under the grates of two kilns, while the remainder is charged into a stack. From this stack another blower takes the gas required by the third kiln and the balance is permitted to escape. The fire doors are left open so that a secondary air supply is taken in over the fires. The fuel bed is kept pretty thick, and is replenished every 5 or 10 minutes. Temperature of the waste gases is about 150° C; of the kiln 1350° C; of the lime as drawn, red to white hot. The figures furnished by the company show a capacity of about 17 tons of lime per kiln-day and a fuel ratio of about 4 pounds of lime per pound of coal. This figure does not include the power required to run the blowers.

The lime is drawn into iron buggies and dumped on the floor to cool. It is then sorted into two grades according to color, white or yellow. There seems to be no appreciable difference in the composition of the two kinds, and the yellow lime is sold as second grade merely because of its poorer appearance. It slakes rather more slowly than the white lime and is somewhat more plastic. Both grades are sold exclusively for building lime. The analysis of the best quality, furnished by the company (authority not stated), is:

	Per cent
Silica (SiO_2)	2.84
Iron and alumina (R_2O_3)	.74
Lime (CaO)	55.86
Magnesia (MgO)	40.24
Loss (CO_2 and H_2O)	.32
Total	100.00

4. NEW JERSEY LIME CO., HAMBURG, N. J.

The New Jersey Lime Co. is operating two plants, one of seven kilns at McAfee, and one of eight kilns about halfway between McAfee and Hamburg, in Sussex County, N. J. Both are on the Lehigh & Hudson River Railroad and each has its own quarry. A hydrate mill at McAfee is supplied with lime from both plants.

The geology of this district has been described in detail in the Franklin Furnace Folio (No. 161), Geological Atlas of the United States, United States Geological Survey, 1908. The Franklin limestone is believed to be of pre-Cambrian age. The deposit extends in a northeasterly direction from south of Ogdensburg, N. J., to Mounts Adam and Eve in Orange County, N. Y. It is apparently monoclinal in structure, with a maximum width of about 1 mile at McAfee. Large areas of it are overlain with younger rocks which have been partially eroded, thus producing a number of isolated outcrops parallel to the main deposit. The stone has been completely metamorphosed, probably by the intrusion of dikes of gneiss and pegmatite. As a result of the severe treatment which it has undergone, the deposit is of a very heterogeneous character. A large variety of impurities are found, either in pockets or distributed throughout the limestone. Dolomite and calcite are so intermingled that it is generally impossible to separate them by their appearance. Bedding planes can seldom be identified and pockets of foreign materials occur in unsuspected localities.

The crystallization of the limestone is very coarse and prominent, and the crystal faces generally show black specks of graphite. The following analyses by the United States Geological Survey in 1909 give the average composition of the stone in the two quarries:

	McAfee	Hamburg
	Per cent	Per cent
Silica (SiO_2)	0.85	1.21
Alumina (Al_2O_3)	.06	.41
Iron (Fe_2O_3)	.20	.45
Calcium carbonate ($CaCO_3$)	96.70	95.70
Magnesium carbonate ($MgCO_3$)	2.04	2.25
Total	99.85	100.02

The peculiar formation of the deposit has made quarrying very irregular, for it has been found more economical to open a new quarry than to cut through a dike of pegmatite or to blast out and cart away a pocket of quartzite. For this reason there is a large number of small abandoned quarries scattered over the deposit. The opening now in use at McAfee is located in the side of a hill, at the foot of which stand the kilns. It is about 80 feet north and south by 126 feet east and west. It is being cut back into the southeastern slope of the mountain, and has already reached a working face 100 feet high. The quarry at the Hamburg plant is an opening in one of the isolated deposits a short distance southwest of the kilns. It is circular in shape and about 75 feet in diameter. The floor of the quarry slopes so that the working face of stone is 16 feet high on one side and nothing on the other. It is proposed to work this quarry down to water level and then open it out in all directions. The stripping is very variable in both quantity and quality. In some places the stone outcrops on the surface. In others it is overlaid by 50 feet of gravel or 10 feet of cap rock. The stripping is removed by hand or by dynamite when necessary. Holes are drilled in the stone with steam, and it is blasted with dynamite. After sledging the impurities are sorted out as thoroughly as possible. The good stone is loaded in cars by hand and taken to the kilns by horse. The cars run on tracks which are so graded that the horses can pull them directly to the tops of the kilns.

The spawls and quarry refuse are sold to some extent for fluxing purposes, but no attempt has been made to develop a large market for this material.

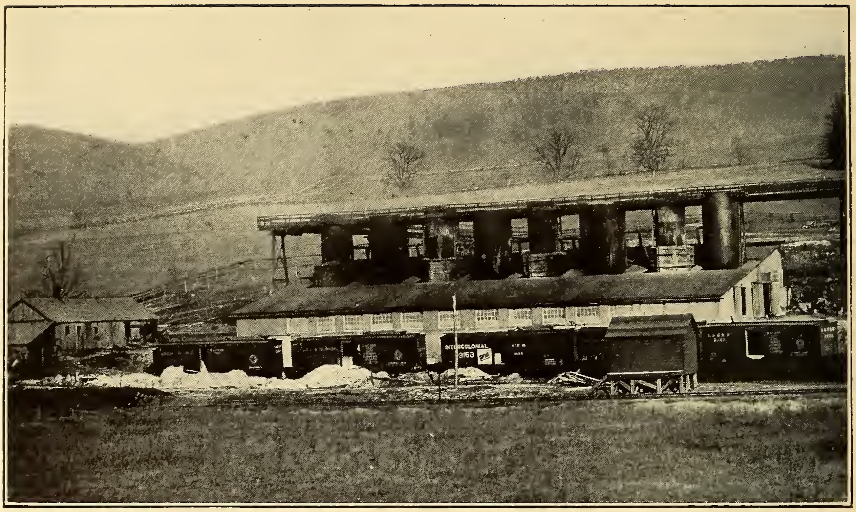

Fig. 12.—*Hamburg plant of the New Jersey Lime Co.*

Fig. 13.—*McAfee plant of the New Jersey Lime Co.*

Of the 15 kilns, the shells of 6 are steel; 4 more are inclosed in brick to above the fire boxes and steel in the upper part; the shells of the rest are of stone. Fire boxes and burning zones to 6 feet above the grates are lined with mica schist; the upper parts are lined with fire brick. Four of the kilns have conical tops and stacks 3 feet in diameter by 24 feet high; the tops of 4 more are closed by plates, which carry charging doors, and pipes through which the gas is removed; the tops of the other 7 are open. The linings of the kilns are all circular at the top, with inside diameters varying from 5½ feet to 8½ feet. The walls are either drawn in, are straight, or are flared out, so that the dimensions at the fires are either ellipses 8½ feet by 5½ feet or circles 6½ feet in diameter. The height above the grates varies from 12 feet to 20 feet; below the grates, from 8 feet to 12 feet. The coolers of some kilns are lined with fire brick; others are unlined. The lime is drawn through shears or doors in the bottoms of the coolers. Each kiln is provided with two fire boxes, one on each side. Some of these have 18-inch dead plates in front. The grate areas vary from 29 to 40 inches deep and from 24 to 34 inches wide. Some of the arches are 29 inches high; others slope upward from 18 inches at the fire door to 36 inches where they enter the kilns. Some of these arches are supported at their inner ends by two pillars 8 inches by 12 inches.

Stone is charged into the kilns whenever it comes from the quarry, at no definite interval of time. The lime is drawn out every seven or eight hours. The coal used contains about 36 per cent volatile matter and 54 per cent fixed carbon. It is burned in rather thick beds, and in some of the kilns the fire doors are left open to permit a secondary air supply being taken in over the fire. The draft for some of the kilns is created according to the Eldred process, each kiln being provided with a small fan, which takes some of the waste gas from the top, mixes it with a regulated amount of air, and blows it under the grates. Some of the kilns are provided with forced and induced draft. The forced draft is created by blowing steam under the grates and the induced by means of a fan which exhausts the gas from the top of the kiln. The rest of the kilns are provided with forced draft only. Some of the kilns are operated by the sticking process; others follow down. That is, in some the lime is caused to stick to the lining until it is knocked down with bars, while in others it is permitted to fall down as the lime underneath it is drawn out. In order to make the kiln stick, it is customary to permit the fires to die down for 20 or 30 minutes before drawing. The stone is so soft and coarsely crystalline that it causes a great deal of trouble by falling to pieces in the kiln and choking the draft. The average temperature of the stack gases is about 150° C; of the interior of the kiln, about 1350° C; and the lime is white hot when drawn. An average analysis of the stack gases is: Carbon dioxide, 21.2 per cent; oxygen, 5.6 per cent; carbon monoxide, 1.2 per cent. The figures furnished by the company show the capacity to be: Of the Eldred process kilns, 7 tons of lime per kiln day; of the forced and induced draft, 10 tons; of the forced draft, 8 tons. The fuel ratio of the Eldred process kilns is 2.2 pounds of lime per pound of coal. This includes the power required to run the fans. No figures were available for the other kilns.

The lime is drawn into iron buggies and dumped on the floor to cool. It is then forked, and the fine stuff is sent to the hydrate mill. The lump lime is used to some extent for plastering, but its main market is the chemical trades, such as metal refining and the manufacture of alcohol and soap. Its composition, as analyzed by Ricketts & Banks, New York, in 1904, is:

	Per cent
Silica (SiO_2)	0.81
Iron and alumina (R_2O_3)	.56
Lime (CaO)	97.08
Magnesia (MgO)	.31
Water (H_2O)	.29
Carbon dioxide (CO_2)	.47
Total	99.52

The hydrate mill at McAfee uses all the fine lime from both plants and some lump lime besides. The lime passes through a Gates crusher and is then ground in a Sturtevant pulverizer. It is slaked in a Clyde hydrator, screened through a Jeffreys screen, and packed in bags by a spiral bagging machine. The tailings from the screen are put through a Sturtevant pulverizer and sold as ground limestone for fertilizer.

The hydrate is used in the manufacture of paint and as a germicide for spraying on trees, etc. Its composition, as shown by the Bureau of Standards in 1911, is:

	Per cent
Silica (SiO_2)	0.97
Iron (Fe_2O_3)	.33
Alumina (Al_2O_3)	.29
Lime (CaO)	69.63
Magnesia (MgO)	4.11
Water (H_2O)	22.56
Carbon dioxide (CO_2)	1.88
Total	99.77

5. CHARLES WARNER CO., CEDAR HOLLOW, PA.

The Cedar Hollow plant of the Charles Warner Co. is located in Chester County, Pa., about 2 miles from Cedar Hollow, on the Philadelphia & Reading Railway and one-half mile from Devault, on the Pennsylvania Railroad. Shipping facilities over both roads are provided by private sidings running to the plant.

A deposit of Shenandoah limestone forms the main body of a chain of hills which run in a general northeasterly direction. The stone strikes about south 75° west and dips at about 60° toward the southeast. The beds of stone are not distinct, and the deposit is cut by frequent and promonent jointing planes.

The stone is a fine-grained dolomite which varies in color from blue to yellow. It also varies somewhat in composition, as is shown by the analyses of the United States Geological Survey in 1909.

	East end southern quarry	West end southern quarry	North quarry	Whiteland quarry
	Per cent	Per cent	Per cent	Per cent
Silica (SiO_2)	0.81	0.91	2.27	0.94
Alumina (Al_2O_3)	.56	.09	.51	.15
Iron (Fe_2O_3)	.47	.30	.40	.45
Calcium carbonate ($CaCO_3$)	54.68	63.02	53.16	54.09
Magnesium carbonate ($MgCO_3$)	43.66	35.78	43.89	44.58
Total	100.18	100.10	100.23	100.21

The plant is situated between two hills, both of which are formed by this limestone. Two quarries have been opened by cutting into these hills, maintaining the quarry floor on a level with the ground at the plant. The southern quarry has been cut back about 350 feet, giving a working face about 700 feet long with a maximum height of 60 feet. The northern quarry has been cut into the hill about 125 feet and has a working face 300 feet by 40 feet. A third quarry, which is located at Whiteland, about a mile along the strike of the stone, is circular in shape, about 300 feet in diameter by 50 feet deep.

The stripping averages about 6 feet of red clay, but pockets are occasionally found in which it is much deeper than this. Whenever possible it is removed by means of a steam shovel and hauled away in cars. Holes are drilled horizontally in the stone by means of compressed air. These are sprung with black powder, and the final blast is made with dynamite. After being sledged the stone is sorted. Each bed as it is opened is analyzed, and the analysis determines whether or not it shall be used for burning lime. A sample such as that from the north quarry given above would be rejected. The good stone is loaded by hand in cars, which are hauled by horse to the foot of a tramway, which takes them by cable to the tops of the kilns.

In a similar manner the rejected stone is taken to a crushing plant. This is equipped with two Blake jaw crushers, two rotary screens, a small recrushing plant, and a Fuller Lehigh mill. The capacity is about 600 tons per day, of five sizes. The material is used chiefly for road metal, ballast, concrete, fertilizer, and asphalt.

Only eight of the kilns of this plant were examined in this investigation. Some of these have steel casings and some are inclosed in stone at the burning zone and steel in the upper part. The tops are all open. The linings are of sandstone, circular or elliptical at the top, and drawn into ellipses at the fires. The dimensions of the ellipses vary from 6 feet by 6½ feet to 7½ feet by 16 feet at the fire. The height above the grate varies from 40 feet to 70 feet and below the grates it is about 14 feet. The coolers are all lined and are provided with either doors in the sides or a modification of the usual shears, through which the lime is removed. In some kilns the coolers are divided vertically into two or four compartments by saddle walls, running from the bottom of the coolers to the level of the grates. Each compartment has its own draw door or shears and can be operated independently of the others. This construction has been resorted to because the larger kilns show a tendency to work unevenly and it becomes necessary to draw more lime from one side of the kiln than the other. The kilns are provided with either two fire boxes, one on each side; four fire boxes, two on each side; four gas ports, two on each side; or eight gas ports, four on each side. The grates vary from 42 to 72 inches wide by from 6 feet to 9 feet deep and the arches are 2 feet high.

For direct firing Fairmont, W. Va., coal is used. The producer gas for some of the kilns is generated in Wood producers from Rochester and Pittsburgh coal, each gas-fired kiln having its own producer. Forced and induced draft is created according to the Eldred process. One fan takes the gas from the tops of all the kilns and delivers it to all of them. Means are provided to regulate the amount of this gas and of air supplied to each kiln. The sticking process is used in operating the kilns; that is, the lime is caused to stick to the sides of the kiln until it is knocked down with bars. A thin fire is generally carried on the grates of the direct-fired kilns, and is replenished about every five minutes. The

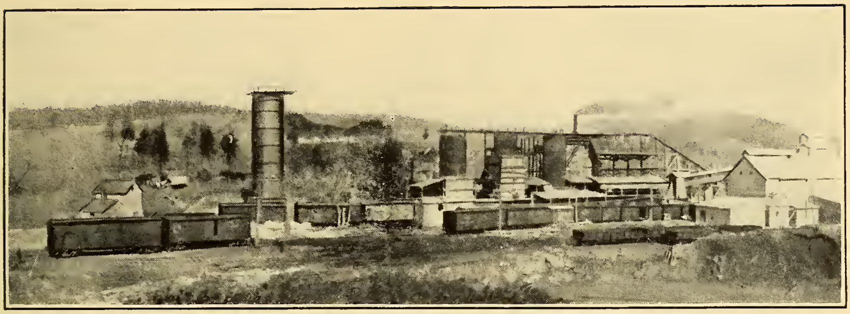

Fig. 14.—*Plant of the Charles Warner Co.*

Fig. 15.—*Quarry of the Lowell M. Palmer Co.*

stone is charged in whenever it comes from the quarry—at no stipulated intervals. The lime is drawn out every four or six hours. The temperature of the waste gases averaged about 95° C; of the interior of the kiln about 1200° C; and some of the lime showed dull red when drawn. The plant is equipped with an automatic recording gas analysis apparatus which can be attached to any kiln. This showed as high as 29 per cent carbon dioxide in the waste gases from one of the gas-fired kilns. The following figures furnished by the company show the average capacities and fuel ratios of the kilns:

	Capacity (tons of lime per kiln per day)	Fuel ratio (pounds of lime per pound of coal)
Direct fired:		
2 fire boxes	12	4.20
4 fire boxes	23	4.27
Gas fired:		
4 ports	17	4.01
8 ports	41	4.53

The fuel ratio figures do not include the power used to create the draft.

Each kiln has its own cooling floor immediately under it, so the lime is merely drawn to this and left there to cool. When cold it is shoveled to a belt conveyor, which runs the entire length of the plant in front of each kiln. This conveyor takes the lime to a revolving wheel provided with slots which act as a coarse screen. The lump lime passes over the wheel, goes up another conveyor, and down a chute into the car. The core is sorted out as it comes down the chute and is thrown away. Lump lime is sold mainly for building purposes, although quite a little of it goes to various chemical industries, such as sulphite paper mills, morocco tanneries, etc.

The fine stuff falls through the slots in the wheel to another conveyor which takes it to the hydrate mill. Here as much lime as is necessary is added, the whole is crushed, and slaked in a Clyde hydrator. The product is screened through a Jeffreys screen, the tailings from which are thrown away. The hydrate passing through the screen is either sold direct for building, fertilizer, or the manufacture of hard wall plaster, or it is put through an air separator and the finer grade thus obtained is used in the manufacture of paper, paint, and soap, or for spraying plants.

Its composition as found by the Bureau of Standards in 1911 is shown by the following analysis:

	Per cent
Silica (SiO_2)	3.78
Iron (Fe_2O_3)	.24
Alumina (Al_2O_3)	3.50
Lime (CaO)	47.78
Magnesia (MgO)	29.80
Water (H_2O)	14.24
Carbon dioxide (CO_2)	.67
	100.01

6. LOWELL M. PALMER CO., YORK, PA.

The plant of the Lowell M. Palmer Co. is located about 2½ miles west of York, in York County, Pa., on the Northern Central Railroad. The limestone here forms the bedrock of a rolling country. The slight elevations are caused partially by the gradual folding of the stone and partially by an increase of thickness of the overlying impure limestone and shale. Where the deposit has been opened, the stone is found in thick, well-defined beds, which strike north 65° west and dip 55° toward the southwest. The beds are broken by prominent jointing planes and lodes of a different kind of limestone have been found in the deposit.

The main beds are either white or blue in color. The blue stone is very hard and dense and is microcrystalline; the white is somewhat coarser and softer. The stone found in the lodes appears to consist of nodules of the white variety embedded in a matrix of the blue, but is harder than either. Owing to this peculiar appearance it is locally designated "calico stone." The following analyses show the compositions of the various kinds of stone:

	White		Blue		Calico	
	E. R. Squibb & Son, 1908	U. S. Geological Survey, 1909	E. R. Squibb & Son, 1908	U. S. Geological Survey, 1909	U. S. Geological Survey, 1909	Bureau of Standards, 1911
	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent
Silica (SiO_2)	0.30	0.53	0.20	0.14	0.27	0.25
Alumina (Al_2O_3)	.38	.04	.19	.02	.07	.03
Iron (Fe_2O_3)		.05		.10	.30	.27
Calcium carbonate ($CaCO_3$)	98.21	99.21	[19] 100.21	98.73	86.43	81.73
Magnesium carbonate ($MgCO_3$)	2.12	.74	.32	1.01	12.98	18.50
Total	101.01	100.57	100.92	100.00	100.05	100.78

The deposit has been opened by sinking a circular pit in the ground and gradually enlarging both the diameter and the depth.

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[19] This figure was given as 56.12 per cent calcium oxide and has been calculated to the carbonate by the writer.

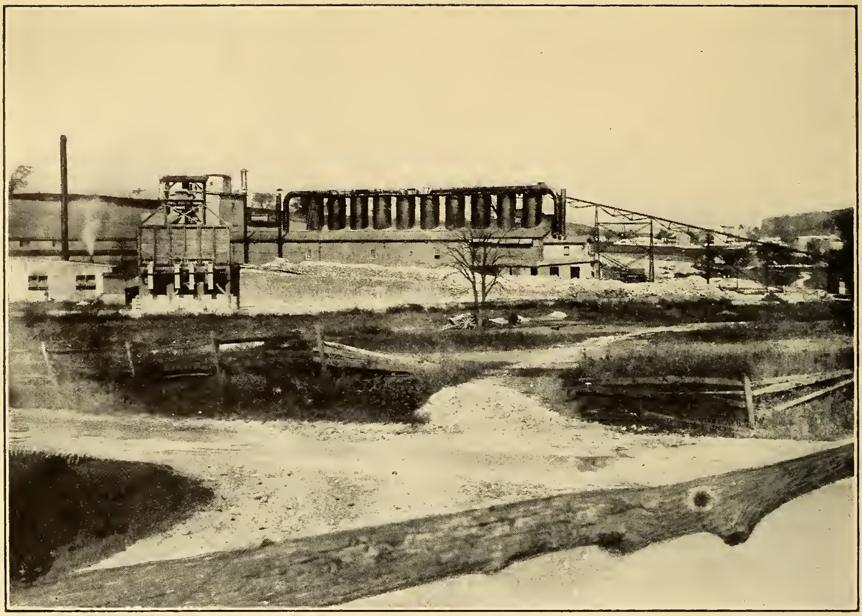

Fig. 16.—*Plant of the Lowell M. Palmer Co.*

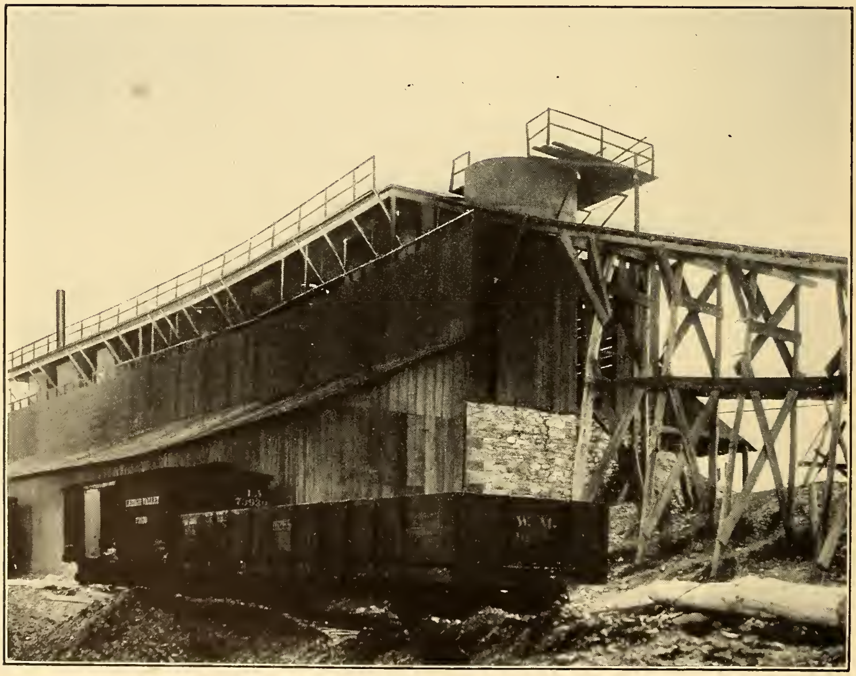

Fig. 17.—*Plant of the Thomasville Stone and Lime Co.*

The quarry is about 330 feet north and south by 550 feet east and west by 20 feet deep. The floor is below water level and is drained to a sump hole, from which the water is removed by means of a bucket elevator.

The clay or shale overburden is removed by hand and carted away. The stone is then drilled with compressed air, blasted with dynamite, sledged, and sorted. The impure cap rock and the spawls are rejected; the calico stone is separated from the blue and white varieties because it retains the same mottled appearance after burning and is unsalable as lump lime. It must therefore be burned in separate kilns. The good stone is loaded by hand into cars which run by gravity to the foot of an incline. A cable hauls them up this to the tops of the kilns.

The crushing plant consists of a Gates crusher and rotary screen. It is used for crushing the cap rock and spawls to ballast or road metal. In connection with it there is also a Williams pulverizer, by which some first-quality limestone is ground to 40 mesh for chemical purposes.

The 10 kilns in this plant are all alike. They consist of steel shells lined with fire brick and closed at the top by steel plates. These plates are provided with pipes, through which the waste gases are removed, and with doors for charging the stone, which are sealed shut after the kiln has been filled. The linings are of two grades of fire brick—a highly refractory kind at the burning zone and a harder variety at the top. The inside shape is circular, 6½ feet in diameter. The walls are straight and extend 35 feet above the grates and 9 feet below. The coolers are also lined with brick and are provided with shears, through which the lime is drawn. Each kiln has two fire boxes, one on each side. These are 4 feet wide by 7 feet deep by 28 inches high.

The fuel used is West Virginia gas coal, and the draft is created according to the Eldred process. For this purpose four fans are operated. One draws the waste gases from five kilns and blows them out a stack; one draws the gases from the other five and blows the unused portion out another stack; from this supply another fan takes the amount of gas required and forces it under the grates of all 10 kilns; the fourth fan supplies the air required for combustion. Means are provided to regulate the quantities of air and gas supplies to each fire box. The kilns are filled with stone once a day. The lime is drawn out every three hours. As it is removed the stone is permitted to follow it down by gravity. The fuel beds are kept thin and are replenished about every 20 minutes. The coking process of firing is used—that is, the coal is put on the dead plate in front of the grates and is gradually pushed back into the fire box as fresh charges are added. The fires are cleaned twice a day, the clinkers being removed from one side at a time, so that the kiln is never permitted to cool down appreciably. The average temperature of the waste gases is about 155° C, of the interior of the kiln about 1250° C, and the lime is red to white hot when drawn. An average of the gas analyses made is: Carbon dioxide = 18.1 per cent; oxygen = 9.2 per cent; carbon monoxide = 0. From data obtained by this Bureau in 1911 this plant has an average capacity of 10.6 tons of lime per kiln per day, with a fuel ratio of 3.78 pounds of lime per pound of coal. The coal equivalent of the power used to create the draft is included in calculating this fuel ratio.

The lime is drawn into iron buggies, weighed, and dumped on the cooling floor. When cold it is sorted. The core is burned over, the fine stuff and lime made from the calico stone are sent to the hydrate mill, and the first-quality lime is sold in the lump for finishing purposes.

In the hydrate mill the lime is ground in a Gates crusher, slaked in a Kritzer hydrator, and then put through a Jeffreys screen. The tailings from this screen are ground in a Fuller-Lehigh mill and returned to the screen again. The finished product is packed by an Urschel-Bates bagging machine and is used for all purposes—finishing, building, chemical, and agricultural. Its composition is shown by the following analyses:

	E. R. Squibb & Sons, 1908		Bureau of Standards, 1911
	Made from first-quality lime	Made from second-quality lime	
	Per cent	Per cent	Per cent
Silica (SiO_2)	0.30	Trace	0.95
Iron (Fe_2O_3)	Trace	Trace	.51
Alumina (Al_2O_3)	Trace	Trace	.50
Lime (CaO)	75.44	75.20	71.66
Magnesia (MgO)	Trace	Trace	.36
Water (H_2O)	24.15	24.55	23.81
Carbon dioxide (CO_2)			1.80
Total	99.89	99.75	99.59

7. THOMASVILLE LIME & STONE CO., THOMASVILLE, PA.

The Thomasville Lime & Stone Co. is operating a lime and crushed-stone plant about one-half mile west of Thomasville, York County, Pa., on the Western Maryland Railroad.

The stone used appears to be from the same deposit which has been opened by the Lowell M. Palmer Co. a little farther east.

The beds are nearly horizontal, the slight elevations of ground being due in part to the folding, but chiefly to a variation in the thickness of the overlying material. The deposit contains prominent jointing and bedding planes, and numerous pockets which have been filled with coarsely crystallized calcite.

The stone is rather fine-grained and very soft. Its color varies from white to pale blue, dark blue, or pink in the different beds, without any appreciable change in the chemical composition. The entire deposit is sufficiently pure for the manufacture of lime, but some crushed stone is made for economic reasons. Its analysis, as shown by the United States Geological Survey in 1910, is:

	Per cent
Silica (SiO_2)	0.15
Alumina (Al_2O_3)	.10
Iron (Fe_2O_3)	.15
Calcium carbonate ($CaCO_3$)	99.02
Magnesium carbonate ($MgCO_3$)	.57
Total	99.99

The quarry has been opened to form a circular pit covering about 2 acres in area. This is being extended downward in benches, each 22 feet deep. The third bench has just been started. Test holes have shown a uniform quality of stone extending to a depth of 186 feet, and it is also possible to enlarge the diameter of the quarry. The floor of the third bench is below drainage, and the water is collected in a sump hole and raised by a steam pump.

After the stripping of about 6 inches of clay has been removed by hand the stone is drilled by steam, blasted with 20 per cent dynamite, sledged, and sorted to size. It is loaded into cars by hand, pushed to the foot of an incline, and trammed by cable to the crushing plant. Here the stone to be burned is dumped into other cars and taken up another incline to the kilns.

The crushing plant consists of two jaw crushers, followed by a rotary and a stationary screen. The sizes of stone made are 5 to 3¼ inches, 3¼ to 2¼, 2¼ to 1½, 1½ to ⅞, ⅞ to ⅜ ("screenings"), and "dust." The daily capacity is about 350 tons of crushed stone, 40 tons of screenings, and 20 tons of dust. The crushed stone is used mainly for ballast, the screenings for concrete, and the dust for fertilizer.

The nine kilns consist of steel casings lined with two grades of fire brick. The tops of eight are open, the other is closed by a flat plate carrying a stack 30 inches in diameter by 20 feet high. The linings are circular in cross section, 11 feet in diameter at the top, drawn into 5½ feet diameter at the burning zone. The kilns are 25 feet high above the grates, and the coolers extend 15 feet below. The coolers are also lined and are provided with doors in the sides for removing the lime. Each kiln is provided with two fire boxes, one on each side. The grates are 44 inches wide by 43 inches deep and have a 6-inch dead plate in front and an 11-inch bridge wall in back. The arches are 30 inches high.

West Virginia slack gas coal is burned with natural draft. The kilns are filled with stone once a day, and the lime is drawn out every two hours. The sticking process is used; that is, the lime is caused to stick fast to the kilns and is knocked down with bars after every third draw. The fuel beds are kept rather thick and are replenished about every 20 minutes. They are cleaned twice a day, one side at a time, so that the kiln is never permitted to cool off appreciably. The waste gases escape at about 200° C., the maximum temperature in the kiln is about 1300° C., and the lime is cold when drawn. Figures furnished by the company indicate a capacity of 8 tons of lime per kiln per day, with a fuel ratio of about 3 pounds of lime per pound of coal.

The lime is drawn into iron buggies. It is sorted as drawn and loaded directly into cars for shipment. The core is put back into the kiln and burned again. Any fine stuff goes with the lump for building or chemical purposes, but when finishing lime is being made, the fine stuff is forked out and sold for fertilizer.

8. AMERICAN LIME & STONE CO., BELLEFONTE, PA.

The American Lime & Stone Co. is operating about 80 kilns in central Pennsylvania. The plants are concentrated around Bellefonte, Tyrone, and Hollidaysburg. Plants Nos. 13, 22, and 28 are located near Bellefonte, and have shipping facilities on the Bellefonte Central Railroad. Plants Nos. 13 and 28 are close together and are about one-half mile from Bellefonte station. Plant No. 22 is 4 miles farther along the strike of the stone.

The deposit consists of numerous thin beds of Trenton limestone, of Ordivician age. These are folded into an anticlinal formation, striking north 50° east and dipping about 65°. This limb of the anticline has been traced for many miles along its strike, and what appears to be the other limb has been opened at Pleasant Gap. Both the bedding and jointing planes are very pronounced, but the deposit is apparently free from pockets or faults.

The stone is dark gray or blue, microcrystalline, and very hard and dense. About 12 beds near the center of the deposit contain stone pure enough to be used for the manufacture of lime. On either side of these the beds contain too high a proportion of impurities, and this stone is therefore crushed. The following analysis

Fig. 18.—*Quarry of the American Lime and Stone Co.*

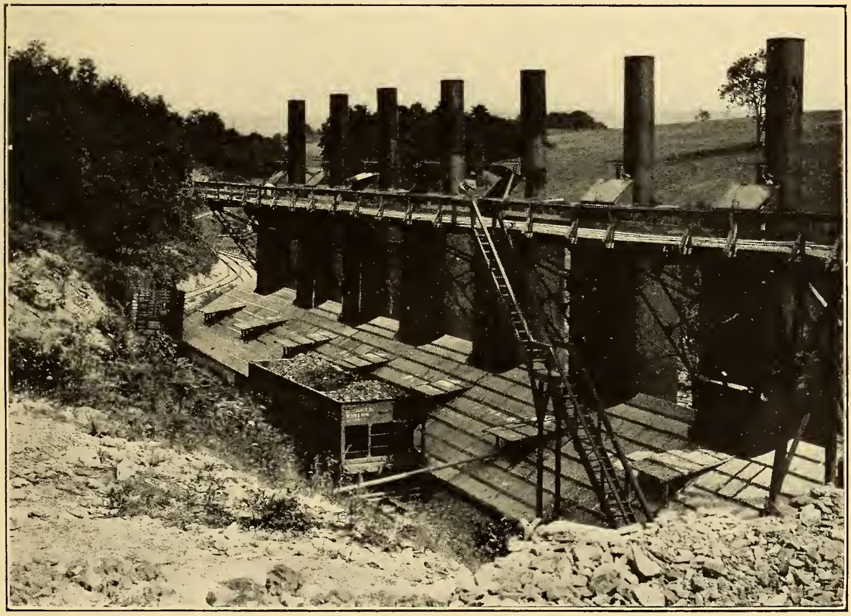

Fig. 19.—*Plant No. 13 of the American Lime and Stone Co.*

made by the chemist of the company in 1908 shows the percentage of variation in composition of stone from the different beds, which are numbered in order of deposition. Only that stone is burned which contains less than 2.5 per cent silica.

	1	2	3	4	5	6	7	8
Silica (SiO_2)	4.32	5.00	5.16	3.72	0.50	0.43	0.69	0.52
Alumina (Al_2O_3)	.60	.60	.74	.88	.18	.26	.31	.30
Irou (Fe_2O_3)								
Calcium carbonate ($CaCO_3$)	92.14	90.90	89.43	91.90	98.05	98.42	96.85	97.43
Magnesium carbonate ($MgCO_3$)	2.94	3.50	4.67	3.50	1.27	.84	2.15	1.75
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

	9	10	11	12	13	14	15	16
Silica (SiO_2)	1.04	2.20	6.20	2.66	1.14	0.72	1.34	0.66
Alumina (Al_2O_3)	.22	.32	1.06	.70	.24	.14	.26	.20
Iron (Fe_2O_3)								
Calcium carbonate ($CaCO_3$)	97.40	96.20	90.16	94.35	97.94	98.30	96.47	97.80
Magnesium carbonate ($MgCO_3$)	1.34	1.30	2.58	2.29	.68	.84	1.93	1.34
Total	100.00	100.02	100.00	100.00	100.00	100.00	100.00	100.00

	17	18	19	20	Average U. S. Geological Survey, 1909
Silica (SiO_2)	1.20	4.10	4.62	2.76	1.41
Alumina (Al_2O_3)	.26	.46	.44	.50	.25
Iron (Fe_2O_3)					.40
Calcium carbonate ($CaCO_3$)	97.43	93.37	91.27	94.00	96.36
Magnesium carbonate ($MgCO_3$)	1.11	2.07	3.67	2.74	1.55
Total	100.00	100.00	100.00	100.00	99.97

The quarry supplying plants 13 and 28 is cut into a hill just back of the kilns at such an elevation that the floor of the quarry is a little higher than the tops of the kilns. The hill was cut into from the side until the vein of stone was found and then was followed along the strike. The present opening, which is 125 feet wide, exposes the ends of 21 beds. The quarry is being worked back along the beds and has already been extended about 650 feet in this direction. The working face, which depends on the height of the hill above the quarry floor, is about 75 feet. The quarry is all above drainage.

The stripping (about 2 feet of clay and gravel) is removed by hand and carted away. The stone is drilled by compressed air and blasted with black powder. It is then sorted for both size and quality; stones larger than 4 inches from any of the 12 beds are sent to the kilns, while anything else goes to the crushers. The stone is loaded by hand into cars and is taken to either kilns or crushers by a steam locomotive.

There are three crushing plants supplied by this quarry, known as Nos. 14, 15, and 27. Plant No. 15 consists of two Gates crushers and a rotary screen. It has a capacity of 650 tons per day of 1¼ to 3 inch stone. In plant No. 27 there is a McCulley crusher, followed by a pair of corrugated rolls, a Jeffrey mill, and a Kent mill. The product is put through Jeffrey screens. This plant has a capacity of 200 tons per day of two sizes—"coarse" (4 mesh) and "medium" (6 to 7 mesh). Plant No. 14 is equipped similarly to plant No. 27, except that the Gates crusher is used instead of the McCulley and an air separator instead of a screen. This plant has a capacity of 125 tons per day of stone varying from "dust" to 60 mesh. The larger sizes of crushed stone are used for ballast, flux, road metal, and concrete, and smaller sizes for chemical purposes, chiefly glass manufacture.

The kilns consist of circular steel casings lined with fire brick at the burning zone and paving brick in the upper part. At plant 22 the tops are left open; at plant 13 they are closed by flat plates carrying stacks 40 inches in diameter by 20 feet high; at plant 28 the same size stacks are mounted on conical tops. The linings at plant 22 are circular in cross section, 4½ feet in diameter throughout the kiln; at plants 13 and 28 they are circular at the top, but are drawn into ellipses 7½ feet by 4½ feet at the burning zone. At plant 22 the kilns are 22 feet high above the grates and 6 feet below; the other kilns are 35 feet above the grates and 6 feet below. The coolers of all kilns are lined and most of them are provided with shears for drawing the lime, although some of them have doors in the sides. The kilns at plant 22 are equipped with three fire boxes, situated 120 degrees apart; the other kilns have four fire boxes, two on each side. The grates are 2 feet wide by 4½ feet deep and the arches are 27 inches high.

Snow Shoe, Pa., run-of-mine coal is burned with natural draft. The fuel beds are kept very thick and are replenished about every 20 minutes. The lime is drawn out every four hours at plant 22 and every six hours from the other kilns. The kilns are filled with stone after each draw. The sticking process is used; that is, the kilns are chilled for one-half hour before drawing, so that the lime sticks to the sides of the kilns until it is knocked down by bars. The average of determinations at kilns of the three plants show the temperature of the waste gases to be about 150° C, the maximum temperature inside the kiln is about 1300° C, the lime is red hot when drawn, and the waste gases carry about 10 per cent carbon dioxide. Figures furnished by the company indicate capacities

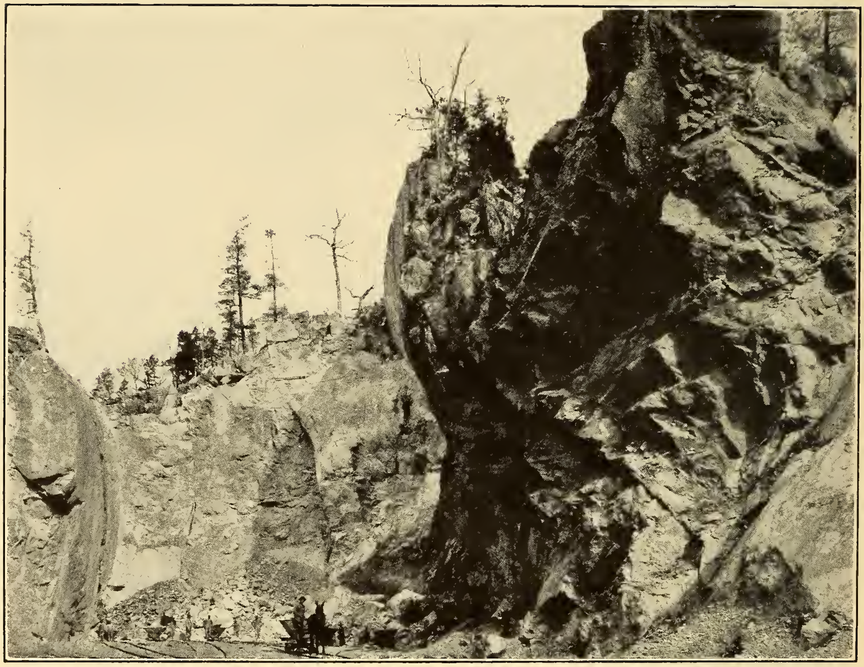

Fig. 20.—*Quarry of the Riverton Lime Co.*

of 7 tons of lime per kiln per day at plant 22 and 10 tons for the other kilns. The fuel ratio for the three plants is about 3.1 pounds of lime per pound of coal.

The lime is drawn into iron buggies, dumped on the floor to cool, and sorted. The core is thrown away and the fine stuff hydrated. Some of the lump lime is shipped in bulk, some is crushed and barreled, and some is ground and sold in iron casks. The lime is crushed by corrugated rolls and a Steadman mill carries the grinding to any fineness required, the capacity being 40 tons per day. The lime is used for chemical and building purposes. Most of the ground lime is sold for water purification. The following analyses were made by the chemist of the company in 1908:

	Fresh lump, best lime	Ground lime
	Per cent	Per cent
Silica (SiO_2)	0.12	2.10
Iron and alumina (R_2O_3)	1.17	1.68
Lime (CaO)	95.48	87.68
Magnesia (MgO)	.98	2.10
Carbon dioxide and water (CO_2+H_2O)	2.17	6.44
Total	99.92	100.00

All fine stuff and as much lime as is needed goes to the hydrate mill. Here it is crushed, slaked in a Clyde hydrator, and screened. The tailings are ground and returned to the system, and the whole product is finally put through an air separator. Two grades of hydrate are made—40 mesh, which is sold for fertilizer, and fine stuff for the manufacture of grease and of hard wall plaster.

9. RIVERTON LIME CO., RIVERTON, VA.

The plant of the Riverton Lime Co. is about one-half mile from Riverton, Warren County, Va. Riverton is the junction point of the Southern and the Norfolk & Western Railroads, but the plant is located on the main line of the latter. The topography of this locality is shown by the topographical map of the Luray quadrangle, published by the United States Geological Survey in 1905.

The deposit of Shenandoah limestone of Cambro-Ordovician age has been folded into an anticlinal formation, which strikes about north 25° east. The beds are massive, and their dip varies from vertical to 60° toward the southeast. Bedding and jointing planes are prominent, and numerous large pockets between the beds have been filled with gravel and other foreign material.

The stone is dark gray or blue, fine grained, and very dense and hard. One bed, 30 feet thick, contains a pure high calcium stone;

two others, with a thickness of 58 feet, contain considerable amounts of magnesia, and the stone from these is burned in separate kilns; the stone from the other beds is too impure to use in the manufacture of lime. The stone from the different beds can be readily distinguished by its appearance. The following analyses show its composition:

	Magnesian U. S. Geological Survey, 1909	High calcium	
		U. S. Geological Survey, 1909	Bureau of Standards, 1911
	Per cent	Per cent	Per cent
Silica (SiO_2)	0.87	0.44	0.32
Iron (Fe_2O_3)	.08	.15	.12
Alumina (Al_2O_3)	.48	.04	.23
Calcium carbonate ($CaCO_3$)	90.97	98.02	98.20
Magnesium carbonate ($MgCO_3$)	6.83	.64	1.37
Total	99.23	99.29	100.24

At a point near the kilns the stone was found to outcrop on the side of a hill. Starting here, an opening 127 feet wide has been cut into the hill along the strike of the stone for a distance of 225 feet. This quarry floor has been kept at the level of the ground at the kilns and is above drainage. The maximum height of the working face, extending from the floor to the top of the hill, is 125 feet.

The stripping, which occurred in pockets often of considerable depth, is removed by hand. The rock is drilled by compressed air and blasted with dynamite. After sledging it is sorted for both size and quality, is loaded by hand into iron cars, and hauled by horse to the foot of an incline, up which it is taken to the tops of the kilns by cable.

There are five kilns, each of which is encased in stone at the burning zone and steel above and is lined with fire brick. The tops are closed by flat plates, which carry gas mains leading to a fan. The linings are circular at the top and are drawn in to ellipses 7½ feet by 5½ feet at the burning zone. They are 35 feet high above the grates. The coolers are lined, but are provided with flues in the lining, through which the air for combustion is taken into the ash pits. They are provided with shears for drawing the lime. Each kiln has two fire boxes, one on each side. The grates are 42 inches wide by 55 inches deep and have a bridge wall 26 inches wide at the back. This supports a pillar 26 inches by 13 inches.

Fairmont, W. Va., gas coal is burned with forced and induced draft. The forced draft is created by steam jets opening into the

Fig. 21.—*Plant of the Riverton Lime Co.*

ash pits; the induced draft by a fan, which takes the gas from all five kilns and blows it out a stack. The fires are kept thin and well coked and are replenished regularly every 20 minutes. Stone is charged into the kilns whenever it comes from the quarry. The lime is drawn every six hours. The fire is permitted to burn out just before the draw, so that the kiln is somewhat chilled, and the lime is caused to stick to the sides of the kiln until it is knocked down with bars. The stack gases show an average temperature of about 200° C, and analyze 15.5 per cent carbon dioxide, 7.1 per cent oxygen, and 0.4 per cent carbon monoxide. The temperature of the interior of the kiln is about 1300° C, and the lime is drawn red to white hot. Measurements made by this Bureau in 1911 indicate a capacity of 12.6 tons of lime per kiln per day, with a fuel ratio of 4.29 pounds of lime per pound of coal. This latter figure includes the heat used to generate the steam and run the fan to create the draft.

The lime is drawn into iron buggies, dumped on the floor to cool, and sorted. The fine stuff is sold for fertilizer and the lump lime mostly for building purposes. The composition of lime burned from the magnesian stone, as found by the United States Geological Survey in 1909, is shown by the following analysis:

	Per cent
Silica (SiO_2)	1.22
Iron (Fe_2O_3)	.31
Alumina (Al_2O_3)	.25
Lime (CaO)	87.04
Magnesia (MgO)	10.63
Carbon dioxide and water (CO_2+H_2O)	.36
Total	99.81

10. E. DILLON'S SONS, INDIAN ROCK. VA.

The plant of E. Dillon's Sons is located on the Chesapeake & Ohio Railroad, at Indian Rock, Botetourt County, Va. The topography of the district is shown by the topographical map of Natural Bridge quadrangle, published by the United States Geological Survey in 1884.

About a mile back in the mountains to the north of the plant a deposit of limestone has been found. The massive beds have been folded until they dip at an angle of 40° toward the southeast and the direction of their strike is north 40° east.

The deposit contains coarsely crystalline, dense, hard limestone, which varies in color from gray to dark blue or black in the different beds. The gray and blue stones are used for the manufacture of lime, but are burned in separate kilns. The black stone is deemed too impure for this purpose. The different kinds of stone have been analyzed, as shown by the United States Geological Survey in 1909, with the following results:

	Gray	Blue	Black
	Per cent	Per cent	Per cent
Silica (SiO_2)	0.28	0.80	1.05
Alumina (Al_2O_3)	.16	.10	.40
Iron (Fe_2O_3)	.20	.35	.55
Calcium carbonate ($CaCO_3$)	98.50	97.05	96.21
Magnesium carbonate ($MgCO_3$)	.78	1.72	1.76
Total	99.92	100.02	99.97

The deposit has been opened in two places, known, respectively, as the upper and lower quarries, the latter being nearer the kilns. The upper quarry has been cut across the beds for 100 feet and extends 50 feet along the strike; 100 feet across the beds at the lower quarry reached the limit of available stone, so that this quarry is being extended along the strike with the ultimate aim of opening into the upper quarry. The length of the opening in this direction is at present 600 feet. The quarry floors have been maintained at such a level that the maximum working face in the upper quarry is 20 feet, in the lower quarry 80 feet, and both are above drainage.

The stripping at present consists of a maximum of 3 feet of red clay, but this grows deeper farther across the beds toward the top of the hill. It is removed by hand and the stone is drilled by steam furnished by boilers in the quarries. After being blasted out with dynamite the stone is sledged and sorted. The stone for the kilns is carried in cars drawn by a steam locomotive. The tracks run into the quarry through a cut which extends to within 50 feet of the working face and is of such a depth that the tops of the cars are on a level with the quarry floor. Planks are laid across the cars. The stone is loaded by hand into wheelbarrows, wheeled out on these planks, and dumped into the cars. These cars are taken directly to the tops of the kilns, where the stone is unloaded by hand into storage bins. From here it is put into the kilns by hand, filling them up after each draw.

The black stone and spawls are put through the crushing plant which is located in the lower quarry. This consists of an Austin crusher and rotary screen. Only one grade is made. The crusher reduces the stone to 2½ inches and smaller and the screen takes out anything less than one-half inch, which is thrown away. The capacity of the plant is about 200 tons per day, which is used for flux and ballast.

The three kilns consist of steel casings lined with fire brick. The tops are conical and are surmounted by stacks 42 inches in diameter by 30 feet high. The linings are circular, 7 feet in diameter throughout the kiln, 16 feet high above the grates. The coolers are 5 feet deep, are unlined, and are provided with shears for drawing the lime. Each kiln has two fire boxes, one on each side. These are 3 feet wide by 6 feet deep by 3½ feet high.

The fuel used is a mixture of wood and West Virginia gas coal burned under natural draft. The fire boxes are filled up about once an hour. The lime is drawn every two hours and each kiln is filled with stone immediately after drawing. The stone is intended to follow down as the lime is drawn out, but it sticks occasionally when the fire becomes too low. The waste gases showed an average temperature of 180° C and a composition of 8.9 per cent carbon dioxide and 11.2 per cent oxygen. The maximum temperature inside the kiln was about 1225° C. The lime is cold when drawn. Figures furnished by the company indicate a capacity of 12½ tons of lime per kiln day, with a fuel ratio of one-fourth cord of wood and 100 pounds of coal per ton of lime.

The lime is drawn into iron buggies. Some of it is cold enough to be loaded immediately; the rest must be dumped on the floor to cool. The gray stone is burned for building and chemical lime. The fine stuff from this is sold for agricultural purposes, for which the blue stone is also burned.

11. TENNESSEE MARBLE LIME CO., KNOXVILLE, TENN.

The Tennessee Marble Lime Co. is operating two plants—one about 4 miles southeast of Knoxville and the other 22 miles northeast, near Luttrell, in Union County. Both have shipping facilities on the Southern Railroad.

The geology of each of these sections is described in the Knoxville (No. 16) and Maynardsville (No. 75) Folios, Geological Atlas of the United States, United States Geological Survey, 1895 and 1901, respectively. The stone is known as the Holston marble, a stratum of the Chickamauga limestone, of Ordovician age. It outcrops in several narrow parallel zones, striking in general toward the northeast. At Knoxville the strike is north 10° east, and the dip varies from 10° to 30° toward the southwest. The beds at Luttrell strike in approximately the same direction, but the dip is directly opposite, being 10° to 30° toward the southeast.

The stone itself is a coarsely crystalline, high calcium limestone, which is familiarly known as the "Tennessee marble." It is not a metamorphic rock; the coarse texture is probably due to resolution and crystallization in place. When the calcium carbonate was dissolved, the impurities were left in thin layers and were finally surrounded by a mass of calcite crystals, giving the stone its peculiar variegated coloring. The composition is shown by the following analyses:

	Columbia School of Mines	U. S. Geological Survey, 1909			Bureau of Standards, 1911
		Knoxville		Luttrell	
		Main opening	All other openings		
	Per cent	Per cent	Per cent	Per cent	Per cent
Silica (SiO_2)	0.125	0.16	0.23	0.65	0.15
Iron (Fe_2O_3)	.260	.06	.20	.30	.14
Alumina (Al_2O_3)	Trace	.13	.08	.05	.14
Calcium carbonate ($CaCO_3$)	99.544	98.93	98.25	84.50	98.52
Magnesium carbonate ($MgCO_3$)	.047	.76	1.26	14.53	.78
Total	99.976	100.04	100.02	100.03	99.73

Both of these plants are running principally to use the waste from the marble quarries, although the latter are operated by distinct corporations. At Knoxville the beds dip into the side of a hill and have a width of about 300 feet of stone suitable for marble. On top of this rests another stratum of exactly the same stone. In this, however, there are too many seams and joints to permit quarrying for dimension stone. At Luttrell the conditions were very similar, but recently the marble company has moved its operations farther along the strike, so that the lime company was forced to open a quarry of its own near the kilns.

At Knoxville the lime company drills and blasts out the upper stratum and takes it to the kilns. Then the marble company cuts out its dimension stone with a channeling machine. The blocks are lifted out of the quarry by derricks, rough dressed by hand at the quarry, and then either shipped direct or sent to the sawmill to be cut to size and finished. All of the trimmings and waste, including sometimes big blocks of unsound stone, are turned over to the lime company. The stone for burning from three of the five openings is loaded by hand into small cars, run by gravity to the stone pile at the base of the kilns, and dumped automatically. In the other two it is loaded in skips, put on a flat car by a derrick, and pulled to the kilns by cable. From this stone pile it is picked by hand into wheelbarrows and raised to the top of the kiln by an elevator.

At Luttrell the process is now much simpler. The stone is all drilled and blasted, is picked into cars, hauled by cable to the tops of the kilns, and dumped.

The four kilns at Knoxville and the two at Luttrell consist of steel casings lined with fire brick at the top and sandstone at the

Fig. 22.—*Quarry of the Tennessee Marble Lime Co.*

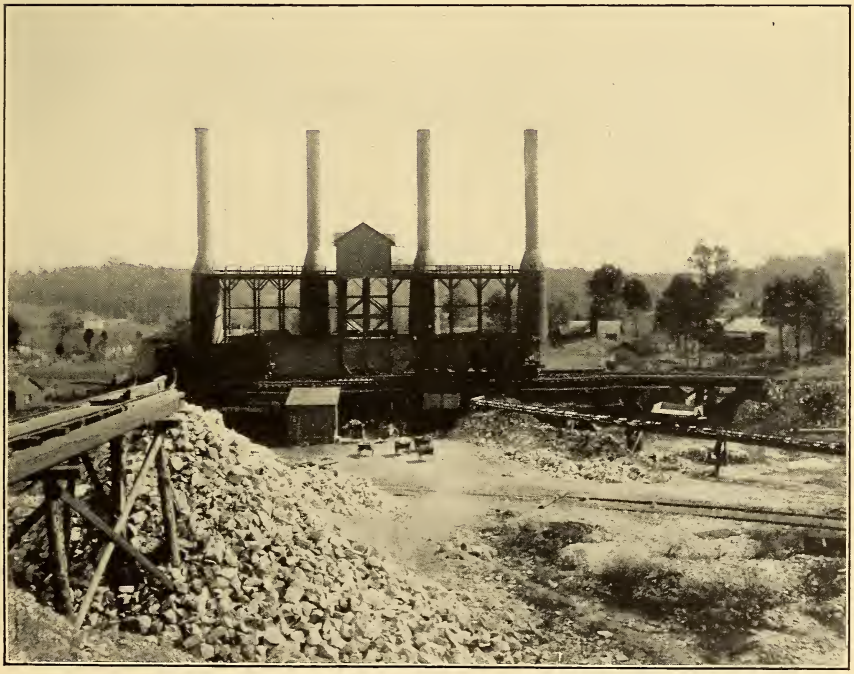

Fig. 23.—*Plant of the Tennessee Marble Lime Co.*

burning zone. The tops of the former are conical and are surmounted by stacks 4 feet in diameter by 40 feet high; the tops of the Luttrell kilns are open. The linings are shaped like inverted cones. Those at Knoxville are 6 feet in diameter at the top by 9 feet in diameter at the fire by 40 feet high above the grates; at Luttrell the diameters are 7½ feet and 9 feet 8 inches, respectively, and the height is 22 feet. The unlined coolers are 11½ feet deep and are provided with shears for drawing the lime. Most of the kilns have three fire boxes 120° apart, but some have four 90° apart. These are 24 to 36 inches wide by 42 to 48 inches deep by 18 to 22 inches high. There is a 6-inch dead plate in front of the grates and an 18-inch bridge wall in back.

Jellico, Tenn., gas coal is burned with natural draft. The fires are kept rather heavy and are replenished about every 20 minutes. The lime is drawn out every hour at Luttrell and every three hours at Knoxville. The stone is permitted to follow down and the kilns are filled up after each draw. The stack gases showed an average temperature of 230° C and an analysis of 16.8 per cent carbon dioxide, 5.5 per cent oxygen, and 0.3 per cent carbon monoxide. The maximum temperature in the kiln was about 1425° C. The lime was cold when drawn. Measurements taken by this Bureau in 1911 indicate the capacity of the Knoxville plant to be 11.7 tons per kiln per day, with a fuel ratio of 2.92 pounds of lime per pound of coal.

The lime is drawn into iron buggies and is cold enough to be weighed and loaded immediately. The core is sorted out as drawn and thrown away. The fine stuff is shipped with the lime. The lime produced by the Knoxville plant is sold exclusively for chemical purposes. The Luttrell plant furnishes mostly building lime. The following analysis shows the composition of lime, as found by the Bureau of Standards in 1911, from the Knoxville plant:

	Per cent
Silica (SiO_2)	0. 33
Iron (Fe_2O_3)	. 31
Alumina (Al_2O_3)	. 29
Lime (CaO)	97. 66
Magnesia (MgO)	. 72
Water (H_2O)	. 36
Carbon dioxide (CO_2)	. 41
Total	100. 08

12. LAGARDE LIME & STONE CO., LAGARDE, ALA.

The plant of the Lagarde Lime & Stone Co. is located at Lagarde, Etowah County, Ala. This "town" possesses no railroad station, but a spur about 1 mile long connects with the main line of the

Louisville & Nashville Railroad at Lagarde Junction. The topography of the district is shown by the topographical map of Anniston quadrangle, published by the United States Geological Survey in 1900.

The limestone dips toward the center from all directions of a mountain which extends nearly north and south. The deposit having been opened on the western side of the mountain the dip measured is about 20° toward the east, north, or south, in different parts of the quarry, and its strike is north 10° east; the beds are massive and regular with very few joints or seams.

The stone is a dense finely crystalline hard material, of gray to dark blue color. Its composition is shown, in percentages, by the following analyses. The samples were taken every 10 feet vertically, beginning at the quarry floor. In general those beds containing over 5 per cent of magnesium carbonate are not used for the manufacture of lime.

Southern States Portland Cement Co.

	1	2	3	4	5	6	7	8	9
Silica (SiO_2), iron (Fe_2O_3), and alumina (Al_2O_3)	1.56	2.92	1.20	2.08	1.24	0.82	0.92	1.56	2.18
Calcium carbonate ($CaCO_3$)	95.30	95.11	72.27	65.31	82.80	98.14	98.32	96.72	94.65
Magnesium carbonate ($MgCO_3$)	1.74	1.07	26.72	32.30	15.58	1.03	.81	1.56	2.22
Total	98.60	99.10	100.19	99.69	99.62	99.99	100.05	99.84	99.05

	10	11	12	13	14	15	16	17
Silica (SiO_2), iron (Fe_2O_3), and alumina (Al_2O_3)	1.44	1.78	1.34	1.52	2.40	3.20	3.20	3.62
Calcium carbonate ($CaCO_3$)	97.07	93.33	96.72	94.04	95.10	93.68	89.87	87.98
Magnesium carbonate ($MgCO_3$)	1.56	5.61	2.15	4.74	2.69	2.24	5.43	8.40
Total	100.07	100.72	100.21	100.30	100.19	99.12	98.50	100.00

	U. S. Geological Survey, 1909 (average of quarry)	Bureau of Standards, 1911 (average of quarry)
Silica (SiO_2)	1.64	0.13
Iron (Fe_2O_3)	.31	.19
Alumina (Al_2O_3)	.33	.21
Calcium carbonate ($CaCO_3$)	94.39	92.59
Magnesium carbonate ($MgCO_3$)	3.42	7.18
Total	100.09	100.30

The deposit has been opened in two places; the lower quarry was started as near the kiln as possible, but the ground rises so abruptly that before the opening could be pushed very far into the mountain the face became so high that economic difficulties were encoun-

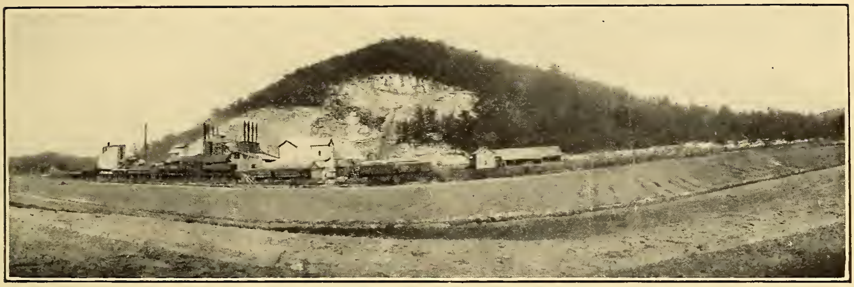

Fig. 24.—*Plant of the Lagarde Lime and Stone Co.*

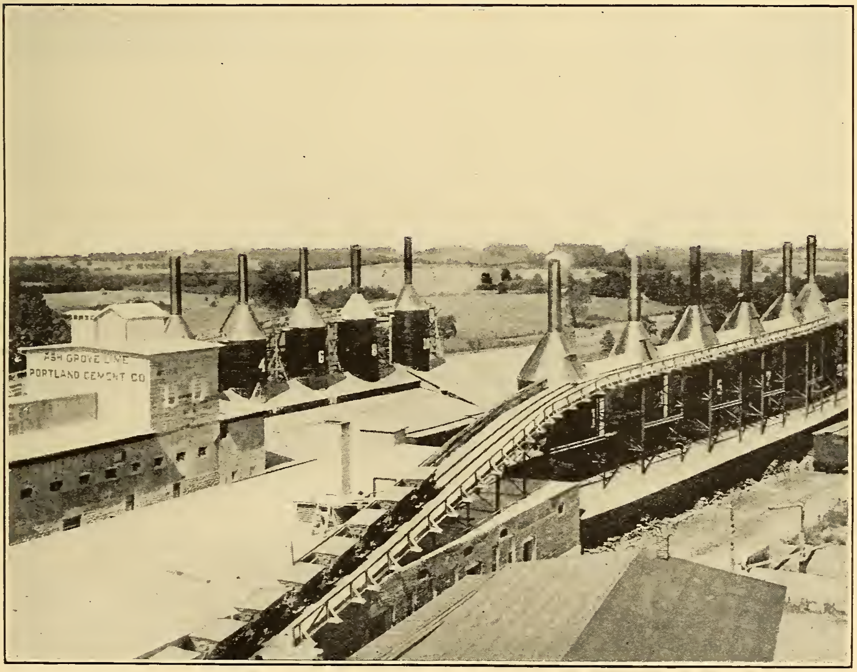

Fig. 25.—*Plant of the Ash Grove White Lime and Portland Cement Association.*

tered in working it. Therefore the upper quarry was started with its floor on a level with the top of the lower one. The two quarries communicate, the northern end of the upper quarry overlapping the southern end of the lower. They are entirely distinct, however, for the upper quarry is cut back farther and at a slightly different angle than the lower. The dimensions of the working faces of these quarries are: Of the lower, 920 feet long by 130 feet high; of the upper, 500 feet long by 94 feet high.

The stone is drilled by compressed air and blasted with dynamite. The stripping is blown down into the quarry with the stone and is then carted away and dumped. After sledging the stone is sorted with regard to both size and quality. The management has proven to its own satisfaction that the size of the stone put into the kilns has a very marked effect on their efficiency. Hence, since the crusher can always take care of the refuse, the stone is sorted to size very closely. The cars containing the stone for burning are sent down a gravity incline from the upper quarry to the lower and are pushed by hand to the foot of another incline, up which a cable takes them to the kilns. The stone from the lower quarry and the fine stuff and the magnesian stone from the upper are taken to the crusher by horse. Some of the larger blocks are shipped as quarried for riprap.

The crusher plant consists of a Gates and a jaw crusher with rotary screens. It has a capacity of 350 tons per day of all sizes from ¼-inch to 5-inch. The product is used for furnace and smelter flux, ballast, road metal, concrete, and roofing gravel.

The eight kilns consist of steel casings lined with fire brick. They are surmounted by stacks 22 inches in diameter by 37 feet high, but these were found to be useless and have been permitted to rust out, until now the kilns have practically open tops. The linings are shaped like inverted cones, 6½ feet in diameter at the top, 8 feet in diameter at the fire, by 37 feet high above the grates. The coolers are unlined and are provided with shears for drawing the lime. Each kiln is provided with four gas ports situated at points 90° apart. These ports are 18 inches in diameter and contain 2-inch pipes through which the air is admitted.

The plant is equipped with three Duff gas producers—one 12 feet 3 inches and two 10 feet 6 inches outside diameter. The fuel used is Cahaiba (Ala.) gas coal. Air is blown into the producers by means of steam jets, and the secondary air supply is forced into the kilns by a fan, one fan for the eight kilns. The kilns are kept full of stone all day, but are not filled during the night. The lime is drawn at the discretion of the fireman, usually about every three hours. The stone is permitted to follow down as the lime is removed. The waste gases showed an average temperature of 80° C and a composition of 9.3 per cent carbon dioxide, 3.5 per cent oxygen, 0.6 per cent carbon monoxide. The maximum temperature in the kiln is about 1100° C, and the lime is cold when drawn. Measurements made by this Bureau in 1911 show a capacity of 10.35 tons of lime per kiln per day, with a fuel ratio of 3.27 pounds of lime per pound of coal. This ratio takes into consideration the heat required to generate the steam and run the fan used to create the draft.

The lime is drawn into iron buggies, and most of it is cold enough to be shipped immediately. The rest is sometimes dumped on the floor to cool, but more often it is put through a small Gates crusher and elevated to a galvanized-iron storage tank, whence it may be fed into barrels by gravity. It is used mostly for building and chemical purposes.

In the hydrate mill a Gates crusher reduces the lime to 10 mesh. It is then slaked in a modification of a Clyde hydrator. In this machine the pan revolves in one direction, the shaft carrying the plows revolves in the opposite direction, and each plow has been replaced by a screw propeller which revolves on its own axis. The water is delivered from an automatic measuring tank, the volume being changed at frequent intervals to allow for variations in temperature, etc. The product is put through a Jeffreys screen and may either be packed directly or a finer grade may be taken out by means of an air separator. The Urschel-Bates bagging machine is used. The finer grade of hydrate is sold for chemical purposes, the rest for building. Its composition, as found by the Bureau of Standards in 1911, is shown by the following analysis:

	Per cent.
Silica (SiO_2)	1. 23
Iron (Fe_2O_3)	. 18
Alumina (Al_2O_3)	. 42
Lime (CaO)	71. 22
Magnesia (MgO)	1. 88
Water (H_2O)	23. 76
Carbon dioxide (CO_2)	1. 37
Total	100. 06

13. ASH GROVE WHITE LIME & PORTLAND CEMENT CO., ASH GROVE, MO.

The Ash Grove White Lime & Portland Cement Co. is operating a lime plant at Ash Grove, Green County, Mo., about 1 mile from the "Frisco" railroad station. The tracks of the main line of this road run through the plant. The topography of this district is shown by the topographical map of Greenfield quadrangle, published by the United States Geological Survey in 1886.

The deposit of stone is about three-fourths of a mile from the kilns. Here the Mississippian upper Burlington formation (Lower Carboniferous) reaches a thickness of about 26 feet, forming the main body of a small hill. The beds are practically horizontal and are cut at frequent intervals by vertical mud seams. Intermittent beds of chert, sometimes 4 inches thick and sometimes disappearing, are found throughout the deposit.

The stone is hard, but porous and coarsely crystalline. Its color varies from pure white to light gray. Its composition is:

	Authority not given	U. S. Geological Survey, 1909
	Per cent	Per cent
Silica (SiO_2)	0.11	0.21
Iron (Fe_2O_3)	.05	.05
Alumina (Al_2O_3)		Trace
Calcium carbonate ($CaCO_3$)	99.33	99.05
Magnesium carbonate ($MgCO_3$)	.68	.88
Total	100.17	100.19

Starting from the east, where the stone outcropped on the bank of the creek the bed has been followed back across the top of the hill. The working face includes the entire deposit and is therefore 26 feet high. The length exposed is about 510 feet.

The stripping consists of red clay and gravel, reaching a maximum depth of 6 feet. This is removed by hand, the stone being drilled by compressed air. The holes are sprung with dynamite and finally blasted out with Judson powder. The stone is sorted for both size and quality. The chert and spawls are carted away and dumped. The stone for burning is loaded by hand into cars and hauled to the kilns by a steam locomotive. Here the train is split up and the cars taken to the top of the kilns by a cable, three at a time.

The 11 kilns are divided into two batteries, 5 on one side of the railroad track and 6 on the other. They consist of steel casings lined with two grades of fire brick. The tops of the kilns are conical and are surmounted by stacks 30 inches in diameter by 10 feet high. The linings are elliptical at the top, 16 feet by 13 feet, and are drawn in to rectangular, 6 feet by 7½ feet, at the burning zone. The total height above the grates is 40 feet. The coolers are lined and are provided with doors in the sides through which the lime is removed. The bottoms of the coolers are formed by grates, through which the fine lime falls into a pit below and can be drawn separately from the lump lime. Each kiln has two fire boxes, one on each side. These are 42 inches wide by 6 feet deep by 36 inches high. There is a 9-inch dead plate in front, and a 12-inch bridge wall in back, which carries a pillar 9 inches by 13 inches. The grates slope upward, being 5 inches higher in back than they are in front.

Hardwood is burned under natural draft. The fire boxes are filled about every 1½ hours. The kilns are filled once a day and the lime is drawn out every 6 hours. The lime is caused to stick to the sides of the kiln until it is knocked down by bars. The temperature of the waste gases is about 340° C, and the composition is 8.2 per cent carbon dioxide, 7.3 per cent oxygen, and 0.1 per cent carbon monoxide. The temperature of the interior of the kiln is about 1200° C and the lime is red hot when drawn. Figures furnished by the company indicate a capacity of 11 tons of lime per kiln per day, with a fuel ratio of one-half cord of wood per ton of lime.

The lime is drawn into iron buggies and dumped on the floor to cool. It is sold chiefly for finishing and chemical purposes.

The fine stuff and whatever lump is needed goes to the hydrate mill. Here it is put through a Gates crusher, slaked in a Clyde hydrator, and screened through a Jeffreys screen. The tailings are ground in a Sturtevant rock emery mill and returned to the screen. The finished product is packed by the Urschel-Bates bagging machine and sold mostly to the chemical trade.

14. GLENCOE LIME & CEMENT CO., GLENCOE, MO.

One of the numerous plants of the Glencoe Lime & Cement Co. is located at Glencoe, St. Louis County, Mo. The kilns are about 2 miles from the station on the Missouri Pacific Railroad, and the quarry is about three-fourths of a mile farther north.

The topography of this district is shown by the topographical map of O'Fallon quadrangle, published by the United States Geological Survey in 1903. The country in this vicinity is composed of a number of small hills. The stone is found at about the same elevation in all of these hills and seems to form a nearly horizontal bed which has been cut away by erosion to form the valleys. The tops of the hills are formed by a deposit of flint and sandstone 2 to 6 feet thick. Under this is a bed of blue and brown limestone which in turn overlies a bed of gray limestone. Both of these stones are burned for lime, but the gray variety is preferred.

The stone is hard, but is coarsely crystalline and porous. Its composition is shown by the following analyses. The white stone is found below the gray and is not quarried at present. The gray stone is somewhat softer than the blue or brown varieties, and is therefore burned in separate kilns.

	Pittsburgh Plate Glass Co., 1905: Gray stone	U. S. Geological Survey, 1909			
		Blue	Brown	Gray	White
	Per cent	Per cent	Per cent	Per cent	Per cent
Silica (SiO_2)	0.33	0.32	0.21	0.26	1.35
Iron (Fe_2O_3)	.40	.30	.15	.20	.40
Alumina (Al_2O_3)		.13	.06	.02	.53
Calcium carbonate ($CaCO_3$)	98.18	98.29	98.89	98.84	94.89
Magnesium carbonate ($MgCO_3$)	Trace.	1.05	.67	.65	3.05
Total	98.91	100.09	99.98	99.97	100.22

The quarry has been opened by cutting into the side of a hill, thus exposing the full depth of the deposit. The working face is about 60 feet high by 680 feet long.

After the soil has been removed by hand, the stone is drilled by compressed air, the holes sprung with dynamite, and finally blasted with Judson powder. The stone is sorted for both size and quality; the flint and sandstone cap rock and the fine stuff are thrown away. The gray limestone is kept separate from the blue and brown varieties, but both are loaded by hand into cars and hauled to the kilns by mules. Here a cable is attached to haul the stone up an incline to the tops of the kilns.

The six kilns consist of steel casings lined with two grades of fire brick. The tops of four of them are open; the other two are closed by flat plates carrying gas mains. The linings are 9 feet square at the top and are drawn into rectangular, 6 feet by 7 feet at the fires. The height above the grates is 22 feet. The coolers are lined and are provided with doors in the sides for drawing the lime. Each kiln has two fire boxes, one on each side. These are 4 feet deep by 4 feet wide by 28 inches high.

The fuel used is Illinois No. 3 washed gas coal, which is burned in rather thick beds, replenished every 45 minutes. The draft for two of the kilns is both forced and induced—forced by blowing steam under the grates and induced by means of a fan which takes all of the gas from the top of the kiln and blows it out a stack. The draft for the other four is created according to the Eldred process. A fan takes as much gas as is needed from the top of the kiln and forces it under the grates, the rest of the gas being permitted to escape through the open top. Each one of the six kilns is provided with its own fan. The kilns are filled twice a day, and the lime is drawn out every six hours. The lime is caused to stick to the sides of the kiln until it is knocked down with bars. The temperature of the waste gases is about 200° C, of the interior of the kiln about 1400° C, and the lime is red hot when drawn. Figures furnished by the company indicate a capacity of about 10 tons of lime per kiln per day, with a fuel ratio of about 3 pounds of lime per pound of coal. This latter figure does not include the power required to run the fans or generate the steam used in creating the draft.

The lime is drawn every six hours into iron buggies and dumped on the floor to cool. The core is discarded. Fine stuff is shipped with the lump, both being used mainly for building purposes. Its composition, as found by Chauvenet, analytical chemist, of St. Louis, in 1905, is:

	Per cent
Silica (SiO_2)	0.05
Iron and alumina (R_2O_3)	.36
Lime (CaO)	98.36
Magnesia (MgO)	.26
Carbon dioxide (CO_2)	.97
Total	100.00

15. MARBLEHEAD LIME CO., MARBLEHEAD, ILL.

The kilns of the Marblehead Lime Co. are located about one-eighth mile from Marble Head station, on the Chicago, Burlington & Quincy and Wabash Railroads, in Adams County, Ill. The quarry is about three-fourths of a mile from the kilns, on a small peninsula formed by a bend in a creek.

The stone is found here in practically horizontal beds, which have been cut through by the creek. There are few joints or seams in it, but it is interbedded with flint and with a more finely crystalline limestone.

The stone is pure white in color, coarsely crystalline, and porous, but very hard. Its composition is:

	Atlas Portland Cement Co., 1907	U. S. Geological Survey, 1909
	Per cent	Per cent
Silica (SiO_2)	0.36	0.21
Iron (Fe_2O_3)	1.22	.10
Alumina (Al_2O_3)		.04
Calcium carbonate ($CaCO_3$)	98.97	98.45
Magnesium carbonate ($MgCO_3$)	Trace	1.28
Total	100.55	100.08

The quarry was originally opened in the left bank of the creek with the intention of following the stone across the peninsula. After going about half the distance, however, the overburden of clay and gravel reached a depth of 20 feet in some places. This was too much to remove economically, so that mining was adopted.

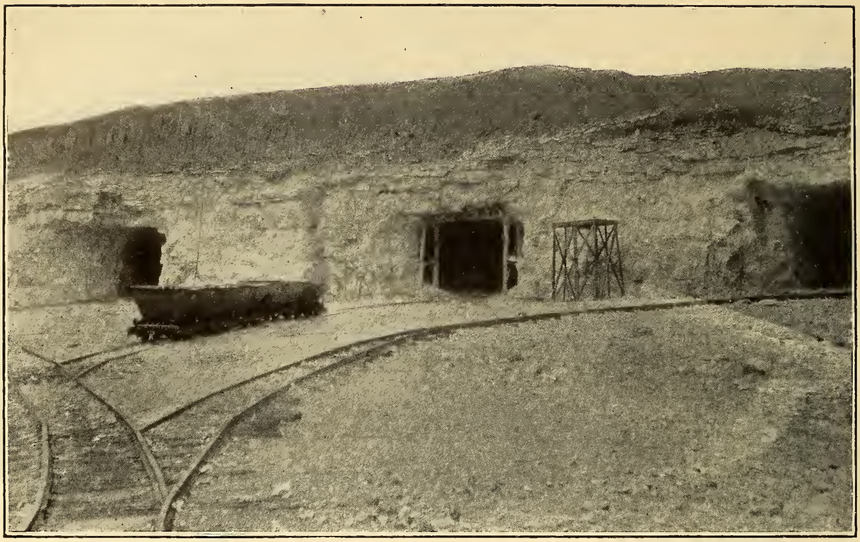

Fig. 26.—*Quarry of the Marblehead Lime Co.*

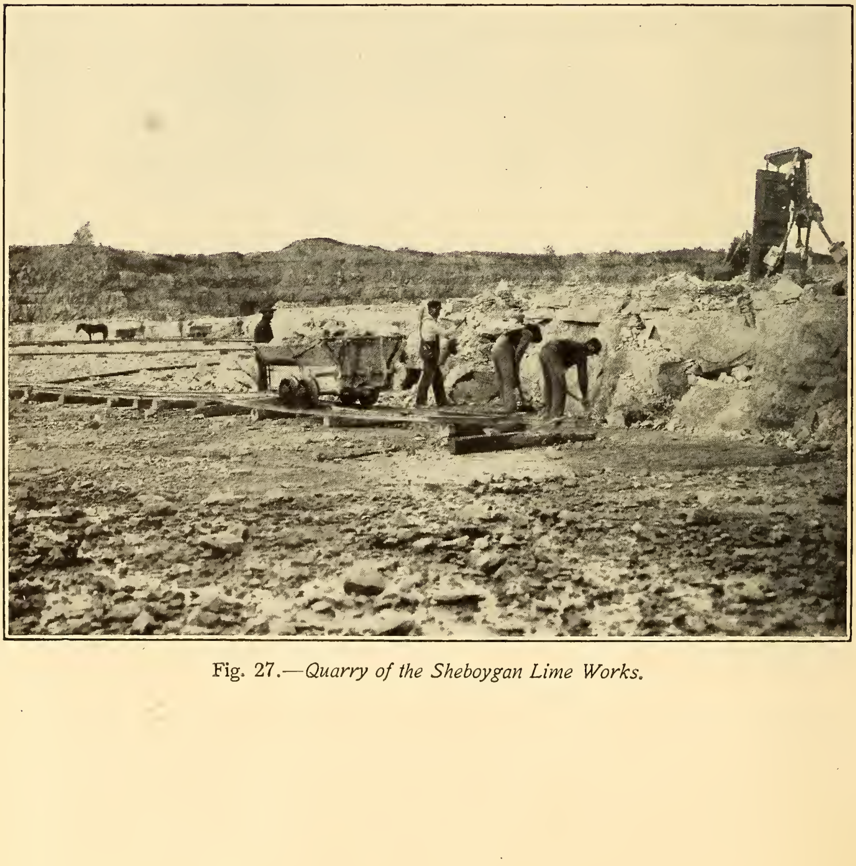

Fig. 27.—*Quarry of the Sheboygan Lime Works.*

Three entries have been driven, the bottoms of which are on a level with the quarry floor, and enough rock is left on top to form a solid roof. These entries are each 50 feet wide by 18 feet high. Two of them have been extended in 100 feet and the other one 60 feet.

The drilling is done by compressed air and the blasting with dynamite. After sledging the stone is sorted for both size and quality. The spawls, flint, and fine-grained stone are crushed. The cars into which the stone has been loaded are hauled to the end of the quarry by horse and taken to either the crusher or kilns by a steam locomotive. This delivers the stone directly to the crushing plant, but the stone for burning is hauled to the top of the kilns by cable.

The crushing plant consists of a Gates crusher with stationary screens. It has a capacity of 120 tons per day. The sizes made are three-eighths inch, three-fourths inch, and 2 inches, all of which are used for concrete. Some of the largest size is also sold for ballast.

The five kilns are built of stone lined with fire brick and have open tops. The linings are rectangular, 5 feet by 7 feet at the fires by 22 to 25 feet high above the grates. The coolers are 7 to 8 feet deep, are brick lined, and are provided with doors in the bottom for removing the lime. Each kiln has two fire boxes, one on each side. These are 5½ to 6 feet deep by 40 inches wide by 30 inches high. There is a 2-foot bridge wall at the back of the grates, which supports a 12-inch square pillar.

The fuel is a mixture of hardwood and Verden, Ill., No. 4 coal, and is burned with natural draft. The fire boxes are filled every hour. The kilns are kept full all day and the lime is drawn out every four hours. The lime is caused to stick to the sides of the kiln until it is knocked down by bars. The waste gases show a temperature of about 350° C, the interior of the kiln 1400° C, and the lime is red to white hot when drawn. Figures furnished by the company show a capacity of about 10 tons of lime per kiln per day, with a fuel ratio of about one-eighth cord of wood and 600 pounds of coal per ton of lime.

The lime is drawn into iron buggies and dumped on the floor to cool. When cool, it is sorted and the lump lime shipped for building purposes. The other products are at present rejected, but a hydrate mill is in process of construction.

16. SHEBOYGAN LIME CO., SHEBOYGAN, WIS.

The plant of the Sheboygan Lime Co. is about 2½ miles from Sheboygan, Wis., on the Chicago & North Western Railroad.

The stone lies in very nearly horizontal beds, in a belt about 1000 feet wide. It is overlain on the southwest by a cherty limestone, and on the northeast it changes to a soft, impure limestone.

The stone is finely crystalline gray dolomite on top, but the content of magnesium carbonate decreases with increasing depth of the quarry. It is fairly free from joints or seams, but contains a few beds where the flint or other impurities make it unfit for burning.

The following analysis by the United States Geological Survey in 1909 shows the average composition:

	Per cent
Silica (SiO_2)	0.55
Iron (Fe_2O_3)	.40
Alumina (Al_2O_3)	.24
Calcium carbonate ($CaCO_3$)	55.09
Magnesium carbonate ($MgCO_3$)	43.91
Total	100.19

Owing to the form of the deposit and the comparative flatness of the country, the direction of quarrying must necessarily be downward. The opening at present is elliptical in shape, covering the full available width of the deposit. It is about 1180 feet by 940 feet by 65 feet deep.

The stripping consists of 6 to 8 feet of red clay and gravel. This is removed by hand and hauled away, some of the gravel being marketable. The stone is drilled with compressed air and blasted with dynamite. After sledging it is sorted for both size and quality. The impure stone and spawls are sent to the crusher. Owing to its peculiar character the good stone is sometimes sorted, since, by selecting stone from any one bed, a special grade of lime can be made containing a specified amount of magnesia. All stone is picked into cars and hauled to the foot of the tramway by horses. There are two of these inclines, one leading to the kilns and the other to the crusher. Each is furnished with an automatic switch at the bottom, which shunts the empty cars out of the way. The cars are pulled up the incline by cables.

The incline to the crushing plant ends in a very steep section, so that the car is tilted backward until almost vertical. At the same time a projection from the side of the building knocks loose the tailboard of the car. Thus, the stone is automatically dumped into a Gates crusher. This has a capacity of about 100 tons per day, crushing to 1 inch and smaller. The stone is graded by a rotary screen and is used mostly for road metal.

Of the four kilns two have square stone casings; the other two are inclosed in cement at the burning zone and steel on top. All kilns are lined with fire brick and have open tops. The linings of the

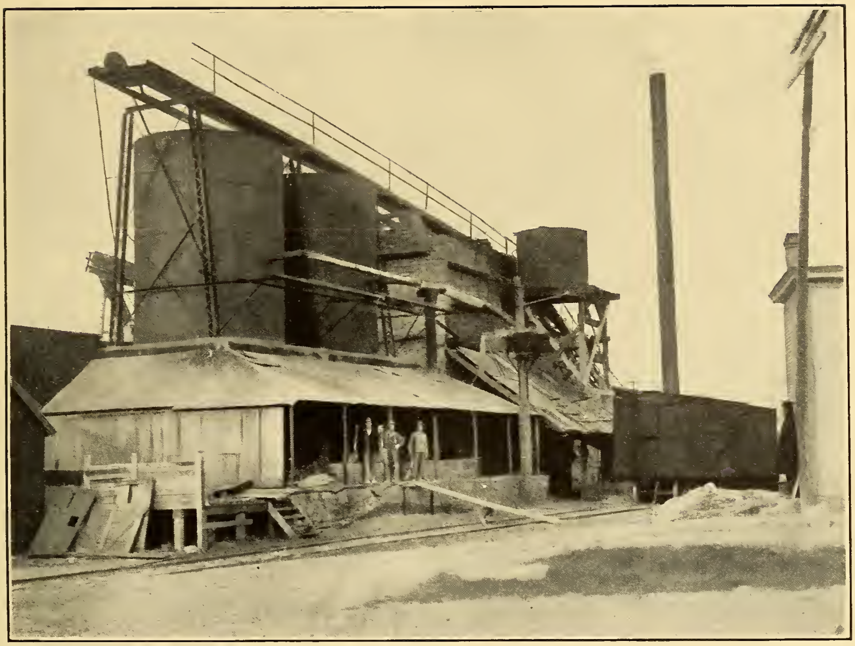

Fig. 28.—*Plant of the Sheboygan Lime Works.*

Fig. 29.—*Plant of the Union Lime Co.*

stone kilns are 6½ feet square at the fires; the others are elliptical, 6 by 6½ feet. The height above the grates is about 30 feet. The coolers are 11 feet deep, are brick lined, and are provided with shears for drawing the lime. Each kiln has two fire boxes, one on each side. These are 4 feet wide by 4½ feet deep by 26 inches high. A pillar 12 inches square is mounted on the bridge wall at the back of the grates. The grates slope upward, being 8 inches higher at the back than at the front.

Three kilns burn Youghiogheny, Pa., gas coal; the other burns wood. The wood is burned with natural draft; for the other kilns the draft is created according to the Eldred process. A fan draws the amount of gas needed from the tops of the kilns and forces it under the grates. One fan supplies the three kilns. The fires are replenished about every 20 minutes. The kilns are filled twice a day, and the lime is drawn out every four hours. The sticking process is used—that is, the lime is caused to stick to the sides of the kiln until it is knocked down by bars. The temperature of the waste gases is about 80° C; of the interior of the kiln about 1225° C, and the lime is red to white hot when drawn. An average analysis of the waste gases is, carbon dioxide, 5.2 per cent; oxygen, 8.7 per cent; carbon monoxide, none. Figures furnished by the company show the capacity to be about 9 tons of lime per kiln per day, with a fuel ratio of about 4½ pounds of lime per pound of coal. This figure does not include the power required to run the fan.

The lime is drawn into iron buggies and dumped on the floor to cool. When cold, the lump lime is sorted out and sold for building purposes. The other products, core and fine lime, are thrown away. Its composition, as found by Davenport Fisher, analytical chemist, of Milwaukee, in 1907, is shown by the following analysis:

	Per cent
Silica (SiO_2)	0. 78
Alumina (Al_2O_3)	. 56
Iron (Fe_2O_3)	. 37
Lime (CaO)	56. 22
Magnesia (MgO)	40. 35
Loss (carbon dioxide and water)	1. 56
Total	99. 84

17. UNION LIME CO., HIGH CLIFF, WIS.

One of the numerous plants of the Union Lime Co. is located at High Cliff, Calumet County, Wis. It is on the shore of Lake Winnebago, which formerly furnished means of water transportation. This has now been abandoned in favor of railroad connections with the Chicago, Milwaukee & St. Paul and the Minneapolis, St. Paul & Sault Ste. Marie Railroads at Sherwood, the nearest station, 2½ miles away.

At High Cliff the land rises abruptly from the shore of the lake to a considerable height. The stone is found in nearly horizontal beds near the top of the hill. The available deposit is about 10 feet thick and is badly cut up by joints and mud seams. It is underlain by another deposit of the same kind of limestone, but this is interbedded with chert to such an extent as to be practically worthless.

The stone is a finely crystalline white dolomite. As analyzed by the United States Geological Survey in 1909, it shows the following composition·

	Per cent
Silica (SiO_2)	1. 12
Iron (Fe_2O_3)	. 40
Alumina (Al_2O_3)	. 06
Calcium carbonate ($CaCO_3$)	54. 82
Magnesium carbonate ($MgCO_3$)	43. 79
Total	100. 19

The quarry has been opened by making a cut near the top of the hill on the side nearest the kilns and is being extended by widening this cut. The working face is 600 feet long by 10 feet high, including the entire thickness of the available stone.

The 1 foot of clay overburden is removed by hand, the stone drilled by steam and blasted with dynamite. It is then sledged and sorted for size only, since all stone from the 10-foot bed worked is good for burning. The spawls are thrown away. The stone for the kilns is loaded by hand into carts and hauled down. So steep is the hill that two horses and a cable are necessary to handle a cart containing 3 cords of stone. The cable is carried around a drum at the top of the hill. One end is fastened to the loaded cart at the top and the other to the empty cart at the bottom. Thus, it helps the horses up the hill and acts as a brake for those going down.

There are three square stone kilns lined with fire brick and having open tops. The linings are 14 feet square at the top and are drawn in to rectangular shafts 7 feet by 8 feet at the fires. The height is 35 feet over all. The coolers are brick lined and are provided with doors in the sides through which the lime is removed. The bottoms of the coolers are formed by grates, through which the fine lime falls into pits, so that it can be drawn separately from the lump. Each kiln has two fire boxes, one on each side. These are 6 feet deep by 5 feet wide by 3 feet high. The bridge wall at the back of the grates carries two pillars, each 9 inches square.

The fuel used is wood burned with natural draft. The fire boxes are filled about every one and one-half hours. The kilns are charged whenever stone comes from the quarry, at no regular intervals. The lime is drawn out every four hours. It is caused to stick to the sides of the kiln until it is knocked down with bars. The temperature of the waste gases is about 90° C; of the interior of the kiln about 1250° C; and the lime is red to white hot when drawn. Figures furnished by the company indicate a capacity of about 12 tons of lime per kiln per day, each ton requiring the consumption of about one-half cord of wood.

The lime is drawn into iron buggies and is sorted as drawn. The lump lime is permitted to stand in the buggies until cold. It is then dumped in the cars and shipped as building or chemical lime. The fine stuff, and whatever lump lime is needed, is taken to the hydrate mill. Here it is put through a Sturtevant rotary crusher and is slaked in a Clyde hydrator. The product is screened by a Jeffreys screen. The tailings from this are put through a Williams pulverizer and bolted. The coarse stuff still remaining is thrown away; the rest is put back on the screens. The hydrate is packed by an Urschel-Bates bagging machine and is sold for building, finishing, and chemical purposes.

18. WHITE MARBLE LIME CO., MANISTIQUE, MICH.

The chief business of the White Marble Lime Co. is the manufacture of cedar posts, ties, and shingles. They found that after the timber was removed some of their land could be worked for limestone, so the lime business naturally followed. At present their operations include four quarries, two batteries of kilns, two crushing plants, and a hydrate mill. The original quarry was opened at Manistique, Mich., about one-half mile from the station of the Minneapolis, St. Paul & Sault Ste. Marie Railroad. At Marblehead, about 6 miles from Manistique, is another quarry and a battery of kilns. There is no railroad station at this place, but a spur three-fourths of a mile long connects with the main line of the same railroad. Another plant is at Blaney, about 22 miles from Manistique. This is on the Blaney & Southern Railroad, which connects with the main line of the Minneapolis, St. Paul & Sault Ste. Marie Railroad at Blaney Junction, about 1½ miles from the quarry. The fourth quarry is at Indian Dam, about 4 miles from Manistique. There is no railroad here, so the quarry is operated only during the winter, when the stone can be hauled into Manistique by sledge.

The deposits all consist of nearly horizontal beds of limestone, lying close to the surface of level ground. The upper beds are thin and badly jointed, but the thickness increases with increasing depth, and the joints and mud seams become less prominent.

The deposits at Manistique and Marblehead consist of coarsely crystalline hard dolomite, which is gray to blue in color. At Indian Dam the stone is somewhat finer grained and more nearly white. The stone from Blaney is a fine-grained dense high calcium limestone. The following analyses show their compositions, by percentages:

	Manistique		Marblehead: U. S. Geological Survey, 1909	Blaney						Indian Dam	
	L. S. C. & I. Co., 1906	U. S. Geological Survey, 1909		Lake Superior Chemical & Iron Co. (different beds), 1906					U. S. Geological Survey, 1909	L. S. C. & I. Co., 1906	U. S. Geological Survey, 1909
Silica (SiO_2)	2.10	1.92	0.56	0.60	1.40	0.25	0.56	1.30	1.23	0.20	1.04
Iron (Fe_2O_3)	.40	.30	.20	.61	Trace.	.36	.26	.28	.50	.21	.25
Alumina (Al_2O_3)		.03	.05						.19		.05
Calcium carbonate ($CaCO_3$)	64.72	54.04	55.00	95.98	97.50	97.93	94.73	93.00	94.38	58.12	54.25
Magnesium carbonate ($Mg\ CO_3$)	33.75	43.81	44.31	2.70	1.00	.38	3.82	5.14	3.74	41.08	44.52
Total	100.97	100.10	100.12	99.89	99.90	98.92	99.37	99.72	100.04	99.61	100.11

The upper beds of stone at the Manistique quarry were found to be unsuitable for the manufacture of lime. Rather than sort out stone from the lower beds it has been found more economical to work the whole deposit for crushed stone only. The stone used for burning is taken mainly from the quarries at Marblehead and Blaney. The badly broken stone from the top beds of the Blaney deposit is crushed and the good stone is burned in the kilns at Manistique. These quarries are semicircular in shape, the floor sloping from the ground level to the depth of the available deposit. The working faces are 2000 feet long by 8 feet high at Marblehead and 600 feet long by 10 feet high at Blaney.

At all of the quarries the small amount of clay overburden is removed by hand, the stone is drilled with steam drills, blasted with dynamite, and sledged. At Manistique it is loaded by hand into cars, hauled by horse to the foot of an incline, and trammed to the crushing plant by cable. At Marblehead the stone is sorted

Fig. 30.—*Manistique Plant of the White Marble Lime Co.*

to size, the spawls being left in the quarry. The good stone is loaded by hand into carts and hauled by horses directly to the top of the kilns. The stone from the upper beds at Blaney is separated from that from the lower beds. Both are loaded by hand into carts and hauled out of the quarry by horses. The former is taken directly to the crushing plant; the latter is dumped into freight cars, shipped to Manistique, unloaded into smaller cars, and trammed by cable to the tops of the kilns.

The crushing plant at Manistique consists of two Gates crushers (Nos. 3 and 4) followed by a rotary screen. It produces about 400 tons of crushed stone per day, most of which, especially the finer sizes, is used for concrete construction. At Blaney there is merely a jaw crusher. This turns out about 100 tons of crushed stone per day, which is put through a rotary screen and sold for ballast and concrete.

The four kilns at Manistique and two at Marblehead consist of square stone casings lined with fire brick. The tops are left open. The linings vary from 10½ to 13 feet square at the top and are drawn in to rectangular, either 6½ by 7½ feet or 7 by 8 feet at the fires. The total height varies from 40 to 42 feet. The coolers are brick lined and are provided with doors in the bottom, through which the lime is drawn. Each kiln has two fire boxes, one on each side. These are 6 feet deep by 5 feet wide by 34 inches high. They are provided with 21-inch bridge walls in back of the grates, which carry pillars 9 inches square.

Wood is burned under natural draft in all kilns, the fire boxes being filled up about once an hour. The kilns are charged whenever the stone comes from the quarry, at no regular intervals. At Manistique the lime is drawn out every hour; at Marblehead every eight hours. The kilns are so operated that the lime sticks to the sides until it is knocked down with bars. The waste gases are very hot, it being occasionally possible to see flames coming out of the tops of the kilns. The interior of the kiln showed a temperature of about 1000° C. The lime is cold when drawn at Manistique; white hot at Marblehead. Figures furnished by the company indicate a capacity of 8 tons of lime per kiln per day at Manistique and 15½ tons at Marblehead. The fuel consumption is about one-fourth cord of wood per ton of lime.

The lime at both plants is drawn into iron buggies and is sorted as drawn, so that it may be left in the buggies to cool. It is used for chemical, building, and finishing lime.

The hydrate mill is supplied exclusively with dolomitic lime from Marblehead. The composition of the lime, as shown by the Lake Superior Chemical & Iron Co., is:

	Manistique	Marblehead
	Per cent	Per cent
Silica (SiO_2)	0.34	0.05
Iron and alumina (R_2O_3)	2.35	.16
Lime (CaO)	92.92	57.28
Magnesia (MgO)	2.07	39.86
Total	97.68	97.35

The hydrate plant is equipped with a Gates crusher, a Clyde hydrator, and a Jeffreys screen. The tailings from the screen are ground in a Sturtevant rock-emery mill and returned to the screen. The product is packed by an Urschel-Bates bagging machine, and is used for building, chemical, and agricultural purposes.

The following analysis by the Bureau of Standards in 1911 shows the composition:

	Per cent
Silica (SiO_2)	3.05
Iron (Fe_2O_3)	.30
Alumina (Al_2O_3)	.20
Lime (CaO)	48.76
Magnesia (MgO)	30.04
Carbon dioxide (CO_2)	.92
Water (H_2O)	16.32
Total	99.59

19. WOODVILLE WHITE LIME CO., WOODVILLE, OHIO.

The plant of the Woodville White Lime Co., is located about one-half mile from Woodville station on the Pennsylvania Railroad, in Sandusky County, Ohio. The topography of this district is shown by the topographical map of Elmore quadrangle, published by the United States Geological Survey in 1903. The deposit consists of thick horizontal beds, which lie close to the surface of a level country. The bedding is even and regular with few joints or seams. The upper beds show the effect of weathering, being very soft and porous and containing numerous small pockets filled with calcite crystals.

The stone is a soft, oolitic, fossiliferous dolomite. It is normally yellow in color, but weathers to gray or blue. Its composition, as analyzed by the United States Geological Survey in 1909, is:

	Per cent
Silica (SiO_2)	0.34
Iron (Fe_2O_3)	.15
Alumina (Al_2O_3)	.02
Calcium carbonate ($CaCO_3$)	56.79
Magnesium carbonate ($MgCO_3$)	42.92
Total	100.22

Owing to the formation of the deposit, the quarry has taken the shape of a circular pit. This is being extended both by enlarging the diameter and lowering the floor. The main opening is about 410 by 450 by 20 feet deep. In the western part of this pit a second bench 200 feet in diameter has been extended downward 25 feet farther.

The small amount of clay stripping is removed by hand, the stone drilled by compressed air and blasted with dynamite. It is generally necessary to sort the stone for size only, although occasionally bedding seams are found filled with calcite, which must be discarded. The stone large enough for burning is loaded into carts, hauled by horses to the foot of the incline, and dumped into tram cars in which it is pulled by cable to the tops of the kilns. The fine stuff is taken to the crusher on the quarry floor.

The crushing plant consists of a Gates crusher and rotary screen. It has a capacity of about 100 tons per day. The three sizes made—fine stuff, one-half inch and 1½ inches—are used exclusively for road metal.

The 15 kilns are built of steel casings lined with fire brick. The tops are left open. The linings are circular, 7 feet in diameter at the top, and are drawn in to ellipses 58 by 70 inches at the fires. The height over all is 31 feet, 23 feet being above the grates. The coolers are lined and are provided with shears for drawing the lime. Each kiln has two fire-boxes, one on each side. These are 6 feet deep by 2 feet wide by 2 feet high. They are provided with dead plates in front of the grates and bridge walls carrying pillars in back.

One of the kilns burns wood with natural draft; the other 14 burn Cambridge (Ohio) coal, the draft for which is forced by steam injectors under the grates. The fires are kept rather thin, and are replenished about every half hour. The kilns are filled once a day and the lime is drawn every four hours. The lime is caused to stick to the sides of the kiln until it is knocked down by bars.

The waste gases showed an average tempertaure of about 75° C, and contained about 14.5 per cent carbon dioxide. The interior of the kiln was about 1285° C, and the lime was red to white hot when drawn. Figures furnished by the company show a capacity of about 14 tons of lime per kiln per day, with a fuel ratio of 4.68 pounds of lime per pound of coal. This figure does not include the heat used to generate the steam for the draft.

The lime is drawn into iron buggies, dumped on the floor to cool, and sorted. The product of the wood-fired kiln is sold in the lump to the local building trade. The core is put back in the kilns and burned again. All the rest of the output is hydrated.

In the hydrate mill the lime is ground to about the size of wheat, hydrated in a Clyde machine, and packed in Urschel-Bates valve bags. The product is sold almost exclusively for finishing lime. Its composition, as found by S. V. Peppel, Columbus, Ohio, in 1909, is shown by the following analysis:

	Per cent
Silica (SiO_2)	0.24
Iron (Fe_2O_3)	.06
Alumina (Al_2O_3)	.22
Lime (CaO)	52.27
Magnesia (MgO)	28.96
Water (H_2O)	16.79
Total	98.54

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