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LIME RESOURCES AND INDUSTRY IN OKLAHOMA

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LIME RESOURCES AND INDUSTRY IN OKLAHOMA.

INTRODUCTORY.

The writer began investigations concerning the lime industry of Oklahoma during the summer of 1916, at which time, while in the employ of the Oklahoma Geological Survey, he visited the three plants then operating in the State. When in the spring of 1917 it was learned that there was only one plant in the State producing lime for commercial purposes, plans were made for doing special work concerning the lime resources of the State.

With Oklahoma's almost inexhaustible resources for lime production in the way of limestone, fuel, and market, it seemed fitting that a study should be made of the conditions of manufacturing lime, with the hope of stimulating the development of the industry.

In the following pages an attempt has been made to gather that information which might be of use to the lime producer and for which, ordinarily, he would be forced to search many publications.

In the preparation of this paper a considerable number of works on the subject has been consulted, a list of the more important of which is appended. From many of these the writer has drawn freely but has made an attempt in each case to fully accredit the proper author.

In gathering the material for this report, all of the producing lime plants of the State and many of the old ones now abandoned were visited. Samples from most of the lime formations in the State that might be useful in the production of lime have been tested. The information gathered by field and laboratory work has been materially supplemented by that gained through questionaires sent to many operators and superintendents of various industrial plants.

The writer wishes to take this opportunity to thank Dr. M. G. Mehl for the interest he has taken in the present paper and his generous assistance in its preparation. The writer is also indebted to Mr. C. W. Shannon, Director of the Oklahoma Geological Survey, who has offered many valuable suggestions and has assisted in a material way; to Mr. V. V. Waite, who has made several analyses of material; and to Mr. J. P. Thoburn, who has assisted the writer in procuring data concerning the early lime production. The writer wishes further to express his appreciation for the hearty co-operation on the part of the various lime companies throughout the State.

LIME.

Few, perhaps, realize on first thought, the importance of lime in the affairs of man. One can scarcely recall any sort of building operations, in which lime does not take some part, and its importance in chemical compounds and the many commodities of every day life can scarcely be over-estimated. Lime has been used since earliest historic times and has become indispensable in the every day life of all civilized peoples. One can scarcely eat a meal in the modern home or restaurant without eating something that contains lime or in the preparation of which lime has played an important part. The china owes its glaze to ceramic properties of lime. It is a necessary constituent of many vegetables and is used in the manufacture of sugar, and preparation of rice, hominy, and many jellies and preserves.

Chemically, lime is a compound of calcium and oxygen, and oxide of calcium (CaO). In the commercial world lime usually means the solid material left after all the carbon dioxide (CO_2) is expelled from limestone. When fresh from the kiln it should contain no water and less than .5 per cent carbon dioxide.

Lime contains by weight 5 parts of calcium and 2 parts of oxygen. It is a very active substance, hence not found free in nature. It is most often found in combination with carbon dioxide (CO_2) and is called calcium or lime carbonate. Substances containing this lime carbonate, such as limestone, marble, calcite, oyster shells, travertine, and coquina are the most common sources of commercial lime. The chief source, however, is limestone. Much lime is produced from marble, which was a limestone before it was metamorphosed, and the physical change has had very little effect on the rock so far as its chemical composition is concerned.

Calcium carbonate is slightly soluble in pure water. One liter of pure water solution, at 8.7° C., will dissolve 0.01 of a gram of the compound.* It is more soluble in carbon dioxide waters which is a solution of carbonic acid. This acid reacts on the calcium carbonate, forming calcium bicarbonate according to the following reaction:

Water (H_2O) plus Carbon dioxide (CO_2)=Carbonic acid (H_2CO_3)

and

Carbonic acid (H_2CO_3) plus Calcium carbonate ($CaCO_3$)=Calcium bicarbonate ($CaH_2(CO_3)2$).

One liter of water saturated with carbon dioxide (CO_2), at 15° C., will dissolve 0.385 gram calcium carbonate ($CaCO_3$) in the form of a bicarbonate. These are laboratory results, however, and are, perhaps, a trifle high for waters at the surface. On the other hand, when water is under pressure, as it obviously is at any considerable depth, it is able to carry much more material in solution.

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*Burchard, E. F. and Emley, W. E., Source, manufacture and use of lime; U. S. Geol. Survey, Mineral resources, 1913, p. 1512.

Water sinking down through the earth gathers more and more carbon dioxide from decaying carbonaceous material. In a lime region the water begins to dissolve the limestone, forming calcium bicarbonate. This reduces the concentration of the carbon dioxide, allowing the water to pick up more and more until it gets below the level of decaying carbonaceous material. Not only the taking up of the carbon dioxide by the calcium carbonate but also the increased pressure itself is supposed to allow a greater concentration of carbon dioxide. This greater concentration, as well as the added pressure makes possible a greater solution of the limestone. The ground-water finally finds its way to the surface and passes on to the rivers.

Calcium carbonate ($CaCO_3$) in solution in streams, is carried to the ocean and deposited in the form of solid remains of lime secreting animals or plants, or as a chemical precipitate. As a matter of fact, however, while the evaporation of sea-water tends toward a concentration of all the minerals in solution in the sea, it is rare that this mineral, although it has a relatively low degree of solubility, ever becomes so concentrated as to form a chemical precipitate. In fact, a chemical analysis of ordinary sea-water shows that of the solids which are in solution, calcium carbonate comes sixth, and of 100 parts solid, calcium carbonate forms 0.434 of one part. This small amount of calcium carbonate in sea-water is a result of its constantly being taken out of solution by the agency of organic life.

Many organisms build skeletons and hard parts with calcium carbonate and when the animals die these hard parts sink to the bottom and form deposits of limestone. While these are chemical deposits in the broader sense, their precipitation is immediately dependent upon organisms, and, therefore, they are called organic deposits. Only when calcium carbonate is deposited as a free chemical precipitate is it so called.

These organic deposits may range from distinctly bedded, flaggy limestones, to thick, heavy-bedded, massive limestones, and from fine-textured, even lithographic stone, and chalks, through granular, crystalline, up to beds composed largely of poorly cemented shells.

With many exceptions all limestone deposits in Oklahoma may be regarded as organic. In the Arbuckle limestone, the Chimney Hill limestone, and the Wapanucka limestone are to be found horizons composed largely of oolite. Whether oolite should be classed as a chemical precipitate or an organic deposit is still a debated question. Oolite is a limestone composed of small, round, concretionary grains cemented togther. The grains resemble the roe of fish and are called "oolites" from the Greek word for egg.

Limestone is found in every degree of purity, ranging from the chemically pure down to a condition in which there is so much other material that it is no longer called limestone, but sandy lime, lime sand, calcareous shale, mud, etc.

In regard to this subject Clark* says:

> It is evident that important limestones may be formed in various ways, which, however, are chemically the same. Calcium carbonate withdrawn from fresh or salt water is laid down under diverse conditions yielding masses which resemble one another only in chemical composition. An Oceanic ooze may produce a soft flour-like substance, such as chalk, or a mixture of carbonate and sand, or one of carbonate and mud or clay. Calcium carbonate transported as a silt, may solidify as a very smooth fine-grained rock while shells and coral yield a coarse structure full of angular fragments and visible organic remains. Buried under other sediments any of these rocks may be still further modified, the fossils becoming more or less obliterated, until in the extreme case of metamorphism a crystalline limestone is formed. All traces of organic origin has then vanished, a change which both heat and pressure have combined to bring about aided perhaps by traces of moisture from which few rocks are free.

The following discussion of varities of limestone by Burchard and Emley** will further serve to emphasize the variations of limestone.

> Limestones include many and widely varying types or rocks, differing in origin, color, texture, hardness, structure and composition. * * * * * The one property they have in common is that of consisting largely of the mineral calcite, (calcium carbonate, $CaCO_3$); or of the mineral dolomite, a combination of calcium and magnesium carbonates ($CaCo_3$, $MgCo_3$). No natural limestones are chemically pure, however, and few are nearly so. All contain more or less foreign material either chemically combined or as a mixed mineral. The more common of these foreign substances are magnesium carbonate ($MgCO_3$) * * * * ferrous carbonate ($FeCO_3$); ferrous oxide (FeO); ferric oxide (Fe_2O_3); silica (SiO_2); alumina (Al_2O_3); clay, carbonaceous matter; mica, talc and minerals of the pyroxide groups. The colors and stains commonly noted in limestone are due to the presence of foreign minerals. The light blue, buff, yellow, pink, red and brown shades are largely due to iron compounds, and the grays and blacks are often due to the presence of carbonaceous matter derived from organic remains. Manganese oxides also act as coloring agents.

Burchard and Emley in continuing their discussion suggest a classification from which the following is adopted.

Classification of limestone as to texture.

1. Lithographic limestone (grain not readily distinguished).
2. Compact, dense, fine-grained limestone.
3. Crystalline limestone (non-metamorphosed).
4. Crystalline limestone or marble (metamorphosed).
5. Oolitic and pisolitic limestone.
6. Fossiliferous limestone.
7. Shell limestone (fragmental, including coral limestone).

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*Clark, F. W. Date of Geological chemistry. Bull. U. S. Geol. Survey, No. 491, p. 531, 1907.

**Burchard, E. F., and Emley, W. E., Op. cit. p. 1509.

8. Chalky limestone.
9. Conglomeratic limestone.
10. Cherty limestone.
11. Travertine, or calc sinter, (calcareous tufa).
12. Stalactitic and stalagmitic limestone and onyx marble.

Classification of limestones according to chemical composition.

1. High-calcium limestone.
2. Magnesian limestone (low-calcium).
3. Dolomite.
4. Argillaceous limestone.
5. Arenaceous and silicious limestone.

The classification of textures is self-explanatory. The second classification may require further discussion.

High-calcium limestone is a limestone which is almost chemically pure and is composed largely of calcium carbonate or a very small amount of magnesium carbonate. The rock may be fine-grained, compact, chalky, highly crystalline (even marble), or it may be composed almost entirely of shells.

Magnesian limestone is a limestone that contains a certain amount of magnesium carbonate, from 8 to 44 per cent. A limestone containing less than this would likely go in the class with high-calcium lime. In texture this lime may include practically all of the twelve varieties listed in the first classification.

Dolomite is a mineral with a definite chemical composition. It is calcium carbonate ($CaCO_3$) and magnesium carbonate ($MgCO_3$), containing 54.35 per cent calcium carbonate and 45.65 per cent magnesium carbonate. It has a definite crystal form and the cleavage faces are usually curved.

In practice the term is applied to limestones with a high percentage of magnesium. A pure dolomite is seldom found; it is usually a limestone with a high percentage of magnesium. It is thought that the dolomite formations are formed by the replacement of calcium carbonate by magnesium carbonate through the agency of percolating waters. When the replacement is complete and the original limestone has been completely changed to dolomite, it occupies only 87.7 per cent of its original space and normally forms a porous rock. If, however, the pressure is sufficient the space is largely eliminated. There are one or two magnesium limestones in the State and one thin dolomite.

Argillaceous limestone is one in which there is a large admixture of clay and shale. It has a high percentage of aluminum, iron, and silicious materials. Argillaceous limestone occurs in many places in Oklahoma. While it cannot be used as a source for commercial lime, it may be used in the making of cement. The Dewey Portland Cement Company at Dewey, Oklahoma, uses an argillaceous limestone which is near the right proportions for the manufacture of Portland cement.

MANUFACTURE OF LIME

GENERAL STATEMENT.

Lime is manufactured from limestone by a very simple process. When limestone is heated to a red glow and allowed to remain in this state for a few hours all the carbon dioxide is expelled and the caustic, or quick-lime, remains. The heating may be done in almost any manner.

HISTORY OF THE MANUFACTURE OF LIME.

Lime has been burned since the earliest historic times. The ancient Egyptians and Babylonians used it in their buildings, the Greeks realized its medicinal value, and since then its field of usefulness has gradually grown until it is almost indispensable in modern every day life. Perhaps the first lime burned in Oklahoma, certainly the first of which we have definite record, was at Fort Towson in 1824.

EARLY METHODS OF MANUFACTURE.

The methods used in the early days were very crude and any one was expected to be able to burn lime. The professional lime burner did not hold a very enviable position. The first lime was probably burned by piling up logs and rock and setting fire to the pile. When the fire went out the work was done. If the lime was well burned, all well and good; if not, it was no more than was expected. Obviously this method produced a very inferior grade of lime.

A second crude method was the use of what is known as the "pot" kiln. This kiln was built of limestone or sandstone and lined with firebrick. It was the shape of a truncated cone or cylinder. It was charged with rock and wood, or coal, well mixed. After the charge had burned itself out the lime was drawn and the kiln recharged. This type of kiln has been used in a few places in Oklahoma as well as in Ohio and Pennsylvania.

A third type of kiln, used by those who burn only a small amount of lime for home use, is built of the limestone rock itself. It is usually about twelve feet square. The chinks in the lower three feet of the walls are closed with mud. At the bottom of each of two opposite walls are left two openings or "eyes." These openings are about two feet across and three feet high. The openings of the opposite walls are connected by tunnels made of loosely placed rocks. A series of iron bars for grates are laid through the tunnels about a foot above the ground to facilitate the draft and allow the drawing off of ashes. Over and around these tunnels the limestone fragments to be burned are loosely piled, and when the whole is built up to the desired height, usually about ten feet, the fires are started in the "eyes." The fire is continued until the lime is completely burned. If the lime is for immediate use the kiln is torn down, but if it is burned for fertilizer it is usually allowed to stand and slake.

MODERN METHODS OF MANUFACTURE.

GENERAL STATEMENT.

Since science has been invading the commercial world it has spread its influence to the manufacture of lime. A scientific construction of the kiln and an orderly method of procedure were demanded to reduce the cost and accelerate the production of lime. The modern method might be divided into three heads: Winning or quarrying, burning, and preparing for market. Orton* gives five: Winning, burning, cooling, preparing for market, and hydrating.

QUARRYING OF ROCK.

GENERAL STATEMENTS.

The term quarrying will be used to include all the processes involved in procuring and placing the stone in the kiln.

Rock quarrying has developed into a science of its own and the methods used vary with the kind of rock quarried and the use to which it is to be put. While limestone is a soft rock, as compared with steel, the scale (common rock scale of hardness) being 3 and 6 or 7, respectively, it presents some difficulties in quarrying.

When limestone for building stone is desired, it is frequently quarried without blasting. The blocks are sawed, channeled or split out by wedge-work. When quarrying for a crusher the fastest way to break the rock down, regardless of its shape and size, is the best, hence blasting is done.

In quarrying rock for lime it is necessary to keep the variation in size within limits. From a few inches to a foot is the usual diameter, while finer material cannot be used in the kiln, and an excessive amount adds materially to the cost of quarry sorting, and in addition, oftentimes accumulates in such quantities on the quarry site as to seriously check further operations. Quarrying for lime requires very little skill. Cheap labor operating comparatively simple machinery is usually sufficient. Blasting is used extensively but large shots where many tons are loosened, as in quarrying for crushed rock, are not used because much fragmentary material results, and, too, large quantities of loose rock necessitates much shifting of the quarry tracks.

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*Orton, Edward Jr., The limestones and the lime industry of Ohio, Bull. Geol. Survey of Ohio, 4th ser., No. 4, 1906.

DRILLING.

In drilling, any kind of equipment may be used, such as the bar drill, the hammer drill, compressed air, steam, or electric drills. All of these methods except the electric are in use in the lime quarries in Oklahoma. The bar and hammer drill method is very slow and costly in time and labor, the only excuse for their use being the expense of installing better equipment.

Steam is successful where the boilers can be close to the quarry. It becomes very costly, however, when the boilers are removed any considerable distance, because of the excessive loss of heat from radiation. It also is somewhat inconvenient to handle on account of the heat.

Compressed air is perhaps the most economical method. After the first cost of installation of the system there is very little cost of maintenance. It can be piped anywhere and any distance, and can be carried by hose and used without danger of scalding the operator.

Electricity can be used only by the larger plants which generate their own current. Where it can be used it is the most convenient of all. There is no pipe fitting to be done and no heavy hose to handle.

BLASTING.

The kind and amount of explosive used depends upon the character of the rock, as well as the cost of the explosives. If the rock is very hard and brittle, as small a charge should be used as will loosen the rock, in order to avoid excessive shattering. Small "pop" shots and sledging are used to reduce the size of the rock after it is loosened from the quarry face. A "pop" shot is a shot of dynamite or powder put into a shallow hole in the rock, or even placed on the sides of the rock, and covered with stiff mud. When the rock has no definite bedding planes and is not inclined to shatter, the first shot may well be large enough not only to loosen, but thoroughly to break it up and thus eliminate sledging, which may have a tendency to shatter. In all the Oklahoma lime quarries the shots are small and are not calculated to lossen many tons of rock at a time. This is probably because the plants are small and too much coarse rock on the quarry might be in the way.

TRANSPORTATION.

There are many methods of transporting the rock. Probably the first method, after there was a definite kiln, was the use of wheelbarrows. The wheelbarrow is perhaps the most convenient method because its course does not depend upon a track but can be moved about to any part of the quarry. The mule cart, too, is independent of a track.

All the lime plants in Oklahoma have a tramway leading from the quarry to the top of the kiln, over which the cars are drawn by cable from a gas or steam engine. The tramways range in length from 70 to 210 feet and in elevation from about 5 to 65 feet or more. The Viola White Lime Company at Bromide is contemplating opening a new

quarry face farther up the hill, which will be at such an elevation that gravity alone will pull the cars to the kiln.

COST.

In Oklahoma the average cost of quarrying the rock and placing it in the kilns is about 4½ cents per barrel of lime, or 45 to 65 cents per ton. In very few of the eastern states has the cost been reduced below 65 cents per ton.*

BURNING.

GENERAL STATEMENT.

The burning of lime as indicated above is a very simple process. Yet with the simplicity of the process the science of burning a good uniform lime is by no means simple. The problem of the lime producer is to burn all the lime, to overburn none of it, and to burn a maximum amount of lime at a minimum expense in the way of labor, fuel, and time.

The subject "Burning of Lime" may be divided into Kiln design, Charging the Kiln, Firing, Drawing, and Cooling.

KILN DESIGN.

This topic is fully discussed by Burchard and Emley:**

> Practically all the lime produced in this country today 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, although it has many advantages over the shaft type, has the one great disadvantage at present, 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, but is growing very rapidly, so that the use of the rotary kiln is fast gaining in favor.
>
> This paper deals only with the 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 pre-heating the stone. Its side 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

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*In these figures the weight of the barrel is included. The empty barrel weighs 20 pounds and when filled weighs 200 pounds.

**Burchard, E. F., and Emley, W. E., Source, manufacture and use of lime. U. S. Geol. Survey, Mineral resources, 1913, pp. 1564-7.

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 used under the 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 this 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 draft 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. 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 if the demand falls off, it will not be necessary to close the entire plant. Recently the custom has been introduced at a few plants to run the kilns at full capacity and to 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 for the gases to leave it 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 quantity of stone causes unnecessary work for the fan.

What is perhaps the simplest type of kiln recognized by modern practice might be constructed as follows: An outer casing or shell is built up of sections of steel rolled to shape and bolted together, so as to form a stack, say, 10 feet in diameter by 30 feet in height. Inside of the casing, and concentric with it, is erected another stack of fire brick. This may be cylindrical in shape, 6 feet inside diameter by 30 feet high, with walls 18 inches thick. The annular space between the fire brick and the steel is filled with ashes, brickbats, or other similar material, which acts as an insulator to prevent loss of heat by radiation ,and which also serves to take up the expansion of the fire brick. Two openings in the fire brick stack, opposite each other and about 3 to 5 feet from the bottom, form the inner ends of the fire boxes. These fire boxes extend out horizontally through the steel casing. They are of the ordinary type used for boilers and may be, for example, 4 feet long (from the outer door to the interior of the kiln) by 3 feet wide by 2 feet high, (from the grate bars to the top of the arch). The kiln as described is supported on what is known as the firing floor. The bottom of the kiln is closed by a conical steel chamber known as the cooler, which is hung under the firing floor. This cooler may be 6 feet in diameter at the top, by 18 inches diameter at the bottom by 4 feet high. The botton is closed by the shears previously mentioned and is generally 4 or 5 feet above the cooling floor, so that a wheelbarrow can be placed under the cooler to receive the lime as it is drawn out of the kiln. A kiln of this type, when used to burn a dense, high-calcium stone, with a good grade of gas coal, will have a capacity of 8 to 10 tons of burned lime per 24 hours.

The design as given is subject to a great variety of modifications. The form, the dimensions, and even the materials may be changed to meet the peculiar requirements of each plant. Thus, if it is desired to increase the natural draft, a stack may be mounted on top of the kiln. This stack should be connected to the shaft by a conical chamber, so that the gas is not compelled to turn sharp corners which would tend to set up eddy currents and reduce the draft. The size of stack must be so selected that there will be no tendency to throttle the gas. Its dimensions can be calculated by the ordinary formulas for chimney design. For the kiln as described, under ordinary conditions, a stack 20 inches in diameter will have sufficient capacity and will add one-eighth inch of water to the draft for every 35 feet of height. If induced draft, or the Eldred process, is to be used, the top of the kiln should be closed by a flat plate bolted to the casing, in order that the fan will not have a large amount of unnecessary air to handle.

The casing of the kiln is sometimes built of stone or concrete instead of steel. These materials probably diminish the amount of heat lost through the kiln wall, but the casing should be designed primarily for strength. Most of the strain is found to be lateral, which tends to push the stone out. It is resisted much better by steel. Reinforced concrete, when properly designed, should combine the strength of the steel with the heat insulating properties of the stone, and is therefore finding favor in modern construction.

The shaft of the kiln may be built of material other than fire brick. In the burning zone, or that part of the shaft extending 8 or 10 feet above the grates, the brick are subjected to a high temperature (2,200 F. to 2,600 F.) and also to the fluxing action of the caustic lime. In the upper part of the shaft the temperature is low, and the wear is caused mainly by abrasion. A good grade of fire brick will stand the former condition pretty well, but is too soft to resist the abrasion. For this reason the upper part of the shaft is frequently built of cut granite, sandstone, paving brick, concrete, or some equally hard and cheap material. Even a good fire brick in the burning zone will wear out in time, owing to the fluxing action of the lime. It has recently been found that silica brick give longer service under some circumstances.

The upper part of the shaft is frequently enlarged to form a hopper. This practice is to be commended, because it gives an opportunity to store a supply of stone, so that the kiln can be operated for a day or two independently of the quarry. Moreover, this stone is stored in such a way that it is preheated, and it requires no further handling. If the kiln has a capacity of 10 tons of lime per day, the hopper should hold 27½ cubic yards of stone, or two days' supply. Care should be taken in designing a hopper, that the slope of the sides shall be steep enough to prevent the stone from arching over instead of sliding freely into the kiln.

The shape of the cross section of the shaft need not be circular but may be square, rectangular, or elliptical. When the products of combustion enter the kiln from the fire boxes they tend to pass upward immediately, along the walls of the shaft. The shaft must be designed so as to force them to penetrate as far as possible toward the center of the kiln. If the shaft is square or rectangular, the corners will form chimneys through which the gases can escape. Obviously, an elliptical shaft gives a larger area with the same distance between the fires than a circular shaft, and this larger area is the cause of increased capacity. The elliptical shaft is therefore the most economical of the four when the capacity of the kiln and the uniformity of the product are considered. The other shapes are frequently used, because they are much cheaper to build and repair. The objections to the circular shape can be overcome by the use of three or four fire boxes instead of two.

The cooler is sometimes lined with fire brick. This retains sufficient heat to complete the calcination of any stone which may have passed through the kiln unburned. The advantage of this process is doubtful, because it necessitates drawing the lime out of the kiln while it is still hot, with the attendant difficulties of handling it.

CHARGING OR FILLING THE KILN.

There are several methods of charging the kiln. The old time Pot kiln was charged with a mixture of limestone and fuel, then the firing took place and the contents of the kiln were entirely burned and the lime drawn out before any more rock was added. The kiln was then recharged.

The burning of lime has become a continuous process. The fire is never drawn and the kiln never emptied except for repairs. This continuous process calls for continuous charging. Many kilns are charged once a day; others have men working continually on the quarry and every time they get a car loaded they send it up to the kiln, where it is dumped into the hopper. Kilns which have a hopper of such size that when full the rock absorbs practically all the heat of the escaping gases, usually hold enough rock to run them from 36 to 48 hours, allowing the kiln to run a day or two without being recharged. But when this is done there is always a loss in heat due to the escaping gases becoming hotter and hotter as the rock in the hopper sinks.

One of the more primitive methods of charging a kiln was to wheel the rock in a wheelbarrow to the base, elevate it in buckets, and dump it into the kiln, or if the kiln was located on the hillside, the rock was wheeled to the top of the kiln. In some places the rock is carried from the quarry in cars to the base of the kiln by gravity, and elevated in large steel buckets on a crane and dumped into the kiln. In other places it is carried in large steel buckets by an air line quarry to the kiln and lowered to where it strikes an automatic dumper which turns the bucket over at the center of the kiln.

The most common method is to draw the rock to the top of the kiln in cars on an elevated tramway, where it is dumped or scooped out. There are two types of cars used in this process, a side dump and a bottom dump. For the side dump car, the track is built at the side of the kiln, so that when the car is turned over, it dumps the rock in the center of the kiln. For the bottom dump car, a track goes across the center of the kiln is used. The bottom dump car is favored because its distribution of the rock in the kiln is better than that of the side dump. When the latter discharges, the rock starts down at an angle and strikes in such a way that the small pieces have a tendency to remain near the center, while the larger ones roll to the outside. Under any circumstances the sides of the kiln tend to form a chimney through which gases find easy escape, hence the strongest draft is naturally along the sides of the kiln. In square or cornered kilns this tendency is very noticeable. If none of the larger rocks are thrown to the side this tendency is greatly exaggerated and there is an unequal distribution of heat. The center dump car discharges its load straight down and the larger rocks remain in the center while the smaller fragments roll to the sides, thus tending to check the draft at the sides and making for a more nearly equal distribution of heat.

FIRING.

As indicated above, the firing in the modern lime kiln is a continuous process. Each kind of fuel demands a special method of firing and the various methods with the same fuel depend upon the method of obtaining a draft. The goal of the fireman is to keep his kiln at a constant temperature; to have complete combustion of all the fuel; to allow no unburned carbon to escape in the form of dense, black smoke; and to admit only enough oxygen for complete combustion. An excess of oxygen is likely to cause over-burning and recarbonation of the lime, as well as using up heat energy which would otherwise be transferred to the rock. A long, cool flame is desired, so as to heat a maximum amount of rock and avoid overburning. Many lime producers demand trained firemen and, if they cannot get them otherwise, they pay an apprentice wages while he takes training.

TEMPERATURE.

The temperature necessary to produce lime from limestone varies with the purity of the limestone and also with the atmospheric pressure under which it is burned. A considerable amount of experimenting has been done along this line by Le Chatelier. He finds that there is a direct relation between the required temperature and the atmospheric pressure. He has worked out a table giving the necessary temperature to completely calcine lime under various atmospheric pressures. His table as given by Peppel* is as follows:

Dissociation of Calcium Carbonate.

Pressure	Temp.	Pressure	Temp.
27 mm. mercury	547° C.	289 mm. mercury	745° C.
46 mm. mercury	610° C.	678 mm. mercury	810° C.
56 mm. mercury	625° C.	753 mm. mercury	812° C.
205 mm. mercury	740° C.	1333 mm. mercury	865° C.

760 millimeters of mercury are considered normal atmospheric pressure at sea level. In reality the pressure at most of the plant locations is somewhat less than this. Using 760 m m. pressure, however, something above 812° C. as shown in the table, would be the lowest temperature at which complete calcination of the limestone is obtained. Statements may be found to the effect that it is necessary to have a temperature as high as 1050° C. However, these experiments and some tests made by Herzfeld** seem to disapprove these statements. Herzfeld found that in examination of 64 different samples of limestones and marbles, a temperature beyond 1040° C. was required by none of them, and a lower temperature was sufficient in most cases. He also found that the presence of steam has a very marked effect on the temperature at which calcium carbonate would be dissociated. He worked out the following table for the behavior of calcium carbonate in the presence of superheated steam

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*Peppel, S. V., The Limestone resources and the lime industry of Ohio, Geol. Survey of Ohio, Bull. No. X, p. 293, 1906.

**Pepple, S. V., Op. Cit. p. 239.

Temperature	500°C.	650°C.	680°C.	790°C.
Per cent of calcium oxide in limestone burnt in steam	0	7%	23%	100%
Per cent of calcium oxide in limestone burnt in air	0	0	0	0

According to the above table it is seen that complete dissociation is obtained at a temperature of 790° C. in the presence of steam, while the same author states that a temperature of 1,040° C. would be necessary to dissociate the same compound with dry heat. This gives a saving of 250° C. in temperature when steam is used. The same table also shows that at temperatures below the point at which the explosion of carbon dioxide is complete, a portion only will be given up, and that the amount of carbon dioxide given off will be stationary for any given temperature and pressure. From these experiments we may conclude that for a dry heat on a pure high-calcium lime a temperature from 950° C. to 1,040° C. is sufficient to expel all carbon dioxide. When water vaper is added this temperature can effectively be lowered.

Experiments with magnesian and dolomitic limestones have failed to establish any definite temperatures at which calcination is complete. This is due to the fact that magnesium carbonate will dissociate at a much lower temperature than will calcium carbonate and the percentage of magnesium is too often a variable quantity to establish any definite figures. Burchard and Emley* state that magnesian and dolomitic limestones usually produce an overburned lime at ordinary kilns, due to the fact that the magnesium in the compound has been dissociated and become overburned before dissociation was complete with the calcium carbonate present. This is mentioned above in the classifications of lime as to chemical composition.

FUEL.

Wood, coal, oil, natural gas, and producers' gas are the fuels in common use in lime plants. Before entering into a discussion of the particular merits of these different fuels, it would be well, perhaps, to outline just what is desired in the way of flame and the distribution of heat, as well as the amount of heat generated.

As stated above, a high calcium lime will be completely dissociated at a temperature of 1040° C., but if the lime is pure calcium carbonate a higher temperature than this will not injure it in any way, even if it is carried almost to the point of fusion. Any impurities in the limestone, however, render it very easily overburned and more especially if these impurities are metallic, such as iron and aluminium. If either of these are present they are likely to enter into chemical composition with the calcium carbonate, causing the product to turn yellow and to

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*Burchard, E. F., and Emley, W. E., Source, Manufacture, and use of Lime, U. S. Geol. Survey Mineral resources, 1913.

make it a very inferior grade. This overburning renders the lime very undesirable for finish work and makes it of much less use even in mortar. If iron is present in any appreciable quantity, it frequently will fuse with some of the carbonate, forming a black clinker which can easily be picked out in the sorting room.

With the possibilities of overburning being very great, the conclusion is that a low fire is desirable. Then, too, the longer the flame the longer the heated area and the greater the amount of rock that will come in contact with the fire at a given time. This obviously, gives a greater output with an increased rate of production.

Wood was the first fuel used in the production of lime. It has been used in all lime production until very recent date and its particular place cannot be filled by any other fuel. It gives exactly the things desired, having a long, cool flame and, if green, gives up a considerable amount of moisture in the form of steam, which aids in the dissociation. Practically all kilns that use wood depend upon the natural draft, because of the fact that wood has a tendency to stand apart and burn well, and also creates its own draft better than any other fuel, with the possible exception of natural gas.

Coal is the most abundant of fuels and must sooner or later replace wood, as well as other fuels, in the lime industry. It is at present used almost exclusively in all of the eastern states. Coal has a short, hot, flame, producing an intense heat immediately above the fire grates. It also makes a dry heat which not only retards the calcination of the lime, but aids in the chemical activity of metallic impurities.

If the coal is used, much care should be exercised in its selection. A coal with a high percentage of sulphur is undesirable because of the danger that the sulphur will chemically affect the lime. To avoid this many manufacturers make it a practice to wash the coal. Washed nut or slack coal is the usual form used.

Charles T. Warner* of Wilmington, Delaware, found that, other things being equal, the best results would be obtained from the coal lowest in fixed carbon and highest in volatile hydrocarbons. He also found that a coal high in hydrogen and low in oxygen content was best suited for use in the production of lime.

Crude oil is not used in the production of lime in very many places at present, probably because of its high cost. It would, however, make an excellent fuel for lime production. It has a long flame which differs from the wood flame in that it is dry and hot. Where oil is used it is a custom to introduce with it a jet of steam.

Natural gas has been used at various times in the East and is still in use in a few places. Usually those who have used natural gas in the past and are now using other fuels have made the change on account of the high cost of gas. However, a lime producer can afford to pay higher fuel rate for gas than for any other fuel because gas can be handled with less labor cost. The gas flame, like that of oil, is long, dry, and very hot, much hotter than the oil flame. The draft can be controlled in a way by controlling the pressure under which the gas is admitted to the kiln. It is a common practice where the gas is used to introduce a jet of steam which serves not so much for creating a draft, as for reducing the intensity of, and distributing, the heat. Great care must be exercised in the use of gas in order to avoid overburning the lime and thus reducing its commercial value.

Producer gas is another form of fuel which has been in more or less common use in the East. The process was to make the gas as close to the kiln as possible. Some of the plants even incorporate the producer within the kiln itself, thus reducing to a minimum the amount of heat loss from radiation. Producer gas has almost the same flame characteristics as does natural gas. Its flame is perhaps a little cooler and the fire is handled largely in the same manner as for natural gas.

In addition to the above named fuels there are a number of artificially prepared fuels in more or less common use. Chief among these are coke, reduced oil, and various manufactured gases other than producer gas. Lignites and peat, compressed into bricks, are more or less extensively used in foreign countries. These, however, will likely never be used at all in Oklahoma because of the absence of such deposits in commercial quantities within the State.

Wood is used exclusively in the lime plants of Oklahoma at present. However, some coal has been used in the past. Oklahoma has an abundant supply of coal, oil, and natural gas, and in some places the supply of wood will not be exhausted for many years. There will be a time, perhaps, when coal will be practically the only fuel in common use in the lime industry. At the present time, however, in view of the fact that Oklahoma has such an abundant supply of natural gas which will probably last for many years, it is the writer's opinion that natural gas would be the most desirable because it could be obtained perhaps as cheaply as any other fuel. In many places the producing gas wells are very close to formations which would make excellent lime. Gas is used as a fuel in the three Portland cement plants in Oklahoma, and at two of these, namely, The Oklahoma Portland Cement plant at Ada and the Choctaw Portland Cement plant at Hartshorne, utilize limestone which would burn to an excellent lime.

DRAFT.

Many methods of producing the desired flame from coal have been used at various times. Some of these methods have been patented, while others are in very common use and go by the name of their inventors. All of these methods use some kind of artificial draft, either forced or induced. Some combine the two.

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*Peppel, V. E., Geol. Survey of Ohio, Bull. 4, p. 275, 1906.

A forced draft is one in which air, or its equivalent, is forced in beneath the grates. This draft increases the pressure in the kiln. The induced draft is obtained by drawing off the kiln gases at the top and reducing the air pressure within the kiln.

The ordinary method of producing a forced draft is to introduce, under each fire box a jet of steam. This not only produces the desired draft, but in passing through the burning coal, is superheated. It is partially dissociated into free hydrogen and oxygen and passes on into the kiln, causing the flame to be lengthened, thus giving the desired distribution of heat and causing the lime to calcine at a lower temperature than it would with dry heat. The dissociated steam recombines when it reaches the cooler parts of the kiln, and gives up its heat. Thus the steam not only serves in producing the draft and distributing the heat, but also actually transfers the point of heat generation from the fire box to the extremities of the heated areas.

A method in common use for producing an induced draft is to build a steel stack above the kiln through which the gases are drawn by a fan. In this type of kiln the charging is done through a door at the top of the kiln left open for that purpose. Pehaps the most successful process of producing a draft without the use of steam is a combination of the forced and induced method, generally known as the Eldred process.

ELDRED PROCESS.

The Eldred process combines both the forced and induced draft. It consists of drawing off the kiln gases and forcing them with fresh air back into the kiln through the fire box. For maximum economy the top of the kiln should be air tight, and all the gases should be removed by a fan, according to the induced draft method. This fan should keep the pressure at a minimum within the kiln. It should be equipped in such a way that it could deliver all of the kiln gases necessary for the fire and send the rest out through the stack. There should be separate and fairly accurate means of controlling the supply of air and kiln gases which are to be forced underneath the fire box. With this equipment the fire can be forced either by pure air, or the kiln gases alone, or any proportional mixture of the two which may be desired. The induced draft tends to prevent recarbonation and 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 slow rate of combustion. This introduction of carbon dioxide into the burning area does not cause recarbonation, probably because of the intense heat which is present. The carbon dioxide serves as a mechanical, as well as chemical, means of transferring the heat from the fire box to the interior of the kiln. In passing through the kiln a certain amount of the carbon dioxide is reduced to carbon monoxide, absorbing a great deal of heat. The carbon monoxide burns to carbon dioxide again when it reaches the interior of the kiln, thus transferring the heat of combustion from the fire box to the burning area. Through this chemical process the introduction of carbon dioxide lowers the temperature in the fire box and increases it in the kiln, where it is required to calcine the limestone. This chemical action is in a way very similar to that of steam but it does not reduce the temper of calcination of the limestone as the steam does. The Eldred process has been in use for several years and is still used by many of the lime producers of the East.

DRAWING.

This is sometimes spoken of as the method of operating the kiln. There are two methods of drawing, which are known as the *"following"* and the *"sticking"* methods.

The *"following"* method consists in drawing burned lime every little while from the bottom of the cooling chamber, allowing the rock above to slide down. Under this method the firing is continuous; the doors are never opened to allow the fire to cool. There is danger with this method of unevenly burning the lime. Theoretically no lime is burned below the level of the grates. The fire and hot gases tend to follow up the sides of the kiln and to leave the center relatively cool until the rock gets very near the grates. In the "following" method the center naturally follows faster because there is a considerable friction between the walls and the rock on the sides. Hence there is danger of the rock in the center following much faster than that on the sides and passing the grates before it is thoroughly calcined, thus producing underburned lime.

In the "sticking" method the lime is drawn at regular intervals, usually every eight hours. The lime above the grates is allowed to get so hot between drawing times that it expands and supports itself while the rock is being taken out of the cooling chamber and placed on the cooling floor. When the cooling chamber is emptied the grate doors are opened, allowing a sudden rush of cold air into the kiln. The cold air cools the lime somewhat, causing it to contract so that it falls easily when loosened with pokers. The cooling chamber is supposed to be large enough to hold all the burned lime, and yet not allow any unburned rock to fall below the grates. After the rock has fallen the fireman builds up the fire and soon has the kiln at normal heat again.

The loss connected with this method is measured in time and fuel. It is about an hour from the time the fire is allowed to start cooling until it is again normal. This loss is compensated for by the uniformity of the product and the elimination of underburned lime. This method is in more general use and is considered best. It is used exclusively in all the kilns now operating in Oklahoma.

COOLING.

After lime has been burned until all the carbon dioxide has been expelled it must be cooled and prepared for shipping. The cooling of the lime demands almost as much thought and attention as does its burning.

There are several things to be considered and the route to maximum efficiency is sometimes a difficult one.

In the first place, the freshly burned lime has a great amount of heat stored up in it which should not be wasted, and again, it must not be kept hot too long for fear of dead burning, that is, overburning in such a way that it is rendered inactive and loses its valuable properties, because of its forming various compounds with whatever impurities the stone may contain. Then, too, if kept in the range of the burning gases of the kiln, recarbonation is likely to result, which returns the rock to its original composition.

Most kilns are equipped with a cooling chamber just below the fire grates where the freshly burned, hot lime falls and is slowly cooled. Here it is cooled in part by the fresh air which comes in at the drawing door and other openings. This air is undesirable because it comes in fresh and pure, and is gradually heated as it ascends until it reaches the level of the grates. By this time it has become thoroughly hot and, on meeting the combustion gases from the furnace, is quickly burned. This makes the kiln very hot at this point and shortens the length of the burning space in the kiln, causing a slower rate of production as well as an overburning of the lime.

Some kilns are so constructed that air is drawn through the cooling chamber and admitted to the fire box. This is obviously a saving of fuel. It is difficult, however, to cause the air to make the loop by way of the fire box instead of passing directly up through the kiln.

A great many plants draw the lime while it is still very hot and thereby loose a good deal of heat and at the same time render the plant uncomfortably warm for some time after each draw.

Where forced or induced draft is not in use and where the hoisting is done by steam, much of the expense ordinarily necessary for generating steam could be eliminated by lining the cooling chamber with water pipes. Perhaps one or two large pipes of sufficient size and strength to withstand the impact of the falling lime might cross the cooling chamber near the top where the rock remains hot longer.

When the lime is drawn from the cooling chamber it is spread out on the cooling floor, where it is allowed to remain until it is cool enough to be handled in preparing it for market.

PREPARING FOR MARKET.

If the lime is to be sold in the lump for building or other purposes, the preparation for market involves very little work. If it is to be stored any considerable length of time it is the general custom at present to hydrate it as soon as it comes from the cooling floor. The process of hydration will be discussed later. Ordinary quicklime is usually marketed in the lump, occasionally in bulk, but most often barreled. It is always barreled when shipped any distance.

Congress recently passed a bill providing a standard barrel for dry measure, which went into effect July 1, 1916. According to this bill (H. R. 4899, 1st Sess. 63rd Congress) the dimensions of the standard barrel are to be as follows:

> Length of staves 28½ inches; diameter of heads, 17⅛ inches; distance between heads 26 inches; circumference at bilge, 64 inches—outside measurement; thickness of staves not greater than four-tenths of an inch. It is further provided that any barrel of different form having a capacity of 7,056 cubic inches shall be a standard barrel.

This barrel is in use in the Oklahoma lime plants and holds 180 pounds of lump lime. The gross weight is 200 pounds, there being 20 pounds tare. In this paper where a barrel of lime is mentioned one of these barrels is referred to, and where a ton is mentioned it means 10 barrels.

In preparing the lump lime for market it is taken from the cooling floor as soon as it is cool enough to be handled and is put into a barrel, which is headed and rolled into the storeroom where it is kept until a carload is shipped out.

CLASSIFICATION OR KINDS OF LIME.

GENERAL STATEMENT.

Before entering into a discussion of the various classes of lime it would be well to consider a few of the characteristics which the various types of lime exhibit.

When lime is drawn it has the same shape as the rock which went into the kiln, sometimes even retaining crystalline forms. Its porosity has been greatly increased, however; 100 pounds of limestone producing on the average about 56 pounds of lime.

CLASSIFICATION OF LIME FROM CHEMICAL COMPOSITION.

Pure limestone has the formula $CaCO_3$, but it may be of varying degrees of purity and still produce commercial lime. The amount of impurities which are permissible in limestone depends on their nature. Impurities such as iron, aluminium, or silica (quartz) are very undesirable and more than 5 per cent of these renders the limestone almost unusable. On the other hand limestone may have as much as 44 per cent impurities such as magnesium carbonate ($MgCO_3$) and still be used successfully for lime. Pure dolomite, which is about 44 per cent magnesium carbonate and 56 per cent calcium carbonate, makes good lime.

Commercial lime is a brittle, white, light-gray, or cream-colored solid, with a specific gravity of 2.3 to 3. It has a very strong attraction, or chemical affinity, for water, and reacts with it with such vigor as to generate great heat. This process is called "hydrating" or "slaking" and takes place according to the following reaction: Lime (CaO) plus water (H_2O) equals calcium hydroxide or calcium hydrate (slaked lime) $Ca(OH)_2$ plus heat. When lime is slaked it swells and crumbles into a white powder which is so fine that 95 per cent of it will pass a 200 mesh sieve. When lime is exposed to the atmosphere for a while it absorbs moisture from the air, and if allowed to remain exposed for a few days it absorbs sufficient moisture to cause it to crumble. It is then said to be air-slaked.

When slaking a high calcium lime much care must be taken to avoid the burning due to intense heat and to the difficulty of distributing the water. When a small lump of lime first comes in contact with water the outer part is slaked first and a coating of hydrate forms which tends to keep the water from penetrating to the inner unslaked lime. This phenomenon necessitates constant stirring and mixing to prevent burning. Even though the lime be entirely under water, this coat is sufficiently impervious, at times, to stop the water. When lime is "burned" in slaking, it is deadened, which makes it tough and hard to work, as well as effectively reducing its strength in the finished product.

As stated above, the heat ordinarily developed in lime during slaking is due to the chemical reaction, hydration. As shown below, magnesium oxide (MgO) when mixed with lime does not react the water, hence does not generate heat, and is, on the other hand, inert matter which must be heated. From this reasoning one may conclude that a lime with a high percentage of magnesium will not take up so much water and will not generate nearly so much heat. Such a conclusion is justified by actual observation. This phenomenon has given rise to the classification of limes as "hot" and "cool" lime. The hot limes are high-calcium limes; and the cool limes contain a considerable percentage of magnesium. The terms are logical and usually well applied, but there is no intermediate term for the lime which is called magnesium lime. There is, however, a tendency for the occurrence of only the two classes, the stone being either high or low in magnesium content. Occasionally a limestone is found which is only partly dolomitic. The classification into "hot" and "cool" would give no place for this product.

In certain eastern states the consumers classify lime as "white" and "gray" applying the term "white" to dolomitic, and "gray" to high-calcium limes. As indicated above, the color, whether white or gray, is entirely dependent upon the amount of coloring impurities in the lime. There is no reason why a dolomite should have more impurities in it than a high-calcium lime, or the reverse, but it so happens that the dolomite in the eastern states almost invariably has a smaller percentage of coloring matter in it than does the high-calcium limestone, hence this classification for that region is consistent. The difficulty lies in the fact that it is entirely dependent on a local condition and would be confusing outside of that particular region.

The following classification is suggested by Orton*

Classification of lime from chemical composition.

White limes, containing usually less than 3% and never more than 5% of sandy and clayey matter.	1. High-calcium or "hot", or "quick" limes; made from limestones containing not less than 85% of carbonate of calcium.
	2. Magnesian limes. Made from limestones containing between 65 and 85% of carbonate of calcium and between 10 and 30% of carbonate of magnesium.
	3. Dolomitic or "cool" or "slow" limes made from limestones containing more than 30% of carbonate of magnesium.
Gray limes containing from 5 to 30% of sand and clayey matter.	4. Hydraulic lime. Made from limestones, either high-calcium or dolomitic, which contain from 5 to 10% of sandy and clayey matter, and which will slake by themselves when placed in water. They gradually harden under water.
	5. Natural cement or Roman cement. Made from limestones, either high-calcium or dolomitic, which contain from 10 to 30% of sandy and clayey matter; and which will not slake without first being fully ground. They harden under water much more rapidly and to a harder final product than hydraulic lime.

Magnesium oxide when produced at ordinary lime kiln temperature is so greatly overburned that it takes up very little or no water on slaking. In fact, very little of it slakes. On this basis is explained the phenomenon of "cool" slaking of a dolomitic lime. Obviously the smaller the amount of calcium oxide the less the amount of heat generated. If there is a considerable percentage of inert material present in the form of magnesium oxide, it not only does not slake and generate heat, but must be heated along with the active calcium oxide, thus tending to cool as well as slow up the process.

Any kind of inert matter would have the same effect in cooling and retarding action as the magnesium oxide does, if it is as well distributed. Underburned lime has more or less calcium carbonate which acts as inert matter. Overburned lime exhibits the same phenomenon. Here the calcium oxide is probably in combination with foreign material, causing not only inert matter to be present but actually prohibiting the reaction of some of the calcium oxide content.

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*Orton, Edward, Jr. The limestones and lime and lime industry of Ohio, Bull. Geol. Survey of Ohio, 4th ser., No. 4, p. 253, 1906.

There is no characteristic color of underburned lime for all stones, but there are distinguishing characteristics for each individual stone; hence one experienced with the particular stone can tell when it is underburned. Overburned lime, on the other hand, is usually yellowish-brown in color and can easily be told from good lime.

The gray limes, including hydraulic lime and natural cement, need little discussion here. So far as the writer knows, no hydraulic limes have been, or are being, produced in Oklahoma. A formation closely related to natural cement is being used by the Dewey Portland Cement Company at Dewey, Oklahoma. This formation is an argillaceous limestone, interstratified with shale in such proportions that little or no more clay material is added.

CLASSIFICATION OF LIME FROM PHYSICAL CHARACTERISTICS.

1. Lump or ground lime.
2. Pulverized lime.
3. Air slacked lime.
4. Hydrated lime.

LUMP OR GROUND LIME.

Lump or ground lime is the most common class of lime marketed. It consists of the lime still in the lump just as it comes from the kiln, hence the name. It receives the name of ground lime in that it is picked off the ground or cooling floor, and marketed without further modifications. It is used for all purposes for which any lime is used. In fact, this is a stage in the production of all limes. Its chief use, however, is for building purposes in mortars and plasters.

PULVERIZED LIME.

Pulverized lime is produced by pulverizing the lump lime in a mill. This lime may be shipped in paper or burlap sacks and is more easily handled than when in barrels.

AIR SLAKED LIME.

Air slaked lime is, as a rule, not purposely produced, and its uses are very limited. When lime is exposed to the air it absorbs moisture and carbon dioxide from the air and forms what is called "air slacked lime." Both these processes are very slow and at various times one might find almost any composition from quick lime to calcium carbonate. Again, if the air is very moist one might get almost a pure calcium hydroxide with very little calcium carbonate.

Because of this variation in composition there has been considerable confusion in the literature in regard to air slaked lime. To avoid this confusion the Bureau of Standards has defined "air slaked" lime as only that produced in which the reaction has been complete; that is, when the calcium carbonate has been formed. The lime then has reverted back to its original composition as limestone. Obviously, air slaked lime may be used for anything for which pulverized limestone is used.

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 slacked. 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. When stones like these are burned, in some cases over 50 per cent of the output of the kiln is fine material. Such fine lime is as good for all purposes as lump lime. It is easier to handle and in a sense will keep better. It is obvious that the top layer of fine lime will air slake and the crust of inert material so formed will prevent access of the air to the quick lime 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 or by some firms, who ship the fine lime in open gondola cars.

HYDRATED LIME.

In the last decade a new product in the form of hydrated lime has found its way into the market and has established itself. This is calcium hydroxide. as the name states. Another name for it is slaked lime. The slaking or hydration is done at the plant as soon as the lime cools.

It was originally thought that hydrated lime would keep better than quicklime, and this was the chief argument in favor of it. There has been considerable investigation of the relative keeping qualities of hydrate and lime and the conclusion reached is that hydrate does not keep any better than quicklime of the same degree of fineness.

In investigating the keeping qualities of lime and hydrate, a few lumps of quicklime from the same barrel were taken and ground so that they passed through a 60-mesh sieve. A part of it was then hydrated. The hydrate and quicklime were exposed to the air under the same conditions and were analyzed for carbon dioxide content at frequent intervals. It was assumed that the two were of the same fineness. The results were as follows:*

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*Burchard, E. F., and Emley, W. E., Source, manufacture and use of lime, United States Geol. Survey, Mineral resource, 1913, p. 1575.

Analyses showing percentage of carbon dioxide in quick lime and hydrated lime.

Age of sample in days	Quick lime	Hydrated lime
	(CO_2)	(CO_2)
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 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. This is true also of quicklime.

These conclusions are reached, however, without due regard to certain pertinent points. First, it is assumed that the hydrate is not the finer. Both were samples passed through a 60-mesh sieve, then one was hydrated. It is well known that where hydration is properly carried on, even though it is from the lump lime and not from pulverized lime, from 75 to 90 per cent of the product will pass a 200-mesh sieve.

Another error, and the one which seems to the writer most significant, is that the analysis being for carbon dioxide content, the results were compared too soon and the last analyses were not taken late enough. Air slaking is a slow process and the lime had to absorb moisture and form hydroxide before it could absorb any carbon dioxide whatsoever. This fact alone, it will be noted, would be sufficient to explain the slow rate of absorption noted in the first eight days, but the attention of the reader should be called to what takes place in the quicklime column between the eighth and tenth days, and also the rapidity of absorption of carbon dioxide by the hydrate during the first few days of the phenomenal slowing up in the last three analyses. The results obtained from plotting the figures given in the table can be stated as follows:

In one case, a curve is obtained which resembles the path of a projectile. It goes perpendicular for a while and then begins to fall; just as it starts to fall the table stops. In the other, a path resembling a variable approaching a limit is obtained. That is, the absorption of carbon dioxide is rapid at first and decreases regularly.

It is the opinion of the writer that after the first fifteen to twenty-five days—sufficient time for the surface of both to become encrusted—there will be no difference whatsoever in the keeping qualities of the two. It is also his opinion that the impervious crust will form quicker and with less carbon dioxide on the hydrate than it will on the quicklime.

The process of hydrating is very simple in principle. The lime is first crushed so that it will pass through an inch-mesh or less. (Some plants, however, take the lime in the lump just as it comes from the kiln). The crushed lime is then brought in contact with water and mixed until hydration is complete. Just enough water is added to combine with all the calcium oxide present and not enough to form a putty. There is sufficient heat generated to quickly drive off all excess water in the form of steam and the hydrate is left, a light, fluffy, very finely divided product. The hydration must be closely watched to prevent burning and the consequent yellowish, tough-working product. The hydration is usually done mechanically by means of what is called a hydrator.

There are two types of hydrators on the market, an intermittent and a continuous type, each demanding its peculiar method of operating.

The intermittent hydrator usually consists of a circular iron pan capable of holding a ton or more of fresh burned lime. The lime is measured, or weighed, usually on an automatic scale from which it is dumped into the hydrator. Water is then added, either automatically or by the operator. If the operator has had sufficient experience, he can usually add the correct amount of water more accurately than could be done automatically, because the amount of water passing off as steam varies with the time of day as well as with the heat of the hydrator itself. The pan is kept revolving and plows or scrapers are suspended within it in such a way that the lime is thoroughly mixed. When hydration is complete a section is opened in the bottom of the pan and the scrapers rake the hydrate through into the bin below. The opening is then closed and the pan is ready for another charge.

The continuous hydrator consists of one or more long, circular, iron tubes through which the lime is carried by means of a screw conveyor. The crushed lime is introduced in a small stream at the end of this tube. As near as posible to the end through which the lime enters, a stack is erected through which the lime enters, and another stack is erected through which water falls in a spray on the lime. The two substances are thoroughly mixed by means of the screw and are at the same time carried through the tube. The revolution of the screw is so regulated that hydration is complete by the time the lime reaches the opposite end of the tube. In this hydrator it is impossible automatically to regulate the amount of water admitted because of the fact that the temperature of the hydrator is continually increasing or decreasing and the loss of water due to evaporation is constantly changing.

A comparison of the two hydrators seems to favor the continuous one. First, since the lime and water are admitted in small quantities and are mixed in small quantities, there is less danger of overburning the lime in the process of hydration. Second, steam generated in the hydrator must pass back along the conveyor and come in contact with any lime dust which may be floating around, dampening it and causing it to settle.

Great care must be taken in hauling hydrated lime to avoid lime dust getting into the air.

SCREENING.

When lime is slacked it increases in volume to such an extent that any lumps in it are broken up and the resulting hydrate is a very fine powder, usually fine enough to pass a 200-mesh sieve. As soon as the lime is hydrated it must be screened in order to separate any impurities which it may contain. There are two methods of separating or screening the hydrate. The first is by means of a sieve through which the hydrate passes, leaving the lumps of impurities on the top, where they may be raked off. A second method of separating is by means of a fan. The hydrate, upon falling in front of the fan, is immediately picked up by a current of air and carried away, while the heavier impurities fall to the floor, where they are drawn off. The air current passes through a restricted tube and out into a larger bin. Immediately on entering the larger bin the velocity of the air current is reduced and the hydrate settles to the floor, the air passing back by means of another opening.

The fan method seems to be more favored because of the fact that it will separate a hydrate which might be damp enough to effectively clog the screen. A second advantage which the fan has over the screen is that it can be made much more nearly dust proof.

After screening the lime is kept in storage bins until the time for packing and shipping.

PACKING.

The following discussion of packing hydrated lime is given by Emley*

> The machine in general use for packing hydrate in bags 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 upon 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 hydrate. The bag is so made that both of its ends appear to be closed, and 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 small muffle-shaped chute is inserted. When the bag has been filled, the pressure of its contents forces the smaller sides against the overlapping portions of the larger sides and thus closes the bag. When made of paper such a bag cannot 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. This 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.

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*Burchard, E. F., and Emley, W. E., op. cit., p. 1578.

USE OF HYDRATED LIME.

There are several arguments in favor of the use of hydrated lime. *First,* it can be used for anything that quicklime is used for, except in certain chemical work. *Second,* it is already slaked and if for immediate use, or if only a small amount is desired, it is easily prepared. *Third,* it is much easier to handle in bags than is the lump lime in barrels. *Fourth,* it keeps better than lump lime and people do not shun it like they do slaked quicklime. *Fifth,* it has been slaked by an expert who has ideal equipment and should get a better quality than could be obtained by ordinary slaking. *Sixth,* it enables the kiln to run all the time instead of just through the summer when the demands are great, because it can be stored. *Seventh,* it is more nearly pure because any underburned or overburned lime, which may have passed the sorter, will not pass the sieve. *Eighth,* it enables the burner to use the lime which will not stand up in the lump, but falls to pieces after burning; this material makes just as good hydrate as that otherwise produced.

One of the objections to hydrate by the consumer is that it contains from 15 to 25 per cent of water on which he must pay freight. It is also stated by contractors that it will not take up as much sand filler per pound as quicklime will. The particular contractors interviewed had failed to consider the weight of the water.

USES OF LIME

GENERAL STATEMENT.

Lime has been used for many centuries as a constituent of mortar. The ancient Egyptians used it as fertilizer and the Romans realized its medicinal value. It is used today in mortar, plaster and cement; in smelters, refineries, soap factories, and glass plants; as a water purifier and softener, a deoxodizer, a disinfectant, insecticide; and for many other purposes too numerous to mention.

MORTAR.

There is perhaps more lime used in mortar than for all other purposes combined. There are many different classes and grades of lime on the market, and the inexperienced might consider that any lime is good enough for use in mortar; in fact, all kinds of lime are used. But the quality of mortar varies widely with the various types of lime. Limes are graded on the amount of mortar that can be made from a unit quantity and from the ease and smoothness with which it can be worked. They are called "fat" limes and "poor" limes.

A fat lime makes a light, fluffy hydrate and a great deal of putty. A poor lime does not make so much putty. High-calcium lime when properly burned and free from impurities, including magnesium, will make 10 cubic feet of putty per barrel (200 lb.) of lime.* The presence of impurities of all kinds tends to increase this amount. The lime must be properly slaked, and the higher the calcium content the more difficult it is to avoid burning in slaking. The more putty, the more sand that can be added to make the mortar, hence the greater amount of mortar from a given amount of lime. This is, however, not always a true proportion, with the argument again in favor of high-calcium lime, for, because of its stickiness, it will carry more sand per unit of putty than the less sticky lime.

Dolomitic limes become considerably harder after setting than do calcium limes, and the crushing strength of the dolomite lime mortar is more than three times** that of the high-calcium lime. It has been calculated that for each vertical foot of a brick wall there is a pressure of one pound to the square inch. Thus a wall 50 feet high would have a pressure on the mortar at the base of 50 pounds to the square inch—a very small amount. It is seen that for all ordinary work the crushing strength of the mortar need not be used as argument against the high-calcium lime, and where pressures are great Portland cement is used in the mortar. High-calcium lime is therefore the best lime for mortar, where it is properly burned and slaked.

PLASTERING.

For surface plastering the high-calcium lime is better, for the same reasons as given in connection with the discussion of mortar. It will cover more space per unit of quicklime, and will give a smoother finish to the whole area covered than will dolomitic limes.

FINISHING.

Finishing lime or lime to be used for white coats should make as much putty as possible, but this is not the controlling factor. Lime for this purpose should be very easily worked, and white in color, and in these two respects dolomite lime seems to out-class the high calcium lime. Frequently the finish tends to become pitted, because small parts of the lime expand and pop off. This is called "popping" or "pitting" and is thought to be caused by particles of lime which were allowed to get too hot and burn in the slaking.

Hydrated lime is thought to be the best type of lime for white wall finish, because it has a better chance to be properly slaked.

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*Emley, W. E., Crushing strength of lime mortar, Nat'l. Lime Mfgrs. Trans., 1913.

**Emley, W. E., loc. cit.,

PORTLAND CEMENT.

A very important constituent of Portland cement is lime, and since a great deal of Portland cement is being used now, perhaps more lime is used in its manufacture than in anything else except mortar. Portland cement is composed approximately of three-fourths calcium oxide, the remainder being silica, alumina, and iron oxide. It makes a rather tough mortar but it has been found that the addition of a small amount of hydrated lime adds greatly to its plasticity without materially altering its other properties.

Hydrated lime is being used more and more in cement where a very smooth finish is desired. It makes the mortar much more plastic, thus making it easier troweled. It is also very fine and tends to fill in between the sand grains, thus making the surface much smoother. It has come to be looked upon as a water-proofing material for cement.

AGRICULTURAL LIME.

A discussion of the use of lime for agricultural purposes by Burchard and Emley* may well be quoted in full:

> The use of lime as a fertilizer dates from the inception of modern scientific farming. Agricultural chemists have shown that there are five or six different functions which lime may perform to benefit a soil, which may be summarized briefly as follows: 1. It is an essential element of plant food. 2. It aids in the conversion of decaying organic matter into humus. 3. It forms compounds with the humic acids which tend to prevent their being leached out of the soil and lost. 4. By producing proper sanitary conditions the growth of injurious bacteria is largely prevented, while the growth of nitrifying bacteria is encouraged. These nitrifying bacteria convert the nitrogen of the humus into a form such that it is available as a plant food. 5. Lime aids in the liberation of potash and phosphorus from inert compounds. 6. It tends to flocculate clay soils, rendering them granular and more porous.
>
> Obviously, permanent results cannot be expected unless care is taken to insure the presence of some organic fertilizer at all times. Lime used alone may be temporarily beneficial, but will eventually be harmful; when used with cowpea vines it becomes more efficient for general purposes than almost any other fertilizer. Of course, lime is not beneficial to all crops to the same extent, and not all soils need lime.

Indian corn is only slightly benefited by the use of lime, while spinach, lettuce, beets, celery, onions, cucumbers, cantalopes. asparagus, cabbage, peanuts, rhubarb, peas, pumpkins, beans, tobacco, alfalfa, clover, barley, wheat, oats, timothy, gooseberries, currants, oranges, quinces, and cherries are much benefited. Cotton, tomotoes, cowpeas, grapes, peaches, apples, and pears are slightly injured and radishes, flax, blackberries, black raspberries, and cranberries are seriously injured by the use of lime.

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*Burchard, E. F., and Emley, W. E., loc. cit., pp. 1,583-5.

Whether a soil will respond to liming or not depends on the amount of available calcium oxide which it already contains. Unfortunately chemical analysis does not distinguish between the total calcium oxide and that which is available to plants. Probably the best indication of the need of lime is the failure to obtain a good crop of clover.

Whether high-calcium or magnesian lime should be used as a fertilizer is a question which has received wide attention from agricultural chemists. It is generally conceded that some magnesia is necessary for the growth of most plants, but that too much of it acts as a poison. However, magnesium carbonate is more soluble than calcium carbonate (in the laboratory, 1 part of the former dissolving in about 5,000 parts of pure water, and 1 of the latter in about 10,000 parts of pure water) and therefore may be more apt to be leached out of the soil by rain. Hence most soils contain more calcium than magnesium, and the use of a magnesian lime should be at least not detrimental. This has been found to be the fact. It may be stated that, for the crops ordinarily raised, the lime to be used as a fertilizer should be so selected that the final ratio of lime to magnesia available in the soil should be about 7 to 4.

The question as to whether lime should be applied to the soil as quicklime, hydrated lime, air-slaked lime, or ground limestone is still the subject of a great deal of controversy. The advocates of ground limestone claim that the caustic properties of quick or hydrated lime will burn up and destroy the organic matter in the soil, whereas limestone can be applied in large quantities at long intervals and will therefore produce a more or less permanent fertility. The advocates of lime claim that one of the main functions which lime has to perform is the destruction of the organic matter and the liberation of the nitrogen in a form such that the plant can use it; that the frequent and judicious use of lime, together with some organic fertilizer, will bring immediate results. Of course the local conditions of each particular case must be considered before a final conclusion can be reached. Thus, it is rational to use quicklime on soils which are exceedingly rich in organic matter, such as peaty and swamp soils. Limestone is safer than quicklime when applied just before planting a crop which is little helped by liming, or when applied to a light sandy soil in hot dry weather.

It will be noted that the value of lime as a fertilizer depends largely on the available calcium oxide which adds to the soil. This depends partly on the calcium oxide present in the material and partly on the size of the grain, which governs its immediate availability. Pure qicklime contains 100 per cent calcium oxide; pure hydrated lime, 76 per cent; and ground pure limestone, 56 per cent. The farmer must pay the cost of freight, hauling, and distribution on 0 per cent, 24 per cent, or 44 per cent of inert material. It costs least to apply ground limestone and most to apply quicklime. It is generally not economical to grind limestone to the same degree of fineness as burned or hydrated lime. Based on these considerations, the statements have been made that 50 pounds of quicklime are equivalent as a fertilizer to about 60 pounds of hydrated lime, 100 pounds of air-slaked lime, or 520 pounds of ground limestone; and that at present prices and taking into account the freight and hauling, quicklime will be found the most economical.

SAND-LIME BRICK.

One industry, the manufacture of sand-lime brick, uses a considerable amount of lime. This brick is formed from sand and lime, as the name would indicate. The sand is a mixture of grains of various sizes in order that there may be a minimum pore space. The lime, usually about 5 per cent by weight, is slaked. The hydration or slaking of the lime must have been carried to completion or there would be danger of weakening the brick by the expansion of the lime as its slaking continued. This mixture is put in moulds and subjected to pressure. Experiments* show that a pressure of 15,000 pounds per square inch produces a brick with a greater tensile strength than any other pressure. After the mixture is moulded by pressure it is subjected to the action of steam at 150 pounds pressure for several hours, after which it is ready for use. The pressure of the mixture tends to expel all air spaces and make the brick solid; the steam causes the calcium hydroxide to enter into chemical combination with a part of the sand forming a calcium silicate which cements the remaining sand together.

A method of manufacturing sand-lime brick from magnesian lime has been patented but failed to prove a success on account of the difficulty of completing the hydration process of the magnesia.

The commercial hydrate is usually more or less incompletely hydrated and for this reason and because the work can be carried on with a hydrator at the brick plant, manufacturers of sand-lime brick make a practice of buying lump lime and slacking it themselves. Where hydration is complete there seems to be very little preference between high-calcium and high magnesian lime, but because of the difficulty in carrying hydration to completion in magnesian limes the high-calcium lime is in favor.

The presence of silicious impurities in small amounts in the lime seems to add to its value.

There are no sand-lime brick plants operating in Oklahoma, so far as the writer knows, but it seems probable that, in view of the fact that the limestone and a pure quartz sand occur in many points in the State within a very short distance of each other, often only a few hundred yards, and the great amount of fuel available in the form of gas, that a sand-lime brick plant might well be established and do a thriving business.

GLASS MANUFACTURE.

Lime is a necessary constituent of all common glass, and is used in many of the varieties of blown ware. High-calcium lime seems to be in almost universal use in the manufacture of glass, as magnesium tends to raise the fusion point of the silica. This, however, is desirable in certain varieties to be used for optical purposes.

Of the 18 glass plants now operating in Oklahoma the writer has obtained data from seven concerning the lime used. The seven plants use high-calcium lime. One plant uses quicklime, two use hydrate, and four use pulverized limestone. In 1916 these seven plants used 285 tons of quicklime, 180 tons of hydrated lime, and 4,500 tons of ground limestone. All require lime 75 per cent pure, or better.

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*Peppel, S. V., Mfg. of artificial sandstone or sandstone or sand-lime brick. Geol. Survey of Ohio, Bull. 5, 1905, p. 42.

Iron and aluminium impurities are objectionable, but the presence of silica is not so serious. The ordinary impurities of limestone are, in general, of no importance to the manufacturer of common glass. For white glass, however, the content of oxide of iron must be less than .3 per cent of the stone.

WATER SOFTENING.

When water has calcium carbonate in solution it is called "hard" water. Calcium carbonate is very insoluble in pure water but is rather soluble when the water contains carbon dioxide. Since all water contains more or less carbon dioxide its hardness usually depends on whether or not it comes from a lime region.

In order to soften water it is necessary to remove the carbon dioxide. This is done by introducing hydrated lime into the water in the form of a cream. The calcium hydroxide combines with the carbon dioxide, forming calcium carbonate, at the same time causing the carbonate which is in solution to be precipitated. High-calcium lime is better for this purpose for four reasons.

First, it is fatter and will give more putty and hence more cream per unit of lime. Second, it is more finely divided and will remain in suspension longer. Third, magnesium oxide does not form a hydroxide so fast and hence does not absorb the carbon dioxide so readily, because the calcium carbonate and the marnesium carbonate is more soluble than the calcium carbonate. Fourth, some of it dissolves, tending to keep the water from becoming as soft as it otherwise would be.

It is estimated that 700 tons of hydrated lime are used each year by Oklahoma City alone for the purpose of softening water. This equals about 500 tons of quicklime.

CERAMICS.

Lime is used in the manufacture of vitrified brick and tile as well as in the glazing process. High-calcium lime seems to be the best fitted for this purpose, in that it tends to bring the point of vitrification and fusion near together while magnesium lime tends to separate them. So far as the writer knows, no brick plants in Oklahoma add lime to their shale, because the shales worked by them usually have a sufficient calcareous content.

CHEMICALS.

Lime is used in the manufacture of soda ash for the purpose of liberating amonia gas, and it is also used in making caustic soda. For these processes high-calcium lime is best suited.

Bleaching powders are composed largely of oxochloride of calcium, which is formed by the action of clorine gas on moistened slaked lime. This requires a relatively pure calcium lime hydrate.

Calcium carbide, the source of acetelene gas, is made by fusing calcium oxide with coke in an electric furnace.

Lime is used as a purifying agent in the manufacture of illuminating gas from coal. When the gas is driven off by heat it is required to pass through layers of moist hydrate which take out the hydrogen sulphide, carbon dioxide, amonia and hydrocyanide—poisonous constituents undesirable in the gas. High-calcium lime, either quick or hydrated, is used.

MISCELLANEOUS USES.

Lime is used as an insecticide and deodorizer in many ways. It is used in sprays for many plants and trees, and in general as a disinfectant. Calcium lime is the only suitable lime for this work.

Lime is used extensively in the manufacture of sugar, both cane and beet. High-calcium is most desirable.

Lime is used in the distillation of wood where gas, pyroli pyroligneous acid, tar, and charcoal are obtained, (calcium oxide).

The manufacture of paper requires considerable lime both for its chemical properties and as a filler. In the manufacture of paper from straw and rags, lime is used to dissolve any fatty impurities which may be present. In the manufacture of paper from wood pulp, there are two methods of reducing the wood to pulp: (1) the soda process; and (2) the sulphite process. Calcium lime is used in the former process while dolomitic lime is used in the latter.

Paints, at least many of them, have lime fillers, and here fineness of grain is the important point; either calcium or magnesium oxide may be used.

Many oils and fats, such as glycerin, are made from garbage and refuse by the action of lime on them.

Tanneries use lime to remove the hair and what ever flesh may be on the hide and also to soften the hide. In the leather industry a freedom from iron impurities is necessary. Magnesium only diminishes the activity of the lime.

Some of the above and others are listed by Burchard and Emley* as follows:

> Lime is used in the "manufacture" of dichromates, magnesia, bone ash, glue and varnish; as a refining and purifying agent in the distillation of mercury, in the classification of grain, in refining fats, greases, butter, linseed oil, and petroleum, in preserving eggs and as a general disinfecting and deodorizing agent; as a filler in paper, textile, linalium and rubber industries; as a mordant in dying; as an abrasive in polishing; in the manufacture of calcium light pencils, and of magnesium for flash light powders; as limewater in medicines; in the recovery of cyanide used in extracting gold and silver from their ores; to neutralize the sulphur acid in pickling steel.

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*Burchard and Emley, Op. cit. p. 1592.

It is used for refractory lining for steel furnaces and refactory crucibles employed in melting platinum. Lime water mixed with equal parts of olive oil makes Carron oil, a most soothing application for burns.

Unslaked or hydrated lime in the form of "milk of lime" is used in the manufacture of glue to remove the flesh, blood and oils, and to disintegrate the tissues and to soften the marrow.

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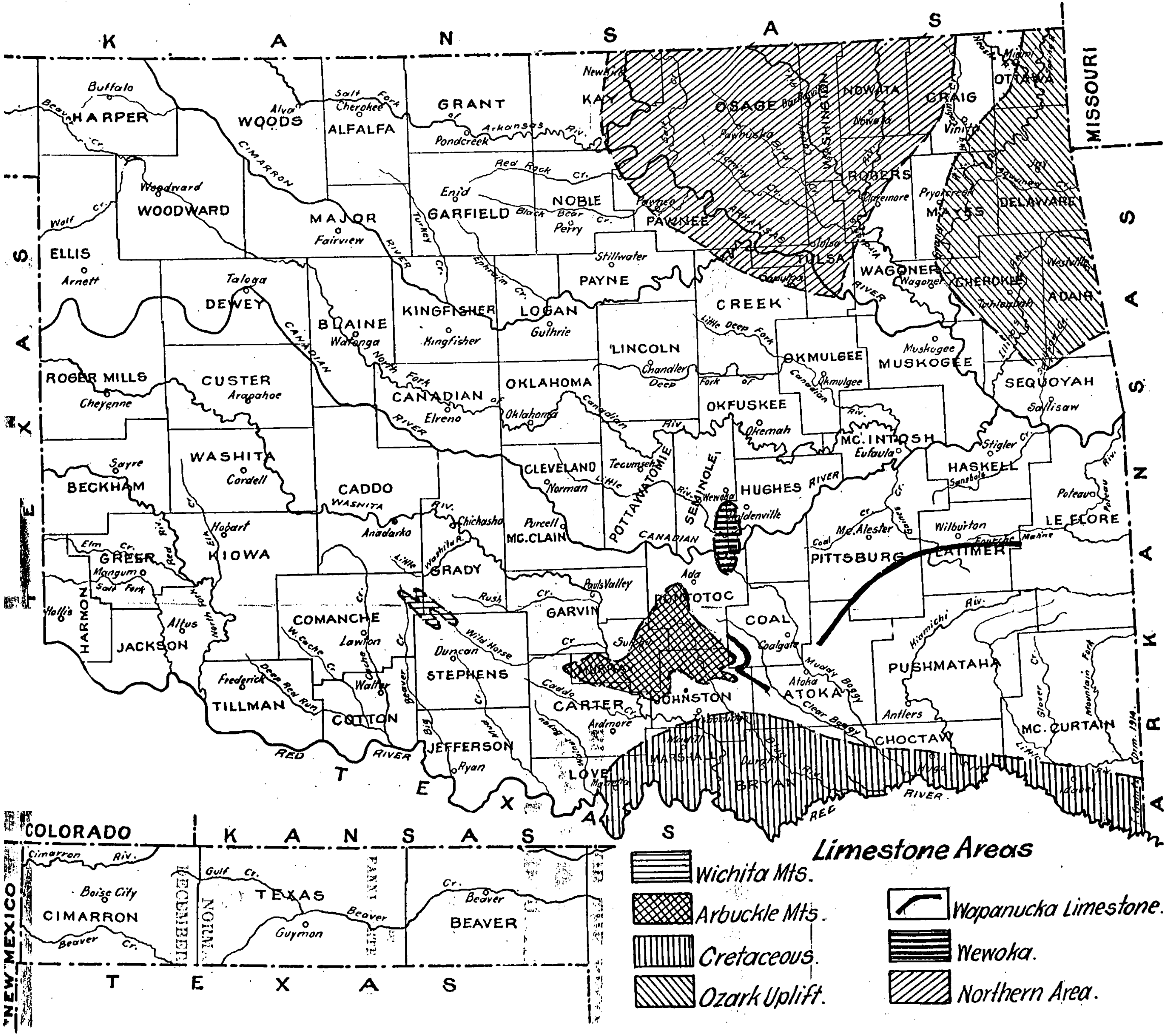

LIME RESOURCES OF OKLAHOMA.

GENERAL STATEMENTS.

Oklahoma's resources for lime have as yet been practically untouched. There are formations of all ages from the Cambrian to the Cretaceous which would make an excellent grade of lime. These limestone formations are widely distributed over the southern and eastern parts of the State, occurring extensively in the Arbuckle Mountains, the Wichita Mountains and in the counties east of Jefferson County along Red River in the southern and southeastern parts of the State, and in the foothills of the Ozarks in the northeast corner, also in the northern part of the State along the Kansas border as far west as Kay County.

In the descriptions of the different formations in the State which would be suitable for lime production no attempt will be made to deal with them other than in a general way. Specific descriptions and sections will be given to the formations now producing lime in connection with the description of the kiln. A list of the different lime formations, together with a short description of each, in order of their location, follows:

LIMESTONES IN THE ARBUCKLE AND WICHITA MOUNTAIN REGION.

ARBUCKLE LIMESTONE.

The Arbuckle limestone is the oldest limestone formation in the State. It occurs over approximately three-fourths of the area covered by the Arbuckle Mountains, located in the south-central part of the State. It is a very thick formation, ranging from 4,000 to 6,000 feet. Shannon* says that a fine quartz conglomerate is found near the base of the formation. There occurs a complete section west of the Tishomingo granite, near Mill Creek in Johnston County, where the strata dip at an angle of approximately 10° to the west, outcropping in a strip about 6 miles wide.

The Arbuckle limestone is also found in the Wichita** Mountain region. Here the limestone is composed of a practically continuous succession of limestone beds, usually 5 feet or less in thickness, and aggregating 4,000 to 6,000 feet. The stone varies here from a dense

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*Shannon, C. W., and Trout, L. E. Petroleum and Natural Gas in Oklahoma, Bull. Okla. Geol. Survey, No. 19, Pt. I, 1915.

**Taff, J. A., Geology of Arbuckle and Wichita Mountains. U. S. Geol. Survey, Prof. Paper, M 31, p. 70, 1903.

fine-grained blue limestone to a milky-white dolomitic limestone, with occasional thin layers of chert, interstratified. Chert nodules are also more or less common and the rock seems to be more silicious in chemical content than it is in the Arbuckle Mountain region. A complete section is not exposed in this area.

The following description of a type section is given by Reeds*.

Beginning at the base there are thin-bedded, silicious limestones 50 feet thick. There is a gradual change upward from these thin beds into the succeeding member, 300-400 feet thick, which consist chiefly of heavy-bedded, dull, bluish and cream-colored dolomites. Many of these massive beds are indistinctly bedded and weather into very irregular brown and sometimes nearly black bowlders. Others are more crystalline, marble-like and pinkish or gray colored. Succeeding these come about 250 feet of thin-bedded granular limestone and compact blue limestones which pass gradually into the main body of the formation, consisting of 3,500 to 4,000 feet of massive, compact magnesian limestone, the lower half of which contains chert in places. These limestones on weathering usually present smooth, white surfaces of practically the same color as the fresh rock. As the top of this thick member is approached the limestone beds become less magnesian and thinner and are succeeded by the highest member, which is composed of limestone interstratified with occasional sandy beds and strata of red, yellow and green clays.

The writer has been unable to make chemical analyses of the different parts of the formation. The following discussion concerning the chemical content of the formation is given by Eckel**:

Samples from the lower part and from the top downward for 600 or 700 feet showed a very small percentage of magnesia. Beds 2,500 feet below the top contain a small amount of magnesia. Probably 2,000 feet of massive beds in the central part of the formation are dolomitic; a sample from approximately the middle of the formation yielded 29.4 per cent lime and 19.2 per cent magnesia, showing it to be a nearly normal dolomite. A sample from the lower part of this dolomitic zone showed 33.1 per cent lime and 14.3 per cent magnesia.

Near the center of the formation east of East Timbered Hills in Murray County, there are chert nodules in more or less abundance, with an occasional stratum which is almost entirely altered to chert. Silicified fossils are also present at this horizon. They stand out on the surface of the limestone, due to the differential weathering.

It will be noticed in the above quotation from Eckel that no reference has been made to the silicious content of the samples analyzed. It appears to be free from disseminated silicious material, the quartz being

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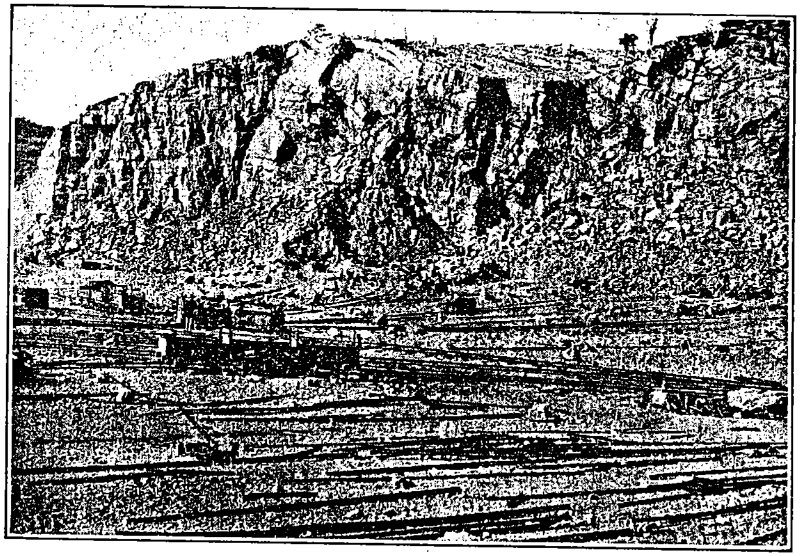
*Reeds, C. A., Geology and Mineral Resources of Arbuckle Mountains, Bull. Okla. Geol. Survey, No. 3, 1910, p. 33.

**Eckel, E. C., Cement Resources of United States, Bull. U. S. Geol Survey, No. 22, 1913, p. 304.



(a)

(b)

segregated in the form of nodules which are very easily distinquished on sight. It is the opinion of the writer that any lime producer who might care to open a quarry in either the high-calcium, the magnesium limestone, or the dolomitic limestone horizons could with little difficulty pick out a formation which is practically free from any silicious content. This formation offers the widest opportunity for the production of a dolomitic lime of any formation in the State. It is practically the only formation, of workable thickness which contains any considerable percentage of magnesia.

There are at present no lime plants located on this formation.

VIOLA LIMESTONE.

The Viola limestone, from 500 to 790 feet thick, occurs both in the Arbuckle and Wichita Mountain regions, along with the Arbuckle limestone. It is a very resistant formation, and where dipping to any considerable degree, stands out above the surrounding area, in long, well rounded "hogbacks." It is divided lithologically and paleontologically into three members—the lower, middle, and upper.

The lower member is usually described as being 100 feet in thickness, but Wallis* found it to be 550 feet thick in a section described by him. It consists of a dense, fine-grained, blue limestone, almost lithographic in texture. It is very hard and brittle, having a distinct concoidal fracture. It contains a considerable amount of silicious material which seems to have been deposited along with the calcium carbonate. In places it weathers out into a fairly good type of tripoli which seems to contain perfect bedding planes and will split into very thin sheets. Locally the lower member seems to be some 200 feet in thickness.

The middle member is some 300 feet in thickness. It is a dense, blue limestone, which in itself is relatively pure, but is interstratified with chert and contains an abundance of chert nodules.

The upper member varies from 100 to 300 feet in thickness, and is a highly crystalline formation of unusual purity.

A section described by Wallis* in N. W. ¼ Sec. 27, T. 2 S., R. 8 E., is as follows:

Description.	Thickness in feet.
White, gray and pink crystalline limestone	150
Fossiliferous limestone with lentils and nodules of chert	300
Dense cream-colored limestone with veins of calcite	550
Total	1000

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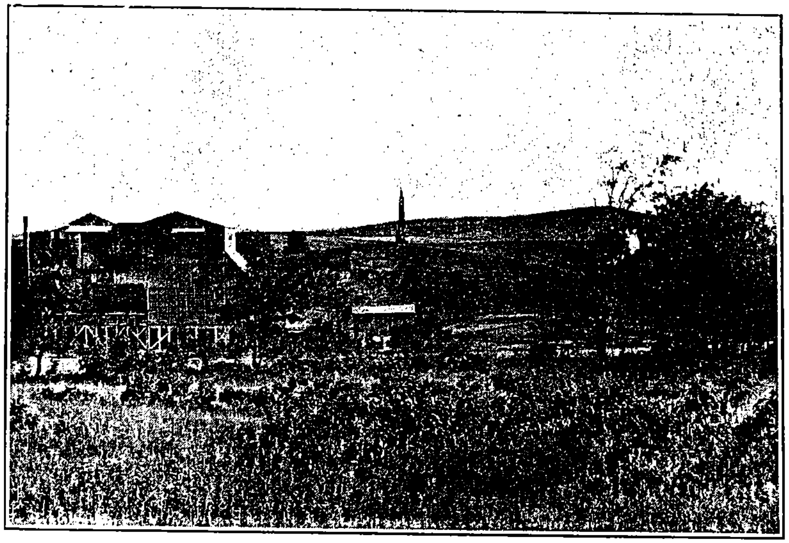
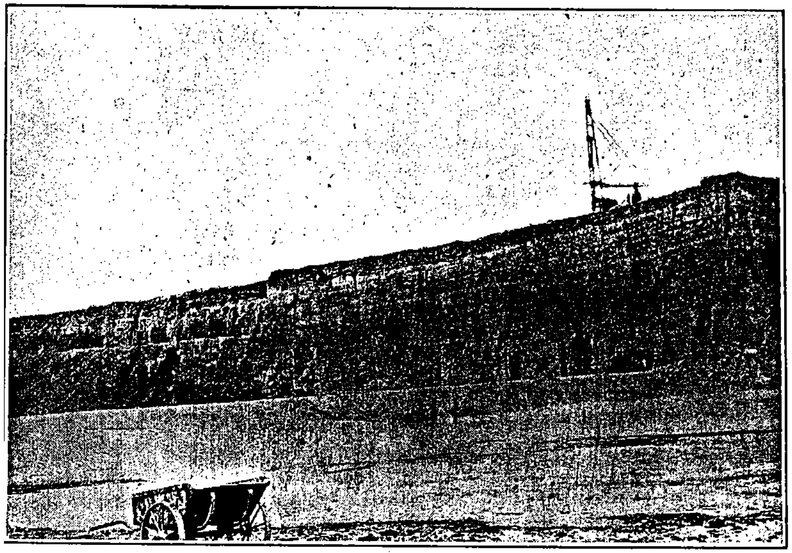
*Wallis, F. Geology and economic value of the Wapanucka limestone, Bull. Okla. Geol. Survey, No. 23, 1915.

*Wallis, F. Op. cit.

PLATE III.





The Viola limestone is burned for lime by the Viola White Limestone Company at Bromide, Oklahoma. A description of the quarry at Bromide will be given in detail along with the discussion of the plant on a following page.

Chemical Analyses of Viola Limestone at Lawrence.

SiO_2	15.21%
Fe_2O_3, Al_2O_3	25.62%
CaO	33.16%
MgO	2.82
Loss on ignition	23.19%

CHIMNEY HILL LIMESTONE.

The Chimney Hill limestone, or lower member of the Hunton formation, is a massive to thin-bedded limestone which varies from 30 to 60 feet in thickness. The lower member is very massive and is locally composed of a pure, white, large-grained oolite. At other places it is more or less fine-grained and thinner. The writer has found quite a number of iron pyrite crystals in this member. The middle member is relatively thin-bedded with occasional beds of shale interstratified. Locally, this member contains an abundance of limonite and iron hydroxide. This member also thickens and thins and is usually much thinner than either of the other two. The upper member is described by Reeds* as a pink crinoidal limestone. The iron content, as mentioned above, is probably more or less a local condition.

The formation outcrops along with the Viola limestone in the Arbuckle Mountain region, and stands out in noticeable escarpments where it could be quarried.

Wallis gives the following chemical analysis of this formation:

Analysis of Chimney Hill Limestone.

	Per cent
Calcium carbonate	97.94
Magnesia	.55
Iron and alumina	1.91
Total	100.40

The writer does not know from which member of the formation the analyzed sample was taken, or whether it was a composite sample of the entire formation. However, the formation which would give this analysis would make a very excellent grade of lime.

BOIS D' ARC LIMESTONE.

The Bois d'Arc limestone is the upper member of the Hunton formation, as found in the Arbuckle Mountains. The outcrop parallels that of the Chimney Hills and Viola limestones. It is a light-gray limestone weathering to a brownish-yellow. It is thin-bedded and crystalline, with interstratified layers and frequent nodules of chert. In a weathered condition it shows a considerable amount of argillaceous material. Its thickness varies from 0 to 90 feet, and has an average of about 40 feet, which is fairly constant over a great part of the area.

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*Reeds, C. A. The Hunton Formation in the Arbuckle Mts. Am. Jour. of Sci., 4th Series, Vol. 32, Oct., 1911.

This formation, as a rule, would not produce a very good lime; however, there are probably places where it is of sufficient purity to produce a relatively high grade of lime.

SYCAMORE LIMESTONE.

The Sycamore limestone is described as light, bluish to yellow, and probably argillaceous, massive limestones, which on weathering separates into thin beds, a foot or less in thickness, and changes to shades of yellow. It is a lenticular formation which varies in thickness from 0 to 200 feet. Near the extreme western end of the Arbuckle Mountains* it has a thickness of 200 feet. Near Washita River, in the central part of the Arbuckle uplift, the limestone has a thickness of about 50 feet, but it thins out eastward near the granite area in the northeast corner of T. 2 S., R. 3 E. Elsewhere in the uplift, toward the northeast, it is absent or represented by local, thin silicious limestone strata at the top of the Woodford chert.

This formation is, perhaps, unsuited for the production of lime. Following is a section of this formation taken about 300 yards south of the Atchison, Topeka & Santa Fe Railway bridge on the Washita River, two miles south of Crusher.

Heavy beds of brown limestone	
Light brown shale	60 feet
Massive, dense, blue, finely-crystalline limestone	45 "
Soft, slate-colored clay	15 "
Massive bedded, dense, blue limestone	20 "
Soft clay, drab colored	1 "
Massive, irregular bedded clay and earthy limestone	30 "
Base unexposed	
Total	171 "

FRANKS CONGLOMERATE.

The Franks conglomerate is composed largely of well rounded lime cobblestones, cemented together in a matrix of calcium carbonate materials. It is found over the northern and western parts of the Arbuckle Mountains, and in it can easily be recognized pebbles from every formation that was affected by the original Arbuckle uplift. There are

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*Taff, J. A. The Geology of the Arbuckle and Wichita Mountains, U. S. G. S., Prof. Paper, No. 31, p. 33, 1903.

occasional sandstone pebbles, but the formation, as a whole, has a high percentage of lime.

A chemical analysis of a formation of this nature would be difficult to make. It is, however, probably too high in silicious content to produce a good grade of lime.

WAPANUCKA LIMESTONE REGION.

WAPANUCKA LIMESTONE.

The Wapanucka limestone lies along the western border of the Arbuckle Mountains and extends northeastward into Latimer County. The outcrop is more or less continuous from Wapanucka to considerably beyond Hartshorne, and is marked by a well defined escarpment.

According to Wallis* the Wapanucka limestone consists of one or more layers of massive white to light brown limestone, together with chert, sandstone, and shale strata. Near the town of Bromide is found a bed of exceptionally fine, massive oolite, 70 feet in thickness. In the limestone ridge area the formation is composed of several members of fairly constant occurrence, and of variable thicknesses. The formation as a whole has a variable thickness of from 100 to 800 feet and is composed of alternating beds of sandstone, shale, and limestone.

Wallis, in his discussion, divides the formation as to outcrop into the Wapanucka and Limestone Ridge areas. In discussing the Limestone Ridge area, he divides the formation into nine members or beds. The uppermost member is a massive limestone, bluish-gray, weathering to a light-brown almost white color. It is exceedingly fine-grained, hard and compact. It is characterized by minute veins of calcite and has a variable thickness of from 50 to 75 feet. This bed was burned for lime for a few years at a small plant near the town of Wapanucka.

The second and third members are both silicious in content and hence are not of interest to the lime producer. The fourth member is a blue shale from 100 to 200 feet thick, below which the fifth member, a bed of massive limestone, has a variable thickness of from 5 to 170 feet. It is light-brown and weathers to a blue-gray color. This member is a relatively pure limestone and has been used for the production of lime at Hartshorne for several years. It is now used at the same place by the Choctaw Portland Cement Company. The remaining three members are sandstones, shales, and cherty limestones, which need not be described in this paper.

A chemical analysis of the formation used by the Choctaw Portland Cement Company, made by the Kansas City Testing Laboratory, is as follows:

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*Wallis, F. Bull Okla. Geol. Survey, No. 23, p. 30, 1915.

Analyses of Wapanucka Limestone Near Hartshorne.

	Percentage.
Silica (SiO_2)	1.10
Iron oxide (Fe_2O_3)	.10
Alumina (Al_2O_3)	.60
Lime (CaO)	54.70
Magnesia (M_gO)	1.10
Loss (CO_2) and organic matter	42.10
Sulphur trioxide (SO_3)	trace
Alkalies (K_2O and Na_2O)	......
Total	99.70

In the vicinity of Bromide there is a deposit of oolite which varies in thickness from 2 to 70 feet. At Limestone Gap, where the Delaware Creek cuts across the formation, the oolite is 70 feet thick and the formation dips east at an angle of about 10 degrees. Near the town of Wapanucka the oolite member is interstratified with occasional beds of non-oolitic limestone and chert. The oolite is considered a local phase in the formation and is found only in the Wapanucka district with its best development at Limestone Gap near Bromide. Here the Bromide Oolitic Stone Company has opened up a quarry.

The oolite member is a high-calcium limestone and would produce an excellent grade of lime. Its porosity is such that soon after the lime is drawn from the kiln and the air strikes it, only a slight disturbance causes it to crumble and have the appearance of air-slaked lime. This crumbling into fine flour makes it difficult to market on account of the fact that the dealers think they are getting air-slaked lime.

Should a company locate a plant on this formation, install a hydrator and hydrate all their lime, a ready market could probably be found for their product. There is an inexhaustible supply of stone, a plentiful supply of water near at hand and fuel readily accessible, and there would be no difficulties in shipping, in view of the fact that the Missouri, Oklahoma & Gulf Railroad has a spur running out to the town of Bromide, which spur passes through Limestone Gap, between the bluff and the stream. There is already a switch at this place, for the accommodation of the Oolite Stone Company.

A chemical analysis of the stone furnished by the Bromide Oolitic Stone Company is as follows:

Analyses of Bromide Oolitic Limestone.

	Percentage.
Calcium carbonate ($CaCo_3$)	97.83
Magnesium carbonate ($MgCO_3$)	.49
Iron (Fe)	.52
Silica (SiO_2)	.80
Moisture	.10
Total	99.74

Another analysis of the Wapanacka formation, given by Wallis, of one of the non-oolitic members is as follows:

Analyses of Non-oolitic Wapanucka Limestone.

	Percentage.
Calcium carbonate ($CaCO_3$)	96.20
Magnesium carbonate ($MgCO_3$)	1.19
Iron and alumina (Fe and Al)	2.61
Total	99.90

Chemical Analyses of Wapanucka Limestone from Bromide

SiO_2	4.61
Fe_2O_3, Al_2O_3	1.22
CaO	57.24
MgO	6.74
Loss on ignition	29.19

Chemical Analyses of Wapanucka Limestone at Hartshorne.

SiO_2	7.01
Fe_2O_3, Al_2O_3	2.82
CaO	50.19
MgO	8.15
Loss on ignition	30.73

LIMESTONES OF NORTHEASTERN OKLAHOMA.

ST. CLAIR MARBLE.

The St. Clair Marble occurs in the north-central part of Sequoyah County and probably extends across the line into Adair and Cherokee counties. It is brought to the surface by a series of faults. While its complete thickness is not exposed, it is known to be more than 200 feet thick, being exposed for 100 feet and drill holes testing it to an additional 100 feet.

It is described by Taff* as pinkish-white in color and in most parts as a coarsely crystalline marble. The writer observed it to be rather pink near the southern extremity of the outcrop. Near Marble City it is light-blue or white, and continues as such toward the north. A large quarry has been opened on the light blue part of the formation, about a mile northwest of Marble City. This quarry was operated for sevveral years and a considerable amount of building stone was taken out. No work, however, has been done at the quarry since 1914.

No chemical analyses of the formation are at hand, but from its physical characteristics and its highly crystalline nature, it would appear to be a high-calcium formation of unusual purity. It is compact to

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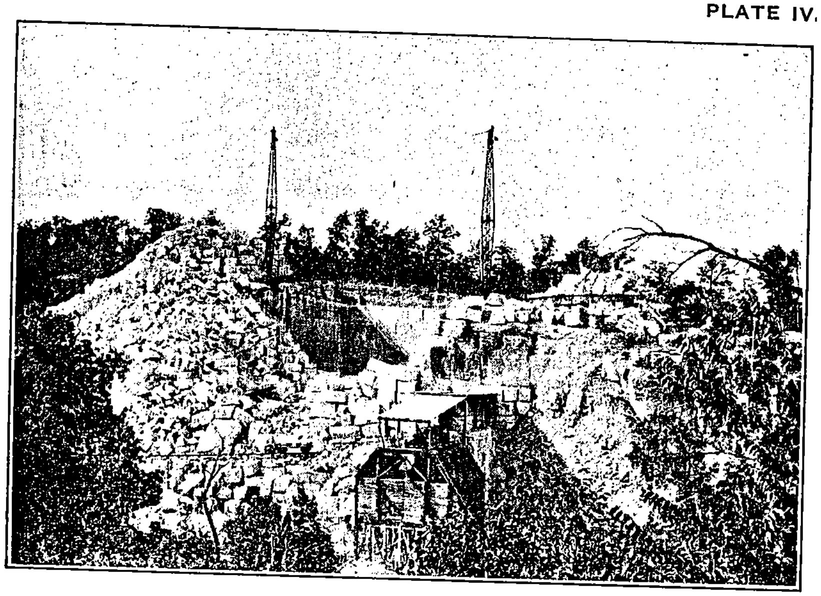
*Taff, J. A. The Geology of the Tahlequah quadrangle. U. S. Geol. Survey, Tahlequah Folio, 1905.

PLATE IV.



such an extent as to make it a good conductor of heat for limestone. This characteristic would tend to enable the center of the stone to reach the point of complete calcination before the outer surface had been raised much beyond the necessary temperature. With the above considerations, it is the opinion of the writer that this formation could be used for the production of lime on a very economical basis. The outcrop is near the southern extremity of the Ozark uplift and timber which could be used for fuel is present in great abundance. So far as is known, the formation has not been used for anything other than for building stone.

BOONE FORMATION.

The Boone formation is a heavy limestone about 300 feet thick, largely chert in the upper horizon. It outcrops over a large area in the northeastern part of the State. Its outcrop includes practically all of Delaware and Adair counties, the eastern and southern portions of Ottawa County, the extreme southeastern part of Cherokee County. The amount of the formation which is chert varies from place to place. As a rule, however, the upper 200 feet are composed almost entirely of chert, and occasionally the limestone members are absent. At the base of the formation there are usually two, and occasionally three, limestone horizons which bear very little, or no, chert, and which are separated from each other by chert strata. At the base of the formation in most localities where it is exposed, there is a considerable thickness of limestone. Taff describes this limestone as a fine-textured, dense, white to pinkish, even-bedded limestone. He correlates it with the St. Joe limestone member of the Boone formation in Arkansas. Taff also describes in the Tahlequah Quadrangle Folio, a crinoidal limestone bed from 10 to 15 feet thick. He mentions the fact that this limestone member is from 5 to 15 feet thick, and even absent locally in the Tahlequah Quadrangle. Snider* finds it present to the north at every place where that part of the formation is exposed, and its thickness gradually increases northward.

There is to be found near the base of the Boone formation, two lime members which do not seem to fit the description given by Snider and Taff of the St. Joe member. The lower of these two members is highly crystalline, almost a marble. It is light blue in color and seems to be of an exceptional purity. It has been metamorphosed to a considerable extent and many of the original bedding planes are characterized by stylolitic structure. It is from 16 to 20 feet thick and is between chert members in the formation. On the hillside the upper two-thirds of the member stands out as one massive layer. This member outcrops along Honey Creek in the north part of Delaware County, where it is burned for lime. It is also reported to be present near Strang in Mayes County. The other limestone member is above and separated from this one by chert formations. The upper member is about 15 feet thick,

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*Snider, L. C. Geology of a portion of northeastern Oklahoma. Bull. Okla. Geol. Survey, No. 24, p. 24, 1915.

is light blue and dense. It is found in the northern part of Delaware County near Grove. It would make a good grade of lime.

PITKIN LIMESTONE.

The Pitkin limestone is described as a light blue to brown, granular, slightly oolitic formation, interbedded with fine-textured, massive layers of limestone. Where the formation is thin, it is chiefly characterized by the granular oolitic type of rock. Where it is thicker, the central portion is massive, fine-grained and relatively pure. There are occasional thin beds of shale interstratified with limestone. The beds vary in thickness from thin plates to beds a foot to 2 feet thick. Where the beds are platy there is usually a considerable amount of argillaceous material. The Pitkin limestone in the Tahlequah quadrangle varies from a thin layer to massive beds aggregating 70 feet. In the Muskogee quadrangle it varies but little from 50 feet, the slight changes which probably occur, being due to erosion of the upper bed prior to the deposition of overlying formation. The Pitkin limestone outcrops in both the Tahlequah and Muskogee quadrangles, where its horizon is brought to the surface. From the Muskogee quadrangle it extends north into the Pryor quadrangle. From a thickness of about 60 feet just south of the Pryor-Muskogee quadrangle line, it thins to about 10 feet in the vicinity of Yonkers, about 8 miles to the northwest, and has not been observed north of the line between Tps. 18 and 19 N.

The Pitkin formation has been used for lime near old Fort Gibson. In the early days, as far back as 1850, it is reported that lime was burned near Muskogee and was floated down the Arkansas to Fort Smith. In view of the fact that this is the only lime formation outcropping near the river in this vicinity, it appears that this was the formation then used for the production of lime.

LIMESTONES OF NORTHERN OKLAHOMA.

GENERAL STATEMENT.

There are a great many limestone ledges in northern Oklahoma between Craig and Kay counties. These limestone formations as a rule are well defined and have a considerable thickness where they cross the Oklahoma-Kansas line. Almost invariably they thin toward the south and are soon replaced by sandstones and shales. There are but two exceptions to this rule: The Dewey and the Avant, which are thin at the northern exposure in Oklahoma, thicken toward the south until a maximum of 20 feet of the former and 50 feet of the latter are reached, then thin out to the south again and are replaced by sandstones and shales.

PAWNEE LIMESTONE.

The Pawnee limestone is generally massive and fine-grained. In Oklahoma its thickness is about 42 feet. At Talala the shale above the Pawnee limestone pinches out and the Pawnee and Altamont join to form the "big lime." Farther south the term is applied to the Oologah formation. This limestone is relatively impure and contains a considerable amount of clay and silicious materials. The weathered surface gives a considerable abundance of chert.

ALTAMONT LIMESTONE.

The Altamont limestone is about 30 feet thick. It is a hard, blue, massive limestone and is highly silicious in character. It outcrops along the banks of Verdigris River from Nowata to Oologah.

LENAPAH LIMESTONE.

The Lenapah limestone in general is described as a single, dense, blue, semi-crystalline limestone with fossils. On weathering, no residual chert is noted. The thickness varies from 8 feet in southern Kansas to fully 30 feet in northern Oklahoma, and finally to 3 feet or less in the region south of Nowata. It is named for the town of Lenapah in Nowata County, near which place a type section may be found.

A chemical analysis of the formation is not available, but one would judge from the foregoing description that it would make a very good grade of lime. It has been used for the production of lime by the Hickory Creek Lime and Stone Company near Lenapah. This company no longer produces lime.

HOGSHOOTER LIMESTONE.

The Hogshooter limestone is about 10 feet thick where it crosses the Kansas line. It thins slowly toward the south, being 6 or 8 feet thick in Hogshooter Creek, and 4 feet thick at Ramona. At the southern limits of the Claremore quadrangle it is less than 3 feet thick. It is a heavy-bedded, massive, fine-grained limestone, grading into shales toward the south.

DEWEY LIMESTONE.

The Dewey limestone extends from the Kansas line south, to beyond the Nowata quadrangle. It is a lens which varies from 3 feet in the north to 20 feet at Dewey, where it has its maximum development, and thins gradually toward the south, being 15 feet in thickness near Ramona. This limestone is a bluish, semi-crystalline limestone and usually contains a considerable amount of clay materials. It is quarried near Dewey by the Dewey Portland Cement Company.

It has been put in the class with the natural cement formations*.

AVANT LIMESTONE.

The Avant limestone is also a lentil which lies about 85 feet to 125 feet above the Dewey formation. It is found first about 5 miles south of Bartlesville and is fairly well developed in the neighborhood of Ochelata. It extends west along Bird Creek to Avant, where it has its most characteristic development. From here it gradually decreases in thickness toward the south and soon pinches out. It is only a few feet thick at its northern extension. Near Ochelata it has a thickness of 20 feet, and near Avant its maximum thickness is about 40 feet. It is in many respects similar to the Dewey in physical and lithological characteristics. It is blue in color and has many calcite veins and an abundance of fossils. The Midland Valley Railroad Company has a large quarry in this formation about 2 miles south of Avant, but, so far as the writer knows, the rock has never been used for the production of lime or cement.

STANTON LIMESTONE.

The Stanton limestone is one of the most persistent limestones which extends from Kansas into Oklahoma. It is a massive, bluish limestone, yielding little chert on weathering. It is well defined and very easily traced. It is, however, thin and on that account, unsuited for the production of lime, being at a maximum only 10 feet thick and is described as being only 2 to 5 feet thick, as a rule. It is probably high in argillaceous materials.

OREAD LIMESTONE.

The Oread limestone in Oklahoma is nowhere more than 17 feet thick, and pinches out about 10 or 12 miles south of the Oklahoma-Kansas line. No data is at hand concerning its lithological and chemical characteristics.

FORAKER LIMESTONE.

The Foraker limestone occurs in the northeastern part of the Foraker quadrangle in the northwestern part of Osage County. It has a maximum thickness of 74 feet. This thickness is largely made up of limestone. A greater part of it is so thin-bedded and soft, however, that in many places it forms no escarpment. It contains a great deal of shale. There is a heavy limestone member in this formation which is fossiliferous and contains an abundance of chert nodules. The part of the formation which is free from chert has a large amount of iron content which, in itself, would render the formation unfit for the production of lime.

RED EAGLE AND NEVA LIMESTONES.

The Red Eagle* and Neva limestones occur in the Foraker quadrangle and extend to the south. The Neva is a well defined limestone formation which is easily identified and traced. Beede** maps the formation from the Kansas line south as far as Pawnee. These two limestone formations may well be described together, in that they are very similar in lithological and chemical characteristics. Each is composed of a series of alternating limestones and shales, neither having a lime-

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*Eckel, E. C. Cement Resources of United States, U. S. Geol. Survey, Bull. 522, 1912.

*Heald, K. C., Oil and Gas Geology of Foraker quadrangle, Bull. U. S. Geol. Survey, No. 641-B., 1916.

**Beede, J. W. The Neva limestone of northern Oklahoma, Bull. Okla Geol. Survey, No. 21, 1914.

stone member of sufficient thickness or low enough in silicious content. The Neva limestone is characterized by its great amount of chert. Both are described as bearing a great deal of iron in the form of limonite.

COTTONWOOD AND CROUSE LIMESTONES.

The Cottonwood and Crouse limestones are both well exposed in the Foraker quadrangle. The Cottonwood limestone has a total thickness of perhaps 16 feet at the Kansas line and thins toward the south. The Crouse is only about 3 feet thick in the quadrangle. The Cottonwood limestone is found on the surface in a ledge only about 2 feet thick, because the remainder of the formation is so soft and has so high a percentage of argillaceous and clay materials that it is easily broken down by erosion. Neither of these formations is suitable for the production of lime.

WREFORD LIMESTONE.

The Wreford limestone has its type section near a small town by that name in Kansas, where it is 40 feet thick. Near Wreford the stone was burned for lime. Here the chief characteristic of the formation is that the lower member contains an abundance of chert.

It outcrops in the Foraker quadrangle and in the eastern part of Kay County. In Oklahoma the formation has a total thickness of perhaps 18 feet. It is a very soft limestone of buff color. It is porous and in places semi-crytalline. The lower member of the formation has a considerable amount of chert. It also contains limonite and would be unsuited for the production of lime.

FORT RILEY LIMESTONE.

The Fort Riley limestone in Kay County is about 52 feet thick. The lower half is massive-bedded and lenses of chert are common at the base. The upper part of the formation is composed of alternating beds of limestone and shale, and occurs in gentle slopes. The lower half is massive limestone and is quarried in several places in Kay County. East of Newkirk the quarry face is composed of 3 layers, with a maximum thickness of 12 feet. These layers are massive and on weathered surfaces often appear as one massive 12-foot bed. At the quarry at Uncas there are 9 layers, ranging in thickness from 1 to 7 feet, with a quarry face 25 feet high. This stone is used principally as a building stone and for railroad ballast. It is reported that lime has been burned from this formation, but the report has not been verified. The formation is high in iron content. A hasty analysis of the formation was made and such a strong test for iron was obtained, and there was so much insoluble material in an *aquaregia* solution that it was deemed unnecessary to make a complete analysis.

WINFIELD LIMESTONE.

The Winfield limestone occurs just west of the Fort Riley in the eastern part of Kay County. It is from 10 to 15 feet thick. The upper

part of the formation is composed of a massive limestone some 8 feet in thickness. Below this there are a number of thin, highly fossiliferous and shaly beds. The heavy bed varies in thickness and lithological characteristics from place to place. Where it is thickest, it is composed of an abundance of Fusulina so intimately mixed that individuals are hard to distinguish, and it very much resembles the Ft. Riley. Where this member is not so well developed it is more dense and has a higher degree of purity. Here it is blue in color. The formation is quarried locally for building stone and fence posts, but so far as the writer knows no other use has been made for it. It would be unsuited for the production of lime.

HERINGTON LIMESTONE.

The Herington limestone occurs about 50 feet above the Winfield, in the eastern part of Kay County. It forms the top of the Newkirk anticline. It is also found capping the hill 3 miles southwest of Ponca City. It is 18 to 20 feet thick, with massive beds below and thin beds above. The thin beds are usually covered by residual material. The massive bed is very similar to the massive beds of the Winfield and Fort Riley, both in its color, fossil content, and chemical composition. Near the base of the formation there is a stratum about 18 inches thick which is unusually honeycombed in a very conspicuous manner, where the formation has been long exposed to the weather. This cavernous feature serves readily to distinguish the basal part of the formation. It is this cavernous member which caps the hills 3 miles southwest of Ponca City.

The formation is unsuited for the production of lime.

LIMESTONES IN SOUTHERN OKLAHOMA.

GOODLAND LIMESTONE.

The Goodland limestone as described by Taff*, Shannon**, and Gould*** is a white, semi-crystalline to chalky limestone, 25 feet in thickness, the lower member of which is composed largely of oyster shells and locally has considerable silicious content. It outcrops in both the Tishomingo and Atoka quadrangles and from the Atoka quadrangle east it follows the general line of the St. Louis & San Francisco Railroad, the outcrop being usually from 1 to 3 miles north of the track. It follows this course to and across the Arkansas line. The formation is reported to have a local thickening near the town of Fort Towson. It is reported in this vicinity to be as much as 70 feet thick,

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*Taff, J. A. The Atoka and Tishomingo Folios (Nos. 79 and 98, respectively), Geol. Atlas U. S., U. S. Geol. Survey, 1903. Taff and Reed, Geology of Madill oil field, Bull. U. S. Geol. Survey, No. 381, p. 509, 1908.

**Shannon, C. W., and Trout, L. E. Bull. Okla. Geol. Survey No. 19, part I, 1915.

***Gould, C. N., Bull. Okla. Geol. Survey, No. 5, 1911.

but the writer was informed by the drillers that the thickness was about 50 feet. There is a lime kiln located on the formation at Fort Towson. At this lime kiln the writer measured a thickness of 38 feet, and at the time calculated that he was as much as 10 and perhaps 20 feet above the base of the formation, which would indicate a thickness of about 50 feet. The thickening appears to be decidedly local and extends over an area about 6 miles long, outcropping back and forth along the streams in a strip about 3 miles wide. A detailed description of the formation at the quarry will be given with the discussion of the Fort Towson White Lime Company in a later chapter.

KIAMICHI FORMATION.

The Kiamichi formation immediately follows the Goodland limestone. It is about 50 feet thick and is composed of beds of oyster shells interstratified with marl and clay. The lower 5 feet is composed almost entirely of oyster shells with marl and an argillaceous matrix. The succeeding 30 feet is composed of a blue clay marl and is succeeded by a thin shaly stratum which is followed by about 20 feet of blue clay marl interstratified with beds of oyster shells. These oyster shell beds occasionally are of unusual purity and could perhaps be used for the production of lime. The beds have not been observed to attain a sufficient thickness for the most economical working of a quarry, with the possible exception of an area in the southern part of Marshall County, about 3 miles south of the post office of Shay. At this place the formation seems to be composed almost entirely of limestone and oyster shell beds, with very little or no marl and clay interstratified.

CADDO LIMESTONE.

The Caddo limestone has a development of from 100 to 150 feet. It contains much clay and marl interstratified with semi-crystalline and yellow marly limestone. The lower 60 feet is chiefly of marly clay; above this there are 20 to 30 feet of marly limestone and chalky limestone interbedded with an occasional bed of oyster shells. Above this the limestone becomes more and more nearly pure until near the top, where the marl layers are mere partings in the limestone strata. From this dcription one would judge that the formation would be unsuited for the production of lime on any considerable scale. However, it would probably be well suited for the production of lime for use as fertilizer, and for local building.

BENNINGTON LIMESTONE.

The Bennington limestone is the youngest limestone deposit in the State. It occurs about 150 feet above the Caddo limestone and is from 10 to 15 feet in thickness. It is a massive, dull, blue limestone and is composed largely of a peculiar, small species of oyster. It usually stands out in low bluffs, and in erosion buttes. The formation caps the hills

south of Caddo and is the surface formation over a large area in the southern part of the Tishomingo and Atoka quadrangles and farther south.

While analysis have not been made, one would judge, from the descriptions, that it would make a relatively good grade of lime and its thickness is such that it could be economically worked.

DEVELOPMENT OF THE LIME INDUSTRY IN OKLAHOMA.

HISTORICAL.

Oklahoma has been producing lime for about 100 years. Probably the first lime burned in Oklahoma was that burned in 1820 for the construction of a Union Mission, whose foundation may still be found about 7 miles southeast of Choteau in Mayes County. It is not definitely known that lime was used in this building, but it is assumed by Mr. Joseph P. Thoburn* to have been used there.

The first place where it is definitely known to have been used was in the construction of Fort Towson in 1824. The chimney and many of the walls of the old fort are still standing, about 2 miles northeast of the town of that name in Choctaw County. Fort Gibson, in Muskogee County, was built in the same year. It was built of wood and later of masonry, but it is most likely that lime was used in the foundation and chimneys in the original structure. At Fort Towson, the Goodland limestone was most likely the source of the lime. The limestone of which the old fort was built was from the Goodland and the lower five-foot oyster shell member of the Kiamichi formation. It is probable that the Pitkin limestone was used at Fort Gibson.

The next record we have of the burning of lime in Oklahoma was in the construction of the fort at Fort Smith, Arkansas, in 1838. Lime for this construction was burned on both sides of the Oklahoma-Arkansas line. It is also reported that at this time lime was burned somewhere up Arkansas River, supposedly in what is now Muskogee County, and was shipped down the river by steamboat to Fort Smith. The limestone burned at Fort Smith was either from the Pitkin or the Boone formation. Both outcrop near Fort Smith. It is supposed that the Pitkin limestone was used in the kilns operated at that time in Muskogee County, as it outcrops in a few places within 2 miles, or less, of Arkansas River. The following year some masonry work is reported to have been done at Park Hill near Tahlequah.

In 1842 Fort Washita was built. The Fort was located about 18 miles south of where Tishomingo is now situated. It was built entirely of masonry, parts of which are still standing. The lime used in this masonry was most likely burned near at hand from one of the Cretaceous limestones which outcrop in that general region.

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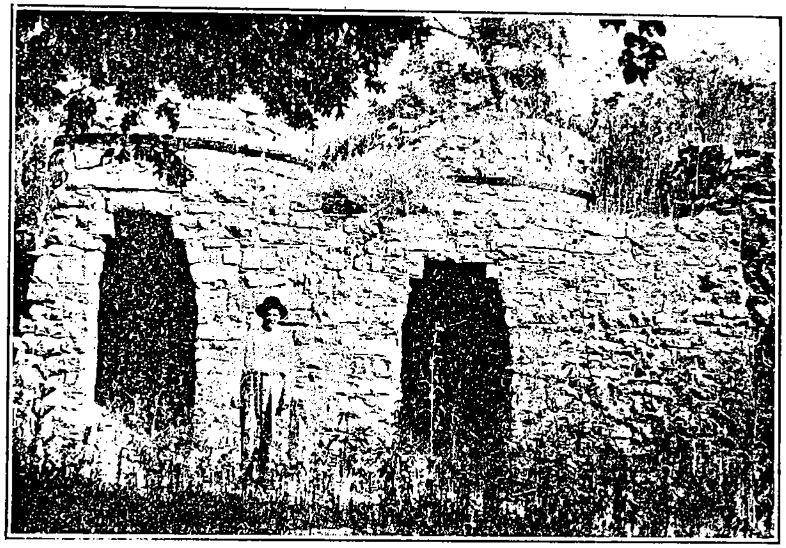
*Historical investigator and Author of Oklahoma History, Oklahoma University.

PLATE V.



In 1848 Fort Gibson was torn down and rebuilt of masonry. The year following (1849) a brick home was built at Saline, on Grand River in Mayes County. The lime used for the mortar was burned from the lower member of the Boone formation. Slabs of this highly crystalline, almost marble member of the Boone formation, were also used in the construction of the building. During the same year the Cherokee Seminaries were built at Tahlequah. These buildings were both of masonry, and lime was used in the construction of each. The writer does not know from which formation the lime was obtained as both the Pitkin and the Boone outcrop in the general region.

In 1850 the Choctaw Indian Academy was built near Bromide. This building is entirely of masonry and is still in a good state of preservation. The lime used in the construction of the building was most likely burned from the oolite member of the Wapanucka limestone, for it has its greatest development at this place. The stone of the building is also from that member.

Two years later, in 1852, Fort Arbuckle, a fort from which the Arbuckle Mountains were named, was built near Davis on the Washita River in Murray County. Because the fort had some masonry in it, it is assumed that lime from one of the limestone formations exposed in the Arbuckle Mountain uplift immediately to the south was utilized.

From 1852 no other records of the production of lime in Oklahoma are at hand until 1902, when the United States Geological Survey reports the value of the production of the year to be $25.

Since 1902 the statistics on production have been very accurately kept by the United States Geological Survey, but the exact amounts are published only when more than two plants report. For this reason, in order to give a connected record of production, it is necessary to estimate the production for certain years. The following table shows the production from 1902 to 1916, as given by the United States Geological Survey and the Oklahoma Geological Survey. For the years 1915-1916, the figures given are those obtained by the writer from the lime producers. Lime has been produced at many places in Oklahoma since 1902, but the places producing on a large scale have been relatively few. Perhaps the greatest number producing at any one time was in 1910, when eight plants reported production. These plants were well scattered over the eastern and southern parts of the State, there being one in each of the following counties: Atoka, Coal, Comanche, Delaware, Dewey, Johnston, Nowata, and Pawnee. The greater number of these plants worked for only a year or two and were closed down for various reasons. The plants in Delaware and in Coal counties continued until the beginning of 1917, reporting considerable production in 1916. The others have been shut down for some time. Other counties reporting lime production at various times are Marshall, Carter, Murray, Pontotoc, Sequoyah, Adair, Cherokee, Mayes, and Craig.

Year	Rank of State by quantity.	Quantity.	Value.	Rank of State by value.	Average price per ton.	No. of plants.
1902			$ 25		$	
1903			4,800			
1904	24	319	3,194	24	10.00	No report
1905	24	415	4,650	23	10.00	No report
1906		630	4,850		7.70	2
1907			e 5,000		7,86	2
1908			e 5,500			
1909			e 6,000			
1910	41	2,140	9,700	41	4.53	3
1911	37	3,472	14,603	40	4.21	4
1912	39	2,651	13,538	38	5.11	3
1913	39	2,640	12,160	39	4.61	4
1914	39	2,293	11,130	39	4,77	4
1915	40	x 3,033	x 23,414	40	7.72	2
1916		x 4,351	x 35,900		x 8.25	x 3

e Estimated.

x Figures obtained by the writer.

The chief reason why so many of these plants were short lived was probably due to the fact that very few of them were equipped for economic production. The writer knows of only three modern kilns in the State, and the production from these three kilns in 1916 was about six times as much as that of the eight kilns in 1910. The three kilns operating in 1916 were located in Choctaw, Coal, and Delaware counties. In the spring of 1917 a plant was installed in Adair County. Later in the year an old plant near Ft. Gibson in Muskogee County was repaired and started operating again.

OKLAHOMA LIME PLANTS OPERATING IN 1916.

FORT TOWSON WHITE LIME COMPANY.

In Choctaw County the Ft. Towson White Lime Company has a plant one mile east of the town of Ft. Towson. This plant was built in 1914, but did not produce very much lime in either 1914 or 1915. In 1916 it was in operation a greater part of the time and reported a fair production. The plant is well equipped, considering the time it has been in operation. It has a capacity of 140 barrels of lump lime per day. It has a circular steel kiln, lined with fire brick. It is 35 feet high and 18 feet in diameter, on the outside. The inner dimensions vary from top to bottom: in the burning area immediately above the fire grate the kiln is 8 feet square, a cooper shop 28 by 30 feet and a store room 26 by 80 feet with a capacity of 2,000 barrels. The tramway is 210 feet long and has an elevation of 65 feet. The car used on the tramway holds 7 barrels of stone and is hoisted by an oil engine.

The plant is located on the Goodland limestone. The formation at this place, from the bottom of the quarry to the top of the formation, is 38 feet thick. The position of the base of the formation could not be determined but it is estimated to be from 10 to 15 feet below the quarry level. This would indicate a thickness of about 50 feet. The limestone is of a dull yellow color when fresh, and a creamy white to almost chalk white when exposed to the sunlight for a few days. There are no well defined bedding planes. The formation is nodular on weathered surfaces and is so soft that in places it can easily be marked with the fingernail. Near the base of the quarry the stone seems to be hard and blue and does not turn so white after drying. It is thought that the white, soft rock above is due to weathering, and that as soon as the quarry face has gone back far enough the entire formation will be of the hard, compact, light-blue variety. Near the top of the quarry face, solution joints, which are accompanied by discoloration, are very common. The quarry face is only 22 feet high and from its top the hill slopes back to where the Goodland limestone is capped by a 5-foot stratum of oyster shells, which, with the marly clay above, composes a part of the lower member of the Kiamichi formation.

The rock at the quarry is composed of fragmentary fossils with occasional well-preserved gastropods and bivalves of considerable size. It has no definite bedding planes or joint planes along which it breaks. When shot it breaks up into pieces a foot or less in diameter and there is a great deal of fine material which is too small to be used in the kiln. As yet the company has not been able to make use of this fine material and it has accumulated until at times it is in the way. However, plans are under way to install a pulverizer which will produce pulverized limestone from the waste material.

The formation is an exceptional pure high-calcium limestone. Following are two analyses furnished by the company and one analysis made by the writer:

Aug. 1912.	Percentage.
Silica	1.3
Iron and aluminum oxide	1.0
Lime	97.8
Magnesia	.6
Total	100.7

Aug. 1914.	
$CaCO_3$	96.89
$MgCO_3$	1.00
Iron oxide	1.28
Silica	.25
Undetermined	.58
Total	100.00

In February, 1917, the writer collected a sample* which gave the following analysis:

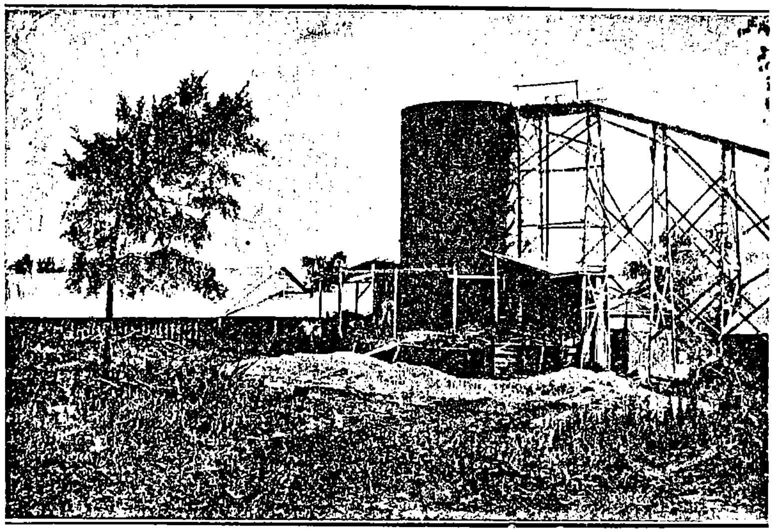
Chemical Analyses of Limestone from Ft. Towson.

	Percentage.
SiO_2	3.14
Fe_2O_3, Al_2O_3	2.60
CaO	47.20
MgO	27.50
Loss on ignition	20.82

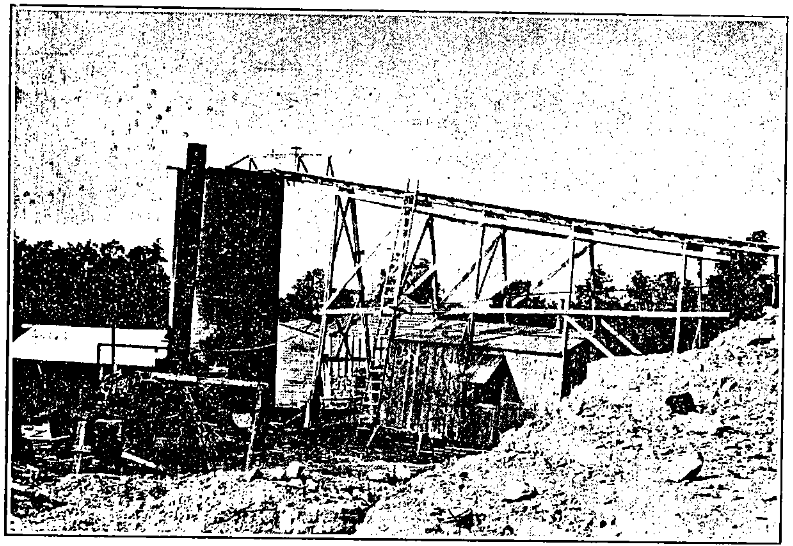
*Special care was taken to obtain a representative sample for analysis from each formation. In collecting this sample the following method was used:

By beginning either at the top or the bottom of the quarry face, a small rock about an inch in diameter was collected from each ten inches of the quarry face. Great care was taken to get these pieces as near the same size as possible and approximately the same distance apart. The sample was placed in a paper sack, well wrapped, then placed in a second paper sack before leaving the quarry. When it arrived at the

PLATE VI.



(a)



(b)

laboratory all rocks were crushed, pulverized, and thoroughly mixed, after which a representative sample was taken for analysis.

The Ft. Towson White Lime Company is at the present time the only plant operating in the State. It was unable to supply its demand in 1916. The company is planning to erect a second kiln, which will be larger and have a greater capacity than the one now in use. In addition to this the company is at present installing a hydrator, and is planning to install a pulverizer in the near future. The St. Louis & San Francisco Railroad has recently built a spur to the plant.

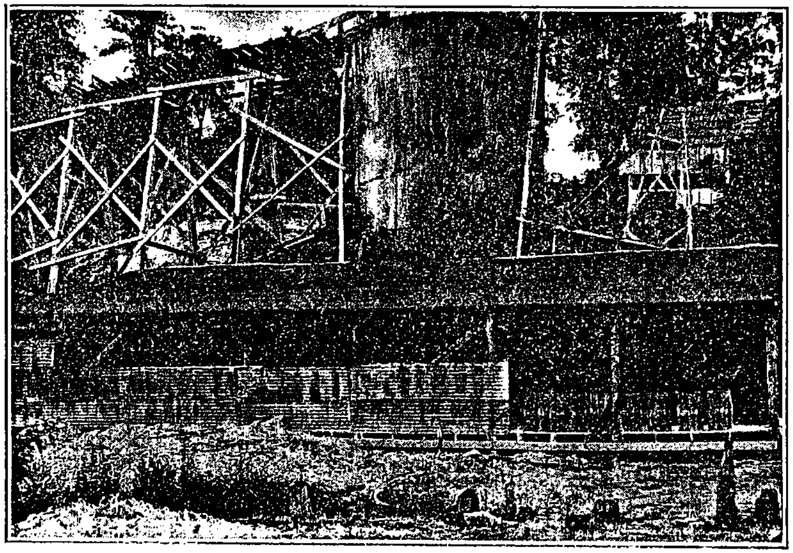
VIOLA WHITE LIME COMPANY.

In Coal County the Viola White Lime Company, at Bromide, has a plant which has been operated since 1908. This plant is located on the Viola limestone and is working the lower member. It has a capacity of 200 barrels per day. It has a circular concrete kiln lined with fire brick. The inside of the kiln is circular down to the fire grates. It is 30 feet high, 11 feet in diameter at the top, and tapers to the fire box, where it is 8 feet in diameter. The plant has a cooling floor 30 by 30 feet, a store room 48 by 54 feet, and a cooper shop 28 by 30 feet. The tramway is about 70 feet long and has an elevation of 4 or 5 feet. Steam is used both in hoisting and for drilling in the quarry.

The quarry is located on the lower member of the Viola limestone formation, which contains a great deal of chert. The formation is well bedded, the beds averaging from 4 to 8 inches in thickness and dipping as much as one degree to the north, away from the kiln. The rock is very easily quarried by placing a shot so that it cuts the bedding planes on the back side, allowing the rock to be easily removed. It is thought by the management that if it were not for the great amount of chert nodules which have to be picked out, that one man could very easily supply the kiln with rock. Interbedded with the limestone are beds, bands, and nodules of chert. A few of the limestone beds also have a high percentage of silica apparently thoroughly disseminated at the time of deposition. From 10 to 15 per cent of the rock is chert, but owing to the fact that it shatters easily and is of different color and texture it is easily picked out and does not often find its way to the kiln. Sorting, however, necessitates extra help at the quarry. The rock containing disseminated silica frequently finds its way to the kiln and causes an inferior grade of lime if it is allowed to pass the sorter on the cooling floor.

The quarry was first started on the level of the base of the kiln. It has been worked up and back in an effort to find a place where the chert was not so abundant. At present the base of the quarry is some 25 feet above the base of the kiln, and extends up to about 50 feet above the top of the kiln. Everywhere, so far, the formation shows a high percentage of chert. The writer found chert all the way from the

PLATE VII.



base of the kiln up to 15 feet above the upper limits of the quarry, that is, 15 feet above the highest place from which any stone has been taken out. Above this point no chert was found. It is probable that a horizon could be found farther up the hill at which the limestone would be relatively free from chert and from which a high grade of lime could be produced.

An analysis of this formation made by Erasmus Haworth* of the Kansas Geological Survey in 1911 is as follows:

Analyses of Viola Limestone.

	Percentage.
$CaCO_3$	97.83
$MgCO_3$	.49
Ferric oxide (Fe_2O_3)	.52
Alumina (Al_2O_3)	.00
Silica (SiO_2)	.80
Total	99.64

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*U. S. Geol. Survey, Mineral Resources, 1911.

Chemical Analyses of Viola Limestone from Bromide.

SiO_2	25.84
Fe_2O_3, Al_2O_3	23.08
CaO	36.84
MgO	3.47
Loss on ignition	9.56

The plant has not been working since November, 1916, but it is hoped by the management that it will start up soon after June 1, 1917. It is located about half a mile northwest of Bromide and one-fourth mile north of the Coal-Johnston County line. It is on a branch line of the Missouri, Oklahoma & Gulf Railroad and it is necessary to haul the lime from the kiln to the depot, a mile and a half distant. The management hopes to secure a spur out to the kiln. Plans are under way for installing a pulverizer to produce a ground limestone for use in glass plants and refineries, as well as for fertilizer.

GROVE WHITE LIME COMPANY.

In Delaware County the Grove White Lime Company has a plant about two and a half miles south of the town of Grove. The plant was built in 1908 and has been running practically all of the time since then. It has a capacity of 125 barrels per day. It has a circular steel kiln 30 feet high, lined with fire brick. Its inside diameter at the top is 20 feet and at the grates 4 feet 6 inches. The cooling chamber is 12 feet deep and cone-shaped. The dimensions of the cooling floor are 18 by 60 feet. The cooper room is 20 by 60 feet and the store room 48 by 60 feet. The tramway is 125 feet long and 35 feet high. Steam is used for hoisting and also for drilling on the quarry.

The kiln is located on one of the crystalline lime members near the base of the Boone formation. The quarry face is 250 yards long and in places 60 feet high. The limestone is very coarsely crystalline and of unusual purity. It is overlaid by chert of considerable thickness. The quarry was opened on the side of a hill which had a slope of approximately 45°. The overlying chert was stripped off, as far back as it could economically be worked. The operators figured that it was cheaper to haul the rock on the tramway than it was to strip the increasing amount of chert and for this reason they extended the quarry on down the side of the bluff. The formation is light blue in color. A detailed description of the formation beginning at the top is as follows:

Heavy beds of blue, hard coarsely crytalline, fossiliferous limestone, with occasional spherical chert concretions from 3 to 10 inches in diameter	7 feet.
A single bed of blue, crystalline, fossiliferous limestone, almost a marble. Banded with fossils varying in abundance, relatively free from chert, occasional stylolitic structure (this is the rock that is most desirable for lime)	10 feet.
Blue limestone with occasional white to yellow chert nodules (perhaps 10% chert)	2 feet.
Yellowish, cherty limestone with abundance of chert noludes (about as much chert as limestone)	2 feet.

Above the limestone there is from 10 to 40 feet of rusty, well-bedded chert which must be removed. As the quarry works back into the hill there is an increasing amount of chert to be removed. The formation dips at a low angle to the north about 15 feet per mile.

This is a high-calcium lime of unusual purity. The owner of the plant did not have an analysis at hand but said that the analysis which had been made gave 98.5 per cent calcium carbonate.

Chemical Analyses of Boone Limestone near Grove.

	Percentage.
SiO_2	18.22
Fe_2O_3, Al_2O_3	5.43
CaO	45.12
MgO	3.04
Loss on ignition	28.19

PLANT AT WATTS.

The plant of the Grove White Lime Company has been sold to the Rogers White Lime Company at Roger, Arkansas. It is being dismantled and moved to Watts, in Adair County, Oklahoma. The writer has been unable to secure any definite information concerning this new plant. It is thought that the quarry will be located on the same horizon in the lower Boone formation as at Grove.

Grove is located at the end of a branch of the St. Louis & San Francisco Railroad which enters Oklahoma from Arkansas. Watts is much more favorably located on the main line of the Kansas City Southern Railway, and from this point shipments can be made to points in Oklahoma more quickly and with less expense.

IMPORTS OF LIME IN OKLAHOMA.

In 1916 Oklahoma produced 4,351 tons or 335 car loads of lime. There are no figures to be had as to the exact amount of lime used in the State during a given period but estimates can be made which will approximate very closely the actual conditions. In making the estimates care has been taken to get representative cities and towns which have no factories or mills to use an excess of lime. The cities and towns of the State were grouped according to population and the records of lime consumption used from representative towns in each group: When this total was obtained the amount used by the glass factories was added. Oklahoma cities and towns are estimated to have used in 1916, 1,370 car loads or 17,710 tons of lime. Of the 18 glass plants, figures from 7 are at hand. Taking half the average of these seven as an average for the other nine, it is estimated that the glass plants of the State used 750 car loads, or 9,750 tons*.

The total estimated amount of lime used in Oklahoma in 1916, then, was 27,460 tons, or 2,120 car loads. This figure is most certainly too low, however, as all towns under 2,000 population, and all factories other than glass plants have been left out of the computation.

It is not known that the 4,351 tons of lime produced in Oklahoma in 1916 was all used in the State, but, granting it was, there must have been something like 1,785 cars of lime shipped in the State in that year.

In view of Oklahoma's unlimited resources for producing lime there seems to be no reason why the importation of lime should not cease and in a short time it would be necessary. Instead, the State should be exporting large quantities to other states less favored.

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*In these figures are included pulverized limestone as well as quick and hydrated lime.