

**OKLAHOMA GEOLOGICAL SURVEY**

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**THE HENRYHOUSE MARLSTONE  
IN THE LAWRENCE UPLIFT,  
PONTOTOC COUNTY, OKLAHOMA  
AND  
ITS COMMERCIAL POSSIBILITIES**

**Mineral Report 28**

by

**A. L. BURWELL**

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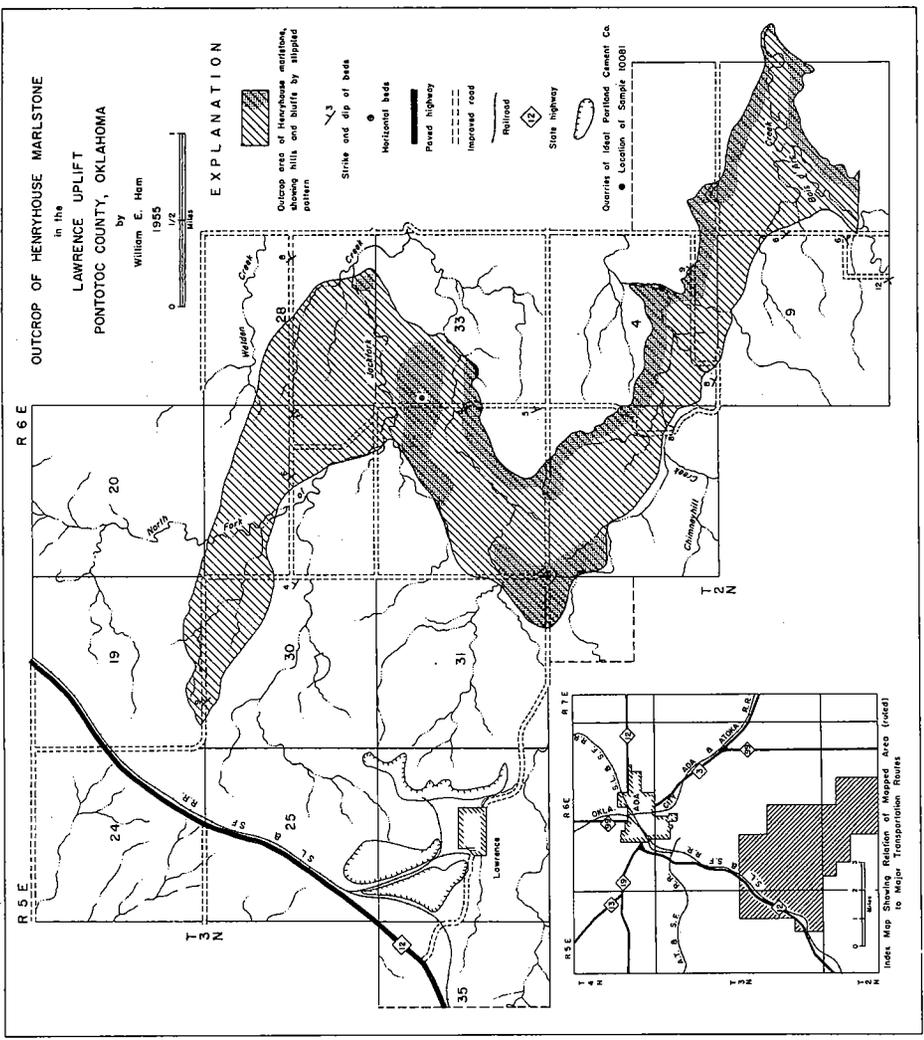
**THE HENRYHOUSE MARLSTONE IN THE LAWRENCE UPLIFT**

By

A. L. Burwell

**ABSTRACT**

The Henryhouse marlstone in the Lawrence uplift, Pontotoc County, Oklahoma, has been mapped and the occurrence described. The various possible uses for the material have been explored, based upon its physical and chemical properties. The composition of the stone indicates that the conversion to a hydraulic lime may offer a potential use. Tests have been made which establish the optimum temperature for calcination. Other tests demonstrate that hydraulic lime made from Henryhouse marlstone may serve in the preparation of structural concrete in combination with various types of aggregate including silica sand, expanded shale, and popped volcanic ash. Tables show the properties of such products.



# GENERAL GEOLOGY

By

William E. Ham

In the preparation of the new geologic map of the Arbuckle Mountains (Ham and McKinley, Okla. Geol. Survey Map A-2, 1955), rocks of the Hunton group were examined and mapped in all parts of the region embracing about 700 square miles. The rock classification now in use is slightly modified from the classification established by Reeds in 1911.<sup>1</sup>

## Classification of the Hunton Group\*

Lower Devonian	Oriskanian	Frisco limestone Bois d'Arc limestone Haragan marlstone	
Middle Silurian	Niagaran	Henryhouse marlstone Pink Crinoidal limestone	} Chimneyhill limestone
Lower Silurian	Alexandrian	Glauconic limestone Oolitic limestone	

\* Ham, W. E., *Oklahoma Geological Survey Guidebook III*, 1955, p. 32.

The maximum thickness of the Hunton group in the Arbuckle Mountains is 375 feet.

The Henryhouse formation, a consolidated argillaceous limestone or marlstone, is the thickest formation of the Hunton group. Maximum thicknesses are 250 feet in the Lawrence uplift, at the northern edge of the Arbuckle Mountains, and 220 feet on the south flank of the Arbuckle anticline on Henryhouse Creek. In other parts of the region the Henryhouse formation is thinner or is absent entirely, owing to erosion at the unconformity which separates the Henryhouse from the overlying Haragan formation.

Not only is the Henryhouse formation thickest in the Lawrence uplift, but this is the only area in the Arbuckle Mountains where the formation crops out over a wide area as the result of low dip. The outcrop area, extending as a curved band 0.5 to 1 mile wide, covers approximately 4 miles in the southwestern part of T. 3 N., R. 6 E., and the north-central part of T. 2 N., R. 6 E. The area is accessible to Ada, the nearest town, by improved roads, paved highways, and a railroad (Fig. 1).

The accessibility and large areal extent of the Henryhouse formation in the Lawrence uplift have stimulated the present investigation of its potential uses.

The formation is almost entirely exposed in Chimneyhill Creek and in the bluffs to the north, in the NE $\frac{1}{4}$  SE $\frac{1}{4}$  sec. 5 and the NW $\frac{1}{4}$  SW $\frac{1}{4}$  sec. 4, T. 2 N., R. 6 E. A section measured at this locality in 1947 with Dr. A. R. Loeblich, Jr., U. S. National Museum, and Dr. Heinz A. Lowenstam, Illinois Geological Survey, showed the Henryhouse formation to be 250 feet thick and to consist mostly of fine-grained argillaceous dolomitic limestone interbedded with calcareous shale. These strata are dominantly pale greenish gray or pale yellowish gray, and some beds contain abundant remains of fossil brachiopods, corals, crinoids, trilobites, sponges, and Bryozoa. The formation is relatively homogeneous, as the chief difference among the various beds is the percentage of clay and fossils they contain.

Although nearly all parts of the outcrop could be worked in pit quarries by removing a few feet of soil overburden, the most promising localities are in the low hills and bluffs south of Jackfork Creek (Fig. 1). The upper beds of the formation are exposed in a bluff 50-100 feet high that extends continuously from the west-central part of sec. 33, T. 3 N., R. 6 E. southward into the SW $\frac{1}{4}$  sec. 10, T. 2 N., R. 6 E. Reserves in this bluff are measurable in millions of tons, and hillside quarries could be opened at many localities. Another favorable quarry area is in the low hill in the NE $\frac{1}{4}$  sec. 32 and the NW $\frac{1}{4}$  sec. 33, T. 3 N., R. 6 E., just south of Jackfork Creek, where the marlstone strata are virtually flat-lying. A third area is in the low hills centered around the common corner of secs. 31 and 32, T. 3 N., R. 6 E. and secs. 5 and 6, T. 2 N., R. 6 E., in the lower part of the Henryhouse formation. At all these localities the dips range from 1-9° and average about 4°.

The channel sample obtained from fully exposed outcrops along the bluff in the SE $\frac{1}{4}$  sec. 4, T. 2 N., R. 6 E., which forms the basis for the present report, is believed to be representative of all the formation in the Lawrence uplift. Stone at localities considered for quarry sites in the northern part of the area probably will be closely similar in chemical composition and physical properties to the analyzed sample from sec. 4.

#### Henryhouse Marlstone

A "channel" sample of the Henryhouse formation was taken from a bluff near the center of the SW $\frac{1}{4}$  of section 4, Township 2 N., Range 6 E., Pontotoc County where about 60 feet of the formation is exposed. The sample represents the 40 feet immediately above the stream bed, and does not include any portion of the bluff above this point. The character of the bluff is shown in Figure 2. This sample is designated Laboratory No. 10081. The location from which it was taken is shown on the map

(Figure 1). Its chemical analysis is shown in Table 1. Calculations indicate its mineral composition as 66.75 percent calcium carbonate, 9.54 percent magnesium carbonate, and the balance of 23.71 percent mainly clay. Accordingly, this material is in reality a marly limestone and conforms to the definition of a limestone more closely than to the definition of a shale (1952)<sup>2</sup> (1948)<sup>3</sup>. Since a marl is clay mixed with calcareous material in variable proportions, it seems appropriate to designate the Henryhouse in the Lawrence anticline as a marlstone, a name that will be used in this report. However, from the standpoint of commercial utilization the Henryhouse should be classified as an impure limestone.

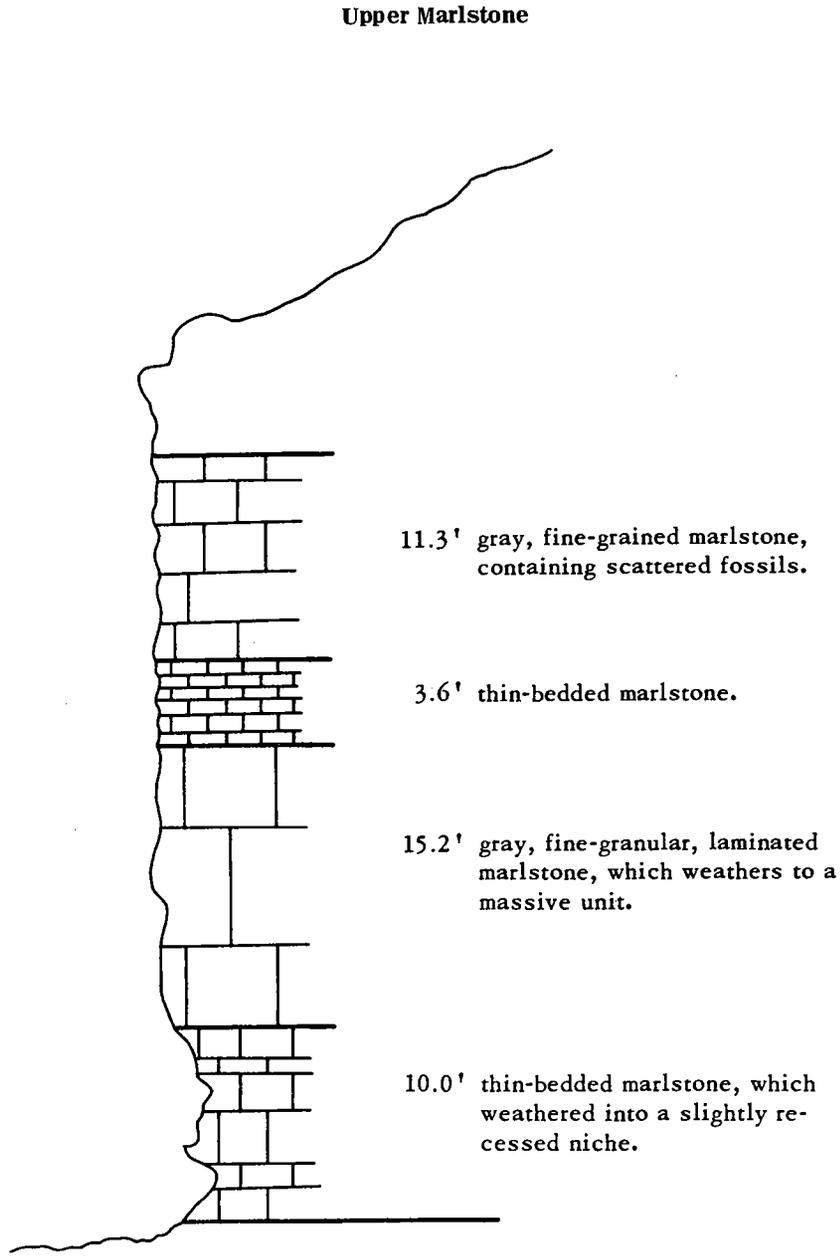


Figure 2

Table I.  
**Chemical Analysis of Henryhouse Marlstone**  
 Lab. No. 10081  
 from  
 near center of SE¼ section 4, T. 2 N., R. 6 E.  
 Pontotoc County, Oklahoma

SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	TiO <sub>2</sub>	CaO	MgO	K <sub>2</sub> O	Na <sub>2</sub> O	CO <sub>2</sub>	H <sub>2</sub> O	Cl	R <sub>2</sub> O <sub>3</sub>	L.O.I.
14.38	3.97	1.00	0.06	37.40	6.05	0.90	0.38	34.33	1.85	0.035	5.03	36.19

**Hypothetical Composition  
 calculated from the chemical analysis**

Calcium carbonate (CaCO <sub>3</sub> )	66.75%	Magnesium carbonate (MgCO <sub>3</sub> )	9.54%	Impurities	23.71%
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**Composition of Impurities**

(SiO <sub>2</sub> )	(Fe <sub>2</sub> O <sub>3</sub> ·Al <sub>2</sub> O <sub>3</sub> ·TiO <sub>2</sub> )	(MgO)	(K <sub>2</sub> O·Na <sub>2</sub> O)	(H <sub>2</sub> O)
59.71%	20.96%	6.22%	5.34%	7.77%

**Acid Extraction of Henryhouse Marlstone**

Acid insolubles - 21.29%	Calculated impurities - 23.71%
(from cold 1:5 Hydrochloric acid)	(from chemical analysis)

**Henryhouse Hydraulic lime (calculated).**

SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	TiO <sub>2</sub>	CaO	MgO	K <sub>2</sub> O	Na <sub>2</sub> O	R <sub>2</sub> O <sub>3</sub>
22.42	6.19	1.56	0.09	58.31	9.43	1.41	0.59	7.84

### Impure Limestones

Rocks classed commercially as limestones may contain varying amounts of material other than calcium carbonate ( $\text{CaCO}_3$ ). Most of them contain more or less magnesium carbonate ( $\text{MgCO}_3$ ),<sup>3</sup> up to as much as 30 percent, above which the rock is called a dolomite.<sup>3</sup> Except in rare instances a limestone will be found to contain at least a small amount of silica ( $\text{SiO}_2$ ), alumina ( $\text{Al}_2\text{O}_3$ ), and iron oxide ( $\text{FeO}$  or  $\text{Fe}_2\text{O}_3$ ). Any appreciable amount of these impurities, either combined or uncombined, places the rock in the impure class of limestones. Impure limestones are used for building and structural purposes, for agricultural stone, for portland cement, for natural cement, and for hydraulic lime manufacture.

For building and structural purposes the suitability of a limestone is determined more by its physical properties than by its chemical composition. The physical properties that are considered include color, strength, density, texture, hardness, workability, absorption, and porosity.

**Table 2**  
**Physical Properties of Limestones**

Color:	white when pure, but range through gray, buff, red, brown, to black.
Strength: compressive	range from 850 to 52,600 psi, with 13,600 average (1942) <sup>4</sup>
Density, bulk: air-dried	range from 1.74 to 2.86 (108 to 178 lbs/cu. ft.) (1942) <sup>4</sup>
Texture:	normally crystalline, some with spherical concretions.
Hardness:	3 Mohs scale.
Workability:	normally worked with ease unless highly siliceous.
Porosity:	range from 0 to 37.6 percent by volume; 8.3 average (1942) <sup>4</sup>

**Table 3**  
**Physical Properties of Henryhouse Marlstone**  
**near center of SE $\frac{1}{4}$  section 4, T. 2 N., R. 6 E.**

Color:	pearl gray
Strength: compressive	4,380 psi
Density: Bulk, air-dried	2.42 (approx. 150 lbs/cu. ft.)

Table 3, (Con't).

Apparent, dried 110° C.	2.46 – 2.50 (approx. 154-156 lbs/cu. ft.)
Texture:	inequigranular, compact, scattered fossils
Hardness:	3 Mohs' scale
Workability:	saws easily; somewhat brittle
Absorption:	normal absorption from atmosphere 1.2 percent or more; maximum by immersion 4.6 percent by weight
Porosity:	11.3 percent by volume

### Henryhouse Marlstone for Building and Structural Use

The physical properties of the Henryhouse marlstone from this particular location do not suggest its use as aggregate in concrete or for road construction (1948)<sup>5</sup>, but there is a possibility that it might find use as a building and structural stone. Its compressive strength is not as great as required in some specifications, but is well above any probable load likely to be encountered in this area. It does not have a pleasing color or appearance as might be desired, being somewhat drab and lusterless. It has also a tendency to "weather" and "chalk" and is rather brittle. However, its occurrence in massive beds and its ease of sawing are favorable factors.

Absorption and porosity are important in judging the permanence of stone. Absorption is best determined by immersion in water, raising the temperature to boiling, maintaining at a boil until the entire specimen has attained that degree, cooling submerged, removing excess moisture from the exterior, and weighing. Absorbed water is subject to freezing and thawing and thus is a definite factor in the deterioration of stone. The amount of pore space and the size of the pores have a bearing on the probable freezing and thawing damage. Under normal atmospheric conditions it was found that the Henryhouse marlstone contains upward of 1.2 percent absorbed moisture and that the maximum obtained by the above method was 4.6 percent by weight. The porosity was determined using a non-aqueous medium instead of water because of the possible effect of water on the clay content of the stone. The porosity found was higher than the average for limestones but the pore size appears to be smaller than the average. Some investigators report that stress and strain due to freezing and thawing is more pronounced in stone with small pores than in stone with larger ones, the cushioning effect of occluded air being greater in the large pore (1948)<sup>5</sup>.

Attention is directed to compression strength and porosity figures on limestones when taken from different sources (1942)<sup>4</sup> (1949)<sup>6</sup>. Considerable variance will be noted, the differences being due probably to the differences in the methods employed in the determination as well as

other causes. It is believed that those presented here are representative and reliable. It seems evident that the Henryhouse marlstone is not as desirable a building and structural stone as might be wished for, especially from a competitive viewpoint in this area where other stones are being quarried or are available.

### Henryhouse Marlstone as Agstone

Limestone for agricultural purposes must meet certain specifications which have in the past been established by federal or state agencies. The principal requirement pertains to the neutralizing value on soil acids and is measured in terms of the calcium carbonate equivalent. In Oklahoma the minimum acceptable calcium carbonate equivalent has been 85 percent and in only a very few states is the minimum as low as 80 percent. The Henryhouse marlstone does not meet even the lowest figure and therefore its use can not be advocated for agricultural purposes.

### Henryhouse Marlstone for Portland Cement

The manufacture of portland cement is carried out under most rigid control of its composition. Natural cement stone that will satisfy the requirements as raw material for portland cement, or a blend of stone that will satisfy these requirements, will contain oxides in the following ratios, according to Dixon (1942)<sup>7</sup>.

$$(1) \frac{\text{CaO} - \text{MgO}}{\text{SiO}_2 - \text{Al}_2\text{O}_3 - \text{Fe}_2\text{O}_3} = 1.9 \text{ to } 2.15 \quad (2) \frac{\text{SiO}_2}{\text{Al}_2\text{O}_3} = 2.5 \text{ to } 4.0$$

The Henryhouse marlstone ratios computed from the chemical analysis are:

$$(1) \frac{\text{CaO} - \text{MgO}}{\text{SiO}_2 - \text{Al}_2\text{O}_3 - \text{Fe}_2\text{O}_3} = 2.14 \quad (2) \frac{\text{SiO}_2}{\text{Al}_2\text{O}_3} = 4.68$$

Ratio 1 is within but close to the upper limit, whereas ratio 2 is over the limit. Further, the percentage of magnesium carbonate in this stone was found to be 9.5 whereas 5 percent is the maximum allowable. Therefore, the Henryhouse marlstone can not be recommended for portland cement manufacture.

### Natural Cements and Hydraulic Limes

Early in the eighteenth century, it was known that certain limestones containing clay could be burned to yield products with true hydraulic properties. The burned stone, after slaking with water, would

"set". Depending on the proportions of clayey material in the stone and its ratio to the alkaline-earth oxides, products were obtained that possessed more or less hydraulic properties ranging from natural cements to hydraulic limes (1951)<sup>3</sup>.

According to Dixon (1942)<sup>7</sup> stone that will yield a natural hydraulic cement contains from 13 to 35 percent clayey material (silica, alumina, and iron oxides) and from 35 to 50 percent alkaline-earth oxides (lime and magnesia). If the calcination is carried out at a temperature in the range from 1000 to 1200° C., the clay minerals are dehydrated and the alkaline-earth carbonates dissociate into carbon dioxide and the alkaline-earth oxides. The moisture and carbon dioxide escape and the alkaline-earth oxides and the dehydrated clay react to produce alkaline-earth silicates and aluminates which possess hydraulic properties. A temperature of 1200° C. is not sufficient to cause such vitrification as is necessary in making portland cement, and the compounds formed are not the same as at a higher temperature or at least not in the same proportions. The product will not slake with water as does ordinary lime but it does combine with the water to produce a firm mass, that is, it "sets" (1942)<sup>7</sup>. The percentage range of the several components as given by Dixon cannot be considered as critical since Rosendale stone from which a major portion of the natural cement produced in the United States is made is reported to contain 36 to 41 percent clayey material, 27 to 30 percent calcium and magnesium oxide, and 4 to 8 percent soda and potash (1949)<sup>9</sup>.

Stone suitable for the production of *hydraulic lime* has been found to contain from 10 to 17 percent clayey material (silica, alumina, and iron oxide) and from 40 to 45 percent calcium oxide (lime). Magnesia may replace the lime to a considerable extent without disadvantage. Calcination is carried out in the temperature range from 600 to 900° C. and yields a product that will slake with water in a manner similar to ordinary quicklime and possessing hydraulic properties ranging from feeble to those that harden quite satisfactorily under water (1942, p. 871)<sup>7</sup>. The Henryhouse marlstone contains lime and magnesia in an amount within the above limits. The amount of clayey materials is slightly above the limit placed on these ingredients.

Whether a stone will yield an acceptable quicklime, a weakly hydraulic lime, a strongly hydraulic lime, a Roman cement, or a portland cement can be determined approximately according to Platzman who established a table based upon composition for this purpose (1924)<sup>10</sup>. The table is given on the following page.

	CaO-MgO after burning	Clay content $\text{SiO}_2 \cdot \text{Al}_2\text{O}_3 \cdot \text{Fe}_2\text{O}_3$	Water content after slaking
Quicklime	90 to 100	0 to 10	25 to 26
Weakly hydraulic lime	85 to 90	10 to 15	20 to 24
Strongly hydraulic lime	65 to 85	15 to 35	17 to 22
Roman cement	55 to 60	40 to 45	-----
Portland cement	60 to 65	35 to 40	-----
Henryhouse lime	67.8	30.3	13.8

This comparison indicates that the Henryhouse marlstone should make a strongly hydraulic lime but it should not be expected to find use in either Roman or portland cement although it might possibly be a component of a blend for portland cement if it were not for the magnesia.

In the early days of this country the only hydraulic cement available was the so-called Roman or natural cement. In recent years the tonnage of natural cement manufactured has gradually decreased. The manufacture of portland cement has increased and almost supplanted the natural cement. The same sort of change has taken place in the hydraulic lime business, this product being replaced by blends of portland cement and lime especially for mortar. Accordingly, the prospects in the hydraulic lime business might be considered questionable. It is encouraging to read the article by Nathan C. Rockwood, a recognized authority on non-metallic mineral utilization, offering contrary evidence and predicting a reversal of the trend (1948)<sup>11</sup>. In the same issue, Mr. Rockwood editorializes on "Progress? in Cement and Concrete Research". A portion is here quoted:

"As a student of engineering history, as well as by necessity a reader of current literature on the subject, we have taken an interest in work of the early researchers on hydraulic cements. They had one great advantage. They started with little knowledge of the subject. Hence, they were interested in all kinds of hydraulic cements. Since lime is the most essential ingredient of all hydraulic cements, their research was based on a study of the chemistry of lime.

We hazard the suggestion that the same approach would be helpful today. The development of portland cement was possible because the early experimenters had observed the effect of argillaceous ingredients in limestone. Hydraulic lime was

the first manufactured hydraulic cement. In some ways it still appears to be the best."

In the technical article referred to, Mr. Rockwood compares the permanence of structures made with the old-time natural cements with those more modern and made with portland cement. The comparison is definitely favorable to the old-time products. The reason advanced for the better results from the older materials is that they contained lime (CaO) and silica (SiO<sub>2</sub>) in a lower ratio, forming the monocalcium silicate rather than the dicalcium and tricalcium compounds, and that the mono compound is much more stable as proven by its occurrence in nature. The fundamental difference in the mode of manufacture between the older products and modern portland cement lies in the temperature used in their manufacture. Natural cements and hydraulic limes are burned at temperatures below that where sintering occurs, and portland cement is burned to obtain a sinter. The types of product, therefore, are radically different in their reaction with water. Recognition of this difference and of the difference in the chemistry of the calcium silicates produced could presage a return to hydraulic lime for many structural purposes. Among the uses for which hydraulic lime seems well adapted are the making of concrete building blocks and pre-cast shapes and slabs. The fact that generally hydraulic limes are slaked immediately prior to their use, furnishing a much more reactive product, may account for the claimed superiority of concrete products made from it.

#### Henryhouse Marlstone and Hydraulic Lime

Reeds comments in his article on the Hunton formation of Oklahoma (1911)<sup>1</sup> "At the present time, no natural cement rock is being worked in Oklahoma. The Hunton limestone, however, of the Arbuckle Mountains, in its middle shaly horizons, gives some indications that it might be so used, but it has not been tested." This statement held good until early in 1953 when an investigation of the properties of the Henryhouse marlstone was instigated at the Oklahoma Geological Survey. This investigation was the result of an inquiry from Ron Bailey, at that time manager of the Ada Chamber of Commerce, who brought a specimen of the stone to the writer. The inquiry led to a field trip on which William E. Ham, staff geologist, and the writer were accompanied by Mr. Bailey, Mayor Allen of Ada, and W. E. Little, editor of the Ada News. A prominent bluff in the southeast quarter of section 4, T. 2 N., Range 6 E., Pontotoc County, was visited and a large sample representing the lower 40 feet of its face was taken and used for analyses and preliminary experiments. Material from this exposure has been used throughout the investigation.

### Calcining

The question first up for consideration concerns the size of raw material to be processed. If the vertical kiln is to be used, the stone should preferably be in 6 to 8 inch size. The rotary kiln will handle material from 2½ inch to dust size, but for the sake of product uniformity the feed is usually quite closely sized. Since World War II, two new types of kilns have been developed. The Ellerman kiln produces a pebble lime from ¼ to 1½ inch in size. This kiln handles only 6 to 15 tons per day but requires a relatively small investment. The Dorcco fluo-solids kiln handles minus 10-mesh material and is said to be especially adapted to stone or lime that has granulating tendencies (1952)<sup>2</sup>.

The second question has to do with the proper temperature in calcining. To determine this, a quantity of marlstone was crushed and ground, yielding a product with particle size as follows:

On	80-mesh	10.7%
On	100-mesh	6.1%
On	200-mesh	35.2%
Through	200-mesh	47.0%

Portions of the pulverized material were calcined at 1200°, 1000°, 950°, 900°, 800°, and 700° C., as shown in Table 4, yielding products which on re-ignition at 1000° C. showed losses of 0, 0.63, 0.54, 1.81, 13.25, and 29.67 percent respectively. The several calcined products were slaked with water and the putty mixed with sand. The mixtures were cast in standard 1" x 1" bar molds and allowed to dry. The bars were alternately wet and dried over a four-week period. The apparent density, absorption, porosity, and compressive strength were determined on each specimen. The results were inconclusive except to show that calcining temperatures above 1000° C. produced products of little worth as hydraulic lime, but that products calcined between 800° and 1000° C. possess hydraulic properties; and that the density, absorption, and porosity depended more upon the water incorporated in the mixture than upon the temperature of calcination. The compressive strength was also influenced by the amount of water used. The hydraulic properties of the lime calcined at 800° C., together with the further loss on ignition of the lime at higher temperature, indicates that the dolomite in the stone has been dissociated, but the calcite has not. The products from calcination in the temperature range from 900° to 1000° C. are quite similar to each other. A temperature of 950° C. was accepted as satisfactory for further trials.

**HENRYHOUSE MARLSTONE**  
**Insulation Concrete**  
**Table V**

Test No.	Lime, % by wt.	Aggregate, % by wt.	Water, % by wt.	Bulk Density	Porosity % by vol.	Absorption % by wt.	Strength p. s. i.
1.	100	0	83	1.35	47.4	36.0	1300
2.	95	5	83	1.26	43.5	34.4	1325
3.	90	10	83	1.07	42.8	40.0	1325
4.	85	15	83	1.05	40.4	38.5	1325
5.	80	20	83	0.95	41.1	43.4	1225
6.	75	25	105	0.90	45.6	50.9	1125
7.	70	30	110	0.75	39.9	53.3	700
8.	65	35	115	0.73	44.6	61.0	850
9.	50	50	150	0.48	72.2	150.2	575
9a.	50	50	150*	0.50	63.0	126.0	250

Henryhouse marlstone ground to pass 100 mesh and fired at 1740° F. A weighed amount of the "calcine" slaked with measured amount of water, and mixed with a weighed amount of popped Dustin volcanic ash. The mixture cast in bar mold 1" x 1" x 14½". On removal, the bars were alternately dried and wet. After several weeks the dried bars were cut into approximately 2" lengths for testing.

Note:\* Part of this water was used to slake the lime, the balance added later. The mixture was held overnight before molding.

Table 4. Henryhouse Marlstone  
Concrete Masonry Tests

Marlstone crushed and ground:	Sieve analysis		Product loss on ignition at 1000° C.	Test mixture: product, silica sand, and water.	Apparent Density	Porosity % by vol.	Absorption % by weight	Compressive Strength in psi.
	On 80-mesh - 10.7% Smaller	On 200-mesh - 35.2% Smaller						
1200	16	----	----	100 gms. product 200 gms. sand 118 mls. water	1.61	43.4	27.0	200
1000	12	0.63%		100 gms. product 200 gms. sand (a) 90 mls. water (b) 133 mls. water	1.83 1.45	31.6 47.9	17.3 33.0	1300 2000
950	18	0.54%		100 gms. product 200 gms. sand (a) 90 mls. water (b) 133 mls. water	1.93 1.53	35.3 42.5	18.3 27.8	900 2100
900	20	1.81%		100 gms. product 200 gms. sand (a) 90 mls. water (b) 175 mls. water	1.90 1.49	30.1 49.2	15.8 33.1	1600 1800
800	20	13.25%		100 gms. product 200 gms. sand 90 mls. water	1.86	34.0	18.3	800
700	30	29.67%		100 gms. product 200 gms. sand 90 mls. water	-----	-----	-----	-----

Mortar and Concrete from Calcined Henryhouse Marlstone

The first trials consisted in slaking the lime using 12 parts water to 10 parts lime, and allowing the slaked lime to age for 2 hours before mixing with the aggregate. Mixtures were prepared using lime to silica sand ratio of 1 to 5 and 1 to 10. The mixtures were cast into bars having dimensions 1" x 1" x 14". Within a few hours after casting the bars had "set" sufficiently so that they could be handled without distortion. The bars were air dried, and cut into shorter lengths for testing purposes. It was found later that on immersion in water the dried pieces had a tendency to swell, warp, crack, and disintegrate. This tendency was due, no doubt, to incomplete hydration which is characteristic of dolomitic limes(1952)<sup>12</sup>. The difficulty was overcome in the laboratory by carrying out the slaking in a can with lid and maintaining the high temperature developed by the reaction for several hours through application of external heat. Also, it was found advantageous to store the cast bars prior to drying in an atmosphere saturated or nearly saturated with moisture. It is recommended that before slaking any lime the operator should read the directions given in ASTM report (1926)<sup>13</sup>, and Knibbs and Thyer's article on lime hydration (1955)<sup>14</sup>.

Trials were also made in which the lime was converted to a powdered dry hydrate rather than to a "putty" as in the first trials. This hydration was carried out in a closed container using water in the amount theoretically required to convert the calcium and magnesium oxides to the hydroxides but without excess. The product conforms to the definition and requirements of Magnesium Hydraulic Hydrated Lime (1942)<sup>15</sup>.

Mixtures with aggregates were prepared as in previous work and bars cast for test purposes. The initial "set" was not as evident where the dry hydrate was employed as where the "putty" was used. Also, test blocks were made by thoroughly blending on a weight basis 18 parts dry hydrate, 60 parts silica sand, and 10 parts water and pressing into a 2 1/4" cylinder at 800 psi. After aging for 15 days in moist air the blocks were dried. After storage for several months the blocks were found to withstand up to 3000 psi pressure before crushing.

The current demand in the construction business for lightweight concrete in monolithic and precast forms lead to tests using lime prepared from the Henryhouse marlstone together with lightweight bloated shale and popped volcanic ash. The results of tests using popped volcanic ash are shown in Table V and include the effect of variation in the proportions of lime and aggregate on the bulk density, porosity, absorption and crushing strength of the products. The slight irregularity in the porosity and absorption may be attributed to the change in amount of water required to produce a castable mixture as the percentage of aggregate was increased. As was to be expected, the crushing strength decreased with lowering of the bulk density.

So far, all tests on the Henryhouse marlstone have been conducted on material calcined by conventional methods. As has been shown, the

hydration of dolomitic lime is seldom complete unless great care is exercised in control of the reaction. Within the past few years there has been considerable research on catalytic calcination of limestones and dolomites. Based upon the work of McIntire and Stansel on steam catalysis in calcination (1953)<sup>16</sup>, experiments were made looking to the production of a thoroughly hydrated product directly from pulverized stone.

Our experiment consisted in spreading a half inch layer of pulverized marlstone on a silicon carbide slab which was the hearth of an electric furnace equipped with automatic temperature controls. When the furnace had attained 150° C. a stream of live steam was introduced and the flow continued throughout the calcination. When the furnace reached 700° C. it was held at this temperature for three hours after which the source of heat was cut off and the furnace allowed gradually to cool. Only when the temperature had dropped to 150° C. was the steam cut off. The furnace was then opened and allowed to cool to room temperature. The temperature of 150° C. was adopted because it was still hot enough that the product would be dry when cool and also because it was below the dissociation temperature of both calcium and magnesium hydroxide, a condition which should be conducive to a high yield of these products. Theoretically, the product should show a 19.8 percent ignition loss at 1000° C. whereas the actual loss was 21.6 percent, indicating a product of approximately the desired composition. Further research on this process is contemplated, since a completely hydrated product would avert stresses and strains in concrete and mortar due to unhydrated magnesia and thus prevent deterioration now recognized as caused by unhydrated magnesia.

#### Summary

The Henryhouse marlstone in the Lawrence uplift has been mapped, disclosing a tremendous reserve of this impure limestone with a number of desirable quarry sites. Commercial uses for this stone appear to be limited. The physical properties of the stone are not attractive but the massive occurrence and ease of sawing are favorable considerations for its use as building stone. Calcination of the stone to produce a hydraulic lime offers the best chance for commercial exploitation. Laboratory experiments indicate that lime prepared from this stone by calcining in the range of 900° to 1000° C. possesses hydraulic properties which in admixture with siliceous aggregate yield satisfactory mortars and concrete.

#### References Cited

1. Reeds, C. A., Hunton Formation of Oklahoma. Amer. Journ. Science, Vol. 18, pp. 256-68 (1911).
2. Encyclopedia of Chemical Technology, Interscience Ency. Inc. (1952).
3. Rice, C. M., Dictionary of Geologic Terms. Edwards Bros., Inc. (1948).
4. Handbook of Physical Constants. Geol. Soc. Amer., Special Paper 36 (1942).
5. Rhoades, Roger and Mielenz, Richard C., Petrographic and Mineralogic Characteristics of Aggregates. Amer. Soc. Testing Materials, Spec. Tech. Publ. No. 83 (1948).
6. Handbook of Chemistry and Physics. 31st ed. (1949).
7. Dixon, Tod G., Cement, Lime, and Plaster. Rogers Manual of Ind. Chem., 6th ed., Van Nostrand (1942).
8. Ladoo, Raymond B., and Myers, W. M., Nonmetallic Minerals, 2nd ed., McGraw-Hill (1951).
9. Myers, W. M., Cement Materials, Industrial Minerals and Rocks, Amer. Inst. Mining Met. Engineers, p. 161 (1949).
10. Platzman, quoted by Rockwood, Nathan C., Rock Products (Nov. 15, 1924).
11. Rockwood, Nathan C., Future for Hydraulic Cements, Rock Products, p. 122 (Jan. 1948).
12. Rockwood, Nathan C., Progress? in Cement and Concrete Research, Rock Products, p. 73 (Jan. 1948).
13. Wells, Lansing S., Clarke, Walter F., and Levin, Ernest M., Effect of Aging on the Soundness of Regularly Hydrated Dolomitic Lime Putties. Nat. Bur. of Standards, Building Materials and Structural Report 127 (1952).
14. Quicklime for Structural Purposes, Amer. Soc. Testing Materials designation: C5-26 appendix.\*
15. Knibbs, N. V. S., and Thyer, E. G. S., Increased Efficiency in Hydration of Lime. Rock Products, p. 84 (June 1955).
16. Hydraulic Hydrated Lime for Structural Purposes, Amer. Soc. Testing Materials designation: C141-42.\*
17. McIntire, W. H., and Stansel, T. B., Steam Catalysis in Calcination of Dolomite and Limestone Fines. Ind. and Eng. Chem., p. 1548 (July 1953).

\*Note: in Amer. Soc. Testing Materials designations the final figure indicates the year of original adoption or the year of last revision. Information is from Amer. Soc. Testing Materials Standards, part 3 (1952).