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BULLETIN 91

# THE MANUFACTURE OF LIGHTWEIGHT CONCRETE AGGREGATE FROM KANSAS CLAYS AND SHALES

By

NORMAN PLUMMER AND WILLIAM B. HLADIK

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# THE MANUFACTURE OF LIGHTWEIGHT CONCRETE AGGREGATE FROM KANSAS CLAYS AND SHALES

By

NORMAN PLUMMER AND WILLIAM B. HLADIK

## ABSTRACT

Lightweight aggregates have been in increasing demand during the past few years for use in all types of concrete, but particularly in vibrated concrete blocks. This increasing demand has been due to several advantages the lightweight materials have over the conventional heavy aggregates. These advantages include better sound and heat insulation and savings in both cement and structural steel due to the lessened dead weight. Supplies of bloated shale aggregates have been entirely inadequate to meet the demands not only in Kansas but over most of the United States. The need for the lighter weight materials is so acute that an enormous tonnage of pumice has been shipped from New Mexico and elsewhere to as far from the source of supply as Chicago.

Tests on 227 samples taken from 47 counties in Kansas indicate that raw materials suitable for the production of lightweight aggregates are available throughout most of the State. The most abundant supply of raw materials has been found in the eastern one-third of Kansas, but in the western two-thirds the supply of suitable raw materials is far in excess of any possible demand.

Tests were conducted in a high-temperature electric furnace and a batch-type rotary kiln. Results were checked in a 30-foot pilot-plant continuous rotary kiln. Materials tested include shales of Pennsylvanian, Permian, and Cretaceous age, and clays of Cretaceous, Tertiary, and Pleistocene age.

## INTRODUCTION

### PURPOSE OF THE INVESTIGATION

*Needs and potentialities.*—The manufacture of lightweight aggregate from shale by means of rapid heating to a high temperature in a rotary kiln had its most significant beginning in Kansas City in 1919 when Stephen J. Hayde constructed the first Haydite plant. The Brick and Clay Record publicized this development in their issue of September 9, 1919, and predicted a great future for the lightweight aggregate industry. For the past 30 years the industry has developed very slowly, but since the end of World War II interest in lightweight building materials of all types has had a decided impetus, and the demand for lightweight aggregates has increased very sharply.

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The increased demand for lightweight aggregates has originated chiefly with the construction industry. Contractors and architects are realizing the value and economy of lightweight structures that require less concrete and steel. Economy in the use of reinforcing and other structural steel is of particular importance because of both scarcity and cost. The cellular structure and low density of the lightweight materials result in effective insulation against the transmission of heat and sound. The value of such insulating properties is becoming increasingly apparent, especially with the development in air-conditioning and the realization of increased comfort and resulting efficiency in the reduction of noise.

The Brick and Clay Record (1950a, p. 41) asserts that lightweight aggregate is "a natural for the 1950's" and it looks as if they were right. The demand for aggregate of all types for the production of concrete blocks has reached an average of 18,000,000 cubic yards per year in this country for the past three years, from which one billion blocks per year (55 blocks per cubic yard of aggregate) are manufactured. It has been estimated that 35 to 40 percent of the demand for lightweight aggregate can be supplied while 60 to 65 percent is yet to be produced (Miller, 1950). These figures concern the concrete block industry only. It is generally believed that as soon as sufficient high-grade lightweight aggregate is available it will replace heavy aggregate in monolithic structures made from poured concrete where benefits can be realized from the increased insulating properties and low density.

In Kansas between 21,000,000 and 24,000,000 concrete blocks or equivalent units were produced in 1949, according to a reliable source that prefers to remain anonymous. Most concrete block manufacturers are attempting to obtain lightweight aggregates, but the supply of expanded shale aggregate is entirely inadequate. A large amount of pumice is being shipped into this State from New Mexico. The total cost of New Mexico pumice was $5.20 a yard in Wichita in May 1950. Expanded shale aggregate can be produced locally and transported to the block manufacturers at a competitive price. Furthermore, the expanded shale, if properly made, is definitely a superior product.

The use of lightweight poured concrete is only in the beginning stages due largely to the lack of suitable aggregates. This

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potential market would include not only concrete for use in buildings but also highway construction. Furthermore, the lightweight expanded shale is an ideal aggregate for bituminous matt and similar types of road surfacing. Engineers of the Atchison, Topeka, and Santa Fe Railroad have expressed the opinion that a moderately expanded clay or shale makes an excellent railroad ballast. An investigation of the suitability of Kansas materials for this purpose has been reported by Plummer and Hladik (1948).

*Geologic factors.*—The clays or shales of the five geologic systems cropping out in Kansas have distinctly different ceramic properties, especially in respect to their bloating characteristics as revealed in the experimental production of lightweight aggregate in our laboratories. These five systems, named in ascending order, are the Pennsylvanian, Permian, Cretaceous, Tertiary, and Quaternary. The areas in which most of these rocks crop out in Kansas are shown on Figures 1, 2, and 3.

Easily bloated or expanded shales occur in abundance in the rocks of Pennsylvanian age cropping out in approximately the eastern one-third of the State (Fig. 1). These shales are interlayered with limestones and some sandstones. The limestones are suitable for heavy concrete aggregates, road surfacing, and other similar uses, as well as supplying building stone in various grades. Sand and gravel is also abundantly available in this area. Thus all the conventional materials for which bloated shale may be substituted are in good supply, and the development of lightweight aggregates in eastern Kansas will be dependent entirely upon the advantages of low density rather than a general scarcity of aggregate materials. The demand for all types of building materials, including aggregates, can be expected to be greater in the eastern one-third of the State than in other sections because of the much greater density of population.

The area in which the rocks of Permian age are exposed at the surface (Fig. 2) is not as well supplied with suitable limestones as the Pennsylvanian outcrop area, although limestones of good quality are fairly abundant in the easternmost and stratigraphically lower part of the Permian rocks. Sand and gravel, however, is in sufficient supply throughout most of the area. The Permian shales, on the other hand, are much less suitable for the production of lightweight aggregate than either the Pennsylvanian or Cretaceous shales. It is probable that many of them could be

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made into a lightweight aggregate in the sintering machine described elsewhere in this report. Pleistocene loesses (Fig. 3) and allied alluvial deposits are available, however, in a considerable portion of this area. These materials can be made into an excellent lightweight aggregate, although with less ease than is the case with the Pennsylvanian and Cretaceous shales.

The shales of Cretaceous age (Fig. 2) that are especially suitable for the production of lightweight aggregates include the Kiowa, Graneros, Carlile (Blue Hill), and Pierre. Clays of the Dakota formation, lying above the Kiowa and below the Graneros shale (Plummer and Romary, 1947) are refractory and commonly are adaptable to rotary kiln production of bloated products only by the addition of a bloating agent. The outcrop area of Cretaceous rocks, which occur above the Permian, extends from the western limits of exposed Permian rocks into Colorado. The materials lying between the bloating shales consist of soft chalky shales and chalky limestones, neither of which is suitable for aggregate or other uses supplied by a crushed hard limestone. Sand and gravel is generally available, but these materials do not produce a high grade of concrete if used as the total aggregate. Some excellent available materials include the cemented sandstone of the Dakota formation, locally called quartzite (Swineford, 1947) and the silicified rock in the Ogallala formation (Frye and Swineford, 1946). On the whole, however, western Kansas is lacking in high-grade aggregate material and in some areas even the low-grade materials are not available. Shales suitable for the production of lightweight aggregate are abundant along the outcrop belt of the Cretaceous shales mentioned (Fig. 2). In the case of the Kiowa and Blue Hill shales a superior type of product was made in our experimental kiln.

From the bentonitic clays of Tertiary age that have been sampled at scattered localities in the western part of the State we have produced some high-class lightweight aggregate having properties that may possibly make it valuable for special uses. These clays do not occur in a well-defined outcrop belt like the shales of Pennsylvanian, Permian, and Cretaceous age. In some cases they occur in localities where other materials are not available for the production of lightweight aggregate and may be of importance for this reason.

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The only ceramic raw materials of Quaternary age considered in this report are the Pleistocene loesses and associated alluvial silts deposited as stream terraces. These materials, especially the loess (Fig. 3), occur in great abundance in the northern counties of Kansas (Frye and others, 1949). Scattered deposits occur throughout most of the northern half of the State and some extend into the southern half. The wind-deposited and the water-laid materials are very much alike in ceramic properties; in sampling for this report no sharp distinction was made. The Pleistocene deposits occur in areas that are in many cases devoid of any other type of ceramic material suitable for the production of lightweight aggregate and where hard limestones are completely lacking.

*Economic factors.*—The demand for lightweight concrete aggregates in preference to heavier materials is based on the two important advantages of decreased total weight of the concrete structure and better insulation against both heat and sound transmission. The decreased weight means that less material is required for foundations and supporting structure.

California has led in the utilization of lightweight aggregate in concrete construction. Reported savings on the General Petroleum Building in Los Angeles total $180,000 on structural steel on an expenditure of $61,000 for the lightweight concrete. Other instances are cited wherein about 13,000 tons have been eliminated in structures weighing 30,000 tons. Savings in structural steel in such cases amounted to about 1,200 tons (Conley and others, 1948).

In the case of pre-fabricated units such as concrete block important savings in transportation costs are realized. Furthermore, the crushed aggregate can be shipped at a lower cost than the heavier materials because of the greater volume per unit weight.

At present (1951) only a small fraction of requirements for bloated shale aggregate can be supplied by local production. The Carter-Waters Corporation Haydite plant at New Market, Missouri, is producing the only bloated shale aggregate in this area, and very little of their production gets out of the Kansas City area. Approximately 400,000 yards of pumice is being shipped into Kansas from New Mexico and elsewhere. Shipping charges represent a major portion of cost of pumice in Kansas block manufacturing plants. The total cost of pumice was $5.20

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a yard in Wichita in May 1950. Haydite or other bloated shale aggregates are superior to pumice in strength and workability. For these reasons practically all block manufacturers have expressed their eagerness to purchase the shale aggregate as soon as it is available in sufficient quantities.

*Types of uses.*—The use of lightweight materials as an aggregate for concrete, especially concrete blocks, is commonly emphasized. At present the greatest demand for lightweight aggregates is in the concrete block industry, but contractors and architects predict that when the lighter material is available in sufficient quantity it will replace 90 percent of the heavy aggregate now being used.

Although the use of these lightweight materials as a concrete aggregate is doubtless of major importance, their utility is by no means limited to this application. Bloated shale is also an ideal aggregate for bituminous matt road surfacing. Heavier more vitreous shale and clay has been shown to be an excellent railroad ballasting material (Plummer and Hladik, 1948).

Successful experiments have been conducted at North Carolina State College and at the Statesville (North Carolina) Brick Company with the production of a lightweight clay unit containing bloated shale or clay aggregate bonded with clay or shale and re-fired. A vibrated block similar to the conventional concrete block is being made. The fired block has high compressive strength and resists moisture penetration (Foster, 1949). The Kansas Geological Survey ceramics laboratory conducted similar experiments about three years ago with equal success.

Haydite and other bloated shale aggregates are proving to be very successful in installations requiring insulation at moderately high temperatures. In most cases the aggregate is bonded with refractory cement for monolithic kiln bottoms and tops. Temperatures encountered in these installations must necessarily be lower than the fusing temperatures of the clay or shale. The low-density bloated shales, especially those running around 20 pounds to the cubic foot, should make an excellent loose-fill insulation for kiln crown and the like. It is also probable that the lightest weight material would be suitable for loose-fill insulations for ordinary temperatures in walls and ceilings.

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## SAMPLING

### Methods of Sampling

Sampling for bloating tests is complicated by the fact that deeply weathered or oxidized shales do not behave like the same material when sampled from fresh exposures. Ordinarily the shales are oxidized 8 to 20 feet below the friable surface materials. The zone of oxidation is indicated by light-gray and yellowish colors as distinguished from the gray or blue-gray color of the unoxidized shale. For this reason samples were obtained so far as possible from brick and tile plant shale pits, quarries, or recent excavations such as road cuts. In most cases representative samples were obtained by channeling.

On more deeply weathered outcrops an attempt was made to obtain at least partially unoxidized samples by digging fairly deep holes at regular intervals from the bottom to the top of the exposure. The same technique was also used in the case of extremely thick beds such as the Blue Hill shale member of the Carlile shale, where separate samples were taken at 5-foot intervals. Each 5-foot sample was tested separately by the briquette method. The usable parts of the beds were combined for rotary kiln tests.

In the case of materials such as the Pleistocene loesses that are either completely oxidized or not affected by weathering, the usual methods of channel sampling or augering were used.

### Geologic Formations Sampled

The samples obtained represent fairly well the clays and shales of all the geologic systems exposed in Kansas, with the exception of the Mississippian. These systems, named in ascending order, are the Pennsylvanian, Permian, Cretaceous, Tertiary,

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and Quaternary. Because of the economic importance of lightweight aggregate in the area in which they are exposed, we attempted to obtain samples of most of the Pennsylvanian shales (Fig. 1). These include the Cherokee group, Pleasanton group (Coffeyville formation), Kansas City group (Fontana, Wea, and Quivira shale members of Cherryvale formation; Lane and Bonner Springs shales), Lansing group (Vilas shale), Pedee group (Weston shale), Douglas group (Vinland and Robbins shale members of Stranger formation; Lawrence formation), Shawnee group (Heumader shale member of Oread limestone; Jackson Park and Stull shale members of Kanwaka shale; Calhoun shale), and Wabaunsee group (Severy, Aarde, White Cloud, Silver Lake, Auburn, Harveyville, Willard, Pierson Point, Langdon, Dry, French Creek, and Caneyville-Pony Creek shales).

Only a few of the Permian shales were tested because of the poor results obtained with the rotary kiln method. One of the lower Permian shales, probably the West Branch or the Towle, proved to be a good bloating material but the Wellington, Ninnescah, and Chikaskia were indifferent in quality and were not sampled extensively (Fig. 2).

All the clay shales of the Cretaceous System were sampled. These include the Kiowa, Graneros, Blue Hill, and Pierre (Fig. 2). The Tertiary bentonitic clays sampled were from the Ogallala formation. The bulk of the Pleistocene clays were loesses from the Sanborn formation (Fig. 3).

## Geographic Distribution

The east to west distribution of the samples obtained was determined largely by the stratigraphic sequence in which the lowermost beds occur in southeastern Kansas and the upper in the western part of the State. An exception to this is the Pleistocene loess which occurs as the uppermost material across the entire State in the northern tier of counties and less regularly in many other areas.

For economic reasons and in order to determine horizontal variations in the formations, an attempt was made to sample all important shales and clays at as many points as possible across the northeast-southwest outcrop belt.

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The geographic distribution of the areas of outcrop of the shales younger than Pennsylvanian in age and the location of samples obtained are shown in Figure 2. The location of samples obtained from the Pennsylvanian shales are not shown on the geologic map for eastern Kansas (Fig. 1).

## TESTING

### Methods and Equipment Used in Testing

In this investigation three methods were used to determine the bloating characteristics of clays and shales. The first method, used only as a preliminary test to eliminate obviously unsuitable materials and to obtain a rough approximation of firing temperatures required, consisted of the rapid heating of lump samples placed in roasting dishes. In preparation for the flash heating the samples were placed in the fire-clay roasting dishes, then calcined in a gas-fired kiln to approximately 1000° F. in order to eliminate moisture and prevent disruption of the samples on rapid heating. The pre-heated calcined samples were transferred as rapidly as possible to a Globar-heated electric kiln that had been brought up to bloating temperature range. The samples remained in the kiln for 10 to 20 minutes. A range of temperatures was used for firing. Samples that failed to bloat at the lower limit first tried were carried up to higher temperatures on subsequent tests. This method was abandoned as the testing progressed because of its limited usefulness.

In the second type of test the same equipment was used: a gas-fired muffle kiln with about 11 cubic feet capacity, and a high-temperature electrically heated kiln equipped with Globar elements which has a capacity of approximately 1 cubic foot (Pl. 1A). Instead of using the lump samples, however, the clay or shale was crushed to pass a 10-mesh screen and hand molded into small bricks approximately 1 inch square and 3½ inches long. Standard ceramic data were taken on these bricks, both for this investigation and for future reference in respect to the general ceramic properties of the materials. Of chief importance to this investigation was the weight of the dried brick and the volume. Volumes on unfired bricks were determined by means of the displacement method by submergence in kerosene. A part of the small bricks were fired to cone 06 (about 1850° F.)

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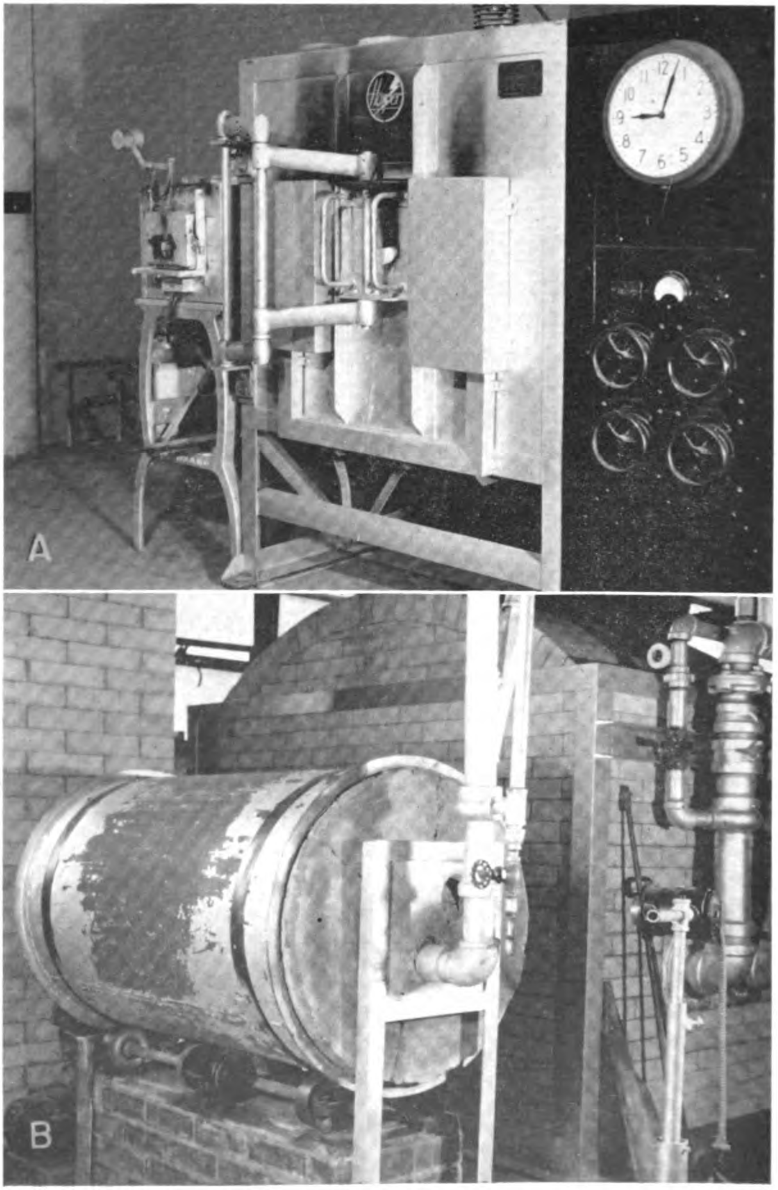


PLATE 1. Kilns used in laboratory tests. *A*, High-temperature electric kiln used in brick bloating tests. *B*, Batch-type gas-fired rotary kiln used for bloating shales and clays; pre-heating kiln is in background.

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to determine the normal fired volume before any bloating occurred. The bricks to be tested for bloating were placed in regular order on fire-clay shelves coated with silica flour to prevent sticking and racked in the gas-fired kiln. The heat was brought up slowly until a temperature ranging from 900° to 1200° was reached. This temperature was not critical, but better results were usually obtained if it was above 1100° F. After reaching the required heat the burners were turned off, but the pilot lights left on in order to maintain temperature. While the samples were calcining the electric kiln was brought up to bloating temperature. In most cases three temperatures were used for bloating—2180°, 2220°, and 2260° F., beginning with the lowest temperature (Pl. 2A).

The calcined bricks were taken from the gas-fired kiln on the fire-clay slab and transferred immediately to the electric kiln. After the transfer a few minutes was required to bring the electric kiln back to the required temperature, after which the test bricks were maintained at this temperature for 15 minutes. At the end of this period the bricks were withdrawn and placed in the calcining kiln for cooling. The 15 minutes of bloating time is probably too long for most shales. Results more consistent with bloating in the rotary kiln can be obtained by heating for 8 to 10 minutes. In some of the later tests the shorter bloating period was used.

After cooling, the bloated bricks were again weighed dry and also after submersion in boiling water to determine absorption. Volumes were taken on the saturated bricks by means of the displacement of water.

The data obtained from these tests gave us the exact bulk specific gravity of both the unbloated and the bloated bricks. The percentage absorption obtained enabled us to approximate the amount of closed pore space in the bricks as well as the easily saturated pore space. In respect to easily tabulated numerical data the brick bloating tests were superior to those run in the rotary kiln. Unfortunately the correlation between behavior in the brick bloating tests and those in the rotary kiln was only approximate. In general it was possible to use much lower temperatures for bloating in the rotary kiln. The use of a greater range of temperatures for the brick bloating tests would help eliminate some of the discrepancies.

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The third and most practical method of testing consisted of heating the ground shale or clay in a batch-type rotary kiln (Pl. 1B), 17 inches inside diameter by 32 inches in length, fired by a forced-draft gas burner. A charge of approximately 20 pounds of shale or clay was used for each firing. Temperatures were determined by means of a radiation-type pyrometer and recorder with the radiation unit focused on the charge.

In the first experimental runs we attempted to do the entire heating of the shale in this kiln, but the rate of heating was obviously too slow. Subsequently the charge was preheated in a down-draft gas-fired kiln adjacent to the rotary kiln (Pl. 1B). The empty rotary kiln was brought up to a temperature pre-determined by the brick bloating tests. The samples preheated to about 1000° F. were transferred as rapidly as possible to the hot rotary kiln. After the charge was transferred the temperature of the rotary kiln usually dropped to about 1950° F., but increased rapidly to the previously attained temperature of the empty kiln. The heating charge was observed carefully to note initial bloating and first evidence of attaining the pyroplastic condition as evidenced by sticking of the shale lumps to one another. Temperatures were usually increased until the shale charge had formed a loose roll in the kiln. After the heat was turned off the charge was allowed to cool rapidly in the kiln, with the kiln continuing to rotate. Usually this rotation sufficed to break up the roll into lumps.

Comparison runs were made in a pilot plant continuous rotary kiln 30 inches in inside diameter by 30 feet in length. This necessary step in the testing procedure was made available to us through the courtesy of The Mineral Products Company and the Mackie-Clemens Fuel Company. The lightweight aggregate produced in our batch-type rotary kiln and that produced in the pilot plant kiln were nearly identical in appearance and bulk density. Temperatures varied somewhat, however. Usually our recorded temperature was lower than that of the pilot plant kiln. This could be attributed to a number of causes, chief of which was believed to be that the oil-fired continuous rotary kiln produced a luminous flame, whereas our gas-fired batch kiln produced a blue nonluminous flame.

The lightweight aggregate produced in the experimental rotary kiln was passed through a roll crusher with the rolls set

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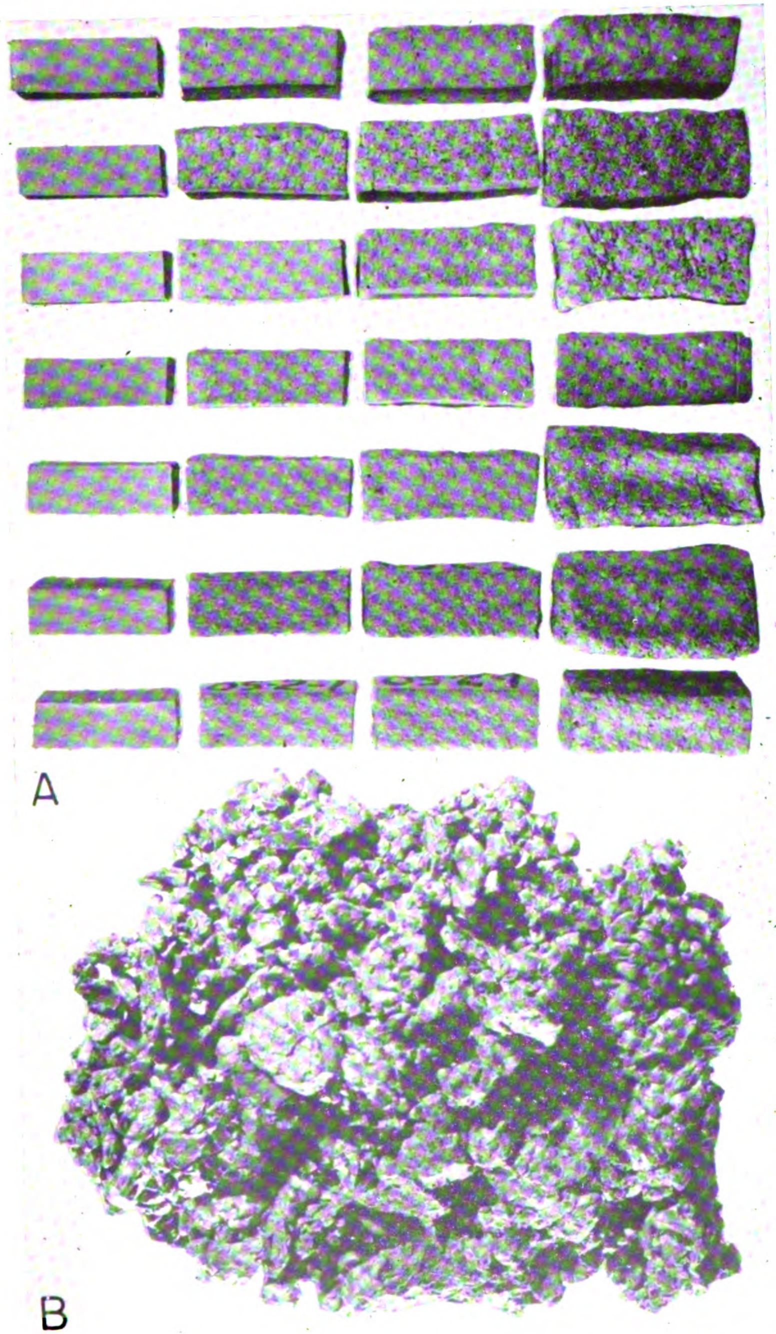


**Plate 2.** *A,* Effect of increasing bloating temperatures on bricks made from seven samples of Blue Hill shale (OS-2). From left to right, bricks fired to 1850° F., 2220° F., 2300° F., and 2340° F. *B.* Agglomerated mass of bloated Blue Hill shale produced in rotary kiln.

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three-sixteenths of an inch apart. This produced an aggregate largely passing a three-eighths inch screen but poorly graded. Bulk density of the crushed but ungraded aggregate was determined according to A.S.T.M. (1949) standard designation C29-42, test for unit weight of aggregate. Following this determination the aggregate was sized according to a predetermined grading that is in accordance with specified size distribution curves and that previous experience had proved to be a suitable grading for the manufacture of concrete building blocks (R. G. Hardy, personal communication). Inasmuch as the grading produced by one pass through rolls set three-sixteenths inch apart was low in the fine sizes, it was necessary to recrush a portion of the coarser aggregate through rolls set about one-sixteenth of an inch apart. One grading was used for all aggregates produced so that the unit weight data are comparable. The size distribution is shown below.

*Grading used for aggregates produced*

| Screen size | Percent retained on screen |
|---|---|
| 3/8 inch | 0.0 |
| No. 4 | 11.0 |
| No. 8 | 27.0 |
| No. 16 | 21.0 |
| No. 30 | 17.0 |
| No. 50 | 11.0 |
| No. 100 | 6.0 |
| Pan | 7.0 |

After sizing to the grading shown above the density of each aggregate was again determined. The unit weight, in pounds per cubic foot, was appreciably increased by correct sizing. In the case of aggregates having unit weights less than 40 pounds per cubic foot, it will probably prove advisable to increase the proportion of fines in order to obtain sufficient compressive strength in concrete made from the aggregate. The increased proportion of fines will also reduce the amount of cement needed for a sound product and improve the workability.

Concrete test cylinders made with both the vibrated dry mix and regular wet-mixed concrete were made on representative samples by W. C. McNown. The results of these tests

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are discussed in a subsequent section. Standard-sized concrete blocks were also made by companies interested in using shales from some of the deposits sampled. These provided a commercial standard of comparison.

In general the equipment used and our methods of testing are similar to and comparable to those used by the Bureau of Mines in its investigation on the production of lightweight concrete aggregates (Conley and others, 1948).

## Chemical and Mineralogical Properties

Chemical analyses on a number of samples were run in the geochemistry laboratory of the Geological Survey (Table 1). Although a knowledge of chemical composition is not necessary to the development of a lightweight aggregate industry, there is doubtless a close relationship between chemical composition and bloating characteristics. Percentages of the various oxides are primarily determined by the mineralogical composition of the clays or shales. The tendency of illite shales to bloat at high temperatures is almost diagnostic of the mineral, but not completely (Grim and Bradley, 1940). To the best of our knowledge kaolinitic clays do not bloat except by overfiring, and clays containing a large percentage of montmorillonite such as bentonites show bloating characteristics that differ distinctly from the illite materials. The montmorillonite clays that we have tested bloat to a low density material with gas vesicles almost microscopic in size.

It is probable that compounds not present in the clay lattice but which occur as minor impurities in the clay or shale play an important role in the bloating phenomenon. Just how these impurities produce bloating is not completely known. It is probable that the reduction of ferric iron compounds to ferrous silicates in the pyroplastic stage accounts for some of the bloating. Iron occurs in clays as hematite, limonite, siderite, magnetite, pyrite, marcasite, ilmenite, and probably in other compounds.

It is fairly well established that presence of gypsum in minor amounts will cause bloating in a clay or shale. We have produced bloating in a nonbloating clay by the addition of 1 percent powdered gypsum. The Bureau of Mines produced bloating

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TABLE 1.—*Chemical analayses of some of the clays and shales used in the experimental production of lightweight aggregate, arranged in stratigraphic sequence from the oldest to youngest rocks*

| Sample No. | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | $TiO_2$ | CaO | MgO | $K_2O$ | $Na_2O$ | $P_2O_5$ | $SO_3$ | Ign. loss | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | **Pennsylvanian** | | | | | | |
| CR-6 | 67.56 | 19.90 | 2.16 | 1.15 | 0.31 | 0.52 | 1.91 | 0.18 | 0.05 | nil | 6.02 | 99.71 |
| CR-7 | 67.45 | 17.10 | 4.63 | 1.01 | 0.27 | 1.23 | 2.38 | 1.03 | 0.17 | nil | 4.72 | 100.00 |
| CR-9 | 60.92 | 18.48 | 6.82 | 1.68 | 0.49 | 1.76 | 3.47 | 1.20 | 0.22 | nil | 5.39 | 100.43 |
| LN-1-1&2 | 61.91 | 17.70 | 5.43 | 1.74 | 0.50 | 1.62 | N.D. | N.D. | 0.34 | Tr. | 5.15 | 94.39 |
| MG-3 | 57.09 | 20.31 | 7.47 | 1.55 | 0.69 | 1.86 | 2.44 | 0.87 | N.D. | 0.10 | 6.83 | 99.31 |
| JN-7 | 55.14 | 21.05 | 7.59 | 1.47 | 1.32 | 2.12 | 3.56 | 1.08 | 0.22 | 0.22 | 6.90 | 100.60 |
| AL-2 | 53.99 | 16.21 | 6.18 | 1.09 | 6.60 | 1.72 | 3.93 | 0.80 | 0.18 | 0.22 | 9.20 | 100.00 |
| MG-2 | 54.73 | 17.90 | 8.05 | 0.87 | 3.55 | 2.56 | 3.07 | 1.42 | 0.28 | Tr. | 8.33 | 100.76 |
| LV-5 | 55.25 | 17.92 | 5.48 | 0.99 | 4.55 | 2.08 | 3.01 | 0.92 | 0.11 | 0.19 | 8.97 | 99.77 |
| FR-6-AB | 51.56 | 22.50 | 8.21 | 1.27 | 1.09 | 2.27 | 3.54 | 0.59 | 0.22 | 0.23 | 7.77 | 99.47 |
| FR-6-C | 54.28 | 21.90 | 8.28 | 1.01 | 0.65 | 1.96 | 3.69 | 0.67 | 0.13 | Tr. | 6.79 | 99.49 |
| LV-4 | 61.54 | 18.52 | 6.54 | 1.36 | 0.41 | 1.75 | 2.97 | 0.79 | 0.18 | Tr. | 5.89 | 99.95 |
| MG-1-1 | 68.23 | 14.72 | 5.89 | 1.54 | 0.46 | 1.33 | 2.52 | 0.55 | 0.15 | nil | 4.81 | 100.20 |
| MG-1-2 | 62.69 | 17.61 | 6.62 | 1.20 | 0.61 | 1.49 | 2.95 | 0.67 | 0.14 | nil | 5.62 | 99.60 |
| WL-1 | 55.94 | 22.42 | 7.47 | 1.76 | 0.49 | 1.93 | 3.14 | 0.67 | 0.20 | Tr. | 7.40 | 100.60 |
| DG-15 | 58.96 | 18.44 | 6.15 | 1.27 | 3.02 | 1.64 | 2.83 | 0.69 | 0.20 | Tr. | 7.13 | 100.33 |
| DG-14 | 58.38 | 19.96 | 6.95 | 1.15 | 1.24 | 1.75 | 3.17 | 0.74 | 0.23 | Tr. | 6.10 | 99.67 |
| DN-4 | 60.38 | 18.60 | 6.94 | 1.31 | 0.84 | 2.05 | 2.63 | 0.85 | 0.19 | Tr. | 5.99 | 99.78 |
| WL-2 | 60.04 | 19.13 | 6.94 | 1.60 | 0.42 | 1.86 | 3.04 | 1.31 | 0.18 | Tr. | 5.94 | 100.46 |
| EK-1 | 54.20 | 19.87 | 6.37 | 0.98 | 3.30 | 2.04 | 3.12 | 0.49 | 0.18 | 0.14 | 8.32 | 99.19 |
| SH-2 | 57.45 | 20.75 | 6.48 | 1.37 | 0.82 | 2.07 | 3.54 | 1.08 | 0.23 | Tr. | 6.67 | 100.46 |
| EK-5 | 62.50 | 16.95 | 6.61 | 1.08 | 0.68 | 2.24 | 2.88 | 1.75 | 0.19 | 0.01 | 4.56 | 99.63 |
| SH-3 | 59.30 | 16.73 | 5.10 | 1.10 | 3.56 | 2.63 | 3.51 | 1.98 | 0.21 | Tr. | 6.85 | 100.54 |
| PT-1 | 54.72 | 15.99 | 5.73 | 1.01 | 6.70 | 2.56 | 3.06 | 0.87 | 0.21 | Tr. | 9.27 | 100.12 |
| BR-5 | 57.32 | 15.89 | 6.04 | 1.20 | 5.12 | 2.23 | 2.99 | 1.04 | 0.20 | Tr. | 8.03 | 100.11 |
| BR-6 | 54.51 | 15.19 | 6.83 | 1.26 | 6.37 | 2.23 | 3.07 | 1.89 | 0.26 | 0.10 | 8.69 | 100.35 |
| LY-4 | 55.74 | 21.00 | 7.49 | 1.02 | 0.70 | 2.57 | 3.77 | 1.54 | 0.17 | nil | 5.97 | 100.14 |
| BR-3-1 | 55.33 | 20.69 | 7.58 | 1.22 | 0.86 | 2.55 | 3.03 | 0.49 | 0.23 | 0.53 | 6.75 | 99.26 |
| BR-3-2 | 56.22 | 20.61 | 8.26 | 0.59 | 0.55 | 2.67 | 3.45 | 0.56 | 0.18 | 0.17 | 6.20 | 99.46 |

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| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | **Permian** | | | | | | |
| M-5 | 44.33 | 13.68 | 5.05 | 1.10 | 7.86 | 9.66 | 2.51 | 0.67 | 0.18 | Tr. | 14.09 | 99.13 |
| RO-2 | 52.36 | 15.81 | 7.03 | 0.91 | 3.10 | 9.14 | 3.28 | 0.65 | nil | N.D. | 7.72 | 100.00 |
| SU-2 | 34.84 | 9.92 | 4.09 | 0.94 | 12.05 | 14.46 | 1.68 | 0.36 | 0.18 | Tr. | 21.56 | 100.08 |
| | | | | | | **Cretaceous, Kiowa shale** | | | | | | |
| CL-6 | 75.61 | 10.97 | 3.27 | 0.93 | 0.40 | 1.03 | 1.76 | 0.27 | 0.17 | 0.37 | 4.53 | 99.31 |
| S-18 | 60.56 | 18.96 | 5.86 | 1.09 | 1.37 | 1.84 | 2.32 | 0.11 | 0.12 | 1.19 | 6.53 | 100.07 |
| | | | | | | **Cretaceous, Dakota formation** | | | | | | |
| C-27 | 59.60 | 25.44 | 1.58 | 1.32 | 0.22 | 0.64 | 1.78 | 0.73 | N.D. | N.D. | 7.80 | 99.11 |
| L-4-C | 59.64 | 17.98 | 8.14 | 2.36 | 0.94 | 2.09 | 1.93 | 0.29 | 0.04 | 0.21 | 6.69 | 100.30 |
| | | | | | | **Cretaceous, Graneros shale** | | | | | | |
| R-15 | 55.30 | 16.02 | 8.31 | 0.59 | 2.06 | 0.79 | 2.18 | | 0.24 | 4.70 | 10.70 | 100.89 |
| W-65 | 59.02 | 17.97 | 6.78 | 1.51 | 0.65 | 1.64 | 2.72 | 0.19 | 0.19 | 0.36 | 8.97 | 100.00 |
| | | | | | | **Cretaceous, Carlile shale, Blue Hill member** | | | | | | |
| ES-1 | 60.43 | 18.68 | 5.36 | 1.06 | 0.81 | 1.35 | 3.14 | 0.46 | 0.14 | 1.03 | 8.19 | 100.65 |
| MT-1 | 66.06 | 16.94 | 4.01 | 0.81 | 0.51 | 1.56 | 3.04 | 0.48 | 0.05 | 0.04 | 6.40 | 99.81 |
| NS-1 | 63.31 | 18.61 | 4.29 | 1.09 | 0.40 | 1.72 | 3.62 | 0.25 | 0.07 | 0.07 | 6.40 | 99.84 |
| OS-2 | 60.61 | 19.03 | 4.50 | 0.84 | 0.41 | 2.07 | 3.29 | 0.33 | 0.05 | 0.04 | 8.53 | 99.70 |
| | | | | | | **Cretaceous, Pierre shale** | | | | | | |
| LO-2 | 52.16 | 13.46 | 7.41 | 1.58 | 4.36 | 0.90 | 2.60 | 0.46 | 0.23 | 7.10 | 10.79 | 99.94 |
| PH-2 | 61.52 | 21.47 | 2.56 | 0.03 | 3.46 | 0.06 | 1.11 | 0.50 | N.D. | N.D. | 8.71 | 99.42 |
| | | | | | | **Tertiary** | | | | | | |
| LE-1 | 60.26 | 18.35 | 5.45 | 1.42 | 1.07 | 3.40 | 2.98 | 0.63 | 0.17 | Tr. | 6.27 | 100.00 |
| WC-1 | 54.90 | 13.63 | 5.97 | 0.64 | 7.06 | 3.43 | 4.10 | 0.54 | 0.48 | 0.12 | 9.09 | 99.96 |
| | | | | | | **Quaternary** | | | | | | |
| A-6 | 70.97 | 15.98 | 3.32 | 1.39 | 2.28 | 0.42 | N.D. | N.D. | N.D. | N.D. | 4.60 | 98.96 |
| CR-5 | 73.43 | 12.43 | 6.00 | 1.26 | 0.38 | 0.62 | 1.12 | 0.23 | 0.05 | nil | 4.59 | 100.06 |
| CR-8 | 64.79 | 16.17• | 7.37 | 1.65 | 0.38 | 0.99 | 2.24 | 0.83 | 0.05 | nil | 5.69 | 100.11 |
| NN-6 | 70.56 | 13.12 | 3.27 | 0.73 | 2.85 | 1.56 | 2.68 | 1.18 | 0.09 | Tr. | 4.36 | 100.40 |

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in clays in some cases by the addition not only of gypsum but of flowers of sulfur, carbon, various carbonates, pyrite, and sulfates other than gypsum (Conley and others, 1948, pp. 26-29). Gypsum seems to be especially suitable as an admixture to produce bloating because of its low cost and the fact that it releases $SO_4$ gas at about 2190° F. and higher. Many clays and shales become pyroplastic within this temperature range, thus trapping the $SO_4$ gas and producing a vesicular structure. Other sulfates would produce similar results.

Bloating resulting from the addition of carbonates probably is due largely to the fluxing action of the metallic ions rather than the release of $CO_2$ since the carbon dioxide is released below the pyroplastic stage in the case of most compounds. The fluxes, including calcium, magnesium, potassium, and sodium, form glassy compounds at temperatures low enough to permit the trapping of gases formed by other compounds. The bloating of illite shales and bentonitic clays can be attributed to the glass-forming fluxes of magnesium, potassium, calcium, and sodium. In the case of these materials the gas released to cause the bloating is probably oxygen.

Almost any clay or shale will bloat under some conditions, but many are not suitable for the production of lightweight aggregate. Bloating must not occur at temperatures that require excessive fuel, due to the limitations on cost. It is probable that 2400° F. is as high as any lightweight aggregate producer would care to use. If bloating occurs in the fluid glass stage the material is not suitable for rotary kiln production because the glass will stick to the kiln lining and cause excessive erosion of the refractories. Shales or clays containing a relatively high proportion of calcium or magnesium compounds tend to form a fluid glass a few degrees above the initial softening point (incipient fusion and complete fusion are not separated by a sufficient temperature range).

A clay having an alumina content in excess of about 25 percent is usually too refractory to bloat satisfactorily within a reasonable temperature range. High silica content will produce the same result. Clays containing little else but kaolinite and quartz do not bloat except at extremely high temperatures ranging from 2800° to more than 3000° F.

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The conditions and compositions necessary to cause bloating in clays have been studied in considerable detail by Riley (1951). Under suitable conditions ferrous sulfide, ferrous sulfate, ferrous chloride, sodium chloride (common salt), calcium sulfate (gypsum), sodium carbonate, calcium carbonate (limestone), dolomite, and ferric oxide will produce bloating.

## Data on Firing Tests and Physical Properties of Bloated Aggregates

Table 2 shows the essential firing data on the batch-type rotary kiln production of lightweight aggregates, the densities of the crushed but ungraded product, and the density of the aggregate after grading to an acceptable distribution of sizes. The grading used was one that R. G. Hardy (personal communication) was able to produce with a roll crusher without excessive regrinding and screening. The grading used is tabulated on page 18.

In addition to the firing data and the physical properties of the aggregate, Table 2 also gives the stratigraphic position of the bed sampled, the thickness of the bed included in the sample, and the location where the sample was obtained.

All the aggregates produced in the rotary kiln were first crushed through rolls spaced three-sixteenths of an inch apart, and the unit weights determined by the standard method. Screen analyses were made on the aggregates after this preliminary crushing in order to show the natural size distribution or grading that could be produced by one crushing without sizing and re-crushing. The results of these tests are given in Table 3. The samples are arranged in order of increasing unit weights in order to facilitate comparisons. These unit weights are also reported in Table 2, but parallel with unit weights determined on the correctly graded aggregates.

More than twice as many samples were tested by rapid heating of small bricks in the electric kiln as were tested in the batch-type rotary kiln. The bloating of the small bricks was used to test various levels in thick deposits and also as a means of eliminating the less desirable materials from the more laborious rotary kiln tests. The results obtained from bloating small bricks in the high-temperature electric kiln are given in Table 4. This method of testing permits the determination of the density

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TABLE 2.—*Results of experimental production of*

| Sample No. | County | Location | Strati-graphic position | Thickness, in feet Sampled | Available |
|---|---|---|---|---|---|
| | | | **Pennsylvanian** | | |
| | | | *Cherokee group* | | |
| CK-6 | Cherokee | Cen. SW SW 34-31-24 E. | Above Mineral coal | 20.0 | 20.0 |
| CR-6 | Crawford | NW SE 18-30-25 E. | Under Pilot coal | 12.0 | 12.0 |
| CR-7 | do | do | Shale below Pilot coal underclay | 6.0 | 20.0± |
| CR-9 | do | NE SE 16-16-25 E. | Shale | 10.0 | 20.0 |
| CR-10 | do | do | do | 20.0 | 30.0 |
| CK-7 | Cherokee | Cen. S½ 2-32-22 E. | Above Weir-Pittsburg coal | 10.0 | 10.0 |
| | | | *Marmaton group* No sample | | |
| | | | *Pleasanton group* | | |
| LN-1-1 | Linn | NE SW 18-22-24 E. | Shale | 26.5 | 26.5 |
| LN-1-2 | do | do | do | 16.0 | 16.0 |
| MG-3 | Montgomery | W½ 2-35-16 E. | Coffeyville fm. | 25.0 | 60.0 |
| | | | *Kansas City group* | | |
| JN-7 | Johnson | N. line NE NE 21-13-25 E. | Fontana-Wea shale | 37.0 | 37.0 |
| MG-4 | Montgomery | NW NE 5-32-17 E. | Cherryvale shale | 10.0 | 70.0± |
| AL-1 | Allen | SW SW 35-24-18 E. | Lane shale & Lane-Bonner Spgs shale | 30.0 | 50.0 |
| AL-2 | do | NE SW 33-25-18 E. | do | 30.0 | 50.0± |
| MG-2 | Montgomery | NE SW 7-31-16 E. | do | 15.0 | 50.0± |
| JN-4 | Johnson | Cen. S½ 14-12-23 E. | Lane shale | 6.0 | 20.0± |
| JN-5 | do | SW NW 36-12-23 E. | do | 7.0 | 25.0± |
| JN-9 | do | SW NE 14-12-23 E. | do | 10.0 | 25.0± |
| LV-3 | Leavenworth | SE SE 13-11-22 E. | do | 10.0 | 15.0 |
| WY-5 | Wyandotte | NW NE 13-10-23 E. | Island Creek shale | 5.0 | 43.0 |
| JN-6 | Johnson | NW SW 36-12-23 E. | Bonner Springs sh. | 11.0 | 26.0 |
| WY-6 | Wyandotte | W½ 28-11-23 E. | do | 25.0 | 25.0 |
| | | | *Lansing group* | | |
| AN-2 | Anderson | Cen. NW SE 12-20-19 E. | Vilas shale | 5.8 | 5.8 |
| AN-3 | do | NW NW 17-23-19 E. | do | 14.0 | 14.0 |
| LV-5 | Leavenworth | NW NE 19-9-23 E. | do | 20.0 | 24.0 |
| LV-6 | do | NW NW 20-9-23 E. | do | 20.0 | 20.0 |
| | | | *Pedee group* | | |
| CQ-2 | Chautauqua | SE NW 22-34-12 E. | Weston shale | 30.0 | 30.0± |
| DG-13 | Douglas | Cen. NE SW 10-14-20 E. | do | 12.0 | 20.0 |
| FR-3 | Franklin | NW NW 23-17-19 E. | do | 50.0 | 80.0 |
| FR-3 | do | do | do | 15.0 | 20.0 |
| FR-4 | do | Cen. W½ SW 34-15-20 E. | do | 30.0 | 70.0 |
| FR-5 | do | NE NE 28-15-20 E. | do | 11.5 | 60.0 |
| FR-5 | do | do | do | 11.5 | 60.0 |
| FR-6 | do | Cen. SW 29-15-21 E. | do | 48.5 | 60.0 |
| LV-4 | Leavenworth | Cen. E. side 35-9-22 E. | do | 30.0 | 30.0± |
| MG-1-1 | Montgomery | N. line SE SW 1-35-13 E. | do | 27.0 | 70.0± |
| MG-1-2 | do | do | do | 29.0 | 45.0 |

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*lightweight aggregate in batch-type rotary kiln*

| | | Firing temperatures, degrees F. | | | | Unit weight lbs. per cu. ft. | | | |
|---|---|---|---|---|---|---|---|---|---|
| Degree of oxidation on outcrop | Time in kiln, minutes | Initial softening | Optimum for bloating | Formation of kiln roll | Maximum attained | Crushed, unsized* | Crushed, sized** | Color of crushed aggregate | Sample No. |
| Unoxidized | 12 | 2280 | ........ | 2320 | 2390 | 67.6 | 92.7 | Dark gray | CK-6 |
| Mostly oxidized | 18 | 2330 | ........ | ........ | 2400 | 81.0 | 103.4 | Gray | CR-6 |
| Mostly unoxidized | 11 | 2200 | 2240 | 2230 | 2360 | 36.6 | 39.1 | Dark gray | CR-7 |
| Mostly oxidized | 9 | 2230 | 2240 | 2240 | 2270 | 52.5 | 57.4 | do | CR-9 |
| Partially oxidized | 13 | 2250 | ........ | 2280 | 2300 | 75.1 | 84.4 | Gray | CR-10 |
| Unoxidized | 8 | 2000 | 2220 | 2230 | 2250 | 33.7 | 41.1 | Pink & gray | CK-7 |
| Partially oxidized | 9 | ........ | 2150 | 2160 | 2160 | 42.6 | 54.1 | Red & gray | LN-1-1 |
| do | 7 | 2240 | 2250 | 2270 | 2300 | 59.1 | 66.9 | Dark gray | LN-1-2 |
| Unoxidized | 6½ | 2030 | 2160 | 2180 | 2250 | 39.1 | 43.6 | Red & gray | MG-3 |
| Mostly unoxidized | 5 | ........ | ........ | ........ | 2220 | 46.3 | 54.6 | Red & black | JN-7 |
| Unoxidized | 7 | 2120 | 2130 | 2140 | 2240 | 31.7 | 40.0 | Dark gray | MG-4 |
| do | 11 | ........ | ........ | ........ | 2250 | 52.0 | 61.2 | Black | AL-1 |
| do | 12 | 2160 | 2170 | 2170 | 2170 | 50.1 | 59.1 | Dark gray | AL-2 |
| do | 6 | 2080 | 2100 | 2110 | 2190 | 43.0 | 49.4 | do | MG-2 |
| Mostly oxidized | .... | 2000 | 2030 | 2050 | 2270 | 64.3 | 78.2 | do | JN-4 |
| Mostly unoxidized | .... | ........ | ........ | 2140 | 2250 | 62.7 | 75.5 | do | JN-5 |
| Mostly oxidized | 9 | 2140 | 2150 | 2160 | 2210 | 59.4 | 67.4 | Red & black | JN-9 |
| do | .... | 2190 | 2200 | 2210 | 2380 | 68.9 | 85.7 | Dark gray | LV-3 |
| Mostly unoxidized | .... | 2040 | 2080 | 2080 | 2110 | 67.6 | 76.9 | do | WY-5 |
| Partially oxidized | 8 | 2170 | 2200 | 2210 | 2230 | 45.4 | 53.0 | do | JN-6 |
| Unoxidized | 8 | 2120 | 2170 | 2170 | 2170 | 39.7 | 47.3 | do | WY-6 |
| Mostly unoxidized | 11 | 2100 | 2120 | 2130 | 2160 | 48.3 | 59.3 | Pink & gray | AN-2 |
| Slightly oxidized | 8 | 2110 | 2200 | 2210 | 2220 | 46.2 | 51.8 | do | AN-3 |
| Unoxidized | 8 | 2190 | 2190 | 2200 | 2210 | 47.2 | 56.7 | Dark gray | LV-5 |
| Slightly oxidized | 9 | 2150 | 2150 | 2160 | 2160 | 50.2 | 60.6 | Red & gray | LV-6 |
| Unoxidized | 8 | ........ | 2180 | 2200 | 2200 | 48.0 | 49.0 | Red & black | CQ-2 |
| do | 6 | ........ | 2200 | 2220 | 2280 | 31.5 | 37.8 | Red & gray | DG-13 |
| do | 5 | 2125 | 2170 | 2150 | 2270 | 42.7 | 47.3 | Red & black | FR-3 |
| Oxidized | 9 | 2200 | 2240 | 2240 | 2300 | 44.7 | 48.0 | do | FR-3 |
| Mostly oxidized | 8½ | 2150 | 2160 | 2170 | 2170 | 49.9 | 58.1 | do | FR-4 |
| Unoxidized | 7 | 2080 | 2100 | 2110 | 2250 | 30.9 | 40.3 | Red & gray | FR-5 |
| do | .... | ........ | ........ | ........ | 2180 | 44.9 | 52.8 | do | FR-5 |
| Mostly unoxidized | 10 | 2100 | 2240 | 2250 | 2290 | 42.6 | 51.7 | do | FR-6 |
| do | 9 | 2060 | 2150 | 2160 | 2340 | 51.3 | 62.6 | Gray | LV-4 |
| Unoxidized | 7 | 2150 | 2160 | 2180 | 2240 | 47.0 | 53.6 | Dark gray | MG-1-1 |
| do | 6½ | 2170 | 2180 | 2230 | 2280 | 40.8 | 45.4 | do | MG-1-2 |

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TABLE 2.—*Results of experimental production of lightweight*

| Sample No. | County | Location | Strati-graphic position | Thickness, in feet Sampled | Available |
|---|---|---|---|---|---|
| WL-1 | Wilson | NW SW 11-29-14 E. | do | 32.0 | 100.0± |
| Haydite | ........ | New Market, Missouri | do | ...... | ...... |
| | | | *Douglas group* | | |
| DG-15 | Douglas | Cen. S SW 15-14-20 E. | Vinland shale | 20.0 | 30.0± |
| DG-14 | do | SW NW 27-14-20 E. | Lawrence shale | 20.0 | 25.0 |
| DN-4 | Doniphan | Cen. W½ SW 33-3-22 E. | do | 25.0 | 25.0 |
| GW-2 | Greenwood | SE NW 3-28-12 E. | do | 18.0 | 20.0 |
| WL-2 | Wilson | NW SW 12-27-15 E. | do | 25.0 | ...... |
| WD-1 | Woodson | SW SW 25-25-13 E. | do | 10.0 | 20.0 |
| EK-1 | Elk | W½ SW¼ 22-31-13 E. | Robbins shale | 22.0 | 22.0 |
| | | | *Shawnee group* | | |
| WD-2 | Woodson | Cen. S. line 8-25-14 E. | Stull shale | 31.0 | 75.0 |
| A-8 | Atchison | SE NW 12-6-20 E. | Jackson Park shale | 10.0 | 10.0 |
| EK-2 | Elk | Cen. SW¼ 22-30-12 E. | Heumader-Jackson Park shale | 32.5 | 32.5 |
| SH-2 | Shawnee | Cen. N½ SW¼ 15-11-16 E. | Calhoun shale | 15.0 | 15.0 |
| | | | *Wabaunsee group* | | |
| EK-5 | Elk | SW NW 2-30-10 E. | Severy shale | 22.0 | 40.0 |
| EK-4 | do | Cen. N½ 16-30-10 E. | White Cloud shale | 31.0 | 50.0 |
| GW-1 | Greenwood | SE NE 25-22-11 E. | Silver Lake shale | 10.0 | 35.0 |
| SH-3 | Shawnee | SW SW 30-11-14 E. | Harveyville shale | 12.0 | 12.0 |
| PT-1 | Pottawatomie | SW NE 13-10-9 E. | do | 15.0 | 20.0 |
| BR-5 | Brown | SW SW 4-4-18 E. | Willard shale (lower) | 12.0 | 30.0± |
| BR-6 | do | NE SE 36-4-17 E. | Willard shale (upper) | 16.0 | 30.0± |
| LY-1 | Lyon | NE SW 2-20-11 E. | Willard-Langdon sh. | 15.0 | 30.0 |
| LY-2 | do | NW NW 19-16-13 E. | Langdon shale | 11.0 | 18.0 |
| LY-3 | do | Cen S. line SE 32-19-11 E. | do | 12.5 | 25.0 |
| LY-4 | do | NE SW 35-17-12 E. | do | 11.0 | 11.0 |
| LY-5 | do | SW NW 22-18-12 E. | Dry shale | 20.0 | 20.0 |
| EK-3 | Elk | SW SW 16-30-10 E. | French Creek shale | 17.0 | 27.0 |
| LY-6 | Lyon | NW SW 34-21-10 E. | do | 14.5 | 22.0 |
| WB-1 | Wabaunsee | NW SW 31-12-13 E. | do | 5.0 | 40.0 |
| WB-2-1 | do | NE NW 20-14-13 E. | do | 6.0 | 6.0 |
| WB-2-2 | do | do | do | 5.0 | 12.0 |
| BR-3-1 | Brown | SE SE 31-1-17 E. | Caneyville-Pony Creek shale | 8.5 | 8.5 |
| BR-3-2 | do | do | do | 4.5 | 4.5 |
| | | | **Permian** | | |
| SG-3 | Sedgwick | NW Cen. 22-28-3 W. | Wellington shale | 10.0 | 30.0+ |
| RO-2 | Reno | 21-25-6 W. | Ninnescah shale | 11.3 | 30.0± |
| | | | **Cretaceous** | | |
| CL-6 | Clark | NW NW 18-32-22 W. | Kiowa shale | 31.8 | 50.0 |
| K-3 | Kiowa | SE NW 33-29-16 W. | do | 90.0 | 150.0 |
| M-6 | Marion | NW NW 34-18-1 E. | do | 10.0 | 30.0 |
| S-16 | Saline | NE NW 28-14-3 W. | do | 11.0 | 16.0 |
| S-18 | do | NE NE 8-15-4 W. | do | 27.0 | 27.0 |
| C-27 | Cloud | NE NW 32-8-2 W. | Dakota clay | 12.0 | 12.0 |

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*aggregate in batch-type rotary kiln, continued.*

| Degree of oxidation on outcrop | Time in kiln, minutes | Firing temperatures, degrees F. Initial softening | Optimum for bloating | Formation of kiln roll | Maximum attained | Unit weight lbs. per cu. ft. Crushed, unsized* | Crushed, sized** | Color of crushed aggregate | Sample No. |
|---|---|---|---|---|---|---|---|---|---|
| Mostly unoxidized | 6½ | 2150 | 2170 | 2180 | 2180 | 28.2 | 40.5 | Mostly red | WL-1 |
| Unoxidized | 6 | 2070 | 2160 | 2160 | 2250 | 44.8 | 51.2 | Pink & gray | Haydite |
| Mostly oxidized | 8 | 2180 | 2220 | 2230 | 2280 | 53.6 | 67.0 | Gray | DG-15 |
| do | 7 | 2060 | 2250 | 2260 | 2300 | 40.2 | 45.3 | do | DG-14 |
| Partially oxidized | 8 | 2120 | 2150 | 2170 | 2280 | 46.4 | 54.0 | do | DN-4 |
| Slightly oxidized | 8 | 2140 | 2190 | 2200 | 2240 | 50.6 | 58.2 | Red & gray | GW-2 |
| Mostly unoxidized | 9 | 2140 | 2150 | 2160 | 2200 | 44.9 | 51.6 | do | WL-2 |
| Unoxidized | 10 | 2120 | 2140 | 2150 | 2160 | 53.3 | 62.5 | do | WD-1 |
| Unoxidized | 9 | 2130 | 2190 | 2200 | 2260 | 36.0 | 42.3 | Dark gray | EK-1 |
| Mostly oxidized | 10 | 2180 | 2200 | 2200 | 2210 | 63.3 | 78.3 | Red & gray | WD-2 |
| Unoxidized | .... | 2150 | 2160 | 2180 | 2220 | 50.8 | 60.4 | Gray | A-8 |
| Slightly oxidized | 9 | 2190 | 2210 | 2210 | 2260 | 52.5 | 61.3 | do | EK-2 |
| Unoxidized | 6 | 2130 | 2140 | 2150 | 2250 | 41.1 | 48.5 | Red & gray | SH-2 |
| do | 9 | 2110 | 2180 | 2180 | 2260 | 35.8 | 44.6 | Gray | EK-5 |
| Semi-oxidized | 10 | 2180 | 2220 | 2220 | 2240 | 55.8 | 59.8 | Dark gray | EK-4 |
| Unoxidized | 7 | 2160 | 2180 | 2180 | 2240 | 34.5 | 41.4 | Pink & gray | GW-1 |
| Slightly oxidized | 8 | 2160 | 2170 | 2180 | 2230 | 46.2 | 57.1 | Black | SH-3 |
| Partly oxidized | 9 | 2190 | 2200 | 2210 | 2280 | 49.4 | 59.5 | do | PT-1 |
| Mostly oxidized | 11 | 2190 | 2200 | 2210 | 2220 | 47.4 | 54.0 | Red& black | BR-5 |
| Mostly unoxidized | 8 | 2110 | 2120 | 2130 | 2220 | 49.0 | 58.3 | Black | BR-6 |
| Mostly oxidized | 8 | 2190 | 2220 | 2270 | 2280 | 46.1 | 52.2 | Gray | LY-1 |
| Unoxidized | 8 | 2140 | 2170 | 2190 | 2240 | 48.7 | 55.1 | do | LY-2 |
| Mostly oxidized | 10 | 2130 | 2140 | 2170 | 2170 | 62.0 | 71.9 | Pink & gray | LY-3 |
| Unoxidized | 7 | 2080 | 2120 | 2130 | 2180 | 38.8 | 40.4 | Red & gray | LY-4 |
| Oxidized | 9 | 2200 | 2230 | 2250 | 2250 | 61.5 | 76.6 | Dark gray | LY-5 |
| Unoxidized | 8 | 2160 | 2170 | 2180 | 2250 | 50.6 | 53.2 | do | EK-3 |
| Mostly oxidized | 8 | 2160 | 2175 | 2190 | 2200 | 64.7 | 72.3 | do | LY-6 |
| Unoxidized | 13 | 2180 | 2200 | 2210 | 2220 | 53.6 | 66.8 | Red & gray | WB-1 |
| do | 9 | 2160 | 2170 | 2180 | 2180 | 41.7 | 43.5 | Red & blk. | WB-2-1 |
| Partially oxidized | 10 | 2200 | 2210 | 2200 | 2220 | 50.8 | 65.9 | Almost blk. | WB-2-2 |
| Unoxidized | 6 | 2020 | 2100 | 2110 | 2210 | 28.2 | 37.8 | Red & gray | BR-3-1 |
| do | 6 | 2200 | 2240 | 2250 | 2260 | 44.8 | 55.9 | Pink & gray | BR-3-2 |
| Oxidized | 10 | 2100 | 2140 | 2120 | 2150 | 49.3 | 57.5 | Pink & gray | SG-3 |
| do | 9 | 2170 | 2230 | 2200 | 2240 | 57.3 | 67.5 | Gray | RO-2 |
| Unoxidized | 9 | 2090 | 2100 | 2100 | 2220 | 46.0 | 53.7 | Lt. gray | CL-6 |
| do | 7 | 2050 | 2090 | 2100 | 2250 | 28.8 | 33.7 | Pink & gray | K-3 |
| Partly oxidized | 8 | 2060 | 2080 | 2080 | 2100 | 56.3 | 82.0 | do | M-6 |
| Unoxidized | 10 | 2140 | 2160 | 2150 | 2160 | 49.8 | 70.1 | Gray | S-16 |
| do | 15 | 2080 | 2140 | 2150 | 2180 | 42.7 | 56.3 | Pink & gray | S-18 |
| do | 11 | 2340 | 2370 | 2370 | 2440 | 60.9 | 70.4 | Lt. gray | C-27 |

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TABLE 2.—*Results of experimental production of lightweight*

| Sample No. | County | Location | Strati-graphic position | Thickness, in feet Sampled | Available |
|---|---|---|---|---|---|
| El-32-D | Ellsworth | NW NE 21-15-6 W. | do | 67.0 | 90.0± |
| L-4-C | Lincoln | SW NW 36-11-7 W. | do | 14.2 | 20.0± |
| S-15 | Saline | NE SE 34-13-4 W. | do | 7.0 | 20.0± |
| R-15 | Russell | NW NW 35-12-14 W. | Graneros shale | 14.0 | 14.0 |
| W-65 | Washington | SW SW 1-3-1 E. | do | 7.0 | 17.0 |
| ES-1 | Ellis | NE SE 21-13-19 W. | Blue Hill shale | 13.0 | 30.0+ |
| ES-3 | do | Cen. NE 24-11-17 W. | do | 111.3 | 116.0 |
| ES-4 | do | NE NE 8-15-20 W. | do | 109.8 | 150.0± |
| FY-2 | Finney | Cen. N½ 2-22-29 W. | do | 123.0 | 123.0 |
| MT-1 | Mitchell | NW NW 26-8-10 W. | do | 79.5 | 90.0 |
| OS-1 | Osborne | Cen. N. line 20-10-15 W. | do | 31.0 | 100.0 |
| OS-2 | do | Cen. SW 12-7-15 W. | do | 59.0 | 100.0 |
| LO-2 | Logan | Cen. S½ 8-12-36 W. | Pierre shale | 25.0 | 30.0 |
| PH-2 | Phillips | SE NE 10-1-18 W. | do | 20.0 | 20.0 |
| | | | **Tertiary** | | |
| WC-1 | Wallace | SW 19-12-41 W. | Ogallala | 10.0 | 14.0 |
| CH-5 | Cheyenne | NE 24-3-41 W. | do | 7.0 | 15.0 |
| | | | **Pleistocene** | | |
| A-6 | Atchison | Cen. N. line 12-7-18 E. | | 32.0 | 32.0 |
| CR-5 | Crawford | NW SE 18-30-25 E. | Terrace deposit | 4.0 | 4.0 |
| CR-8 | do | NE SE 16-16-25 E. | do | 9.0 | 9.0 |
| NM-2 | Nemaha | SW SW 29-2-14 E. | ........................ | 5.0 | 12.0 |
| NN-6 | Norton | NW 26-2-23 W. | Sanborn fm. | ...... | ...... |
| SG-1 | Sedgwick | SW SW 3-28-1 W. | do | 10.0 | 15.0± |
| SG-2 | do | SW SW 17-27-1 W. | do | 16.0 | 20.0+ |

*Crushed through roll set 3/16 of an inch apart.
**Crushed through roll set 3/16 of an inch apart and graded according to curve discussed in text.

of the solid aggregate rather than unit weights of the crushed material of irregular shape that is produced in the rotary kiln (Pl. 2B) and which includes a large percentage of voids between particles. An unbloated vitrified shale or clay has a density of about 2.3 grams per cubic centimeter, or 143 pounds per cubic foot, whereas the most extreme bloating will produce a brick having a density as low as 0.45 grams per cubic centimeter, or about 30 pounds per cubic foot. In the latter case the bloated brick may be as much as 3.7 times as large as the original unfired brick (Pl. 2A). This ratio of volume of bloated brick to unfired brick is given in column 5 of Table 4. The percentage absorption after 5 hours immersion in boiling water was also determined. The percentage loss on ignition was included because it is of value

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*aggregate in batch-type rotary kiln, concluded*

| Degree of oxidation on outcrop | Time in kiln, minutes | Firing temperatures, degrees F. | | | | Unit weight lbs. per cu. ft. | | Color of crushed aggregate | Sample No. |
|---|---|---|---|---|---|---|---|---|---|
| | | Initial softening | Optimum for bloating | Formation of kiln roll | Maximum attained | Crushed, unsized* | Crushed, sized** | | |
| do | 13 | 2350 | 2430 | 2430 | 2440 | 63.0 | 70.5 | Dark gray | El-32-D |
| do | 7 | 2180 | 2370 | 2240 | 2380 | 46.4 | 47.6 | do | L-4-C |
| do | 12 | 2250 | 2270 | 2280 | 2290 | 60.0 | 72.0 | Gray | S-15 |
| do | 9 | 2170 | 2210 | 2220 | 2270 | 40.1 | 56.4 | Red & gray | R-15 |
| do | 8 | 2120 | 2160 | 2170 | 2220 | 43.2 | 58.8 | Gray | W-65 |
| do | 8 | 2000 | 2160 | 2210 | 2260 | 39.8 | 51.3 | Pink & gray | ES-1 |
| do | 20 | 2150 | 2160 | 2170 | 2350 | 32.0 | 36.2 | Dark gray | ES-3 |
| do | 8 | 2100 | 2150 | 2160 | 2230 | 39.3 | 51.2 | Red & gray | ES-4 |
| do | 8 | 2150 | 2230 | 2230 | 2320 | 49.2 | 63.5 | Dark gray | FY-2 |
| do | 4 | 2050 | 2150 | 2150 | 2400 | 31.6 | 41.1 | Pink & gray | MT-1 |
| do | 8 | 2050 | 2170 | 2180 | 2230 | 31.7 | 41.0 | do | OS-1 |
| do | 16 | 2020 | 2150 | 2160 | 2230 | 43.7 | 55.2 | Red & gray | OS-2 |
| do | 5 | 2100 | 2260 | 2220 | 2280 | 40.7 | 49.7 | Pink & gray | LO-2 |
| do | 6 | 2180 | 2250 | 2230 | 2280 | 40.8 | 47.2 | Lt. gray | PH-2 |
| do | 7 | 2090 | 2100 | 2110 | 2120 | 46.4 | 48.9 | Red brown | WC-1 |
| do | 7 | 2050 | 2160 | 2170 | 2230 | 68.4 | 74.6 | Pink & gray | CH-5 |
| Oxidized | 7 | 2220 | 2250 | 2260 | 2290 | 65.7 | 77.0 | Gray | A-6 |
| do | 15 | 2290 | ........ | ........ | 2400 | 74.6 | 81.9 | Red & gray | CR-5 |
| do | 15 | 2210 | ........ | 2290 | 2410 | 69.3 | 79.9 | Dark gray | CR-8 |
| do | 18 | 2250 | 2260 | 2260 | 2320 | 65.9 | 76.8 | Red & gray | NM-2 |
| do | 10 | 2200 | 2210 | 2210 | 2300 | 50.9 | 58.8 | Gray | NN-6 |
| do | 8 | 2040 | 2200 | 2140 | 2300 | 51.6 | 61.9 | Red & gray | SG-1 |
| Oxidized | 15 | 2120 | ........ | 2150 | 2440 | 67.5 | 97.2 | Red & gray | SG-2 |

to the prospective manufacturer in determining the percentage loss of weight from raw material to finished product.

Owing to the fact that the tabulated data necessarily permit only an incomplete diagnosis of the quality of the materials, the various formations sampled are discussed under separate headings. The sequence of the headings is determined by the stratigraphic position.

## PENNSYLVANIAN SYSTEM

The thickness of exposed formations belonging to the Pennsylvanian System totals about 3,100 feet (Moore and others, 1951). Of this total thickness two-thirds to three-fourths is shale, much of which is usable for the production of lightweight

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aggregate. Judging from chemical analyses, mineralogical analyses of the same shales in other states, and electron photomicrographs (Pls. 3, 4, 5, and 6) of representative shales occurring in Kansas, the dominant mineral constituent of the Pennsylvanian shales belongs to the illite group of clay minerals. This doubtless accounts for the fact that almost all the Penn-

TABLE 3.—*Screen analyses and unit weights of lightweight aggregates crushed through rolls spaced three-sixteenths inch apart* (arranged in order of increasing unit weights)

| Sample No. | Percent retained on following screen sizes 3/8 | No. 4 | No. 8 | No. 16 | No. 30 | No. 50 | No. 100 | Pan | Unit weight, lbs. per cu. ft. |
|---|---|---|---|---|---|---|---|---|---|
| BR-3-1 | 7.8 | 38.4 | 24.6 | 12.1 | 5.9 | 3.3 | 2.9 | 5.5 | 28.2 |
| WL-1 | 3.5 | 39.7 | 27.6 | 12.8 | 6.2 | 3.3 | 3.0 | 4.9 | 28.2 |
| K-3 | 1.0 | 30.5 | 32.8 | 15.8 | 7.9 | 4.2 | 2.4 | 5.3 | 28.8 |
| FR-5 | 15.6 | 34.6 | 23.2 | 10.4 | 5.6 | 3.2 | 2.5 | 5.0 | 30.9 |
| DG-13 | 7.5 | 34.7 | 27.2 | 11.3 | 5.8 | 3.3 | 3.3 | 6.8 | 31.5 |
| MT-1 | 2.0 | 35.9 | 31.2 | 14.7 | 5.7 | 2.6 | 2.6 | 5.4 | 31.6 |
| MG-4 | 4.3 | 35.5 | 23.5 | 11.7 | 6.3 | 4.8 | 6.8 | 7.0 | 31.7 |
| OS-1 | 3.6 | 38.5 | 33.4 | 13.2 | 5.3 | 2.0 | 1.1 | 2.8 | 31.7 |
| ES-3 | 1.3 | 33.9 | 32.4 | 14.2 | 6.3 | 3.2 | 2.7 | 6.1 | 32.0 |
| CK-7 | 11.7 | 35.1 | 24.6 | 12.7 | 6.9 | 3.6 | 2.3 | 3.6 | 33.7 |
| GW-1 | 2.4 | 24.8 | 34.3 | 15.4 | 7.7 | 4.3 | 3.1 | 8.1 | 34.5 |
| EK-5 | 0.7 | 25.5 | 30.5 | 13.4 | 6.9 | 5.4 | 5.4 | 12.0 | 35.8 |
| EK-1 | 1.1 | 26.8 | 32.3 | 17.3 | 8.5 | 5.1 | 4.7 | 4.2 | 36.0 |
| CR-7 | 0.3 | 32.8 | 20.7 | 11.3 | 8.5 | 7.5 | 7.8 | 11.1 | 36.6 |
| LY-4 | 4.6 | 31.7 | 28.9 | 12.8 | 7.0 | 3.9 | 4.0 | 7.0 | 38.8 |
| MG-3 | 4.4 | 30.8 | 27.9 | 13.8 | 7.2 | 5.1 | 4.8 | 6.0 | 39.1 |
| ES-4 | 2.3 | 31.4 | 36.9 | 15.3 | 7.2 | 2.6 | 1.6 | 2.8 | 39.3 |
| WY-6 | 1.7 | 30.4 | 29.7 | 13.8 | 7.9 | 5.1 | 3.6 | 7.7 | 39.7 |
| ES-1 | 1.8 | 23.7 | 38.3 | 19.7 | 9.7 | 4.2 | 1.2 | 1.4 | 39.8 |
| R-15 | 1.2 | 30.2 | 34.2 | 16.5 | 8.1 | 4.0 | 2.0 | 3.7 | 40.1 |
| DG-14 | 1.9 | 30.1 | 30.3 | 15.3 | 8.1 | 4.5 | 2.7 | 7.0 | 40.2 |
| LO-2 | 4.8 | 27.3 | 30.3 | 18.0 | 11.3 | 5.2 | 1.2 | 2.0 | 40.7 |
| MG-1-2 | 4.0 | 33.7 | 30.3 | 12.7 | 6.3 | 3.1 | 2.9 | 7.0 | 40.8 |
| PH-2 | 0.2 | 28.2 | 35.8 | 17.2 | 8.0 | 3.6 | 2.0 | 5.1 | 40.8 |
| SH-2 | 4.4 | 32.6 | 29.7 | 13.5 | 7.0 | 3.7 | 3.1 | 6.0 | 41.1 |
| WB-2-1 | 2.1 | 33.3 | 32.7 | 12.0 | 6.1 | 4.0 | 3.6 | 6.2 | 41.7 |
| FR-6 | 0.1 | 19.7 | 57.2 | 11.6 | 5.1 | 2.7 | 1.3 | 2.4 | 42.6 |
| LN-1-1 | 1.0 | 29.5 | 29.5 | 13.0 | 8.0 | 5.1 | 4.8 | 9.2 | 42.6 |
| S-18 | 1.9 | 39.6 | 33.9 | 15.2 | 4.5 | 1.8 | 1.1 | 2.0 | 42.7 |
| FR-3 | 0.2 | 36.0 | 32.1 | 14.3 | 7.1 | 3.7 | 2.4 | 4.2 | 42.7 |
| MG-2 | 4.9 | 34.0 | 28.8 | 13.4 | 7.0 | 4.0 | 2.7 | 5.2 | 43.0 |
| W-65 | 8.7 | 36.4 | 29.4 | 14.6 | 5.4 | 2.2 | 1.3 | 2.0 | 43.2 |
| OS-2 | 1.0 | 34.7 | 35.1 | 15.0 | 6.5 | 2.6 | 1.6 | 3.6 | 43.7 |
| FR-3 | 0.4 | 38.1 | 30.1 | 12.3 | 6.5 | 3.5 | 2.5 | 6.6 | 44.7 |
| BR-3-2 | 7.9 | 41.3 | 23.8 | 11.5 | 5.9 | 3.1 | 2.5 | 3.9 | 44.8 |
| Haydite | 3.1 | 27.9 | 30.1 | 16.3 | 10.1 | 4.0 | 2.9 | 5.4 | 44.8 |
| WL-2 | 0.7 | 31.5 | 32.4 | 13.5 | 7.2 | 3.9 | 3.5 | 7.4 | 44.9 |
| JN-6 | 2.8 | 33.1 | 32.0 | 12.8 | 4.9 | 3.9 | 5.2 | 5.3 | 45.4 |
| CL-6 | 0.5 | 25.2 | 34.9 | 13.2 | 6.5 | 3.7 | 3.7 | 8.9 | 46.0 |
| LY-1 | 2.3 | 32.5 | 29.4 | 12.7 | 7.0 | 4.3 | 4.9 | 6.9 | 46.1 |

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| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| WC-1 | 1.8 | 43.6 | 26.5 | 11.9 | 5.9 | 3.4 | 2.4 | 4.6 | 46.1 |
| AN-3 | 1.6 | 27.3 | 36.2 | 16.5 | 8.2 | 4.0 | 2.1 | 4.0 | 46.2 |
| SH-3 | 1.7 | 31.8 | 30.9 | 13.5 | 8.8 | 4.8 | 3.7 | 4.7 | 46.2 |
| JN-7 | 3.0 | 32.6 | 29.5 | 14.6 | 8.2 | 5.0 | 5.0 | 4.5 | 46.3 |
| DN-4 | 3.5 | 31.9 | 29.2 | 12.9 | 6.8 | 4.3 | 4.0 | 7.3 | 46.4 |
| L-4-C | 0.4 | 24.3 | 34.3 | 14.4 | 8.9 | 5.4 | 4.1 | 8.2 | 46.4 |
| MG-1-1 | 1.0 | 31.9 | 32.9 | 13.2 | 6.3 | 3.5 | 3.4 | 7.8 | 47.0 |
| LV-5 | 3.5 | 27.2 | 29.0 | 16.9 | 9.3 | 4.7 | 4.0 | 5.3 | 47.2 |
| BR-5 | 0.8 | 31.5 | 31.3 | 12.0 | 8.0 | 6.2 | 4.7 | 5.6 | 47.4 |
| CQ-2 | 0.5 | 32.3 | 32.7 | 12.3 | 6.1 | 3.5 | 3.3 | 9.3 | 48.0 |
| AN-2 | 6.3 | 34.0 | 30.7 | 13.3 | 7.8 | 3.5 | 3.1 | 2.7 | 48.3 |
| BR-6 | 1.4 | 32.2 | 27.7 | 12.0 | 7.8 | 6.8 | 7.1 | 5.1 | 49.0 |
| FY-2 | 2.0 | 33.1 | 37.2 | 16.0 | 6.1 | 2.2 | 1.2 | 2.2 | 49.2 |
| SG-3 | 1.0 | 37.1 | 36.0 | 12.8 | 5.5 | 3.0 | 1.7 | 2.8 | 49.3 |
| PT-1 | 1.0 | 31.4 | 33.0 | 13.2 | 7.4 | 5.2 | 5.0 | 3.8 | 49.4 |
| S-16 | 26.1 | 38.2 | 19.2 | 8.9 | 3.6 | 1.7 | 1.0 | 1.1 | 49.8 |
| S-16 & loess | 0.4 | 29.8 | 34.1 | 13.7 | 7.4 | 4.0 | 3.1 | 6.5 | 49.8 |
| FR-4 | 2.3 | 30.6 | 31.1 | 13.4 | 7.2 | 4.1 | 3.5 | 7.9 | 49.9 |
| AL-2 | 0.8 | 39.8 | 32.1 | 11.5 | 5.7 | 3.6 | 2.7 | 3.8 | 50.1 |
| LV-6 | 7.7 | 40.6 | 26.5 | 12.4 | 4.6 | 2.9 | 2.3 | 2.9 | 50.2 |
| EK-3 | 1.2 | 31.8 | 34.6 | 14.6 | 6.4 | 3.5 | 2.3 | 5.5 | 50.6 |
| GW-2 | 2.5 | 27.4 | 36.7 | 15.4 | 7.5 | 4.1 | 2.2 | 4.1 | 50.6 |
| A-8 | 1.5 | 29.9 | 32.4 | 16.0 | 8.1 | 3.9 | 3.1 | 5.2 | 50.8 |
| WB-2-2 | 0.8 | 30.4 | 30.3 | 13.4 | 9.4 | 6.8 | 4.8 | 4.3 | 50.8 |
| NN-6 | 1.1 | 36.9 | 26.5 | 10.8 | 6.6 | 5.5 | 4.5 | 8.0 | 50.9 |
| LV-4 | 3.3 | 33.5 | 29.3 | 13.7 | 5.9 | 3.8 | 4.3 | 6.1 | 51.3 |
| SG-1 | 0.2 | 22.2 | 34.2 | 12.9 | 7.0 | 6.0 | 5.2 | 12.4 | 51.6 |
| AL-1 | 3.6 | 32.9 | 28.7 | 13.4 | 8.3 | 5.2 | 3.8 | 4.1 | 52.0 |
| CR-10 | 1.4 | 29.9 | 33.7 | 14.2 | 7.1 | 4.6 | 3.1 | 6.0 | 52.5 |
| EK-2 | 0.9 | 25.2 | 41.2 | 15.0 | 7.0 | 3.7 | 2.2 | 4.6 | 52.5 |
| WD-1 | 0.3 | 27.1 | 38.0 | 15.3 | 8.3 | 4.1 | 2.7 | 4.1 | 53.3 |
| DG-15 | 3.8 | 33.7 | 30.9 | 14.5 | 6.0 | 3.7 | 2.0 | 5.3 | 53.6 |
| WB-1 | 1.6 | 34.5 | 30.1 | 13.2 | 6.7 | 4.6 | 4.9 | 4.4 | 53.6 |
| LY-2 | 1.4 | 33.0 | 31.2 | 13.3 | 6.9 | 4.2 | 4.2 | 5.9 | 55.1 |
| EK-4 | 1.6 | 28.6 | 36.6 | 13.8 | 6.7 | 3.7 | 2.6 | 6.4 | 55.8 |
| M-6 | 12.2 | 36.8 | 28.9 | 12.8 | 5.2 | 1.9 | 0.9 | 1.3 | 56.3 |
| RO-2 | 1.1 | 28.8 | 35.5 | 14.1 | 7.3 | 5.0 | 3.3 | 5.0 | 57.3 |
| LN-1-2 | 2.3 | 31.3 | 32.2 | 14.3 | 7.5 | 3.9 | 3.8 | 4.8 | 59.1 |
| JN-9 | 3.5 | 31.3 | 32.0 | 14.1 | 7.3 | 3.8 | 3.4 | 4.5 | 59.4 |
| S-15 | 18.7 | 34.3 | 24.8 | 11.8 | 5.0 | 2.4 | 1.5 | 1.6 | 60.0 |
| C-27 | 0.7 | 37.5 | 36.7 | 9.4 | 6.6 | 3.9 | 2.2 | 2.9 | 60.9 |
| LY-5 | 4.7 | 30.9 | 32.5 | 13.8 | 7.3 | 4.1 | 3.0 | 3.8 | 61.5 |
| LY-3 | 5.5 | 32.9 | 30.5 | 13.9 | 7.1 | 3.7 | 3.1 | 3.3 | 62.0 |
| JN-5 | 5.2 | 41.6 | 28.0 | 12.3 | 5.5 | 2.6 | 2.3 | 2.6 | 62.7 |
| EL-32-D | 0.9 | 39.3 | 27.8 | 12.5 | 6.5 | 4.0 | 2.8 | 6.2 | 63.0 |
| WD-2 | 2.7 | 31.3 | 32.6 | 16.7 | 6.9 | 3.3 | 2.5 | 3.9 | 63.3 |
| JN-4 | 7.2 | 34.3 | 28.0 | 13.4 | 6.7 | 3.1 | 2.6 | 4.6 | 64.3 |
| LY-6 | 7.5 | 31.3 | 31.3 | 13.8 | 6.9 | 3.4 | 2.6 | 3.4 | 64.7 |
| A-6 | 0.3 | 24.5 | 39.7 | 18.1 | 9.0 | 4.1 | 1.7 | 2.6 | 65.7 |
| NM-2 | 0.6 | 31.0 | 35.1 | 13.8 | 7.0 | 4.1 | 3.3 | 5.1 | 65.9 |
| SG-2 | 0.2 | 23.4 | 43.7 | 12.4 | 6.4 | 3.6 | 4.1 | 6.4 | 67.5 |
| CK-6 | 3.4 | 32.9 | 33.2 | 12.9 | 6.8 | 3.8 | 2.7 | 3.7 | 67.6 |
| WY-5 | 3.8 | 36.0 | 32.6 | 13.8 | 5.6 | 2.8 | 2.2 | 3.0 | 67.6 |
| CH-5 | 0.2 | 10.2 | 28.3 | 26.6 | 23.3 | 7.0 | 2.7 | 1.6 | 68.4 |
| LV-3 | 7.6 | 31.0 | 29.0 | 14.8 | 7.9 | 3.4 | 2.8 | 3.4 | 68.9 |
| CR-8 | 0.5 | 33.5 | 37.1 | 12.9 | 6.6 | 3.4 | 2.3 | 3.7 | 69.3 |
| CR-5 | 0.3 | 24.7 | 45.2 | 14.4 | 6.5 | 3.2 | 1.8 | 3.9 | 74.6 |
| CR-9 | 2.2 | 30.4 | 35.4 | 13.5 | 6.7 | 3.6 | 2.2 | 5.9 | 75.1 |
| CR-6 | 0.6 | 39.1 | 45.6 | 16.6 | 7.3 | 3.3 | 1.8 | 1.9 | 81.0 |

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TABLE 4.—*Bloating resulting from rapid firing of bricks in an electric kiln at various temperatures*

| Sample No. | Temperature, degrees F. | Density Grams per cc | Density lbs. per cu. ft. | Ratio of bloated to unfired vol. | Absorption, 5 hrs. boiling percent | Loss on ignition, percent |
|---|---|---|---|---|---|---|
| | | | PENNSYLVANIAN | | | |
| *AL-1 | 1850 | 1.78 | 111.07 | 0.99 | 19.14 | 8.98 |
| | 2180 | 1.34 | 83.62 | 1.32 | 13.04 | 9.26 |
| | 2220 | 1.55 | 96.72 | 1.14 | 10.80 | 9.27 |
| | 2260 | 1.32 | 82.37 | 1.34 | 14.78 | 9.16 |
| *AL-2 | 1850 | 1.77 | 110.45 | 1.01 | 18.70 | 9.18 |
| | 2160 | 1.95 | 121.68 | 0.92 | 8.37 | 9.47 |
| | 2220 | 1.42 | 88.61 | 1.26 | 14.14 | 9.35 |
| *AN-2 | 1850 | 2.06 | 128.54 | 0.87 | 9.19 | 5.24 |
| | 2180 | 1.23 | 76.75 | 1.46 | 12.70 | 5.93 |
| | 2220 | 1.25 | 78.00 | 1.45 | 27.58 | 5.56 |
| | 2260 | 1.23 | 76.75 | 1.47 | 27.56 | 5.84 |
| *AN-3 | 1850 | 2.15 | 134.16 | 0.82 | 7.59 | 6.60 |
| | 2170 | 1.41 | 87.98 | 1.25 | 10.16 | 6.76 |
| | 2230 | 1.31 | 81.74 | 1.34 | 16.43 | 6.63 |
| | 2290 | 1.25 | 78.00 | 1.40 | 18.42 | 6.86 |
| *A-8 | 1850 | 1.97 | 122.93 | 0.88 | 11.82 | 7.39 |
| | 2160 | 1.36 | 84.86 | 1.27 | 24.30 | 8.20 |
| | 2220 | 1.01 | 63.02 | 1.69 | 36.81 | 8.86 |
| | 2260 | 0.73 | 45.55 | 2.32 | 64.60 | 9.52 |
| *BR-3-1 | 1850 | 1.96 | 122.30 | 0.87 | 11.97 | 5.79 |
| | 2160 | 0.94 | 58.66 | 1.80 | 56.59 | 6.28 |
| | 2200 | 0.65 | 40.56 | 2.60 | 71.82 | 6.51 |
| | 2260 | 0.63 | 39.31 | 2.67 | 84.09 | 6.41 |
| *BR-3-2 | 1850 | 1.95 | 121.68 | 0.88 | 12.50 | 5.55 |
| | 2160 | 1.15 | 71.76 | 1.49 | 39.33 | 5.66 |
| | 2220 | 0.96 | 59.90 | 1.78 | 39.15 | 5.92 |
| | 2260 | 0.95 | 59.28 | 1.81 | 43.23 | 5.78 |
| *BR-5 | 1850 | 1.93 | 120.43 | 0.96 | 12.09 | 7.76 |
| | 2160 | 1.21 | 75.50 | 1.52 | 2.86 | 7.90 |
| | 2220 | 0.89 | 55.54 | 2.04 | 3.57 | 10.10 |
| | 2260 | 1.01 | 63.02 | 1.83 | 11.48 | 8.34 |
| *BR-6 | 1850 | 1.79 | 111.70 | 0.97 | 17.86 | 7.92 |
| | 2160 | 1.44 | 89.86 | 1.20 | 14.14 | 8.44 |
| | 2220 | 1.06 | 66.14 | 1.64 | 17.32 | 8.01 |
| | 2260 | 1.07 | 66.77 | 1.61 | 26.92 | 8.59 |
| *CK-6 | 1850 | 1.78 | 111.07 | 0.99 | 19.26 | 4.69 |
| | 2180 | 2.18 | 136.03 | 0.80 | 6.18 | 4.95 |
| | 2220 | 2.23 | 139.15 | 0.79 | 4.40 | 4.82 |
| | 2260 | 2.20 | 137.28 | 0.80 | 4.54 | 4.96 |
| *CK-7 | 1850 | 2.04 | 127.30 | 0.90 | 12.01 | 7.15 |
| | 2180 | 1.86 | 116.06 | 0.98 | 5.06 | 7.42 |
| | 2220 | 1.73 | 107.95 | 1.06 | 6.33 | 7.33 |
| | 2260 | 1.33 | 82.93 | 1.37 | 7.74 | 7.49 |
| *CQ-2 | 1850 | 1.93 | 120.43 | 0.97 | 11.81 | 4.81 |
| | 2160 | 2.23 | 139.15 | 0.84 | 4.86 | 5.06 |
| | 2220 | 2.20 | 137.28 | 0.85 | 3.70 | 5.14 |
| | 2280 | 1.72 | 107.33 | 1.09 | 10.06 | 5.23 |
| *CR-6 | 1850 | 2.06 | 128.54 | 0.92 | 10.91 | 7.84 |
| | 2170 | 2.30 | 143.52 | 0.82 | 2.86 | 7.91 |
| | 2230 | 2.32 | 144.77 | 0.81 | 2.22 | 7.74 |
| | 2290 | 2.28 | 142.27 | 0.83 | 2.06 | 7.70 |
| *CR-7 | 1850 | 1.83 | 114.19 | 0.94 | 16.57 | 6.18 |
| | 2170 | 2.16 | 134.78 | 0.79 | 1.44 | 6.45 |

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| | | | | | | |
|---|---|---|---|---|---|---|
| | 2230 | 1.68 | 104.83 | 1.02 | 4.90 | 6.81 |
| | 2290 | 1.33 | 82.99 | 1.29 | 12.33 | 6.56 |
| *CR-9 | 1850 | 1.89 | 117.94 | 0.92 | 15.02 | 5.25 |
| | 2170 | 2.14 | 133.54 | 0.97 | 1.82 | 5.62 |
| | 2230 | 1.69 | 105.46 | 1.23 | 6.65 | 5.56 |
| | 2290 | 1.39 | 86.74 | 1.49 | 13.08 | 5.52 |
| *CR-10 | 1850 | 1.80 | 112.32 | 1.00 | 18.40 | 4.06 |
| | 2170 | 2.05 | 127.92 | 0.87 | 9.72 | 4.35 |
| | 2230 | 2.03 | 126.67 | 0.88 | 7.78 | 4.48 |
| | 2290 | 1.77 | 110.45 | 1.01 | 8.72 | 4.48 |
| *DG-13 | 1850 | 2.00 | 124.80 | 0.89 | 12.47 | 6.37 |
| | 2180 | 2.16 | 134.78 | 0.82 | 2.52 | 6.58 |
| | 2220 | 2.19 | 136.66 | 0.81 | 2.11 | 6.67 |
| | 2260 | 1.89 | 117.94 | 0.94 | 5.19 | 6.77 |
| *DG-14 | 1850 | 1.92 | 119.81 | 0.91 | 13.52 | 5.55 |
| | 2180 | 1.93 | 120.43 | 0.91 | 3.50 | 5.74 |
| | 2220 | 1.74 | 108.58 | 1.01 | 8.77 | 5.82 |
| | 2260 | 1.66 | 103.58 | 1.05 | 9.12 | 5.79 |
| *DG-15 | 1850 | 1.90 | 118.56 | 0.93 | 13.33 | 6.77 |
| | 2180 | 2.04 | 127.30 | 0.86 | 2.34 | 7.02 |
| | 2220 | 1.78 | 111.07 | 0.99 | 8.66 | 6.98 |
| | 2260 | 1.63 | 101.71 | 1.08 | 11.40 | 6.73 |
| †DN-4-1 | 1850 | 1.92 | 119.81 | 0.94 | 14.44 | 5.89 |
| | 2160 | 2.23 | 139.15 | 0.81 | 2.46 | 6.13 |
| | 2220 | 1.93 | 120.43 | 0.94 | 5.11 | 6.30 |
| | 2260 | 1.54 | 96.10 | 1.17 | 14.18 | 6.42 |
| †DN-4-2 | 1850 | 1.87 | 116.69 | 0.94 | 14.12 | 5.27 |
| | 2160 | 2.16 | 134.78 | 0.81 | 2.43 | 5.87 |
| | 2220 | 1.86 | 116.06 | 0.95 | 6.04 | 5.79 |
| | 2260 | 1.51 | 94.22 | 1.16 | 19.49 | 5.85 |
| †DN-4-3 | 1850 | 1.90 | 118.56 | 0.94 | 13.86 | 5.11 |
| | 2160 | 2.17 | 135.41 | 0.82 | 1.99 | 5.72 |
| | 2220 | 1.80 | 112.32 | 0.99 | 7.59 | 5.64 |
| | 2260 | 1.50 | 93.60 | 1.18 | 19.86 | 5.61 |
| *EK-1 | 1850 | 2.03 | 126.67 | 0.86 | 7.99 | 7.76 |
| | 2170 | 1.51 | 94.22 | 1.16 | 8.84 | 7.86 |
| | 2230 | 1.37 | 85.49 | 1.28 | 17.66 | 7.77 |
| | 2290 | 1.28 | 79.87 | 1.37 | 20.43 | 7.79 |
| *EK-2 | 1850 | 1.99 | 124.18 | 0.91 | 10.27 | 7.13 |
| | 2170 | 2.16 | 134.78 | 0.85 | 2.37 | 6.74 |
| | 2230 | 1.88 | 117.31 | 0.97 | 5.80 | 6.60 |
| | 2290 | 1.51 | 94.22 | 1.21 | 13.07 | 6.79 |
| *EK-3 | 1850 | 1.99 | 124.18 | 0.90 | 11.71 | 5.97 |
| | 2170 | 1.60 | 99.84 | 1.11 | 7.12 | 6.39 |
| | 2230 | 1.30 | 81.12 | 1.37 | 20.34 | 6.56 |
| | 2290 | 1.18 | 73.63 | 1.51 | 27.69 | 6.52 |
| *EK-4 | 1850 | 1.87 | 116.67 | 0.91 | 14.69 | 5.83 |
| | 2170 | 2.28 | 142.27 | 0.75 | 1.51 | 5.80 |
| | 2230 | 1.97 | 122.93 | 0.87 | 3.63 | 5.68 |
| | 2290 | 1.61 | 100.46 | 1.06 | 8.23 | 5.90 |
| *EK-5 | 1850 | 1.80 | 112.32 | 0.97 | 17.75 | 4.49 |
| | 2170 | 2.02 | 126.05 | 0.86 | 3.27 | 4.45 |
| | 2230 | 1.47 | 91.73 | 1.01 | 13.95 | 4.35 |
| | 2290 | 1.05 | 65.52 | 1.65 | 35.93 | 4.55 |
| *FR-5 | 1850 | 1.90 | 118.56 | 0.92 | 7.53 | 7.76 |
| | 2160 | 2.36 | 147.26 | 0.75 | 1.47 | 7.36 |
| | 2220 | 2.01 | 125.42 | 0.88 | 4.34 | 4.34 |
| | 2280 | 1.58 | 98.59 | 1.12 | 10.90 | 10.90 |
| *GW-1 | 1850 | 1.86 | 116.06 | 0.89 | 15.57 | 6.73 |
| | 2170 | 2.00 | 124.80 | 0.82 | 4.11 | 6.71 |

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TABLE 4.—*Bloating resulting from rapid firing of bricks in an electric kiln at various temperatures, continued*

| Sample No. | Temperature, degrees F. | Density Grams per cc | Density lbs. per cu. ft. | Ratio of bloated to unfired vol. | Absorption, 5 hrs. boiling percent | Loss on ignition, percent |
|---|---|---|---|---|---|---|
| | 2230 | 1.70 | 106.08 | 0.97 | 8.13 | 6.83 |
| | 2260 | 1.39 | 86.74 | 1.19 | 17.93 | 6.80 |
| *GW-2 | 1850 | 2.00 | 124.80 | 0.90 | 11.91 | 6.33 |
| | 2170 | 2.27 | 141.65 | 0.79 | 2.79 | 6.38 |
| | 2230 | 2.14 | 133.54 | 0.84 | 3.19 | 6.26 |
| | 2290 | 1.70 | 106.08 | 1.05 | 6.98 | 6.43 |
| *JN-4 | 1850 | 1.87 | 116.69 | 0.95 | 15.06 | 4.81 |
| | 2180 | 2.18 | 136.03 | 0.82 | 2.32 | 4.90 |
| | 2220 | 1.96 | 122.30 | 0.91 | 4.45 | 4.88 |
| | 2260 | 1.78 | 111.07 | 1.00 | 8.73 | 4.82 |
| *JN-5 | 1850 | 1.87 | 116.69 | 0.92 | 16.29 | 5.45 |
| | 2180 | 1.76 | 109.82 | 0.98 | 7.07 | 5.70 |
| | 2220 | 1.43 | 89.23 | 1.20 | 19.50 | 5.81 |
| | 2260 | 1.28 | 79.87 | 1.34 | 22.68 | 5.74 |
| *JN-6 | | Does not bloat at any temperature | | | | |
| *JN-7 | 1850 | 1.97 | 122.93 | 0.91 | 12.81 | 6.73 |
| | 2180 | 1.68 | 104.83 | 1.05 | 7.01 | 7.02 |
| | 2220 | 1.58 | 98.59 | 1.12 | 12.51 | 7.09 |
| | 2260 | 1.52 | 94.85 | 1.17 | 11.70 | 6.97 |
| ‡JN-8 | | Does not bloat at any temperature | | | | |
| *JN-9 | 1850 | 1.91 | 119.18 | 0.93 | 13.59 | 5.62 |
| | 2180 | 1.96 | 122.30 | 0.91 | 4.19 | 5.74 |
| | 2220 | 1.75 | 109.20 | 1.02 | 10.64 | 5.77 |
| | 2260 | 1.66 | 103.58 | 1.07 | 10.51 | 5.84 |
| *LV-3 | 1850 | 1.85 | 115.44 | 0.93 | 16.35 | 5.45 |
| | 2180 | 1.95 | 121.68 | 0.88 | 2.73 | 5.46 |
| | 2220 | 1.73 | 107.95 | 1.00 | 7.44 | 5.60 |
| | 2260 | 1.58 | 98.59 | 1.09 | 11.38 | 5.80 |
| ‡LV-4 | 1850 | 1.86 | 116.06 | 0.96 | 15.75 | 5.54 |
| | 2180 | 2.28 | 142.27 | 0.78 | 2.14 | 5.61 |
| | 2220 | 2.24 | 139.78 | 0.80 | 1.87 | 5.57 |
| | 2260 | 2.09 | 129.17 | 0.85 | 3.11 | 5.67 |
| *LV-5 | 1850 | 1.82 | 113.57 | 0.96 | 15.12 | 8.47 |
| | 2180 | 1.39 | 86.74 | 1.26 | 15.17 | 8.89 |
| | 2220 | 1.06 | 66.14 | 1.66 | 28.83 | 8.91 |
| | 2260 | 0.86 | 53.66 | 2.03 | 37.61 | 9.08 |
| *LV-6 | 1850 | 1.87 | 116.69 | 0.93 | 15.35 | 7.66 |
| | 2180 | 1.65 | 102.96 | 1.05 | 2.98 | 7.93 |
| | 2220 | 1.28 | 79.87 | 1.35 | 20.85 | 8.13 |
| | 2260 | 1.08 | 67.39 | 1.61 | 34.68 | 7.89 |
| *LN-1-1 | 1850 | 1.89 | 117.94 | 0.94 | 15.17 | 4.50 |
| | 2160 | 2.15 | 134.16 | 0.84 | 1.06 | 4.88 |
| | 2220 | 1.48 | 92.35 | 1.23 | 18.98 | 3.97 |
| | 2260 | 1.51 | 94.22 | 1.19 | 18.51 | 4.85 |
| *LN-1-2 | 1850 | 1.89 | 117.94 | 0.96 | 14.87 | 4.11 |
| | 2160 | 2.16 | 134.78 | 0.84 | 3.84 | 4.23 |
| | 2220 | 1.52 | 94.85 | 1.19 | 21.14 | 4.42 |
| | 2260 | 1.55 | 96.72 | 1.16 | 20.06 | 4.31 |
| *LY-1 | | Does not bloat at any temperature | | | | |
| *LY-2 | 1850 | 1.78 | 111.07 | 0.91 | 17.43 | 4.77 |
| | 2160 | 2.24 | 139.78 | 0.72 | 0.32 | 5.15 |
| | 2220 | 1.63 | 101.71 | 0.99 | 12.36 | 4.94 |
| | 2280 | 1.20 | 74.88 | 1.34 | 25.24 | 5.09 |

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| | | | | | | |
|---|---|---|---|---|---|---|
| *LY-3 | 1850 | 1.86 | 116.06 | 0.94 | 14.19 | 5.74 |
| | 2160 | 2.29 | 142.90 | 0.76 | 1.51 | 6.19 |
| | 2220 | 2.06 | 128.54 | 0.84 | 3.34 | 6.27 |
| | 2280 | 1.75 | 109.20 | 0.99 | 8.21 | 6.27 |
| *LY-4 | 1850 | 1.93 | 120.43 | 0.87 | 7.45 | 6.02 |
| | 2160 | 1.85 | 115.44 | 0.91 | 6.29 | 5.57 |
| | 2220 | 1.27 | 79.25 | 1.32 | 25.65 | 5.70 |
| | 2280 | 1.05 | 65.52 | 1.60 | 35.83 | 5.70 |
| *LY-5 | 1850 | 1.93 | 120.43 | 0.91 | 9.73 | 7.46 |
| | 2160 | 2.17 | 135.41 | 0.81 | 2.39 | 7.76 |
| | 2220 | 1.91 | 119.18 | 0.91 | 7.00 | 7.72 |
| | 2280 | 1.62 | 101.09 | 1.08 | 12.34 | 7.72 |
| *LY-6 | 1850 | 1.88 | 117.32 | 0.87 | 5.52 | 7.41 |
| | 2160 | 2.28 | 142.27 | 0.72 | 0.12 | 6.95 |
| | 2220 | 1.90 | 118.56 | 0.87 | 6.56 | 6.84 |
| | 2280 | 1.74 | 108.58 | 0.95 | 5.75 | 6.85 |
| *MG-1-1 | 1850 | 1.98 | 123.55 | 0.97 | 13.19 | 4.39 |
| | 2160 | 2.25 | 140.40 | 0.85 | 4.06 | 4.49 |
| | 2220 | 2.19 | 136.66 | 0.88 | 2.99 | 4.66 |
| | 2260 | 1.67 | 105.46 | 1.15 | 15.17 | 4.63 |
| *MG-1-2 | 1850 | 2.00 | 124.80 | 0.93 | 12.15 | 5.38 |
| | 2160 | 2.28 | 142.27 | 0.82 | 2.23 | 5.49 |
| | 2220 | 1.96 | 122.30 | 0.95 | 5.60 | 5.57 |
| | 2260 | 1.67 | 104.21 | 1.12 | 13.71 | 5.06 |
| *MG-2 | 1850 | 1.88 | 117.31 | 0.97 | 15.98 | 7.32 |
| | 2160 | 1.62 | 101.09 | 1.13 | 7.02 | 7.93 |
| | 2220 | 0.94 | 58.66 | 1.94 | 12.98 | 7.91 |
| | 2260 | 0.49 | 30.58 | 3.60 | 52.48 | 11.21 |
| *MG-3 | 1850 | 1.94 | 121.06 | 0.92 | 14.69 | 6.72 |
| | 2170 | 2.09 | 130.42 | 0.86 | 3.67 | 7.10 |
| | 2230 | 1.72 | 107.33 | 1.04 | 7.49 | 7.14 |
| | 2290 | 1.42 | 88.61 | 1.27 | 14.83 | 7.15 |
| *MG-4 | 1850 | 1.87 | 116.69 | 0.97 | 16.31 | 7.80 |
| | 2180 | 1.57 | 97.97 | 1.17 | 4.79 | 8.02 |
| | 2220 | 1.38 | 86.11 | 1.33 | 7.77 | 8.13 |
| | 2260 | 1.08 | 67.39 | 1.70 | 16.61 | 8.01 |
| *NM-2 | 1850 | 1.94 | 121.06 | 0.99 | 12.18 | 4.12 |
| | 2220 | 1.54 | 96.10 | 1.25 | 13.40 | 4.28 |
| | 2260 | 1.42 | 88.61 | 1.35 | 16.52 | 4.15 |
| | 2340 | 1.05 | 65.52 | 1.83 | 48.60 | 4.19 |
| ‡OG-2 | 1850 | 1.84 | 114.82 | 0.93 | 15.63 | 6.67 |
| | 2160 | 1.65 | 102.96 | 1.04 | 14.85 | 6.71 |
| | 2220 | 1.28 | 79.87 | 1.34 | 27.07 | 6.81 |
| | 2260 | 0.85 | 53.04 | 2.01 | 47.19 | 6.71 |
| ‡OG-3 | 1850 | 1.84 | 114.82 | 0.87 | 15.61 | 11.36 |
| | 2160 | 1.04 | 64.89 | 1.54 | 39.15 | 11.49 |
| | 2220 | 0.73 | 45.55 | 2.19 | 50.43 | 12.12 |
| | 2260 | 0.81 | 50.54 | 1.98 | 62.05 | 11.83 |
| ‡OG-4 | 1850 | 2.06 | 128.54 | 0.84 | 6.62 | 7.04 |
| | 2160 | 1.82 | 113.57 | 0.95 | 8.22 | 6.94 |
| | 2220 | 1.80 | 112.32 | 0.96 | 9.45 | 6.72 |
| | 2260 | 1.80 | 112.32 | 0.96 | 9.20 | 6.78 |
| ‡OG-5 | 1850 | 1.70 | 106.08 | 1.11 | 10.75 | 6.31 |
| | 2160 | 1.19 | 74.26 | 1.59 | 25.47 | 6.36 |
| | 2220 | 1.14 | 71.14 | 1.65 | 24.30 | 6.63 |
| | 2260 | 1.12 | 69.89 | 1.68 | 24.97 | 6.41 |
| ‡OG-6 | 1850 | 1.73 | 107.95 | 0.98 | 20.31 | 4.77 |
| | 2160 | 2.18 | 136.03 | 0.77 | 6.05 | 4.81 |
| | 2220 | 1.86 | 116.06 | 0.90 | 5.91 | 4.91 |
| | 2260 | 2.04 | 127.30 | 0.82 | 4.80 | 4.95 |

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TABLE 4.—*Bloating resulting from rapid firing of bricks in an electric kiln at various temperatures, continued*

| Sample No. | Temperature, degrees F. | Density Grams per cc | Density lbs. per cu. ft. | Ratio of bloated to unfired vol. | Absorption, 5 hrs. boiling percent | Loss on ignition, percent |
|---|---|---|---|---|---|---|
| ‡OG-7 | 1850 | 1.71 | 106.70 | 0.99 | 21.03 | 4.73 |
| | 2160 | 2.11 | 131.66 | 0.80 | 7.11 | 5.35 |
| | 2220 | 1.68 | 104.83 | 1.00 | 14.64 | 5.32 |
| | 2260 | 1.83 | 114.19 | 0.92 | 10.90 | 5.35 |
| ‡OG-8 | 1850 | 1.65 | 102.96 | 1.00 | 23.23 | 5.07 |
| | 2170 | 1.98 | 123.55 | 0.83 | 11.78 | 5.74 |
| | 2230 | 1.91 | 119.18 | 0.86 | 7.85 | 5.84 |
| | 2290 | 1.25 | 78.00 | 1.31 | 23.52 | 5.83 |
| *PT-1 | 1850 | 1.90 | 112.32 | 0.94 | 11.82 | 8.78 |
| | 2180 | 1.36 | 84.86 | 1.32 | 1.43 | 8.84 |
| | 2220 | 1.05 | 65.52 | 1.70 | 2.23 | 8.82 |
| *SH-2 | 1850 | 1.83 | 114.19 | 0.91 | 15.21 | 5.97 |
| | 2180 | 1.53 | 95.47 | 1.09 | 17.99 | 6.22 |
| | 2220 | 1.32 | 82.37 | 1.26 | 22.28 | 6.34 |
| | 2260 | 1.24 | 77.38 | 1.34 | 27.41 | 6.20 |
| *SH-3 | 1850 | 2.01 | 125.42 | 0.90 | 9.09 | 6.87 |
| | 2180 | 1.00 | 62.40 | 1.79 | 3.62 | 7.21 |
| | 2220 | 1.40 | 87.36 | 1.28 | 9.98 | 6.92 |
| *WB-1 | 1850 | 1.81 | 112.94 | 0.94 | 16.03 | 4.81 |
| | 2160 | 2.04 | 127.30 | 0.83 | 4.51 | 5.35 |
| | 2220 | 1.39 | 86.74 | 1.23 | 20.93 | 5.35 |
| | 2280 | 0.89 | 55.54 | 1.91 | 47.02 | 5.63 |
| *WB-2-1 | 1850 | 1.77 | 110.45 | 0.96 | 16.85 | 7.73 |
| | 2160 | 1.84 | 114.82 | 0.91 | 7.66 | 8.22 |
| | 2220 | 0.92 | 57.41 | 1.84 | 44.20 | 8.34 |
| *WB-2-2 | 1850 | 1.77 | 110.45 | 0.96 | 16.94 | 8.33 |
| | 2160 | 2.02 | 126.05 | 0.83 | 0.22 | 9.02 |
| | 2220 | 0.97 | 60.53 | 1.74 | 2.27 | 8.98 |
| *WD-1 | 1850 | 1.76 | 109.82 | 1.04 | 15.03 | 7.08 |
| | 2160 | 2.25 | 140.40 | 1.07 | 3.41 | 6.90 |
| | 2220 | 2.05 | 127.92 | 1.44 | 5.58 | 6.99 |
| | 2280 | 1.74 | 108.58 | 1.91 | 12.19 | 7.14 |
| *WD-2 | 1850 | 1.82 | 113.60 | 0.99 | 13.48 | 6.99 |
| | 2160 | 2.25 | 140.40 | 0.80 | 3.41 | 6.90 |
| | 2220 | 2.05 | 127.92 | 0.87 | 5.58 | 6.99 |
| | 2280 | 1.74 | 108.58 | 1.03 | 12.19 | 7.14 |
| *WL-1 | 1850 | 2.00 | 124.80 | 0.93 | 13.42 | 7.09 |
| | 2160 | 2.30 | 143.52 | 0.81 | 2.60 | 7.32 |
| | 2220 | 2.13 | 132.91 | 0.88 | 2.60 | 7.32 |
| | 2260 | 1.74 | 108.58 | 1.07 | 6.10 | 7.39 |
| *WL-2 | 1850 | 1.87 | 116.69 | 0.97 | 15.86 | 5.57 |
| | 2160 | 2.20 | 137.28 | 0.79 | 2.63 | 5.75 |
| | 2220 | 2.01 | 125.42 | 0.90 | 4.37 | 6.06 |
| | 2260 | 1.58 | 98.59 | 1.14 | 16.17 | 5.94 |
| *WY-5 | 1850 | 1.75 | 109.20 | 0.88 | 11.53 | 6.16 |
| | 2180 | 1.12 | 69.89 | 1.52 | 18.28 | 6.68 |
| | 2220 | 1.05 | 65.52 | 1.62 | 27.79 | 6.74 |
| | 2260 | 1.00 | 62.40 | 1.70 | 37.17 | 6.69 |
| *WY-6 | 1850 | 2.00 | 122.80 | 0.91 | 12.79 | 5.39 |
| | 2170 | 1.74 | 108.58 | 1.04 | 4.62 | 5.47 |
| | 2230 | 1.36 | 84.86 | 1.33 | 10.59 | 5.47 |
| | 2290 | 1.12 | 69.88 | 1.61 | 28.20 | 5.50 |

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|---|---|---|---|---|---|---|
| ‡BR-4 | 1850 | 1.69 | 66.70 | 0.97 | 20.83 | 15.05 |
| | 2160 | 1.63 | 101.71 | 1.00 | 3.99 | 15.59 |
| ‡M-2 | 1850 | 1.69 | 105.46 | 0.95 | 22.37 | 16.59 |
| | 2160 | 1.82 | 113.57 | 0.88 | 4.44 | 16.76 |
| ‡M-5 | 1850 | 1.81 | 112.94 | 0.90 | 19.98 | 13.87 |
| | 2160 | 1.77 | 110.45 | 0.92 | 1.26 | 14.16 |
| ‡M-8 | 1850 | 1.76 | 109.82 | 0.95 | 22.01 | 14.75 |
| | 2160 | 1.84 | 114.82 | 0.91 | 3.40 | 15.21 |
| ‡SU-1 | 1850 | 1.80 | 112.32 | 0.92 | 17.55 | 13.01 |
| | 2160 | 1.56 | 97.34 | 1.07 | 0.85 | 12.24 |
| ‡SU-2 | 1850 | 1.68 | 104.83 | 0.94 | 26.50 | 21.09 |
| | 2160 | 2.00 | 124.80 | 0.79 | 13.54 | 21.44 |
| | 2220 | 1.83 | 114.19 | 0.86 | 3.33 | 20.90 |
| | 2260 | 1.81 | 112.94 | 0.87 | 4.92 | 21.29 |
| ‡SU-3-1 | 1850 | 1.77 | 110.45 | 0.89 | 19.00 | 13.16 |
| | 2160 | 1.46 | 91.10 | 1.09 | 1.15 | 12.88 |
| ‡SU-3-2 | 1850 | 1.92 | 119.81 | 0.90 | 15.48 | 9.69 |
| | 2160 | 1.25 | 78.00 | 1.38 | 20.49 | 9.55 |
| | 2200 | 1.05 | 65.52 | 1.66 | 18.54 | 7.53 |
| | 2260 | 1.14 | 71.14 | 1.55 | 21.56 | 7.82 |
| ‡S-19-1 | 1850 | 1.80 | 112.32 | 1.02 | 18.31 | 6.14 |
| | 2180 | 1.91 | 119.18 | 0.96 | 14.34 | 6.09 |
| | 2220 | 1.94 | 121.06 | 0.94 | 10.43 | 6.45 |
| | 2260 | 1.67 | 104.21 | 1.09 | 17.78 | 6.62 |

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|---|---|---|---|---|---|---|
| †CL-6-1 | 1850 | 1.72 | 107.33 | 0.97 | 18.56 | 5.09 |
| | 2220 | 0.81 | 50.54 | 2.06 | 76.27 | 5.70 |
| | 2260 | 0.64 | 39.94 | 2.59 | 102.51 | 5.53 |
| | 2340 | 0.47 | 29.33 | 3.50 | 147.60 | 6.02 |
| †CL-6-2 | 1850 | 1.68 | 104.83 | 1.00 | 20.82 | 4.76 |
| | 2220 | 0.98 | 61.15 | 1.71 | 58.39 | 5.45 |
| | 2260 | 0.77 | 48.05 | 2.15 | 80.84 | 5.73 |
| | 2340 | 0.56 | 34.94 | 2.93 | 123.27 | 6.03 |
| †CL-6-3 | 1850 | 1.63 | 101.71 | 1.00 | 22.38 | 4.59 |
| | 2220 | 1.07 | 66.77 | 1.52 | 50.69 | 5.30 |
| | 2260 | 0.88 | 54.91 | 1.84 | 67.22 | 5.37 |
| | 2340 | 0.68 | 42.43 | 2.39 | 101.67 | 5.63 |
| †CL-6-4 | 1850 | 1.55 | 96.72 | 1.01 | 25.19 | 3.76 |
| | 2220 | 1.42 | 88.61 | 1.09 | 29.84 | 4.73 |
| | 2260 | 1.32 | 82.37 | 1.17 | 33.23 | 4.80 |
| | 2340 | 0.91 | 56.78 | 1.70 | 67.93 | 4.99 |
| †CL-6-5 | 1850 | 1.62 | 101.09 | 0.98 | 22.32 | 4.73 |
| | 2220 | 1.23 | 79.87 | 1.24 | 34.53 | 5.59 |
| | 2260 | 1.11 | 69.23 | 1.43 | 43.78 | 5.35 |
| | 2340 | 0.73 | 107.95 | 2.16 | 89.61 | 5.58 |
| †CL-6-6 | 1850 | 1.81 | 112.94 | 0.95 | 14.37 | 6.45 |
| | 2220 | 0.97 | 60.53 | 1.77 | 42.84 | 6.72 |
| | 2260 | 0.84 | 52.42 | 2.05 | 55.80 | 6.74 |
| | 2340 | 0.56 | 34.94 | 3.06 | 126.15 | 6.94 |
| †CL-6-7 | 1850 | 1.75 | 109.20 | 1.01 | 18.62 | 4.06 |
| | 2220 | 1.07 | 66.77 | 1.65 | 50.40 | 4.16 |
| | 2260 | 0.91 | 56.78 | 1.94 | 65.80 | 4.26 |
| | 2340 | 0.77 | 48.05 | 2.29 | 87.57 | 4.38 |
| †CL-6-8 | 1850 | 1.92 | 119.81 | 0.92 | 13.04 | 5.73 |
| | 2220 | 1.03 | 64.27 | 1.71 | 40.79 | 5.99 |
| | 2260 | 0.94 | 58.66 | 1.88 | 49.64 | 5.92 |
| | 2340 | 0.62 | 38.69 | 2.85 | 106.65 | 6.01 |

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**TABLE 4.**—*Bloating resulting from rapid firing of bricks in an electric kiln at various temperatures, continued*

| Sample No. | Temperature, degrees F. | Density Grams per cc | Density lbs. per cu. ft. | Ratio of bloated to unfired vol. | Absorption, 5 hrs. boiling percent | Loss on ignition, percent |
|---|---|---|---|---|---|---|
| †CL-6-9 | 2180 | 0.52 | 32.45 | 2.60 | 147.83 | 8.41 |
| | 2220 | 0.91 | 56.78 | 1.46 | 66.08 | 8.85 |
| | 2300 | 1.38 | 86.11 | 0.97 | 27.05 | 8.87 |
| †K-3-1 | 1850 | 1.71 | 106.70 | 0.87 | 17.91 | 9.20 |
| | 2220 | 1.71 | 106.70 | 0.87 | 12.23 | 9.35 |
| | 2300 | 1.23 | 76.75 | 1.21 | 18.20 | 9.25 |
| | 2340 | 1.21 | 75.50 | 1.23 | 17.55 | 9.39 |
| †K-3-2 | 1850 | 1.79 | 111.70 | 0.92 | 15.94 | 7.48 |
| | 2220 | 1.13 | 70.51 | 1.44 | 28.59 | 7.89 |
| | 2300 | 0.94 | 58.66 | 1.74 | 41.57 | 7.97 |
| | 2340 | 0.91 | 56.78 | 1.79 | 36.45 | 8.16 |
| †K-3-3 | 1850 | 1.80 | 112.32 | 0.90 | 14.32 | 7.75 |
| | 2220 | 1.30 | 81.12 | 1.24 | 21.59 | 8.48 |
| | 2300 | 1.08 | 67.39 | 1.48 | 26.11 | 8.27 |
| | 2340 | 1.07 | 66.77 | 1.50 | 29.22 | 8.34 |
| †B-3-4 | 1850 | 1.78 | 111.07 | 0.90 | 16.93 | 7.50 |
| | 2220 | 1.23 | 76.75 | 1.30 | 27.74 | 7.84 |
| | 2300 | 1.04 | 64.90 | 1.53 | 34.46 | 8.01 |
| | 2340 | 1.00 | 62.40 | 1.59 | 36.72 | 7.93 |
| †K-3-5 | 1850 | 1.83 | 114.19 | 0.91 | 14.29 | 8.37 |
| | 2220 | 1.15 | 71.76 | 1.45 | 26.62 | 8.88 |
| | 2300 | 0.96 | 59.90 | 1.73 | 41.59 | 8.99 |
| | 2340 | 0.90 | 56.16 | 1.84 | 44.49 | 9.10 |
| †K-3-6 | 1850 | 1.70 | 106.08 | 0.99 | 20.71 | 5.41 |
| | 2220 | 1.26 | 78.62 | 1.32 | 32.71 | 5.96 |
| | 2300 | 1.03 | 64.27 | 1.61 | 45.65 | 6.08 |
| | 2340 | 0.89 | 55.54 | 1.87 | 58.16 | 6.02 |
| †K-3-7 | 1850 | 1.84 | 114.82 | 0.90 | 15.52 | 8.23 |
| | 2220 | 1.07 | 66.77 | 1.54 | 28.49 | 8.89 |
| | 2300 | 0.91 | 56.78 | 1.80 | 40.73 | 8.99 |
| | 2340 | 0.77 | 48.05 | 2.13 | 55.90 | 9.30 |
| †K-3-8 | 1850 | 1.91 | 119.19 | 0.89 | 10.86 | 7.87 |
| | 2220 | 1.25 | 78.00 | 1.35 | 20.29 | 8.79 |
| | 2300 | 1.01 | 63.02 | 1.67 | 30.26 | 8.82 |
| | 2340 | 0.92 | 57.41 | 1.82 | 38.79 | 8.96 |
| †K-3-9 | 1850 | 1.82 | 113.57 | 0.95 | 17.29 | 6.99 |
| | 2220 | 1.20 | 74.88 | 1.43 | 35.32 | 7.84 |
| | 2260 | 1.02 | 63.65 | 1.67 | 45.60 | 7.84 |
| | 2340 | 0.69 | 43.06 | 2.48 | 88.65 | 8.51 |
| †K-3-10 | 1850 | 1.79 | 111.70 | 0.99 | 18.10 | 4.62 |
| | 2220 | 1.73 | 107.95 | 1.01 | 15.18 | 5.74 |
| | 2260 | 1.58 | 98.59 | 1.11 | 20.41 | 5.68 |
| | 2340 | 1.08 | 67.39 | 1.60 | 45.23 | 6.46 |
| †K-3-11 | 1850 | 1.86 | 116.06 | 0.91 | 13.19 | 7.53 |
| | 2220 | 1.07 | 66.77 | 1.58 | 32.87 | 8.06 |
| | 2260 | 0.85 | 53.04 | 1.99 | 54.12 | 8.14 |
| | 2340 | 0.67 | 41.81 | 2.52 | 82.85 | 8.14 |
| †K-3-12 | 1850 | 1.88 | 117.31 | 0.92 | 9.45 | 7.02 |
| | 2220 | 1.05 | 65.52 | 1.63 | 19.70 | 7.77 |
| | 2260 | 0.93 | 58.03 | 1.84 | 41.09 | 7.75 |
| | 2340 | 0.69 | 43.06 | 1.89 | 56.67 | 7.68 |
| †K-3-13 | 1850 | 1.55 | 96.72 | 1.15 | 14.77 | 7.54 |
| | 2220 | 0.92 | 57.41 | 1.88 | 24.54 | 10.47 |

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|---|---|---|---|---|---|---|
| | 2260 | 1.02 | 63.65 | 1.74 | 28.54 | 7.89 |
| | 2340 | 0.87 | 116.69 | 2.02 | 40.30 | 8.12 |
| †K-3-14 | 1850 | 1.88 | 117.31 | 0.95 | 13.14 | 8.06 |
| | 2220 | 0.93 | 58.03 | 1.86 | 55.31 | 11.27 |
| | 2260 | 0.60 | 37.44 | 2.87 | 87.96 | 11.43 |
| †K-3-15 | 1850 | 1.65 | 102.96 | 1.08 | 14.01 | 11.02 |
| | 2220 | 0.77 | 48.05 | 2.27 | 65.69 | 12.04 |
| | 2260 | 0.59 | 36.82 | 2.99 | 92.06 | 12.11 |
| *M-6 | 1850 | 1.96 | 122.30 | 0.94 | 11.92 | 5.72 |
| | 2160 | 1.79 | 111.70 | 1.03 | 13.03 | 5.66 |
| | 2220 | 1.43 | 89.23 | 1.27 | 21.92 | 7.02 |
| | 2260 | 1.61 | 100.46 | 1.14 | 17.00 | 5.92 |
| ‡M-7 | 1850 | 1.74 | 108.58 | 0.92 | 22.07 | 14.99 |
| | 2160 | 1.61 | 100.46 | 0.99 | 8.99 | 15.40 |
| *S-16 | 1850 | 1.74 | 108.58 | 1.05 | 8.99 | 6.61 |
| | 2160 | 2.14 | 133.54 | 0.85 | 3.89 | 6.72 |
| | 2220 | 1.85 | 115.44 | 0.99 | 8.70 | 6.88 |
| | 2280 | 1.47 | 91.73 | 1.24 | 16.07 | 6.92 |
| *S-18 | 1850 | 1.31 | 81.70 | 1.35 | 24.03 | 6.67 |
| | 2160 | 1.81 | 112.94 | 0.97 | 7.83 | 7.26 |
| | 2220 | 1.35 | 84.24 | 1.30 | 16.67 | 7.38 |
| | 2280 | 1.00 | 62.40 | 1.75 | 32.83 | 8.13 |
| | | | *Dakota formation* | | | |
| ‡D-1 | 1850 | 1.83 | 114.19 | 0.98 | 16.24 | 5.90 |
| | 2160 | 1.84 | 114.82 | 0.97 | 16.13 | 6.10 |
| | 2220 | 1.87 | 116.69 | 0.96 | 14.69 | 6.07 |
| | 2260 | 1.94 | 121.06 | 0.93 | 11.86 | 6.02 |
| ‡D-2 | 1850 | 1.87 | 116.69 | 1.00 | 15.90 | 7.41 |
| | 2160 | 1.95 | 121.68 | 0.95 | 11.62 | 7.64 |
| | 2220 | 1.95 | 121.68 | 0.95 | 10.49 | 7.75 |
| | 2260 | 1.96 | 122.30 | 0.95 | 10.23 | 7.72 |
| *S-15 | 1850 | 2.03 | 126.70 | 0.88 | 10.19 | 5.59 |
| | 2160 | 2.23 | 139.15 | 0.79 | 1.00 | 6.94 |
| | 2220 | 1.98 | 123.55 | 0.89 | 4.51 | 6.77 |
| | 2280 | 1.55 | 96.72 | 1.14 | 12.83 | 6.84 |
| *L-4-C | 1850 | 2.18 | 136.03 | 0.86 | 4.89 | 8.03 |
| | 2160 | 1.74 | 108.58 | 1.07 | 11.28 | 7.99 |
| | 2220 | 1.42 | 88.61 | 1.32 | 19.96 | 8.14 |
| | 2280 | 1.23 | 76.75 | 1.52 | 24.36 | 8.13 |
| | | | *Graneros shale* | | | |
| *R-15 | 1850 | 2.03 | 126.70 | 0.86 | 11.02 | 7.05 |
| | 2160 | 1.94 | 121.06 | 0.89 | 3.67 | 8.65 |
| | 2220 | 1.20 | 74.88 | 1.44 | 27.20 | 8.79 |
| | 2280 | 0.99 | 61.78 | 1.74 | 32.67 | 8.81 |
| *W-65 | 1850 | 1.83 | 114.19 | 0.87 | 11.75 | 7.67 |
| | 2220 | 0.78 | 48.67 | 2.01 | 61.30 | 8.95 |
| | 2260 | 0.69 | 43.06 | 2.28 | 74.84 | 8.80 |
| | 2340 | 0.43 | 26.83 | 3.66 | 141.99 | 9.05 |
| | | | *Blue Hill shale* | | | |
| †ES-3-1 | 1850 | 1.91 | 119.18 | 0.89 | 11.81 | 6.89 |
| | 2220 | 1.09 | 68.02 | 1.56 | 81.97 | 7.34 |
| | 2260 | 0.92 | 57.41 | 1.84 | 38.73 | 7.19 |
| | 2340 | 0.68 | 42.43 | 2.47 | 54.06 | 7.52 |
| †ES-3-2 | 1850 | 1.91 | 119.18 | 0.90 | 11.61 | 6.35 |
| | 2220 | 1.55 | 96.72 | 1.10 | 9.28 | 6.76 |
| | 2260 | 1.30 | 81.12 | 1.32 | 13.18 | 6.57 |
| | 2340 | 1.04 | 64.90 | 1.64 | 24.95 | 6.78 |
| †ES-3-3 | 1850 | 1.91 | 119.18 | 0.91 | 11.73 | 6.19 |
| | 2220 | 1.44 | 89.86 | 1.20 | 14.10 | 6.63 |
| | 2260 | 1.23 | 76.75 | 1.41 | 17.13 | 6.60 |

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TABLE 4.—*Bloating resulting from rapid firing of bricks in an electric kiln at various temperatures, continued*

| Sample No. | Temperature, degrees F. | Density Grams per cc | Density lbs. per cu. ft. | Ratio of bloated to unfired vol. | Absorption, 5 hrs. boiling percent | Loss on ignition, percent |
|---|---|---|---|---|---|---|
| | 2340 | 0.92 | 57.41 | 1.88 | 40.25 | 6.78 |
| †ES-3-4 | 1850 | 1.86 | 116.06 | 1.13 | 14.40 | 6.33 |
| | 2220 | 1.53 | 95.47 | 1.38 | 11.87 | 6.50 |
| | 2260 | 1.31 | 81.74 | 1.61 | 13.67 | 6.40 |
| | 2300 | 0.69 | 43.06 | 2.49 | 56.02 | 7.68 |
| †ES-3-5 | 1850 | 1.84 | 114.82 | 0.91 | 15.46 | 6.36 |
| | 2220 | 1.29 | 80.50 | 1.29 | 14.08 | 6.67 |
| | 2260 | 1.14 | 71.14 | 1.46 | 14.93 | 6.60 |
| | 2340 | 0.87 | 54.29 | 1.91 | 33.22 | 6.62 |
| †ES-3-6 | 1850 | 1.85 | 115.44 | 0.89 | 15.10 | 6.67 |
| | 2220 | 0.91 | 56.78 | 1.80 | 39.17 | 7.63 |
| | 2260 | 0.76 | 47.42 | 2.15 | 53.05 | 7.34 |
| | 2340 | 0.67 | 41.81 | 3.42 | 79.09 | 7.99 |
| †ES-3-7 | 1850 | 1.86 | 116.06 | 0.90 | 14.16 | 6.32 |
| | 2220 | 1.13 | 70.51 | 1.47 | 18.75 | 6.55 |
| | 2260 | 0.98 | 61.15 | 1.71 | 25.65 | 6.45 |
| | 2340 | 0.67 | 41.81 | 2.50 | 47.50 | 6.63 |
| †ES-3-8 | 1850 | 1.87 | 116.69 | 0.89 | 14.51 | 6.52 |
| | 2220 | 1.18 | 73.63 | 1.41 | 15.28 | 6.71 |
| | 2260 | 1.00 | 62.40 | 1.66 | 20.61 | 6.84 |
| | 2340 | 0.76 | 47.42 | 2.18 | 48.21 | 6.86 |
| †ES-3-9 | 1850 | 1.88 | 117.31 | 0.89 | 13.49 | 6.75 |
| | 2220 | 1.40 | 87.36 | 1.19 | 10.64 | 7.16 |
| | 2260 | 1.18 | 73.63 | 1.41 | 18.08 | 6.78 |
| | 2340 | 0.90 | 56.16 | 1.86 | 29.01 | 7.09 |
| †ES-3-10 | 1850 | 1.78 | 111.07 | 0.90 | 17.89 | 6.74 |
| | 2220 | 1.54 | 96.10 | 1.04 | 9.79 | 7.09 |
| | 2260 | 1.34 | 83.62 | 1.20 | 10.60 | 6.87 |
| | 2340 | 1.00 | 62.40 | 1.61 | 18.74 | 7.03 |
| †ES-3-11 | 1850 | 1.75 | 109.20 | 0.89 | 19.24 | 8.20 |
| | 2220 | 1.40 | 87.36 | 1.11 | 13.30 | 8.33 |
| | 2260 | 1.22 | 76.13 | 1.27 | 15.19 | 8.22 |
| | 2340 | 0.99 | 61.78 | 1.56 | 19.98 | 8.41 |
| †ES-3-12 | 1850 | 1.82 | 113.57 | 0.92 | 16.52 | 7.13 |
| | 2220 | 1.63 | 101.71 | 1.03 | 30.96 | 7.30 |
| | 2260 | 1.08 | 67.39 | 1.56 | 17.07 | 7.16 |
| | 2340 | 0.83 | 51.79 | 2.01 | 29.54 | 7.47 |
| †ES-3-13 | 1850 | 1.45 | 90.48 | 1.12 | 16.81 | 7.52 |
| | 2220 | 1.26 | 78.62 | 1.29 | 14.11 | 7.72 |
| | 2260 | 1.08 | 67.39 | 1.50 | 19.27 | 7.72 |
| | 2340 | 0.88 | 54.91 | 1.84 | 32.18 | 7.83 |
| †ES-3-14 | 1850 | 1.79 | 111.70 | 0.90 | 18.11 | 7.01 |
| | 2220 | 1.36 | 84.86 | 1.18 | 13.70 | 7.83 |
| | 2260 | 1.21 | 75.50 | 1.33 | 15.36 | 7.76 |
| | 2340 | 0.95 | 59.28 | 1.67 | 31.79 | 8.11 |
| †ES-3-15 | 1850 | 1.87 | 116.69 | 0.87 | 14.68 | 6.74 |
| | 2220 | 1.13 | 70.51 | 1.43 | 19.64 | 7.05 |
| | 2260 | 0.96 | 59.90 | 1.69 | 27.40 | 6.83 |
| | 2340 | 0.72 | 44.93 | 2.26 | 44.20 | 6.96 |
| †ES-3-16 | 1850 | 1.88 | 117.31 | 0.90 | 14.53 | 6.27 |
| | 2220 | 0.93 | 58.03 | 1.81 | 37.99 | 6.38 |
| | 2260 | 0.78 | 48.67 | 2.15 | 44.64 | 6.26 |
| | 2340 | 0.50 | 31.20 | 3.37 | 71.49 | 6.51 |

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| | | | | | | |
|---|---|---|---|---|---|---|
| †ES-3-17 | 1850 | 1.88 | 117.31 | 0.94 | 13.85 | 5.16 |
| | 2220 | 1.28 | 79.87 | 1.38 | 25.55 | 5.40 |
| | 2260 | 1.11 | 69.26 | 1.58 | 36.11 | 5.47 |
| | 2340 | 0.92 | 57.41 | 1.90 | 41.46 | 5.63 |
| †ES-3-18 | 1850 | 1.89 | 117.94 | 0.91 | 13.20 | 6.00 |
| | 2220 | 1.20 | 74.88 | 1.44 | 24.83 | 6.49 |
| | 2260 | 1.03 | 64.27 | 1.68 | 35.76 | 6.01 |
| | 2340 | 0.87 | 54.29 | 1.97 | 44.01 | 6.36 |
| †ES-3-19 | 1850 | 1.91 | 119.18 | 0.93 | 12.22 | 5.29 |
| | 2220 | 1.32 | 82.37 | 1.34 | 27.06 | 5.44 |
| | 2260 | 1.14 | 71.14 | 1.55 | 34.94 | 5.46 |
| | 2340 | 0.95 | 59.28 | 1.87 | 40.63 | 5.51 |
| †ES-3-20 | 1850 | 1.74 | 108.58 | 1.00 | 18.27 | 3.64 |
| | 2220 | 1.83 | 114.19 | 0.94 | 11.83 | 3.87 |
| | 2260 | 1.71 | 106.70 | 1.01 | 12.71 | 3.69 |
| | 2340 | 1.24 | 77.38 | 1.39 | 26.09 | 3.99 |
| †ES-3-21 | 1850 | 1.80 | 112.32 | 1.00 | 16.48 | 3.16 |
| | 2220 | 1.54 | 96.10 | 1.17 | 4.43 | 4.43 |
| | 2260 | 1.89 | 117.94 | 0.95 | 10.01 | 3.26 |
| | 2340 | 1.44 | 89.86 | 1.25 | 18.48 | 3.18 |
| †ES-4-1 to †ES-4-6 | | Melted instead of bloating | | | | |
| †ES-4-7 | 1850 | 1.73 | 107.95 | 0.88 | 19.84 | 9.99 |
| | 2220 | 0.88 | 54.91 | 1.70 | 42.23 | 11.78 |
| †ES-4-8 | 1850 | 1.89 | 117.94 | 0.87 | 12.31 | 8.61 |
| | 2220 | 1.34 | 83.62 | 1.23 | 13.41 | 9.12 |
| | 2300 | 1.14 | 71.14 | 1.44 | 21.70 | 9.33 |
| †ES-4-9 | 1850 | 1.90 | 118.56 | 0.89 | 12.03 | 7.55 |
| | 2220 | 1.17 | 73.01 | 1.44 | 17.59 | 8.09 |
| | 2300 | 0.88 | 54.91 | 1.91 | 38.67 | 8.03 |
| †ES-4-10 | 1850 | 1.85 | 115.44 | 0.90 | 13.52 | 6.62 |
| | 2220 | 1.03 | 64.27 | 1.62 | 24.39 | 7.33 |
| | 2300 | 0.80 | 49.92 | 2.08 | 46.60 | 7.26 |
| †ES-4-11 | 1850 | 2.00 | 124.80 | 0.89 | 6.84 | 6.90 |
| | 2220 | 0.98 | 61.15 | 1.82 | 26.15 | 7.23 |
| | 2300 | 0.82 | 51.17 | 2.17 | 38.28 | 7.28 |
| †ES-4-12 | 1850 | 1.89 | 117.94 | 0.95 | 8.41 | 6.63 |
| | 2220 | 1.26 | 78.62 | 1.42 | 20.50 | 7.03 |
| | 2300 | 1.14 | 71.14 | 1.57 | 23.61 | 6.99 |
| †ES-4-13 | 1850 | 1.86 | 116.06 | 0.98 | 7.58 | 6.96 |
| | 2220 | 0.94 | 58.66 | 1.94 | 38.14 | 7.33 |
| | 2300 | 0.78 | 48.67 | 2.31 | 52.09 | 7.63 |
| †ES-4-14 | 1850 | 1.86 | 116.06 | 0.97 | 8.81 | 7.28 |
| | 2220 | 1.09 | 68.02 | 1.66 | 30.96 | 7.48 |
| | 2300 | 0.90 | 56.16 | 2.00 | 42.57 | 7.69 |
| †ES-4-15 | 1850 | 1.85 | 115.44 | 1.00 | 7.20 | 6.63 |
| | 2220 | 1.46 | 91.10 | 1.27 | 14.48 | 6.88 |
| | 2300 | 1.27 | 79.25 | 1.46 | 17.90 | 6.72 |
| †ES-4-16 | 1850 | 1.82 | 113.57 | 1.02 | 8.42 | 6.89 |
| | 2220 | 1.42 | 88.61 | 1.31 | 15.23 | 7.12 |
| | 2300 | 1.24 | 77.38 | 1.50 | 20.87 | 6.88 |
| †ES-4-17 | 1850 | 1.87 | 116.69 | 0.98 | 8.31 | 6.56 |
| | 2220 | 1.44 | 89.86 | 1.26 | 15.90 | 7.92 |
| | 2300 | 1.36 | 84.86 | 1.34 | 14.19 | 6.72 |
| †FY-2-1 | 1850 | 1.96 | 122.30 | 0.92 | 7.44 | 6.62 |
| | 2220 | 0.51 | 31.82 | 3.52 | 72.54 | 7.11 |
| | 2260 | 0.40 | 24.96 | 4.48 | 79.38 | 7.07 |
| | 2340 | 0.36 | 22.46 | 4.76 | 80.12 | 7.00 |

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TABLE 4.—*Bloating resulting from rapid firing of bricks in an electric kiln at various temperatures, continued*

| Sample No. | Temperature, degrees F. | Density Grams per cc | Density lbs. per cu. ft. | Ratio of bloated to unfired vol. | Absorption, 5 hrs. boiling percent | Loss on ignition, percent |
|---|---|---|---|---|---|---|
| †FY-2-2 | 1850 | 1.98 | 123.55 | 0.90 | 7.49 | 6.87 |
| | 2220 | 1.04 | 64.90 | 1.70 | 25.14 | 7.51 |
| | 2260 | 0.92 | 57.41 | 1.94 | 35.49 | 7.35 |
| | 2340 | 0.61 | 38.06 | 2.88 | 75.03 | 8.07 |
| †FY-2-3 | 1850 | 1.99 | 124.18 | 0.90 | 8.69 | 6.64 |
| | 2220 | 0.78 | 48.67 | 2.27 | 51.67 | 7.15 |
| | 2260 | 0.49 | 30.58 | 3.64 | 83.74 | 7.12 |
| †FY-2-4 | 1850 | 1.98 | 123.55 | 0.90 | 8.50 | 6.45 |
| | 2220 | 1.00 | 62.40 | 1.78 | 32.92 | 6.83 |
| | 2260 | 0.86 | 53.66 | 2.08 | 42.59 | 6.95 |
| | 2340 | 0.58 | 36.19 | 3.03 | 86.33 | 7.60 |
| †FY-2-5 | 1850 | 2.00 | 124.80 | 0.90 | 8.89 | 6.66 |
| | 2220 | 0.83 | 51.79 | 2.15 | 43.15 | 6.79 |
| | 2260 | 0.66 | 41.18 | 2.72 | 60.70 | 6.95 |
| | 2340 | 0.48 | 29.95 | 3.75 | 61.77 | 6.88 |
| †FY-2-6 | 1850 | 2.02 | 126.05 | 0.89 | 8.04 | 6.66 |
| | 2220 | 0.93 | 58.03 | 1.93 | 37.83 | 6.83 |
| | 2260 | 0.81 | 50.54 | 2.22 | 48.79 | 7.06 |
| | 2340 | 0.69 | 43.06 | 2.49 | 41.39 | 10.41 |
| †FY-2-7 | 1850 | 1.99 | 124.18 | 0.89 | 9.07 | 6.77 |
| | 2220 | 0.99 | 61.78 | 1.79 | 31.92 | 6.80 |
| | 2260 | 0.88 | 54.91 | 2.02 | 102.08 | 6.74 |
| | 2340 | 0.69 | 43.06 | 2.56 | 156.09 | 7.44 |
| †FY-2-8 | 1850 | 1.97 | 122.93 | 0.90 | 9.57 | 6.92 |
| | 2220 | 0.85 | 53.04 | 2.09 | 47.31 | 7.23 |
| | 2260 | 0.67 | 41.81 | 2.64 | 66.90 | 7.12 |
| | 2340 | 0.51 | 31.82 | 3.46 | 79.23 | 7.31 |
| †FY-2-9 | 1850 | 1.96 | 122.30 | 0.91 | 10.08 | 6.96 |
| | 2220 | 0.41 | 25.58 | 4.36 | 123.22 | 7.35 |
| | 2260 | 0.34 | 21.22 | 5.23 | 115.26 | 7.69 |
| | 2340 | 0.24 | 14.98 | 7.47 | 113.08 | 7.99 |
| †FY-2-10 | 1850 | 1.99 | 124.18 | 0.91 | 9.05 | 6.10 |
| | 2220 | 1.17 | 73.01 | 1.56 | 26.62 | 6.19 |
| | 2260 | 1.00 | 62.40 | 1.82 | 33.33 | 6.17 |
| | 2340 | 0.80 | 49.92 | 2.26 | 48.52 | 6.26 |
| †FY-2-11 | 1850 | 1.99 | 124.18 | 0.91 | 8.58 | 6.12 |
| | 2220 | 1.56 | 97.34 | 1.16 | 14.82 | 6.11 |
| | 2260 | 1.35 | 84.24 | 1.34 | 17.77 | 6.20 |
| | 2340 | 1.14 | 71.14 | 1.59 | 24.72 | 6.31 |
| †FY-2-12 | 1850 | 1.94 | 121.06 | 0.92 | 9.97 | 6.71 |
| | 2220 | 1.53 | 95.47 | 1.16 | 14.07 | 6.87 |
| | 2260 | 1.27 | 79.25 | 1.40 | 20.02 | 6.88 |
| | 2340 | 1.02 | 63.65 | 1.72 | 31.37 | 7.45 |
| †FY-2-13 | 1850 | 1.97 | 122.93 | 0.93 | 8.88 | 6.03 |
| | 2220 | 1.43 | 89.23 | 1.29 | 18.98 | 5.91 |
| | 2260 | 1.23 | 76.75 | 1.50 | 26.02 | 6.04 |
| | 2340 | 1.00 | 62.40 | 1.82 | 32.34 | 6.36 |
| †FY-2-14 | 1850 | 2.01 | 125.42 | 0.93 | 7.94 | 6.06 |
| | 2220 | 1.32 | 82.37 | 1.41 | 23.40 | 6.19 |
| | 2260 | 1.16 | 72.38 | 1.60 | 29.45 | 6.31 |
| | 2340 | 0.96 | 59.90 | 1.94 | 38.19 | 6.49 |
| †FY-2-15 | 1850 | 1.97 | 122.93 | 0.92 | 11.28 | 5.47 |
| | 2220 | 1.63 | 101.71 | 1.09 | 14.60 | 7.39 |

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| | | | | | | |
|---|---|---|---|---|---|---|
| | 2260 | 1.51 | 94.22 | 1.17 | 18.68 | 8.03 |
| | 2340 | 1.20 | 74.88 | 1.44 | 31.03 | 9.63 |
| †FY-2-16 | 1850 | 1.89 | 117.94 | 0.96 | 8.26 | 7.25 |
| | 2220 | 1.26 | 78.62 | 1.44 | 26.03 | 7.37 |
| | 2260 | 1.14 | 71.14 | 1.60 | 31.82 | 7.62 |
| | 2340 | 0.99 | 61.78 | 1.83 | 36.76 | 7.78 |
| †FY-2-17 | 1850 | 2.01 | 125.42 | 0.94 | 8.73 | 5.44 |
| | 2220 | 0.96 | 59.90 | 1.95 | 47.84 | 5.83 |
| | 2260 | 0.86 | 53.66 | 2.18 | 50.44 | 5.27 |
| | 2340 | 0.66 | 41.18 | 2.83 | 62.09 | 6.30 |
| †FY-2-18 | 1850 | 2.01 | 125.42 | 0.94 | 8.89 | 5.74 |
| | 2220 | 0.96 | 59.90 | 1.97 | 46.17 | 5.89 |
| | 2260 | 0.80 | 49.92 | 2.36 | 54.73 | 5.81 |
| | 2340 | 0.62 | 38.69 | 3.02 | 70.81 | 6.03 |
| †FY-2-19 | 1850 | 2.04 | 127.30 | 0.91 | 6.60 | 6.29 |
| | 2220 | 1.21 | 75.50 | 1.54 | 29.62 | 6.41 |
| | 2260 | 1.05 | 65.52 | 1.76 | 34.64 | 6.35 |
| | 2340 | 0.91 | 56.78 | 2.04 | 42.53 | 6.39 |
| †FY-2-20 | 1850 | 1.92 | 119.81 | 0.96 | 8.31 | 6.84 |
| | 2220 | 1.53 | 95.47 | 1.20 | 16.46 | 7.02 |
| | 2260 | 1.27 | 79.25 | 1.44 | 22.86 | 6.96 |
| | 2340 | 1.11 | 69.26 | 1.64 | 28.85 | 7.35 |
| †FY-2-21 | 1850 | 2.08 | 129.79 | 0.92 | 6.31 | 5.48 |
| | 2220 | 1.56 | 97.34 | 1.23 | 16.57 | 5.38 |
| | 2260 | 0.55 | 34.32 | 1.50 | 27.20 | 5.49 |
| | 2340 | 0.56 | 34.94 | 1.68 | 30.99 | 5.61 |
| †FY-22 | 1850 | 2.02 | 126.05 | 0.92 | 7.92 | 5.68 |
| | 2260 | 1.45 | 90.48 | 1.28 | 18.94 | 5.76 |
| | 2340 | 1.29 | 80.50 | 1.44 | 23.34 | 5.84 |
| †FY-2-23 | 1850 | 1.96 | 122.30 | 0.97 | 10.86 | 4.56 |
| | 2260 | 1.56 | 97.34 | 1.21 | 16.51 | 4.82 |
| | 2340 | 1.37 | 85.49 | 1.39 | 23.00 | 4.71 |
| †MT-1-1 | 1850 | 1.76 | 109.82 | 0.90 | 15.84 | 7.80 |
| | 2220 | 1.44 | 89.86 | 1.10 | 9.57 | 8.06 |
| | 2260 | 1.31 | 81.74 | 1.21 | 10.40 | 8.12 |
| | 2340 | 0.75 | 46.80 | 2.11 | 19.33 | 8.07 |
| †MT-1-2 | 1850 | 1.79 | 111.70 | 0.91 | 17.85 | 7.19 |
| | 2220 | 0.93 | 58.03 | 1.73 | 32.69 | 7.53 |
| | 2260 | 0.78 | 48.67 | 2.05 | 46.34 | 7.48 |
| | 2340 | 1.05 | 65.52 | 1.54 | 47.55 | 7.57 |
| †MT-1-3 | 1850 | 1.79 | 111.70 | 0.90 | 18.08 | 7.46 |
| | 2220 | 1.46 | 91.10 | 1.10 | 9.43 | 7.79 |
| | 2260 | 1.25 | 78.00 | 1.29 | 11.22 | 7.72 |
| | 2340 | 0.90 | 56.16 | 1.78 | 28.04 | 7.63 |
| †MT-1-4 | 1850 | 1.73 | 107.95 | 0.90 | 20.13 | 7.85 |
| | 2220 | 1.51 | 94.22 | 1.02 | 10.46 | 9.10 |
| | 2260 | 1.34 | 83.62 | 1.16 | 10.12 | 8.02 |
| | 2340 | 0.97 | 60.53 | 1.60 | 18.56 | 8.13 |
| †MT-1-5 | 1850 | 1.75 | 109.20 | 0.89 | 19.20 | 7.66 |
| | 2220 | 1.54 | 96.10 | 1.01 | 8.85 | 8.04 |
| | 2260 | 1.32 | 82.37 | 1.18 | 10.61 | 7.96 |
| | 2340 | 0.94 | 58.66 | 1.66 | 18.87 | 7.91 |
| †MT-1-6 | 1850 | 1.79 | 111.70 | 0.88 | 17.55 | 8.46 |
| | 2220 | 1.01 | 63.02 | 1.51 | 24.25 | 10.95 |
| | 2260 | 0.86 | 53.66 | 1.85 | 36.25 | 6.98 |
| | 2340 | 0.94 | 58.66 | 1.66 | 56.36 | 8.98 |
| †MT-1-7 | 1850 | 1.91 | 119.18 | 0.94 | 10.10 | 5.03 |
| | 2220 | 1.52 | 94.85 | 1.18 | 12.69 | 5.56 |
| | 2260 | 1.30 | 81.12 | 1.38 | 20.29 | 5.41 |
| | 2340 | 0.93 | 58.03 | 1.93 | 40.31 | 5.30 |

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TABLE 4.—*Bloating resulting from rapid firing of bricks in an electric kiln at various temperatures, continued*

| Sample No. | Temperature, degrees F. | Density | | Ratio of bloated to unfired vol. | Absorption, 5 hrs. boiling percent | Loss on ignition, percent |
|---|---|---|---|---|---|---|
| | | Grams per cc | lbs. per cu. ft. | | | |
| †MT-1-8 | 1850 | 1.87 | 116.60 | 0.94 | 13.70 | 5.47 |
| | 2220 | 1.49 | 92.93 | 1.18 | 15.03 | 5.71 |
| | 2260 | 1.34 | 83.62 | 1.31 | 16.72 | 5.72 |
| | 2340 | 0.99 | 61.78 | 1.77 | 37.69 | 5.71 |
| †MT-1-9 | 1850 | 1.75 | 109.20 | 0.96 | 18.87 | 5.18 |
| | 2220 | 1.62 | 101.09 | 1.04 | 13.64 | 5.59 |
| | 2260 | 1.84 | 114.82 | 0.92 | 9.30 | 5.51 |
| | 2340 | 1.04 | 64.90 | 1.62 | 35.42 | 5.55 |
| †MT-1-10 | 1850 | 1.80 | 112.32 | 0.96 | 17.01 | 5.70 |
| | 2220 | 1.31 | 81.74 | 1.32 | 20.41 | 6.04 |
| | 2260 | 1.56 | 97.34 | 1.11 | 13.90 | 5.77 |
| | 2340 | 0.82 | 113.57 | 2.09 | 54.92 | 6.04 |
| †MT-1-11 | 1850 | 1.79 | 111.70 | 0.94 | 17.66 | 6.00 |
| | 2220 | 1.53 | 95.47 | 1.11 | 14.50 | 6.06 |
| | 2260 | 1.82 | 113.57 | 0.93 | 6.27 | 5.90 |
| | 2340 | 0.94 | 58.66 | 1.80 | 42.41 | 6.14 |
| †MT-1-12 | 1850 | 1.84 | 114.82 | 0.94 | 16.19 | 5.47 |
| | 2220 | 1.32 | 82.37 | 1.31 | 25.52 | 6.52 |
| | 2260 | 1.47 | 91.73 | 1.17 | 19.21 | 6.14 |
| | 2340 | 0.75 | 46.80 | 2.27 | 74.90 | 7.90 |
| †MT-1-13 | 1850 | 1.78 | 111.70 | 0.98 | 17.88 | 4.77 |
| | 2220 | 1.48 | 92.35 | 1.19 | 19.24 | 4.86 |
| | 2260 | 1.59 | 99.22 | 1.03 | 14.31 | 4.83 |
| | 2340 | 0.90 | 56.16 | 1.96 | 53.40 | 4.98 |
| †MT-1-14 | 1850 | 1.80 | 112.32 | 0.99 | 17.13 | 4.26 |
| | 2220 | 1.46 | 91.10 | 1.21 | 21.46 | 4.42 |
| | 2260 | 1.78 | 111.07 | 1.00 | 13.48 | 4.36 |
| | 2340 | 1.47 | 91.73 | 1.21 | 14.17 | 4.51 |
| †MT-1-15 | 1850 | 1.82 | 113.57 | 1.01 | 15.86 | 3.66 |
| | 2220 | 1.99 | 124.18 | 0.92 | 7.11 | 3.87 |
| | 2260 | 1.98 | 123.55 | 0.92 | 8.99 | 3.88 |
| | 2340 | 1.28 | 79.87 | 1.43 | 28.59 | 3.69 |
| *NS-1 | 1850 | 1.97 | 122.90 | 0.90 | 8.48 | 6.20 |
| | 2170 | 1.40 | 87.40 | 1.08 | 15.51 | 9.73 |
| | 2230 | 1.14 | 71.10 | 1.46 | 25.53 | 8.38 |
| | 2290 | 0.86 | 53.70 | 1.94 | 33.95 | 7.64 |
| †OS-2-1 | 1850 | 1.83 | 114.19 | 0.89 | 15.36 | 8.25 |
| | 2220 | 1.20 | 74.88 | 1.35 | 15.84 | 8.58 |
| | 2300 | 0.96 | 59.90 | 1.69 | 30.39 | 8.60 |
| | 2340 | 0.88 | 54.91 | 1.84 | 36.32 | 8.33 |
| †OS-2-2 | 1850 | 1.82 | 113.57 | 0.88 | 15.95 | 9.02 |
| | 2220 | 0.53 | 33.07 | 3.00 | 93.96 | 9.15 |
| | 2300 | 0.25 | 15.60 | 6.38 | 142.01 | 10.93 |
| †OS-2-3 | 1850 | 1.81 | 112.94 | 0.90 | 16.59 | 8.42 |
| | 2220 | 1.12 | 69.89 | 1.45 | 19.25 | 8.82 |
| | 2300 | 0.73 | 45.55 | 2.22 | 53.40 | 8.89 |
| | 2340 | 0.65 | 40.56 | 2.51 | 53.90 | 8.52 |
| †OS-2-4 | 1850 | 1.77 | 110.45 | 0.89 | 18.16 | 9.17 |
| | 2220 | 1.11 | 69.26 | 1.42 | 16.70 | 9.49 |
| | 2300 | 0.82 | 51.17 | 1.93 | 42.43 | 9.43 |
| | 2340 | 0.71 | 44.30 | 2.22 | 55.64 | 9.78 |
| †OS-2-5 | 1850 | 1.78 | 111.07 | 0.90 | 18.31 | 10.88 |
| | 2220 | 1.19 | 74.23 | 1.38 | 14.17 | 8.48 |

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| | | | | | | |
|---|---|---|---|---|---|---|
| | 2300 | 0.92 | 57.41 | 1.78 | 29.17 | 8.40 |
| | 2340 | 0.81 | 50.54 | 2.00 | 42.62 | 8.46 |
| †OS-2-6 | 1850 | 1.79 | 111.70 | 0.88 | 17.23 | 9.24 |
| | 2220 | 1.06 | 66.14 | 1.49 | 19.12 | 9.59 |
| | 2300 | 0.76 | 47.42 | 2.12 | 42.09 | 8.08 |
| | 2340 | 0.75 | 46.80 | 2.08 | 46.21 | 10.94 |
| †OS-2-7 | 1850 | 1.88 | 117.31 | 0.91 | 12.58 | 7.37 |
| | 2220 | 0.90 | 56.16 | 1.90 | 36.88 | 8.29 |
| | 2300 | 0.54 | 33.70 | 3.17 | 69.35 | 8.35 |
| | 2340 | 0.69 | 43.06 | 2.49 | 86.72 | 7.98 |
| †OS-2-8 | 1850 | 1.76 | 109.82 | 0.98 | 17.88 | 5.63 |
| | 2220 | 1.19 | 74.26 | 1.44 | 33.87 | 5.90 |
| | 2300 | 0.98 | 61.15 | 1.75 | 44.67 | 6.00 |
| | 2340 | 0.82 | 51.17 | 2.08 | 75.00 | 6.36 |
| †OS-2-9 | 1850 | 1.73 | 107.95 | 1.00 | 19.08 | 4.24 |
| | 2220 | 1.71 | 106.70 | 1.00 | 11.93 | 4.64 |
| | 2260 | 1.60 | 99.84 | 1.08 | 13.02 | 4.60 |
| | 2340 | 1.10 | 68.64 | 1.56 | 46.31 | 4.84 |
| †OS-2-10 | 1850 | 1.76 | 109.82 | 0.98 | 17.90 | 5.25 |
| | 2220 | 1.48 | 92.35 | 1.17 | 20.02 | 5.29 |
| | 2260 | 1.36 | 84.86 | 1.27 | 22.59 | 5.32 |
| | 2340 | 1.03 | 64.27 | 1.69 | 52.89 | 5.19 |
| †OS-2-11 | 1850 | 1.74 | 108.58 | 1.00 | 18.66 | 4.43 |
| | 2220 | 1.69 | 105.46 | 1.02 | 13.56 | 4.90 |
| | 2260 | 1.54 | 96.10 | 1.12 | 17.40 | 4.84 |
| | 2340 | 1.07 | 66.77 | 1.62 | 49.95 | 4.92 |
| | | | *Pierre shale* | | | |
| *LO-2 | 1850 | 1.75 | 109.20 | 0.90 | 19.98 | 8.49 |
| | 2170 | 1.11 | 69.26 | 1.40 | 35.40 | 9.17 |
| | 2230 | 0.75 | 46.80 | 2.06 | 67.59 | 9.82 |
| | 2290 | 0.41 | 25.58 | 3.67 | 117.04 | 11.55 |
| ‡CH-6 | 1850 | 1.72 | 107.33 | 0.95 | 16.84 | 8.81 |
| | 2160 | 1.26 | 78.62 | 1.61 | 3.14 | 9.16 |
| | 2220 | 0.57+ | 35.57 | 2.84 | 22.44 | 9.11 |
| *PH-2 | Good Bentonitic material; test bars crumbled | | | | | |
| | | | **TERTIARY** | | | |
| | | | *Ogallala* | | | |
| *CH-5 | 1850 | 1.58 | 83.10 | 1.05 | 12.37 | 5.26 |
| | 2160 | 0.64 | 39.94 | 2.60 | 5.60 | 5.20 |
| | 2220 | 0.49 | 30.58 | 3.39 | 8.48 | 4.51 |
| | 2280 | 0.38 | 23.71 | 4.35 | 9.74 | 5.43 |
| ‡LE-1 | Good bentonitic materials; test bars crumbled | | | | | |
| ‡WC-1 | | | do | | | |
| | | | **QUATERNARY** | | | |
| | | | *Pleistocene* | | | |
| *A-6 | 2170 | 2.15 | 134.16 | 0.88 | 5.28 | 4.53 |
| | 2230 | 1.89 | 117.94 | 1.00 | 6.49 | 4.59 |
| | 2290 | 1.37 | 85.49 | 1.52 | 19.86 | 4.64 |
| *CR-5 | 1850 | 1.95 | 121.68 | 0.99 | 12.30 | 4.50 |
| | 2170 | 2.01 | 124.42 | 0.96 | 11.06 | 4.70 |
| | 2230 | 2.03 | 126.70 | 0.95 | 10.21 | 4.63 |
| | 2290 | 2.04 | 127.30 | 0.94 | 8.86 | 4.72 |
| *CR-8 | 1850 | 1.93 | 120.43 | 0.94 | 12.77 | 5.72 |
| | 2170 | 2.21 | 137.90 | 0.82 | 4.48 | 5.67 |
| | 2230 | 2.18 | 136.03 | 0.84 | 3.62 | 5.51 |
| | 2290 | 1.71 | 106.70 | 1.06 | 8.79 | 5.66 |
| †FR-1-A | 1850 | 1.92 | 119.81 | 0.99 | 13.79 | 3.91 |
| | 2160 | 2.10 | 131.04 | 0.91 | 7.23 | 3.97 |
| | 2220 | 2.11 | 135.41 | 0.90 | 4.23 | 4.06 |
| | 2260 | 1.63 | 101.71 | 1.17 | 15.74 | 3.92 |

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TABLE 4.—*Bloating resulting from rapid firing of bricks in an electric kiln at various temperatures, concluded*

| Sample No. | Temperature, degrees F. | Density Grams per cc | Density lbs. per cu. ft. | Ratio of bloated to unfired vol. | Absorption, 5 hrs. boiling percent | Loss on ignition, percent |
|---|---|---|---|---|---|---|
| †FR-1-B | 1850 | 1.93 | 120.43 | 1.00 | 13.64 | 3.45 |
| | 2160 | 2.07 | 129.17 | 0.93 | 8.51 | 3.55 |
| | 2220 | 2.10 | 131.04 | 0.92 | 6.26 | 3.56 |
| | 2260 | 1.86 | 116.06 | 1.04 | 10.49 | 3.48 |
| †FR-1-C | 1850 | 2.00 | 124.80 | 0.97 | 12.63 | 5.22 |
| | 2160 | 1.63 | 101.71 | 1.16 | 15.81 | 5.54 |
| | 2220 | 1.44 | 89.86 | 1.32 | 21.03 | 5.71 |
| | 2260 | 1.26 | 78.62 | 1.51 | 36.45 | 5.50 |
| †FR-2-A | 1850 | 1.91 | 119.18 | 1.01 | 13.35 | 3.64 |
| | 2160 | 2.02 | 126.05 | 0.94 | 9.63 | 3.85 |
| | 2220 | 2.11 | 131.66 | 0.90 | 6.09 | 3.63 |
| | 2260 | 1.97 | 122.93 | 0.97 | 6.56 | 3.69 |
| †FR-2-B | 1850 | 1.94 | 121.06 | 1.01 | 12.48 | 3.04 |
| | 2160 | 2.05 | 127.92 | 0.94 | 9.26 | 3.09 |
| | 2220 | 2.14 | 133.54 | 0.90 | 5.87 | 3.12 |
| | 2260 | 1.99 | 124.18 | 0.96 | 6.03 | 3.07 |
| *NN-6 | 1850 | 1.77 | 110.45 | 1.03 | 17.62 | 4.75 |
| | 2160 | 1.32 | 82.37 | 1.37 | 27.71 | 4.92 |
| | 2220 | 0.86 | 53.66 | 2.12 | 42.84 | 4.96 |
| | 2280 | 0.70 | 43.68 | 2.60 | 37.54 | 5.01 |
| *NN-6 | 1850 | 1.77 | 110.45 | 1.03 | 17.62 | 4.75 |
| and | 2160 | 1.73 | 107.95 | 0.99 | 4.44 | 4.54 |
| gypsum | 2220 | 1.06 | 66.14 | 1.61 | 15.89 | 4.34 |
| | 2280 | 0.84 | 52.41 | 2.03 | 11.31 | 4.11 |
| ‡S-17 | 1850 | 1.66 | 103.58 | 1.13 | 18.84 | 4.95 |
| | 2160 | 2.10 | 131.04 | 0.89 | 7.13 | 5.08 |
| | 2220 | 2.05 | 127.92 | 0.91 | 6.26 | 5.16 |
| | 2280 | 1.49 | 92.98 | 1.25 | 19.45 | 5.26 |
| †SG-1-A | 1850 | 1.82 | 113.57 | 1.00 | 17.06 | 4.74 |
| | 2160 | 2.09 | 130.42 | 0.87 | 8.00 | 4.75 |
| | 2220 | 2.08 | 129.79 | 0.87 | 4.77 | 4.82 |
| | 2260 | 1.67 | 104.21 | 0.86 | 13.66 | 4.78 |
| SG-1-B† | 1850 | 1.92 | 119.81 | 1.02 | 13.96 | 2.68 |
| | 2160 | 2.00 | 124.80 | 0.98 | 11.13 | 2.88 |
| | 2220 | 2.03 | 126.67 | 0.96 | 9.12 | 2.80 |
| | 2260 | 2.07 | 129.17 | 0.95 | 6.36 | 2.86 |
| *SG-2 | 2160 | 1.94 | 121.06 | 0.98 | 12.76 | 2.54 |
| | 2220 | 1.99 | 124.18 | 0.95 | 10.45 | 2.46 |
| | 2260 | 2.06 | 128.54 | 0.92 | 6.76 | 2.49 |

* Details of location and description of material sampled are given in Table 2.
‡ Details of location, stratigraphy, and thickness of beds given in Table 5.
† Part of a composite sample reported in Table 2. Location, stratigraphy, and thickness of beds given in Table 5.

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**TABLE 5.**—*Location, stratigraphic position, and thickness of beds for samples reported in Table 4 but not in Table 2*

| Sample No. | County | Location | Stratigraphic position | Depth below top of section, feet | Thickness, feet |
|---|---|---|---|---|---|
| | | | **Pennsylvanian** | | |
| DN-4-1 | Doniphan | Cen. W½ SW 33-3-22 E. | Lawrence shale | 12 to 25 | 13 |
| DN-4-2 | do | do | do | 7 to 12 | 5 |
| DN-4-3 | do | do | do | 0 to 7 | 7 |
| JN-8 | Johnson | SW SW 7-13-25 E. | Lane shale | 50 to 70 | 20 |
| OG-2 | Osage | 7-15-14 E. | Auburn shale | | |
| OG-3 | do | 22-16-14 E. | Aarde shale | | |
| OG-4 | do | 12-15-13 E. | Pierson Point shale | | 15 |
| OG-5 | do | 12-18-14 E. | Upper Topeka limestone | | 2 |
| OG-6 | do | 35-16-14 E. | Upper Severy shale | | 20 |
| OG-7 | do | 35-16-15 E. | Middle & lower Severy shale | | 20 |
| OG-8 | do | SE SW 17-16-15 E. | Severy shale | | 47 |
| | | | **Permian** | | |
| BR-4 | Brown | SE NE 22-2-16 E. | Towle-Hawxby shale | | 20 |
| M-2 | Marion | SW SW 29-19-2 E. | Wellington formation | | 10 |
| M-5 | do | SW SE 34-21-1 E. | do | | 14 |
| M-8 | do | NE NE 21-18-1 E. | do | | 15 |
| SU-1 | Sumner | SE NE 21-31-2 W. | do | | 5 |
| SU-2 | do | SW NW 26-32-1 W. | do | | 11 |
| SU-3-1 | do | SW NW 27-32-1 W. | do | 9 to 21 | 12 |
| SU-3-2 | do | do | do | 2 to 9 | 7 |
| S-19-1 | Saline | SE 18-14-2 W. | do | | 10 |
| | | | **Cretaceous** | | |
| CL-6-1 | Clark | NW NW 18-32-22 W. | Kiowa shale | 39 to 41 | 3 |
| CL-6-2 | do | do | do | 35 to 39 | 4 |
| CL-6-3 | do | NW NW 18-31-22 W. | do | 30 to 35 | 4 |
| CL-6-4 | do | do | do | 25 to 30 | 5 |
| CL-6-5 | do | do | do | 22 to 25 | 3 |
| CL-6-6 | do | do | do | 19 to 22 | 3 |
| CL-6-7 | do | do | do | 15 to 19 | 5 |
| CL-6-8 | do | do | do | 12 to 15 | 3 |
| CL-6-9 | do | do | do | 9 to 12 | 3 |
| K-3-1 | Kiowa | SW NW 33-29-16 W. | do | 85 to 90 | 5 |
| K-3-2 | do | do | do | 79 to 85 | 6 |
| K-3-3 | do | do | do | 74 to 79 | 5 |
| K-3-4 | do | do | do | 69 to 74 | 5 |
| K-3-5 | do | do | do | 63 to 69 | 6 |



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TABLE 5.—*Location, stratigraphic position, and thickness of beds given for samples reported in Table 4 but not in Table 2, continued*

| Sample No. | County | Location | Stratigraphic position | Depth below top of section, feet | Thickness, feet |
|---|---|---|---|---|---|
| K-3-6 | do | do | do | 58 to 63 | 5 |
| K-3-7 | do | do | do | 53 to 58 | 5 |
| K-3-8 | do | do | do | 48 to 53 | 5 |
| K-3-9 | do | do | do | 42 to 48 | 6 |
| K-3-10 | do | do | do | 37 to 42 | 5 |
| K-3-11 | do | do | do | 32 to 37 | 5 |
| K-3-12 | do | do | do | 26 to 32 | 6 |
| K-3-13 | do | do | do | 21 to 26 | 5 |
| K-3-14 | do | do | do | 16 to 21 | 5 |
| K-3-15 | do | do | do | 10 to 16 | 6 |
| M-7 | Marion | SW SE 21-18-1 E. | do | | 5 |
| D-1 | Dickinson | SE SW 22-16-1 E. | Dakota formation | 7 to 12 | 5 |
| D-2 | do | SW SE 24-16-2 E. | do | 10 to 16 | 6 |
| ES-3-1 | Ellis | Cen. NW 24-11-17 W. | Blue Hill shale | 120.0 to 125.3 | 5.3 |
| ES-3-2 | do | do | do | 114.7 to 120.0 | 5.3 |
| ES-3-3 | do | do | do | 109.4 to 114.7 | 5.3 |
| ES-3-4 | do | do | do | 104.1 to 109.4 | 5.3 |
| ES-3-5 | do | do | Blue Hill shale | 98.8 to 104.1 | 5.3 |
| ES-3-6 | do | do | do | 93.5 to 98.8 | 5.3 |
| ES-3-7 | do | do | do | 88.2 to 93.5 | 5.3 |
| ES-3-8 | do | do | do | 82.9 to 88.2 | 5.3 |
| ES-3-9 | do | do | do | 77.6 to 82.9 | 5.3 |
| ES-3-10 | do | do | do | 72.3 to 77.6 | 5.3 |
| ES-3-11 | do | do | do | 67.0 to 72.3 | 5.3 |
| ES-3-12 | do | do | do | 61.7 to 67.0 | 5.3 |
| ES-3-13 | do | do | do | 56.4 to 61.7 | 5.3 |
| ES-3-14 | do | do | do | 51.1 to 56.4 | 5.3 |
| ES-3-15 | do | do | do | 45.8 to 51.1 | 5.3 |
| ES-3-16 | do | do | do | 40.5 to 45.8 | 5.3 |
| ES-3-17 | do | do | do | 35.2 to 40.5 | 5.3 |
| ES-3-18 | do | do | do | 29.9 to 35.2 | 5.3 |
| ES-3-19 | do | do | do | 24.6 to 24.9 | 5.3 |
| ES-3-20 | do | do | do | 19.3 to 24.6 | 5.3 |
| ES-3-21 | do | do | do | 14.0 to 19.3 | 5.3 |
| ES-4-1 | do | NE NE 8-15-20 W. | do | 15.0 to 20.9 | 5.3 |
| ES-4-2 | do | do | do | 10.3 to 15.6 | 5.3 |
| ES-4-3 | do | do | do | 5.0 to 10.3 | 5.3 |



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| | | | | | |
|---|---|---|---|---|---|
| ES-4-4 | do | do | do | 20 ft. above ES-4-3 | 5.3 |
| ES-4-4 | do | SW SE 8-15-20 W. | do | 45.8 to 40.3 | 5.3 |
| ES-4-5 | do | do | do | 35.8 to 40.3 | 5.3 |
| ES-4-6 | do | do | do | 30.5 to 35.8 | 5.3 |
| ES-4-7 | do | do | do | 19.9 to 30.5 | 10.6 |
| ES-4-8 | do | do | do | 14.6 to 19.9 | 5.3 |
| ES-4-9 | do | do | do | 9.3 to 14.6 | 5.3 |
| ES-4-10 | do | do | do | 4.0 to 9.3 | 5.3 |
| ES-4-11 | do | NE SE 8-15-20 W. | Blue Hill shale | 5.3 above ES-4-10 | 5.3 |
| ES-4-11 | do | do | do | 40.8 to 46.3 | 5.3 |
| ES-4-12 | do | do | do | 35.5 to 40.8 | 5.3 |
| ES-4-13 | do | do | do | 30.2 to 35.5 | 5.3 |
| ES-4-14 | do | do | do | 25.9 to 30.2 | 5.3 |
| ES-4-15 | do | do | do | 20.6 to 25.9 | 5.3 |
| ES-4-16 | do | do | do | 15.3 to 20.6 | 5.3 |
| ES-4-17 | do | do | do | 10.0 to 15.3 | 5.3 |
| FY-2-1 | Finney | N½ NE 2-22-29 W. | do | 131.6 to 136.9 | 5.3 |
| FY-2-2 | do | do | do | 126.3 to 131.6 | 5.3 |
| FY-2-3 | do | do | do | 121.0 to 126.3 | 5.3 |
| FY-2-4 | do | do | do | 115.7 to 121.0 | 5.3 |
| FY-2-5 | do | do | do | 110.4 to 115.7 | 5.3 |
| FY-2-6 | do | do | do | 105.1 to 110.4 | 5.3 |
| FY-2-7 | do | do | do | 99.8 to 105.1 | 5.3 |
| FY-2-8 | do | do | do | 94.5 to 99.8 | 5.3 |
| FY-2-9 | do | do | do | 89.2 to 94.5 | 5.3 |
| FY-2-10 | do | do | do | 83.9 to 89.2 | 5.3 |
| FY-2-11 | do | do | do | 78.6 to 83.9 | 5.3 |
| FY-2-12 | do | do | do | 73.3 to 78.6 | 5.3 |
| FY-2-13 | do | do | do | 68.0 to 73.3 | 5.3 |
| FY-2-14 | do | do | do | 62.7 to 68.0 | 5.3 |
| FY-2-15 | do | do | do | 57.4 to 62.7 | 5.3 |
| FY-2-16 | do | do | do | 52.1 to 57.4 | 5.3 |
| FY-2-17 | do | do | do | 46.8 to 52.1 | 5.3 |
| FY-2-18 | do | do | do | 41.5 to 46.8 | 5.3 |
| FY-2-19 | do | do | do | 36.2 to 41.5 | 5.3 |
| FY-2-20 | do | do | do | 30.9 to 36.2 | 5.3 |
| FY-2-21 | do | do | do | 25.6 to 30.9 | 5.3 |
| FY-2-22 | do | do | do | 20.3 to 25.6 | 5.3 |
| FY-2-23 | do | do | do | 15.0 to 20.3 | 5.3 |
| MT-1-1 | Mitchell | NW NW 26-8-10 W. | do | 88.9 to 94.2 | 5.3 |
| MT-1-2 | do | do | do | 83.6 to 88.9 | 5.3 |
| MT-1-3 | do | do | do | 78.3 to 83.6 | 5.3 |
| MT-1-4 | do | do | do | 73.0 to 78.3 | 5.3 |
| MT-1-5 | do | do | do | 67.7 to 73.0 | 5.3 |



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TABLE 5.—*Location, stratigraphic position, and thickness of beds given for samples reported in Table 4 but not in Table 2, concluded*

| Sample No. | County | Location | Stratigraphic position | Depth below top of section, feet | Thickness, feet |
|---|---|---|---|---|---|
| MT-1-6 | do | do | do | 62.4 to 67.7 | 5.3 |
| MT-1-7 | do | do | do | 57.1 to 62.4 | 5.3 |
| MT-1-8 | do | do | do | 51.8 to 57.1 | 5.3 |
| MT-1-9 | do | do | do | 46.5 to 51.8 | 5.3 |
| MT-1-10 | do | do | do | 41.2 to 46.5 | 5.3 |
| MT-1-11 | do | do | do | 35.9 to 41.2 | 5.3 |
| MT-1-12 | do | do | do | 30.6 to 35.9 | 5.3 |
| MT-1-13 | do | do | do | 25.3 to 30.6 | 5.3 |
| MT-1-14 | do | do | do | 20.0 to 25.3 | 5.3 |
| MT-1-15 | do | do | do | 14.7 to 20.0 | 5.3 |
| OS-2-1 | Osborne | Cen. SW 12-7-15 W. | do | 53.0 to 58.3 | 5.3 |
| OS-2-2 | do | do | do | 47.7 to 53.0 | 5.3 |
| OS-2-3 | do | do | do | 42.4 to 47.7 | 5.3 |
| OS-2-4 | do | do | do | 37.1 to 42.4 | 5.3 |
| OS-2-5 | do | do | do | 31.8 to 37.1 | 5.3 |
| OS-2-6 | do | do | do | 26.5 to 31.8 | 5.3 |
| OS-2-7 | do | do | do | 21.2 to 26.5 | 5.3 |
| OS-2-8 | do | do | do | 15.9 to 21.2 | 5.3 |
| OS-2-9 | do | do | do | 10.6 to 15.9 | 5.3 |
| OS-2-10 | do | do | do | 5.3 to 10.6 | 5.3 |
| OS-2-11 | do | do | do | 0.0 to 5.3 | 5.3 |
| CH-6 | Cheyenne | SW NW 29-3-40 W. | Pierre shale | | 10 |
| | | **Tertiary** | | | |
| LE-1 | Lane | SW NW 23-16-27 W. | Ogallala formation | | 8 |
| WC-1 | Wallace | Cen. SW 19-12-41 W. | do | | 10 |
| | | **Pleistocene** | | | |
| FR-1-A | Franklin | NE NE 14-16-20 E. | Terrace deposits | 2 to 5 | 3 |
| FR-1-B | do | do | do | 5 to 10 | 5 |
| FR-1-C | do | do | do | 10 to 12 | 2 |
| FR-2-A | do | SE SW 1-16-20 E. | do | 0.0 to 3.3 | 3.3 |
| FR-2-B | do | do | do | 3.3 to 7.5 | 4.2 |
| S-17 | Saline | NE NE 28-14-3 W. | Sanborn formation | | 10 |
| SG-1-A | Sedgwick | SW SW 3-18-1 W. | Terrace deposits | 0.5 to 6.0 | 5.5 |
| SG-1-B | do | do | do | 6.0 to 10.5 | 4.5 |



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sylvanian shales can be bloated to some extent. Those that are considered nonbloaters are usually extremely sandy or silty.

The bloating characteristics of the Pennsylvanian shales are obviously affected to a great extent by the length of time they have been exposed to weathering conditions. The chief evidence of weathering is the change of color from some shade of gray to limonitic yellow, due to oxidation of iron compounds. Doubtless other chemical or mineralogical changes take place during weathering, but their exact nature is not known. In most cases the weathered shales bloat much less readily than the unweathered material from the same formation. This characteristic of Pennsylvanian shales is well known to the brick and tile manufacturers of the State. Inasmuch as bloating must be avoided in the burning of these products for their purposes, the oxidized zone, in some cases as much as 20 feet thick, is preferred to the gray unoxidized shale. If the unoxidized unweathered shale is used for the manufacture of brick, tile, or sewer pipe a great deal of care is exercised in firing or burning to insure complete oxidation in the kilns.

The Pennsylvanian rocks are discussed under group headings. Areas in which these groups crop out in eastern Kansas are shown in Figure 1.

*Cherokee group.*—All the exposed Pennsylvanian rocks in Kansas below the base of the Fort Scott limestone are classed as the Cherokee group (Moore, 1949). Rocks of Cherokee age crop out in Cherokee, Crawford, Bourbon, and Labette Counties (Fig. 1). These deposits, whose average total thickness is about 400 feet, are composed predominantly of shale, much of which is clayey and probably susceptible to being bloated into a lightweight aggregate. In proportion to the total amount of shale available in the Cherokee group, relatively few shale samples were tested because unweathered natural exposures of the shale are almost completely lacking. Man-made exposures such as those found in the strip pits in the coal mining area are restricted in stratigraphic position. Samples CK-7 and CR-7 indicate that some of the Cherokee shale has very good bloating characteristics, producing an aggregate of low density without sticking in the kiln at moderate temperatures. Other samples, especially oxidized ones, produced a rather dense aggregate.

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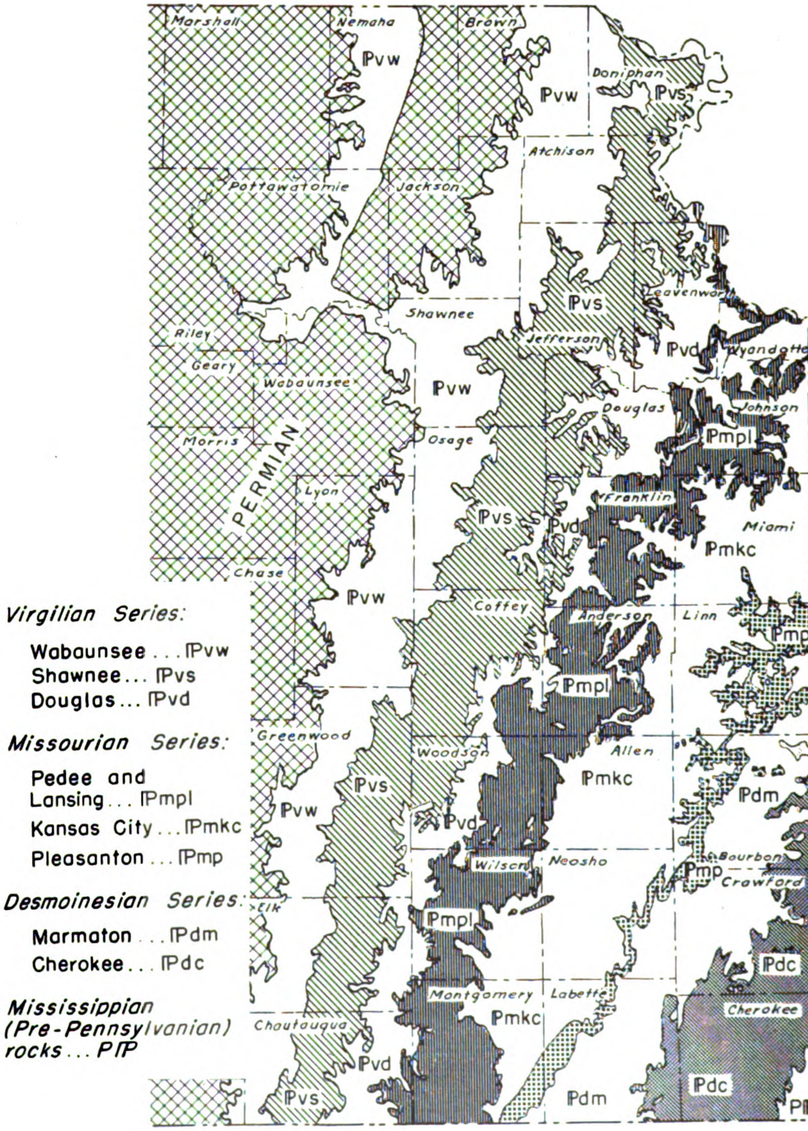


FIG. 1.—Geologic map of eastern Kansas showing distribution of Pennsylvania rocks (by groups).

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*Marmaton group.*—No shales were sampled from the Marmaton group because at all the exposures examined the shales were either too thin or too sandy. One or more of the prominent limestones in the Marmaton rocks usually dominate on the exposures or occur above the shales as an overburden too thick and hard to be removed economically.

*Pleasanton group.*—Shale is the predominant type of rock in the Pleasanton group. The shale tends to be light gray to yellowish gray, and although sandy or silty in places thick beds of rather pure clay shale are common. Equivalent beds in the southern part of the outcrop area are classed as part of the Coffeyville formation (Moore, 1949). Sample MG-3 from the shale pit of the Ludowici-Celadon Company at Coffeyville is a bloating shale from the Coffeyville formation. Location LN-1 near Mound City in Linn County includes two samples of equivalent shale from the Pleasanton group. The Linn County samples do not bloat as easily as the Coffeyville sample. We believe the difference is due chiefly to the degree of weathering. The shale pit sample from Coffeyville (MG-3) is largely unoxidized.

*Kansas City group.*—The Bronson rocks representing the lower part of the Kansas City group were not sampled for this investigation owing to the predominance of limestones and sandy or silty shales. In the Linn subgroup of the Kansas City the Fontana, Wea, and Quivira are bloating shales of some importance. In the northern part of the outcrop area the Fontana and the Wea are separated by the thin Block limestone. Sample JN-7 from eastern Johnson County includes both the Wea and Fontana shales. Farther south the three shales are not readily separable and are classified as the Cherryvale formation. A 70-foot section of Cherryvale (MG-4) was measured and sampled north of the town of Cherryvale in Montgomery County. The total thickness in this area is reported to be more than 100 feet. Despite the distance separating the outcrops samples JN-7 and MG-4 proved to be very similar in the bloating tests. These shales are not entirely uniform, however, as might be concluded from the samples mentioned. The Fontana and Wea beds as exposed north of Osawatomie are too silty to be good bloating shales. At other exposures in Miami and Johnson Counties the Wea and Fontana are seemingly rather pure clay shales that should be entirely suitable for the production of lightweight

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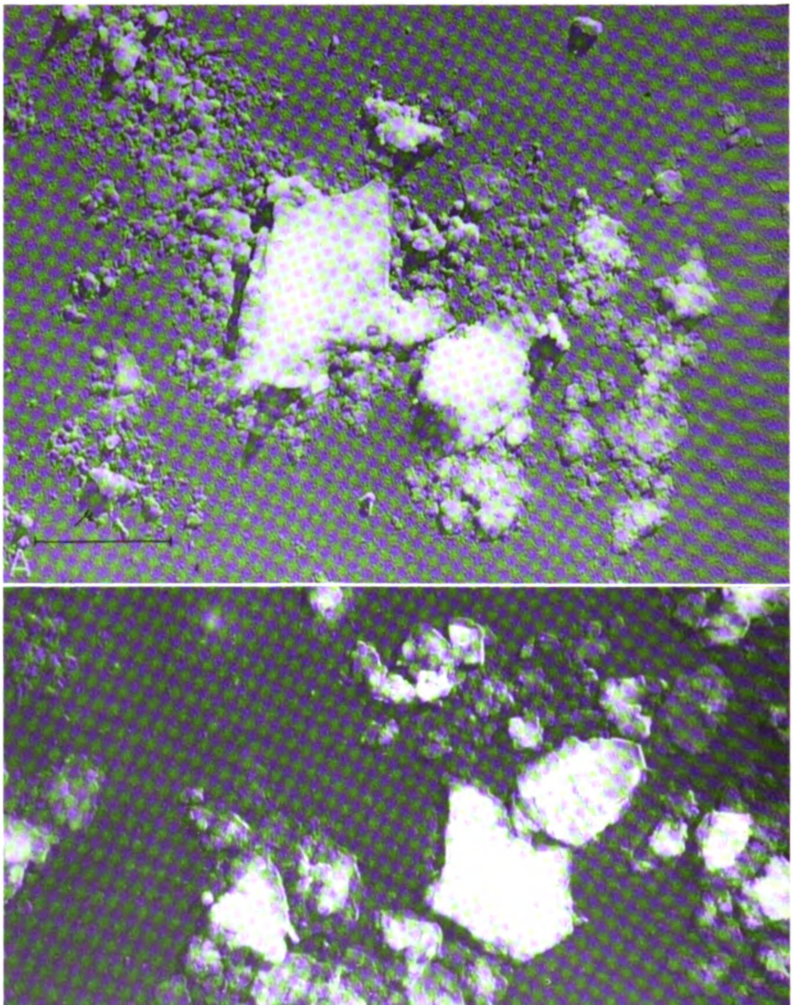

PLATE 3. Electron micrographs of the less-than-1-micron fraction of illitic shales. *A,* Reference sample of illite from Fithian, Illinois; magnification 18,000 X. *B,* Langdon shale (Pennsylvanian) from Lyon County; magnification 18,000 X. Electron micrographs by C. C. McMurtry, Department of Oncology, University of Kansas Medical School. Preparation was shadow cast with 120 A of chromium at an angle of 18°.

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aggregate, but the shales are badly weathered and completely oxidized on the outcrop, and for that reason were not sampled.

The Lane shale and the Bonner Springs shale occur in the upper part of the Kansas City group (Zarah subgroup). The Lane shale ranges from 15 to 110 feet in thickness, but where sufficiently clayey to be used for the production of lightweight aggregate it is not more than 35 feet in thickness. In the thicker sections most of the shale is sandy. The Bonner Springs consists of 10 to 25 feet of buff or gray shale, the lower part of which is usually sandy. The Wyandotte limestone, which lies between the Lane and Bonner Springs shales, pinches out south of Franklin County and the entire section is known as the Lane-Bonner Springs shale. On most outcrops the Lane and Bonner Springs shales are weathered and oxidized to a considerable extent. Samples from such outcrops bloated very little. Other samples taken from unweathered or only slightly weathered exposures proved to be good bloaters. The unweathered samples were taken in a railroad cut (Lane shale, JN-5), from a cement plant quarry (Lane shale, WY-6), from an abandoned brick plant pit at Iola (Lane-Bonner Springs shale, AL-1), and from the shale pit of the Humboldt Brick and Tile Company (Lane-Bonner Springs shale, AL-2). Samples WY-6 and AL-2 were rather silty in appearance, but nevertheless a low density aggregate was produced from them as can be seen from the data in Table 2.

*Lansing group.*—In the Lansing group only the Vilas shale was sampled. Although this shale averages about 15 feet in thickness in the northern part of the outcrop area, abrupt changes in thickness are characteristic of the Vilas. In the shale pit (LV-5) and the quarry (LV-6) at Kansas State Prison at Lansing, the Vilas is 20 to 24 feet in thickness. North of Garnett in Anderson County (AN-2) this shale is only about 6 feet thick, but east of Colony (AN-3) 14 feet was sampled. All four of the above samples, only slightly weathered and oxidized, have excellent bloating characteristics. Farther south much reddish-brown soft sandstone and sandy shale occur locally in the Vilas. This shale in all exposures examined by us in the southern part of the State was judged to be unsuitable for the production of lightweight aggregate, although a more detailed exploration doubtless would reveal some usable shale.

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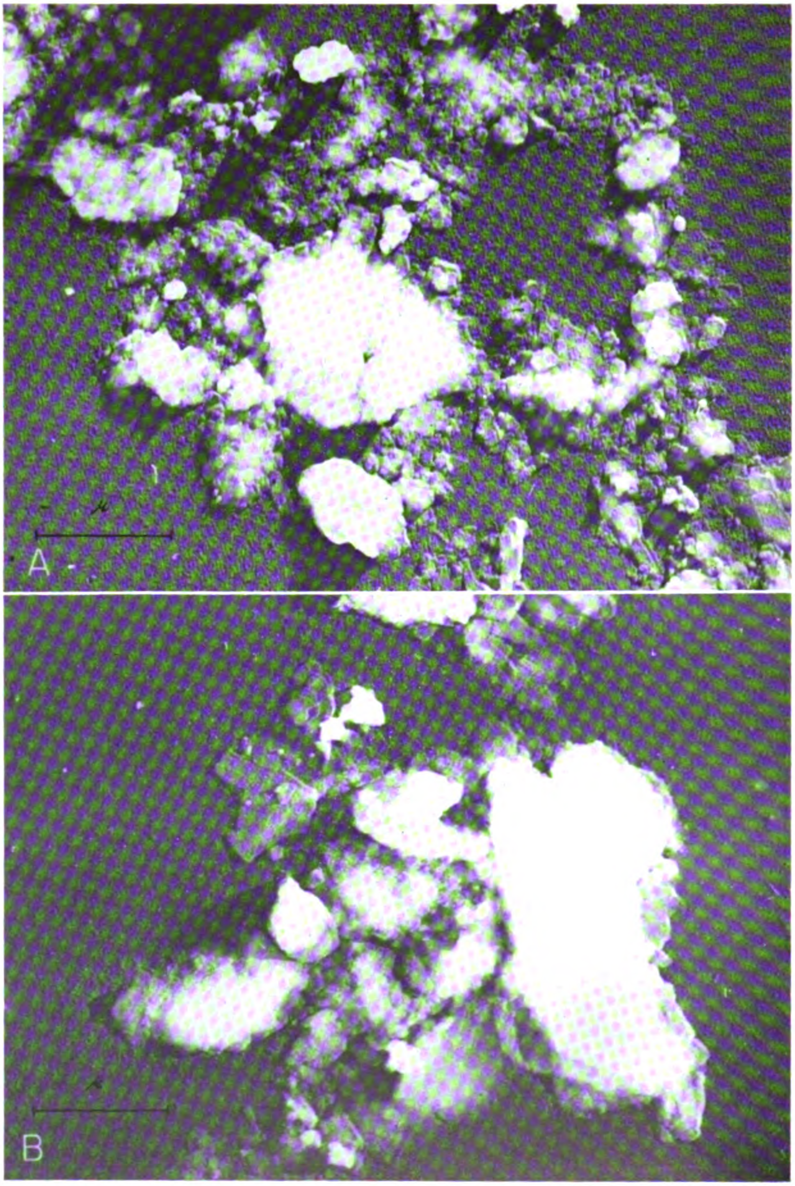


PLATE 4. Electron micrographs of the less-than-1-micron fraction of illitic Pennsylvanian shales. *A*, Coffeyville shale from Montgomery County; magnification 18,000 X. *B*, Cherokee shale from Cherokee County; magnification 18,000 X. Electron micrographs by C. C. McMurtry, Department of Oncology, University of Kansas Medical School. Preparation was shadow cast with 120 A of chromium at an angle of 18°.

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*Pedee group.*—The Weston shale (Pls. 5B and 7C) comprises the greater part of the Pedee group. The upper formation of the Pedee group, the Iatan limestone, is recognized only north of Kansas River (Moore, 1949). In places both the Iatan and the Weston are missing due to erosion after the deposition of Pedee beds. In such cases sandstone and conglomerate have replaced the Iatan and Weston. In some places the Weston shale is as much as 200 feet thick. Unoxidized samples of Weston from relatively unweathered exposures were easily bloated to produce a low density lightweight aggregate, as shown by the data on samples FR-3, FR-5, FR-6, LV-4, MG-1, and WL-1. The last sample, WL-1, was obtained from the shale pit of the Excelsior Brick and Tile Company at Fredonia, and was completely unweathered and unoxidized. The density of the aggregate after crushing but before grading was only 28 pounds per cubic foot. The bulk density of partially oxidized samples ranged from 41 to 51 pounds per cubic foot. In cases where the shale was mostly light gray and yellow showing rather complete oxidation the bulk density of the ungraded aggregate ran about 55 pounds to the cubic foot. If correctly sized and graded such materials will have a bulk density of about 65 pounds per cubic foot.

The Weston shale is one of the better Pennsylvanian shales as far as the production of lightweight aggregate is concerned. Available thicknesses ranging from 40 to 80 feet are common. The shale seems to be uniform in its characteristics across the entire outcrop belt, and in many places overburden is nearly lacking or of moderate thickness.

The Weston shale is now being used by the Carter-Waters Corporation for the production of Haydite at New Market, Missouri. This is a few miles east of Atchison County, Kansas.

*Douglas group.*—Shales of the Douglas group sampled include the Vinland and Robbins shales (Stranger formation) and shale in the Lawrence formation. According to Moore (1949, p. 133) the Vinland shale consists of 9 to 50 feet of gray argillaceous, calcareous, or sandy shale, and locally some sandstone. The Vinland shale was sampled at only one locality (DG-15) south of Vinland, Kansas, where 20 feet of clay shale is exposed. The shale sample was mostly oxidized and produced a rather heavy

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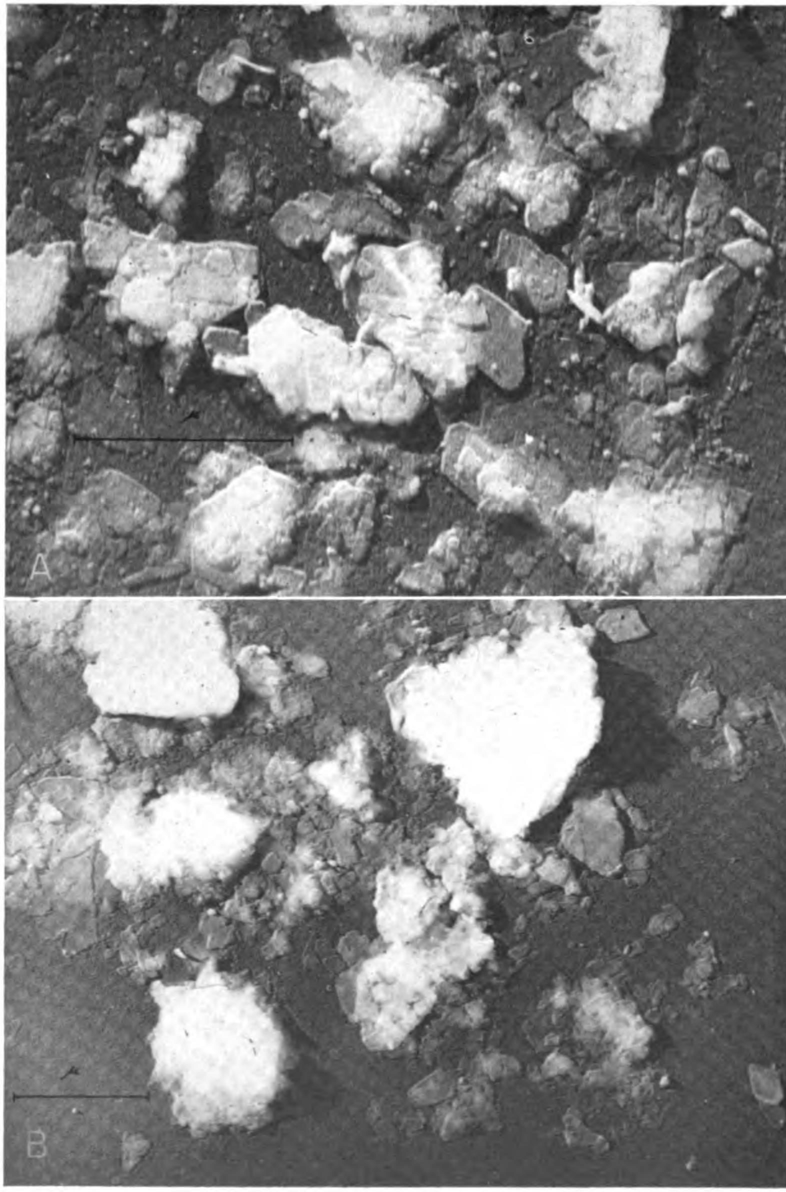


**Plate 5.** Electron micrographs of the less-than-1-micron fraction of illitic (and kaolinitic?) Pennsylvanian shales. *A,* Severy shale from **Elk** County; magnification 29,000 X. *B,* Weston shale from Franklin County; magnification 18,000 X. Electron micrographs by C. C. McMurtry, Department of Oncology, University of Kansas Medical School. Preparation was shadow cast with 120 A of chromium at an angle of 18°.

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(54 and 67 pounds) aggregate. The unoxidized shale should produce a lighter product.

The only sample of Robbins shale tested was taken in Elk County (EK-1), where the entire thickness of 22 feet is exposed. This sample produced an aggregate of unusually low density and apparently of high grade. The Robbins shale is restricted to areas southward from Woodson County. The total thickness of the shale ranges from a featheredge to 110 feet.

A number of exposures of Lawrence shale were examined in order to obtain unweathered samples of clay shale, but in most cases the shale is deeply weathered and poorly exposed. Samples of Lawrence shale that were only partially oxidized to limonitic yellow bloated normally. These include DN-4 and WL-2. Sample DG-14 was taken from a weathered exposure where the shale was mostly yellow. A heavier type of lightweight aggregate suitable for load-bearing concrete was produced from these materials.

The Lawrence formation is comprised largely of shale, but sandstone, shaly siltstone, limestone, and coal are also found in this unit. Details of the lithology are lacking because of poor exposures, but near Vinland where sample DG-14 was taken a clay shale at least 20 feet in thickness occurs near the top of the Lawrence formation. The total thickness of the Lawrence formation at measured exposures ranges from 40 to 175 feet. Doubtless this formation offers an abundant source of raw material for the production of lightweight aggregate, but in most localities satisfactory exploration would be possible only by drilling.

*Shawnee group.*—These shale members of the Shawnee group were sampled for testing: Jackson Park, Heumader-Jackson Park, Stull, and Calhoun. The Jackson Park shale where sampled near Atchison (A-8) is an unoxidized gray clayey shale. It bloats easily, and is entirely suitable for the production of a lightweight aggregate. Although the bed is rather thin in many places it reaches a maximum of more than 50 feet along Kansas River (Moore, 1949). Shale assigned to the Heumader-Jackson Park interval was sampled in Elk County (EK-2). The bloated shale was rather heavy, probably due to the fact that the shale was oxidized.

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The Stull and the Calhoun shales contain a great deal of sand and sandy shale, but fairly thick zones of sufficiently pure shale occur in these beds in some of the outcrops examined. The Stull shale where sampled in Woodson County (WD-2) is almost completely oxidized to a limonitic yellow, and a rather heavy aggregate was produced from it. It is possible that the unoxidized material would work satisfactorily. The Calhoun shale was sampled north of Kansas River just east of Topeka. At this outcrop about 30 feet of sand and sandy shale overlies the clayey part sampled (SH-2) plus several feet of the Topeka limestone. It is probable that the usable portion of the shale could be found in deposits where the overburden is thin enough for economical mining. Although somewhat silty in appearance the sample (SH-2) of the Calhoun shale produced a lightweight aggregate with about the optimum density (Table 2).

*Wabaunsee group.*—Normally the rocks of the Wabaunsee group total about 500 feet in thickness. Shales are prominent in this group, but much of the shale is sandy, and at several horizons there are extensive sandstones. Portions of these shale beds, and in some cases the entire thickness, are sufficiently clayey to produce a good lightweight aggregate. The shales sampled include the Severy, Aarde, White Cloud, Silver Lake, Auburn, Harveyville, Willard, Pierson Point, Willard-Langdon, Langdon, Dry, French Creek, and the Caneyville-Pony Creek. Most of these shales, except where completely oxidized, bloated to a lightweight material of sufficiently low density (Table 2).

We were able to obtain only one unweathered sample of the Severy shale (EK-5). This sample included the upper 22 feet of a possible 40 feet of usable shale. Despite the fact that the shale is very silty it bloated into a lightweight product at 2180° F.

The one sample of White Cloud shale tested was partially oxidized and produced a heavier than average aggregate (EK-4). This shale was in part rather silty, but it is possible that a lighter aggregate can be produced from unoxidized material. The total thickness of the White Cloud shale ranges from 30 to 80 feet. Ten feet of a possible 35 feet of Silver Lake shale was sampled in Greenwood County (GW-1). One of our lightest aggregates was produced from this sample.

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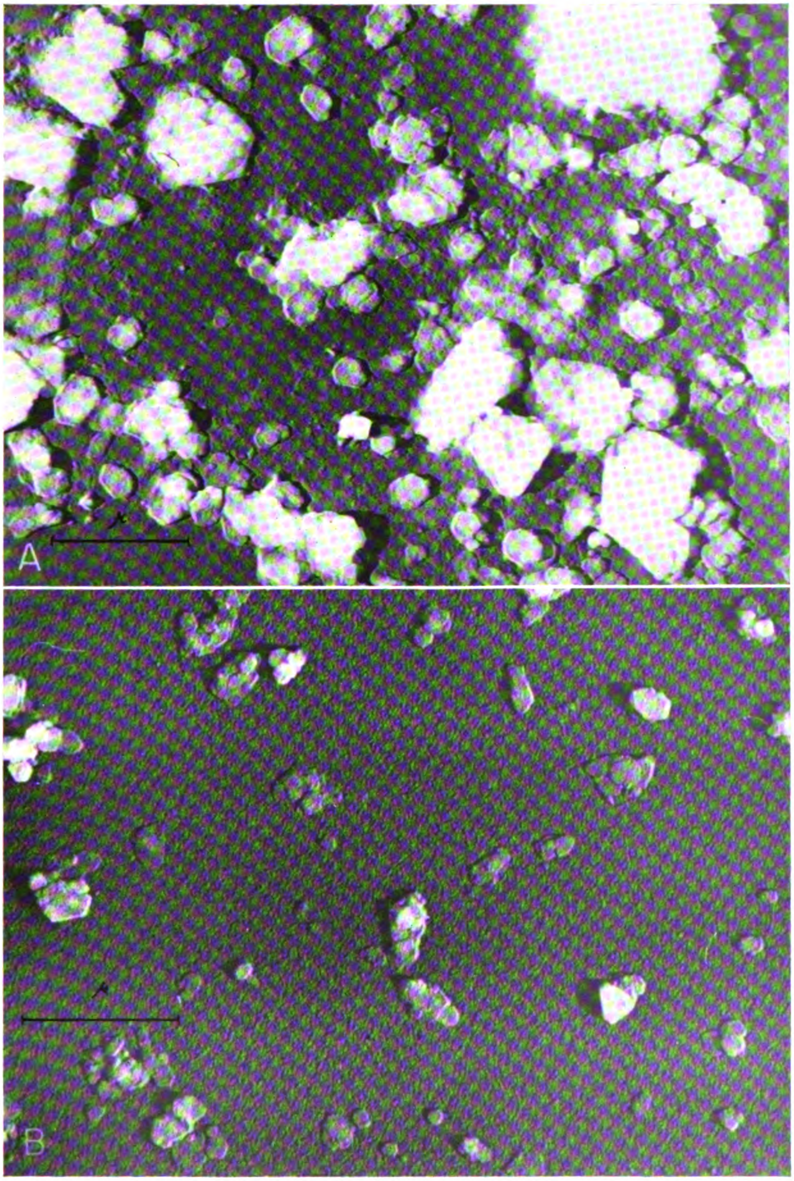


**Plate 6.** Electron micrographs of the less-than-1-micron fraction of kaolinitic clays. *A*, Kaolinite from Macon, Georgia; magnification 18,000 X. *B*, Dakota formation clay from Ellsworth County; magnification 21,000 X. Electron micrographs by C. C. McMurtry, Department of Oncology, University of Kansas Medical School. Preparation was shadow cast with 120 A of chromium at an angle of 18°.

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Two samples of Willard shale were tested, both from Brown County. Sample BR-5 included 12 feet of the lower part of the Willard shale and was mostly oxidized on the exposure. The aggregate produced weighed 47 and 54 pounds per cubic foot. Sample BR-6 from the upper part of the Willard was mostly unoxidized and produced a much heavier aggregate, weighing 49 and 58 pounds per cubic foot. This seems to be a reversal of the usual relationship of oxidized to unoxidized shale, but further tests would probably reveal that the lower part of the Willard is superior to the upper in bloating characteristics, and that an unoxidized sample of the lower Willard would produce an aggregate below the average in density.

The two samples of Harveyville shale that were tested produced aggregates somewhat above the average in unit weights, but acceptable. The samples (SH-3 and PT-1) were partially oxidized. The Langdon shale was sampled at three localities in Lyon County (LY-2, LY-3, and LY-4). Samples LY-2 and LY-4 were from mostly unoxidized exposures. The aggregates produced were 46 and 57 pounds per cubic foot, and 39 and 40 pounds per cubic foot. The oxidized sample (LY-3) was among the heavier aggregates produced, weighing 62 pounds per cubic foot ungraded and 72 pounds graded.

Only one sample of the Dry shale was obtained (LY-5). On this exposure the shale was not only oxidized but rather deeply weathered. The condition of the sample is reflected in a unit weight for the aggregate produced of 62 and 77 pounds per cubic foot. The French Creek shale was sampled from four exposures (EK-3, LY-6, WB-1, and WB-2). Unit weights ranged from 41 and 44 pounds per cubic foot to 64 and 72 pounds per cubic foot, depending largely upon the degree of oxidation. The Caneyville-Pony Creek shale was sampled at one locality in Brown County (BR-3). Two samples were taken at this locality, and although both were unoxidized, the lower part (BR-3-1) produced an aggregate weighing only 28 and 38 pounds per cubic foot, whereas a much heavier aggregate was produced from the upper part (BR-3-2).

## PERMIAN SYSTEM

Rocks of Permian age crop out in a belt extending from Washington, Marshall, Nemaha, and Brown Counties on the

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northern boundary to Meade, Clark, Comanche, Barber, Harper, Sumner, and Cowley Counties on the Kansas-Oklahoma line. The total outcrop thickness is about 3,000 feet.

*Wolfcampian Series.*—The older Permian rocks of Kansas, made up of gray, greenish-gray, and maroon shales and light-colored limestones, are named Wolfcampian Series. The limestones are rather prominent and the shales tend to be calcareous or dolomitic. In many places where exposed, heavy limestones occur above the shale beds, or relatively thin shales alternate with limestone.

*Leonardian Series.*—The Leonardian Series occurs next above the Wolfcampian and contains two thick shale formations, the Wellington and the Ninnescah. The Wellington shale averages about 700 feet in thickness and is dominantly a clay shale on the outcrops. Unfortunately the Wellington shale is characteristically calcareous or dolomitic and is not adapted to bloating in a rotary kiln by ordinary methods. It is probable that the addition of 1 to 2 percent powdered coal or other organic material would make it possible to bloat the Wellington shale in a rotary kiln. The coal would have to be ground or pugged into the wet clay, thus increasing the cost. This shale could also be bloated in a sintering machine by pugging 5 to 15 percent powdered coal with the shale. The Wellington could be mined economically because of the great thickness of relatively uniform shale.

The Ninnescah shale is similar to the Wellington in its bloating characteristics and chemical composition, but does not occur in uniform beds of so great a thickness. Thin beds of gypsiferous shale are common in the Ninnescah.

Both the Wellington and the Ninnescah are deceptive in that shale beds seeming to be lithologically uniform are actually made up of alternating layers differing in maturing temperatures by as much as 60° F. In the rotary kiln such shales fire out as a mixture of chalky unvitrified flakes and partially fused glass. If these shales were pulverized and pugged together with a sufficient amount of powdered coal their deficiencies will be overcome and they can be bloated successfully in a rotary kiln or a sintering machine.

Permian shales above the Ninnescah were not tested, but the shaly portion of the Chikaskia member of the Harper sand-

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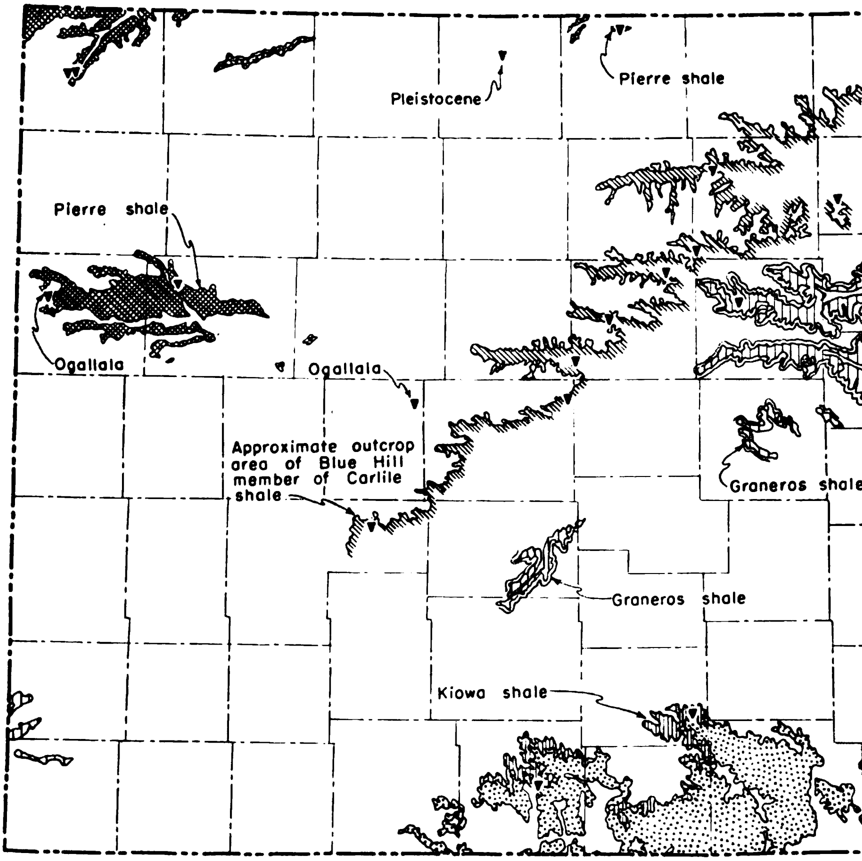


FIG. 2.—Map of Kansas showing distribution of Cretaceous clays and

stone formation is quite similar to the Ninnescah shale. Shales above the Chikaskia tend to be highly gypsiferous or sandy, and were not sampled.

*Guadalupian Series.*—No samples were taken from the shales of the Guadalupian Series both because they are not promising in appearance and because high-grade bloating shales are available in the general area of outcrop.

On the whole the shales of the Permian System are the least desirable of the Kansas materials available for the production of lightweight aggregate. It is to be expected that these shales

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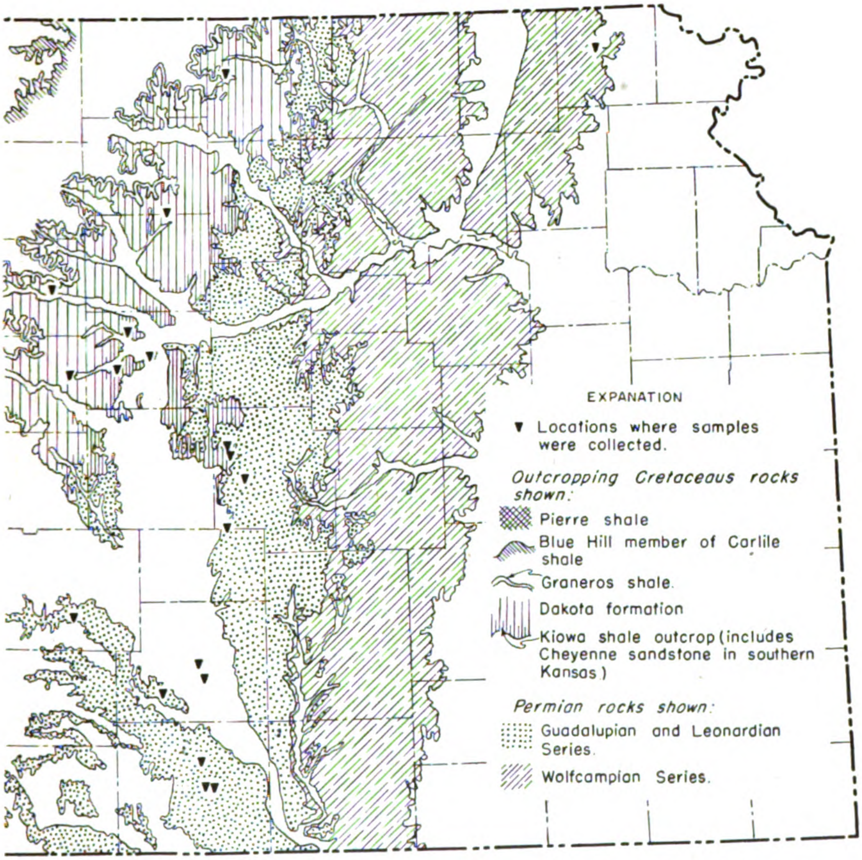


shales, main divisions of the Permian rocks, and locations sampled.

will not be used unless a special need arises in an area where no other bloating materials are available.

### CRETACEOUS SYSTEM

The outcrop belt of the Cretaceous rocks lies west of the area in which Permian rocks are found exposed at the surface (Fig. 2); they underlie or crop out at the surface over much of central and western Kansas. The Cretaceous rocks are mostly marine and are composed dominantly of clayey or chalky shales, although chalky limestones are prominent in the Greenhorn and Niobrara. The Cheyenne sandstone and Dakota formation

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are considered continental in origin and are composed of sandstone and kaolinitic fire clays. These continental beds in general are too refractory for use in the production of ordinary lightweight aggregate, but are suitable for making lightweight refractories.

The Cretaceous clayey shales, which include the Kiowa, Graneros, Carlile (Blue Hill), and Pierre, are especially adaptable to the production of lightweight aggregate in a rotary kiln. In general these shales are uniform in bloating characteristics and are not affected by oxidation due to prolonged weathering. Much of the Pierre shale is not adequately exposed at the surface, but the few samples taken from the total of 1,000 to 1,400 feet thickness are fairly satisfactory. The Blue Hill shale, ranging from 75 to 200 feet in thickness, is almost an ideal raw material for the production of lightweight aggregate. The clayey parts of the Graneros shale are very similar to the Blue Hill, but the average thickness is only 45 feet. The Kiowa shale is also quite similar to the Blue Hill, and in southern Kansas is as much as 290 feet thick. This shale thins northeastward along the outcrop belt, however, and seemingly is completely lacking north of Clay County.

The bloating Cretaceous shales are composed dominantly of illite clay minerals, but contain some bentonitic clays composed chiefly of the clay mineral montmorillonite. Inasmuch as shales containing either of these clay minerals bloat satisfactorily, the distinction is not important.

In the following paragraphs the headings list the various shales or shale members and formations rather than groups because there are only two named groups in the Cretaceous of Kansas.

*Kiowa shale.*—Characteristically the Kiowa shale consists of thinly laminated gray to dark-gray clay shale. Cream and other light colors have been noted in the upper part, and in some cases these lighter shales are bentonitic. In general, however, the Kiowa is composed dominantly of the illite clay minerals. In addition to the clay shale the Kiowa also contains thin limestone beds composed of fossil shells and large lenses of sandstone. Gypsum, usually in the form of selenite, is common throughout the formation, as are also small ironstone concretions that weather reddish brown. Despite these extraneous materials

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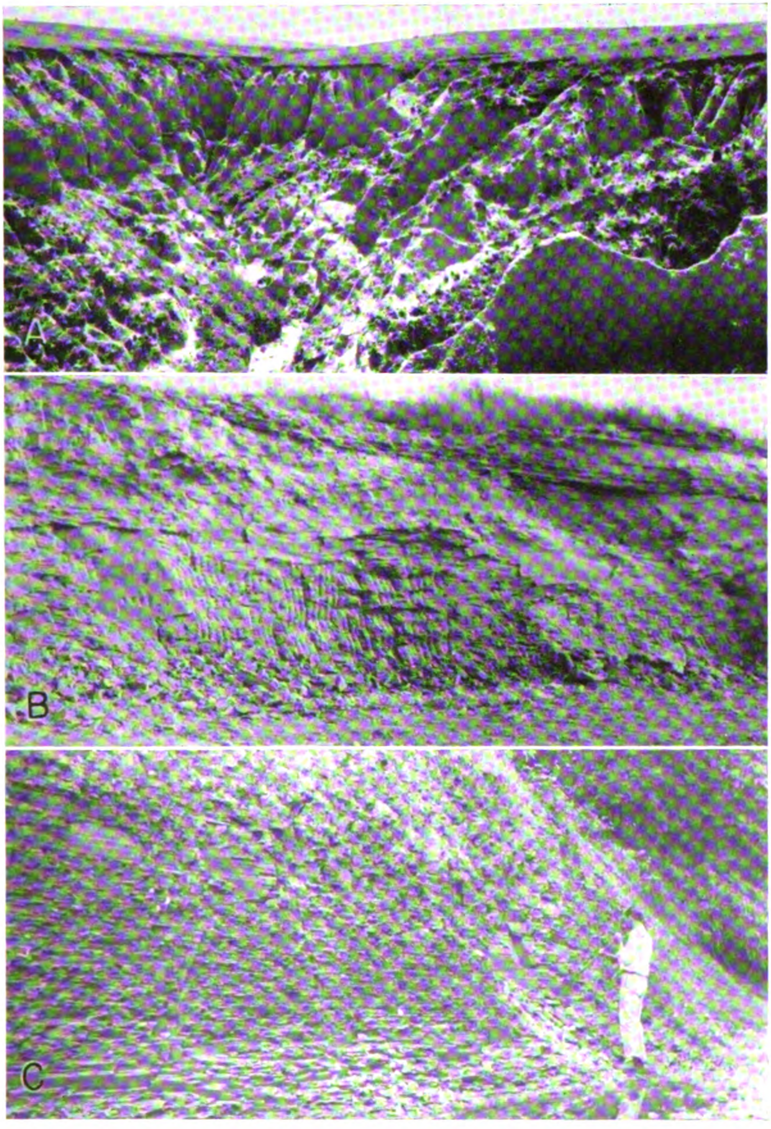


PLATE 7. *A*, Exposure of Pleistocene loess in northwestern Cheyenne County. Ravine is approximately 80 feet deep. *B*, Clay pit at Cloud Ceramics, Concordia, showing exposure of typical Dakota formation clay. *C*, Creek bank exposure of Weston shale in Franklin County (FR-5).

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sufficient thicknesses of usable shale can be found in most places in the area of outcrop. In the southern part of the outcrop area where the greatest thickness of Kiowa is found, as much as 293 feet was logged in a test hole (Latta, 1946). A total thickness of 90 feet is exposed where the Kiowa was sampled at location K-1 and Latta (1946) measured a total of 122.3 feet of Kiowa shale in the E½ sec. 16, T. 30 S., R. 17 W., Kiowa County. Farther north the base of the Kiowa shale is at the major unconformity between the Permian and Cretaceous beds, and the formation thins northeastward and is probably completely missing north of Clay County. The thickness of the shale varies greatly where it rests on the formerly eroded surface of the Permian rocks. Usable thicknesses of shale are found, however, as far north as Ottawa County. In the SE¼ sec. 11, T. 10 S., R. 1 W., more than 40 feet of Kiowa shale was measured. At one place in Saline County, on the other hand, the total thickness of the Kiowa does not exceed 30 feet (location S-18).

The clayey portions of the Kiowa shale can be manufactured into a very high grade lightweight aggregate. Although the bulk density tends to be unusually low the compressive strength of the concrete made from Kiowa shale aggregate is above the average. This unusual combination of low density and high strength probably is due to small closely packed bubbles, and a tendency to break down into cubelike chunks when crushed. The thin laminations that are conspicuous on the weathered outcrops of Kiowa shale are almost completely lacking in shale samples obtained a few feet below the surface and even the laminated material tends to consolidate into irregular masses when fired in the rotary kiln.

*Dakota formation.*—The clays of the Dakota formation (Pl. 7B) are dominantly kaolinitic (Pl. 6B) and are relatively refractory. Highly plastic fire clays of the ball clay type are rather common and occur in large deposits. Similar clays containing varying amounts of finely divided quartz ranging up to highly siliceous fire clays occur even more abundantly. About two-thirds of the clays in the Dakota formation contain hematite or limonite visible as red or yellow stain and blotches, and fire to colors ranging from dark buff to dark red. The plastic clays containing a fairly high percentage of iron oxide are the ones most susceptible to bloating, although the temperatures re-

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quired are quite high, especially if nothing is added to the clay to increase the bloating characteristics. We have found that the addition 1 to 1.5 percent powdered coal not only increases the bloating in these clays but also lowers the temperature required. The quality of bloated Dakota clays is high, and they are more refractory than other materials found in Kansas. The buff-firing fire clays produce a refractory lightweight aggregate that would be extremely useful in refractory concrete, lightweight refractory bricks, and high-temperature loose-fill insulation. It is probable that the slight additional cost of producing aggregate from Dakota formation clays will limit their use to special lightweight aggregates described above.

The ceramic characteristics and occurrence of the clays of the Dakota formation are described in detail by Plummer and Romary (1947).

*Graneros shale.*—The Graneros shale is a fissile gray to dark-gray clay shale very similar to the Kiowa. Like the Kiowa it contains irregular sandstone beds, clay ironstone concretions, and selenite crystals in abundance.

The average thickness of the Graneros is only 45 feet, and in many places much less than this consists of usable shale. Nevertheless, sufficient thicknesses of bloating shale are available in the majority of outcrops. Exposed beds of this shale are commonly covered with a considerable thickness of Greenhorn limestone due to the limestone's superior resistance to weathering. An abundance of Graneros shale is available under little or no overburden, but in such deposits the shale will be found under gentle grass-grown slopes, and is very poorly exposed.

The bloating characteristics of the Graneros shale are similar to those of the Kiowa, and like the Kiowa the material is the same a few feet below the surface as at greater depths.

*Blue Hill shale.*—The Blue Hill shale member of the Carlile shale formation is a gray to dark-gray clay shale that weathers platy on the outcrop, but like the Kiowa shale seems to be blocky a few feet below the surface. The shale contains bands of septarian concretions, some ironstone concretions, and an abundance of selenite crystals on the outcrops.

The thickness of the Blue Hill shale ranges from 75 feet in Hamilton County to 200 feet in Russell County. The bloating characteristics of the shale vary but little throughout the entire

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thickness. In some places an upper lighter gray and somewhat siltier zone was found in approximately the upper 20 feet. It is probable that the shale in this zone is related in origin to the Codell sandstone zone that locally occurs in the upper part of this shale member. Despite the perceptible lithologic difference the aggregate produced from this upper zone was equal or in some cases superior to the major part of the Blue Hill shale.

Taking all factors into consideration, this shale is probably the most suitable in Kansas for the production of lightweight aggregate. Although the quality of the aggregate produced from the Blue Hill shale is no better than that produced from the shale part of the Kiowa, the Blue Hill is much more uniform in bloating characteristics and the thickness of the shale is much greater. The Blue Hill is free from major irregularities such as lenticular sands, occurs in large tonnages free or nearly free of overburden, and is not seriously affected by weathering.

The aggregate produced from the Blue Hill shale ranges from extremely low density material to that of average density, depending on the firing temperature and the rate of firing. In general the low density material is preferable in that almost all flat particles are eliminated (Pl. 2B) and after being crushed and properly sized the concrete blocks made from the lighter material are equal in compressive strength to the denser aggregate.

*Pierre shale.*—The Pierre shale consists chiefly of gray to dark-gray clay shale. Some rather bituminous shales as well as cream-colored bentonites occur in the Pierre but are relatively a small part of the formation. This shale also contains some chalky beds, concretions of various types, and an abundance of selenite crystals on the outcrops.

Although the Pierre shale ranges from 1,000 to 1,400 feet in thickness in northwestern Kansas, good exposures of the shale are relatively rare. The few samples of Pierre shale that were tested (LO-2, CH-6, and PH-2) are bloating shales, but differ markedly in appearance of both the raw shale and the aggregate produced from it. No attempt was made to sample the Pierre in detail both because of the lack of exposures and the relatively poor market available for lightweight aggregate in the area of outcrop, but we believe we are safe in assuming that the greater part of the total thickness of the Pierre shale

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is suitable for use in the manufacture of lightweight aggregate. Some parts of the Pierre, as exemplified by sample LO-2, contain a large amount of gypsum in the form of selenite crystals. These crystals calcine to chalky anhydrite on firing, and may possibly be an objectionable feature in the bloated aggregate.

## TERTIARY SYSTEM

In Kansas the deposits of Tertiary age are mostly sand, gravel, caliche, and sandy to silty clays not suitable for use in the production of lightweight aggregate.

*Ogallala formation*.—Locally bentonitic clay beds occur in the base of the Ogallala formation, and locally above a few feet of sand and gravel. Such deposits have been noted in Wallace, Phillips, Lane, Norton, and Scott Counties, and doubtless occur elsewhere in the western part of the State. Thicknesses of known deposits range up to 30 feet, but commonly the maximum thickness is seldom more than 10 feet.

Elias (1931) believes these clays to be derived in part from the alteration of Tertiary volcanic ash deposits. John C. Frye (personal communication) favors the theory that these Ogallala clays are closely related to the underlying Pierre shale, and that they are either colluvial or residual clays derived from the Pierre shale. This theory is reasonable in that bentonite beds are common in the Pierre.

Elias named the Wallace County deposits the "Woodhouse clay," and doubtless similar deposits elsewhere in the State are equivalent in age and in origin.

Although the deposits of "Woodhouse clay" are limited in extent and in many cases poorly exposed, the quality of the aggregate produced from this clay is satisfactory. The few samples tested (LE-1, CH-5, and WC-1) indicate that the bloated aggregate contains much smaller gas vesicles than those produced in most of the shales and clays tested. It is to be expected that this finer textured aggregate will be superior to the coarser materials in respect to insulating qualities and water absorption.

## QUATERNARY SYSTEM

Deposits of Quaternary age occur in every county in Kansas, although they are much thicker and more extensive in some

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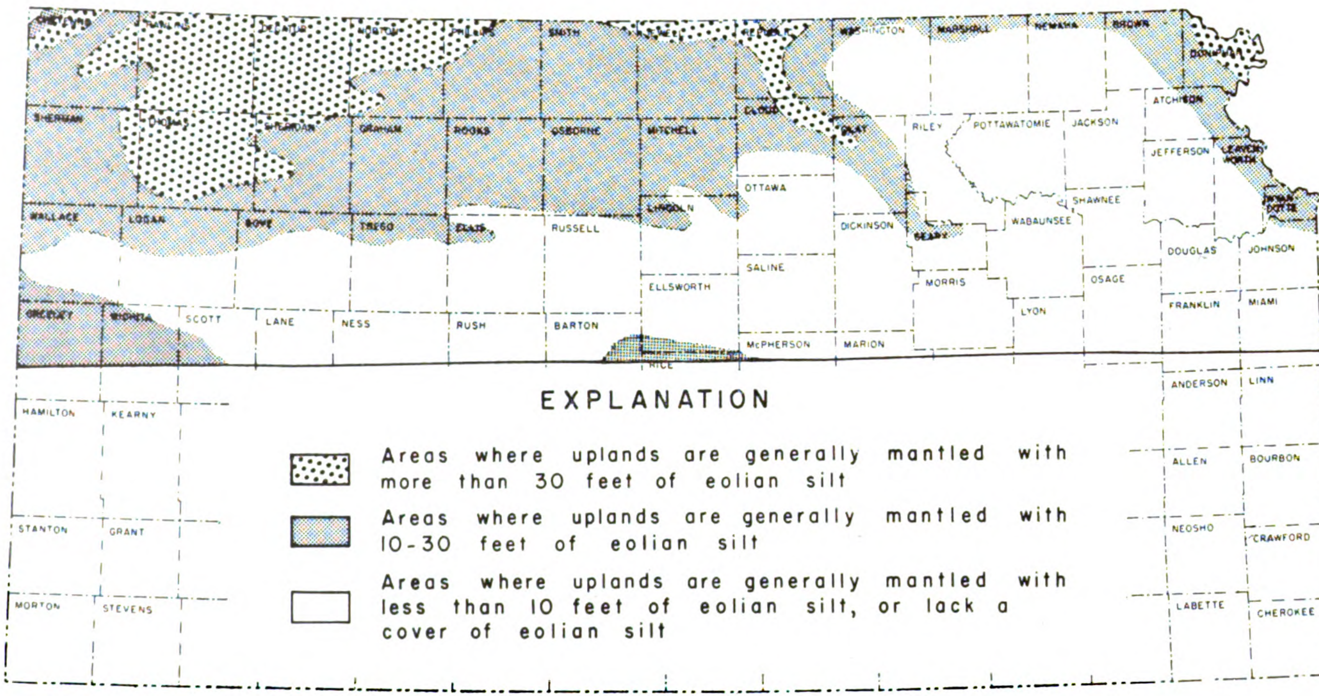


FIG. 3.—Map of northern Kansas showing generalized thickness of loess deposits.

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parts than in others. These deposits include sediments deposited by streams, glaciers, and glacial streams, and by wind; they range in age from early Pleistocene to Recent deposits laid down only yesterday.

*Pleistocene Series.*—From the point of view of materials suitable for the production of lightweight aggregate the most important materials are those of late Pleistocene age. Although glacial tills and outwash deposits are quantitatively important in northeastern Kansas, and in many instances are suitable for the production of lightweight aggregate, the Pleistocene loesses or wind-blown deposits of the Sanborn formation are the only Quaternary materials considered to be of major importance.

Since the ceramic utilization of northern Kansas Pleistocene loesses has been treated in some detail in a previous Geological Survey report (Frye and others, 1949), only the salient points will be discussed in this report.

The Pleistocene loess (Pl. 7A) and related deposits range in lithology from silts, dominantly composed of finely divided quartz, to plastic clays chiefly composed of the illite clay minerals. Both caliche and disseminated calcium carbonate occur in varying amounts in some zones. Thicknesses of the loess deposits are considerably more than 100 feet in many places and large areas are covered with 30 feet or more of loess. The map in Figure 3 shows generalized thicknesses and distribution of the loess deposits in the northern half of Kansas. These deposits are not restricted to the northern part of the State, but they are less continuous and generally thinner in the southern half.

The outstanding advantage in the use of these materials for the production of ceramic products is the fact that they can be mined with a minimum of cost. The silts and clays are friable and easily excavated and for all practical purposes may be considered completely lacking in overburden. Furthermore, the materials are relatively uniform and therefore would not have to be mined selectively.

There are some disadvantages to the use of the loesses as a raw material for the production of lightweight aggregate. The chief of these disadvantages is the fact that if fired in a rotary kiln as they come from the pit these clays or silts must be heated to rather high temperatures before bloating occurs. The type

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of bloating produced is chiefly that of high temperature overfiring at 2400° F. or more. At these temperatures the bloated clay tends to stick to the kiln or form massive rolls that hold up the flow of materials through the kiln.

In general the loesses containing the maximum of plastic clay are the best bloaters. Such materials have a relatively long firing range and form a viscous glass in the pyroplastic stage of firing. If in addition to these qualifications the material contains a moderate amount of fluxing materials such as calcium carbonate or alkalies the firing temperature will be reduced to within the range for economical production of lightweight aggregate.

Persons interested in the Pleistocene loesses can select the most likely materials from Tables 3 and 4, in Bulletin 82 part 3 (pp. 88-119, Frye and others, 1949), where ceramic data for more than 300 samples from 46 localities are given. The samples reported in these tables were zoned stratigraphically and usually represent only a few feet of the total thickness of the deposits. This is an advantage in that less suitable materials are clearly revealed, and if they occur in the lower part of the deposit can be eliminated. A rough selection of suitable materials can be made on the basis of these data by including those materials that contain some plastic clays, have a pyrometric cone equivalent of cone 7 or less, and have a firing range of at least four pyrometric cones.

We believe that the most suitable method of producing lightweight aggregate from Kansas loesses will include the use of additives such as gypsum or powdered coal. If the sintering process is used the addition of powdered coal or coke is an essential part of the process. If the sintering machine is used 5 to 15 percent powdered coal or coke must be used, in addition to some previously fired aggregate to open up the charge. These additions must be pugged with the previously ground clay and in some cases pelletized after pugging or intimate mixing with water.

It is not necessary to use a sintering machine, however. Equally good aggregate can be produced in a rotary kiln by the standard methods if 1 to 2 percent gypsum or powdered coal is pugged with the loess before firing in the kiln. In many cases a better aggregate can be achieved by forming the mix-

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ture into pellets, but this is true of any raw material. Armour Research Foundation found that an excellent lightweight aggregate could be produced from Iowa loess, which has no intrinsic tendency to bloat, by the addition of 1 to 1.5 percent sawdust to the raw material (Flint, 1950, p. 66). Since very little sawdust is available in Kansas, we tried 1.5 percent powdered coal as an additive for the loess, and found that it produced excellent results in an average type of material (NN-6). Powdered gypsum worked equally well in some cases, but the powdered coal more commonly produces bloating and has the added advantage of replacing part of the fuel. The few tests we ran also indicate a substantial lowering of the maturing temperature required, thus bringing the loesses within the same firing temperature range as the Kansas shales tested.

Volcanic ash deposits of both Pliocene and Pleistocene age occur extensively in the western half of Kansas. This material can be manufactured into either a cellular block or into a fluffy extremely lightweight aggregate similar to perlite. Burwell and Ham (1949) successfully produced both types of product from Oklahoma volcanic ash. We have produced the cellular product with Kansas volcanic ash, and a company at Hutchinson is producing the perlite-like material on a small scale.

## Fired-Clay Aggregate for Use in Making Building Blocks

By W. C. McNown

### INTRODUCTION

The following is a report on the quality of fired-shale aggregate made from various Kansas shales for use in the making of lightweight building blocks. Concrete prepared for the manufacture of building blocks is of necessity nonplastic and therefore on the dry side of the water-cement ratio. It is therefore lower in strength due to lack of water, and in preparing the mix of fresh concrete as much moisture should be used as is consistent with block-making techniques. This is accomplished by placing the aggregate in the mixer with enough water to moisten it, then rotating the mixer for 2 or 3 minutes before the cement and remainder of the water are added. Such a procedure permits the water to make easy entrance into the pores of the aggregate before they are clogged by the cement.

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The A.S.T.M. specification governing the quality of hollow load-bearing masonry units (C 90-44) states that the minimum strength of an individual grade A unit having 1¼-inch walls shall be 800 psi. over its gross area when tested in compression. No age of block is given with this specification so the assumption is that this strength must be attained before the block is required to sustain a load in a wall. The corresponding strength of identical concrete, when made into standard cylindrical test specimens, is yet to be determined. In the absence of such a correlating factor, 1,500 psi. will be adopted for the purpose of interpreting the results of this investigation.

### GRADING OF THE AGGREGATE

Fired-shale aggregate commonly is graded after it is crushed; therefore a grading that is suited to the quality and the economy of the making of building blocks may be adopted. In this investigation the aggregate came to the Concrete Laboratory graded according to specifications (Fig. 4, curve A) adopted by R. G. Hardy, a ceramic engineer employed by a company that is interested in the manufacture and promotion of the use of fired-shale aggregate. This grading is shown in Table 6, in comparison with a grading suggested and used by me (curve B).

The general principle governing the selection of a grading for mineral aggregate to be used in the making of concrete is that the amount of material in each size fraction (percent on each sieve) shall be such that the voids in the total compacted aggregate shall be a minimum, resulting in a maximum density for the mass. A second desirable consideration is that the grading shall have the largest amount of the larger fractions that

TABLE 6.—*Grading of aggregates used for tests*

| Sieve size | Curve 1 Percent on | Curve 1 Percent retained | Curve 2 Percent on | Curve 2 Percent retained |
|---|---|---|---|---|
| ⅜ inch | 0 | 0 | 0 | 0 |
| No. 4 | 11 | 11 | 22 | 22 |
| No. 8 | 27 | 38 | 17 | 39 |
| No. 14 | 21 | 59 | 16 | 55 |
| No. 28 | 17 | 76 | 15 | 70 |
| No. 48 | 11 | 87 | 12 | 82 |
| No. 100 | 6 | 93 | 8 | 90 |
| No. 200 | 4 | 97 | 7 | 97 |
| Passing | 3 | 100 | 3 | 100 |
| Total | 100 | | 100 | |

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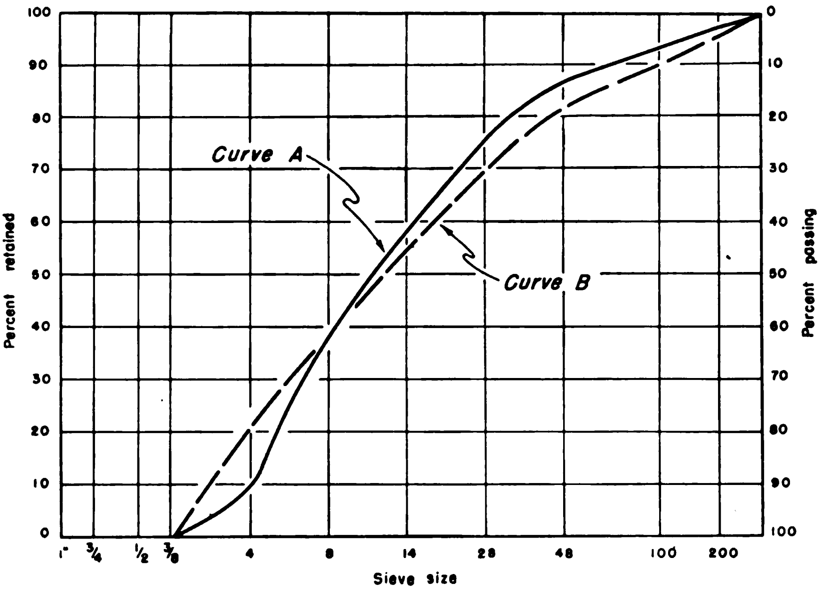


FIG. 4.—Grading curves for fired-clay aggregates to be used in making lightweight building blocks. Curve A is the curve adopted by R. G. Hardy; curve B is the curve suggested by W. C. McNown.

is consistent with good workability of the fresh concrete. This principle is based upon the common sense consideration that the larger particles should not be crushed to bits and then extra cement, an expensive ingredient, supplied to bind them together again. Also from 15 to 20 percent of the material should pass the No. 48 sieve to aid in filling the smallest voids, thus reducing the amount of cement-water paste needed to complete a workable mix. The maximum size of the aggregate is here taken as ⅜ inch, but there may be a tolerance of a few percent passing the ½-inch and retained on the ⅜-inch sieve.

## CEMENT REQUIREMENT

It will be necessary at all times to use enough cement to provide the strength needed to satisfy the specification. Since many block manufacturers make and sell concrete building blocks without the benefit of frequent tests, the Portland Cement Association has urged them to limit their production to 20 standard building blocks per sack of cement where ordinary

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TABLE 7.—*Bloated shale aggregates in building block concrete*

| No. | Mark | Unit weight of aggregate lbs. per cu. ft. | | Mix by volume | Yield, cu. ft. per sack | Blocks per sack | Weight of concrete, lbs. per cu. ft. | | Weight of dry block, pounds | Comp. strength, 28 days, 3" x 6" | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Vibr. | Conc. | | | | Wet | Dry | | | |
| | | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | |
| 1 | BR 5 | 62.2 | 62.5 | 1-6.4 | 6.3 | 20.0 | 81.0 | 69.0 | 21.4 | | Aggregate harsh and difficult to mix. |
| 2 | WL 1 | 42.2 | 40.4 | 1-6.4 | 6.8 | 21.8 | 80.0 | 68.0 | 21.2 | 1185 | Value of unit weight (col. 2) probably in error. |
| 2a | WL 1 | 42.4 | 47.3 | 1-5.8 | 5.3 | 17.0 | 81.0 | 69.0 | 21.6 | 1590 | |
| 3 | FR 5 | 42.5 | 48.2 | 1-7.2 | 6.4 | 21.6 | 82.7 | 70.0 | 21.8 | 1260 | |
| 3a | FR 5 | 44.2 | 49.6 | 1-6.9 | 6.3 | 20.2 | 79.5 | 67.6 | 21.1 | 1940 | |
| 4 | SH 3 | 62.2 | 67.4 | 1-6.3 | 5.8 | 18.6 | 96.5 | 82.0 | 25.6 | 2400 | |
| 4a | SH 3 | 62.2 | 64.8 | 1-6.4 | 6.2 | 19.8 | 90.5 | 77.0 | 24.0 | | |
| 5 | BR 3-2 | 60.6 | 66.3 | 1-6.5 | 5.9 | 19.0 | 97.5 | 83.0 | 26.9 | 2200 | |
| 5a | BR 3-2 | 60.6 | 64.2 | 1-6.8 | 6.4 | 20.5 | 90.0 | 76.6 | 23.9 | | |
| 6 | AL 1 | 70.3 | 75.2 | 1-7.0 | 6.5 | 20.8 | 104.0 | 88.5 | 27.6 | 1190 | |
| | Lone Star | | | | | | | | | | |
| 7 | SH 2 | 52.8 | 54.0 | 1-7.5 | 6.4 | 20.5 | 81.8 | 69.5 | 21.7 | 1810 | |
| 8 | WY 6 | 52.8 | 56.3 | 1-7.5 | 6.8 | 22.6 | 83.3 | 70.9 | 22.1 | 1600 | Too many blocks per sack of cement. |
| 8a | WY 6 | 53.3 | 57.6 | 1-6.2 | 5.8 | 18.5 | 89.0 | 75.0 | 23.6 | 2510 | Repeated. |
| 9 | MG 3 | 50.3 | 53.3 | 1-6.7 | 7.1 | 22.8 | 82.5 | 70.0 | 21.8 | 1740 | |
| 9a | MG 3 | 54.7 | 55.3 | 1-6.3 | 6.2 | 19.8 | 86.8 | 73.8 | 23.2 | 2130 | |
| 10 | DN 4 | 57.5 | 57.8 | 1-6.8 | 6.8 | 21.7 | 83.3 | 71.0 | 22.2 | 1620 | |
| 11 | LV 5 | 65.5 | 66.5 | 1-6.2 | 6.1 | 19.5 | 97.0 | 82.4 | 25.5 | 2490 | |
| 12 | DG 13 | 41.4 | 45.1 | 1-6.5 | 6.5 | 19.1 | 74.7 | 65.3 | 20.4 | 1280 | Mix a little too dry. |
| 12a | DG 13 | 41.6 | 46.4 | 1-7.1 | 6.4 | 20.4 | 74.2 | 63.0 | 19.6 | 1650 | Repeated to obtain more blocks per sack of cement. |
| 12b | DG 13 | 41.6 | 47.2 | 1-8.3 | 7.3 | 23.5 | 76.1 | 64.8 | 20.2 | 1215 | do |
| 13 | BR 3-1 | 40.0 | 44.1 | 1-6.7 | 6.1 | 19.5 | 76.6 | 65.2 | 20.2 | 1930 | do |
| 14 | LY 2 | 61.7 | 63.7 | 1-6.4 | 6.2 | 19.8 | 94.5 | 80.5 | 25.0 | 2820 | do |
| 15[10] | BR 3-1 | 40.0 | 31.5 | 1-2.43 | 3.09 | | 85.0 | 75.0 | | 2540 | |

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[1] The dry aggregate was placed in a one-half cubic foot unit weight container, completely covered with a steel plate, and vibrated to refusal. The weight divided by volume equals the unit weight. Since the amount of the aggregate was not sufficient to fill the containers, some small inconsistencies may have resulted.

[2] Computed dry bulk density of the aggregate in the finished concrete. The number of pounds of dry aggregate used in the making of a given volume of concrete was known and was reduced to pounds per cubic foot. In every instance it was greater than the unit weight value given in (1) due to the lubricating effect of the cement-water paste.

[3] Mix computed in the conventional manner; the number of cubic feet of dry aggregate that would need to be placed with one sack of cement using the unit weight from (1).

[4] The number of cubic feet of concrete vibrated in place that would result from the use of one sack of cement and a given mix.

[5] The value in (4) divided by the volume of one standard building block will give the number of blocks per sack of cement. The value 0.312 cubic foot was used as the volume of concrete in one 8x8x16 inch building block.

[6] Weight of 1 cubic foot of damp concrete in the moist condition when taken from the mold the day following making.

[7] (6) reduced by 15 percent for the weight of moisture contained.

[8] (7) multiplied by 0.312 to give an approximate value for the weigh of one dry building block made from the given concrete.

[9] Average of three to five test specimens. Such strengths vary principally with the quality of the aggregate and the amount of cement used.

[10] Plastic concrete made using the remainder of BR-3-1 aggregate (to determine the value of such aggregate in structural concrete). Water cement ratio, 1.1; consistency, 4-inch slump; allowance for absorption, 2 percent by weight of dry aggregate. BR-3-1 is the lightest aggregate submitted. Yield was good considering the small amount of coarser fraction in the sample. This aggregate when crushed is not harsh and gives a smooth workable concrete. This, and its lightness (75 pounds per cubic foot dry), are highly desirable characteristics to be considered when making a selection for a site for a plant for making such aggregate.

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sand, gravel, or crushed rock is used for aggregate. If such a limit is maintained and if sufficient water is used in the mix, their strength should easily satisfy the foregoing specification requirement. There is a tendency on the part of the block-makers to use too dry a mix which causes a very considerable loss in the strength and quality of the product.

In this investigation of fired-shale aggregate for block-making purposes, an attempt was made to keep to the 20 block per sack limit and to let the strength of the resulting concrete reflect the quality of the aggregate. Since it is not possible to know in advance what the yield will be for a given aggregate, a close determination may require an additional trial as may be noted in Table 7. If the strength of the concrete made using a given aggregate in a mix giving 20 blocks per sack of cement is greater than required, then obviously the number of blocks per sack may be increased.

In making the test specimens in this investigation, the concrete was compacted in the molds by the use of a small electrically operated hammer having a 3-inch diameter hard wood block mounted on its stem. The material was hammered to refusal in four nearly equal lawyers. If as a result of the compaction a small amount of water appeared at the edge of the bottom of the mold, the water content was considered to be sufficient. If not, the material was broken up and returned to the mixing pan, and more water added to the entire batch. Such amount of water was considered to be the maximum that could be used in making concrete blocks where the forms must be slipped off as soon as the blocks have been compacted.

TABLE 8.—*Characteristics of lightweight aggregate concrete blocks weighing less than 21 pounds*

| Sample | Block weight | Compressive strength, lbs. per sq. in. | Blocks per sack | Unit weight of aggregate* |
|---|---|---|---|---|
| DG-13 | 19.6 | 1,650 | 20.4 | 41.6 |
| BR-3-1 | 20.2 | 1,930 | 19.5 | 40.0 |
| FR-5 | 21.1 | 1,940 | 20.2 | 44.2 |
| MG-3 | 23.2 | 2,130 | 19.8 | 54.7 |
| SH-2 | 21.7 | 1,810 | 20.5 | 52.8 |
| WY-6** | 22.8 | 2,055 | 20.5 | 53.0 |
| Average | 21.3 | 1,920 | 20.1 | 47.7 |

*Same as third column in Table 7.
**The average of the two values in Table 7. One mix had too little cement and one had too much.

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TABLE 9.—*Characteristics of lightweight aggregate concrete blocks weighing more than 25 pounds*

| Sample | Block weight | Compressive strength, lbs. per sq. in. | Blocks per sack | Unit weight of aggregate* |
|---|---|---|---|---|
| SH-3 | 25.6 | 2,400 | 18.6 | 62.2 |
| BR-3-2 | 26.9 | 2,200 | 19.0 | 60.6 |
| LV-5 | 25.5 | 2,490 | 19.5 | 65.5 |
| LY-2 | 25.0 | 2,820 | 19.8 | 61.7 |
| Average | 25.6 | 2,478 | 20.1 | 60.1 |

*Same as third column in Table 7.

## QUALITY OF THE RESULTING CONCRETE

The two desirable characteristics that enter into the quality of a building block are lightness and strength. Table 7 shows that DG-13, DR-3-1, and FR-5 are the superior ones. Closely following are WL-1, MG-3, SH-2, and WY-6.

Table 8 assembles significant data for easy comparison of the characteristics of aggregates producing blocks weighing less than 21 pounds. Table 9 shows these four aggregates producing blocks weighing 25 pounds or more.

The values in Table 9 are significant in that they show that the compressive strength of the concrete is roughly proportionate to its density with the cement content averaging 20.1 blocks per sack of cement. The strengths obtained are greater than necessary for block concrete and could be reduced to obtain more blocks per sack, perhaps 21 or 22, and a lighter weight, say 23 or 24 pounds per block. The conclusion is that these shales make good fired-shale aggregate and should not be given a low rating. They should be considered also when selecting aggregate for use in making structural grade concrete.

## PLASTIC CONCRETE

It was not the purpose of this investigation to consider the physical qualities of plastic concrete made from the several aggregates. In one instance, however, such concrete was made using BR-3-1 as aggregate (No. 15, Table 7). A water-cement ratio of 1 : 1 by volume, or 8.25 gallons per sack of cement was chosen.

The strength in compression was 2,540 psi. which is practically the same as has been found for the strength of concrete

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having this water-cement ratio and using local sand and crushed limestone for aggregate. The yield of 3.09 cubic feet per sack of cement is low since BR-3-1 is a fine-graded aggregate having a maximum particle size of three-eighths inch, where in concrete such as is ordinarily used in building construction, the aggregate is graded up to the three-fourths inch size, with a resulting yield for the 1 : 1 water-cement ratio of about 6.0 cubic feet per sack of cement. The weight of 75 pounds per cubic foot for dry concrete is very significant, being only 54 percent that of similar concrete using ordinary local aggregates.

Good structural grade concrete can be made using fired shale for aggregate. Such aggregate has qualities, not detailed here, that enable the making of first-class concrete. Since the aggregate particles tend to be rough and angular, the yield of concrete made from it is not as great as that made using ordinary aggregate materials. The difference in the yields is on the order of 1 cubic foot per sack, for instance 5.0 and 6.0 cubic feet for a water cement ratio of 1 : 1. The fireproof quality of the fired-shale aggregate concrete is considered to be superior to that of concrete made using sand and crushed rock or gravel.

## COMMERCIAL APPLICATIONS AND METHODS OF PRODUCTION

### Uses

At present the chief demand for lightweight aggregates is for use in the production of concrete building blocks. This outlet will doubtless continue to be an important one, and as more and cheaper bloated shale aggregate becomes available with expanding plant capacity, the total consumption for use in concrete blocks can be expected to increase both due to the replacement of such aggregates as pumice and sand and to the increased demand for concrete blocks when the lightweight units are more readily available.

It has also been suggested that the use of lightweight units has not been exploited to the fullest extent. Brick and Clay Record (1950b, p. 64) points out the possible use of lightweight aggregate blocks for the insulation of floor slabs that rest directly on earth fills, and as a back-up for metal spandrels that are being used on many buildings today. Denver Terra Cotta Company, Denver, Colorado, is producing lightweight reinforced

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concrete roof slabs that are used as fillers between roofing beams. These slabs seem to be entirely successful, but are not produced in most areas.

The general opinion seems to be that the greatest future for lightweight aggregates is in poured concrete for all types of structures, especially massive ones such as large buildings, bridges, and dams. Due to the lessening of dead weight made possible by the use of a lightweight concrete, substantial savings both in concrete and structural steel are made possible, and the increased insulation against the transmission of both heat and sound in floor and roof slabs adds to the advantages of the lighter weight material. Aggregate for poured concrete must necessarily be produced with more care than that intended for use only in concrete blocks. Most of the bloated shale or clay aggregates produced have sufficient strength for inclusion in structural concrete, although for some applications a heavier stronger aggregate will be required. The chief requirement for poured concrete aggregate will be workability. Many bloated aggregates tend to be harsh and difficult to handle. The most workable aggregate is one which is composed of nearly spherical particles that are bloated inside but coated on the outside with a smooth hard layer of vitreous shale. Many shales can be made into this type of aggregate by the very simple expedient of sizing the shale before firing it in the rotary kiln. The individual chunks of shale bloat separately, and come out of the kiln covered with a nearly impervious skin. Other clays and shales must be ground and pelletized to produce this type of aggregate.

In addition to the use of bloated shale and clay as aggregate in concrete products these lightweight materials may be bonded with clay and shale, made into a variety of units, and fired to produce an all-clay product. Extensive development work has been done on this type of product in North Carolina (Foster, 1949), and the results look very promising. The ceramics division of the Geological Survey of Kansas produced this type of lightweight aggregate experimentally three years ago and concluded that it had the possibilities since verified in other laboratories. The advantages of the all-clay unit include chemical stability, superior resistance to weathering, and ease of making the unit impervious to water by the application of either a vitreous clay coating or a glaze.

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Other uses suggested for lightweight aggregates produced from clay or shale include undercoat plasters which must be acoustically insulating and light in weight; insulation within walls as a loose fill; as railroad ballast and riprap; in filter beds; as a packing for acid towers; and as an asphalt filler for use in bituminous road surfacing, roof coatings, grouts, and mastics.

The use of burned clay as a railroad ballast and constructional aggregate has been discussed in another Geological Survey bulletin (Plummer and Hladik, 1948). In this report the emphasis was placed on a denser unbloated type of aggregate, but in most cases a semibloated material would be preferable to the denser kind. It should be kept in mind also that the densest type of burned clay aggregate has a much smaller unit weight than solid rock or sand and gravel aggregates of equivalent grading.

Two types of lightweight material have been produced from volcanic ash. A bulletin of the Geological Survey of Oklahoma describes these processes in detail (Burwell and Ham, 1949). Heating of the loose volcanic ash in refractory molds to a high temperature produces a cellular product that can be formed as slabs or blocks capable of being sawed or nailed. This product was named Pumicel by the Oklahoma Geological Survey. Volcanic ash was also "popped" by feeding the ash into the air intake of an inspirator type gas burner. The finished product is very similar to expanded perlite, having a very low density. It is suitable for use in acoustical and insulating plasters, or any of the uses to which perlite is adapted.

## Qualifications

As far as standard specifications are concerned the physical qualities of lightweight aggregates can vary widely. The American Society for Testing Materials specifications for lightweight aggregates for concrete (1949, Designation: C 130-42) apply to materials other than expanded clay or shale in respect to ignition loss and organic impurities. It would be difficult to produce a lightweight aggregate from clay or shale that had either a loss of weight on ignition or that contained organic impurities. The grading requirements for lightweight aggregates also vary widely. It is possible to produce a poorly graded

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aggregate that falls within the specified limits, or a well-graded aggregate that does not meet the specifications. The grading requirements specified by the A.S.T.M. are given in Table 10.

This grading is not intended as a guide to the design of concrete mixtures but to designate limits to assist the producer and consumer. In most cases better concrete can be made with aggregates containing a higher percentage of material finer than 50 mesh than is commonly designated. If the wall thickness and surface texture desired will permit, the concrete will also be benefited by a greater proportion of the coarse sizes. Almost any type of crushing tends to produce an aggregate containing a disproportionate percentage of one or two screen sizes, usually on the intermediate sizes.

There is no ideal grading of aggregate for concrete. Harsh angular aggregates require a different grading from rounded smooth aggregates. Vibrated concrete with a low water content such as used in the manufacture of concrete blocks should not have the same grading for the aggregate as that used in poured concrete with a higher water content.

The quality that determines whether or not an aggregate is lightweight is the density of the individual pieces, which in turn determines the unit weight. The unit weight is the weight per unit volume of the crushed tamped aggregate. The American Society for Testing Materials designates that a fine lightweight aggregate shall not have a unit weight of more than 75 pounds per cubic foot when graded according to the limits given in

TABLE 10.—*A.S.T.M. grading requirements for lightweight aggregate* (A.S.T.M., 1949, Designation: C 130-42)

| Size designation | Percentage passing sieves having square openings | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1 in. | ¾ in. | ½ in. | ⅜ in. | No. 4 | No. 8 | No. 16 | No. 50 | No. 100 |
| **Fine aggregates:** | | | | | | | | | |
| **¼ in. to dust** | ........ | ........ | ........ | 100 | 95-100 | ...... | 45-80 | 10-30 | 5-15 |
| **⅜ in. to dust** | ........ | ........ | 100 | 95-100 | 55-80 | ...... | ........ | 10-25 | 5-15 |
| **Coarse aggregates:** | | | | | | | | | |
| **½ in. to No. 4** | ........ | 100 | 90-100 | 40-75 | 0-15 | 0-5 | ........ | ........ | ........ |
| **½ in. to No. 8** | ........ | ........ | 100 | 85-100 | 0-20 | 0-5 | ........ | ........ | ........ |
| **¾ in. to No. 4** | 100 | 90-100 | ........ | 20-55 | 0-10 | 0-5 | ........ | ........ | ........ |

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the preceding requirements, and that the coarse lightweight aggregate shall not have a unit weight exceeding 55 pounds per cubic foot (A.S.T.M. Designation: C 130-42). It is generally agreed by both producers and consumers and in published articles (Flint, 1950, p. 65) that unit weights ranging from 40 to 50 pounds per cubic foot are desirable. Unit weights lower than 30 pounds per cubic foot can be produced from some shales. Although the heavier aggregates tend to produce a concrete with greater compressive strength than the lighter ones, there are many exceptions. In fact, according to tests conducted by W. C. McNown some of the very lightweight aggregates may be superior both in compressive strength and working properties to the heavier aggregates when incorporated in a concrete mix (Table 7). It is difficult to make comparisons with published determinations of unit weights of aggregates because of the lack of standardization in grading.

According to our findings a crushed unsized aggregate may be as much as 15 pounds per cubic foot lighter in weight than the same aggregate after grading according to the size distribution we used as a standard throughout this report (Tables 2 and 3). Unit weight differences were more commonly 5 to 8 pounds, however. In the case of either the graded or the crushed unsized aggregate our determinations should be considered as made on a fine aggregate. Coarser aggregate grading will result in unit weights as much as 20 pounds per cubic foot lighter than graded fine aggregates. The grading used throughout the series of tests included in this report was one that R. G. Hardy (personal communication) fixed upon as falling on an acceptable distribution curve and at the same time one that could be produced with a minimum of screening and recrushing. The grading used by us is given on page 18. This sizing was used on all aggregates for the determination of unit weights and in most of the concrete tests made by W. C. McNown from the aggregates to determine compressive strength.

Lightweight aggregates vary widely in physical characteristics even when produced under the same conditions. This variation is especially marked in the case of clays and shales from different formations. Even with the same raw materials such important characteristics as unit weight, size of pores or vesicles, shape of crushed particles, and color can be varied by the rate

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of heating, degree of oxidation or reduction in the kiln, and the final temperature. Some users, especially concrete block manufacturers, prefer a sharp aggregate with particles as nearly cubic in shape as possible. Others prefer a preponderance of nearly spherical particles that are coated on the surface with a skin of vitreous shale. In many cases these variations can be produced with the same shale or clay. Everyone agrees that flat particles are undesirable, and that contaminating materials such as calcined gypsum and limestone should be kept to a minimum. Just what property in the aggregate contributes to the compressive strength of the concrete has not been determined with the exception, of course, that hard dense aggregates tend to be stronger than light frothy ones. The density of the aggregate seems to be less important in this respect, however, than the ability of the individual pieces of aggregate to be bonded firmly with the cement. This is not necessarily related to the surface roughness of the aggregate, although it may be a factor in many cases.

The minimum compressive strengths of various concrete masonry units is specified by the American Society for Testing Materials (1949). Grade A hollow load-bearing units with a minimum face shell thickness of 1¼ inches are required to have an average minimum compressive strength on five units of 1,000 psi., with a minimum on any individual unit of 800 psi. Grade B units must have an average compressive strength of not less than 700 psi., with a minimum for individual units of 600 psi. (A.S.T.M., 1949, Designation: C 90-44).

Grade A solid load-bearing concrete masonry units are required to have an average minimum compressive strength of 1,800 psi. on five units, with a minimum of 1,600 psi. on any individual unit. Grade B solid units must have an average minimum of 1,200 psi., with an individual minimum of 1,000 psi.

As reported in the preceding section, compressive strength tests made by W. C. McNown on concretes made with aggregates manufactured in our laboratory indicate that concrete having compressive strengths well above the minimums specified can be made from any of the lightweight aggregates produced. This holds true not only for wet concrete mixes but also for vibrated dry mixes such as used in concrete blocks. If the aggregate is not properly sized and the aggregate, cement, and water not

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correctly proportioned, or the forming process carelessly done, the compressive strengths may be quite low with the best of aggregates.

## MANUFACTURING METHODS

From the year 1919 when Hayde produced the first Haydite in Kansas City until very recently, the rotary kiln was used exclusively for the production of lightweight aggregates from shales and clays. Despite the recent developments in the use of sintering machines of various types the rotary kiln can be considered as standard equipment for this manufacturing process.

The lightweight aggregate plant of the Hydraulic-Press Brick Company, South Park, Ohio, as described by Brick and Clay Record (1950, pp. 40-48) is typical of the better equipped plants in this country. Their product is marketed under the trade name Haydite. In this plant the shale is excavated by a 1½-cubic yard electric shovel and loaded into two trucks having capacities of 4 cubic yards. The shale is trucked about one-half mile to the two storage bins which hold a 24-hour supply when fully loaded. The shale is carried from the bottom of the bins by chain conveyors to two 9-foot dry pans driven by 40-horsepower electric motors. After crushing, the shale is hoisted 20 feet by a bucket elevator to a horizontal belt conveyor which deposits the ground shale in the tops of two storage silos. These storage silos are 20 feet in diameter and 20 feet high. They are located directly behind the rotary kilns. The ground shale is moved from the bottom of the silos by belt feeders to a bucket elevator which raises the material to the feed pipes at the ends of the kilns. The shale is fed into the upper end of the kiln.

This plant uses two rotary kilns 50 feet long and 6 feet in diameter, lined with 6 inches of fire brick. The kilns turn at approximately 60 revolutions per hour and are sloped 1 inch per foot of length. Powdered coal is used for fuel which is injected at the lower end of the kilns. The processing temperature used at this plant is about 2200° F. At the upper end of the kiln where the shale is introduced and where the gases of combustion escape the temperature is approximately 600° F. The shale remains in the kilns 40 to 45 minutes before being discharged

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into pits at the lower ends of the kilns as hot clinker. The clinker ranges in size from small pellets to lumps a foot or more in diameter.

The clinker is allowed to cool for a short time in these pits and is then placed in large mounds by a crane. The cooling and annealing in these mounds continues for 30 days or longer. Production from both kilns ranges from 260 to 280 cubic yards per day.

The clinker is removed to the screening plant hopper from the mounds with a 5-ton overhead crane having a 2½-yard clamshell bucket. The clinker is moved from the bottom of this hopper to the crushers by a reciprocating feeder. After passing through the crusher powered by a 60-horsepower motor the material is lifted on an inclined bucket elevator to the screening tower. The aggregate passes through a series of screens which produce three gradings of material; these are channeled into their respective storage bins.

The unit weight of this aggregate (dry rodded) is 59 pounds per cubic foot. The grading used for the determination of unit weight was not stated. One particular mix used to determine the strength of concrete made with this aggregate consisted of one part cement to three parts aggregate with 5½ gallons of water per sack of cement. The compressive strength of the concrete made with this mix was 4,000 (plus) psi. at the end of 28 days.

This plant employs 20 persons, including crew and office force, for a 24-hour a day operation. In addition to the equipment mentioned above a modern plant would need temperature recording equipment, speed indicators, and automatic pressure or draft controls.

Although this plant uses pulverized coal for fuel, it is probable that Kansas plants would use natural gas, or oil if the gas were not available. Little data on the fuel requirements for the manufacture of lightweight aggregate are available. The Bureau of Mines (Conley and others, 1948) published data on runs made in a 3-foot by 30-foot rotary kiln in which consumption of fuel oil ranged from 21 gallons to more than 30 gallons per yard of finished aggregate. Since they were using 140,000 B.t.u. per gallon fuel oil this is equivalent to a natural gas consumption ranging from 2,900 to 4,200 cubic feet per yard of

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finished aggregate, assuming 1,000 B.t.u. per cubic foot for the gas. It is safe to assume that the fuel requirements per yard of aggregate would be considerably less for larger kilns.

Fuel requirements are obviously dependent upon the final temperature required for bloating the clay or shale. These temperatures range from 1900° to 2400° F. The upper limit is placed at 2400° F. because temperatures much in excess of this result in too much fuel consumption for economical production. Another very important factor to be considered, and one that is often overlooked, is the amount of fuel required to evaporate moisture from the shale or clay. Such materials rarely contain more than 10 percent moisture as they come from the earth, and shales may contain as little as 3 percent. An increase in moisture content from 10 to 20 percent may increase the fuel requirements by as much as 10 percent, and with a moisture content of 30 percent about 17 percent more fuel would be used. The exit temperature of the gases of combustion also has an important bearing on the amount of fuel required to process a yard of aggregate. For example, increasing the stack temperature from 400° to 800° F. will necessitate using about 1½ times as much fuel on an average temperature material (Conley and others, 1948). It is reasonable to assume that it would be possible to maintain lower temperatures at the exit or stack end of the kiln by using a longer kiln. With this thought in mind Smithwick Concrete Products of Portland, Oregon, constructed a kiln 100 feet long and 8 feet in diameter for the production of Haydite. Mr. Otto Frei, Executive Vice-President of the company, informs us that their expectations in regard to fuel economy have been realized and no special problems have arisen due to the increased length of the kiln. To quote Mr. Frei's letter, "Our experience to date leaves us firmly convinced that the longer rotary kiln is highly desirable in the lightweight aggregate industry and we should like to investigate the utilization of even longer kilns in the future." The initial production rate of this kiln was 300 cubic yards per day (Brick and Clay Record, 1950c).

To the best of our knowledge the longest rotary kilns now producing lightweight aggregate in this country are at the plant of Rocklite Products, near Ventura, California. Their kilns are 125 feet long and 8 feet in diameter. The plant produces 450

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to 500 cubic yards per 24-hour day in three kilns (Lenhart, 1950). Considering the size of the kilns this production rate seems rather low, but the special types of products produced by the company probably account for this.

The total cost of a plant for the manufacture of lightweight aggregate cannot be estimated accurately from the data in literature available to us, but we believe that a rotory kiln with a daily capacity of 250 to 300 yards of aggregate will cost at least $150,000 and perhaps as much as $250,000. A rotary kiln 60 feet long and 5 feet in diameter could be purchased delivered and erected in Chicago in April 1950 at a total cost of about $28,000. Since a nationally known company manufactures rotary kilns in Kansas the cost in this State should not be greatly in excess of $30,000.

Within the past few years a great deal of interest has developed in the use of a sintering machine for the production of lightweight aggregates, and several plants are now manufacturing aggregates by this method. The sintering process is especially adapted to the bloating of clays or shales having a short firing range, and will handle materials not suited for processing in a rotary kiln. The Permian shales of Kansas could be bloated in a sintering machine, but are not well suited to the rotary kiln method.

One of the better known sintering machines is the Dwight-Lloyd, which consists essentially of a series of moving grates or pallets which contain the material to be expanded in a mixture with 5 to 15 percent pulverized coke or coal. The material is ignited under an ignition hood by means of a gas flame, and then over a windbox which pulls air down through the charge, thus burning the coke or coal and bloating the shale or clay. The charge must be open to permit the passage of air through it to support combustion. To accomplish this the material must be formed into pellets, or opened with an addition of previously bloated aggregate. Commonly a layer of aggregate is placed on the grates below the charge to prevent burning of the grates. It is usually necessary to recirculate about 30 percent previously fired material (Flint, 1950). The aggregate produced by the sintering machine is usually harsher than that produced in a rotary kiln, but this is not especially disadvantageous as far as the manufacture of concrete blocks is concerned. For poured

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concrete, however, an aggregate with a minimum harshness is desirable.

A Dwight-Lloyd traveling grate sintering machine capable of producing 168 cubic yards of aggregate per 24-hour day costs about $58,000 f.o.b. plant. Despite the fact that sintering machines are more costly than rotary kilns of corresponding capacity the cost per yard of aggregate produced is reported to be somewhat lower.

The tests conducted for this investigation were aimed at evaluation of materials for production in a rotary kiln, but this detracts but little from the value of the data to the persons interested in producing aggregate by one of the sintering machines.

Hard shales such as those found in the Pennsylvanian rocks of Kansas require little preparation for processing in a rotary kiln. Chiefly the preparation will consist of breaking the shale into smaller lumps. It is possible to produce a satisfactory aggregate by feeding rather large lumps into the kiln. The lumps tend to shatter because of the rapid heating in the kiln. It is probably an economy, however, to reduce the lumps to 1 inch or smaller maximum diameter. Brick and Clay Record (1950d, p. 56) recommends particles ranging from the size of marbles to BB shot. Such sizing will result in an aggregate made up of rounded particles coated with an impervious shell if the shale used has a fairly long firing range. Short firing range shales will agglomerate and produce larger masses regardless of the original sizing. Friable clays can be pelletized to produce an aggregate consisting of discrete rounded particles. It is recommended that the larger chunks of shale should be run separately from the fines if a rounded type of aggregate is to be produced. This procedure is advisable because the finer particles heat up more rapidly than the larger and tend to become fused to the larger ones.

The lightweight aggregate consisting of rounded pieces coated with a vitreous shell is especially desirable for use in poured concrete both because of improved workability and low water absorption. Harsher aggregates are satisfactory for use in the relatively dry concrete used for the production of concrete blocks.

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Most aggregate requires crushing and sizing after it comes from the rotary kiln. This is accomplished in most plants either by a pan mill type of crusher, a roll crusher, a gyrating crusher, or a combination of these methods. These types of crushers apparently produce a better size grading in the aggregate than others, but it is impossible to produce a satisfactory distribution of sizes with any crusher by one pass through it. Table 3 in this bulletin gives the size grading obtained by passing the aggregates produced by us through a roll crusher set with the rolls three-sixteenths of an inch apart. A preponderance of material resting on the No. 4 and No. 8 screens was obtained by this method. Setting the rolls closer together only shifted the excess to the finer screens. To obtain a size grading that would fit a passable distribution curve it was necessary to recrush a part of the material resting on the three-eighths inch, the No. 4, and the No. 8 screens. This procedure tends to produce an excess of the finer sizes, especially the dust passing through the No. 100 screen.

## Nature of Deposits and Mining Methods

The shales of Pennsylvanian age in the eastern third of the State are usually hard tough materials that show definite lamination on weathered outcrops. The overburden often includes some limestone or sandstone, but in most cases the shales can be mined under shale slopes where the overlying rocks have been removed by erosion. Most of the Pennsylvanian shales oxidize rather deeply, and usually the upper part is too deeply weathered to permit easy bloating. For this reason the overburden in some cases may be 20 feet or more in thickness over parts of the minable areas. For shale beds ranging from 40 to more than 100 feet in thickness this is not an excessive amount of overburden.

The lower part (Wolfcampian Series) of the Permian includes a number of limestones interlayered with relatively thin shale beds. On the majority of outcrops the limestone overburden is excessive in relation to relatively thin shale beds. In the upper part of the Permian the shales, such as the Wellington and the Ninnescah, can be found in large deposits that are relatively free of limestone overburden. The shales are hard on unweathered exposures.

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The shales of Cretaceous age are somewhat softer and break down into easily excavated material on weathered outcrops. A few feet below the surface these shales are nearly as hard as those of Pennsylvanian and Permian age. In the case of the Kiowa, Blue Hill, and Pierre shales the overburden consists chiefly of weathered shale or of younger deposits such as Pleistocene loess. These materials are relatively soft and could be removed by drag line or almost any method commonly employed.

The unweathered shales of Pennsylvanian, Permian, and Cretaceous age can be excavated by a power shovel or possibly with a bulldozer. If a drag line is used it is probable that the materials first would have to be loosened by shooting or plowing.

The Pleistocene loesses and terrace deposits are relatively friable and can be excavated by drag line or any other method suitable for use in similar materials. In most cases usable clay or silt extends to the surface so that no overburden would have to be removed.

## Other Economic Considerations

*Fuel.*—For rotary kiln production of lightweight aggregates natural gas is the most adaptable and economical fuel to use. The sintering process also requires gas or oil for the initial ignition of the charge on the grates. Oil or powdered coal can be used for the firing in a rotary kiln. Oil is more expensive in Kansas than either natural gas or powdered coal. The powdered coal compares favorably with natural gas near a source of supply. The sintering process usually requires powdered coal or coke breeze to mix with the charge.

*Water.*—Very little water is needed in the production of lightweight aggregates. In some plants the hot aggregate is cooled with water, but it is not necessary to use this method. In most localities water sufficient for use at a plant could be obtained from wells.

*Transportation.*—Unless all the aggregate produced in a plant is to be consumed in the local area railroad connections are necessary and are desirable in any case to facilitate shipping in the heavy plant equipment such as rotary kilns and refractories. Obviously an all-weather road is almost a necessity also both for the transportation of plant personnel and shipping of the

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finished product. In most areas plant sites can be selected where both types of transportation are available.

Because the materials studied for this report crop out over wide areas it is not practical to describe the nature of the deposits and the availability of fuel, water, and transportation for specific localities. The most practical approach to the problem of site location is to study the general area in which the desired shale crops out and to select several possible sites in which the necessary fuel, water, and transportation facilities are available. A check of these tentative sites will usually reveal one or more where the materials can be mined economically.

## SUMMARY AND CONCLUSIONS

In this report data are given for 227 samples from 47 counties. More than 100 of these samples were tested in the batch-type rotary kiln and five different shales were checked in a 30-foot pilot plant kiln. Unit weights on the crushed but ungraded materials bloated in the batch-type rotary kiln ranged from 28 to 81 pounds per cubic foot. Approximately three-fourths of the samples had unit weights less than 55 pounds per cubic foot. Bloating temperatures ranged from 2080° to 2430° F., but approximately nine-tenths of the samples bloated between 2100° and 2300° F. The length of time required for bloating in the batch-type rotary kiln ranged from 4 to 18 minutes. This represents the length of time the materials should take in progressing through the high-temperature zone of a continuous rotary kiln.

Thick deposits of shales suitable for the production of lightweight aggregates are available over almost the entire eastern one-third of Kansas where shales of Pennsylvanian age are exposed at the surface. The central area of the State where rocks of Permian age are exposed is not so well supplied with first-class materials, but taking into consideration the thick loess deposits in the northern part of this area and the fact that the sinter process can be used successfully to bloat the Permian shales, the supply is adequate. In north-central and western Kansas enormous tonnages of Cretaceous shales are available in well-defined outcrop belts. These shales can be mined eco-

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nomically and are well suited to the rotary kiln production of lightweight aggregate.

At the present time (June 1951) construction has been started on two lightweight aggregate plants in eastern Kansas. The Buildex, Inc. plant 2 miles south of the city limits of Ottawa will include two rotary kilns 125 feet long by 8 feet in diameter and will include the latest features in automatic controls and fuel-saving construction. The aggregate will be made from a Weston shale deposit that will be mined about three-fourths of a mile southwest of the plant (FR-3). George K. Mackie, Jr. president of the company, estimates that 600 cubic yards of aggregate will be produced daily.

The second plant, being constructed by Mineral Products Company, Kansas City, will employ the Dwight-Lloyd sintering process, and will be the first aggregate plant of the type in this general area. Powdered coal will be mixed with the clay, and oil will be used to ignite the charge. The raw materials supply is available from a deposit of Pleistocene loess located within a short distance of the plant and just west of the city limits of Kansas City, Kansas. Pilot plant production from this material by the sintering process reveals that the aggregate produced is nearly identical to that produced by the rotary kiln method as reported in a previous publication (Plummer and Hladik, 1948) as location JN-2. Kenneth A. Spencer, president of Mineral Products Company, estimates the daily production of the plant at 600 cubic yards.

At least two more plants are anticipated. According to present plans one of the prospective plants will use the sintering process. The other will use rotary kilns and may produce a hot-pressed block containing only bloated shale.

It is obvious that Kansas has sufficient reserves of materials suitable for the production of lightweight aggregates in almost every county. This in conjunction with a relatively cheap and abundant supply of natural gas, adequate transportation facilities, and a large potential market indicate a good future for the lightweight aggregate industry in this State.

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