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Illinois Clay Resources for Lightweight Ceramic Block

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ILLINOIS CLAY RESOURCES FOR LIGHTWEIGHT CERAMIC BLOCK

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ABSTRACT

Seven samples of clays and shales from Illinois were tested to determine their bonding properties. The clay materials are composed of illite, kaolinite, montmorillonite, chlorite, or mixed-layer clay minerals. The materials were ground, mixed with various percentages of water and lightweight shale aggregate, molded into blocks that measure 8" x 8" x 8", and fired to temperatures of 1850° to 1900°F. Compressive strengths were then determined.

A mixture of 20 parts clay to 80 parts aggregate, with 16 pounds of water per 100 pounds of mix, appeared to give optimum results. Blocks made with this composition had compressive strengths greater than 1,000 pounds per square inch. Blocks with the greatest compressive strength generally were obtained from the materials that contained abundant montmorillonite and mixed-layer clay minerals.

INTRODUCTION

Over the last century, there have been various attempts to make lightweight ceramic products. A lightweight aggregate was patented as early as 1875, but it was about forty years later, when Stephen Hayde built the first Haydite plant near Kansas City, that the manufacture of lightweight aggregate from shale was advanced most significantly. Until the middle 1940's, the industry developed slowly, but since the end of World War II, there has been increasing interest in the uses of lightweight aggregate in the building industry. Lightweight aggregate and Portland cement have been used as a binder for concrete blocks and poured concrete floors and walls.

Bell and McGinnis (1951) first developed a large, lightweight ceramic building block. They used a sintered lightweight aggregate made from clay materials bonded with clay. These blocks, which were made on a concrete block machine, measured 8" x 8" x 16", weighed approximately 25 pounds, and had compressive strengths of 1,700 pounds per square inch. Bell and McGinnis concluded that:

"(1) Clay building tile having only slight firing shrinkage and essentially no drying shrinkage can be made; (2) these tile may be dried and fired very rapidly without damage; (3) a wide range in the physical properties of these tile may be obtained by proper selection and blending of the clays and aggregates used." Caruso (1959), Moffitt (1961), and Robinson (1961; 1962) have discussed the fabrication of lightweight clay bonded block.

Most of the papers mentioned above were interested in the lightweight ceramic block as a finished product. The purpose of this investigation is to study the bonding properties of various clay minerals in Illinois, after being fired, and to describe possible locations of clay materials that would be useful in the manufacture of lightweight ceramic block. In many respects, however, the finished products and raw materials cannot be considered separately.

Acknowledgments

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STRATIGRAPHIC OCCURRENCE OF CLAY AND SHALE

In Illinois, clays and shale that can be used in the manufacture of clay bonded blocks range in age from Ordovician to Pleistocene. Figure 1 shows the outcrop areas of the bedrock clay and shale deposits that range in age from Ordovician through Tertiary; figure 2 shows the areas where refractory clays crop out; and figure 3 shows the areas of glacial tills and residual clays. The clays and shales crop out along stream valleys, in highway and railroad cuts, and in strip mines. Clay and shale deposits that may be used as bonding materials in the manufacture of lightweight building block occur in several stratigraphic units. Their relative ages are shown in the following list.

- Cenozoic Era
  - Quaternary System
    - Pleistocene Series
      - Wisconsinan Stage
      - Illinoian Stage
      - Kansan Stage
  - Tertiary System
    - Paleocene Series

Porters Creek Formation

Mesozoic Era

Cretaceous System

Paleozoic Era

Pennsylvanian System

Mattoon Formation

Bond Formation

Modesto Formation

Carbondale Formation

Spoon Formation

Abbott Formation

Caseyville Formation

Mississippian System

Chesterian Series

Valmeyeran Series

Warsaw Formation

Kinderhookian Series

Hannibal Group

Grassy Creek Formation

Ordovician System

Maquoketa Group

Scales Formation

Orchard Creek Shale

Ordovician Shales

Maquoketa Shale

Maquoketa Shale crops out in Alexander, Calhoun, Carroll, Grundy, Jersey, Jo Daviess, Kane, Kankakee, Kendall, LaSalle, Lee, Monroe, Ogle, Stephenson, and Union Counties. The colors of the Maquoketa Shale (Rubey, 1952, p. 22) may be bluish gray, blue, green, buff, tan, red, maroon, purple, lavender, or white. The shale may range from massive to fissile. The lithology ranges from an argillaceous dolomite to a slightly calcareous shale, which may have a noncalcareous portion near the top. In Calhoun County, about 20 feet of noncalcareous, gray, platy shale is exposed along the east bluff of the Mississippi River, near Batchtown. In Kankakee County, noncalcareous beds are exposed along the Kankakee River. The thickness of the Maquoketa Shale ranges from 350 feet, in northern Illinois, to 80 feet, in the southern part of the state (Weller and Weller, 1939, p. 7; Templeton

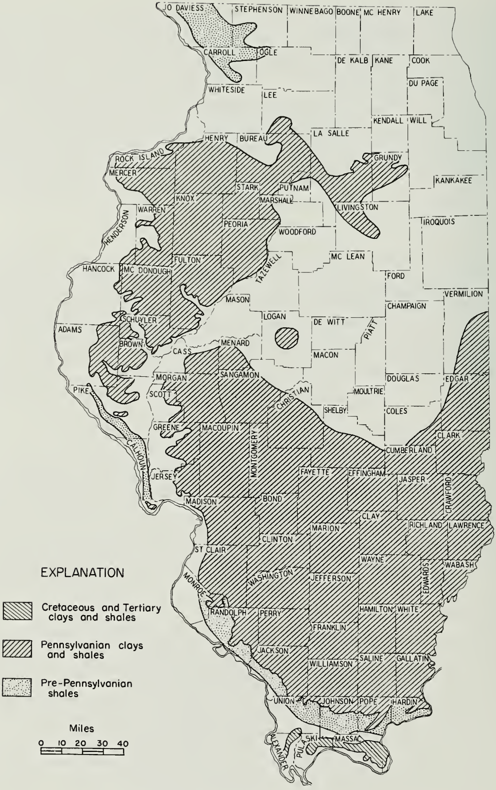

Figure 1 - Distribution of bedrock clay deposits which crop out in Illinois.

and Willman, 1963, p. 131). The shale contains illite, chlorite, and some mixed-layer clay minerals.

Orchard Creek Shale Member of the Scales Formation

The Orchard Creek Shale is 20 feet thick in Alexander County, where it crops out along the east valley wall of the Mississippi River between Thebes and Fayetteville. North of Fayetteville, the shale is green and well laminated. At Fayetteville, the shale is illitic and contains very little, if any, lime.

Mississippian Shales

Grassy Creek Shale

The Grassy Creek Shale is a black fissile shale that weathers to a bluish or greenish gray. It is 50 feet thick where it crops out in the Mississippi River bluff near Rockport and Atlas in Pike County and in the Illinois River bluff near Bedford. The shale thickens to the north and east (Krey, 1924, p. 34).

Since the fresh shale is fissile and contains organic matter, it is not a good bonding clay; however, the weathered shale is plastic. The shale is illitic.

Hannibal Shale

The Hannibal Shale ranges in thickness from about 30 feet, near Grafton in Jersey County, to nearly 100 feet, near the north line of Calhoun County. In Pike County, the Hannibal Shale rests on the Grassy Creek Shale. To the south, in Calhoun and Jersey Counties, the shale is mostly calcareous and nonlaminated, whereas in the northern part of Pike County, it may be a massive, calcareous sandstone, becoming more siliceous to the north. The shale has, for the most part, a greenish gray color.

In some areas of northern Calhoun County, the Hannibal Shale has a low lime and sand content, which makes it suitable for a bonding clay. The areas of production would have to be carefully selected, however, to assure the necessay low calcium carbonate and sand contents. The shale is illitic.

Chesterian Shale

The Chesterian shales range from calcareous to noncalcareous, and in many areas, they contain lenses and/or beds of limestone. Their thickness varies from a few feet to several tens of feet. The Chesterian shales range from thinly laminated to massive. The colors may be red, green, blue-gray, and dark gray.

The Chesterian shales crop out in Gallatin, Hardin, Jackson, Johnson, Massac, Monroe, Pope, Randolph, and Union Counties. In some areas, these shales contain too much lime for use as a bonding clay. With careful prospecting, portions of the Chesterian shales that are suitable for bonding clay can be found. The Chesterian shales are illitic for the most part.

Pennsylvanian Shales and Claystones

The Pennsylvanian shales and underclays are by far the most important bonding clay resources. These shales crop out over a much larger area of the state than the

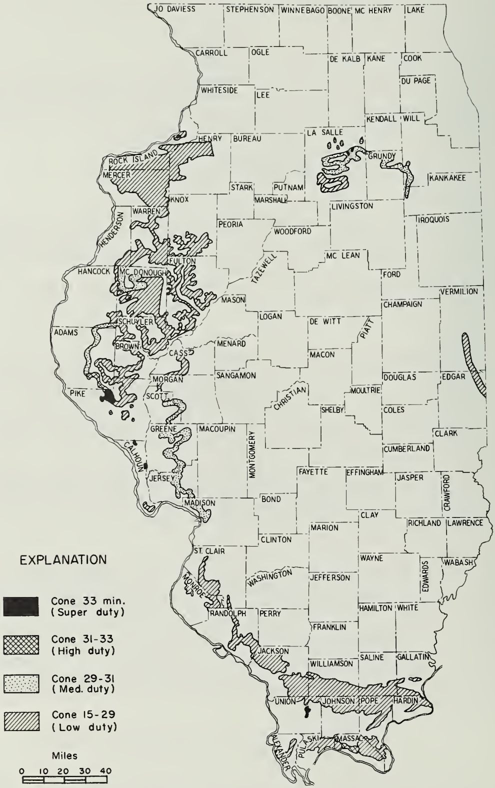

Figure 2 - Distribution of strippable refractory clays in Illinois.

older shales. Although most of the thick Pennsylvanian shales are noncalcareous, some may contain limestone nodules, lenses, and/or beds. The underclays below the Colchester (No. 2) Coal are usually noncalcareous, and those above the Summum (No. 4) Coal are usually calcareous.

The exposed underclays in the Caseyville, Abbott, and Spoon Formations are refractory (i.e., they fuse above pyrometric cone 15). If these underclays are used with a nonrefractory aggregate, the addition of a flux is necessary. The Abbott and Spoon Formations, which crop out in Adams, Brown, McDonough, Pike, Schuyler, and Warren Counties, also contain shales that are refractory. The refractoriness decreases from the west edge of the basin, southeastward towards the center of the basin. For the most part, the shales and underclays of the Carbondale, Modesto, Bond, and Mattoon Formations are nonrefractory.

Cretaceous Clays and Shales

Clay materials of Cretaceous age occur in southern Illinois in Alexander, Massac, Pope, Pulaski, and Union Counties. These clays and shales usually contain appreciable percentages of kaolinite, and are, therefore, refractory. A flux is required to make them a good bonding clay. The clays and shales vary in color from dark gray to light gray.

Tertiary Clay

Porters Creek Clay

The Porters Creek Clay is a montmorillonite clay that crops out in Pulaski County in southern Illinois. It is a dark green-gray clay that turns buff when weathered. The Porters Creek Clay is a good bonding clay because of the high montmorillonite content.

Pre-Pleistocene and Early Pleistocene Residual Clays

The residual clays, commonly found in western and southern Illinois, are usually quite plastic. The clays may be white, red, or yellow in color. Some are quite cherty. The thickness is variable. Some of the clays contain kaolin and are, therefore, refractory. A flux is needed to reduce the vitrification range. Some of these clays contain montmorillonite and/or mixed-layer clay minerals and no flux would be needed.

Pleistocene Clay

Till might be a suitable source of bonding clay. A till that contains 30 percent clay and few rocks might be considered a bonding clay resource. The Wisconsinan till, which underlies the northeastern one-third of Illinois, is usually calcareous, except for the upper few inches. The till ranges in texture from clayey to rather sandy and rocky. To make till a useful bonding clay, the calcium carbonate particles must be removed. The clay mineral in till is chiefly illite.

The Illinoian till (fig. 3) is noncalcareous in the upper few feet only. It could be used as a bonding clay if the lime and material larger than fine sand were removed.

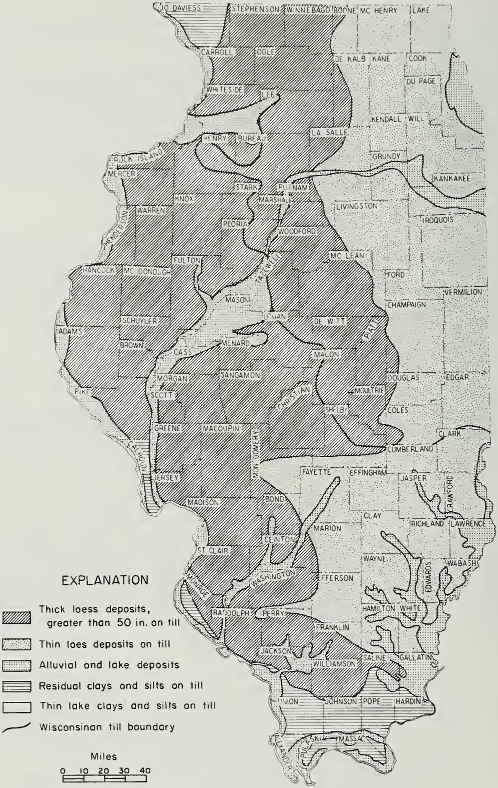

Figure 3 - Distribution of surficial clay deposits in Illinois.

The older Kansan till crops out in western Illinois. The till is noncalcareous in the upper few feet. In areas west of the Illinois River, particularly near the Mississippi River, the Kansan and Illinoian tills are more montmorillonitic (Willman, Glass, Frye, 1963, p. 23) and are probably the best bonding clays of Pleistocene age.

CLAY MATERIALS INVESTIGATED

The following samples were studied.

Sample 1415 - NE$\frac{1}{4}$ NW$\frac{1}{4}$ sec. 13, T. 6 N., R. 5 W., about 3 miles east of New Douglas, Bond County, south of blacktop road. The clay is till 5± feet at top; shale, yellow, plastic 6± feet; and shale, blue, plastic 8 feet at bottom. The till is Illinoian of Pleistocene age and the shale is from the Bond Formation of Pennsylvanian age. The clay mineralogy of the shale is illite 4 parts, kaolinite 3, and chlorite 3 parts in 10.

Sample 866 - NE$\frac{1}{4}$ sec. 11, T. 33 N., R. 8 E., 7 miles east of Morris, Grundy County. The clay is 3 feet thick under 6 feet of Pleistocene overburden. The clay is Spoon Formation of Pennsylvanian age. The clay mineral components are illite 3, kaolinite 1, and mixed-layer clay mineral 6 parts in 10.

Sample 2042 - SW$\frac{1}{4}$ SE$\frac{1}{4}$ NE$\frac{1}{4}$ sec. 15, T. 12 N., R. 9 E., east cut bank of stream east of road. About $\frac{1}{2}$ mile southwest of Sparland, Marshall County. About 3 feet of underclay beneath Danville (No. 7) Coal in the Carbondale Formation of Pennsylvanian age. The clay mineral components are illite 3, and mixed-layer clay minerals 7 parts in 10.

Sample 1422 - NW corner sec. 24, T. 11 N., R. 3 E., about 1 mile southwest of Shelbyville, Shelby County, on east roadcut of north-south county road in south valley wall of creek. Six feet of shale is exposed in roadcut with thin overburden. The shale is in the Bond or Mattoon Formation of Pennsylvanian age. The clay mineral components are kaolinite 2, chlorite 1, swelling chlorite 3 to 4, and illite 2 parts in 10.

Sample 996N - NW$\frac{1}{4}$ SW$\frac{1}{4}$ NW$\frac{1}{4}$ sec. 10, T. 4 S., R. 5 W., about 2$\frac{1}{4}$ miles north of Hadley, Pike County, on north side of old roadcut before road turned north, in south valley wall of Hadley Creek. Eight feet of clay rests on Mississippian Limestone and has from 10 to 140 feet of overburden. The clay occurs in the Spoon or Abbott Formation of Pennsylvanian age. The clay mineral component is kaolinite.

Sample FE113 - NE$\frac{1}{4}$ SE$\frac{1}{4}$ sec. 27, T. 15 S., R. 1 E., southeast of Olmsted, Pulaski County, on the west cut bank of Ohio River. The clay, about 20 feet thick with 20 to 40 feet of overburden, is in the Porter Creek Formation of Tertiary age. The clay mineral components are montmorillonite 5, mixed-layer clay minerals 3, and illite 2 parts in 10.

Sample 2043 - Near center NE$\frac{1}{4}$ sec. 23, T. 1 N., R. 12 W., northeast cut roadbank in southwest valley of Illinois valley wall above where road crosses tributary, Schuyler County. The clay is Kansan till of Pleistocene age and is 5 feet thick. The clay mineral components are illite 1, kaolinite 1, montmorillonite 4, and mixed-layer clay minerals 4 parts in 10.

Mineralogy

The mineralogy of the clays studied was determined by X-ray diffraction. Samples composed of illite, montmorillonite, kaolinite, chlorite, and mixed-layer clay minerals were used in this study.

Procedure

About 500 pounds of clay were collected from each location. Lightweight, bloated shale aggregate was purchased from Poston Brick and Concrete Products Company of Springfield and Western Brick Company of Danville. An 8-inch Raymond hammer mill was used to grind the clay so that it would pass through a .010" x .47" slot screen. One hundred pounds of dry clay and aggregate were mixed in a plaster mixer for 4 minutes; water was then added, and mixing was resumed for another 4 minutes. With clays that contained enough kaolinite or quartz to make them more refractory than the aggregate, it was necessary to add a flux to reduce the fusion temperature of the clay. In only sample 996N, one pound of fluorspar was used for each 20 lbs. of clay and 80 lbs. of aggregate that were mixed.

The sample blocks were formed on either a concrete block machine or a hydraulic press with a vibrating mechanism. The blocks were allowed to dry in air. They were then placed in an electric kiln and fired to 1850°-1900° F. (1010 to 1038° C.) for 24-hours. After firing, the blocks were capped. A Riehle compression machine (300,000 lbs. maximum capacity) was used to test for compressive strength. The maximum capacity was applied to the blocks for 2 minutes. The results are given in table 1.

Fragments of the crushed tile were placed in cold water for 24 hours. The samples were then weighed and placed in an oven at 110° C., overnight. The samples were weighed again to determine the porosity.

Test Results

Forming Properties

The strongest blocks were made from mixtures in which 20 percent clay and 80 percent aggregate (1/16"-0) were mixed dry and about 16 percent water added and mixed. FE113 was an exception, however. Good blocks were obtained with only 10 percent clay (FE113). To use a larger percentage of clay, more water would be necessary. An excess of water, however, caused the mix to stick to the machine; an insufficiency of water caused the blocks to be crumbly when air dried. When less than 16 percent of water was used, a reduction in block strength resulted. This suggests that there was not enough water to allow the bonding mechanism of the clay to develop fully. This bonding mechanism is probably due to the development of a wedge-shaped mass of clay at the junctions of the aggregate grains (Grim and Cuthbert, 1946, p. 15) and the formation of a glassy phase, which bonds the vitrified clay wedge and the aggregate together. The clay must be lubricated with water so that it can coat the particles of aggregate to give the best bond structure when the blocks are fired.

Drying Properties

The sample blocks were dried in air; however, the open-pore structure of the blocks would allow them to be dried without difficulty at a more rapid rate. Bell and McGinnis (1951, p. 338) state that no difficulty was encountered in drying blocks at above 212° F.

Firing Properties

The samples were fired for 24 hours at 1850-1900° F. Bell and McGinnis (1951, p. 338) used a $7\frac{1}{2}$ hour schedule, whereas Caruso (1959, p. 80) used a tunnel kiln with a 5 hour and 40 minute firing schedule.

The total shrinkage in this study ranged from 5 to 13 percent (table 1).

Block can be flashed in the same manner as brick. One group of blocks was fired in an atmosphere of insufficient oxygen; these samples did not bloat. The color of the blocks in this group was much lighter, and some of the blocks were pink instead of the red produced in a completely oxidizing atmosphere. The strength of these blocks was similar to the strength of those burned in an oxidizing atmosphere.

Other Properties

The sample blocks (figs. 4 and 5) had a pleasing appearance. The colors were similar to those found in brick. Color can be changed by additives, flashing in kiln, or varying the temperature of the kiln. Blocks can be glazed to obtain colors that cannot be produced by the above processes.

Ceramic blocks show a thermal expansion more nearly equal to that of brick than do concrete blocks. Texture can be changed by increasing or reducing the percentage of the fines and by using a larger aggregate size. The clay block will not shrink.

If a white burned product is desired, the white burning clay should be used as a glaze or terra sigillatta on the surface of the block. When a white burning clay is used as a bonding clay, it only lightens the burning color of the aggregate.

Clays containing montmorillonite may require less clay to give the desired strength (sample FE113) or more nonclay material can be tolerated (sample 2043).

All seven clays tested produced blocks that had a strength of over 1,000 pounds per square inch. Five of the clays had an average strength of over 1,400 pounds. The average strength of blocks from one clay (sample 1415) was over 1,700 pounds per square inch, and some of these blocks had a strength of 1900 psi.

Blocks fired to 1850° F. were soft enough that nails driven into them did not bend (fig. 5), and they could be sawed with a handsaw.

TABLE 1 - POROSITY AND STRENGTH OF CLAY AND AGGREGATE MIXES

Sample No.	Mixture Percent		H_2O Percent	After Firing		Remarks
	Clay	Aggregate		PSI	Percent Porosity	
FE113	10	90	15.0	603	—	
	10	90	20.0	1406	25.2	
	10	90	10.0	—	—	
	15	85	20.0	356	—	
	15	85	10.0	—	—	
	10	90	10.6	262	—	
866	15	85	20.0	1442	26.2	Too wet
	15	85	15.0	1124	22.0	
	20	80	15.0	635	—	
	20	80	20.0	1880	22.6	
	20	80	9.0	374	—	Too dry
996N	10	90	20.0	1304	—	
	10	90	10.0	740	—	Coarser Aggregate
	10	90	10.0	360	32.0	Finer Aggregate
	15	85	20.0	—	32.0	
	20	80	15.0	1439	28.0	
	20	80	10.0	509	—	
	20	80	9.0	300	—	
	30	70	10.0	278	—	
	30	70	5.0	—	—	Too dry
1415	15	85	15.0	1714	13.5	
	20	80	15.0	1292	19.0	
	20	80	10.0	<252	31.5	Too dry
	20	80	11.0	596	—	Too dry
1422	15	85	15.0	774	25.5	
	20	80	15.0	1109	17.3	
	20	80	10.0	<400	28.0	
	20	80	12.3	850	—	
2042	10	90	5.0	184	—	Too dry
	15	85	15.0	1092	29.0	
	20	80	20.0	—	—	Too wet
	15	85	10.0	275	—	
	20	80	15.0	1033	—	
	20	80	10.0	979	25.6	
	25	75	20.0	780	—	
	25	75	15.0	760	—	
	30	70	10.0	430	—	
	20	80	10.3	603	—	
2043	15	85	10.0	480	—	
	20	80	15.0	1472	30.0	
	20	80	10.0	900	25.5	
	20	80	15.0	967	—	
	20	80	11.0	313	—	

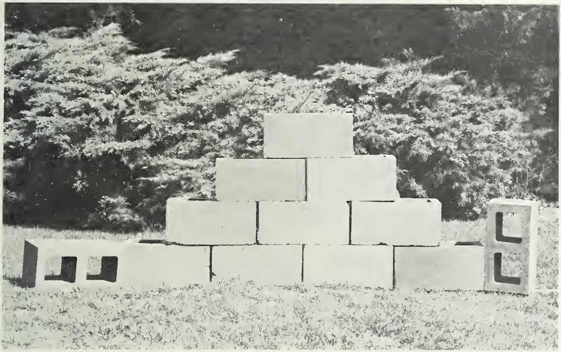

Figure 4 - Lightweight block made from various Illinois clays and lightweight aggregates.

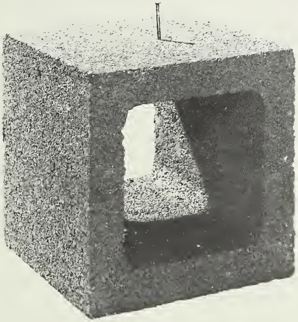

Figure 5 - Lightweight ceramic block made from Illinois clays. Block will accept nails and can be cut with a handsaw.

CONCLUSIONS

1. Many of the deposits of clay and shale in Illinois could be used in the manufacture of lightweight ceramic blocks.
2. Either the brick industry or the concrete block industry could produce ceramic blocks as a second product with a minimum of additional equipment. Brick manufacturers already have the processing machinery for preparing the clay and the kiln for firing the finished product, whereas a plant that manufactures concrete block would have the mixing equipment and the shaping machinery.
3. The blocks make excellent building materials because they are strong and aesthetically pleasing.
4. Clay block can be used in most places where concrete block can be used.
5. Clay blocks will not shrink.
6. A curing period is not required.
7. Clay blocks would be more compatible with the thermal and permanent expansion of brick than would concrete blocks.
8. Generally, clay material with abundant montmorillonite and mixed-layer clay minerals are good bonding clays. If clays containing montmorillonite are used, less clay may be required to give the desired strength (sample FE113). Clay materials that contain abundant nonclay material (sample 2043) may require a higher ratio of clay to aggregate than clays with less nonclay components.

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