KANSAS BUILDING STONE

by

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ABSTRACT

From the earliest pioneer days stone has been a useful building material within the state of Kansas. Reported value of dimension stone, mainly limestone, produced annually now amounts to several hundred thousand dollars.

Building stone is produced at widely scattered points across the state. Most of the stone produced each year comes from limestone beds of Permian age, but Pennsylvanian, Cretaceous, and Tertiary rocks are also quarried, and Quaternary glacial deposits provide boulders for some structures. Quarrying methods are described.

Kansas stone-processing plants produce stone in every degree of finish. In recent years, production has trended toward cut and finished stone and away from rough building stone.

As timber becomes scarcer and more expensive there is a likelihood that stone will become more widely used in buildings of all types.

INTRODUCTION

Purpose

This study was undertaken to investigate the sources and characteristics of building stone produced in Kansas, and the methods used to produce the stone. Although the study relates chiefly to stones now being produced on a commercial basis, other stones known to have been produced in appreciable quantity in the past are discussed briefly.

It is hoped that the report not only will provide an insight into an important segment of the Kansas mineral industries but may also give guidance to those who in the future may be seeking suitable sources and methods for producing Kansas building stone.

Acknowledgments

The cooperation and assistance of the building-stone producers and processors of Kansas in making this study possible and the help of the staff of the Kansas Geological Survey are gratefully acknowledged. Special thanks are given to Dr. J. M. Jewett for his help in the identification of stones and deposits, and to Dr. Ada Swineford and Mrs. Grace Muilenburg who provided many of the pictures used in the report.

Importance of Stone

The use of building stone as a construction material in Kansas dates back to the construction of many of the buildings erected by the earliest settlers. In a plains area almost devoid of trees, the beds of rock that crop out at many places within the state provided a ready source of material for the construction of houses and various farm structures. As settlement progressed, stone was used in the construction of stores and other business buildings and in schools and other public structures. Many of those early buildings are still is use today, after 75 years of service or more.

Beds of rock cropping out within the state also provided material with which to construct bridges both for the early wagon roads and the growing network of railroads.

As the transportation system was improved, lumber became more readily available, and the importance and significance of stone began to wane. The development of cement and increased use of concrete contributed to further decline in importance of stone for many uses. As time went by, the use of stone in residential construction continued to decrease, and stone became primarily a material for the construction of commerical and public buildings. This remains true today, although in recent years there has been some return to the use of natural stone as a veneer material in residential construction.

In recent years, production of building stone in the United States for all uses has shown a marked increase. The total production in 1956 was estimated by the United States Bureau of Mines at slightly more than 20,000,000 cubic feet having a value of $50,000,000. Table 1 shows the kinds and quantities of stone

TABLE 1.—*Building stone sold or used by producers in United States*[1] *in 1956, by kind*

Kind	Cubic feet	Value
Granite	1,380,623	$ 6,856,925
Basalt	705,108	322,092
Marble	981,887	8,837,470
Limestone	10,143,500	19,773,225
Sandstone	6,698,041	12,390,508
Miscellaneous	436,031	2,605,008
Total	20,345,190	$50,785,228

[1] Includes Pureto Rico.
Source: U.S. Bureau of Mines.

produced and values of the various kinds making up this total. Limestone and sandstone accounted for about 83 percent of the total quantity produced and about 63 percent of the total value. In Kansas, limestone is most important by far, although sandstone also is produced for use in construction.

States leading in the production of dimension limestone, quantitatively the most important building stone, are shown in Table 2. Although Kansas production accounted for only 3 percent of the total value of dimension limestone produced in 1954, Kansas ranked fourth among producing states that year. Stone in all categories was produced in Kansas, but finished building stone far exceeded the other classes, both in tonnage and value.

Because the largest amount of building stone goes into nonresidential construction, a close relationship exists between the activity in such construction work and the quantity of building stone produced. Figure 1 compares nonresidential construction in the United States and building stone production. How closely the two parallel each other depends somewhat upon the type of nonresidential construction. Nonresidential construction indicated in the chart includes the following categories: commerical, educational and science, hospital and institutional, manufacturing, public, religious, social and recreational, and miscellaneous. It might be anticipated that construction in the commerical, manufacturing, and miscellaneous categories would use less building stone than construction of a more public nature, as seems to be borne out by the chart. Manufacturing, commerical, and miscellaneous building normally constitutes 50 to 60 percent of total nonresidential construction, most of which ordinarily is constructed of reinforced concrete or steel. In 1939, such buildings constituted 55.3 percent of the total construction. During the war years, construction in these categories reached a maximum of 88 percent of the total. Since that time, such construction has ranged between 50 and 60 percent, and a much closer parallel between construction and stone production may be seen on the chart.

Production of Kansas stone, except for minor variations, fairly closely paralleled that for the United States as a whole. Fluctuations from year to year are somewhat greater for Kansas than for the nation, probably because of the greater influence any large individual projects undertaken within the state during the year have on production in the small market area served. Production

FIG. 1.—Chart comparing production of dimension limestone in the United States and in Kansas with non-residential construction contract awards in the United States. 1935-1957.

TABLE 2.—*States leading in production of dimension limestone in 1954*

		Building											
		Rough				Finished (cut and sawed)		Rubble		Flagging		Total	
		Construction		Architectural									
State	Active plants	Short tons	Value	Cubic feet	Value	Cubic feet	Value	Short tons	Value	Cubic feet	Value	Short tons (approx.)	Value
Indiana	21	16,222	$96,918	2,498,519	$3,154,864	5,054,282	$11,427,362	49,556	$128,984	....	....	613,356	$14,808,128
Wisconsin	20	11,829	53,751	24,001	26,107	364,812	807,007	7,538	14,175	65,157	81,313	55,685	982,353
Alabama	1	....	....	72,652	97,549	154,370	703,869	1,322	1,322	....	....	18,349	802,740
Kansas	12	6,500	5,800	30,563	17,076	285,139	717,583	6,663	16,748	9,993	7,220	40,847	764,427
Minnesota	6	....	....	89,300	62,050	153,275	689,200	3,060	3,535	12,775	8,680	23,488	763,465
Texas	6	....	....	98,187	113,715	219,474	410,705	....	....	4,000	1,185	23,321	525,605

Source: U.S. Bureau of Mines.

TABLE 3.—*Dimesion limestone sold or used by Kansas producers during selected years, by kind*

		Building											
		Rough				Finished (cut and sawed)		Rubble		Flagging		Total	
		Construction		Architectural									
Year	Active plants	Short tons	Value	Cubic feet	Value	Cubic feet	Value	Short tons	Value	Cubic feet	Value	Short tons (est.)	Value
1940	13	32,030	$23,529	65,200	$12,080	(1)	(1)	64,860	$35,755	....	....	106,800	$114,157
1943	19	2,090	2,945	37,630	10,787	....	....	4,190	4,063	....	....	9,780	17,975
1945	15	4,650	6,996	....	....	....	....	2,630	2,420	....	....	7,280	9,386
1947	12	2,850	2,019	11,890	5,351	96,020	$210,249	5,220	19,758	710	$ 475	17,030	238,032
1950	17	6,070	92,650	104,100	58,955	191,290	508,717	12,430	22,691	7,210	2,062	44,220	685,075
1955	12	(1)	(1)	32,474	16,671	270,776	690,560	13,486	19,547	(1)	(1)	40,875	731,665

[1] Withheld to avoid disclosure of data on individual company operations.
Source: U.S. Bureau of Mines.

within the state has grown considerably since the low of 1945, but never has regained the volume reported for the year 1940.

Although the quantity of building stone produced in Kansas in recent years has never attained its pre-war heights, there has been a tremendous gain in the dollar value of stone produced. From a minimum of $10,000 reported in 1945, the value has risen to an average of well over half a million dollars in the years since 1951. A maximum of $825,000 was reported in 1952 (Fig. 2).

The greatly increased value of production as compared to quantity is partly due to the rising costs accompanying inflation, but this accounts for only a small part. Most of the increase in total value of production can be attributed, instead, to the increased proportion of finished stone. In 1947, more than 88 percent of the total value was in finished stone, and only 2.7 percent was the less expensive rubble (Table 3).

Nature has endowed Kansas with supplies of building stone adequate to last for many years. Many of the deposits, however, lie at considerable distance from large centers of population where the greatest demand can be anticipated. Most Kansas stone is used within the state, but some of it is shipped to surrounding states. Interestingly, very little Kansas stone finds a market in the Kansas City area, owing to the fact that more popular stones can be shipped in from other areas at the same or lower prices than the Kansas stone.

Building stone produced in Kansas comes from quarries widely scattered across the state. Their locations and the type of stone produced by each are shown in Appendix A. The individual quarry operations are described in the section on Kansas Resources.

Appendix B lists the stone processing plants of Kansas. Most of the companies operating the plants also have their own quarries. All of the plants turn out cut stone, and some manfuacture products ranging from the simplest forms of cut stone to the most intricate carvings. The larger plants contain such equipment as gang saws, circular saws, planers, guillotines, and carving tools.

STONE AS A BUILDING MATERIAL

General

In many of its former uses, building stone has been replaced to a large extent by concrete. Such things as retaining walls, foundations, culverts, bridges, curbings, and sidewalks in which stone commonly was used in the past are now constructed of concrete. Today, the use of stone is confined principally to the construction of churches, schools, monuments, institutions, and other buildings where its natural beauty and permanence make it

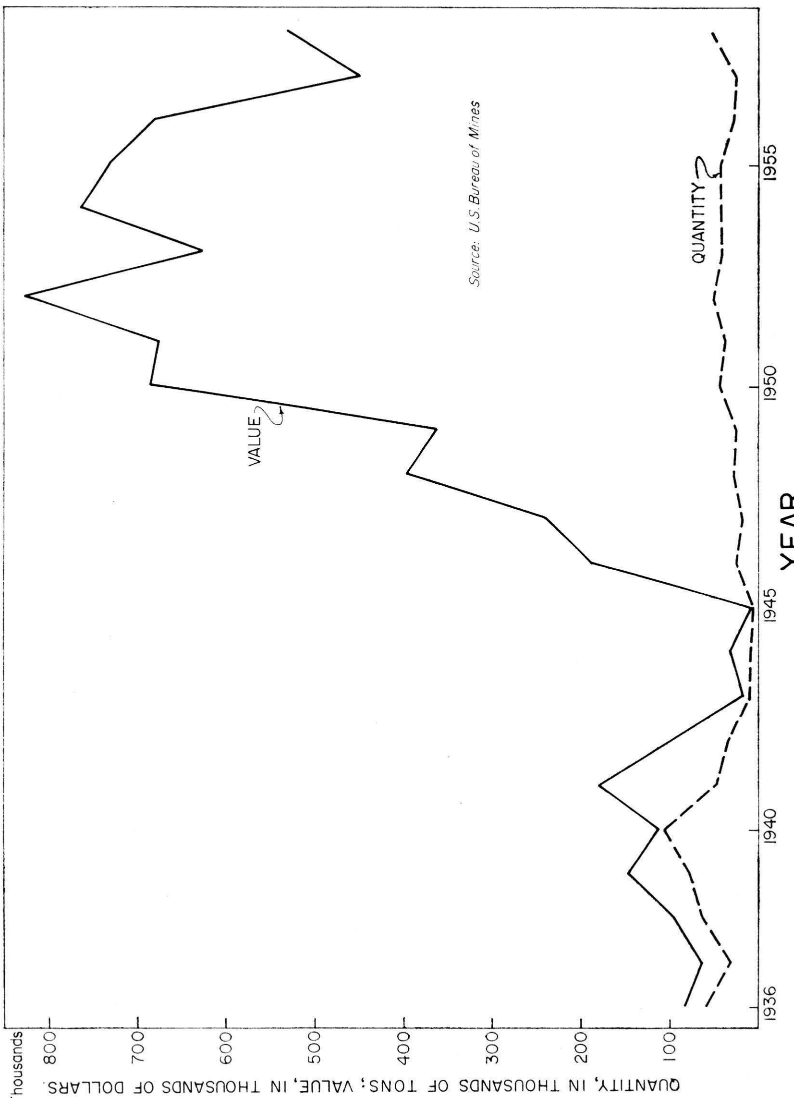


FIG. 2.—Chart of tonnage and value of dimension limestone sold or used by Kansas producers, 1936-1958.

especially desired. To an increasing extent, it also is being used as a veneer material in the construction of residences.

Whereas, in the past it was common to build entire supporting walls of large structures completely of stone, this is no longer the practice. Today, the supporting framework in most buildings is made of reinforced concrete or steel, and a veneer of stone is used as a facing.

Types of Building Stone

The term "building stone" may be broadly used to include any stone forming a part of a structure. The term is applied more generally, however, to cut or rough-hewn blocks forming the exterior walls of a building. Stone used for wall construction is classified as rubble, rough building stone, ashlar, or cut stone.

Rubble consists of fragments of irregular shape and size. Many such fragments have but one good face, and are laid in the wall so the good face is exposed.

Rough building stone is blocks of stone of various shapes and sizes. The blocks are hewn into rough shapes and fitted into the wall to form irregular joints, without definite design or pattern. In former years, construction with rough stone was common, but more recently the use of ashlar has replaced it to a considerable extent.

Ashlar refers generally to small rectangular blocks of stone having sawed, planed, or rough-faced surfaces, but not finished or accurately sized as are blocks of cut stone. Ashlar blocks may be of uniform length, but more commonly are of random lengths. They may be laid in an even-height course pattern, in which all the blocks of any course are of equal height, or in a random pattern in which blocks of two or more heights are fitted into a pattern. In random pattern, the various heights of blocks are such that the smaller blocks, combined with the standard mortar joint, make a height equal to that of the larger blocks. Some ashlar stone is cut on all six sides; more commonly, however, the exposed side has a rough unfinished face. It may be "broken-face" ashlar (sometimes known as split-face), in which the face presents a rough but fairly straight face, or it may be "pitched-face" in which the edges of the exposed face are chiseled back to leave a bulging or protruding face exposed. The back and ends of the block may be either rough or sawed.

Cut stone is stone carefully cut to a particular shape and size so that it will fit into a specified place in the structure. Frequently, such stone is shaped according to detailed drawings, and may be cut into blocks of various sizes and shapes or carved into intricate designs.

Another commonly used type of stone is known as *flagging*. Flat slabs, or flags, are sawed from blocks of stone by gang saws, or are obtained by splitting slabs from thin-bedded sandstone or limestone layers. Flagging is used principally for sidewalks and floors, but is also used as veneer on the exterior walls of houses and other small buildings. In this use, the flags may be placed on edge so that the large flat surface is exposed, or split into narrow strips and laid so that the edges are exposed.

Requisite Properties

To be satisfactory for building, stone must have those properties that make for strength, durability, and pleasing appearance. Its weight, hardness, workability, and mode of occurrence are features of major importance, also.

Strength

Most stones meeting all other requirements for building use also are sufficiently strong to withstand loads normally placed upon them. Most important in a stone is its *compressive strength* (i.e., crushing or bearing strength), which is a measure of the stone's ability to withstand weight placed upon it by the portion of the structure that it supports. The bottom course of stone in all buildings, and in structures such as bridge piers and abutments, must be able to support a considerable weight. Stones having a compressive strength equal to 5,000 pounds per square inch are satisfactory for almost any purpose; stones having considerably less strength have proved satisfactory for most ordinary uses. The load to which stone in a structure is subjected seldom exceeds a few hundred pounds per square inch. It has been estimated that the load supported by the base course of the Washington Monument is not more than 700 pounds per square inch (Bowles, 1939, p. 28).

In addition to compressive strength, stone used for some purposes must also have considerable *transverse strength*. Transverse strength governs the load-supporting ability of a length of stone supported only at the ends; it determines a stone's suitability for use as lintels to span windows, doorways, and similar openings.

Durability

A good stone must be durable. Its durability depends, in general, on its resistance to weathering and to mechanical wear or abrasion.

Abrasion resistance is dependent primarily on hardness. Hardness, therefore, may be of considerable importance if the stone is used where it is subjected to constant wear, as on floors or steps.

Any stone used in exterior surfaces must have resistance to weathering. One of the most importance factors in weathering is the effect of changes in temperature, especially those changes resulting in freezing and thawing. Repeated freezing and thawing of some stones tends to reduce greatly their compressive strength and may cause them to spall off and break down. It was thought, at one time, that susceptibility to such damage was dependent upon the porosity of the stone and the extent to which it absorbed water. Recently, it has become more generally accepted that pore size and ability to give up water are more important factors than resistance to the original absorption of water. Experiments by Lanning (1954, p. 383) led him to believe that the extent to which the individual pores remain unfilled when a stone is soaked by water is the important factor in resistance to freeze-thaw deterioration. He concluded that the air space remaining provided room for expansion as the water froze, and therefore reduced damage to the rock material itself.

Most stone when freshly quarried contains a certain amount of moisture, or sap, which is gradually lost as the stone is exposed to the air. If freezing occurs before this drying process is completed, the stone may be severly damaged, and such damage may not be apparent at the time but its effects will later become obvious.

Many stones tend to "season" or "case-harden" during the drying process that takes place after quarrying. This seasoning or hardening has been attributed to several causes. One of the most commonly accepted explanations is that quantities of the same kind of materials that form the binder cementing the individual grains of the stone together are held in solution in the water occurring naturally within the stone. When the freshly quarried stone is exposed to the air, the solution is drawn to the surface through capillary action, and the water evaporates, leaving the cementing material behind to form a protective coating at the surface of the stone. The weather-resistance of stone seems to be increased by this process. In some stones the case-hardening effect seems to be accentuated by further alternate saturation and drying (Flint and others, 1953).

In order to conserve the benefits of the case-hardening effect, cutting or carving of stone should preferable be accomplished while the nature moisture is still present within the stone.

It has been found that stones that are sufficiently durable for use as building materials in one climate may deteriorate rapidly if moved to another climate. This tendency has been especially noted in some stones native to arid regions when transferred to more humid areas. Stones affected in this manner should not be used in contact with the ground or in other places where they will be subjected to water or excessive moisture.

It has been found, too, in industrial areas, that contaminating elements in the air (probably mostly the products of fuel combustion, such as carbon dioxide, sulfur dioxide, and the oxides of nitrogen) mix with rain to form solutions that cause damage to stone surfaces.

Hardness and Workability

The effect of hardness on durability has been discussed. Of equal or perhaps even greater importance is the effect of hardness on the cutting or processing of a stone. Hardness, together with the uniformity of grain and the manner in which a stone fractures, are major factors governing the workability of a stone. This is especially true of a stone that is to be hand-tooled or carved.

The hardness of otherwise satisfactory stones may be too great to permit their use, because of the expense involved in cutting or carving them. Excessive hardness tends to retard the cutting rate and increase the wear on saws and other equipment. Production is slowed down, capital equipment and labor are less productive, and all costs tend to increase.

On stones that tend to case-harden, it generally is easier to perform the processing operations within a short time after the stone has been quarried than after drying.

Weight

The weight, or density, of a stone can be of considerable significance, especially if the stone must be shipped long distances. Weight also affects the ease with which the stone can be handled in processing and in laying.

Beauty and Color

Stone having all the other requisite properties of a good building stone may be unacceptable because it does not present a pleasing appearance. Major factors determining the attractiveness of a stone are texture and color.

Texture involves the composition, size, and uniformity of the individual grains that make up the stone.

The color of a stone is a blend of the colors of the individual minerals within it. A principal source of color is iron, in combination with one or more of the other elements.

Many stones tend to lose their original color after they have been exposed to the weather for a period of time. For example, some limestones that are light or bluish gray when freshly quarried tend to turn red, tan, or brown because of oxidation of ferrous iron within the stone. Browns and reds, in general, are the most stable of the colors, because in them the iron is already in ferric oxide form. To avoid stone that might attain a color not desired, one should examine weathered samples before a stone is used.

In large cities, smoke and dirt tend to stain and discolor stone. Although such stain may be removed periodically by sand-blasting or other means, it is a factor to be considered in the selection of stone for city buildings.

PRODUCTION METHODS

The production of stone for building use generally is accomplished in two stages: (1) quarrying operations, by which the stone is obtained from the earth, and (2) milling, or preparation procedures by which the stone is brought to the desired size and degree of finish. Under some conditions, it is possible to combine the two stages so that stone can be removed directly from the rock formation in the desired shapes and sizes.

Nearly all building stone is obtained from open quarries or pits; only a very small amount comes from underground operations. Underground operations normally are limited to production of stone of exceptionally high quality or other special characteristics, because of the extra expense involved in obtaining the stone.

Quarrying

The term quarrying is applied to the process by which stone is removed from the rock formation in which it naturally occurs.

Overburden Removal

Preliminary to all other phases of quarrying in surface operations is the removal of overburden. Soft or unconsolidated material covering the rock usually can be removed with scrapers or pushed aside with bulldozers. Where lack of space or the nature of the terrain makes it necessary to move the material from the quarry area, it usually is loaded into trucks by power shovels and hauled away.

Overburden consisting of solid rock requires a much more difficult stripping operation. Such material must be drilled and blasted before it can be removed. This blasting may be accomplished without difficulty where the waste rock and the desired rock are separated by beds of shale or by well-defined seams, but where waste rock forms part of the layer to be quarried, considerable care must be taken to ensure that rock desired for building stone is not damaged by blasting. Under these circumstances, the stripping process is as expensive as the actual quarrying. In some quarries a wire saw can be used successfully to make a horizontal cut to separate the desired rock from waste rock above it, and the waste can then be blasted without damage to the better rock beneath. In other places, in order to avoid damage to the stone it is necessary to quarry the adjoining waste material by the same method used to quarry the building stone.

Although the expense for removing overburden consisting of solid rock generally exceeds that for unconsolidated, the overburden may be suitable for crushing and marketing, thereby offsetting part of the cost.

The relation of thickness of overburden to that of the seam to be quarried is of extreme significance. A cost that might be justified in removing large quantities of overburden material to reach a thick deposit could easily make quarrying a relatively thin seam of even the best stone uneconomical.

Quarry Blocks

After the rock layer has been cleared of overburden, quarrying of the stone begins. The thickness of the layer of rock to be quarried governs to a large degree the types of stone that can be produced. Thin layers may be quarried for ashlar, rough building stone, or flags. For sawed, carved, or processed stone, the layer of rock must be not only thick enough to provide large blocks of stone but relatively free of cracks and planes of weakness.

Quarry blocks vary widely in size, and in general range from 4 to 12 tons in weight. Blocks quarried from the Fort Riley Limestone are the largest produced in Kansas (Pl. 1A). Most are 4 to 5 feet wide, 6 to 8 feet long, the full thickness of the layer of rock from which they are obtained, and range from 8 to 12 tons. Blocks quarried from other beds within the state are generally somewhat smaller.

Common practice is to dislodge quarry blocks from the rock formation either by blasting with a light charge of black powder or by wedging them loose with plugs and feathers. Within most rocks there is a direction of easiest splitting, commonly called the "rift". A second line, called the "grain" by most quarrymen, generally will be found running almost at right angles to the rift. To take advantage of the natural tendency to break more readily along these lines, it is customary to make the quarry face parallel to the rift.

When blasting is used in quarrying, a line of holes is drilled parallel to the face and at a distance from the face about equal to the thickness of the bed. The distance between holes is approximately equal to the distance from the face. The holes are drilled to a depth approximately three-fourths the thickness of the bed. A light charge of black powder causes a fracture along the line of holes and shoves the block slightly outward from the quarry face. The block may then be divided into smaller blocks by means of plugs and feathers.

Another means of obtaining quarry blocks is to cut them out with wire saws. In Europe and in several states in this country saws have been used for many years for quarrying stone from massive beds. Recently they have been adapted for use in Kansas at one quarry in the Fort Riley Limstone.

The wire saw consists of a special three-wire strand, which is spliced to form a loop, driven through a series of guide sheaves

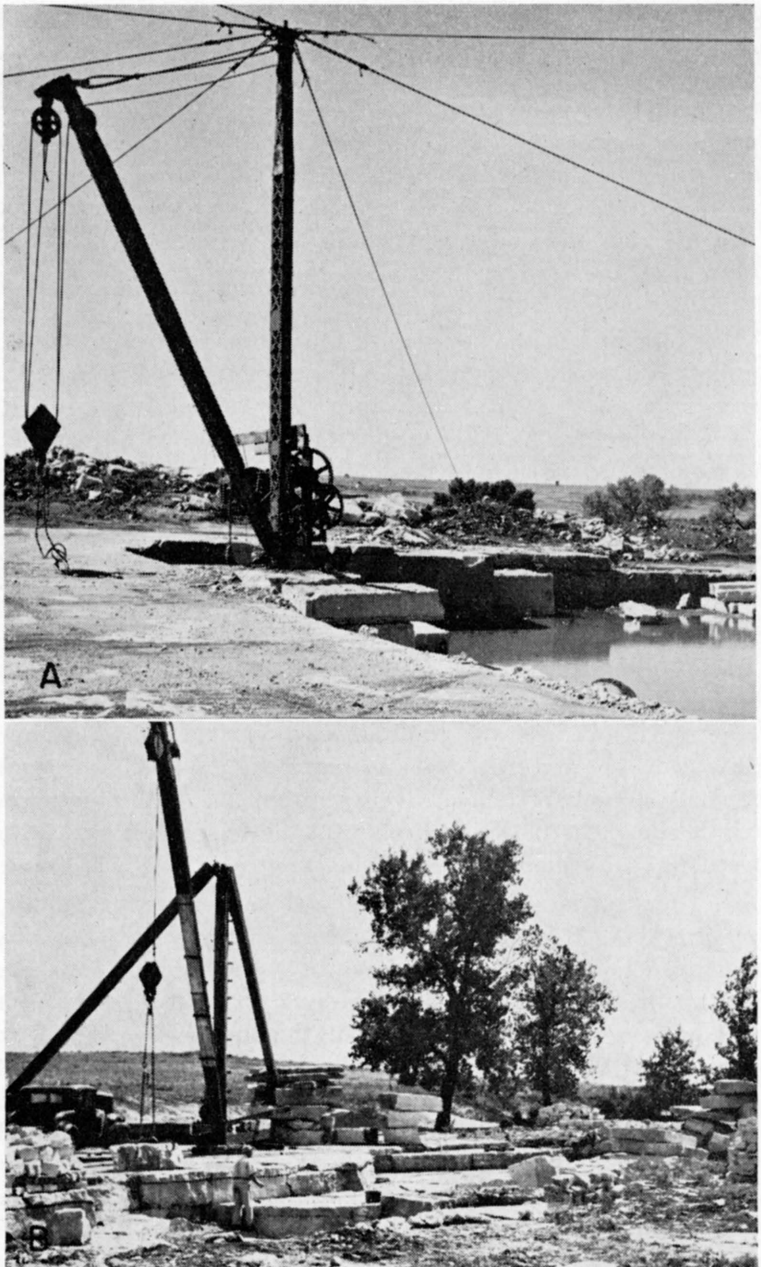


PLATE 1.—**A,** Fort Riley Limestone, Silverdale Cut Stone Quarry, Cowley County. Slabs as much as 3 feet thick have been taken from this quarry. **B,** Cottonwood Limestone, Lardner Quarry, near Cottonwood Falls, Chase County. Crane lifts blocks weighing several tons.

by a gasoline- or electrical-motor-driven pulley, geared to provide a rope speed of about 15 feet per second. In some quarries, a grooved drive pulley is used; in others a rubber-covered flat-faced pulley is used. Guide sheaves are mounted on slides to guide the wire accurately downward through the stone. These slides may be mounted at the edge of the ledge, or in large-diameter (3-foot) boreholes drilled to receive them. Fine sand or grit is fed into the end of the slot where the wire enters. The wire strand drags the sand particles along the groove, causing abrasive action that cuts through the stone.

The plug-and-feather system of quarrying is used in producing most Kansas dimension stones. The plug is a steel wedge, 4 to 6 inches long and about 1 inch thick. The feather is a thin strip of steel having one face flat to make full contact with the wedge and the other rounded to fit the sides of the drill hole. The feather tapers from a thin end, which curls outside the drill hole, to a thicker portion at the other end.

In quarrying with the plug and feather, a series of holes approximately 6 inches deep and 6 inches apart is drilled along the line on which the stone is to be broken. Two feathers are placed in each hole so as to exert pressure in the proper direction for splitting the stone, and a plug is driven between each pair of feathers. The wedges are gradually tightened, by driving them with a sledge, so that they exert a stress along the line in the stone. The stone splits in a comparatively straight line, with only minor irregularities. The blocks, generally about 4 or 5 feet wide, 6 to 8 feet long, and weighing several tons, are then lifted with cranes.

The thickest layers of rock quarried in Kansas for building stone are about 6 feet thick. This means that a larger area must be stripped to produce a given quantity of stone than would be necessary in thicker formations. The quarry procedure is simplified, however, by the fact that the full thickness of the rock layer can be taken in a single block. In the massive deposits of rock found in some states, it is necessary to cut or break the blocks loose from the rock formation on the bottom as well as on all sides. To accomplish this, a specially designed "channeling machine" cuts a 2½-inch vertical slot 8 to 10 feet deep and about 50 feet long, parallel to the quarry face and about 4 feet back from its edge. Next, a series of horizontal holes, pointed toward the bottom of the channel cut, is drilled along the face. Wedges driven into the holes split loose the bottom of a block 4 by 8 by 50 feet. The long block is then divided into smaller blocks about 10 by 4 by 4 feet. Blocks are produced from successively lower levels as the work progresses.

Before quarry blocks are sent to the mill for sawing or further processing, they are trimmed and squared to remove any excessive surface irregularities or projections, which would have to be removed as waste during the sawing or processing operation. This process, known as scabbling, is especially important when blocks are to be shipped so far that the expense of shipping waste material would be appreciable. Rough scabbling is done with picks. When more accurate scabbling is required, it may be done with saws.

After quarrying, the blocks are loaded and transported to the mill for processing. In large quarries, derricks having a capacity of 30 to 50 tons are used. Steel derricks having masts 110 feet high and booms 100 feet long are not uncommon in some parts of the country. In smaller operations, such as most of those in Kansas, steel or wooden derricks of lesser size are used satisfactorily. The size of the quarry blocks that can be produced is limited to what the lifting equipment can safely handle.

In many operations, cranes built on trucks are used to handle blocks weighing 3 or 4 tons. Blocks commonly are transported by rail or in heavy flat-bed trucks or semi-trailers.

Quarry Slabs

In some operations, slabs are cut directly from the formation by means of a wire saw. A single wire may be used to produce one slab, or multiple wires traveling in parallel paths can produce several slabs simultaneously. One Kansas stone company produces slabs from the Fort Riley Limestone as described below:

Bulldozers are used to remove overburden in preparation for quarrying. Where loosening of the overlying strata is required, this is accomplished by blasting. A square or rectangular area of 15,000 to 20,000 square feet is cleaned off. After the overburden has been removed, slabs several inches thick and approximately 80 feet long are cut from the ledge by means of a multiple wire saw. Three saw wires traveling parallel to each other cut slabs simultaneously (Pl. 2A).

PLATE 2.—**A**, Junction City Stone Company Quarry. Multiple wire saw cutting slabs of Fort Riley Limestone. **B**, Sawing direct-cut strips of "shell rock" in Simpson Limestone Quarry, near Simpson.

A drive assembly at one end and an idler assembly at the other guide the wires through the rock. In the idler assembly a sliding rectangular frame carrying the guide sheaves travels up or down vertically within another frame anchored rigidly in place. On the sliding frame are two horizontal shafts, one above the other, each carrying three 24-inch sheaves, which can be spaced along the shaft to give the desired slab thickness. The drive assembly also has a sliding frame, like that of the idler unit, to carry the wires through the cut, and a rigid support frame. Drive pulleys and take-up pulleys to provide tension are mounted in the rigid support frame.

The guide sheaves on the sliding frames of the power and idler assemblies are spaced at corresponding intervals on their respective shafts, so that full-length slabs of uniform thickness will be cut out between the wires. A gasoline engine, mounted on the unit, provides power, which is transmitted to the drive pulleys through rubber belts.

The figure of 80 feet as the most desirable length of cut results from the fact that by the time the 63-inch depth of the seam has been reached, the wire is sufficiently worn to be discarded. In order to maintain 80-foot faces, the quarry is divided into approximately 90-foot squares. After stripping, a 10 by 10-foot well is excavated to the bottom of the ledge approximately 90 feet from the face. The idler unit is installed in the well, the drive unit at the quarry face, and an alleyway is cut between them. The procedure is repeated to cut a second alleyway, 80 feet from the first and parallel to it. The units are then moved to make cuts at right angles to the alleyways. As successive slabs are cut, the units are gradually shifted inward.

In starting the cut, the frame on each unit is raised until the lower guide sheaves are above the top of the ledge. A wire is threaded through each set of pulleys (drive pulley, guide sheaves, and take-up pulley), the ends are spliced together to form a loop, and take-up pulleys are tightened to remove slack in the wire. The wires are put in motion and gradually lowered to the top of the ledge. Sand and water fed onto the wires are dragged along the ledge, gradually cutting through the rock. Cutting to the full depth of the 63-inch ledge requires about 14 hours.

When the cut has been completed the outer slab is turned down onto the floor. Worn-out automobile tires, placed in a row along the face, form a cushion to prevent undesirable breakage of the slab. The slab then is divided into lengths that can be handled and moved away, so that the next slab can be turned down.

Direct-cut Blocks

Several procedures have been developed in recent years for sawing blocks of building stone directly from the bed of rock. This is accomplished by means of circular saws, which cut vertical slots on top of the bed of rock at the correct spacing and to the depth required to provide blocks of the desired size. When the thickness of the rock layer gives the desired block size, the cut block is merely lifted out; otherwise, the block, cut on four sides, is pried or wedged loose from the bottom. The same procedure is used to produce narrow strips of specified dimensions, which can then be broken into desired lengths (Pl. 2B).

Direct-cut blocks normally are obtained from relatively soft rocks that can be cut readily with circular saws. Diamond or carborundum saws commonly are used, although ordinary cordwood saws have been used successfully in the soft chalks of western Kansas. Saw diameters range from about 16 to 36 inches, depending on the depth of cut required.

Saws for direct cutting of blocks are driven by electric motors or gasoline engines ranging to about 30 horsepower. The position of the saw blade is adjustable so that it can be lowered into the rock as the cut begins and raised after cutting is completed. The saw unit is mounted on a small four-wheeled carriage, so that the saw can be moved forward as the cutting progresses.

Some saw carriages are rubber-tire mounted. More commonly, the wheels of the carriage are of steel and are flanged to travel on tracks. A length of track is laid parallel to the direction of cut. As each cut is completed, the track is shifted sidewise a distance sufficient to give the desired block thickness and is carefully positioned to provide a uniform spacing for the entire length of travel, and this procedure is repeated until the required number of slots has been completed in one direction. The track is then shifted in direction and a new series of cuts at right angles to the first is begun.

Flags

Flags, or slabs, are quarried from thin-bedded sandstones or limestones. The flags commonly are broken loose from the thin, relatively horizontal bed by the plug-and-feather method. They are then raised by wedging or prying. In some quarries, saws such as those used in the direct cutting of blocks are used to cut square or rectangular flags. The flags are then raised as with the rough split blocks.

Processing

Stone obtained from quarries in the form of blocks or slabs is sent to mills for processing into the sizes and shapes required. In Kansas, the quarry blocks or slabs commonly are lifted at the quarry by either truck-mounted cranes or stiff-legged derricks and are transported to the mill by truck.

All mills must have some mechanical means of lifting the large masses of stone that are handled in processing and in preparation for shipment. In big mills, large-capacity overhead traveling cranes generally are used. Crane tracks may extend from one end of the plant, where blocks are brought in by trucks or railroad car, to the other, where the final stages of processing are completed. Light traveling cranes or jib-type cranes may be used for intermediate transferring of the lighter-weight loads after processing has begun.

Operations at the mill include drafting and pattern making, sawing, splitting, planing, turning, fluting, cutting, carving, and packing for shipment. Those operations performed in Kansas stone mills will be described briefly below.

Plans and Pattern Making

Mills producing cut stone must have drafting facilities for making accurate drawings of each separate size and shape of stone required in a given structure. Full-scale patterns are provided for carvings and intricate designs.

As each piece of stone is cut and shaped, it is marked with an identifying number to be fitted into a specific place in the structure according to detailed plans.

Sawing

Large mill blocks brought into the mill are sawed into slabs of whatever thickness may be desired, generally at least 2¼ inches. Stone having distinct bedding planes is normally turned on edge, and saw cuts are made parallel to the natural bed. Slabs from the outer edges of the blocks (called "rough backs" because only one surface is smooth) are sold as flagstone or for similar

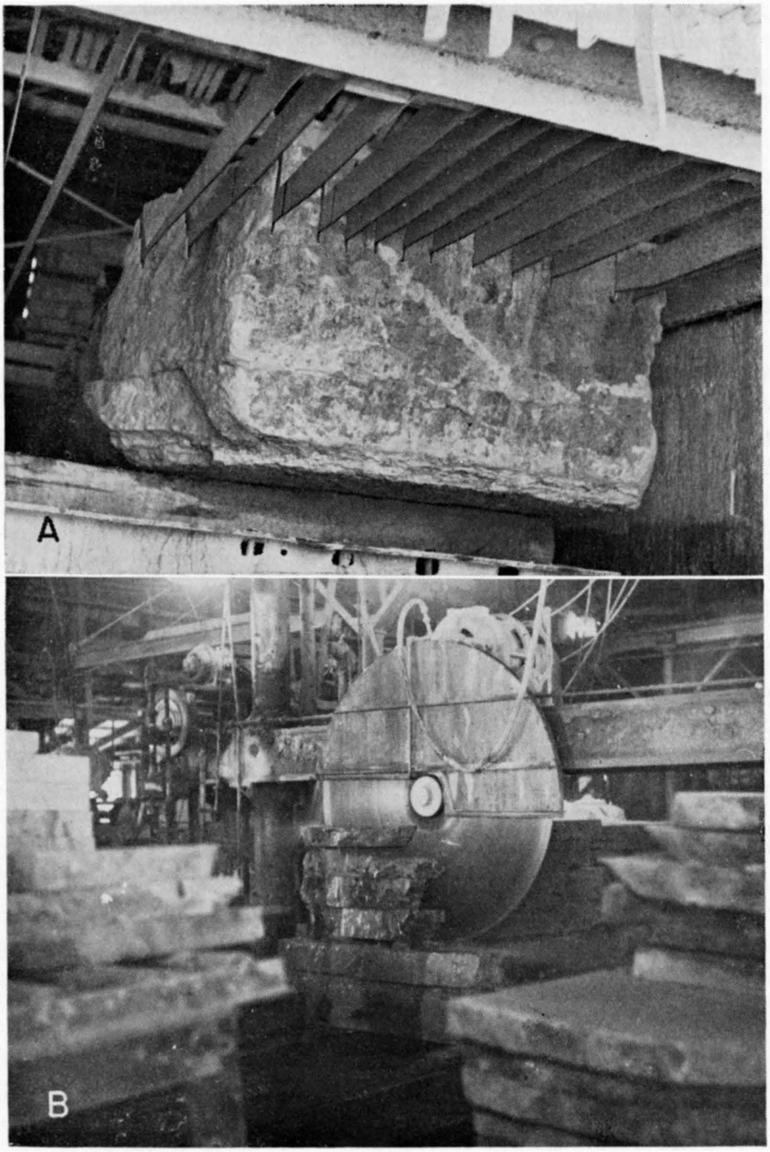


PLATE 3.—Fort Riley Limestone. **A,** Gang saws cutting slabs of stone, Silverdale Limestone Company. **B,** Circular saw trimming cut slabs of stone, Walker Cut Stone Company plant, Junction City.

purposes. The other slabs are processed further into veneer or into cut or carved stone.

Gang saws.—Blocks generally are cut into slabs by gang saws, although large-diameter circular saws may be used. Gangs of ¼-inch by 4-inch flat steel blades are arranged in parallel and fastened lengthwise into a rectangular steel frame about 8 feet by 12 feet (Pl. 3A). The frame is suspended on four rocker arms, which carry it in a lengthwise pendulum-like motion. The rocker arms at each end of the frame swing on a shaft, which is gradually lowered by feed screws as cutting progresses. A long timber pitman arm connects the swinging frame to a crankshaft, which gives it a swing stroke of approximately 18 inches.

To begin a cut, the saw frame is raised, and a small tram car, carrying the block of stone turned on edge, is run into position beneath the saw blades and blocked in place. The saw is then lowered to the stone and sawing begins. Water and sand or shot, fed down past the blades, wash into the saw grooves. As the blades rise at the end of each swing, the sand drops into the slots beneath the blades. Under the pressure of the blade, the sand gradually wears a slot through the stone, and the water washes away the cuttings.

Circular saws.—Large circular saws sometimes are used for cutting slabs from blocks; more commonly they are used in further processing slabs cut by gang saws (Pl. 3B). Diamond saws consist of steel discs ranging from 22 to 72 inches in diameter; industrial diamonds are set into their outer edge or into inserts, which are in turn fitted into notches in the edge of the blade. A stream of water sprayed on the cutting edge cools the blade and washes the cuttings away. Each blade is designed for a specified speed (usually 11,000 to 13,000 lineal feet per minute for the cutting edge) and should be run at the designated speed. In general, diamond saws cut at a rate of 3 to 16 inches per minute, depending on depth of cut and type of stone.

Large circular saws generally are classed either as ripsaws or jointing saws. Ripsaws are mounted in a stationary position, and stone is placed upon a movable deck beneath it. A worm gear actuates the deck to feed the stone into the saw. The jointing saw, traveling on a carriage actuated by a worm gear, is fed into the stone, which is placed on a stationary deck beneath the saw (Pl. 4A). The teeth of the jointing saw are finer than those of a ripsaw, and therefore make a smoother cut surface.

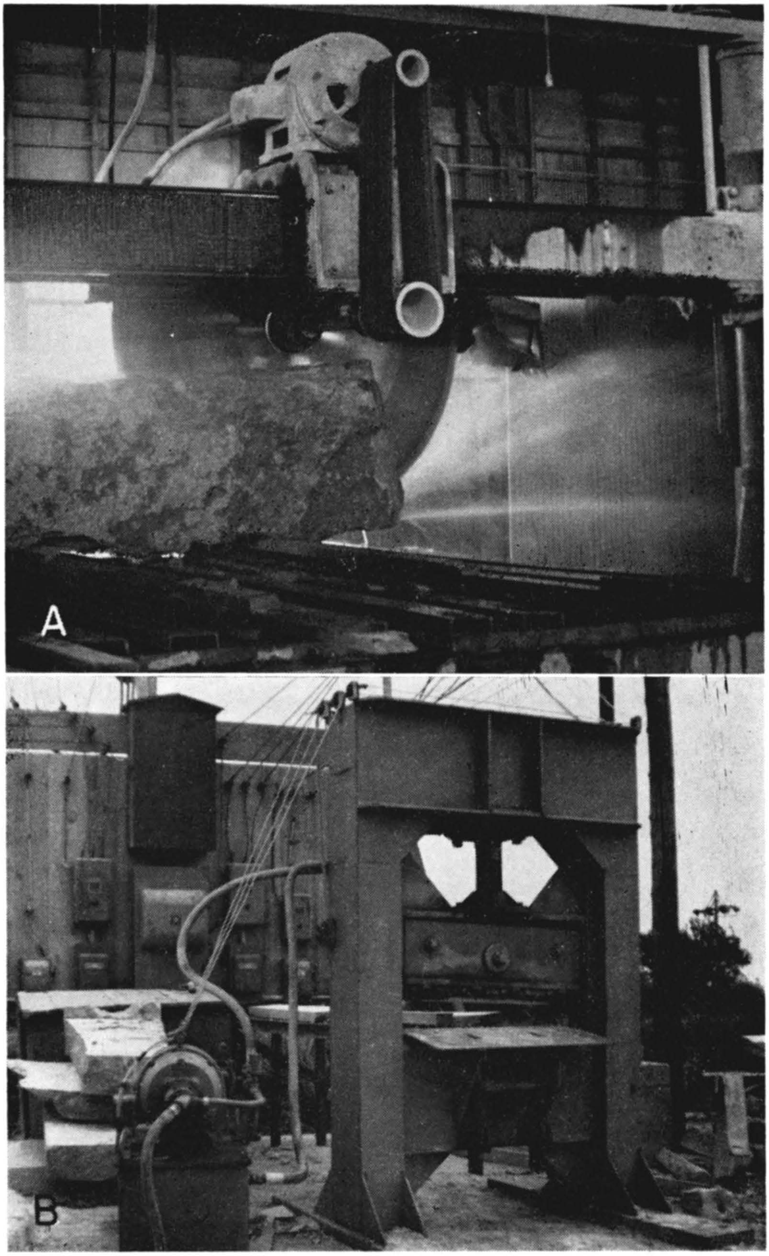


PLATE 4.—**A**, Circular jointing saw, Manhattan Cut Stone Company, Manhattan. **B**, Guillotine used for breaking slabs, Ervin Quarry, Cottonwood Falls.

Smaller circular saws, commonly not more than 24 inches in diameter, are used for trimming and other light cutting. Some of these saws are stationary, having a movable deck beneath them to carry the stone. Others are mounted on rails or guides and are moved across the material to be cut.

Planing

Stones used for lintels, window sills, cornices, moldings, and similar applications usually are shaped by planing. Two general types of planers, the common planer and the carborundum planer, are used.

The stone is clamped securely in place on the deck, or bed, of the common planer. Blades of correct size and shape are clamped into proper position with respect to the stone to be cut. The bed carrying the stone moves slowly toward the blade, which cuts or shaves material from the stone, producing the desired shape. If much material must be removed, several thin cuts are made instead of one deep cut. Either straight or curved surfaces may be produced. In cutting curved moldings, the blades are shaped in reverse of the shape desired.

Carborundum planers are rotating carborundum drums of proper shape to give stone surfaces the desired contour. As the bed advances, the drum grinds away the excess stone. The planer bed travels at 20 to 30 inches a minute and the entire cut is made in one trip.

Turning and Fluting

Round columns are turned on lathes similar to those used for metal or wood turning. Many lathes can handle columns as much as 30 feet long and several feet in diameter.

The block of stone to be turned is first scabbled to a roughly cylindrical shape and then is mounted in the lathe. As the stone block turns, a cutting tool, mounted on the bed of the lathe, moves along the length of the column. The lathe may be set to turn a uniform column or adjusted to vary the diameter of the column as desired.

Fluting is also done on the lathe. After being turned to the proper diameter (or diameters) the column is marked off for fluting. The column is held stationary for each cut while the fluting tool moves back and forth along it. Both blade-type and carborundum fluters are used.

Carving

Although saws, shapers, and grinders can produce large designs, small or intricate patterns require a different procedure and a high degree of skill. Architectural designs are drawn on full-scale patterns and transferred to the stone. Skilled craftsmen, using mallet and chisel or small pneumatic chippers, then gradually cut the stone into the desired form.

Splitting

Formerly, to make split-face or pitch-face veneer, it was necessary to split the gang-saw slabs by means of plugs and feathers. Guillotines, operated either by cam or hydraulically, are now used almost universally for this operation. Slabs of proper thickness are run between the blades of the guillotine and clipped off at the desired width. The upper blade moves downward onto the stone, pressing it against the lower blade (Pl. 4B). The tremendous pressure brought to bear on the stone by the blades causes it to break along a reasonably straight line.

The straight-edged guillotine blades that are used on sawed slabs are unsatisfactory for use in breaking sandstone flags, becaue of the uneven surfaces. The high spots bear the pressure of the straight blades, and the stone does not break in a straight line. To overcome this difficulty, blades have been developed that are made up of teeth individually actuated by hydraulic pressure and set to conform to the contour of the stone's surface. These impart a reasonably straight cut regardless of the irregularities of the surface.

Much of the split-face stone is transformed into pitch-face stone by chiseling back the edges of the broken surface.

KANSAS RESOURCES

Kansas building stones have been obtained from formations deposited over a wide span of geologic time (Table 4). The general areas over which rocks deposited during the various geologic periods are exposed are shown in Figure 3. A detailed description of the succession of rocks occurring in Kansas is given by Moore and others (1951). The geologic map of Kansas (Moore and Landis, 1937) shows the location of individual groups and many rock formations in the state; the Kansas Rock Column (Moore and others, 1951) describes rock units in order of stratigraphic position. Current classification and graphic representa-

TABLE 4.—*Outcropping rocks used as building stone in Kansas**

System	Series, group, or formation	Lithology and distribution	Rock used as building stone
Neogene ("Quaternary")	Pleistocene	Wide-spread surficial deposits including glacial deposits in northeastern Kansas. Thickness: 0 to 300 feet.	Boulders and cobbles contained in glacial drift and outwash in northeastern Kansas used locally in buildings.
Neogene ("Tertiary")	Ogallala Fm.	Mainly stream deposits on High Plains. Thickness: 0 to 250 feet.	Pisolitic limestone at top of formation used locally as building stone in Norton County. Slightly indurated "mortar beds" locally used in construction of small buildings. Opaline sandstone and massive opal also used locally, mainly by Works Progress Administration.
Cretaceous	Niobrara Chalk	In central and western Kansas. Thickness: about 600 feet.	Smoky Hill Chalk member quarried locally for building stone in one- and two-story buildings. Fort Hays Limestone member widely used in both large and small buildings in western Kansas, easily worked. Member is about 40 feet thick.
	Greenhorn Limestone	In north-central Kansas. Thickness: about 100 feet.	"Fencepost" limestone bed in Pfeifer Shale member extensively used in both small buildings and larger structures, as courthouses in Russell and Ellis Counties; uniform thickness of 8 or 9 inches; hardens on exposure to weather. "Shell-rock" bed at top of Jetmore Chalk member has been used locally for building construction. The rock is very similar to the "Fencepost" bed.
	Dakota Formation	In north-central Kansas; composed of claystone, siltstone, and sandstone. Thickness: 100 to 300 feet where exposed north of Rice County.	Sandstone beds cemented by iron oxide formerly quarried locally for numerous small buildings. "Lincoln quartzite" sandstone cemented mainly by calcite used locally near Lincoln, Lincoln County.

TABLE 4.—*Outcropping rocks used as building stone in Kansas,* continued*

System	Series, group, or formation	Lithology and distribution	Rock used as building stone
Permian	Upper Permian	In south-central Kansas. Mainly "redbeds", includes Day Creek Dolostone. Thickness: about 100 feet.	Dolostone bed at base of Day Creek. Dolostone little used as building stone.
	Middle Permian	In south- and east-central Kansas. Mainly "redbeds" in upper part, gray shale in lower part. Thickness: about 1800 feet.	Dolostone beds near top and middle are of slight local importance as building stone.
	Chase Group (Lower Permian)	In east-central and eastern Kansas. Mainly red and green shale and cherty limestone. Thickness: about 335 feet.	Chert-free layers of Winfield Limestone of Chase Group used locally in Cowley County as veneer. Massive bed in lower part of Fort Riley Limestone member of Barneston Limestone widely used near Junction City and Silverdale. The bed is 4 to 5.5 feet thick or thicker, readily cut; dimension stone blocks measuring 4 to 5 by 4 to 6 by 6 to 8 feet. Florence Limestone member of Barnestone Limestone formerly quarried, but contains abundant chert layers. Wreford Limestone formerly used to slight extent near Blue Rapids.
	Council Grove Group (Lower Permian)	Contains thinner and less-massive limestone than Chase Group; gray, red, and green shale. Thickness: about 320 feet.	Funston Limestone ("Onaga" limestone) of Council Grove Group widely used for both dwellings and public buildings. Quarried in Pottawatomie County; dimension blocks weigh about 3 tons. Cottonwood Limestone member of Beattie Limestone widely used as dimension stone. Member is about 6 feet thick; mainly middle and lower parts quarried; mill blocks approximate 2 by 2 by 8 to 10 feet. Neva Limestone member of Grenola Limestone used locally near Manhattan. Americus Limestone member of Foraker Limestone has had slight use locally for small buildings and bridge abutments.

TABLE 4.—*Outcropping rocks used as building stone in Kansas,* concluded*

System	Series, group, or formation	Lithology and distribution	Rock used as building stone
Permian	Admire Group (Lower Permian)	Consists mainly of shale, some limestone and sandstone. Thickness: about 130 feet.	Falls City Limestone of the Admire Group formerly used to slight extent in Brown County.
Pennsylvanian	Virgilian Stage	In eastern Kansas. Includes in descending order the Wabaunsee, Shawnee, and Douglas groups. The stage is about 1200 feet thick; composed principally of shale and limestone, lesser amounts of sandstone, and numerous coal beds.	Limestone and sandstone beds have had some local use as building stone in small structures. Toronto Limestone member of Oread Limestone in Shawnee Group has had extensive local use in and near Lawrence.
	Missourian Stage	Includes in descending order the Pedee, Lansing, Kansas City, and Pleasanton Groups. The stage is about 700 feet thick; composed mainly of shale and limestone, lesser amounts of sandstone, and numerous coal beds.	Westerville Limestone member of Cherryvale Shale in Kansas City Group, known locally as "Kansas City oolite", has been quarried for wide use in public and private buildings in and near Kansas City, Kansas and Missouri. Other limestone beds have had some local use for building stone.
	Desmoinesian Stage	Includes in descending order the Marmaton and Cherokee Groups. The stage is about 750 feet thick. The Marmaton Group is composed mainly of shale and limestone but includes sandstone and some coal. The Cherokee Group is composed mainly of shale and sandstone but includes coal and sparse limestone.	Bandera Quarry Sandstone member of Bandera Shale in Marmaton Group has been extensively quarried in southeastern Kansas mainly for flags and veneer stone, which have been used widely. Limestones in the series have had little use.
Mississippian		Crops out only in the southeast corner of the state.	Limestone from the Mississippian has not had appreciable use as building stone.

* Stratigraphic units that contain no useful building stone are omitted.

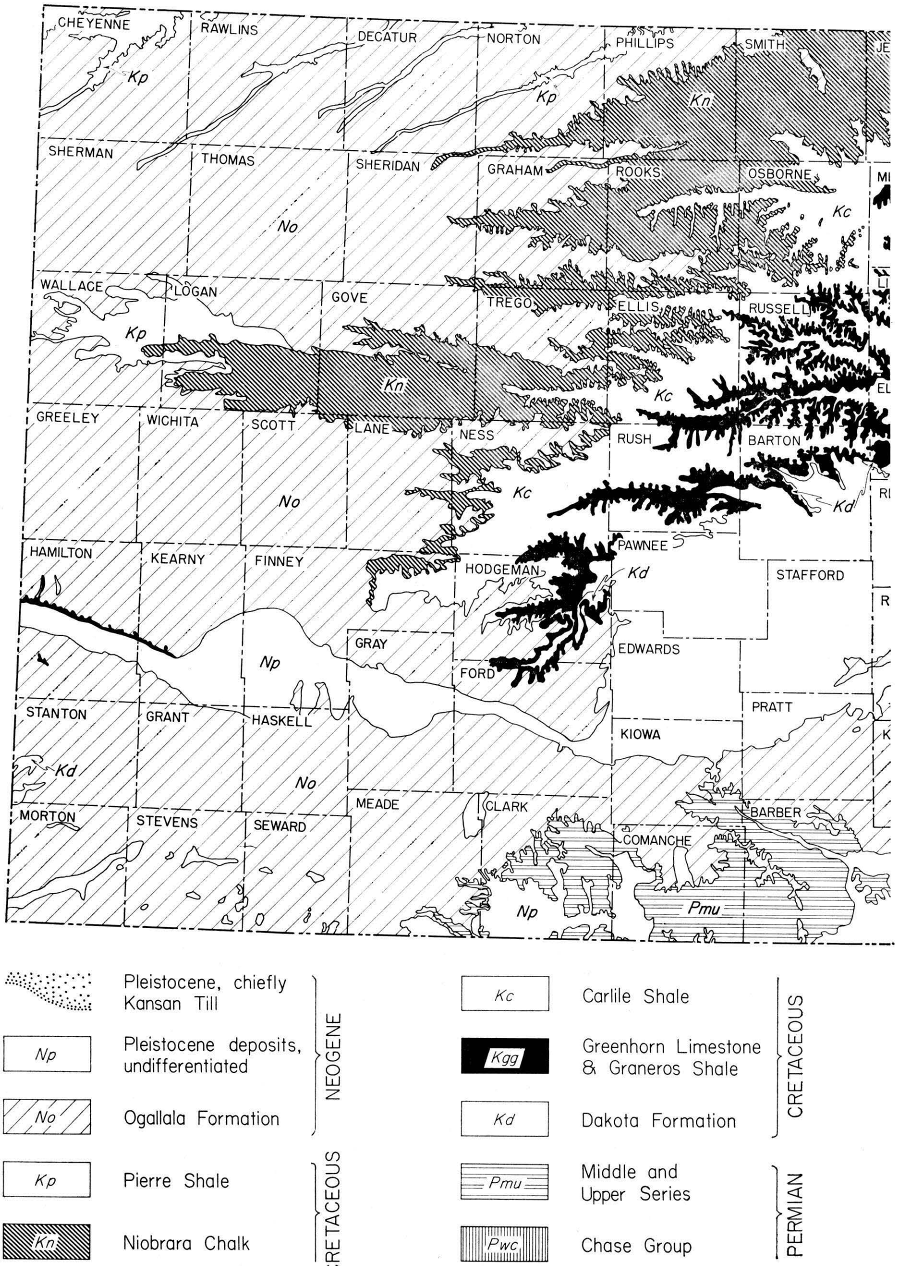
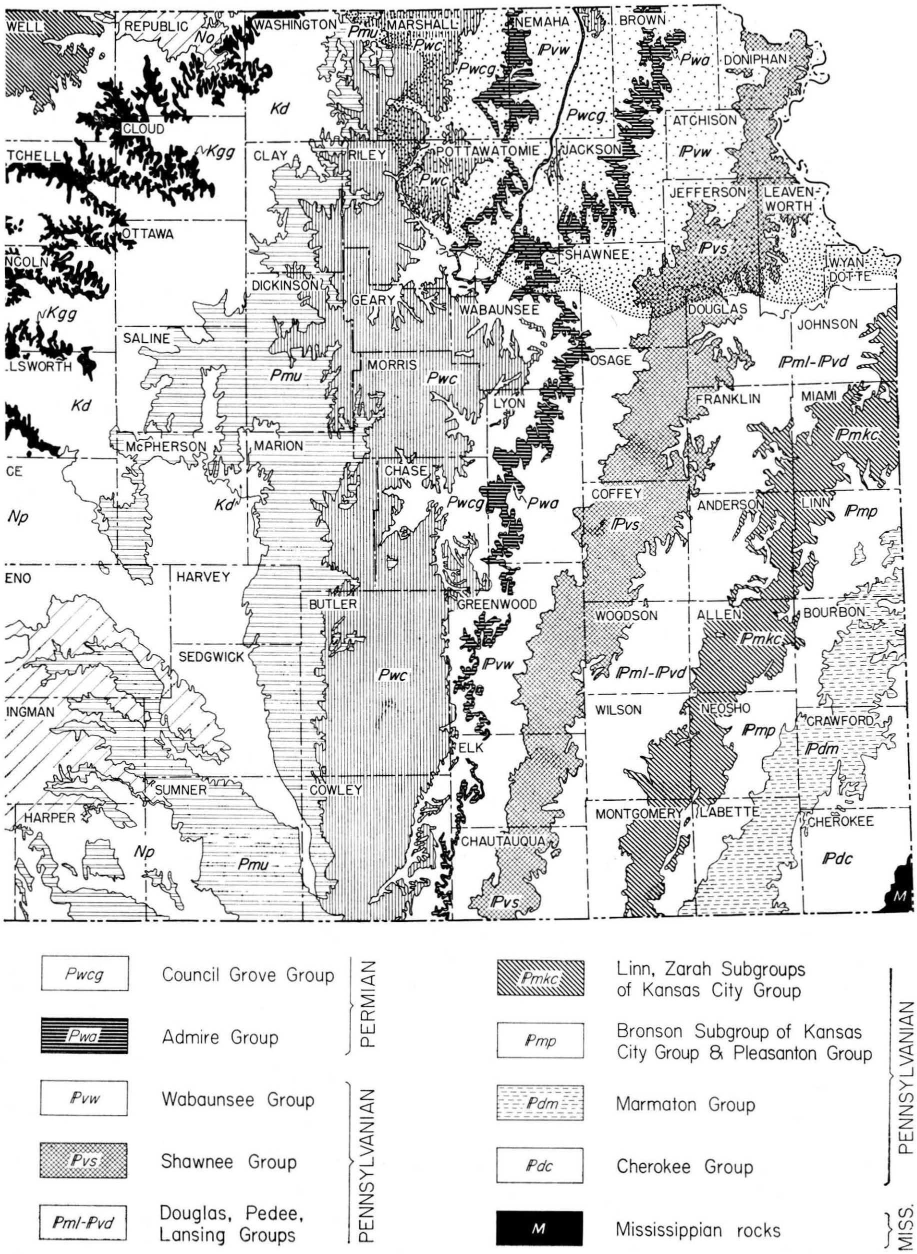


Fig. 3.—Generalized geologic map of Kansas indicating sources of building stone.


REPUBLIC
WASHINGTON
MARSHALL
NEMAHA
BROWN
DONIPHAN
CLOUD
CLAY
RILEY
POTTAWATOMIE
JACKSON
ATCHISON
JEFFERSON
LEAVENWORTH
OTTAWA
SHAWNEE
WYANDOTTE
DICKINSON
GEARY
WABAUNSEE
DOUGLAS
JOHNSON
SALINE
MORRIS
OSAGE
LYON
FRANKLIN
MIAMI
McPHERSON
MARION
CHASE
COFFEY
ANDERSON
LINN
HARVEY
BUTLER
GREENWOOD
WOODSON
ALLEN
BOURBON
SEDGWICK
WILSON
NEOSHO
CRAWFORD
ELK
SUMNER
COWLEY
MONTGOMERY
LABETTE
CHEROKEE
HARPER
CHAUTAUQUA
INGMAN
ENO
CE
Kd
Kgg
No
Np
Pmu
Pwc
Pwcg
Pwa
Pvw
Pvs
Pml-Pvd
Pmkc
Pmp
Pdm
Pdc
M
Pwcg Council Grove Group
Pwa Admire Group
PERMIAN
Pvw Wabaunsee Group
Pvs Shawnee Group
Pml-Pvd Douglas, Pedee, Lansing Groups
PENNSYLVANIAN
Pmkc Linn, Zarah Subgroups of Kansas City Group
Pmp Bronson Subgroup of Kansas City Group & Pleasanton Group
Pdm Marmaton Group
Pdc Cherokee Group
PENNSYLVANIAN
M Mississippian rocks
MISS.

tion of rocks in Kansas are shown on a published chart (Jewett, 1959).

Most Kansas building stone is quarried from Permian and Pennsylvanian rocks, although other rocks also yield small quantities. Limestone is the most important buiding stone, but to a lesser extent sandstone and glacier-deposited boulders or cobblestones also are used.

Neogene Rocks

"Quaternary" Deposits

"Quaternary" sediments in Kansas include the glacial deposits in northeastern Kansas and nonglacial deposits in all parts of the state (Moore and others, 1951, p. 13; Frye and Leonard, 1952). Especially near their margins, the glacial deposits have provided boulders and cobblestones used to some extent for building within Kansas. Most of these boulders are composed of pink to brownish-red Precambrian quartzite. They are extremely hard, but can be split or broken to provide a fairly flat face. More commonly, however, the rounded stones are fitted into walls without modification.

"Tertiary" Rocks

"Tertiary" deposits are widespread over most of the western part of Kansas. The major deposits make up the Ogallala Formation, consisting of gravel, sand, and silt (which in some localities are cemented with calcium carbonate and opal), limestone, volcanic ash, and bentonitic clay. The stratigraphy of the Ogallala Formation is described in detail by Frye, Leonard, and Swineford (1956).

At the top of the upper (Kimball) member of the Ogallala, a dense, hard, nodular, pisolitic limestone occurs locally (Swineford, Leonard, and Frye, 1958). This limestone has been used to some extent for buildings in Norton County and other counties of north-central Kansas. A church in New Almelo was constructed from this material, reportedly quarried in Graham County (Byrne, Beck, and Bearman, 1949, p. 15).

Pisolitic Ogallala limestone can be worked, but it is dense and nodular and contains abundant quartz grains. Ranging from grayish white to pink when freshly broken, it turns dark gray when exposed to the weather. It resists weather reasonably well in a dry climate.

Massive opal from the Kimball Member of the Ogallala Formation was used by the Works Progress Administration in construction of the municipal building in Bird City, Cheyenne County. The rock, which is hard, dense, nodular, and intensely fractured, was quarried about 5 miles south of McDonald, Rawlins County.

Found locally in the rest of the Ogallala Formation are the "mortar beds", consisting of loosely cemented lenses of gravel, sand, and silt. These "mortar beds" have been the source of material used to some extent locally in the construction of farm and school buildings in the north-central part of the state (Byrne, Beck, and Bearman, 1949, p. 15). A typical building of this material is the grade school building at Traer, Decatur County. Material from the "mortar beds" is not uniformly hard, hence the stone becomes pitted when exposed to the weather; damp weather caused rapid deterioration. Because of its lack of resistance to weathering, the material is generally unsuitable for building stone.

Opaline sandstone (Frye and Swineford, 1946) occurring within the Ogallala Formation has also been used to some extent for building in north-central Kansas, mainly by the Works Progress Administration. Several public buildings, including the Norton County Highway Department shops and the Norton Public Library (Pl. 5A) and the high school building at Hill City, Graham County, have been constructed of this material by the Works Progress Administration. The stone occurs in small quantities as lenses in the lower part of the Ogallala Formation. It has a shiny greenish color, which does not alter appreciably when exposed to weather. Opaline sandstone is strong and very weather resistant, but its hardness and the difficulty of working it make its commerical value questionable.

Cretaceous Rocks

Rocks of the Cretaceous System are exposed in Kansas chiefly in the western half of the state. They are of marine origin, with the exception of sandstone from the Dakota Formation and the Cheyenne Sandstone. Silty and calcareous clays and shales constitute the greater part of the rocks of the Cretaceous System, but sandstones and fine-grained, platy and chalky limestones are also present (Moore and others, 1951, p. 21; Plummer and Ro-

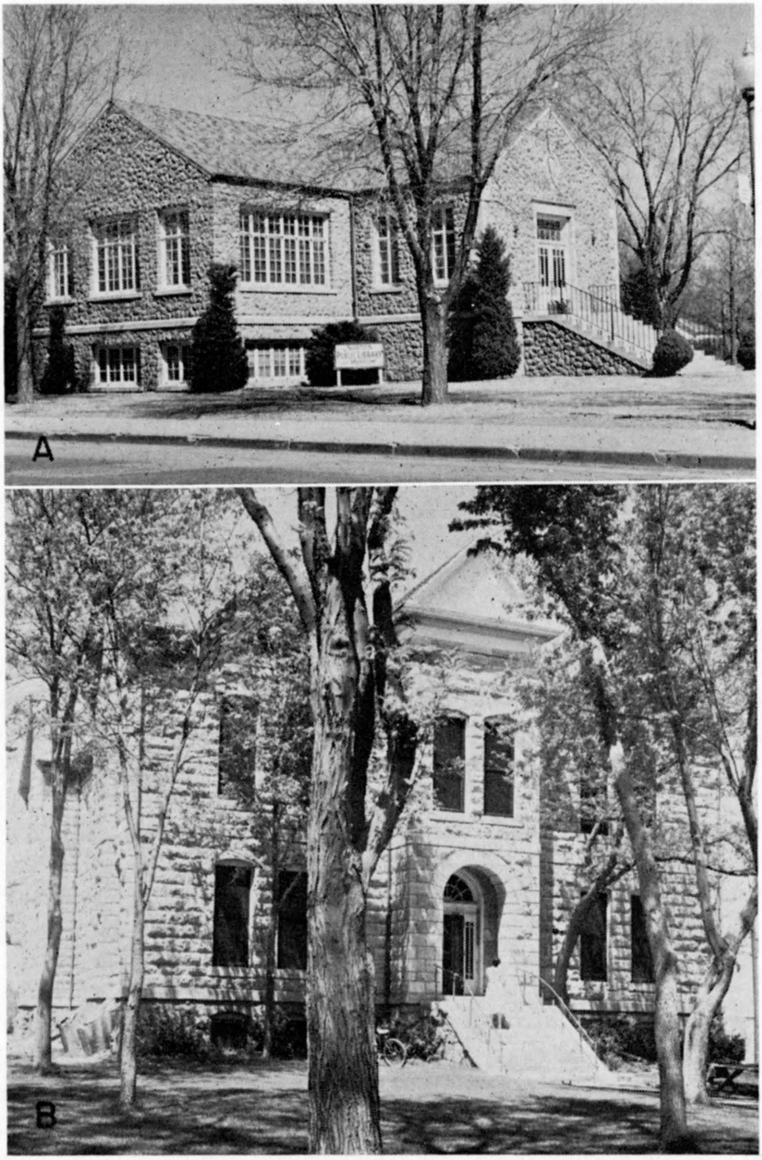


PLATE 5.—**A**, Norton Public Library and Museum, built of rough opaline sandstone from Ogallala Formation. **B**, Greeley County Court House at Tribune, built of Fort Hays stone.

mary, 1942). In general, the rocks dip gently toward the west, but locally may dip in any direction. The total thickness of the Cretaceous rocks in Kansas is about 2,750 feet.

The Cretaceous rocks most suitable for use as building stone occur in the Niobrara Chalk, which averages about 600 feet in thickness. The Smoky Hill Chalk member and the Fort Hays Limestone member (Pl. 5B) have each provided large amounts of stone for building in north-central and western Kansas (Runnels and Dubins, 1949).

The Smoky Hill, the upper member of the Niobrara Chalk, consists of alternate layers of chalk and chalky shale. The individual beds, which contain numerous limonitic concretions, range from about 1 inch to 18 inches in thickness. The Smoky Hill Chalk crops out in a belt extending from Phillips County in north-central Kansas southwestward to the Arkansas River valley in Ford County, where it is covered by river deposits of sand and gravel, and also farther south in Clark and Meade Counties.

The Smoky Hill stone is gray when freshly quarried, but weathers white, yellow, or orange (Runnels and Dubins, 1949, p. 7). It withstands weathering well only when used in dry places, and water causes it to deteriorate rapidly either by slaking or by freeze-and-thaw. For this reason, the Smoky Hill stone is not recommended for use in humid climates, or for bridge abutments or other places where it would come in contact with moist ground. Although of slight compressive strength, it has been used satisfactorily in one- and two-story buildings.

Smoky Hill Chalk has been quarried in many places along its outcrop. Because of its ready availability and the ease with which it can be cut, it was used extensively in the past. Examples of its use in the early days are seen in Smith, Norton, Wallace, and adjacent counties. The municipal auditorium at Leoti (Pl. 6A) and the 4-H Club building in Tribune, Logan County, demonstrate more modern use.

Both the Smoky Hill Chalk and the Fort Hays Limestone have been quarried by cutting building stone directly from the formation. Ordinary cordwood-saw blades 24 or 30 inches in diameter are used, driven by 20- to 30-horsepower gasoline engines. The saw unit is track mounted, and the size of blocks is regulated by the spacing and depth of the cuts. After slots are cut in one direction, a second series is cut at right angles to the first. The blocks, having been cut on four sides, are then easily broken loose from the bottom by prying or wedging. Although blocks of almost any size and shape may be cut, it is customary to make the slots 16 inches deep and to space them so that an 8 by 8-inch block is cut out. By breaking the bottom loose at the 16-inch depth, an 8 by 8 by 16-inch building block is obtained, which is the same size as a standard cement block.

Blocks may be further trimmed or finished on the ends or sides. To finish the surfaces and remove saw marks, a lumber planer may be used. Blocks produced by this method of quarrying are small enough to be hand-loaded into trucks for transportation from the quarry.

The Fort Hays Limestone, the basal member of the Niobrara Chalk, lies below the Smoky Hill Chalk stratigraphically and crops out in a belt roughly parallel and to the east of that of the Smoky Hill Chalk, and is about 40 feet thick. Prominent outcrops may be seen along the south bank of Saline River about 10 miles north of Hays, Ellis County, especially at Cedar Bluffs, and in many other places nearby.

The Fort Hays Limestone is similar to the Smoky Hill Chalk in character and appearance. It is a chalk or chalky limestone, gray to cream color, consisting principally of thick beds separated by thin beds of light- to dark-gray chalky clay shale. Individual beds range from 2 inches to 4 feet in thickness.

The Fort Hays stone is nearly as soft as the Smoky Hill and is easily worked. It withstands weathering very well in the climate of western Kansas, but deteriorates rapidly when subjected to water saturation.

Many buildings have been constructed from Fort Hays Limestone. Examples are particularly numerous in the vicinity of Hays, where it has been used in the construction of buildings on the campus of Fort Hays State College. Historic examples of its use may be found in the block house and guard house still standing on the site of old Fort Hays, just south of the city of Hays.

At present, the stone is produced intermittently from a quarry on the west side of U.S. Highway 183, about 2 miles north of Hays, in the SE¼ sec. 16, T. 13 S., R. 18 W. It is sawed directly from the bed to form building blocks, by the same method that has been used for processing the Smoky Hill stone.

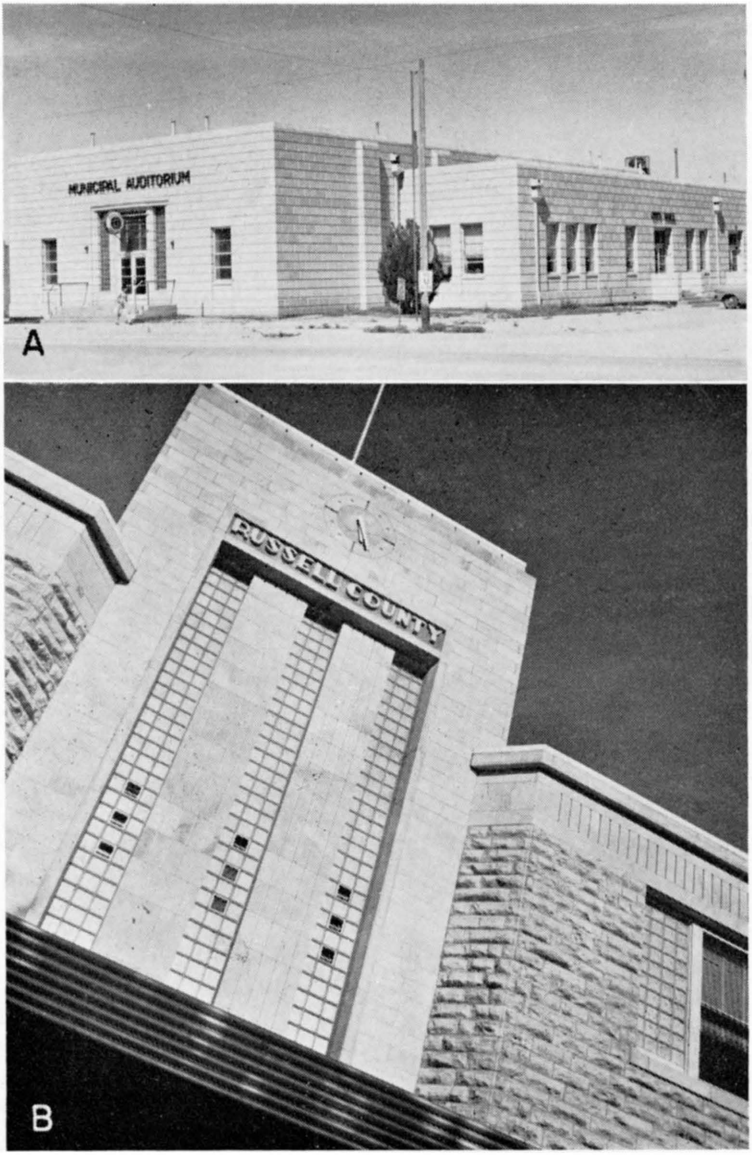


PLATE 6.—**A**, Municipal Auditorium at Leoti constructed of Smoky Hill cut stone. **B**, Russell County Court House. "Fencepost" limestone, combining pitch-face ashlar and cut stone.

Below the Niobrara Chalk lies the Carlile Shale, and beneath it the Greenhorn Limestone. Within the Pfeifer Shale member of the Greenhorn Limestone is the "Fencepost" limestone bed, used extensively as a source of building stone throughout the area of its outcrop (Byrne, Combs, and Bearman, 1949, p. 17).

The "Fencepost" limestone occurs as a single bed or layer. It crops out in a broad belt extending from Washington and Republic Counties in northern Kansas southwestward to Hodgeman and Pawnee Counties.

The "Fencepost" limestone has a remarkably uniform thickness of 8 to 9 inches. It is soft when freshly quarried, but the hardness increases upon seasoning or "case-hardening". The stone is blue gray and weathers to light tan. In the middle of the bed is a reddish-brown streak about 2 inches thick, which is considerably harder than the rest of the rock.

Many examples of the use of the "Fencepost" stone may be found in structures throughout the area of its outcrop. Two notable examples of modern use are the Russell County Court House at Russell (Pl. 6B) and the Ellis County Court House at Hays. In the former, the stone has been laid on its natural bed in pitch-face ashlar pattern; in the latter it has been cut to provide a smooth-faced stone. Another excellent example of its use as cut stone is found in the new addition to the First Methodist Church at Hays. Many other buildings are constructed from the "Fencepost" stone, notable among which are the Cathedral of the Plains, Victoria, Ellis County, and the Mitchell County Court House at Beloit (Pl. 7A).

Old buildings constructed of the "Fencepost" limestone indicate good resistance to weathering in the comparatively dry climate in which it has been used. Its suitability for use in a more humid atmosphere or in places where it is exposed to excessive moisture might be questioned. It has been found that the stone offers much less resistance to weathering when laid as "shiners" (perpendicular to the natural bed) than when laid on the bedding plane. This tendency toward deterioration may be especially noted in buildings where the stone has been used in both positions and direct comparison can be made. In recent years, it has been the practice to saw or split the stone along the hard red streak in the middle. The stone is then laid so that this harder

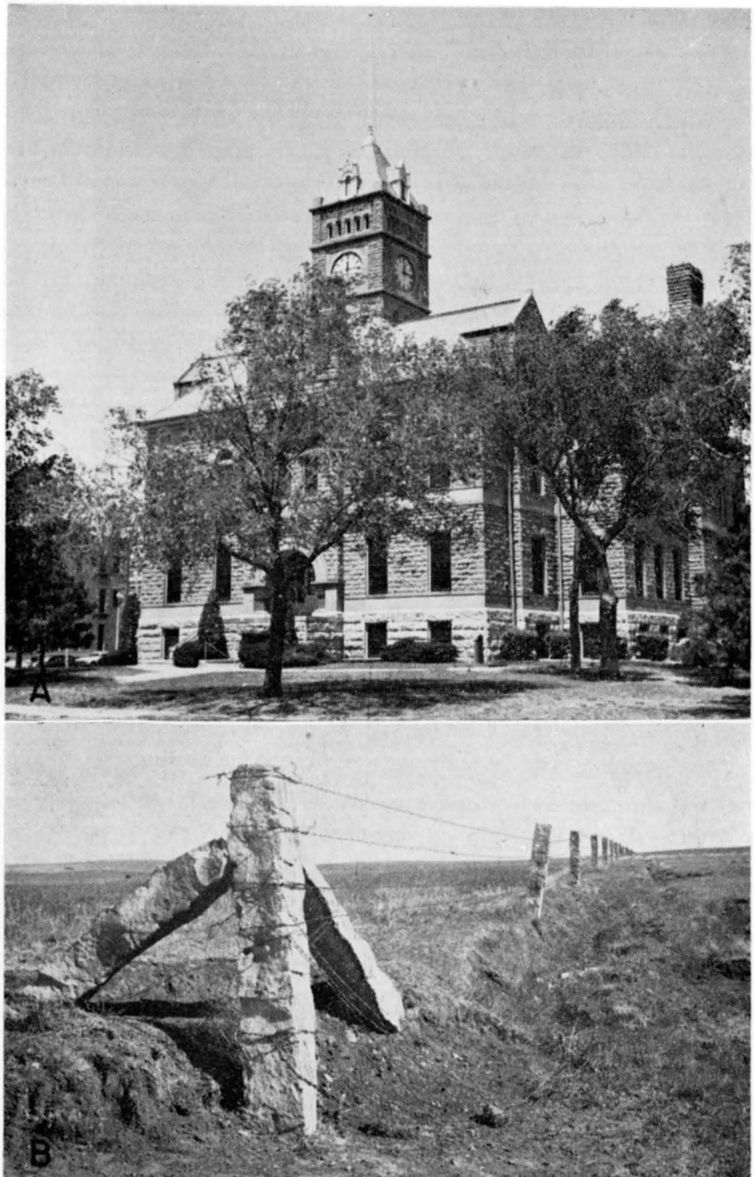


PLATE 7.—"Fencepost" limestone. **A**, Mitchell County Court House built at Beloit in 1901. **B**, Stone fenceposts, Lincoln County.

portion is exposed to the weather. It is supposed that this surface offers much greater resistance to weathering.

The name "Fencepost" limestone comes from the fact that strips of this stone formerly were used extensively as fenceposts in western Kansas, and many of these posts still remain in use today (Pl. 7B). In some places, telephone poles also have been formed from this material. Posts were obtained by drilling parallel rows of holes in the rock and breaking the stone into long strips by means of plugs and feathers, as described in the section on Quarrying. Lying almost level in the comparatively flat terrain in this part of the state, the "Fencepost" bed occurs in many places under very little overburden. As a result, in former years, new quarries were opened whenever overburden in excess of about 3 feet was encountered. Introduction of modern equipment, capable of stripping to a greater depth than formerly, makes it more economical to quarry from under several feet of cover than to move so frequently.

The "Fencepost" stone, like the Smoky Hill and Fort Hays, is quarried by sawing directly from the formation, but because of its greater hardness, a diamond blade is used instead of an ordinary blade in cutting. The blade, 30 inches in diameter, is driven by a 30-horsepower gasoline engine and is mounted so that it can be raised or lowered as desired. The unit is mounted on a wheeled carriage, which travels on tracks.

In operation, the overburden is stripped to provide a clean working floor, and a support rail is laid at each end of the area to be cut. A track is laid perpendicular to the two support rails, one end of the track resting on each rail. A slot is cut along the full length of track, and the track is then shifted to a new position on the support rails. Each slot is cut to the full depth of the ledge. Proper spacing of the track position gives slabs of the desired ashlar course height and 8 inches deep. The 8-inch slabs are next split down the center to form 4-inch ashlar veneer.

A limestone bed, the "shell-rock" bed (Pl. 2B), similar in lithology to the "Fencepost" limestone but lacking the brown zone, has been used as trim in construction of a motel in Lincoln, Lincoln County. The "shell-rock" bed lies approximately 20 feet below the "Fencepost" bed, at the top of the Jetmore Chalk member.

Below the Greenhorn Limestone lie the Graneros Shale and

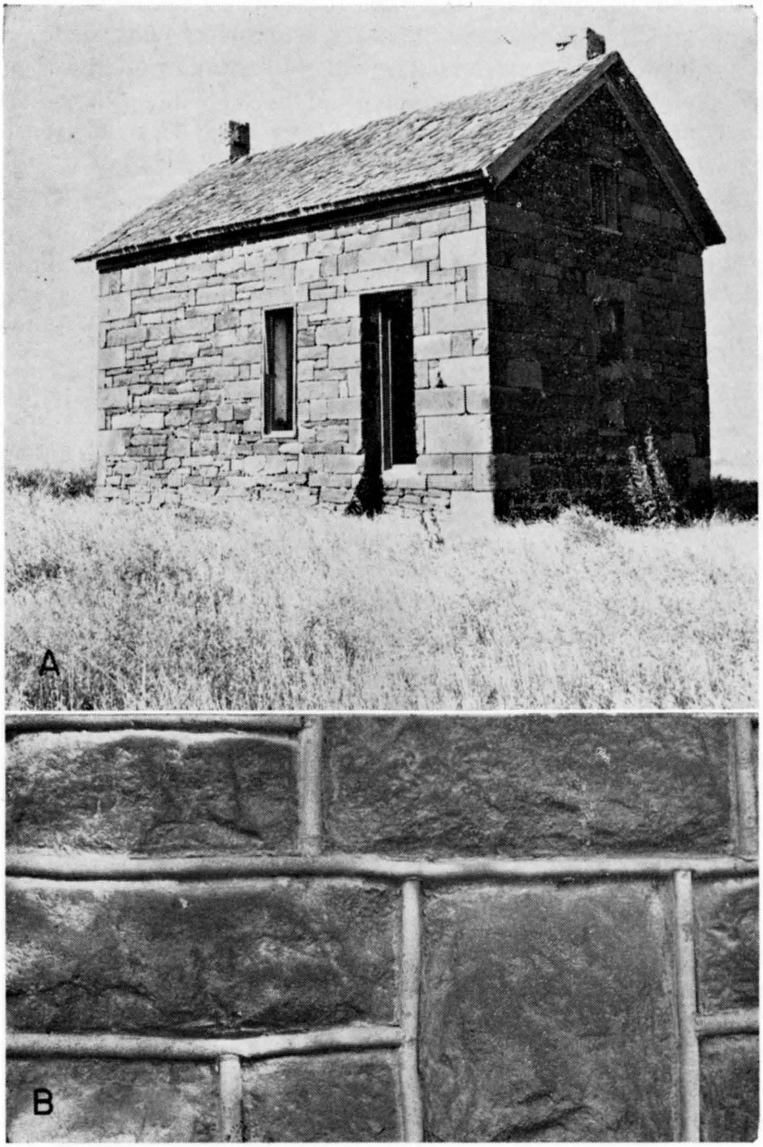


PLATE 8.—Dakota Formation **A**, Old house in Ellsworth County, constructed of sandstone. **B**, Sandstone used in the Holy Apostle Episcopal Church, Ellsworth.

then the Dakota Formation. The Dakota Formation, some of the sandstones of which are described in detail by Plummer and Romary (1942) and Swineford (1947), consists of clay, shale, silt, and sandstone. The sandstone layers are lenticular and coarse- to fine-grained, contain abundant hematite and limonite concretions, and are cemented by one or more materials. Cementing materials include iron oxide, calcite, dolomitic calcite, and silica.

In the early days, the brown, iron-oxide-cemented Dakota sandstone (Pl. 8) was used to a considerable extent in the area of its outcrop. Because of its hardness and possibly its color, it was used very little after improved transportation facilitated importation of softer and more popular stones. Two of the best remaining examples of its use are the old guard house at Fort Harker, in Kanopolis, and the public school building at Brookville. The calcite-cemented sandstone, known as "Lincoln quartzite", has been used locally for building in and around Lincoln, Kansas, but because of its hardness and irregular fracture it has not been used extensively.

Permian Rocks

Permian rocks crop out in Kansas in a belt extending from Washington, Marshall, Nemaha, and Brown Counties on the Nebraska line to Meade, Clark, Comanche, Barber, Harper, Sumner, and Cowley Counties on the southern border. Total thickness of outcropping Permian rocks in Kansas is about 3,000 feet. For the most part these rocks show a gentle westward or northwestward dip of about 15 to 35 feet per mile, although locally the strata are horizontal or dip in other directions.

Permian rocks are a major source of building stone in Kansas. The upper and middle parts of the Permian consist chiefly of shale, siltstone, gypsum, sandstone, and dolomite, although some thin limestone beds also are present. These rocks have been used for very few buildings. Local use of some gypsum (Kulstad, Fairchild, and McGregor, 1956, p. 58) sandstone, siltstone, and dolomite is recorded, but most of these materials deteriorate badly when exposed to weather (Swineford, 1955, p. 171).

Lower Permian rocks, about 785 feet thick at the outcrop, consist of limestone layers alternating with shale beds. The outcrop area extends from Washington, Marshall, Nemaha, and Brown Counties on the Nebraska line to Cowley County on the Oklahoma line. Many of the limestones contain nodules and layers of chert or flint. Some of the shales, especially the thicker ones, are brightly colored red and green. The lower Permian is divided into three groups, the Chase, Council Grove, and Admire.

The Chase Group is the topmost group of lower Permian rocks. Its total thickness averages about 335 feet. Included limestones form prominent escarpments in many places. Uppermost in the Chase Group is the Nolans Limestone, underlain successively by the Odell Shale, Winfield Limestone, Doyle Shale, Barneston Limestone, Matfield Shale, and Wreford Limestone. Chert or flint nodules or layers are present locally in most of the limestone formations of the group, and are especially prevalent in members of the Winfield and Wreford Limestones, and in the Florence Limestone member of the Barneston Limestone. Nevertheless, many individual limestone beds within these formations are free of flint and have been quarried and hand processed for building stone.

Flint-free layers of the Winfield Limestone have been used to some extent, especially around Winfield, Cowley County, and in Wichita. The Winfield Limestone consists of shale and dense gray limestone having a total thickness of as much as 25 feet. The upper part is thin bedded and somewhat shaly. The bottom is dense, hard, massive limestone. Outcrops of the Winfield Limestone are especially prominent on hills around Winfield. Because of its hardness, the Winfield stone is not readily sawed. Locally, the massive ledges contain chert, which increases the difficulty of working the stone. The thin beds are more easily worked and have found some acceptance in modern residential construction, especially in the vicinity of Wichita. Such stone, split into blocks and used as veneer, presents a less formal appearance than stone with cut faces.

The Fort Riley Limestone member of the Barneston Limestone is the most widely used building stone in Kansas at the present time. It crops out in an irregular belt extending across the state from Marshall County on the north to Cowley County on the south. Except for certain areas in the northern part of the state where it is covered by glacial deposits, it can be traced almost continuously from Nebraska to the Oklahoma line.

The total thickness of the Fort Riley member ranges from 30 to 45 feet. The upper part contains a limestone stratum 3 feet thick or thicker. Thin shaly beds, and in some localities clay or shale deposits, form the middle part. The lower part consists of thin shaly beds overlain by a massive bed 4 to 5½ feet thick. This massive bed is most suitable for dimension stone, and has been widely used for buildings in the vicinity of Junction City. The resistant Fort Riley Limestone is overlain by less resistant materials, and as a result, in many places lies near the tops of hills under little overburden. Because of the thin cover, the rock is readily available for quarrying.

The entire thickness of the Fort Riley Limestone is well exposed in deep highway or railway cuts and in quarries where crushed rock is being produced. About 18 feet of it may be seen in a road cut on the west side of U.S. Highway 77, about 1½ miles north of Marysville, Marshall County. A good exposure of both the Fort Riley and Florence members can be seen in an abandoned quarry approximately 3 miles north of Junction City on the Junction City-Alida road. In Cowley County, the entire thickness of the Fort Riley Limestone can be seen in an old quarry 1 mile north of U.S. Highway 166, about 9 miles east of Arkansas City. This quarry is visible from the highway.

Fort Riley stone is light gray to tan and weathers cream color or buff. It is attractive in appearance and is an unusually satisfactory building stone. The stone is sufficiently soft to be readily cut, and may be satisfactorily carved for statuary or similar uses. In the southern part of the state it is fine grained and of uniform texture. Elsewhere, it is more porous and not so uniform in appearance. The finer-grained stone of the Silverdale area is widely known as the "Silverdale" limestone, whereas that produced in the Junction City area is known as the "Junction City" limestone. The difference in appearance and the fact that the main centers of quarrying operations are so widely separated tend to obscure the fact that both stones come from the same rock formation.

Exposure to weather has no apparent detrimental effect, although the color of the stone does change slightly. Many houses and other buildings constructed of this stone 75 years ago or more show little effect of weathering. Resistance to weathering seems to be equally good whether the stone is laid in the wall on its natural bed or on edge as "shiners".

Fort Riley stone has been used extensively both in private and public buildings throughout Kansas, and also has been used in

Nebraska, Oklahoma, Colorado, and to some extent in other states. In recent years large quantities have been shipped to Lincoln, Nebraska, for processing and for sale.

Among older buildings constructed of Fort Riley stone are the buildings of the Fort Riley Military Reservation, Geary County (Pl. 9A), and numerous buildings in Cowley County around Arkansas City and Winfield. The east wing of the State Capitol Building at Topeka is constructed of this stone quarried near Junction City. Buildings more recently constructed, such as Lindley Hall (Mineral Resources Building) and Allen Field House at The University of Kansas in Lawrence and the Field House at Kansas State University in Manhattan (Pl. 9B) offer an opportunity to examine the stone in modern types of architecture. In addition to that used in many public buildings, a great quantity of this limestone has been used as veneer on houses and other small structures, where it provides an extremely attractive and durable material.

Fort Riley stone has been quarried in many places along its outcrop. In pioneer days small quarries provided stone for local building. In more recent years, most of the stone has been obtained from the vicinities of Silverdale, Cowley County, and Junction City, Geary County. Considerable amounts also have been quarried near Alta Vista in Wabaunsee County and in the vicinity of El Dorado in Butler County.

In the vicinity of Silverdale, Cowley County, Fort Riley Limestone is quarried in sec. 24, 25, and 26, T. 34 S., R. 5 E., and in sec. 33, T. 34 S., R. 5 E. It lies near the tops of hills or ridges, hence the overburden is relatively thin, and much of it can be moved easily by bulldozers. Just above the quarry layer, however, is a layer 1½ to 2 feet thick known locally as the "J" ledge, which must also be removed. The quarry layer is about 4 feet thick. Vertical holes are drilled with jackhammers to within about 12 inches of the bottom of the layer, charged with black powder, and blasted non-electrically. In blasting, advantage is taken of the rift or of natural seams by placing the rows of drill holes parallel to them. In many places a thin seam of clay separating the quarry blocks from the rock beneath permits slippage of the blocks and greatly increases effectiveness of blasting.

Large blocks are divided into 8- to 10-ton blocks approximately 4 by 4 by 8 feet by use of plug and feather or light blast-

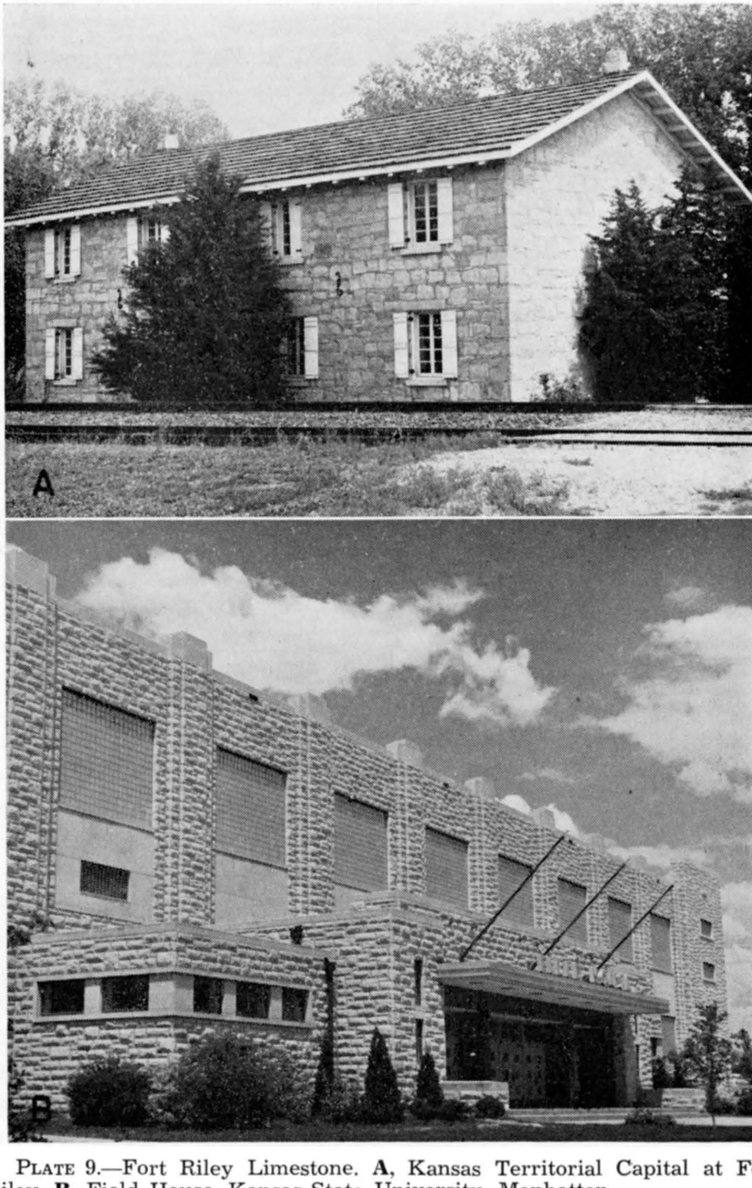


PLATE 9.—Fort Riley Limestone. **A**, Kansas Territorial Capital at Fort Riley. **B**, Field House, Kansas State University, Manhattan.

ing. Mill blocks thus obtained then are lifted by derrick and loaded onto trucks for transportation to the mill.

Fort Riley Limestone is quarried near Junction City in sec. 10, T. 12 S., R. 5 E. Here, mill blocks 5 by 6 by 6 feet and weighing approximately 12 tons are quarried. The main quarry ledge is approximately 63 inches thick and is overlain by relatively thin shaly limestone beds, which must be removed before quarrying of dimension stone can begin. In some places, the overburden must be blasted before stripping; in others, no blasting is necessary.

Blasting with black powder and non-electrical caps is used in quarrying blocks from the ledge. Wagon drills are used to drill blast holes, 2 inches in diameter, to within 12 inches of the bottom of the ledge. Holes are spaced at approximately 6-foot intervals, in rows about 6 feet back from the face. Where possible, the position of the row of holes takes advantage of the rift or of natural seams to provide easier blasting.

Large blocks obtained by blasting are drilled with jackhammers and divided into mill-size blocks by plugs and feathers. A stiff-leg derrick of 20-ton capacity lifts blocks onto trucks for transportation to the mill.

Another quarry producing Fort Riley Limestone operates in sec. 35, T. 13 S., R. 6 E., about 3½ miles northeast of Skiddy in Geary County. Overburden is removed by bulldozers, and slabs are cut directly from the quarry layer by means of a multiple wire saw of the sort described in the section on Quarrying.

The Florence Limestone member of the Barneston Limestone was used to a considerable extent in early-day building in the Flint Hills region. Although layers of flint lie within the limestone, it is possible in places to find flint-free layers thick enough for building stone. These can be worked satisfactorily by hand, but cannot be processed efficiently with machinery. For this reason the Fort Riley, which occurs in close proximity to the Florence, is now preferred. The Florence stone is light gray or tan and the color does not change appreciably on weathering. The stone resists weathering satisfactorily, as indicated by the condition of houses and farm buildings constructed along the south bank of Mill Creek, south of Alma, Wabaunsee County.

The Wreford Limestone is another of the flint-bearing limestones. It is made up of numerous beds, most of which contain flint, but in many places a non-flinty bed about 3 feet thick is present in the upper part. The Wreford is light gray to nearly white when freshly quarried, and weathers gray or light cream color. It resists weathering very well, generally, but some parts become pitted or cellular in structure. The non-cherty layers are soft enough to be worked easily but no bed free of flint is thick enough to justify the use of power equipment for processing it. Because of the chert it contains, the Wreford has been used only to a slight extent, locally in the vicinity of its outcrop. Examples may be found in buildings in and around Blue Rapids, Kansas.

Below the shales and chert-bearing limestones of the Chase Group is the Council Grove Group. It comprises limestones and shales totaling slightly more than 300 feet in thickness. The limestones, in general, are less massive than those of the overlying Chase Group. The group comprises, in descending order, the Speiser Shale, Funston Limestone, Blue Rapids Shale, Crouse Limestone, Easly Creek Shale, Bader Limestone, Stearns Shale, Beattie Limestone, Eskridge Shale, Grenola Limestone, Roca Shale, Red Eagle Limestone, Johnson Shale, and Foraker Limestone. The Funston Limestone and the Cottonwood Limestone member of the Beattie Limestone have provided stone widely used for construction. Crouse Limestone has been used locally as building stone in Wabaunsee County (Mudge and Burton, 1959, p. 119).

The Funston Limestone crops out in a belt extending from Nemaha County in the north to Cowley County in the south. In most places the main part of the Funston is a hard bed 24 to 30 inches thick, but near the eastern edge of Pottawatomie County the rock is much thicker and is soft enough to be readily cut and worked. Stone has been quarried from the Funston in this area for many years and has acquired the name of "Onaga limestone" because of its proximity to the town of Onaga. Extensive search along the outcrop has failed to disclose any other place in which the characteristics found in this particular location are duplicated.

The rock crops out within a small area south of the intersection of Kansas Highways 16 and 63 in Pottawatomie County. This outcrop is marked by a band of large flat stones lying on the surface slightly downhill from the outcrop. The bed is almost uniformly 5 feet thick within the small area in which it is quarried.

The complete thickness is exposed in quarries in the S½ sec. 15, T. 7 S., R. 12 E., about ¾ mile east and 1½ miles south of the highway intersection.

The stone obtained from the "Onaga" is light tan and weathers somewhat darker. There is some variation in texture and color within the bed. The lower part is more porous and is darker than the upper. In some places the lower part is too porous for use. An 8- to 10-inch layer at the top of the bed is much harder than the rest. The rock can be quarried in large blocks and sent to the mill. It could be sawed with gang saws, but at present large-diameter circular saws generally are used to saw slabs from the blocks. It is soft enough to be cut readily with an ordinary hand saw, and this method was used for shaping much of it in the past.

Numerous examples of use of the Onaga variety of the Funston stone may be found. In earlier days its use was almost confined to the area in the vicinity of its outcrop, but in recent years it has gained wider distribution. Numerous houses and farm buildings along State Highway 16 east of its intersection with State Highway 63 have been standing for many years and show no signs of deterioration. Other examples of the use of "Onaga" stone include the armory at St. Marys in Pottawatomie County, the Eisenhower Museum at Abilene, Dickinson County (Pl. 10), and the new Topeka Public Library, Shawnee County.

Funston ("Onaga") stone is obtained from a quarry in the SW¼ sec. 15, T. 7 S., R. 12 E., and one in the southeast corner of the same section on the east side of Pottawatomie County. Most of the overburden is removed by bulldozers. A stratum of hard rock 2 feet thick lying 3 feet above the quarry layer must be drilled and broken before stripping can be completed. Plugs and feathers are used for quarrying in one of the quarries. Holes 6 to 8 inches deep and spaced at 6-inch intervals are drilled in line, taking advantage of natural seams where possible. In the other quarry, holes are drilled with jackhammers to within about 8 inches of the bottom of the layer and blasted with a light charge of black powder. A clay seam beneath the quarry layer allows blocks to be more easily displaced by either plug-and-feather or blasting procedure.

The full seam in this quarry is 60 inches thick. In most places an 8-inch layer, harder than the rest of the bed, is wedged loose

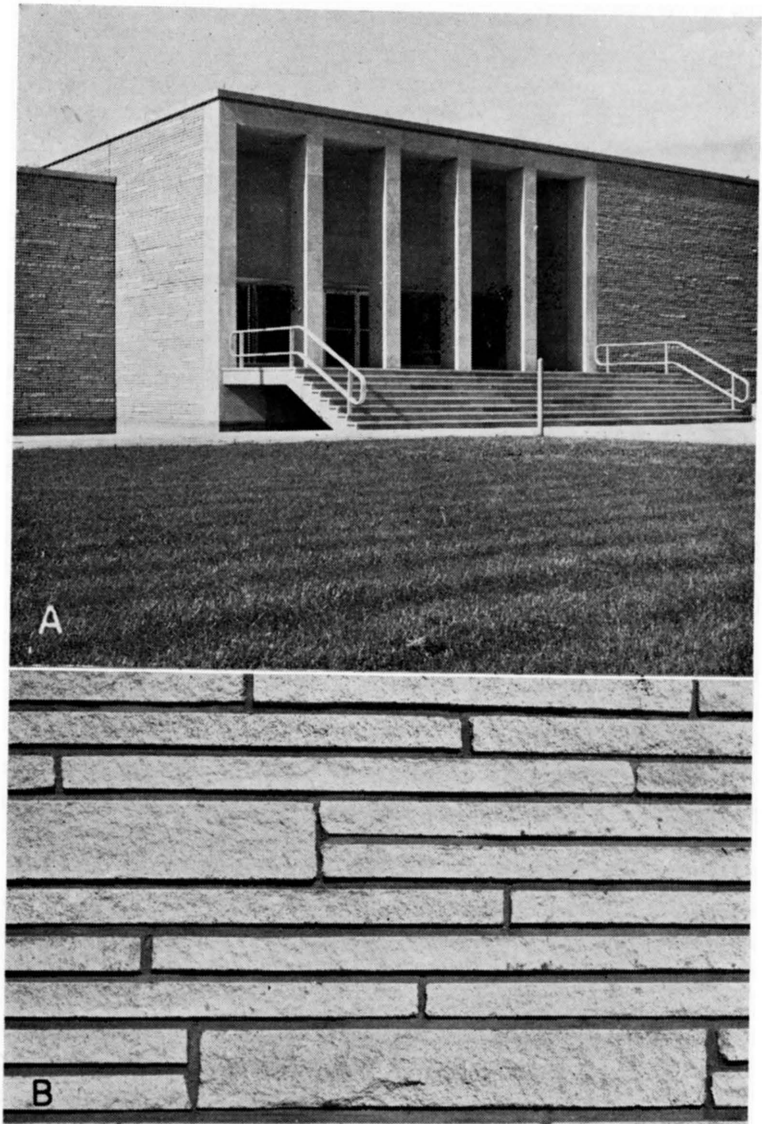


PLATE 10.—Funston Limestone ("Onaga" stone). **A**, Eisenhower Museum, Abilene, built of limestone in split-face ashlar pattern. **B**, Split-face ashlar finish on "Onaga" stone, Eisenhower Museum.

from the top and discarded. Of the rest of the bed, the upper 3 feet is sound rock, light gray or tan. In some places, the lower part of the ledge is extremely soft and porous and carries a dark-brown stain. Where this condition exists, the defective lower portion is split from the block and discarded. Large blocks broken from the quarry face are divided into blocks weighing approximately 3 tons. These are loaded by truck-mounted derricks and transported to the mill for processing.

The Cottonwood Limestone member of the Beattie Limestone is one of the better known building stones of Kansas. Outcrops of the Cottonwood Limestone extend from the vicinity of Beattie, Marshall County, on the north, to Matfield Green, Chase County, on the south. In the northern part of Kansas the rock is covered in many places by glacial deposits. South of Matfield Green the Cottonwood Limestone becomes thinner and more shaly than farther north and is less suitable for building stone.

Additional outcrops of Cottonwood Limestone, east of the more extensive outcrops described above and separated from them by a distance of 15 to 25 miles, form a narrow loop crossing the Nebraska line and extending southward almost to Kansas River in the vicinity of Belvue. Like the northern part of the more extensive outcrop area, much of the rock is covered by glacial material.

In most places the outcrop of the Cottonwood is well defined and is marked by large, flat, grayish-white stones lying below the outcrop. In the Flint Hills region, it is also marked, in many places, by a fringe of shrubs that shows up conspicuously on the grass-covered slopes. Locations of abandoned quarries and descriptions of the Cottonwood Limestone in Lyon and Chase Counties are given by O'Connor and others (1953) and by Moore and others (1951b). Mudge and Burton (1959) discuss uses and distribution of Cottonwood Limestone in Wabaunsee County.

The Cottonwood Limestone is almost uniformally 6 feet thick except in the southern part of its outcrop area and is made up in most places of two or more beds showing distinctly different characteristics. Most quarrying has been done in the two main beds that make up the middle and lower portions of the rock. The middle portion is fairly open grained rock containing many slender wheat-grain-shaped fossils called fusulinids. In many places, the middle part of the rock contains a layer of chert nodules. In other places, notably in the area near Cottonwood Falls, Chase County, the chert is less prominent. The lower portion is a very fine, close-grained material and is more nearly uniform in texture.

The Cottonwood stone is light buff when freshly quarried and weathers almost white. It is sufficiently soft to be cut readily with gang saws or circular saws but is harder than most stones being commercially quarried in Kansas at present. The fine-grained lower portion of the member is somewhat harder than the upper portion and less resistant to weathering, especially when in contact with the ground. The stone may be satisfactorily carved, but the layer is too thin to provide blocks for large carvings. It has an attractive appearance either as broken or pitch-face veneer or as cut stone. Its strength and resistance to weathering are well demonstrated by the present condition of structures built before 1900. Many of these buildings are now 75 years old or more.

Among the more prominent examples of the use of Cottonwood stone in older buildings are the south and west wings of the State Capitol Building in Topeka, and the Chase County Court House in Cottonwood Falls, built in 1872. Of particular interest from a structural standpoint is the stone arch bridge ½ mile south of Clements, Chase County, (Pl. 11A), which was built in 1891 of huge blocks of stone quarried from the Cottonwood member and is still in use. More modern applications of the Cottonwood stone are the school house at Strong City and many stone-veneered homes throughout the state. The Memorial Campanile (Pl. 11B) on the University of Kansas campus was built mainly of Cottonwood stone, although some Fort Riley stone also was used in the structure. As this building becomes older a close examination will show the contrast in color between the two stones when they are exposed to weather, as it does in the State Capitol Building today.

The Cottonwood Limestone was at one time the most important source of building stone in Kansas (Haworth, 1898, p. 74; Prosser and Beede, 1904, p. 5). It formerly was quarried at many places along its outcrop, but at present is produced much less extensively than in former years.

Cottonwood stone is used less extensively at present than is Fort Riley stone. This may be attributed, at least partly, to the

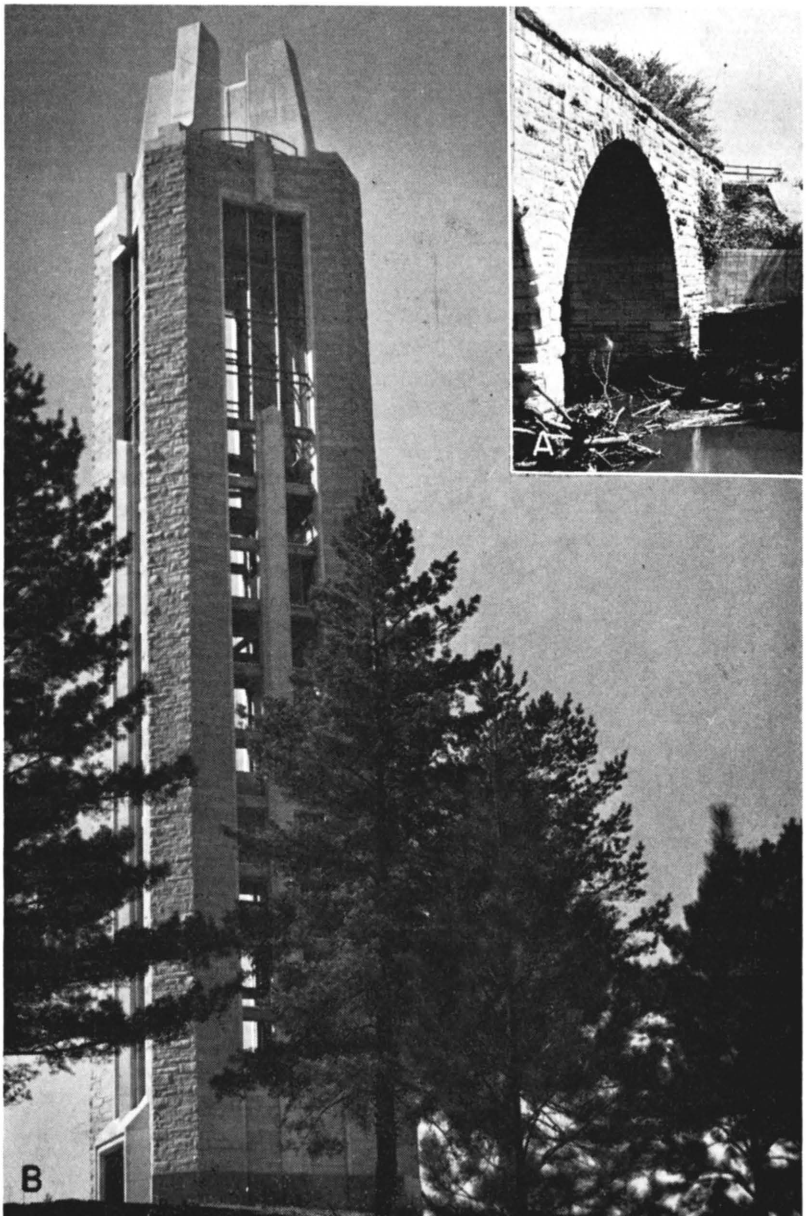


PLATE 11.—Cottonwood Limestone. **A**, Bridge built near Clements, Chase County, in 1891. **B**, Memorial Campanile, The University of Kansas, Lawrence.

somewhat greater hardness of the Cottonwood and the manner in which it occurs. Because of the seams in the rock, the middle and lower portions usually are quarried separately. This produces blocks that are too thin for most economical cutting with a gang saw. Even if the entire thickness could be quarried in one block it still would be necessary to cut out a slab including the plane of contact between the two portions. It is necessary, also, to avoid the layer of chert nodules. These factors not only lead to increased sawing expense, but also result in considerable wastage of stone. Where the stone is hand-dressed instead of sawed, the above factors are of less importance.

In former years, stone from the Cottonwood Limestone was produced in large quantities from quarries in Chase County. At present, the only quarry producing Cottonwood stone is operated in the S½ sec. 23, T. 10 S., R. 7 E., Riley County, about 3 miles southwest of Manhattan. Loose overburden and the strata overlying the quarry layer are removed and crushed. Only the lower portion of the Cottonwood is saved for building stone. The upper portion contains chert nodules, which make quarrying it for building stone impractical.

Mill blocks 2 feet thick, 2 feet wide, and 8 to 10 feet long are quarried by the plug-and-feather system; 6- to 8-inch holes for the plugs are drilled with a jackhammer. Blocks are loaded onto trucks for transportation to the mill.

The Neva Limestone member of the Grenola Limestone appears in an outcrop paralleling that of the Cottonwood Limestone. The main bed of the Neva is a gray brecciated fossiliferous limestone as much as 6 feet thick. The stone is dense and hard, and locally has almost a marble-like appearance, but weathers pitted or cellular. Because of its hardness, the Neva stone is expensive to cut or work with machinery, but can be hand dressed satisfactorily. Some of the layers of the Neva Limestone have good resistance to weathering, but others indicate a lack of resistance to freezing and thawing when used in contact with the ground. The Neva stone has been used locally in and around Manhattan, Riley County. Local quarries, working intermittently, have supplied the demand.

The Americus, which is a member of the Foraker Limestone, is a dark-gray limestone as much as 5 feet thick. It has been used to some extent along its outcrop for farm buildings, bridge abutments, and similar uses. The outcrop is marked by rhombic blocks of limestone from the lower ledge. The Americus stone can be obtained in blocks 2 feet thick. It withstands weather satisfactorily, turning dark gray upon exposure. Because the hardness exceeds that of other stones occurring nearby, production of the Americus stone has never attained much significance.

The lower part of the Permian rocks exposed in Kansas consists chiefly of clastic deposits but also contains thin beds of limestone and some coal, and locally some sandstone. The average thickness of the rocks is about 130 feet. Successively downward, they include the Hamlin Shale, Five Point Limestone, and West Branch Shale members of the Janesville Shale, the Falls City Limstone formation, and the Hawxby Shale, Aspinwall Limestone, and Towle Shale members of the Onaga Shale. The Indian Cave Sandstone of the Towle Shale locally is as much as 250 feet thick. The Five Point Limestone has been used in Wabaunsee County (Mudge and Burton, 1959, p. 119). The Falls City Limestone formerly was used as a building stone in Brown County, especially in and around Hiawatha. Aspinwall Limestone from the Onaga Shale has been used in Wabaunsee County (Mudge and Burton, 1959, p. 119).

Pennsylvanian Rocks

In Kansas, only the upper three stages (Virgilian, Missourian, and Desmoinesian) of the Pennsylvanian System are exposed on the surface. Their occurrence and description are discussed in detail by Moore (1949). Pennsylvanian rocks crop out throughout most of the eastern one-fourth of Kansas, except where covered by glacial deposits and other unconsolidated materials. Except for a very small area in the extreme southeast corner of the state, all of the territory east of the Flint Hills falls within the outcrop area of the Pennsylvanian System.

The rocks dip slightly north of west, at an average rate of about 25 feet to the mile. The harder rocks form generally eastward-facing escarpments throughout the area. Softer rocks, principally shales, form lowlands or gentle slopes below or between the escarpments formed by harder rocks.

The Pennsylvanvian rocks consist principally of alternate shales and limestones but include an occasional sandstone or coal bed. The limestones and some of the shales are of marine origin; the coal beds, some of the shales, and most of the sandstones are nonmarine.

The Virgilian Stage, the uppermost stage of Pennsylvanian rocks in Kansas, is divided into the Wabaunsee, the Shawnee, and the Douglas Groups.

The Wabaunsee Group, topmost division of the Virgilian Stage, consists of thin but persistent beds of limestone, sandstone, and shale. Within the upper part of the Wabaunsee Group the Grayhorse Limestone member of the Wood Siding Formation (Mudge and Burton, 1954, p. 119) and the Dover Limestone have been used to a slight extent. In the middle part of the Wabaunsee Group is the Tarkio Limestone, a member of the Zeandale Limestone, which was used locally along its outcrop for building stone. The Tarkio Limestone is a gray, hard, fusulinid-bearing limestone weathering deep yellowish brown; it crops out northward across the state from a point in northern Lyon County. The hardness of the Tarkio Limestone makes sawing difficult, but the stone can be hand-dressed satisfactorily. In the lower part of the Wabaunsee Group is the Utopia Limestone member of the Howard Limestone. The Utopia was formerly quarried in Osage County as flagstone, which was used extensively as sidewalks throughout eastern Kansas.

The Shawnee Group of the Virgilian Stage comprises seven formations, four of which are chiefly limestone and the other three mainly shale. The limestones form prominent escarpments in an outcrop belt averaging about 20 miles wide and extending from Doniphan County on the north to Chautauqua County on the south. North of Kansas River the escarpments are masked by glacial drift, which covers much of the area. Within the Shawnee Group, members of the Topeka Limestone, Lecompton Limestone, and Oread Limestone have provided some building stone.

The Hartford Limestone member, lying at the base of the Topeka Limestone, has been used to some extent for construction in and around Topeka and at other places near its outcrop. It is a hard bluish-gray limestone, which turns dark brown when weathered. Its hardness makes sawing difficult, but it can be hand dressed without difficulty. The outcrop extends completely across the state from north to south, but is particularly prominent near Topeka.

Within the Lecompton Limestone, the Big Springs Limestone member has been used to some extent for building in the area of its outcrop and especially in the vicinity of Lecompton. The Big Springs Limestone crops out across the state from north to south.

It commonly occurs as a single layer marked by prominent vertical jointing, but in other places it consists of two or three layers separated by shale. The thickness ranges from 1 to 5 feet. The stone withstands weathering satisfactorily. It is dark bluish gray when freshly quarried, and weathering produces a yellowish-brown film on the surface. The stone can be hand dressed satisfactorily, but its hardness makes for difficult sawing.

The Kereford Limestone member, which forms the top of the Oread Limestone, has also been used to some extent, especially in the vicinity of Atchison.

The Toronto Limestone, lowest member of the Oread Limestone, has been used to a considerable extent, especially in Douglas County (Pl. 12A). Most of the older buildings on The University of Kansas campus are constructed of stone from the Toronto. It generally occurs as a massive ledge ranging from 8 to 12 feet in thickness from Douglas County northward. In the southern part of Kansas, the member becomes generally thin and unsatisfactory for building stone. The Toronto Limestone is hard and dense. The brownish-gray color of freshly quarried stone changes to a deep brown upon weathering. The stone withstands weathering well. It can be hand worked, but its hardness makes sawing difficult and generally impractical. In many places, the Toronto member is overlain by other thick limestone layers, which make quarrying for building stone expensive unless the overlying rock can be quarried for other purposes.

The Douglas Group includes, in addition to sandstone and shale, only a small amount of limestone, some of which has been used locally as building stone. Locally sandstone beds are massive and have been used as building stone for rural schools and farm buildings.

Rocks of the Missourian Stage in Kansas form an outcrop belt extending southwestward from the vicinity of Kansas City to Montgomery County. Within the stage, prominent limestones alternate with shale units, some of which vary greatly in thickness. Sandstone within the stage is of minor importance, and coal beds are too thin to be of any significance.

Uppermost in the Missourian Stage is the Pedee Group, which contains the Iatan Limestone, which has been identified in Kansas only in the vicinity of Leavenworth. The stone used in the old stone wall on the Fort Leavenworth Military Reservation seemingly came from this formation.

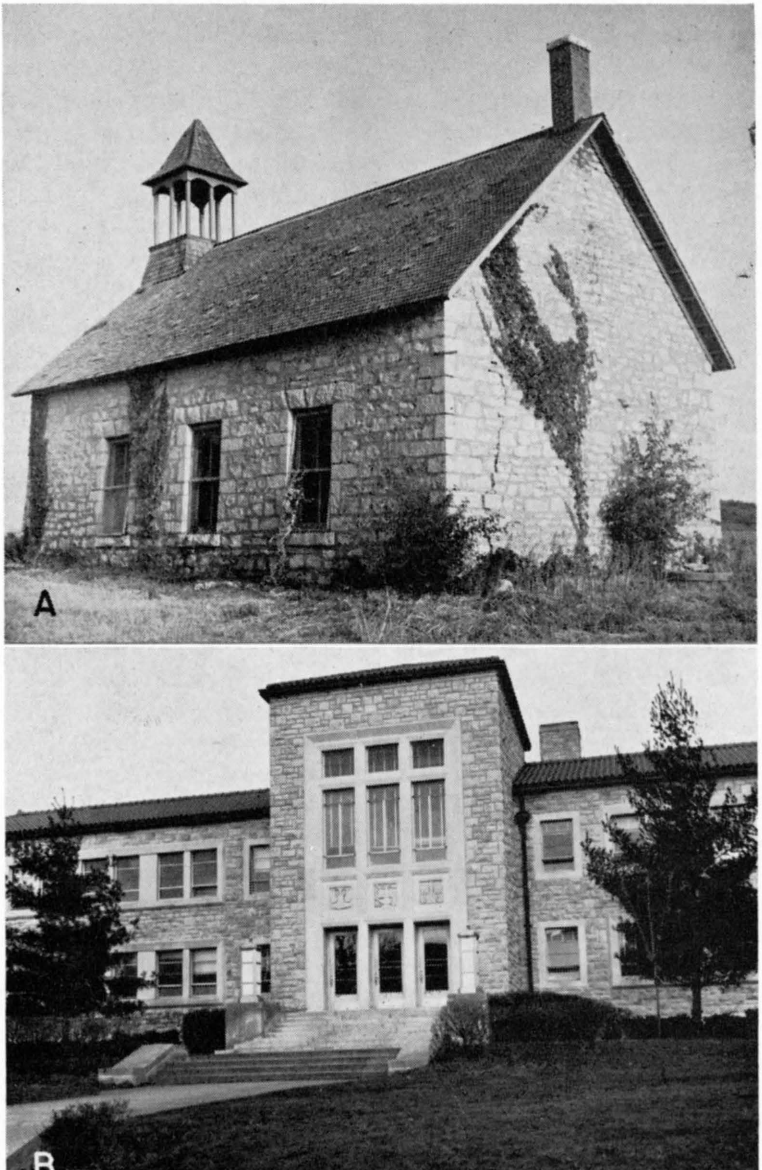


PLATE 12.—**A**, Rural school in sec. 16, T. 12 S., R. 18 E., Douglas County, built of rough Toronto Limestone. **B**, Westerville Limestone ("Kansas City oolite"), Law Building, University of Kansas City, Missouri.

Next below the Pedee Group is the Lansing Group, which contains some limestone that has been used locally as building stone.

The thickest division of the Missourian Stage is the Kansas City Group. Relatively thick, persistent limestones are characteristic of the group. Between the limestones are shales of variable thickness. Sandstone makes up a prominent part of the group throughout the outcrop, but its presence is especially pronounced in the southern part of Kansas where its quantity equals or exceeds that of the limestones of the group.

The rocks of the Kansas City Group crop out prominently in a belt extending from the vicinity of Kansas City to the southern border of Kansas. They are especially well exposed in bluffs along the valley of Kansas River and other streams.

The Zarah Subgroup, uppermost in the Kansas City Group, constitutes about one third of the total thickness of the group. The subgroup contains the Wyandotte Limestone, which in turn contains the Farley Limestone member and Argentine Limestone member. The Farley has been used to some extent locally for construction.

The Linn (middle) Subgroup contains limestone, relatively prominent shale, and locally much sandstone. Most limestone units are only a few feet thick but are persistent. The Iola Limestone has provided building stone in numerous localities along its outcrop, but no extensive quarries have been developed. The Cherryvale Shale contains the Westerville Limestone member, which has been quarried extensively for building stone.

The Westerville stone has been very popular in Kansas City, where it has been used in many public and private buildings and is commonly known as "Kansas City oolite". Especially good examples of its use are found on the campus of the University of Kansas City, where it was used in the gymnasium and in other buildings (Pl. 12B).

Lack of widespread use of the Westerville Limestone can be attributed almost entirely to its mode of occurrence. In most places the quarry member is overlain by a massive ledge of extremely hard cherty limestone. Removal of this hard ledge makes the quarrying of the Westerville for dimension stone very costly, unless the hard ledge can be sold as crushed rock. In some areas in Johnson County, south of Kansas City, the cherty ledge is absent, and the Westerville can be quarried directly, but these areas are of small extent and are not being worked at present.

Considerable quantities of Westerville Limestone have been quarried from outcrops along Muncie Bluff Road (State Highway 32) a short distance west of Kansas City, Kansas. Stone for some of the buildings at the University of Kansas City, Missouri, is reported to have come from a quarry in the SW¼ SW¼ sec. 4, T. 13 S., R. 25 E. (0.2 mile east and 0.25 mile north of 103d Street and Nall Avenue) in Johnson County.

The stone generally has been used as rubble or has been hand dressed, but some has been quarried in large blocks and sawed. It is light gray when quarried and retains is light color. Exposure to weather seems to have little effect on the Westerville stone.

The Bronson Subgroup underlies the Linn Subgroup and contains prominent limestone beds that have been used locally for farm and other small buildings.

The Desmoinesian Stage is the lowest major division of Pennsylvanian rocks cropping out in Kansas. Within the Marmaton Group (Jewett, 1945) of this stage lies the Bandera Quarry Sandstone member of the Bandera Shale. The Bandera Quarry Sandstone has been an important source of building stone for many years.

The Bandera Quarry stone is a thin-bedded, very fine grained micaceous sandstone occurring in layers a fraction of an inch to 5 inches thick. The total thickness of the member is 40 to 50 feet. Some of the layers are relatively smooth, but others have surfaces that are rippled. The stone is light gray and presents an attractive appearance.

Large quantities of stone from the Bandera Quarry Sandstone have been produced in Crawford, Bourbon, Labette, and Neosho Counties. At the turn of the century, quarries were operating near Gilfillan, Redfield, Farlington, and Bandera (Haworth, 1898, p. 72). At present a quarry is being operated in sec. 29, T. 25 S., R. 23 E., in Bourbon County (Pl. 13A). A pit about 50 feet square and 15 to 18 feet deep on the edge of an older quarry complex is being operated. A carriage-mounted diamond saw is used to cut through the strata (Pl. 13B), forming rectangular flags, which are then pried loose from underlying strata. The blade depth is adjustable to any cut desired. Flags are hoisted from the pit and are marketed as flagstone or are processed into split-face veneer.

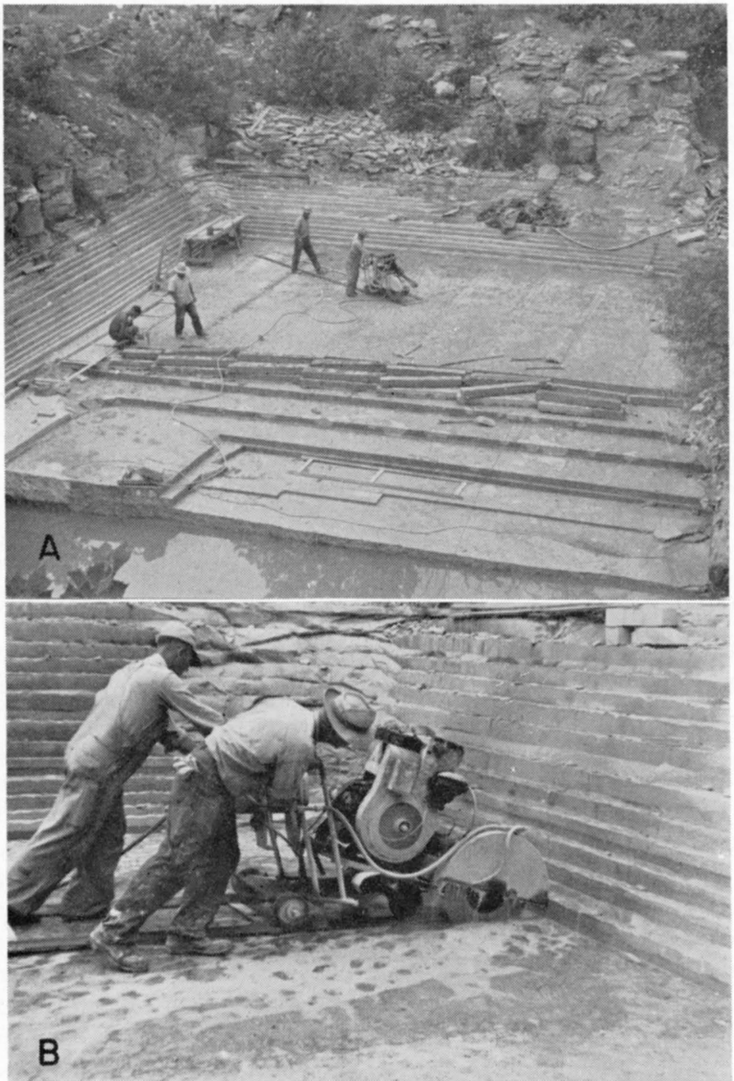


PLATE 13.—Bandera Quarry Sandstone. **A**, Bandera Stone Quarry operations, Bourbon County. Sandstone strips being produced for flagstone or for veneer. **B**, Diamond saw cutting rectangular flags.

The veneering stone is obtained by splitting successive strips off the flags cut from the quarry. Because of the rippled surfaces, many of the flags cannot be split accurately with a straight-bladed guillotine. A toothed guillotine is used to obtain straight breaks.

Another procedure also is used for the production of veneer stone from the thicker ledges. Cuts are made at proper spacing to obtain the desired course height. One of the faces of the stone thus obtained is pitched, and the blocks are laid as "shiners" (i.e., with the bedding planes on edge).

Stone produced from the Bandera Quarry Sandstone has been used as a building stone in Kansas, Oklahoma, Missouri, and Nebraska, and to a lesser extent in some other states. Currently, the most common uses are as veneer and as flagging. In the past, it was used extensively for sidewalks and curbs throughout eastern Kansas. It has also been used as roofing material, as slate is used.

Mississippian Rocks

Rocks of the Mississippian System crop out in the extreme southeastern corner of Kansas. None of the limestone from the Missssippian System has been used to any appreciable extent for building stone.

ECONOMIC CONSIDERATIONS

The stone industry is highly competitive in the production of finshed and special stones, and perhaps only slightly less so in the production of veneer and other types of rougher building stone.

Most contracts for the stone work in the construction of large structures or of public buildings are awarded on the basis of competitive bids. Many stone-producing concerns have within their organizations skilled stone masons, so that they are in a position to supply both the labor and materials for a job, and are able to make their bids on that basis. This makes such construction work a highly competitive business.

On houses and other small structures, a local contractor usually is chosen to do the building. If stone work is required, he generally is able to do the work himself, to hire someone to do it, or to subcontract it to a contract mason. The stone is ordinarily bought from the nearest producer. It is in these circumstances that the local producer of stone enjoys an advantage, because of his proximity to the job. This is especially true on small jobs where the quantity of stone is so small that less-than-carload rates must be paid if it is shipped by rail.

In the small-building field, the stone producer's main competition comes from other, cheaper, building materials, especially lumber. Where first cost is of vital importance, the cost of material and labor in stone construction often prohibits its use. Where long-term cost is the determining factor, stone enjoys a stronger position. Its chief strong point in such competition is its durability and low maintenance cost.

Production Cost Factors

The competitive position of a good stone is determined to a large extent by the delivered price at the site of construction. This price, in turn, is influenced by the many factors that enter into determining the production cost, among which are character of the stone, location and mode of occurrence, required investment, and labor costs.

The character of a stone affects its suitability for building purposes and its competitive position in several ways. A stone of exceptional quality generally brings a better price or sells more readily at a given price than a stone of ordinary quality. Also, the character of the stone determines to some extent the ease with which it can be quarried and the ease or difficulty with which it can be cut and worked.

The accessibility of a rock deposit and distance from the market exert a strong influence on the delivered cost of stone. On some projects, freight costs equal or exceed the price of the stone. Other things being equal, the producer who is nearest the market ordinarily enjoys an additional profit margin equal to the freight differential between quarries.

The manner of occurrence, with respect to bed thickness and type and amount of overburden, is important. All the dimension stone quarried and processed in Kansas is obtained from comparatively thin beds, rarely more than 6 feet and more commonly 5 feet thick. The quarrying of thin beds has advantages and disadvantages.

Beds of rock normally are exposed only along hillsides and bluffs, and are covered by soil or by other layers of rock. Because only a small amount of stone can be obtained from the outcrop, it is necessary to remove the overburden and expose the bed for further quarrying. In places where the dip of the bed and the slope of the surface are slight, the thickness of overburden increases very gradually, and large quantities of rock can be uncovered at slight expense. In places where the depth of the cover increases more rapidly, a much greater volume of cover must be stripped off to expose the same volume of rock. It is readily apparent that the quarryman who must strip a given amount of overburden to expose a bed of rock 5 feet thick is at a disadvantage when competing with one who, by removing the same amount of overburden, can expose a bed 40 to 50 feet thick.

The quarrying of thin beds, however, is not completely without its advantages. Blocks obtained from thick beds must be quarried from the bottom as well as from the sides and ends, in order to obtain saw blocks that can be handled and which will fit the gang saws and other equipment. In thinner seams, from which blocks can be produced that can be handled easily and that fit well into the equipment, quarrying is required only on the sides and ends. This greatly simplifies the quarrying procedure. All dimension stone quarried in Kansas is produced from beds that are sufficiently thin to provide blocks utilizing the entire bed.

Required Investment

The investment required for producing dimension stone ranges from a few thousand dollars to tens or hundreds of thousands, depending upon the scale of operations and the type of product desired.

Standard types of heavy equipment such as gang saws, cut-off saws, guillotines, planers, and grinders are expensive but necessary for shaped and finished stone products. For less specialized stone, such as veneer and common ashlar building stone, much less equipment will suffice.

Labor

Large operations employ a great many skilled workmen, whose wages constitute an appreciable portion of the total production cost. Here, the efficiency of the workmen, the effectiveness of the tools with which they work, and the prevailing wage rates greatly influence the production costs.

The small operator who performs much of the work himself is able to profit both from his work and from the sale of his product.

Long Term Prospects

In a nation whose timber resources are being gradually depleted, other building materials are certain to assume a greater importance. The increasing scarcity of good timber leads to higher lumber prices and tends to reduce the cost advantage that frame construction normally enjoys as compared to masonry. It seems logical, therefore, that the popularity of stone, especially in house construction, should grow.

At present, the cost of stone construction is higher than that of frame construction. The difference is due both to the cost of laying stone and to the cost of the material used.

To offset at least partly the disadvantage of greater initial cost, well-constructed masonry buildings have several distinct advantages over those of frame construction. Maintenance costs, especially for painting, are less. Also, stone buildings have greater resistance to destruction by fire, insects, and other agents. Houses built of stone have an attractive appearance and give the impression of permanency, traits desired by many people.

It may be reasonably assumed that as timber becomes more scarce, its cost will rise to approach more nearly that of masonry construction. The use of stone and other masonry materials will then become more commonplace in every type of construction.

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APPENDIX A

Dimension stone quarries operating in Kansas, 1956

Operator	Stone	Location
Edmund Leiker, Rt. 5, Hays (operates intermittently)	Fort Hays Limestone	Ellis County, SE¼ sec. 16, T. 13 S., R. 18 W.
Simpson Quarry, Joe Prickett Construction Company	"Fencepost" limestone bed and "shell-rock" bed, Greenhorn Limestone	Cloud County, NW¼ sec. 19, T. 8 S., R. 5 W.; Mitchell County, SE¼ sec. 24, T. 8 S., R. 6 W.
Silverdale Cut Stone Company, Silverdale	Fort Riley Limestone ("Silverdale")	Cowley County, E½ NE¼ sec. 24, T. 34 S., R. 5 E.; N½ sec. 26 and SE¼ sec. 25, T. 34 S., R. 5 E.
Silverdale Limestone Company, Silverdale	Fort Riley Limestone ("Silverdale")	Cowley County, sec. 33, T. 34 S., R. 5 E.
Walker Cut Stone Company, Junction City	Fort Riley Limestone ("Junction City")	Geary County, NW¼ sec. 10, T. 12 S., R. 5 E.
Junction City Stone Company, Junction City	Fort Riley Limestone ("Junction City")	Geary County, E½ sec. 35, T. 13 S., R. 6 E.
Manhattan Stone Company (Bayer), Manhattan	Funston Limestone ("Onaga")	Pottawatomie County, SW¼ sec. 15, T. 7 S., R. 12 E.
Manhattan Cut Stone Company, Manhattan	Funston Limestone ("Onaga")	Pottawatomie County, SE¼ sec. 15, T. 7 S., R. 12 E.
Ervin Stone Company, Cottonwood Falls	Cottonwood Limestone	Chase County, NW¼ sec. 36, T. 19 S., R. 8 E.
Manhattan Stone Company (Bayer), Manhattan	Cottonwood Limestone	Riley County, SW¼ sec. 23, T. 10 S., R. 7 E.
Bandera Sandstone Quarry, Redfield	Bandera Quarry Sandstone	Bourbon County, S½ sec. 29, T. 25 S., R. 23 E.

APPENDIX B

Stone processing plants operating in Kansas, 1956

Name	Location	Products
Kansas Natural Stone Company	Hays, Ellis County	Cut stone, trim and carved stone, planer work
Silverdale Cut Stone Company	Silverdale, Cowley County	Quarry blocks, slabs, cut stone, carved stone, split-face and pitch-face veneer, lathe and planer work
Silverdale Limestone Company	Silverdale, Cowley County	Quarry blocks, slabs, split-face and pitch-face veneer
Walker Cut Stone Company	Junction City, Geary County	Quarry blocks, slabs, cut stone, carved stone, split-face and pitch-face veneer, lathe and planer work
Junction City Stone Company	Junction City, Geary County	Slabs, cut stone, split-face and pitch-face veneer
Manhattan Cut Stone Company	Manhattan, Riley County	Cut stone, split-face and pitch-face veneer, planer work
Bayer's Manhattan Stone Company	Manhattan, Riley County	Cut stone, split-face and pitch-face veneer, stone novelties
J. T. Lardner Stone Company	128 N. Van Buren, Topeka, Shawnee County	Cut stone, carved stone, planer work

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PART 1. DESCRIPTION OF A DAKOTA (CRETACEOUS) CORE FROM CHEYENNE COUNTY, KANSAS, by D. F. Merriam, W. R. Atkinson, Paul C. Franks, Norman Plummer, and F. W. Preston, p. 1-104, fig. 1-13, pl. 1-4, April 15, 1959.

PART 2. CEMENT RAW MATERIALS IN KANSAS, by Russell T. Runnels, p. 105-124, fig. 1-5, May 1, 1959.

PART 3. SANDSTONES OF THE DOUGLAS AND PEDEE GROUPS IN NORTHEASTERN KANSAS, by Donald T. Sanders, p. 125-159, fig. 1-5, pl. 1-2, May 15, 1959.

PART 4. GERMANIUM IN KANSAS COALS, by John A. Schleicher, p. 161-179, fig. 1-2, May 15, 1959.

PART 5. COAL RESOURCES OF THE CHEROKEE GROUP IN EASTERN KANSAS. I. Mulky Coal, by Walter H. Schoewe, p. 181-222, fig. 1-6, pl. 1-6, June 1, 1959.

PART 6. CROSS-STRATIFICATION, DAKOTA SANDSTONE (CRETACEOUS), OTTAWA COUNTY, KANSAS, by Paul C. Franks, George L. Coleman, Norman Plummer, and W. Kenneth Hamlin, p. 223-238, fig. 1-3, pl. 1-2, August 1, 1959.

PART 7. THE MINERAL INDUSTRY IN KANSAS IN 1958, by Walter H. Schoewe, p. 239-287, fig. 1-3, October 15, 1959.

PART 8. MARINE BANK DEVELOPMENT IN PLATTSBURG LIMESTONE (PENNSYLVANIAN), NEODESHA-FREDONIA AREA, KANSAS, by John W. Harbaugh, p. 289-331, fig. 1-3, pl. 1-13, December 30, 1959.

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1960 REPORTS OF STUDIES

PART 1. DAKOTA FORMATION REFRACTORY CLAYS AND SILTS IN KANSAS, by Norman Plummer, M. P. Bauleke, and W. B. Hladik, p. 1-52, fig. 1-5, pl. 1-9, March 1, 1960.

PART 2. KANSAS BUILDING STONE, by Hubert E. Risser, p. 53-122, fig. 1-3, pl. 1-13, September 1, 1960.