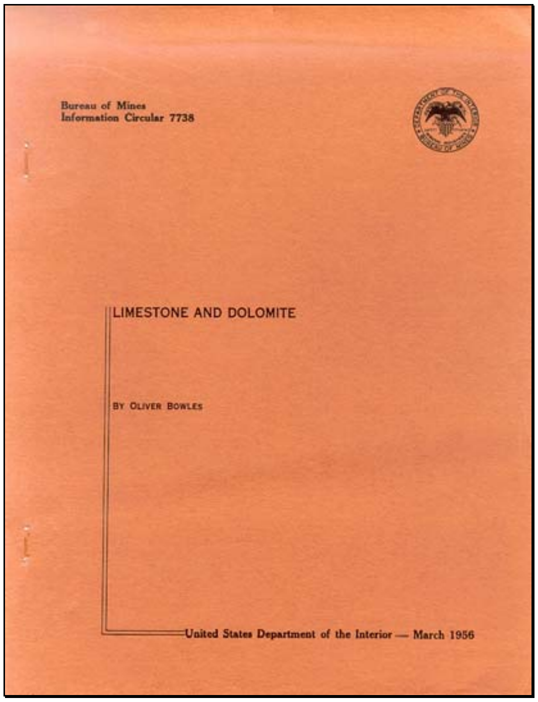

LIMESTONE AND DOLOMITE

BY OLIVER BOWLES

Information Circular 7738

UNITED STATES DEPARTMENT OF THE INTERIOR
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BUREAU OF MINES
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March 1956

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by
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ILLUSTRATIONS

INTRODUCTION

Limestone, including dolomite, is the most widely used of all rocks - nearly 300 million tons annually in the United States alone. It occurs in some form in every State and is produced in thousands of localities. Because of its attractiveness, substantiality, and durability it is employed extensively as a building stone. In crushed and broken form it is used for concrete aggregate and railroad ballast and in highway construction, metallurgy, agriculture, and a host of chemical and industrial processes.

This paper proposes to furnish general information on the origin and occurrence of limestone and dolomite, chief production centers, major uses, and methods of quarrying and preparing stone for market. Footnote references will guide the reader to sources of more complete information.

COMPOSITION AND ORIGIN

The essential constituent of limestone is calcium carbonate ($CaCO_3$). If the magnesium carbonate content is small the rock is known as a “high-calcium” limestone. If 10 percent or more of magnesium carbonate is present it is called “magnesian” or “dolomitic” limestone. When the content of magnesium carbonate approaches 45 percent it is known as dolomite, which is the double carbonate of calcium and magnesium ($CaCO_3.MgCO_3$). The term “limestone” in its broader sense includes dolomite.

Limestones are named on the basis of their prevailing impurities, provided the impurities are present in considerable quantities. Thus siliceous or cherty limestones contain considerable quantities of silica; argillaceous limestones contain clay; and ferruginous limestones contain iron oxides, which make the rock reddish or yellowish. Carbonaceous or bituminous limestones contain peat or other organic materials, which may make the rock dark gray or black.

Limestones consist chiefly of calcareous shells of organisms that inhabit oceans and lakes. Countless generations of them have lived and died, and their shells have accumulated, sometimes to great depths, on sea and lake floors. Such supplies are supplemented by chemically precipitated calcium and magnesium carbonates. Some deposits consist almost entirely of the carbonates and become the sources of pure, high-grade limestones. In other places sand, clay, iron oxide, or other detrital material may be mixed or interbedded with the carbonates in larger or smaller quantities. During later ages beds of sand or clay may have been superimposed, and the resulting earth pressure gradually consolidated the carbonates and other minerals into firm rock. Through long geologic ages of earth adjustment some of the rocks so formed may have been elevated to occupy land areas where they can be exploited for commercial use.

In most instances the original shells have been so comminuted by wave action or reduced by pressure and earth movement that the shell structure has been almost completely destroyed. In some deposits, however, the shells may remain more or less intact. Such rocks may consist predominantly of shells of one kind, and the limestone may be named accordingly, for instance, coral, crinoid, or coquina limestones. Chalk is a fine-grained white, friable limestone composed largely of minute shells of foraminifera. Oystershell beds may be regarded as present-day unconsolidated limestones that may in future geologic ages become beds of firm, hard rock.

Another series of names is applied to limestones according to their physical character. Common compact is the most widespread type, it consists of a fine-grained, dense, homogeneous aggregate varying in color from light gray to almost black. Lithographic is a very fine-grained crystalline variety, usually drab or yellowish.

Oolitic limestone is made up of small, rounded grains of lime carbonate with a concentrically laminated structure.

Two varieties of limestone, travertine and Mexican onyx, consist of calcium carbonate that has been deposited from solution. The first is a product of chemical precipitation from hot springs. It is deposited in successive layers; and as chemical composition and conditions of deposition may vary during the process, a banded structure commonly results. The rock is characterized by numerous irregular cavities. The second type, Mexican or cave onyx, is deposited from cold-water solutions, usually in limestone caves; it is to be distinguished from true onyx, which consists of silica. As Mexican onyx can be polished it is classed with marbles rather than with limestones and is commonly designated onyx marble.

BRANCHES OF THE INDUSTRY

The limestone industry is divided into two distinct branches - dimension stone and crushed stone. The outstanding distinction is that dimension stone is prepared in the form of rectangular blocks and as cut stone in specified sizes and shapes. Rough building stone may consist of more or less irregular blocks, but usually at least one good face is demanded. On the other hand, crushed and broken stone consists of irregular fragments.

The two branches have little in common. In quarrying dimension stone explosives are employed very sparingly because the integrity of blocks must be preserved, but heavy charges of explosive are used in a crushed-stone quarry to reduce the rock to fragments. All subsequent methods and equipment for preparing the products for market are dissimilar, and marketing problems are different also.

The crushed- and pulverized-limestone industries are subdivided into three main branches; one includes stone sold or used in its natural state except for crushing, grinding and sizing, and the other two involve calcining processes used in manufacturing cement and lime - the two important primary products manufactured in conjunction with quarrying. To indicate the magnitude of the limestone industry, table 1, showing statistics for a recent 3-year period, has been included.

TABLE 1. - Limestone sold or used in the United States, 1950-52, in short tons

	1950	1951	1952
Dimension stone	808,000	807,000	787,000
Crushed and broken stone..	254,452,000	285,468,000	296,919,000
Total	255,260,000	286,275,000	297,706,000

DIMENSION STONE

Requisite Qualities

Although numerous limestone deposits occur throughout the country, only a few consist of rock that will satisfy the exacting requirements of dimension stone. Deposits with irregular or closely spaced joints are unsuitable because large blocks free from cracks or lines of weakness are demanded. Limestones are variable in physical properties, such as texture, porosity, hardness, strength, and color, and upon these properties depends their adaptability as dimension stone. Only those limestones that are compact, easily workable, uniformly textured, and attractively colored merit consideration for such use.

Purity is not regarded as an essential property of a building limestone, although some types of impurities may impair its quality or workability: Silica may make a stone difficult to work, and iron sulfides, pyrite or marcasite in a building stone may result in iron stains on weathered surfaces.

Uses

Dimension limestone is used principally for building. It may be employed for entire exteriors or in conjunction with brick or other building materials. It is used also for columns and for interior structural and decorative purposes. Thin slabs are used for flagging.

Structural Units

Cut stone consists of blocks that are cut to specified dimensions and surface tooled. Nowadays ashlar is included with cut stone. The term “ashlar” is applied to the smaller rectangular blocks. Even-course ashlar consists of blocks of uniform height for each course, although succeeding courses may be of thicker or thinner blocks. Random ashlar consists of blocks of several sizes that may be fitted together to make a wall having unequally spaced joints. Small blocks with untooled surfaces are sometimes included with ashlar, but during recent years they have usually been included with the class known as house-stone veneer, which consists of rough-surfaced blocks or strips broken in irregular lengths and used extensively as a facing or veneer on residences or other structures.

Rough building stone consists of rock-faced masses of various shapes and sizes. Stonemasons build them into walls having irregular joints. They are widely used in residential construction for chimneys, basements, or entire walls and also to some extent for public buildings, bridges, fences, and the more ornamental types of retaining walls.

Rubble is the crudest form of building stone. The term is generally applied to irregular fragments having at least one good face. Such stone was once in ordinary use for basement walls, retaining walls, or similar types of construction for which concrete is now generally used. The use of rubble has declined greatly since the portland-cement era began.

Flagstones consist of thin slabs that may have irregular outlines or may be sawed into rectangular blocks.

Location of Deposits

The following locations are the most important as current sources of commercial building limestone.

Alabama

Limestone occurring in a belt about 20 miles long in Franklin County is known as the Bangor formation of Palaeozoic age. Gray to buff commercial stone lies in beds 20 to 25 feet thick. It is oolitic in texture (resembling fish roe) and consists of about 97 percent $CaCO_3$ and a small percentage of magnesium carbonate. The largest quarry is near Rockwood, where the stone is fabricated in a large mill. It has been sold widely for many years.

Indiana

Indiana is the chief source of building limestone in the United States; it furnishes about 60 percent of the total. The Salem oolitic limestone, of Lower Carboniferous age, occurs in a massive bed 25 to about 100 feet thick extending from near New Albany on the Ohio River northwest to a point north of Greencastle, about 125 miles. Active quarrying is confined chiefly to the Bedford-Bloomington area in Lawrence and Monroe Counties. The commercial stone ranges in composition from 97 to 98 percent $CaCO_3$. The availability of the rock in large, sound blocks and its easy workability, uniform texture, and durability have encouraged extensive development. The stone is shipped to virtually all parts of the country, and some is exported. Several large quarries and more than a dozen fully equipped mills operate in the area.

Kansas

A buff to ligh-cream limestone is quarried near Silverdale, Cowley County. It is similar in texture and physical properties to Indiana limestone.

Minnesota

Virtually all of the limestones of Minnesota are dolomitic. The Onesta dolomite of Ordovician age furnishes most of the building limestone. It has been quarried for many years at Mankato, Blue Earth County, Kasota, Le Sueur County, and Winona, Winona County. The stone at Mankato is available in large blocks well adapted for bridges and other heavy masonry. The general color tone is buff; the bottom ledge is bluish, but when exposed it slowly turns buff by oxidation of iron. The Kasota stone has been recrystallized to such an extent that it is sometimes classed as marble. The yellow and pink varieties are popular for interior trim and decoration. The gray to white Winona stone is quarried high on the Mississippi River bluffs. Some beds are porous and are marketed as travertine. The magnesium content is high enough to class it as a dolomite.

Missouri

Stone quarried at Carthage, Jasper County, and Phenix, Greene County, is sold chiefly as marble, but some of it is classed as limestone. Rough construction stone and rubble are produced at Perryville, Perry County, St. Charles, St. Charles County, and various other locations.

Pennsylvania

Considerable quantities of rough building stone and rubble are produced at various points, particularly in southeastern counties.

Texas

At Cedar Park, Williamson County, a ledge about 30 feet thick provides a pale-buff to cream oolitic limestone which is quarried for building stone. Certain beds contain large fossils and are porous, resembling travertine. At Lueders, Jones County, a deposit of thin-bedded, light-gray and variegated limestone, harder than the Cedar Park stone, is quarried for building purposes.

Wisconsin

A thin-bedded, gray dolomite is quarried near Lannon, Waukesha County and is used widely as building stone and flagging. It contains about 51 percent $CaCO_3$, 41 percent $MgCO_3$, and 6 percent silica.

Prospecting and Development

Development should not be begun on a deposit without reasonable assurance of an adequate supply of limestone suitable for dimension-stone uses. Generally it is deemed unwise to expend large sums in establishing quarries and finishing mills unless a reserve for at least 20 years' operation is assured. The extent and quality of the deposit should be investigated as far as possible from outcrops. The spacing and arrangement of joints are important because these natural partings govern the maximum size of blocks obtainable. A deposit should be capable of furnishing rectangular blocks several feet in length and width and 1 to several feet thick free from cracks or incipient seams. The arrangement and spacing of joints and the soundness and uniformity of the rock can best be judged from exposures. Where the overburden is thin, stripping or trenching may be desirable for wider visual inspection.

Core drilling is usually desirable for determining the extent and quality of a deposit. The cores will show the general quality and uniformity of the stone and the thickness of the beds.

Color, texture, and uniformity of a limestone are important. Representative samples should be submitted to architects and builders for comment because a favorable reaction from the building trades is essential to success.

Most deposits of limestone usable as dimension stone are approximately flat lying and of moderate thickness. Overburden is usually removed with power shovels or other earth-moving equipment. The hydraulic method may be employed advantageously where the surface contour is favorable, water abundant, and a disposal area available. The method is especially advantageous for washing clay from mud seams.

Quarrying

Making Primary Cuts

Channeling machines are generally used to make primary cuts for block separation. The cutting mechanism operates with a chopping action similar to that of a reciprocating drill and cuts a channel or narrow trench on one or both sides as themachine travels back and forth on a track. The edge of the cutting tool is 1-7/8 to 2-1/8 inches wide and makes a channel about 2 or 2-1/4 inches wide.

In small quarries primary breaks may be made by discharging light charges of blasting powder in drill holes. This method is most successful in relatively thin bedded limestones having open bed seams.

Wire saws are used to some extent in Indiana as substitutes for channeling machines. The wire runs as a belt and cuts by abrasion. Sand is used as the cutting agent. Details of its use have been published (14).[2/]

Bed Lifting

Bed lifting is the term applied to the process of breaking the channeled blocks free from the quarry floor. This is a necessary process in the absence of open bed seams. In Indiana beds are lifted by driving wedges in a series of horizontal drill holes at the quarry floor. Masses of rock thus broken loose may be 50 or 60 feet long, 12 feet high, and 4 or more feet wide.

Block Subdivision

The large masses of stone that have been separated are first turned down with sheave and tackle before they are subdivided. Blocks of desired sizes are laid out with square and straightedge. Holes are drilled in line 6 to 8 inches deep and 12 to 18 inches apart. Fractures are made by the "plug-and-feather" method. The "feathers" consist of strips of iron that are flat on one side for contact with the wedge and curved on the other to fit the wall of the drill hole. Two are placed in a drill hole, and a plug - a steel wedge about 6 inches long - is driven between them. They are sledged lightly in succession until a fracture appears. Blocks are commonly 10 by 4 by 3 feet, and 10 by 4 by 4 feet. Figure 1 shows blocks that have been turned down ready for subdivision.

Hoisting

The blocks are hoisted generally with steel or wooden derricks of 30- to 50-ton capacity. Most of them are of the swinging-boom type.

Yard Operations

Storage and Transportation

Large storage capacity is essential, especially in cold climates where enough stone must be accumulated during the summer to supply winter mill demands. Outdoor storage may be maintained at the quarry or mill or at both places. The blocks may be piled and reclaimed by derricks with swinging booms or by overhead traveling cranes.

Scabbling

The term "scabbling" is applied to the process of trimming blocks of stone to desired dimensions and smooth surfaces. It is particularly important at quarries that ship limestone blocks to distant mills, because careful trimming reduces freight charges on waste.

2/ Underlined numbers in parentheses refer to items in the bibliography at the end of this report.

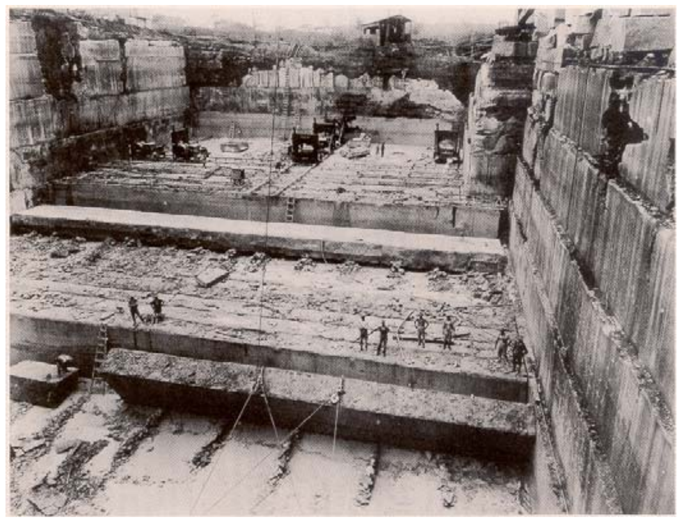

Figure 1. - Blocks of dimension limestone turned down ready for subdivision.
(Courtesy Building Stone Association of Indiana, Inc.)

Several methods are employed. Scabbling picks similar to ordinary double-pointed miners' picks are sometimes used, but sawing is generally more satisfactory and economical. Diamond-tooth drag saws or diamond-tooth circular saws may be employed. Scabbling planers are effective substitutes for saws. They consist of two sets of massive vertical blades that scrape off irregularities as the block is dragged between them. Wire saws are used also, enabling several blocks to be lined up and trimmed at the same time.

Milling

Drafting and Pattern Making

Before a cut-stone job can be begun, accurate detailed drawings must be made of every piece of stone to be used that differs from another in size or shape. Architects' drawings usually are insufficient because the stone must be fitted securely to the steel framework, and detailed data on the size and position of each steel member are necessary before the stoneworkers' shop drawings can be made. Patterns for molded and carved work are made of zinc or other soft metal. Sometimes paper patterns or stencils are used. For the more intricate carved work, plaster models are used.

After shop drawings are made draftsmen prepare a ticket for every block of stone on which is a drawing of the block with exact dimensions indicated. The ticket is numbered, and if a pattern is to be used its number also is shown. The man in charge of gang sawing first gets the ticket and cuts the block or slab. As the block passes to the planer, jointer, and all subsequent machines, the ticket goes with it, and each worker consults it before any work is begun. By this means workmanship is constantly verified, and few mistakes occur. Great skill and care are required, because one small error may ruin a block.

Block Handling

Mills are generally equipped with overhead traveling cranes. Commonly two cranes are used - a heavy one for placing blocks on saw beds and a lighter, more rapidly moving machine for handling smaller blocks and slabs.

Sawing

The first step in manufacture is to saw rough blocks to required dimensions. Gang saws are used almost exclusively for this purpose. They consist of a series of soft steel blades set in parallel positions in a frame that swings backward and forward. As the frame moves, actuated by a crank and connecting rod (pitman), the cutting blades lift toward the end of each stroke. This permits the sand abrasive to wash under them, promoting effective abrasive action. The blades may be spaced for thin slabs or thick blocks. An adjustable automatic gear feeds the gangs downward at any desired rate. An average cutting rate on standard mill blocks is about 6 inches an hour.

Another type, a straight steel blade set with diamond teeth, is used as a drag saw for making single cuts.

For making subsequent cuts, circular diamond saws are widely used. The blades are steel, one-fourth inch thick, with a series of square notches around the rim. Teeth mounted with diamonds are set in the notches and held in place with copper rivets. A stream of water cools the cutting edge and carries away the cuttings. The sawing rate is 3 to 15 inches a minute, depending upon the depth of the cut.

Planing

Planers are used for cutting stone blocks and slabs to smooth surfaces and desired thicknesses and also for cutting moldings and shaping curved designs. The frame that holds the cutting tool has lateral and vertical motion. The top and sides of a block may be planed simultaneously. A block of stone is carried beneath a planer on a traveling bed called a platen at a rate of 30 to 45 feet a minute, and the cutter scrapes a thin layer from the surface. Cutting tools are shaped to fit molding designs; that is, the tool is the reverse of the pattern.

A carborundum planer consists of two saws with a drum of smaller diameter between them. The saws trim the sides of the slab while the drum smooths the upper surface. The planer bed travels at a rate of only 20 to 30 inches a minute but finishes the job in 1 cut.

Turning and Fluting

In making columns the block of stone is first scabbled to cylindrical shape and then mounted in a lathe in which it rotates against a tool traveling slowly back and forth over the full length of the stone. The fluted columns also are made in a lathe. The flutes are drawn with pencil or crayon on the surface of the column; and the fluting tool, attached to the tool post of the lathe, travels back and forth while the column remains stationary. This process is continued until the line bounding the flutes is reached. When a flute is completed, the column is rotated with a hand bar, and the process is repeated in the new position. The ends are finished with pneumatic tools.

Cutting and Carving

Cutting usually is defined as straightline work and carving as curved work. Carving requires great skill, and most of it is done by experienced workers. Pneumatic tools are generally used, a heavy one for removing the larger fragments and smaller ones for completing designs. The hand chisel and mallet are still used for certain operations.

Finishing

Various types of surface finish are achieved by using different tools. A tooled surface, which is one covered with fine grooves in parallel lines, is made with a pneumatic or planer tool having fine teeth. A bush-hammered surface is rough and pitted, the hammer used having a face covered with small projections. A 4-cut surface is made with a planer tool having 4 corrugations to the inch. A shot-sawed or ripple surface is deeply scored or grooved by using steel shot as abrasive for the gang saw. Chat-sawed is smoother than shot-sawed stone.

Physical and Chemical Properties

The physical properties and chemical composition of representative limestones are given in tables 2 and 3. The data have been compiled from reports of the National Bureau of Standards, State geological survey reports, and various reference and text books.

TABLE 2. - Physical properties of limestones

Source	Type	Compressive strength,1/ lb. per sq. in.	Transverse strength1/ (modulus of rupture), lb. per sq. in.	Specific gravity	Absorption, percent	Weight per cubic foot, lb.
Bedford, Ind.	Oölitic	4,000	900 to 1,600	2.17	3.6 to 5.5	135
Do...........	do.	4,000 to 7,000	1,510	2.28	4.0	142
Bloomington, Ind..	do.	4,000 to 5,700	900 to 1,600	2.17	7.0	136
Do...........	do.	5,700	1,355	2.42	5.1	150
Rockwood, Ala.....	do.	9,700	1,610	2.34	4.5	146
Silverdale, Kan...	do.	6,700	1,055	2.10	8.9	131
Mankato, Minn.....	Dolomitic (cream)	13,500	1,565	2.45	3.66	155
Kasota, Minn......	Dolomitic (pink)	21,320	1,995	2.53	3.4	158
Winona, Minn......	Travertine	17,000	955	2.53	2.8	158
Lueders, Tex......	Oölitic	8,900	1,120	2.22	6.5	139
Cedar Park, Tex...	do.	2,600	640	1.87	12.3	117
Lannon, Wis.......	Dolomitic	-	-	2.85	9.0	170

1/ Perpendicular to bedding.

TABLE 3. - Chemical composition of limestones

Source	Type	CaO	MgO	CO_2	Fe_2O_3	Al_2O_3	SO_3	Insol.
Rockwood, Ala.	Oölitic	54.70	0.72	43.13	0.32	0.28	0.05	-
Bedford, Ind.	do.	54.80	.72	43.30	.15	.55	.07	-
Bloomington, Ind.	do.	54.54	.59	42.90	.08	.68	.06	-
Mankato, Minn.	Dolomite	27.40	18.90	42.10	1.10	-	-	10.40
Kasota, Minn.	do.	27.76	15.40	38.72	-	-	-	13.18
Winona, Minn.	Travertine	30.80	19.70	45.70	.60	-	-	3.20

Specifications

Specifications have been established for stone (including limestone) to be used in Federal building projects. For exterior building stone the specifications are comprised in a 12-page pamphlet entitled "Stone Work," issued by General Services Administration, Public Buildings Service, dated March 1950. Copies may be obtained by addressing a request to Public Buildings Service, GSA, Washington 25, D. C. The specification indicates the physical and chemical properties required and covers the dimensions, design, surface finish, workmanship, and setting. For non-Government construction the architects or builders may prepare specifications, but more generally they use the specifications promulgated by the limestone-producing companies, with such modifications as may be mutually agreed upon.

Marketing

Dimension stone is sold by the cubic foot, and much of it commands a price high enough to give it a nationwide market. Two-thirds or more of all building limestone is sold as rough blocks or sawed slabs to mills in consuming centers, where it is fabricated chiefly for small or moderate-size buildings. The balance of the production is manufactured for specific projects, usually of large size, in mills operated in conjuction with quarries or in independent mills. The smaller limestone quarries usually sell their stone to local builders and contractors.

CRUSHED AND BROKEN STONE

Production of crushed and broken limestone (excluding that used in making cement and lime) has experienced remarkable growth. In 1922 it reached 52,684,000 tons; in 1942, 142,025,000 tons; and in 1952, an alltime high of 216,468,000 tons. This fourfold increase in 30 years is due primarily to the rapid growth in highway and building construction and to wide expansion in the metallurgical, chemical, and processing industries for which limestone is an essential raw material. Limestone made up 72 percent of all crushed and broken stone sold in 1952.

Uses

Wide Range of Applications

For many of the uses of crushed limestone, physical properties are of primary importance; for others, chemical composition is a dominant requirement. Many limestones have the physical qualities that render them adaptable to virtually all of the uses for which any crushed stone may be employed, but limestone also has active chemical properties that make it not only useful but essential to many chemical and industrial processes. Limestone has the widest and most diversified uses of all varieties of stone.

Table 4 indicates the magnitude of the requirements for various uses of crushed and broken stone in 1951 and 1952. Corresponding figures for later years are given in the Stone chapters of the Minerals Yearbook published annually by the Bureau of Mines.

Uses for Which Physical Properties Are Most Important

Concrete Aggregate

A vast tonnage of limestone is used as aggregate for concrete in which form it is consumed chiefly in highway construction and in the building trades. Data on specifications are given later under Marketing.

Although consumers may differ in some respects as to. the requisite qualities of stone for use as aggregate, generally it should consist of clean, hard, strong, durable, uncoated fragments free from injurious amounts of soft, friable, thin, elongated, or laminated pieces. Alkalies and organic matter are usually undesirable. Soluble sulfides are objectionable because they oxidize, and the sulfuric acid formed will attack calcareous materials that may be present and form gypsum, which expands during crystallization and disrupts concrete.

Various tests are made to ascertain the fitness of limestone. They formerly included the Deval abrasion test, the Dory hardness test, the Page impact test, and ordinary crushing-strength tests, but these tests have been almost universally supplanted by the Los Angeles abrasion test. For determining soundness the more important are the freezing and thawing, the sodium sulfate, and the magnesium sulfate tests. Each involves freezing or crystallization of a substance in the pores or cracks, which results in heavy interior strain. The resistance of the stone to disruption is a measure of its soundness.

TABLE 4. - Limestone, crushed and broken, sold or used in the United States, by principal uses, 1951-52

Use	1951		1952	
	Short tons	Value	Short tons	Value
Concrete and roadstone	112,717,000	$140,354,000	127,379,000	$163,581,000
Railroad ballast	9,085,000	9,575,000	8,827,000	9,390,000
Fluxing stone	39,930,000	45,622,000	34,909,000	41,119,000
Agriculture	19,401,000	31,052,000	21,152,000	34,464,000
Riprap	3,101,000	4,043,000	4,872,000	6,424,000
Alkali works	7,709,000	7,207,000	6,558,000	6,448,000
Calcium carbide	889,000	904,000	723,000	762,000
Coal-mine dusting	385,000	1,523,000	422,000	1,685,000
Filler	2,023,000	5,703,000	1,953,000	5,412,000
Filter beds	193,000	306,000	89,000	146,000
Glass factories	794,000	1,907,000	814,000	1,933,000
Limestone sand	800,000	962,000	1,698,000	2,158,000
Limestone whiting	710,000	6,702,000	762,000	7,165,000
Paper mills	446,000	943,000	360,000	821,000
Poultry grit	99,000	524,000	79,000	604,000
Refractory (dolomite)	1,112,000	1,520,000	708,000	1,048,000
Road base	1,485,000	1,310,000	1,371,000	1,245,000
Sugar factories	563,000	1,369,000	541,000	1,404,000
Other and unspecified	3,231,000	7,822,000	3,251,000	8,054,000
Total	204,673,000	$269,348,000	216,468,000	$293,863,000
Cement	64,284,000	(1)	64,305,000	(1)
Lime	16,511,000	(1)	16,146,000	(1)
Grand total (approximate)	285,468,000	(1)	296,919,000	(1)

1/ Data not available.

Much study is being devoted to proper sizing of aggregates and proper proportioning of the various sizes to obtain maximum strength and durability with a minimum of cement.

Road Stone

Stone of various sizes ranging from 3-1/2 inch to dust is used in road construction. The size gradations vary according to use. The principal types of application are waterbound macadam, graded aggregate base course, bituminous macadam, bituminous plant mixes, bituminous surface treatment, and portland-cement concrete. Detailed size gradations for each of the above uses are given in Simplified Practice Recommendation R 163-48, issued by the United States Department of Commerce.

The requisite qualities of road stone are similar to those of aggregate, except that resistance to abrasion is of primary importance. A soft stone disintegrates under traffic; and a laminated stone, even if fairly hard, breaks into flat or elongated pieces that may not compact solidly. Stone of low porosity is desirable; otherwise, water may penetrate and soften the structure of the road. Road stone should break into sharply angular, chunky fragments that, when properly graded for size, will interlock and press firmly into the surface of the road.

Various standard methods of testing, sampling, and mechanically analyzing road materials are given in the American Society for Testing Materials Standards.

Railroad Ballast

Large quantities of limestone are used by railroad companies for maintaining road beds. A minimum of 3/4 inch and a maximum of 2-1/2 inches (round openings) for ballast sizes has been widely used, but lately there has been a trend toward the use of smaller sizes. The requirements as to quality are generally the same as for aggregate and road stone.

Asphalt Filler

Limestone dust, approximately 80 percent of which will pass a 200-mesh screen, is used as a filler in road asphalt surface mixtures. Much of it is classed as a byproduct at crushed-stone plants, although the preparation of asphalt filler is a substantial part of the business of some quarrying companies.

Riprap

Riprap consists of heavy, irregular blocks used chiefly for river and harbor work, such as spillways at dams, shore protection, and docks. It is a low-priced product and is usually procured from nearby quarries. Any type of dense, sound limestone may be used; there are no general specifications.

Coal-Mine Dusting

Operators of bituminous-coal mines employ fine, incombustible dusts for distribution throughout their mines as a means of preventing or checking coal-dust explosions. Limestone dust is particularly satisfactory for this purpose, because it is essentially carbonate of lime and, being white, is readily discernible. To comply with the Federal Coal-Mine Safety Act amendment of 1952, rock dusts must contain not more than 5 percent of free and combined silica and must be ground so that 100 percent will pass through a 20-mesh screen and 70 percent or more will pass through a 200-mesh screen.

Sewage Filter Beds

Crushed limestone is satisfactory for sewage filter beds. Either high-calcium or dolomitic limestone may be so used, and siliceous impurities are not objectionable if they are fine grained and evenly distributed. Certain other impurities, notably pyrite, marcasite, and clay, are to be avoided. The stone should be strong and compact, with pore space evenly distributed, and the fragments should be rough to provide anchorage for bacteria. Fines and dirt should be screened out.

Stucco and Terrazzo

Dense, compact limestones of attractive colors may be crushed into small fragments for terrazzo floors, but marble chips that will take a polish are generally preferred. Limestone reasonably impervious to moisture finds some use in stucco and pebbledash work.

Poultry Grit

Limestone crushed to granules and screened to uniform sizes is sold for poultry grit. Almost any type of limestone may be so used. The products may be graded by sizes into turkey grit, chicken grit, pigeon grit, and bird grit.

Sand

Limestone crushed to the size of sand grains, when carefully washed and graded, may be substituted for silica sand in mortar, wall plaster, and concrete. Large tonnages of limestone sands have been used in concrete highway construction in the Middle West.

Roofing Gravel

Screened limestone chips are sold as gravel to be used with tar for coating flat roofs,

Yard and Playground Surfacing

Limestone screenings without a binder afford good surfaces for school yards, playgrounds, walkways, station platforms, and tennis courts.

Concrete-Block Manufacture

Limestone screenings are used as aggregate in manufacture of concrete blocks, and limestone chips may be embedded in the surface to make the blocks resemble cut stone.

Chalk, Whiting, and Whiting Substitutes

Chalk is a soft, friable, fine-grained, light-colored type of limestone. The distinguishing physical characteristics of true chalk have never been fully defined; probably its noncrystalline and colloidal properties are most important. Whiting is a pulverized, purified, and carefully sized chalk. Whiting substitutes consist of finely ground limestone or dolomite, ground marble, white marl, and also chemically precipitated calcium carbonate. Very little true chalk has been produced in the United States.

True whiting is preferred for calcimine and cold-water paints and in the manufacture of putty. Both true whiting and substitute materials are used as ceramic raw materials and as fillers in numerous products, such as rubber, paint, paper, oilcloth, window shades, and linoleum.

Uses for Which Chemical Properties Are Most Important

Cement Manufacture

Limestone is the chief raw material used in making portland cement. Although pure limestone is not required, constancy in chemical composition is desirable. The general requirements are: (1) The stone should be free of concretions rich in iron minerals; (2) the silica and alumina contents should be sufficiently low and in such proportions that they will not interfere with the desired silica-alumina ratio in the finished product; (3) the magnesium content should be low enough that the finished product will not contain more than 5 percent magnesia (MgO); (4) the content of iron should be low enough that the ferric oxide content of the cement does not exceed 4 percent: (5) the sulfur content should be low.

Cement rock is an argillaceous limestone that contains enough clay as it occurs in nature to adapt it for the manufacture of cement. Sometimes it may be necessary to adjust its composition by adding small quantities of either high-calcium limestone or clay.

Lime Manufacture

For lime manufacture limestone must conform with rather rigid physical and chemical requirements. Exceptionally pure stone, total carbonates ranging from 97 to more than 99 percent, is generally used because virtually all impurities remain in the lime that results from calcination. The most common impurities are silica, alumina, iron, and sulfur. For shaft-kiln operation the stone should be sound and compact because porous and friable types break down during calcination and the fines retard the draft. For the same reason fines are screened from the kiln feed. For rotary-kiln operation finer materials may be used. Both high-calcium and high-magnesium stones are used. More detail on lime manufacture appears in another Bureau report (3).

Agricultural Uses

The most important uses for limestone in agriculture are as fertilizer, soil conditioner, and corrective for soil acidity. Pure limestone is desirable but not essential, because, although ordinary impurities lessen the percentage of calcium or magnesium available for improving the soil, they are not injurious to plant growth. Therefore, it may be more economical to use a local impure limestone than to purchase high-grade material that must bear a relatively heavy transportation charge. There is some difference of opinion regarding the suitability of dolomitic limestone, but most authorities agree that magnesium is of equal value with calcium and that the value of stone for agricultural purposes may be measured by the percentage of total carbonates present. Dolomitic limestone is preferred for magnesium-starved soils.

Small quantities of limestone are used in commercial fertilizers as diluting material or filler. Pulverized limestone is also added to stock food as a bone builder.

Mineral Wool

The name mineral wool or rock wool is applied to interlaced threads or filaments of mineral silicates used chiefly in heat insulation. It is usually made by melting argillaceous limestone, slag, or other calcareous and siliceous compounds in a cupola furnace and blowing the molten material into fine threads with a steam jet. The combination of raw materials most desired is one that will melt into a liquid slag at a relatively low temperature. Substantial quantities of siliceous and argillaceous limestones are used.

Chemical and Industrial Uses

Limestone is an important raw material used in metallurgy and in many chemical industries, such as alkali, calcium carbide, sugar, paper, and glass manufacture. Information on such uses is given in some detail in another publication of the Bureau of Mines and will not be repeated herein (7).

Uses of Dolomite and High-Magnesian Limestone

Some uses for which a magnesium content is essential or preferred are covered in preceding sections of this report. There are, in addition, several special uses.

Dolomite is employed extensively as a refractory lining in metallurgical furnaces. It is generally dead burned, but, particularly for patching, it may be used raw. A dead-burned product is made by calcining the dolomite at about 1,500° C., usually with addition of roll scale or iron oxide.

Dolomite is used to manufacture basic magnesium carbonate (technical carbonate) which is employed with addition of asbestos for making "85-percent magnesia" pipe and boiler covering.

During recent years dolomite has been employed as a source of magnesium metal.

Dolomite is widely used for calcining into lime. As indicated in the discussion of chemical and industrial uses in Information Circular 7402 mentioned previously (7), dolomitic limes have certain special uses, but they are also used extensively in the building trades, particularly in finishing-coat plasters.

Further details on the uses of dolomite are given in a Bureau report (8).

Distribution of Deposits

Deposits of limestone occur in all States, and in 1952 were utilized commercially in every State except Delaware, New Hampshire, and North Dakota. In some States deposits are very extensive and are quarried in many places. The general distribution of limestones and dolomites is indicated in the following sections. More detailed information on the locations of dolomite deposits is available in another Bureau of Mines report (18).

New England States

Many of the limestones of New England are so highly crystallized that they are classed as marbles. In Maine steeply dipping beds of crystalline limestone occur near Rockland and are utilized for lime and cement manufacture. A massive type occurs in Aroostook County.

In Vermont massive limestones are found principally in the northwestern counties. Waste marble in the Rutland County area is used at times as limestone. Low-magnesian limestone appears in northern Rhode Island. Large deposits of limestone and dolomite occur in western Connecticut and Massachusetts. Small occurrences in New Hampshire are of no commercial importance.

New York, New Jersey, and Pennsylvania

In New York limestones occur extensively in the counties between the Adirondacks and Lake Ontario, and crystalline dolomite occurs in St. Lawrence County. Limestones also crop out to the south in Herkimer, Saratoga, Washington, and Warren Counties and in a small area in the Champlain Valley. Another formation containing stone of 95 percent or more calcium carbonate crops out at various points in the eastern Adirondacks from Saratoga County north to the Canadian boundary. Deposits are quarried along the lower Hudson River near Poughkeepsie. Important belts extend east from Buffalo and the Niagara district to Lake Oneida and southeast to the Delaware River. The principal centers of production are in the Hudson River Valley for the New York market; in Oneida, Madison, and Onondaga Counties in central New York; and in Monroe, Genesee, and Erie Counties for Buffalo and other western markets.

The coarsely granular, crystalline Franklin limestone, which ranges in composition from a nearly pure calcium carbonate to a dolomite, is the calcareous rock of greatest commercial importance in New Jersey. It is available in Sussex and Warren Counties. The Kittatinny magnesian limestone occurs in thick, highly folded beds that are most readily available in Sussex, Warren, Somerset, and Hunterdon Counties.

The limestone industries of Pennsylvania are in the lead of those in all other States. Their preeminence is due to the availability of an abundance of high-grade stone and to extensive markets, particularly for fluxing stone in the iron and steel industries, for aggregate in highway and building programs, and for raw materials for large cement- and lime-manufacturing industries. Those of greatest commercial importance are found in the central and southeastern counties and in an area north of Pittsburgh. Pre-Cambrian limestones occur in Chester, Bucks, Berks, and Northampton Counties. Cambro-Ordovician limestones appear in a valley that crosses the State through Easton, Allentown, Lebanon, and Chambersburg and in Lancaster and York Valleys. An argillaceous phase constitutes the well-known cement rock in the Lehigh Valley district. The Helderberg and other limestones occur in narrow, curving bands in south-central Pennsylvania. Carboniferous limestones are widespread throughout the north-central and western half of the State. Pennsylvania limestones have been described in detail (13).

Maryland, Delaware, Virginia, West Virginia, North Carolina, and South Carolina

Limestones appear prominently in Carroll, Baltimore, and Harford Counties, Md. Washington, Frederick, Allegany and Garrett Counties in western Maryland also have numerous deposits that are utilized for making aggregates and also for lime and cement manufacture.

High-grade limestones of the Shenandoah Valley of Virginia and West Virginia have great commercial value. They occupy much of the two western tiers of counties throughout the entire length of Virginia. Lime manufacture is an important industry in this area.

Limestones occur in the western counties of North and South Carolina but are not utilized extensively. Marls are abundant on the coastal plain of Virginia, North Carolina, and South Carolina.

Tennessee, Mississippi, Alabama, Georgia, and Florida

Limestone deposits are extensive in Tennessee, particularly in the central and eastern parts. The Holston formation includes the well-known marble belt of the Knoxville area. Limestones are utilized widely in middle and eastern Tennessee, particularly in Knox, Rutherford, Coffee, White, Cumberland, and some other counties. Cement, lime, and aggregates are the more important limestone products.

Limestone beds are utilized to some extent in the vicinity of Vicksburg and Jackson, Miss. The Selma chalk crops out in a zone about 30 miles wide in the northeastern counties.

High-quality limestones are abundant in Alabama. They are quarried extensively in the Birmingham area, particularly to supply furnace flux and lime. Important centers of production are in Blount, Etowah, Shelby, and Jefferson Counties. Dolomite is quarried in Jefferson County.

The commercial limestones of Georgia are confined chiefly to the northwestern counties - Polk, Dade, Bartow, Fannin, Gilmer, Cherokee, and Pickens. They are used chiefly for lime and cement manufacture and as aggregates.

Limestones are plentiful in Florida, but many of them are the soft, friable shell types. The Tampa limestone of the west-central counties is fairly hard and compact. Coral and oolitic limestones form the foundation of the Keys and border the east side of the Everglades.

Wisconsin and Michigan

Limestones are extensive in the north-central and northern sections of Wisconsin, appear in a broad belt along the eastern border of the State, extend across the southern counties, and are available in some areas along the western side. Nearly all of them are dolomites or high-magnesian limestones. Quarries are numerous, and their chief products are lime and aggregates.

Important limestone deposits border the northern part of the Southern Peninsula of Michigan. What is probably the largest limestone quarry in the world is at Rogers City, Presque Isle County. Other important deposits are in the Northern Peninsula. Deposits of commercial value appear also in a belt through Lenawee, Monroe, and Wayne Counties in southeastern Michigan, in several southern counties, and in an area near Saginaw Bay. The entire range of limestone products is made of Michigan limestone. Large quantities are shipped by water to other States.

Illinois, Indiana, Ohio, and Kentucky

Commercial limestones of both the high-calcium and dolomitic varieties occur in about one-third of the area of Illinois, including the northern end and belts along the western and southern borders. Scattered deposits of less economic importance are found in the remaining two-thirds of the State. The aggregate industries of the Chicago area are extensive.

Limestones occur widely in Indiana, the most important beds forming a belt about 20 miles wide extending northwestward through the central part of the State and including the famous oolitic building limestones quarried in Lawrence and Monroe Counties. Owen, Crawford, Harrison, and Washington Counties have high-calcium deposits. Farther north magnesian limestone occurs in several counties. Aggregates and cement are the leading products.

Limestones underlie a large part of Ohio. Dolomite of high purity in Wood, Sandusky, Ottawa, and several other counties is used extensively for magnesian lime manufacture. A second area farther south extending as far as Columbus has deposits of high-calcium and low-magnesium limestones. High-calcium stone occurs also in eastern Ohio and dolomite in Adams County in the south. Ohio leads all the States as a producer of lime, has a large cement industry, and ranks high as a producer of fluxing stone, aggregates, and many other products.

Kentucky is underlain with the same limestone formations that occur in Illinois, Indiana, and Ohio, and they appear in many eastern, southeastern, central, north-central, and western counties. Quarries producing crushed stone are operated in 30 or more counties distributed in various parts of the State.

States Between Mississippi River and Rocky Mountain Area

In Minnesota commercial limestones occur only in the southeast. Nearly all of them are high in magnesium, and many are nearly pure dolomites. Minnesota is well supplied with sand and gravel, and both traprock and granite are available in places, hence limestone is not used extensively as aggregate. The largest quarries are in the vicinity of Minneapolis and St. Paul. No lime or cement is made from Minnesota limestones.

The only limestone formations of North Dakota are argillaceous, chalklike beds in the far north and thin, more or less cherty beds, occurring as the upper strata on buttes in the western area. They are not utilized commercially.

Hard limestones occur in the Black Hills district of South Dakota. They are utilized for aggregate and sugar manufacture and for making cement and lime in Pennington County. They are quarried also at times in Custer, Lawrence, Fall River, and Meade Counties.

Limestones are abundant in Iowa. The dolomitic limestones of the eastern and northeastern counties are those most widely used for aggregate, ballast, flux, and agricultural and various other uses. Stone for similar applications is quarried in the central counties and in the extreme southeast. Limestones are quarried extensively in central and northern Iowa and in Scott County on the eastern border for cement manufacture.

The more important limestones of Nebraska are those of Pennsylvanian age in the southeastern area. Cass and Serpy are the most productive counties. The Niobrara chalk formation is utilized for cement manufacture in Nuckolls County.

Limestones are abundant and widely distributed in Missouri. Dolomites abound in southeastern counties, and low-magnesian limestones, mostly of high purity, crop out along the Mississippi River at various points from Cape Girardeau north to Marion County. High-calcium limestones occur along the Missouri River and in southwestern counties. The most important aggregate-producing areas are in the vicinity of St. Louis and Kansas City. Important cement and lime industries are centered chiefly in the eastern counties.

Commercial limestones are confined chiefly to the eastern third of Kansas. They are used extensively for cement manufacture in the southeastern corner of the State. Limestones in the southeast, in the Kansas City area, and at various other points are quarried for aggregate and other crushed-stone uses. Cretaceous chalk abounds in western Kansas but has little commercial importance at this time.

The principal limestone area of Arkansas lies in the northern part of the State in the Ozark Plateau. The most important is the Boone formation, with a maximum thickness of 425 feet, extending from White County to the Oklahoma line. The limestone of Marion County was used as aggregate for constructing Bull Shoals Dam on the White River. The chalk formations of the southwest have been utilized to some extent.

The commercial limestones of Louisiana are confined to 2 occurrences - 1 in Winn and the other in Evangeline Parish. Oystershells are utilized on the Gulf coast.

The largest limestone area in Oklahoma is in the east-central Arbuckle Mountain district. Quarries producing crushed stone are operated in Murray, Coal, Atoka, Pittsburg, and several other counties.

Limestones are distributed widely in Texas, particularly in the eastern half of the State. The Austin chalk occurs in a well-defined belt running from the Red River in the northeast west through central Texas and then south and southwest, terminating near San Antonio. It is important as a raw material for cement manufacture. Other limestone beds parallel to this formation lie to the west, and still larger areas are exposed in the Edwards Plateau west of San Antonio. Except for those near El Paso the crushed-stone plants are chiefly in the east-central area. Asphalt-bearing limestones occur in Uvalde and Kinney Counties.

In Montana limestone occurs chiefly in massive beds along the flanks of mountain ranges in the western part of the State. Rock of exceptional purity occurring in Jefferson County is used for furnace-flux and sugar manufacture. Other important quarry centers are in Deer Lodge, Gallatin, Powell, Granite, and Cascade Counties.

Limestones occur in many parts of Wyoming but have not been utilized extensively. The best-known deposits are in Albany, Laramie, and Platte Counties in the southeast and in Weston County in the northeast. High-calcium limestones suitable for sugar manufacture are available.

Colorado limestone deposits are in two groups - an eastern division forming a belt immediately east of the Front Range and a second division lying west of the range. Limestone of the eastern division extends from north of Fort Collins to the middle of Douglas County, passing a little west of Denver. It continues with interruptions through several south and southeastern counties. The best rock contains over 90 percent total carbonates. Some of the limestones west of the range are high quality, but their location has discouraged development. The largest operations are in Pueblo, Fremont, and Chaffee Counties. The stone is used for cement manufacture, furnace flux, furnace refractory, and sugar mills.

The limestones of New Mexico have been utilized to some extent in San Juan and San Miguel Counties.

Western and Pacific Coast States

The limestone deposits of Idaho occur chiefly in the southeastern and northern counties. Bannock and Cassia Counties near the southeast corner of the State supply stone for making cement and for aggregate, flux, and sugar manufacture. Stone for sugar manufacture is produced in Butte and Teton Counties also. Limestone applied to many uses is quarried at times in Kootenai, Bonner, Nez Perce, and Clearwater Counties in the far north. Lewiston, Lewis County, also in the northern area, is an important center of production.

The most important limestones of Utah are those occurring in the Wasatch Mountains in the north and north-central region, chiefly in Cache, Weber, Tooele, and Utah Counties. They are used chiefly in cement and lime manufacture, as furnace flux, and as aggregate.

Arizone limestones are not used extensively. They supply the large smelter industries of the State with moderate quantities of lime and fluxing stone. Production is centered in Cochise, Yavapai, Gila, and Maricopa Counties.

The principal limestones of Washington occur in western counties from Seattle to the Canadian border. High-quality rock occurs on Orcos and San Juan Islands, San

Juan County. Other deposits are in Stevens and Pend Oreille Counties near the northeast corner of the State. Washington limestones are used chiefly for cement and lime manufacture.

Oregon limestones occur in three widely separated localities - the southwestern, the northwestern, and the northeastern. Those in the southwestern area in Jackson and Josephine Counties are relatively pure and are suitable for lime burning and chemical uses. Most of those in Clackamas and other northwestern counties are impure but are suitable for making cement. High-quality limestones are available in Baker County, northeastern Oregon. Deposits are found also in Grant, Union, and Wellowa Counties in the same section.

Limestones are available in various places in the eastern third of Nevada, but few quarries have been opened because of limited markets. Those in Clark and White Pine Counties are utilized for lime manufacture and metallurgical applications.

Few extensive limestone deposits comparable with those in many of the Eastern States occur in California. Most of the deposits in California are irregular bodies of variable magnesium content. Limestone deposits that are available are used extensively in the more populous areas. Cement manufacture is an important industry, particularly in the Los Angeles area where several large plants operate in San Bernardino, Riverside, Los Angeles, and Kern Counties. These counties are also important centers for lime manufacture and production of crushed-stone aggregate. Other limestone operations are in the following counties, beginning in the southern part of the State: Tulare, Inyo, Monterey, San Benito, Tuolumne, Santa Cruz, Eldorado, Centra Costa, Calaveras, Placer, and Shasta. Virtually the entire range of limestone products originate in the State.

Limestones occur in several places in Alaska. Beds of commercial quality occur in the Alaska Railway belt. They have been described in detail in a Bureau of Mines report (16).

A large deposit of relatively pure limestone containing about 97 percent $CaCO_3$ occurs near Edna Bay, Kosciusko Island, which lies northwest of Prince of Wales Island in southeastern Alaska. It has been explored and tested by a prospective user, but results of the exploration are not available. Limestones occur also on Dall Island near the south end of Prince of Wales Island. They have been quarried and shipped to the State of Washington for cement manufacture. A deposit of limestone is reported on Haceta Island.

Prospecting and Development

Determinations of the extent and quality of a limestone deposit should be made before development work is begun. If the rock crops out in such a way that both area and thickness of the beds are shown, a rough estimate of its quality and probable extent can usually be made. Limestones are as a rule fairly constant in composition throughout a single bed or unit of deposition; the greatest variations are found in passing from one bed to another. Therefore, all beds that may be included in a quarry are usually sampled. If a cross section is not available in nature, test holes are drilled at such intervals as will supply adequate data covering the whole area under consideration. Churn drills are usually employed, and cuttings for analysis are taken at regular intervals. No definite rules can be given either for position or arrangement of the holes. In flat-lying beds of uniform thickness and fairly constant composition they may be spaced at wide intervals - 100 or even 500 feet or more. Where beds are folded or tilted or where changes in composition or structure occur within short distances, they should be more closely spaced. Accurate, permanent records should be kept for all drill holes. When the dimensions of a deposit are known the approximate tonnage may easily be determined. Limestone weighs on an average about 160 pounds a cubic foot. To determine the approximate short tons available, the length, width, and depth in feet may be multiplied and the product multiplied by 160 and divided by 2,000.

For permanent installations a reserve of good rock sufficient for at least 20 years' operation is desirable.

Stripping

Stripping is the process of removing the overburden from the rock surface. The depth of overburden may vary from a few inches to 10, 20, 30, or even 40 feet. Likewise the nature of the material composing it is variable. It may be easily disintegrated loam, sticky, plastic clay, sand, gravel, boulders or a hardpan that may require blasting. The presence of erosion cavities in the limestone surface may make stripping difficult. Many different stripping methods are employed. The more important are the hydraulic method, dragline scraper, power shovel, and clamshell bucket worked from a derrick arm. Several types of efficient modern earth-moving machines are now available for heavy stripping, but the old-fashioned pick and shovel may be necessary to clean out mud seams.

Mining Methods

When beds are tilted at steep angles and are many feet thick an open quarry may be worked to considerable depth, but removal of waste to avoid dangerous overhang involves ever-increasing expense as the floor is deepened. When tilted beds are thin, any lateral extension must be in the direction of strike or outcrop. The narrowness of the working face on a thin bed cramps operations and makes it difficult to obtain large daily tonnages. Underground methods are commonly followed where the overburden is excessive or where comparatively narrow beds stand at steep angles. Underground methods have been described in detail in a Bureau report (17).

Drilling

The churn drill, commonly called the well drill, is widely used for primary drilling. Hand-manipulated, compressed-air hammer drills, using hollow drill steel, are so employed to some extent, but they are used chiefly in secondary drilling, that is, in block holing to break up the larger fragments. Detachable bits are now in common use.

Blasting

Heavy blasting to break rock from the parent ledge is known as primary blasting. A series of deep drill holes in 1, 2, or more rows may be fired at 1 time, throwing down a large mass of rock. Heavy blasts in churn-drill holes are usually considered the most effective. However, advocates of small-hole blasting claim that more general distribution of the explosive throughout the rock mass breaks it more completely and requires less secondary breaking than is usually needed for churn-drill blasting. Undoubtedly different results are obtained in different types of rock. Blasting in deep churn-drill holes is the method commonly employed. The charge in each hole should be regulated according to the estimated tonnage of rock to be moved. In average practice a pound of 40-percent dynamite shatters 3 to 6 tons of rock. The amount depends upon the toughness of the rock.

When electric detonators are used to fire the charges, the drill holes may be connected either in series or in parallel. Another method of firing is to use a detonating fuse such as primacord, the main line of which has a branch to each drill hole. A single detonator fires all the charges at virtually the same time. Such blasting is usually avoided in thickly populated areas.

It has been found that blasting costs can be reduced and rock fragmentation improved by using millisecond-delay blasting methods. The short time intervals between blasts in successive drill holes tend also to reduce earth vibrations that might, under ordinary conditions, damage nearby buildings.

To promote blasting efficiency many quarry superintendents keep accurate records that show for each shot the number and depth of holes, spacing, burden, kind and weight of explosive in each hole, tonnage of rock moved, and condition of fragmentation.

“Secondary” reduction is the process of breaking blocks of stone too large for loading. “Blockholing” is the method most commonly used. Holes several inches deep are sunk with a jackhammer drill, and a stick or part of a stick of dynamite with a fuse attached is placed in each hole. Rock dust or clay is used for stemming. Several shots may be fired in rapid succession.

At many quarries secondary blasting has been superseded by use of the ball breaker, sometimes called a “drop ball.” A heavy mass of steel that may weight up to 7,000 pounds is hoisted by a crane and dropped on the block of stone. It is said to give more rapid results at lower cost than blasting.

Loading

Loading is a large item in quarry cost. Hand loading, which was formerly common practice, is still used in small quarries or where careful selection of stone is desired, but power shovels are virtually indispendable in the average quarry. Dipper sizes range from 3/4 yard to 1-1/4 yards for the smaller quarries and 1-1/2 to 4 cubic yards or greater capacity for the larger quarries. (See figs, 2 and 3.) The size should be proportional to crusher capacity. Electric shovels are now most common, although other types are also used. Steam shovels are now rarely used. Bulldozers are employed widely to repair roadbeds, collect scattered stone fragments, and perform other useful services.

Haulage

Haulage involves the motive power and equipment required to convey rock from the loading point to the crusher. Some years ago the equipment used most extensively consisted of standard-gage or narrow-gage railroad tracks, locomotives, and side-dump or end-dump cars. These have now been superseded in most quarries by truck haulage, either as single units or as tractor-trailers. Many modern trucks are diesel powered for greater fuel economy (see fig. 4). Practice varies according to quarry conditions. Where moderate grades can be maintained the truck may carry the stone to the quarry bank; for steeper grades cable haulage may be necessary. In some instances the stone is conveyed from pit to bank by belt conveyor, or the primary crusher may be placed on the quarry floor and the crushed stone removed from the pit by belt conveyor.

Primary Crushing

Jaw and gyratory crushers are the more common types of primary breakers, although roll crushers are used at times. Hammer mills may be employed for the softer rocks. Jaw crushers may have openings up to 66 by 86 inches and gyratory crushers up to 84 inches. The crusher should be oversize rather than undersize in order that large rock fragments may be accommodated without bridging the crusher opening and thus stopping the crushing process. A vibrating pan or other type of feeder ahead of the primary crusher tends to minimize clogging and promotes a steady flow of stone to the crusher, enlarging the crusher capacity.

Secondary Crushing

Market demand may call for smaller-size stone than that produced by the primary crusher. Also there is at times a heavy demand for stone of the finer sizes for highway maintenance. Cone crushers, small-size gyratory crushers, or hammer mills may be used to reduce the primary-crusher product to 1 inch or smaller.

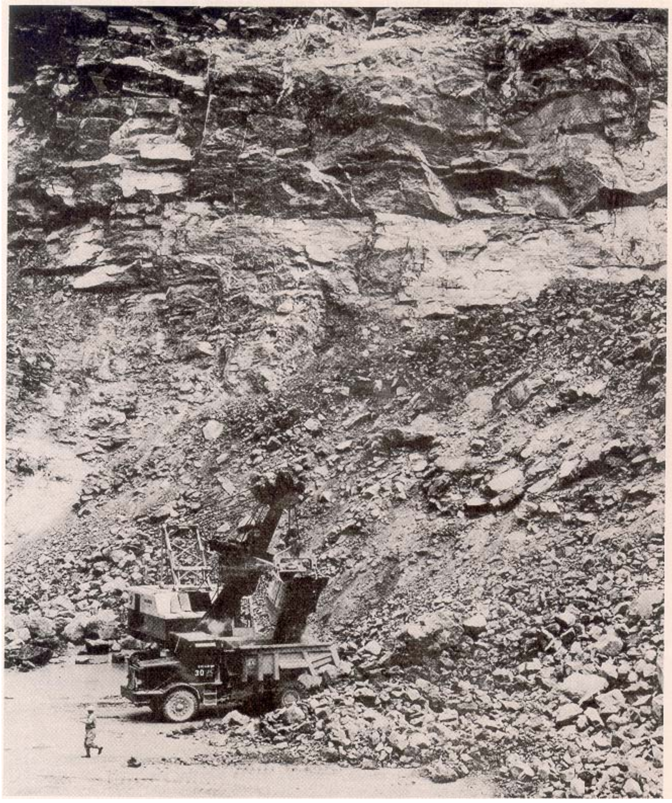

Figure 2. - Limestone is scooped from the quarry floor into a 22-ton truck by power shovel at Jones and Laughlin Steel Co. quarry in West Virginia.

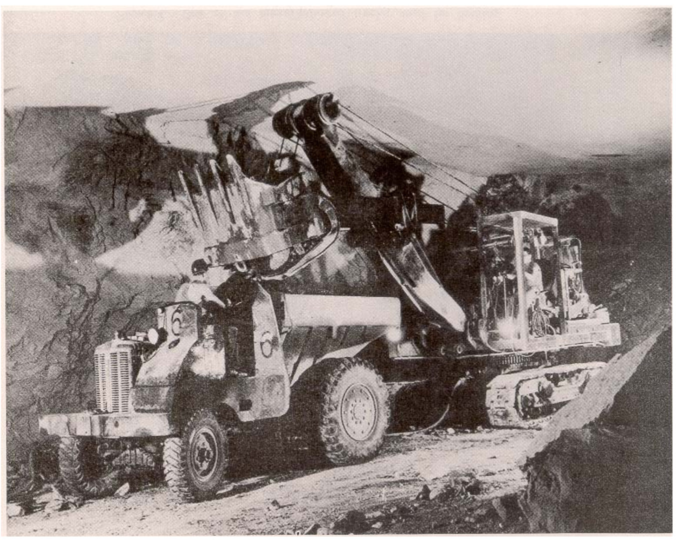

Figure 3. - Electric shovel with 1-½-yard bucket, loading limestone into a diesel-powered truck in Barberton, Ohio.

Fine Grinding

Finely divided limestone has many uses. Small, modified gyratory crushers, rolls, hammer mills, and rod mills are commonly used as reduction units. Even micronizers may be used to reduce the stone to extremely fine powders.

Figure 4. - One of the diesel-powered trucks used for hauling limestone from working faces to shaft in Barberton, Ohio.

Screening

For the larger sizes a railroad-rail bar grizzly having 3- to 5-inch openings is sometimes used. The revolving trommel used extensively some years ago has been superseded by the vibrating screen, although trommels are still used as scalping screens for the larger sizes. The vibrating screen, which was used originally for fine sizes only, is now used for all sizes. Vibrating screens are made in single, double, triple, and even quadruple decks. Vibrating screens for fine sizes are sometimes heated to prevent clogging. Another type of screen is the live roll grizzly, sometimes called the cataract grizzly, or multiroll sizer. It consists of a series of rotating disks having spaces between them through which the finer stone drops.

Washing

During early years crushed stone was seldom washed, but modern specifications have placed such restrictions on fines and dust that washing is now common. A coating of dust can be easily removed by directing a fishtail water spray on the stone during its passage over the screen. Sticky clay or other impurities that adhere closely to the stone are more difficult to remove. Various types of scrubbers or log washers may be used. The log washer consists of a series of rotating paddles, which agitate the stone in water and carry it up an incline against a countercurrent of clean water.

Marketing

Crushed stone is low-priced and has a relatively limited market range, as the transportation charge is usually a large part of the delivered price. Profitable operation depends largely on the extent of local markets. Much of the crushed stone produced goes into highway construction, and more active markets in this field are to be expected if planned extensive highway programs materialize.

Market requirements for aggregates are becoming increasingly rigid. Quality and screen sizes are governed by specifications of the various State highway departments and by those of the American Society for Testing Materials, the Federal Specifications Board, and the Association of State Highway Officials and by the numerous specifications for building projects under the control of private and Governmental agencies.

Demands for aggregate are seasonal. Shipments reach a minimum in winter months except in Southern and Pacific Coast States. Stone for metallurgical and chemical uses moves more regularly.

Producers are most concerned about steady market requirements of nearby builders, contractors, State highway departments, and other users. The prudent operator gages his plant capacity by the normal demand but is prepared to profit by any extraordinary market opportunities.

Demand for aggregates is influenced by availability and cost of such substitute materials as sand and gravel or slag. In the building trades concrete products in which aggregates are used must compete with brick, stone, wood, and other materials.

Prices

Some years ago current prices of crushed stone were quoted in market reports. About 50 quotations represented the chief marketing centers. Prices were so variable from place to place that quotations were abandoned. The selling price is a problem for each producer. It depends upon volume, prices of competitive materials, and various other local factors. Average selling prices f.o.b, plant for the United States and for each producing State for any year may be determined by consulting the annual Stone chapters of the Minerals Yearbook, published by the Bureau of Mines.

Prices of crushed and broken limestone have not advanced during recent years as greatly as those of many other building materials. Average prices f.o.b, crushing plant, at 5-year intervals from 1932, were as follows: 1932 - $0.88; 1937 -$0.91; 1942 - $0.96; 1947 - $1.20; 1952 - $1.36. Constantly increasing efficiency of equipment and methods, together with near-capacity output, have permitted prices to be maintained at a comparatively low level, even in recent years when labor and machinery costs have increased greatly.

Royalties

Many crushed-limestone producers operate in deposits they do not own. It is customary in such instances to pay the owner of the property a royalty of so much per ton of crushed stone sold. Royalties vary greatly, depending upon local conditions. They may range from 2 to 10 cents or possibly more than 10 cents per ton. The lower figures usually prevail where production is large, but sales value per ton, production costs, or competition may influence the amount. A minimum average daily or monthly production is usually a condition of a royalty agreement.

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Int. - Bu. of Mines, Pgh., Pa. 7221