is in turn overstepped eastward by Desmoinesian rocks. The uninterrupted advance of these sediments eastward toward and onto the Nemaha ridge and the Cambridge arch-Central Kansas uplift is evidence that the age of these features is pre-Morrowan (Late Mississippian) rather than post-Morrowan, pre-Atokan (Wichita orogeny) as often claimed. In addition Atokan and Desmoinesian rocks of these areas do not exhibit lateral facies changes involving the influx of coarse clastic sediments from the east that would be expected if the Nemaha ridge and the Cambridge arch-Central Kansas uplift experienced post-Morrowan uplift.

[646-647]

OKLAHOMA GEOLOGY NOTES

Volume 32 June 1972 Number 3

In This Issue

TWO DOLLARS PER YEAR · FIFTY CENTS PER COPY

Volume 32, Number 3, June 1972

OKLAHOMA GEOLOGY NOTES

OKLAHOMA GEOLOGICAL SURVEY / THE UNIVERSITY OF OKLAHOMA / NORMAN, OKLAHOMA 73069

Cover Picture

St. Clair Lime Company's New Rotary Kiln

Shown in the picture is the new 10- by 300-foot rotary kiln of the St. Clair Lime Company's Marble City facility, 1 mile north of Marble City, Sequoyah County, eastern Oklahoma, sec. 14, T. 13 N., R. 23 E. The conveyor belt supplies crushed stone to the feeder bin in the left foreground; the contact cooler and discharge section are at the opposite end of the kiln, at right. The feeder bin and storage silos of the older rotary kiln, also in use, are visible in the background.

The gas-fired kiln, which has a productive capacity of 450 tons per day, calcines high-purity limestone of the Marble City Limestone Member of the Quarry Mountain Formation (Silurian). For more details, see the related article beginning on page 67 of this issue.

—*T. L. Rowland*

(Photograph courtesy of Steve Dunlap)

St. Clair Lime Company Expands Marble City Facility

T. L. Rowland[1]

INTRODUCTION

A recent addition to Oklahoma's industrial development is the expansion of St. Clair Lime Company's Marble City facility, 1 mile north of Marble City, Sequoyah County, eastern Oklahoma, sec. 14, T. 13 N., R. 23 E. (fig. 1). The facility includes an underground limestone mine, a stone-processing plant, a recently completed rotary kiln (see cover picture), and an older rotary kiln (still in use, which began production in July 1964). The company also operates a plant at Sallisaw, 12 miles to the south, consisting of four vertical kilns and an 8- by 125-foot rotary kiln with a total capacity of 300 tons per day. The St. Clair Lime Company has been in the lime and crushed-stone business in the Sallisaw-Marble City area since 1937.

When the company decided to increase its capacity, the Marble City quarry was chosen for the new plant site—principally because of the ample space and a ready source of stone for plant operation. The chief significance of the adjacent limestone deposits lies in their exceptionally high calcium content.

GEOLOGIC SETTING

The plant is on the south margin of the Ozark uplift in a belt of Silurian-Devonian outcrops which attain a maximum thickness of 225 feet. The stone being worked is the high-purity Marble City Limestone, the upper member of the Quarry Mountain Formation of Silurian age (fig. 2). This unit was formerly included in the St. Clair Limestone (see Amsden and Rowland, 1965). The Quarry Mountain Formation is 154 feet thick in the plant-site vicinity. The lower member of the Quarry Mountain Formation, the Barber Member, consists of dolomitic limestone and beds of calcitic dolomite (fig. 2).

The Quarry Mountain Formation is overlain by Early Devonian carbonates of the Frisco Formation, which in turn are overlain by the Sallisaw Formation (fig. 2). In places the Sallisaw rests directly on the Quarry Mountain. The Frisco and Sallisaw together attain a thickness of 15-20 feet in the plant-site vicinity. The Quarry Mountain is underlain by the Tenkiller and Blackgum Formations, also of Silurian age (fig. 2).

At the plant site the Marble City is about 60 feet thick and consists of a skeletal grain-supported limestone (grainstone) of exceptional purity. The $CaCO_3$ content ranges from 98.8 to 99.3 percent, and the SiO_2 plus R_2O_3 content averages 0.3 percent or less. The overlying rocks consist of 450 feet of carbonates, shales, and sandstones of Late Devonian to Middle Pennsylvanian age. (For details of the Silurian-Devonian geology in this area, see Amsden, 1961, and Amsden and Rowland, 1965.)

[1]Geologist, Oklahoma Geological Survey.

Limestone of the Marble City Member has been mined into the side of Quarry Mountain by the room-and-pillar method. The mine has rooms 30 feet high and 55 feet square with pillars 35 feet square. A 65-year supply of Marble City Limestone has been core drilled and tested. Additional large reserves remain to be drilled and tested. The company updates a map of the mine once a month.

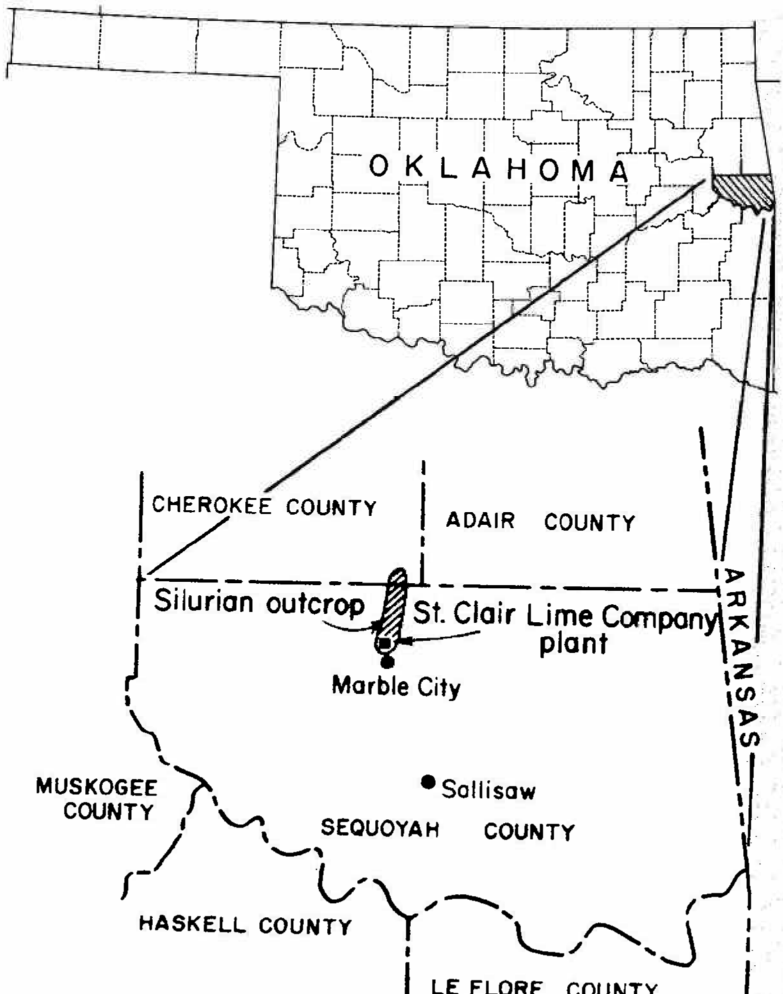

Figure 1. Index map of Marble City area showing location of St. Clair Lime Company's plant in relation to Silurian outcrop.

Drilling is done with a Gardner-Denver 2-drill jumbo using 2¼-inch bits. The drilling operation consists of single V-cut patterns utilizing 12 holes across, 7 rows high; the holes are 16 feet deep. Ammonium nitrate prill and dynamite detonators are used as explosives.

The stone is loaded and hauled during the 8-hour day shift. The scaling of the faces and roof and the drilling and blasting are done in a second 8-hour shift so that the mine has 8 hours to air out before the day shift begins. Since the rock is massive, with essentially no major partings, scaling of the faces and roof is necessary before drilling. A truck with a cable-lift basket is used for this operation.

MARBLE CITY PLANT

The modern, efficient Marble City plant is being expanded in three separate phases. Phase 1, now completed, was installation of the new rotary kiln (cover picture). The conveyor belt leading to the kiln-feed bin is automatic in its operation. The dimensions of the kiln are 10 by 300 feet. The kiln has 4 tires and is driven by a 150-horsepower electric motor. The feed-end temperature is 1,200°F, the mid-kiln temperature is 2,200°F, and the burning-zone temperature is 2,650°F. The kiln contains a high-energy wet scrubber and has a 6-inch refractory lining with 2-30-foot trefoils. The feed size is 2¾ by ⅜

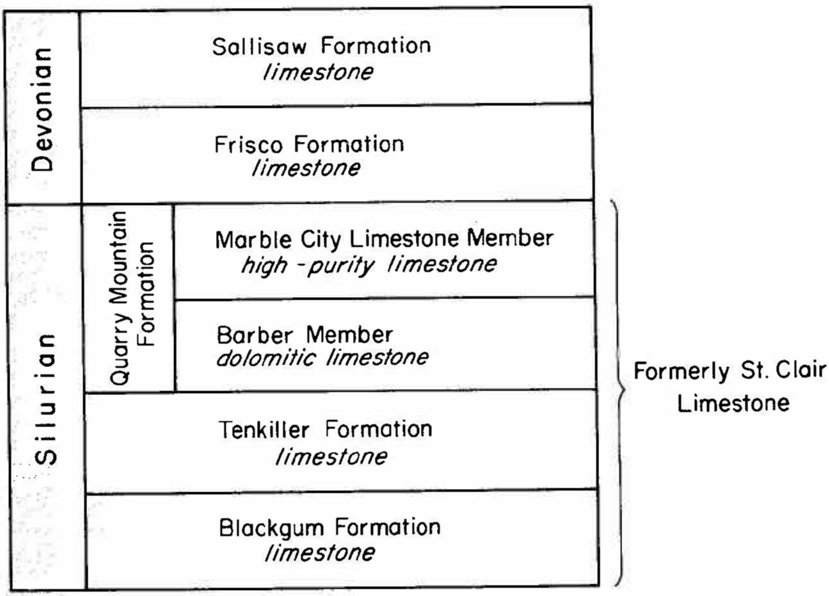

Figure 2. Generalized chart showing Silurian and Devonian formations in the Marble City area and their dominant lithology. Modified from Amsden and Rowland (1965, text-fig. 5).

inches. The kiln has the capability of calcining material of varying sizes. The kiln is fired with natural gas, and gasoline-powered generators are at the site in case of a power failure. All operations, from conveyor feed to final lime storage, are controlled from the kiln floor by a large push-button panel. The productive capacity of this new kiln is 450 tons per day.

Adjacent to the new kiln is the older kiln, which began production in July 1964 and has a productive capacity of 220 tons per day. This kiln is also automated. For details on the operation of the older kiln and the stone-crushing plant, see Trauffer (1965).

Each of the eight storage silos has a 125-ton capacity, and each stores one definite size of screened material, which ranges in size from ¼ to 2¾ inches. Thus customers can readily obtain the desired size of both lime and crushed stone, which can be shipped either by rail or by truck. Much of the total lime produced from the two kilns is sold for water treatment and industrial use.

Phase 2 of the plant expansion is currently under way and involves the enlargement and modernization of the stone-processing plant. Completion is expected soon.

Phase 3 calls for the building of a high-capacity hydrating plant. This plant will include a 15-ton-per-hour hydrator and finishing mill as well as modern bulk-handling and bagging facilities.

In view of the Southwest's current industrial and population growth, it is gratifying to see additional industrial development in Oklahoma, such as the expansion of the St. Clair Lime Company's plant at Marble City. This operation has provided a welcome boost in the growth of Oklahoma's industrial-minerals production.

References

Amsden, T. W., 1961, Stratigraphy of the Frisco and Sallisaw formations (Devonian) of Oklahoma: Oklahoma Geol. Survey Bull. 90, 121 p.

Amsden, T. W., and **Rowland, T. L.**, 1965, Silurian stratigraphy of northeastern Oklahoma: Oklahoma Geol. Survey Bull. 105, 174 p.

Johnson, K. S., 1969 [1970], Mineral map of Oklahoma (exclusive of oil and gas fields): Oklahoma Geol. Survey Map GM-15, scale 1:750,000.

Trauffer, W. E., 1965, St. Clair Lime Company, Sallisaw, Okla.: Pit and Quarry, v. 57, no. 8 (Feb.), p. 94-96, 101-102, 144.

NASA Report on Remote Sensing Released

The National Aeronautics and Space Administration has recently released the results of its study on the uses of remote sensing in detecting air and water pollution. Aspects covered include identifying, measuring, and monitoring water pollutants such as oil, chemicals, and sediments, and the publication culminates with a recommendation for full utilization of new techniques and instrumentation—especially remote sensing from space.

Titled *Remote Measurements of Pollution* (SP-285), the report is available at a cost of $3.00 from National Technical Information Service, Springfield, Virginia 22151.

A Challenge to Oklahoma's Minerals Industry[1]

Charles J. Mankin[2]

Oklahoma ranks fourth in the nation in gross mineral production. For the past 6 years, the value of mineral production has exceeded $1 billion. This mineral production is not only Oklahoma's principal economic base, but it also provides a significant amount of revenue to operate State government.

An analysis of the gross production figures shows that 94 percent of Oklahoma's mineral income is from oil and gas, making petroleum and petroleum products the principal contributors to the State's economic base as well as a main source of tax revenue. I might add here that we are consistently reminded through the news media and other sources that Oklahoma basically has an agrarian economy. I am sure that no one would dispute the importance of the agricultural industry to our State. It is interesting to note, however, that the total annual income from all aspects of the agri-industry amounts to between $800 million and $900 million. Income from the State's minerals industry exceeds that figure by almost 50 percent. Oklahoma, therefore, has been, is now, and will be for a long time in the future an oil-producing state.

In contrast to, and to some extent because of, the mature nature of Oklahoma's oil and gas industry, we find the remainder of the State's minerals industry substantially underdeveloped. In 1971, Oklahoma's production of all other minerals was valued at slightly less than $87 million. By comparison, the neighboring states of Kansas and Arkansas, with smaller populations and similar resources potential, have mineral production values, exclusive of oil and gas, in excess of $136 million and $147 million, respectively.

Another criterion of comparison is the value of mineral production exclusive of oil and gas on a per-capita basis. This comparison yields the following information:

Arkansas	$92
Missouri	$79
Kansas	$59
Texas	$42
Oklahoma	$33

The same criterion applied to a group of Midwestern states provides the following:

Ohio	$50
Illinois	$45
Indiana	$42
Iowa	$42

[1]Keynote address delivered at the symposium, Mineral Development Opportunities in Oklahoma, March 10, 1972, at Norman. A paper on carbonate resources from this symposium begins on page 73 of this issue; abstracts of other papers given at the symposium may be found in pages 95-98.

[2]Director, Oklahoma Geological Survey.

If we assume a per-capita figure of $45 to be a reasonable short-term objective, its attainment would result in an increase in the value of mineral production for Oklahoma of almost $31 million. This would represent a 35-percent increase in the value of mineral production exclusive of oil and gas.

One question that should occur at this point is, if we are so underdeveloped in these mineral commodities, why hasn't something been done about it? I know of no satisfactory single answer to that question, but perhaps a few observations relating to this query will cast some light on the purpose of this conference.

Investment in the petroleum industry is, as all of you well know, a high-risk venture, but high-risk ventures also have the potential for high rates of return. In the industrial-minerals area, the risk factor is substantially reduced and the expected rate of return is correspondingly lower. Persons with investment capital available for mineral development in Oklahoma already understand the risks involved and the expected rate of return from the petroleum industry. However, to sell anyone on the idea of investing in a granite quarry will require a substantial educational process.

Another question that may be raised is, if the minerals industry is underdeveloped, is it because there are no markets for these products? Again, no single answer is available. Unlike the petroleum industry, which has a built-in market for its products, many of the markets for other minerals must be, in a sense, established. In most instances, market demands for mineral commodities are currently being satisfied in some manner. For example, the consumption of salt in Oklahoma, currently more than 100,000 tons per year, is being satisfied largely through importation from Kansas and Texas. Until recently all of the vitrified clay pipe used in the State was made elsewhere and shipped in. A limited use in Oklahoma of granite and other materials such as dimension stone does not mean the absence of need. Rather, the absence of an adequate supply often means that other materials must be substituted. The availability of a good product at a competitive price can create a market.

In summary, the mineral-development opportunities in Oklahoma appear to be at least as good as, if not better than, those of most of our neighbors. The consulting geologist interested in such developments must demonstrate the availability of the raw material and, working with knowledgeable market analysts, demonstrate a need for the product or products. Processing will be required for many raw materials, and for this the geologist should obtain the assistance of skilled engineers. Thus, developing a mineral prospect into a finished, marketable product is no easier than selling a Morrowan test on the flanks of the Anadarko basin. But the opportunity does exist for those interested and willing to accept the challenge.

General Survey of Carbonate Mineral Deposits in Oklahoma[1]

T. L. Rowland[2]

Abstract—Oklahoma contains a substantial amount of surface and near-surface carbonate rocks, many of which are suitable for commercial development. For evaluation purposes, the State has been divided into six provinces: northwestern, southwestern, south-central, southeastern, northeastern, and north-central. Each of these provinces is discussed in terms of general age and types of outcropping rocks, general character of the carbonate rocks, chemical and physical properties of the carbonate units, production for the period 1960-70, and future outlook.

Although most of Oklahoma's deposits are used for crushed stone, some deposits are suitable for use as chemical-grade limestone and in the manufacture of portland cement. With expected industrial expansion in the region of the Arkansas River Navigation System, a statewide increase in construction, advances in technology, and a growing use of carbonate minerals and products for environmental purposes, the outlook appears favorable for expansion of the crushed-stone industry in Oklahoma.

INTRODUCTION

Oklahoma contains a substantial amount of surface and near-surface carbonate rocks, many of which are suitable for commercial development. These rocks range in thickness from as little as 6 feet to as much as 9,000 feet and range in age from Late Cambrian to Cretaceous. The Late Cambrian to Devonian sequence of carbonates reaches thicknesses of 9,000 feet, whereas the Pennsylvanian, Permian, and Cretaceous units are 6 to 100 feet thick. Mississippian carbonates attain thicknesses of 500 feet.

The State can be divided into six provinces for convenience of discussion: northwestern, southwestern, south-central, southeastern, northeastern, and north-central (fig. 1).

NORTHWESTERN OKLAHOMA

The surface rocks in this province of the State are Permian, Cretaceous, and Tertiary in age, with the Permian sediments dominating in volume. These rocks consist of shales, siltstones, sandstones, and gypsums. The only substantial amount of carbonate rocks present are dolomites; however, some limestones and caliche do occur. The dolomites may be characterized as fine grained and laminated, and many units contain a substantial amount of quartz silt and sand. Some coarse-grained dolomite also is present. Most of the dolomite units

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[1]Presented at the symposium, Mineral Development Opportunities in Oklahoma, March 10, 1972, at Norman. The keynote address from this symposium begins on page 71 of this issue; abstracts of other papers given at the symposium may be found in pages 95-98.

[2]Geologist, Oklahoma Geological Survey.

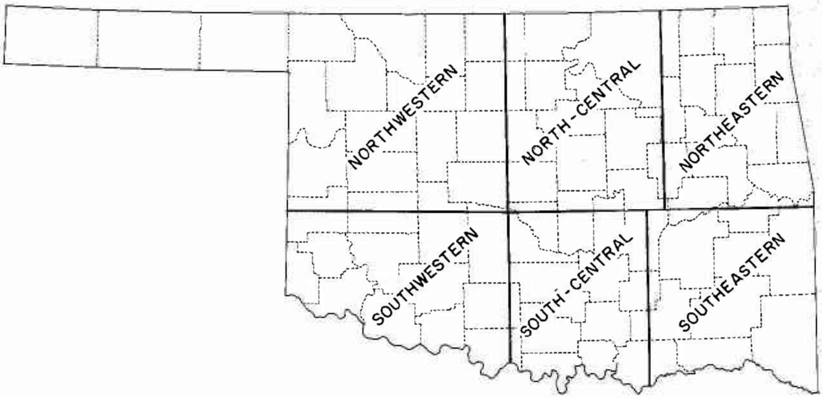


Figure 1. Index map of Oklahoma showing subdivision into six provinces.

are much too thin and discontinuous to form large-scale commercial deposits, but the units shown in figure 2 have been worked in two areas.

The quarried stone in this province is thin by most standards, having thicknesses from 3 feet to 8-12 feet. The northwesternmost outcrop is the Day Creek Dolomite, which is 2-3 feet thick; the Altona Dolomite, shown in Woodward and Major Counties, is 2-3 feet thick; the Relay Creek Dolomite in Blaine County is 2-4 feet thick; and the Weatherford Dolomite averages about 2 feet in thickness. Each of these units attains local thicknesses of 8-12 feet but only for distances of a few hundred feet.

The chemical character of these stones indicates that they are not suitable as chemical-grade dolomites. The $MgCO_3$ content ranges from 36 to 42 percent, the $CaCO_3$ content from 42 to 55 percent, the SiO_2 content from 1½ to 4 percent, and the R_2O_3 content from ½ to 4½ percent. Thus the silica and R-oxide content is much too high for chemical-grade stone.

There are many abandoned pits in this province from which riprap and dimension stone have been produced. The Weatherford Dolomite is presently being worked for dimension stone in Caddo County (fig. 2).

The production from this province from 1960 through 1970 has been reasonably low. No production was reported for 2 years, 1960 and 1964. A total of 380,000 tons has been produced in the last 11 years having a value of $550,000. In 1961, 226,000 tons of this total was produced from southeastern Custer County. Most of this stone was used as concrete aggregate and road material. Aside from this, the remaining production has been used for riprap and building stone. Only one producer of crushed stone presently operates in the region; this operation is in Cimarron County, in the Panhandle, from a caliche deposit.

This area does not provide carbonate rock units that might form large-scale commercial deposits. Limited production of crushed stone for local use and dimension stone provide the only future prospect for this region.

The surface sedimentary rocks in this province are Late Cambrian to Late Ordovician and Permian in age. The lower Paleozoic rocks consist of marine carbonates and sandstones with some shales, and the Permian rocks consist of shales, siltstones, sandstones, dolomites, and gypsums.

The limestones crop out in a series of small hills appropriately called the "Limestone Hills"; they form the north margin of the Wichita Mountain region (fig. 3). Most of these rocks belong to the Arbuckle Group of Cambrian-Ordovician age, comprising the Reagan Sandstone and limestones and dolomites of the Fort Sill, Signal Mountain, McKenzie Hill, Cool Creek, Kindblade, and West Spring Creek formations. The Bromide and Viola formations of Ordovician age crop out in two smaller isolated hills in the north-central part of the region. The limestones may be characterized generally as interbedded mud-supported and grain-supported rocks with zones containing chert,

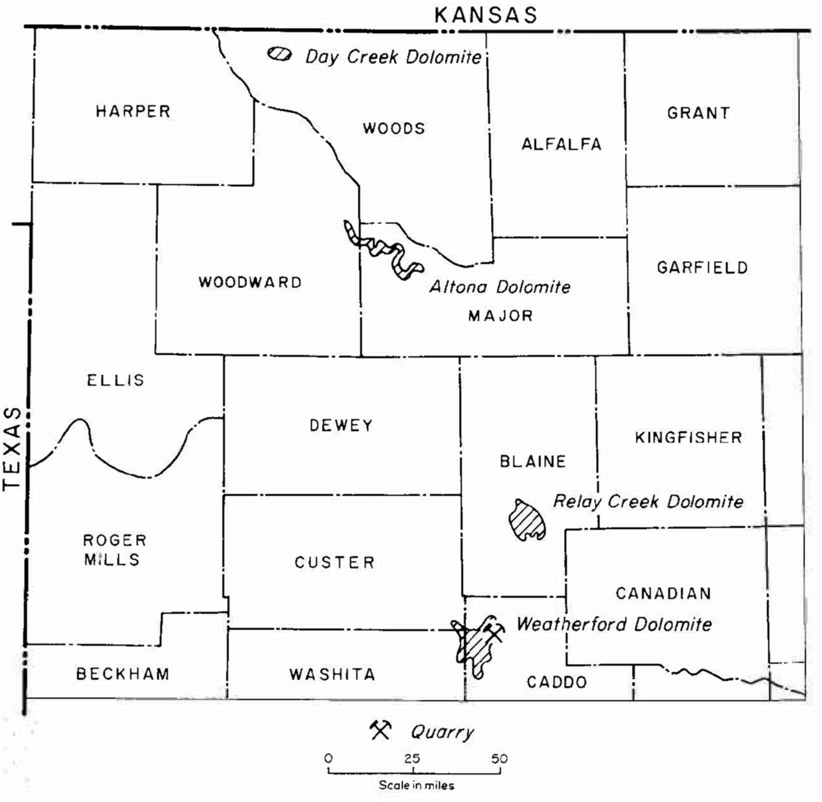


Figure 2. Generalized outcrop map of Permian dolomites in northwestern Oklahoma.

quartz sand, and silt. Some dolomite is also present. The total thickness of the carbonate rocks of the "Limestone Hills" is 6,500 feet.

The Permian carbonates consist of dolomite (fig. 3). The Creta Dolomite is 3-8 feet thick, and the Mangum and Jester Dolomites form a series of outcrops 3-8 feet thick in a band from Beckham County through parts of Greer, Harmon, and Jackson Counties. The Salt Fork and Duke Dolomites also are 3-8 feet thick and crop out in southwestern Harmon County. These dolomites may be characterized as fine grained, rarely coarse grained, and laminated. Some beds contain a large amount of quartz silt and sand grains.

The chemical character of the Paleozoic limestones indicates that they are not suitable as chemical-grade stone. The $CaCO_3$ content is 91-93 percent, the $MgCO_3$ content 2-3 percent, and the SiO_2 content 4-6 percent. As these are general figures, some beds within these units probably have higher $CaCO_3$ contents and fewer deleterious minerals. Physical-test data on much of the stone indicate that it is suitable for concrete aggregate and other uses for crushed stone.

The chemical character of the dolomites also indicates that they do not suffice as chemical-grade stone. The $MgCO_3$ content in these stones ranges from 36 to 40 percent, the $CaCO_3$ content from 48 to 51 percent, and the SiO_2 content from 5 to 8 percent. Physical-test data are available only on the Creta and indicate that this unit is suitable for concrete aggregate. Along most of the outcrop dolomites are or were overlain by gypsum. Solution of the gypsum and underlying dolomite has left much of the stone unsuitable for commercial development.

There are several abandoned pits in the dolomite areas from which dimension stone has been produced. Two quarries presently operate in the region (fig. 3).

The graph in figure 4 shows that from 1960 through 1970 a total of 31 million tons has been produced having a value of $32½ million. Most of this stone has been used as concrete aggregate and road-base material. Most production has been from the Kindblade Limestone, which averages 1,400 feet in thickness.

It is obvious this region contains ample stone for large-scale reserves. The lower Paleozoic carbonates offer the most feasible units for large-scale commercial deposits, as they are thick with essentially bare outcrops. This combination would eliminate overburden removal and provide high working faces.

SOUTH-CENTRAL OKLAHOMA

The surface sedimentary rocks that crop out in this province can be characterized as Late Cambrian to Early Devonian marine sediments, mostly carbonates; Late Devonian and Mississippian dark shales; Pennsylvanian dark shales, sandstones, thin marine limestones, and local conglomerates; Permian red shales, sandstones, and evaporites; and thin marine Cretaceous shales and carbonates. Most of these rocks crop out in the Arbuckle Mountains and the Criner Hills (fig. 5). The carbonate rocks comprise units of the Arbuckle Group, Simpson Group, and Hunton Group and thinner Pennsylvanian and Cretaceous units.

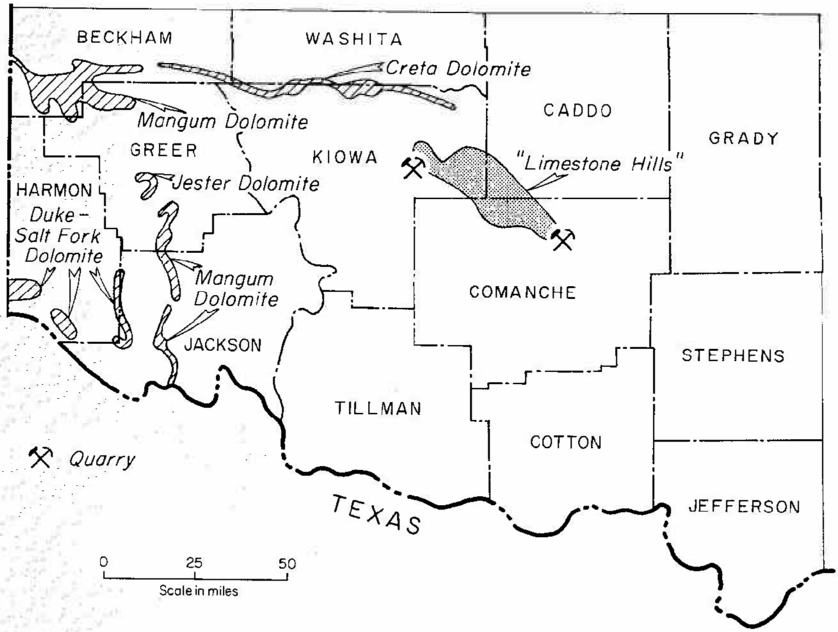


Figure 3. Generalized outcrop map of carbonate units in southwestern Oklahoma. Limestone shown by stippled pattern, dolomite by line pattern.

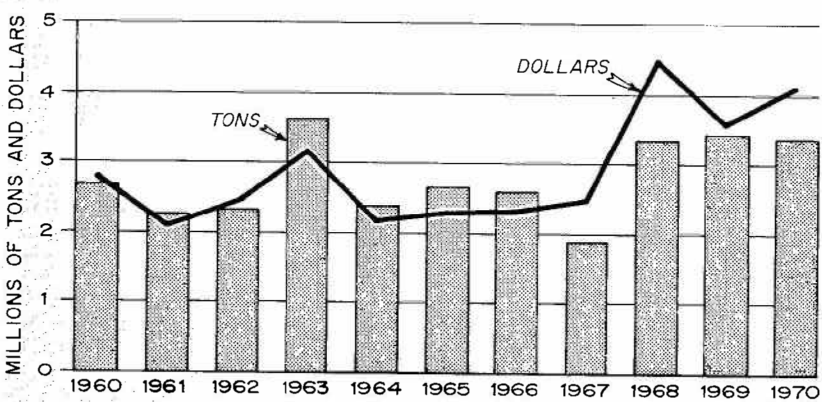


Figure 4. Graph showing production and dollar value of crushed stone from southwestern Oklahoma for 1960-70.

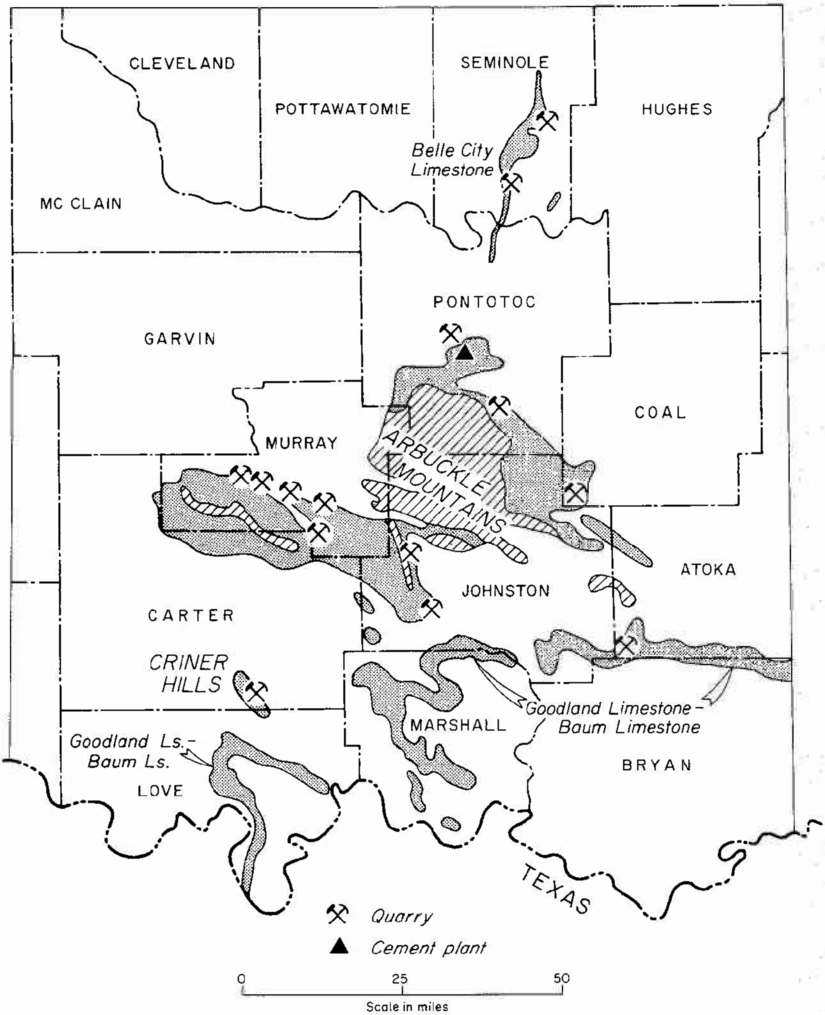


Figure 5. Generalized outcrop map of carbonate units in south-central Oklahoma. Limestone shown by stippled pattern, dolomite by line pattern.

The carbonates can be generally characterized as mud-supported skeletal rocks, but thick beds of skeletal grain-supported rocks occur. Many units contain chert, quartz sand and silt, and substantial amounts of dolomite. The total thickness of the carbonate rocks is 9,200 feet, with the Arbuckle Group the thickest at 6,700 feet. The Simpson Group carbonates are 1,200 feet thick, the Viola is 600-900 feet thick, and the Hunton is 350 feet thick. The Pennsylvanian and Cretaceous units are 10-15 feet thick with some local thickening up to 40 feet.

The chemical character of the lower Paleozoic limestones indicates that they are not suitable for chemical-grade stone, as the $CaCO_3$ content ranges from 90 to 95 percent and the SiO_2 and R_2O_3 content varies with individual units but normally is much too high. The Pennsylvanian Wapanucka oolitic grainstone that crops out on the eastern side of the Arbuckle Mountains is a chemical-grade stone. The $CaCO_3$ content averages 96-98 percent, and SiO_2 and other insolubles average less than 1 percent apiece. The Wapanucka was used to manufacture quicklime and hydrated lime in the middle 1930's. Portions of the Baum Limestone of Cretaceous age also have chemical-grade properties, as the $CaCO_3$ content averages 97½ percent and the SiO_2 and R_2O_3 content is sufficiently low. Much of the Royer Dolomite of Cambrian age is chemical-grade stone and is presently being produced for such use. Physical-test data on most of these limestones indicate that they are suitable for concrete aggregate and other crushed-stone uses.

The graph in figure 6 illustrates that from 1960 through 1970 a total of 33 million tons of stone was produced having a value of $37 million. Most of this stone has been used as concrete aggregate and road-base material.

Much of the stone has been produced from the Kindblade Formation of the Arbuckle Group, which averages 1,500 feet in thickness, and from the Viola Limestone, which averages 700 feet in thickness. The Royer Dolomite also has contributed a good part of this production; it averages 400 feet in thickness. A substantial amount of stone is also produced for the manufacture of portland cement; the unit worked is the Fernvale Limestone, which forms the upper part of the Viola. The Goodland and Baum Limestones of Cretaceous age have also yielded a fair amount of crushed stone. The Belle City Limestone of Pennsylvanian age is being worked in the northern part of the region.

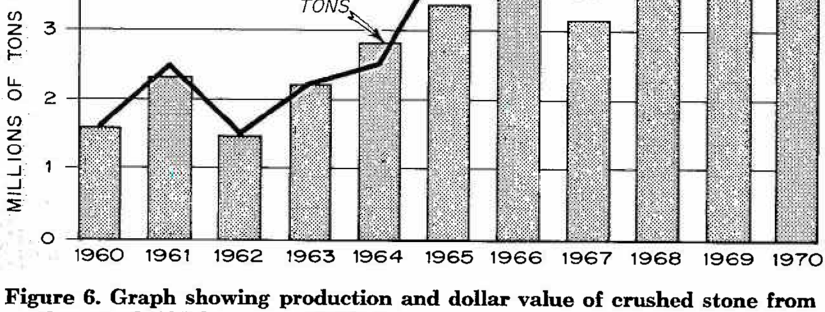


Figure 6. Graph showing production and dollar value of crushed stone from south-central Oklahoma for 1960-70.

This province is much akin to the southwestern Oklahoma province in containing a substantial amount of limestone forming large-scale deposits. Again, the lower Paleozoic limestones offer the most feasible units for crushed-stone reserves, as they are thick with essentially bare outcrops. Also, the Wapanucka and Baum Limestones offer possibilities for chemical-grade limestone deposits. There are presently 14 quarries in this area; however, several are shut down because of a lack of market.

SOUTHEASTERN OKLAHOMA

This province contains several tens of thousands of feet of sedimentary rock outcrops, most of which are noncarbonates. Many of these rocks are shales, siltstones, sandstones, novaculites, and cherts of the Ouachita Mountains and have undergone some low-grade metamorphism. These rocks range in age from Early Ordovician to Middle Pennsylvanian. The only carbonate rocks in this province are illustrated in figure 7. The southernmost outcrops are the marine Goodland Limestone of Cretaceous age, and the outcrops trending northeast and east along the frontal Ouachita Mountains represent the Wapanucka Limestone of Pennsylvanian age.

The Goodland Limestone can be characterized as a skeletal mud-supported rock. It averages 15-20 feet in thickness across the outcrop length. Physical-test data indicate the Goodland to be on the borderline for meeting specifications. However, portions of the Goodland are chemical grade in quality, as the $CaCO_3$ content is 98 percent, the SiO_2 plus R_2O_3 content 0.5 percent, and the $MgCO_3$ content 0.5-0.8 percent. The Wapanucka may be characterized as a spiculiferous, chert-bearing, mud-supported limestone with beds of grain-supported rocks and interbeds of shale. It averages 250 feet in thickness along most of its outcrop length. Physical-test data indicate that it makes excellent aggregate for almost all uses. Its chemical character is not suitable for chemical-grade stone. However, the eastern outcrops south of Wilburton (fig. 7) are well suited chemically and physically for manufacture of portland cement.

Production from this area for the period 1960-70 is illustrated on figure 8. A total of 9¾ million tons of stone was produced having a value of $12½ million. Again, most of this total has been used for concrete aggregate and road-base material.

This area provides abundant reserves of limestone for large-scale deposits, especially in the Wapanucka. Possibilities for reserves of chemical-grade stone exist in portions of the Goodland. Parts of the Wapanucka are suitable for manufacture of portland cement. Four quarries are now operating in the region (fig. 7).

NORTHEASTERN OKLAHOMA

This province contains a substantially large area in which the outcropping sedimentary rocks are mostly carbonates and cherts (fig. 9). These rocks range in age from Late Ordovician to Late Pennsylvanian. The large area of carbonate and chert outcrops illustrated in figure 9 corresponds with the Ozark uplift; the surface rocks are mostly

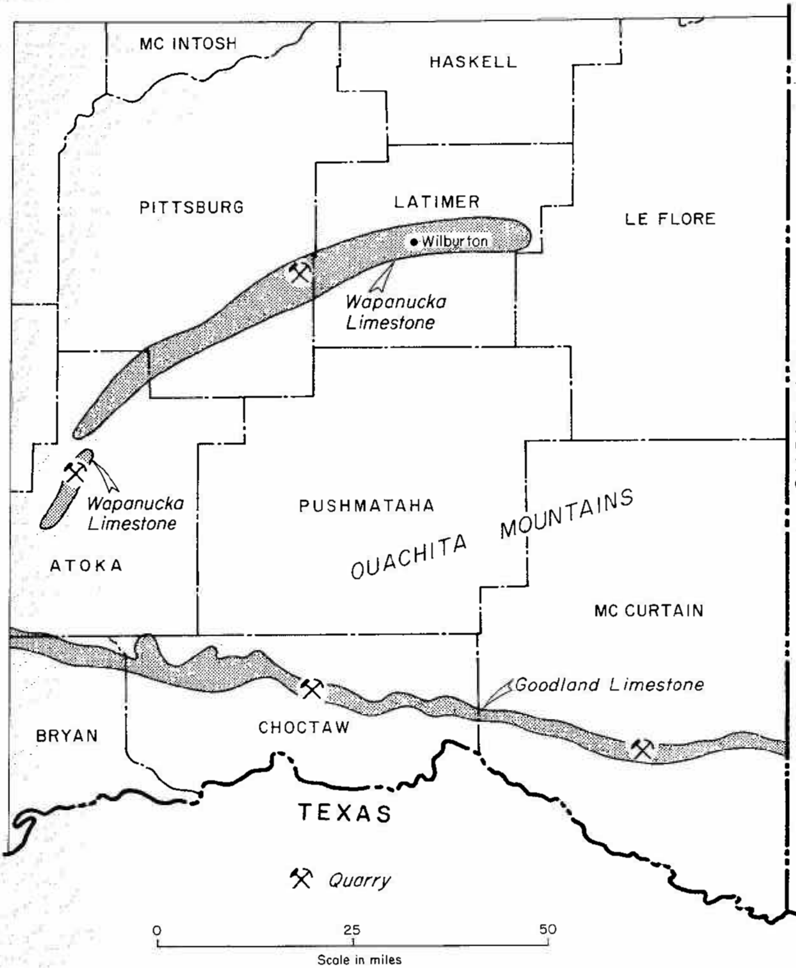


Figure 7. Generalized outcrop map of carbonate units in southeastern Oklahoma.

Mississippian in age. Abundant Pennsylvanian rocks crop out along the edges of the uplift, and some lower Paleozoic rocks also occur. West of the Ozark uplift fairly large areas of Pennsylvanian carbonates crop out; these units include the Fort Scott, Oologah, Hogshooter, and Dewey Limestones (fig. 9).

The carbonates can be generally characterized as mud-supported rocks, but thick units of grain-supported rocks occur. Many units contain quartz sand and silt, and chert is common in some. Dolomite is also present in various beds. The thicknesses of these carbonate rocks vary considerably. Silurian-Devonian units are 150-180 feet thick, Mississippian limestones are as thick as 500 feet, and Pennsylvanian units range from 10 to 100 feet in thickness.

The chemical data from most of these rocks indicate that the SiO_2 plus R_2O_3 content is much too high for chemical-grade stone. However, two units are of exceptionally high purity. The first of these is the Silurian limestone that crops out in northern Sequoyah County. Parts of this stone average 99 percent $CaCO_3$, and it is presently being worked as a chemical-grade stone for the manufacture of quicklime and hydrated lime (fig. 9; see also article beginning on page 67 of this issue). The other unit is the Short Creek Oolite of Mississippian age; parts of this rock average 97 percent $CaCO_3$, with the SiO_2 plus R_2O_3 content about 1 percent. The Pitkin Limestone of Late Mississippian age appears to be a possibility for chemical-grade stone. Many units are chemically suitable for the manufacture of portland cement, and the Pitkin and Oologah Limestones are now being worked for this purpose. Physical-test data indicate that most limestones meet specifications for the various crushed-stone uses.

A total of 54 million tons of crushed stone having a value of $56 million was produced from this province during the period 1960-70 (fig. 10). This province has been the most productive in the State.

Much of the crushed stone has come from the Oologah Limestone in Tulsa County, and abundant chat (crushed limestone and chert)

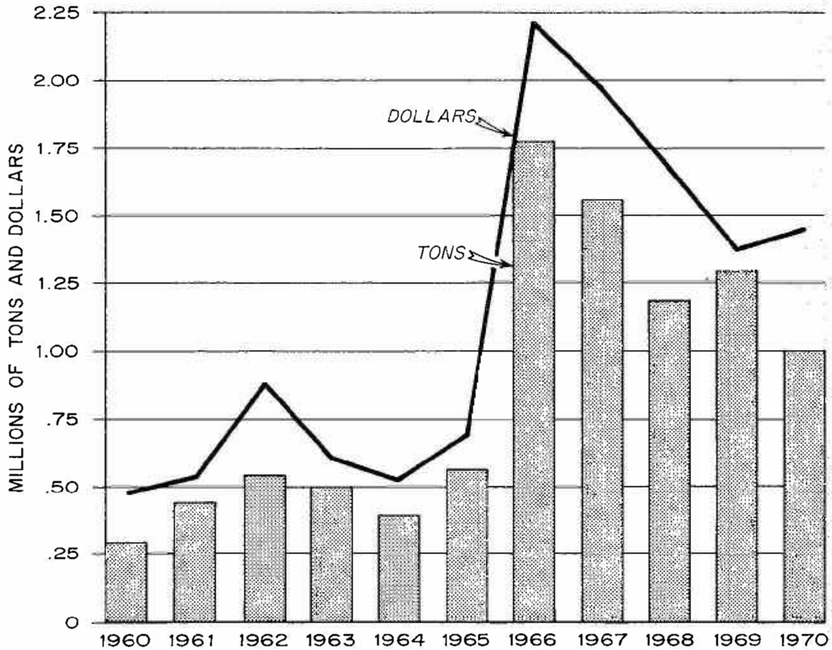


Figure 8. Graph showing production and dollar value of crushed stone from southeastern Oklahoma for 1960-70.

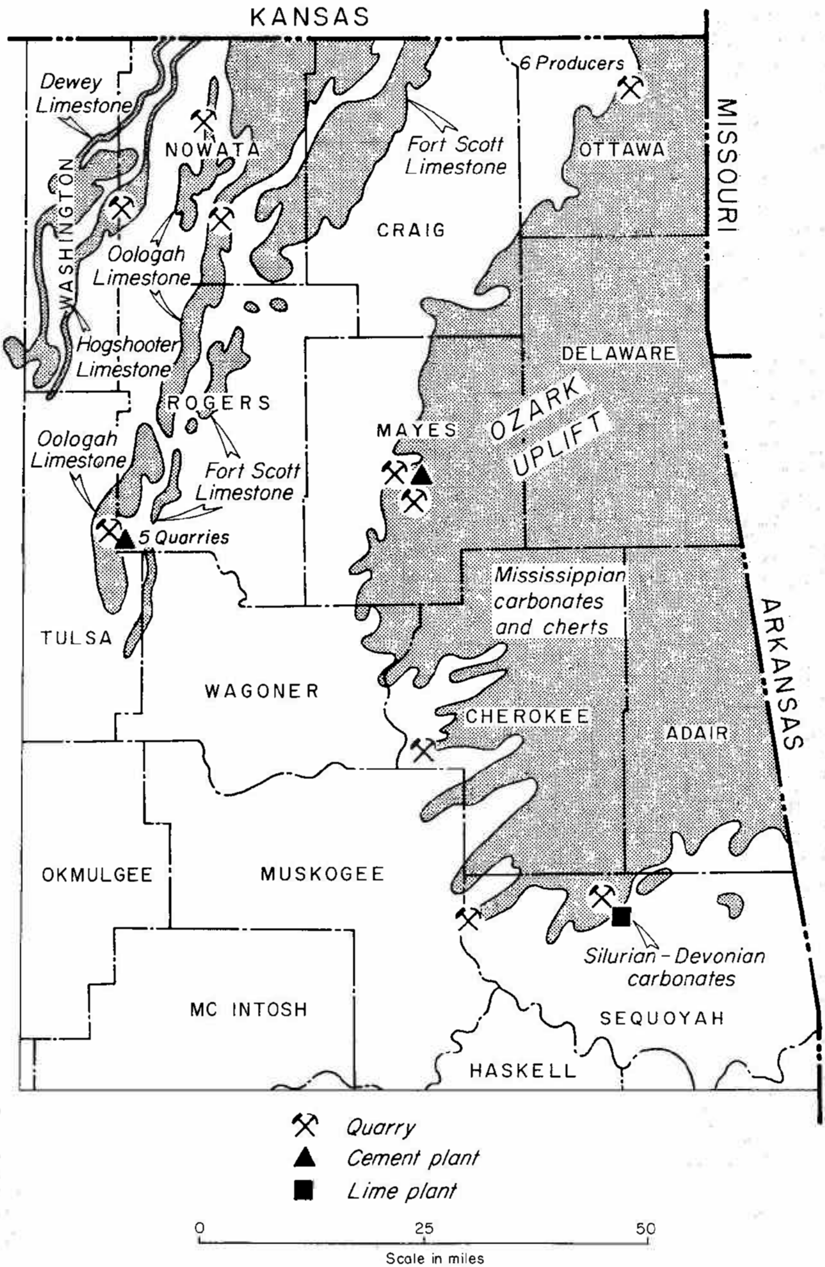


Figure 9. Generalized outcrop map of carbonate units in northeastern Oklahoma.

has been produced from the lead and zinc area of northeastern Oklahoma (fig. 9). The Upper Mississippian-Lower Pennsylvanian limestones have yielded abundant stone in western Cherokee County. Again, much of the crushed stone is used for concrete aggregate and road-base material. In 1970 production declined slightly, as shown in figure 10. At present the region has 19 producers, although several are shut down.

Abundant carbonate rock units form large-scale deposits for future stone reserves including units chemically and physically suitable for the manufacture of portland cement. Three units are of chemical grade.

NORTH-CENTRAL OKLAHOMA

The surface rocks in this province range in age from Middle Pennsylvanian to Early Permian and consist of shales, siltstones, sandstones, and thin marine carbonates. Figure 11 illustrates the generalized carbonate outcrops in this region; the patterned areas do not represent total carbonate outcrops but outline the areas in which thin marine carbonates occur.

These carbonates can be characterized as mud-supported units with a few thin beds of grain-supported rocks. Some beds contain quartz sand and silt, and chert is abundant in a few. Most of these limestones contain thin shale interbeds. Many other thinner limestones occur but

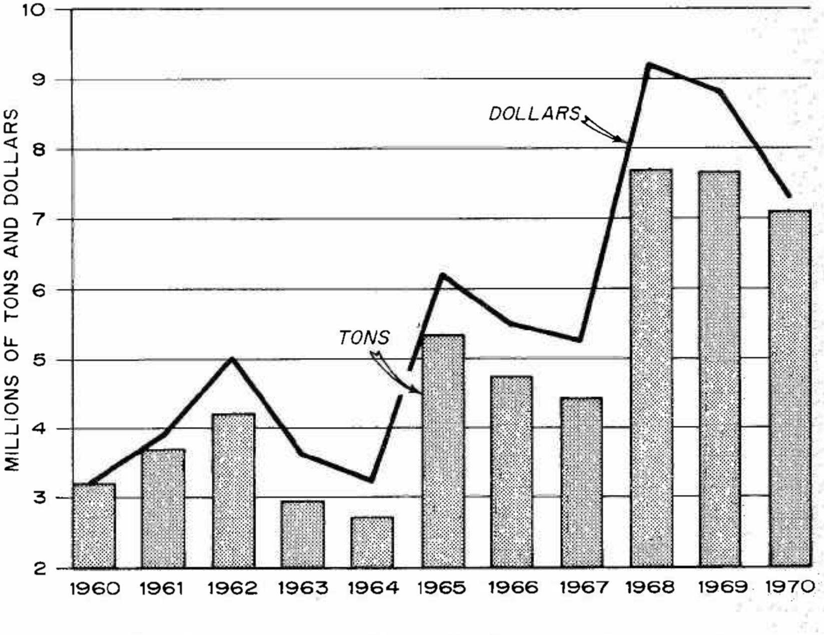


Figure 10. Graph showing production and dollar value of crushed stone from northeastern Oklahoma for 1960-70.

are much too thin for workable deposits. The thicknesses of the rocks illustrated in figure 11 range from 6 to 25 feet.

Chemical-test data indicate that these rocks are not suitable for chemical-grade stone. The SiO_2 plus R_2O_3 content is much too high in most units. Most of the rocks meet specifications for crushed-stone uses, as indicated by physical-test data.

Figure 12 gives the production and dollar value for this province for the period 1960-70. There are 10 quarries in this province, but only 4 are now in operation. Because of limited outcrops and thicknesses, this area is not attractive for exploring for large-scale commercial deposits. In most cases outcrops are not bare; therefore, overburden is a problem. Shale interbeds also present a deterrent for economic development.

STATISTICAL DATA

Figure 13 gives the production and dollar value of crushed stone for the entire State from 1960 through 1970.

The total amount of stone produced in this period is 150 million tons having a value of $176 million. The 1970 figure of 16,950,000 tons having a value of $20,930,000 is higher than the 1971 preliminary figure of 15,858,000 tons having a value of $19,982,000. So a slight decrease is seen for 1971. The essential reasons for this decline in production are the winding down of interstate-highway construction and the completion of the Arkansas River Navigation System.

The carbonate-mineral industry accounts for an average of 23 percent of the total value of all nonpetroleum mineral production in Oklahoma over the past 12 years. In 1972, 44 quarry permits have been issued, but several quarries are temporarily shut down for various reasons. As markets expand, they will probably be reopened.

Table 1 lists the production and value of crushed limestone and dolomite in the United States for 1970, by kind of stone and use. One can readily observe that the carbonate-mineral industry is almost directly dependent on the construction industry. The 1971 figure is expected to be about the same as the 1969 figure, which was some 3 million tons higher than the 1970 figure. Oklahoma produces 2.7 percent of the nation's total crushed limestone and dolomite.

Present prices F.O.B. plant for crushed stone range from $1.00 per ton to $2.30 per ton. Crushed stone for chemical purposes, such as poultry grit and glass stone, range from $3.00 per ton to $7.00 per ton. Transportation costs for rail and truck haulage range from 2½ to 5 cents per ton-mile. Water-transportation costs are more variable but are about 5 mills per ton-mile.

From the production graphs, a sharper increase in prices versus production is apparent. The reason for this is increases in production costs owing to labor and materials costs.

SUMMARY AND FUTURE OUTLOOK

It is clear that Oklahoma contains a vast reserve of stone that meets specifications for utilization in the construction industry. Many units are suitable for manufacture of portland cement, and at least

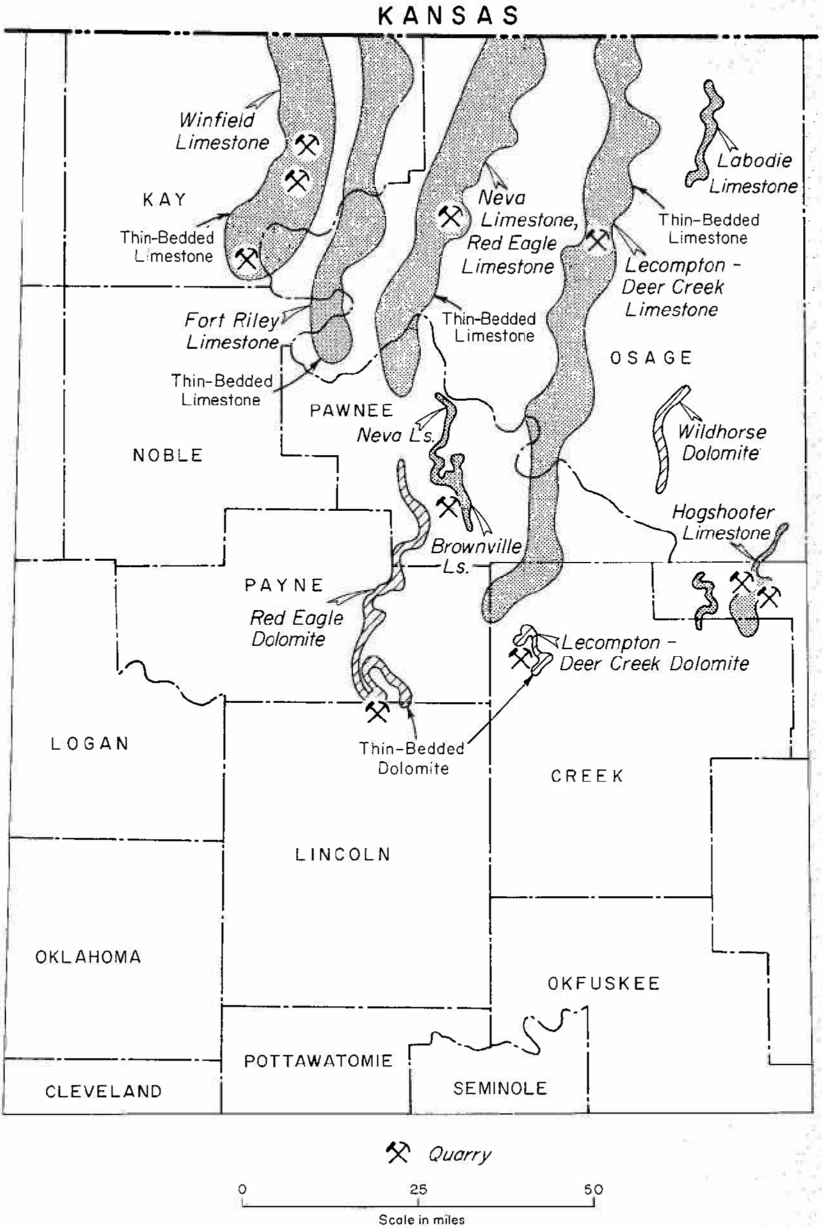


Figure 11. Generalized outcrop map of carbonate units in north-central Oklahoma. Limestone shown by stippled pattern, dolomite by line pattern.

four different limestones are of chemical-grade quality.

The crushed-stone industry in Oklahoma is presently well developed. Although a slight decrease in Oklahoma production was seen

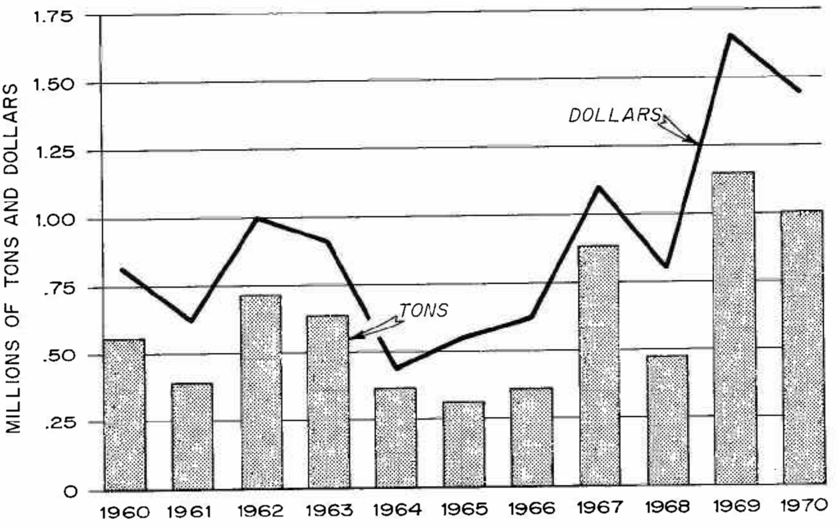


Figure 12. Graph showing production and dollar value of crushed stone from north-central Oklahoma for 1960-70.

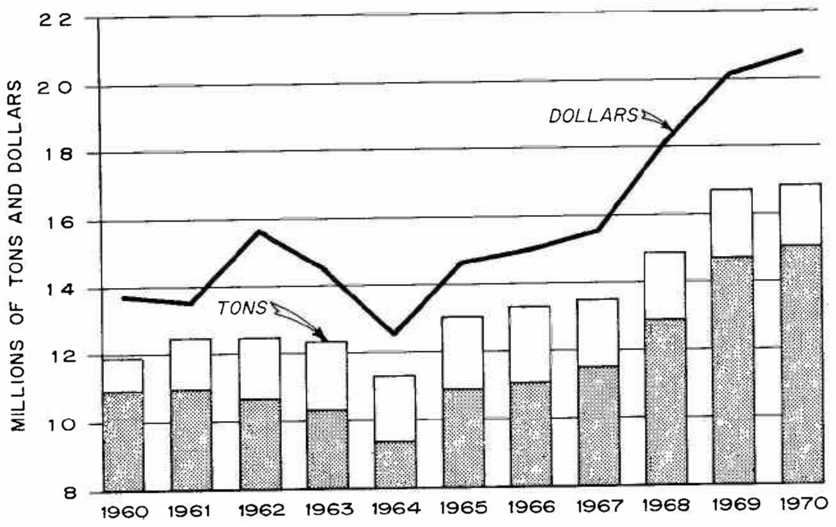


Figure 13. Graph showing production and dollar value of crushed stone for State of Oklahoma for 1960-70. Upper portion of each bar represents approximate amount of crushed stone used in manufacture of cement and lime.

for 1971, a 3-percent increase in United States production is forecast for 1972 and an annual growth rate of about 4½ percent is forecast to the year 2000.

Mineral commodities such as gypsum, salt, and the metallic minerals are restricted in their occurrence throughout the United States; therefore, exporting these commodities from Oklahoma holds promise. Stone, however, is present in all the states; and if carbonate rocks are not available for crushed-stone reserves, igneous or metamorphic rocks or other sedimentary rocks are crushed and used for major tonnage items such as road-base stone and concrete aggregate. The manufacture of such products as portland cement, lime, and flux must, of course, utilize carbonate minerals; therefore future expansion of the carbonate mineral industry could include the shipment of raw stone out of the State for the manufacture of these products. The amount of crushed stone now shipped out of the State is insignificant. It must be pointed out, however, that for the 180 cement plants in the United States markets are restricted to distances of less than 300 miles from these plants. There are 200 lime plants in 39 states, also with an effective market radius of 300 miles.

TABLE 1.—TONNAGE AND DOLLAR VALUE OF CRUSHED LIMESTONE AND DOLOMITE IN THE UNITED STATES IN 1970, BY KIND OF STONE AND USE[1]

(Thousand short tons and thousand dollars)

	QUANTITY	VALUE
Agricultural purposes	37,945	70,483
Concrete aggregate (coarse)	95,879	154,730
Bituminous aggregate	42,312	70,082
Macadam aggregates	24,573	37,390
Dense-graded road-base stone	124,897	171,019
Surface-treatment aggregates	35,567	52,550
Unspecified construction aggregate and roadstone	57,694	89,118
Riprap and jetty stone	11,560	14,277
Railroad ballast	6,387	8,583
Filter stone	747	1,636
Manufactured fine aggregate (stone sand)	3,116	5,100
Terrazzo and exposed aggregate	82	767
Cement manufacture	95,946	104,928
Lime manufacture	25,989	47,440
Dead-burned dolomite	1,990	3,262
Ferrosilicon	714	1,032
Flux	29,462	45,262
Refractory	374	1,023
Chemical stone for alkali works	4,215	7,533
Special uses and products	3,575	21,636
Fill	3,706	2,727
Glass	1,156	3,823
Other uses	8,541	19,284
Uses not listed or unspecified	8,886	12,406
TOTAL[2]	625,313	946,087

[1]Data from U.S. Bureau of Mines preliminary production sheet.
[2]Data may not add to totals shown because of independent rounding.

Other areas of potential expansion in Oklahoma are in construction and expected industrial development along the Arkansas River Navigation System, which will increase demand for flux stone and other aggregate products. Advances in technology, such as development of new calcium compounds and new applications of existing compounds, provide promise. Development of new methods for using cement and concrete is expected to continue, such as pre-stressed concrete, lightweight concrete for walls, concrete for roofs and roof panels, pre-cast concrete, sculptured and exposed aggregate panels, and soil-cement paving. Research and development of processes and devices using limestone to control air and water pollutants are progressing. The utilization of carbonate-mineral products for environmental control is expected to expand rapidly. These are a few of the future directions in which the carbonate-mineral industry may expand. Hopefully, our State will be in the vanguard of this expansion.

Selected References

Amsden, T. W., and **Rowland, T. L.**, 1965, Silurian stratigraphy of northeastern Oklahoma: Oklahoma Geol. Survey Bull. 105, 174 p.

Beach, J. O., and **English, S. G.**, 1940, Dolomite and magnesium limestone: Oklahoma Geol. Survey Mineral Rept. 6.

Blau, P. E., 1961, Petrology of the Goodland limestone (Lower Cretaceous), southeastern Oklahoma: Oklahoma Univ. unpub. M.S. thesis, 148 p.

Cooper, J. D., 1970, Stone, **in** Mineral facts and figures: U.S. Bur. Mines Bull. 650, p. 1219-1235.

English, S. G., **Dott, R. H.**, and **Beach, J. O.**, 1940, Limestone analyses (in Oklahoma): Oklahoma Geol. Survey Mineral Rept. 5.

Huffman, G. G., and others, 1958, Geology of the flanks of the Ozark uplift, northeastern Oklahoma: Oklahoma Geol. Survey Bull. 77, 281 p.

Johnson, K. S., 1969 [1970], Mineral map of Oklahoma (exclusive of oil and gas fields): Oklahoma Geol. Survey Map GM-15, scale 1:750,000.

Koch, R. M., 1971, The limestone industry—retrospect and prospects: Pit and Quarry, v. 63, no. 6, p. 120.

MacMillan, R. T., 1970, Calcium, **in** Mineral facts and figures: U.S. Bur. Mines Bull. 650, p. 903-912.

McMahan, A. B., and **Ham, W. E.**, 1971, The mineral industry of Oklahoma, **in** Area reports: domestic, **v. 3 of** Minerals yearbook 1969: U.S. Bur. Mines, p. 599-617.

Suffel, G. G., 1930, Dolomites of western Oklahoma: Oklahoma Geol. Survey Bull. 49, 155 p.

Wayland, J. R., and **Ham, W. E.**, 1955, General and economic geology of the Baum limestone, Ravia-Mannsville area, Oklahoma: Oklahoma Geol. Survey Circ. 33, 44 p.

Wood, S. O., Jr., and **Carrales, M., Jr.**, 1971, Stone, **in** Metals, minerals, and fuels, **v. 1-2 of** Minerals yearbook 1969: U.S. Bur. Mines, p. 1019-1039.

Highway Geology Proceedings Now Available

The Oklahoma Department of Highways and the Oklahoma Geological Survey have announced publication of *Proceedings of the 22nd Annual Highway Geology Symposium,* a joint project edited by Rosemary Kellner and Bill Rose of the Survey and printed by the Department of Highways. Held in Norman April 23, 1971, at the Oklahoma Center for Continuing Education on The University of Oklahoma campus, the technical sessions consisted of papers by engineers and engineering geologists representing universities, consulting firms, and state and federal agencies. A wide range of subjects was covered, dealing with problems encountered not only in the United States but also in Africa and South America.

Mitchell Smith, physical science engineer for the Department, and Charles J. Mankin, director of the Oklahoma Geological Survey and of OU's School of Geology and Geophysics, served as co-chairmen for the symposium. Papers by Oklahoma authors which were presented at the conference and printed in the *Proceedings* include: "Geology of Oklahoma—A Summary," by Kenneth S. Johnson and Charles J. Mankin, Oklahoma Geological Survey; "Engineering Classification of Highway-Geology Problems in Oklahoma," Curtis J. Hayes, Oklahoma Department of Highways; "Predictability of Shale Behavior," Joakim G. Laguros and Subodh Kumar, School of Civil Engineering and Environmental Science, The University of Oklahoma; "Post-Construction Performance of P-18 Bridge Abutments and Approach Fills, Eastern Oklahoma," Glen Bayless, U.S. Army Corps of Engineers.

The Oklahoma Geological Survey is the sole distributor of the *Proceedings,* which can be obtained at a cost of $3.00 from that office. A limited number of copies of the symposium's official field-trip guidebook, *Highway Geology in the Arbuckle Mountains and Ardmore Area, Southern Oklahoma,* are still available through the Survey for a distribution charge of 50 cents.

The 23rd Annual Highway Geology Symposium was held April 27-28, 1972, in Norfolk, Virginia, and papers presented there are expected to be published by the Virginia Highway Research Council.

Geological Highway Map of Northern Rockies Released

The American Association of Petroleum Geologists has recently released a geological highway map of the Northern Rocky Mountain region, embracing the states of Wyoming, Montana, and Idaho. This map is the fifth in a series of geological highway maps prepared by the AAPG Geological Highway Map Committee under the direction of H. B. Renfro and Dan E. Feray and published by AAPG with the cooperation of the U.S. Geological Survey.

The map follows the handsome format of its predecessors, having been printed in full color at a scale of 1 inch = approximately 30 miles. In addition to depicting the areal geology and highway network of the region, the map provides generalized stratigraphic columns, cross sections, a mileage chart, and physiographic, tectonic, paleogeographic, and lithofacies maps.

The map may be ordered directly from AAPG headquarters, P.O. Box 979, Tulsa, Oklahoma 74101, at a cost of $1.50 each for folded maps and $1.75 each for rolled maps. Folded maps also may be ordered from the Oklahoma Geological Survey for $1.50 each.

The next two maps in the series, the Pacific Northwest region, no. 6, and Texas, no. 7, are expected to be available sometime this summer.

New AAPG Executive Committee Announced

Members of the executive committee of The American Association of Petroleum Geologists for the coming year were recently announced: president, James E. Wilson, Jr., vice-president for exploration and production, Shell Oil Company, Denver; president-elect, Daniel A. Busch, Tulsa consultant and visiting professor of geology at The University of Oklahoma; vice-president, Samuel P. Ellison, Jr., The University of Texas at Austin; secretary, Ted L. Bear, Bear & Kistler, Los Angeles; treasurer, H. B. Renfro, consultant, Dallas; editor, Frank E. Kottlowski, New Mexico State Bureau of Mines and Mineral Resources, Socorro; and chairman of the House of Delegates, Herbert G. Davis, consultant, Oklahoma City. John A. Taylor, Oklahoma City consultant, is serving as AAPG vice-president for the current year.

The incoming executive committee will begin its term of office on July 1.

Oklahoma Gains Deepest Producer

Oklahoma captured another depth record from Texas in April with the completion of Union Oil Co. of California et al. 1-33 Bruner, a Hunton gas discovery in Northeast Mayfield field, Beckham County, as the world's deepest producing well. The producing zone of 24,065-24,584 feet exceeds by some 1,500 feet the former record set by an Ellenburger gas well in Gomez field, Pecos County, Texas, completed by Texaco Inc. last year. The Bruner well initialed at 2,800,000 cubic feet of gas per day from rocks of the Hunton Group of Silurian-Devonian age, with a tubing pressure of 1,000 psi. Improved flows are expected as tubing blockages clear.

Located in the Anadarko basin deep, in northwestern Beckham County, sec. 33, T. 11 N., R. 25 W., the Bruner is about 20 miles west-northwest of the Lone Star Producing Co. 1 Baden Unit, which set a world depth record in February. Plans for the Baden well, meanwhile, call for completion attempts in Atokan rocks at 16,000-17,300 feet following unsuccessful production tests in the Hunton.

OU Sponsors Piceance Basin Studies

The University of Oklahoma is conducting three 1-week courses on energy fuels of the Piceance basin July 31-August 19 in Grand Junction, Colorado. Enrollment can be on a weekly basis or for the entire sequence, with graduate or undergraduate credit available and varying from 1 to 3 hours at the rate of 1 hour of credit per week of instruction.

The courses will combine field studies with a workshop approach: a nuclear-fuels workshop will be presented by the Atomic Energy Commission the first week; oil shales and nuclear stimulation will be topics for the second week; and a study of solid hydrocarbons (gilsonite and coal) will wrap up the sessions. Instructing the course will be Carl A. Moore, OU professor of geological engineering, and additional information can be obtained by contacting him at the Department of Petroleum and Geological Engineering, The University of Oklahoma, Norman, Oklahoma 73069.

Tulsa Geological Society Field Trip

The Tulsa Geological Society conducted a highly successful field trip into the Tri-State mining region on April 29. About 45 persons visited open-pit and underground mines where tripoli, limestone, lead-zinc, coal, and "marble" are being worked in northeastern Oklahoma and southwestern Missouri.

The first stop, near Peoria, Ottawa County, Oklahoma, was an open-pit tripoli operation of the American Tripoli Division of The Carborundum Company. High-purity (90-98 percent SiO_2) tripoli is mined from scattered deposits 8 to 15 feet thick in the Boone Formation of Mississippian age, and is trucked to the company plant at Seneca, Missouri, for drying, grinding, and packaging. Tripoli is used mainly as an abrasive in buffing and polishing compounds or as a filler.

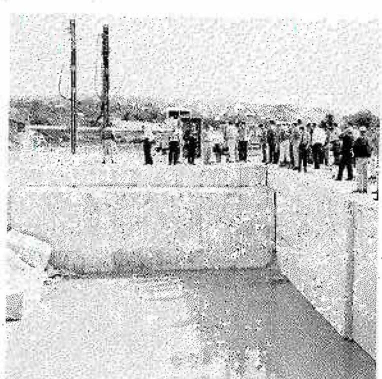
Our second stop was at an underground limestone mine and storage facility at Neosho, Missouri. Southwest Lime Company is mining 18 to 20 feet of the Keokuk Limestone ("M" bed) of Mississippian age for crushed stone and agricultural lime. Ozark Terminal, Inc., a storage company, provides 570,094 square feet of underground storage space for rental purposes in walled-off abandoned sections of the mine. The temperature and humidity are more easily controlled than in surface storage facilities, and all essential utilities are provided.

The third stop, at Oronogo, Missouri, permitted examination of mineralization in a Mississippi Valley-type deposit. Lead and zinc here were first mined underground at many levels, as deep as 260 feet, but in the 1940's the deposit was operated as a mammoth open pit about 1,000 feet in diameter and 260 feet deep. Operations have now ceased, and the pit is nearly filled with water.

Stop 4 was at the mine and quarry of Carthage Marble Corporation, at Carthage, Missouri. Large blocks of Burlington Limestone

No, not an Al Jolson rendition! It's Doug Brockie describing lead-zinc mineralization at Oronogo, Missouri.

Good pickin's for ore and gangue minerals at Oronogo, Missouri.



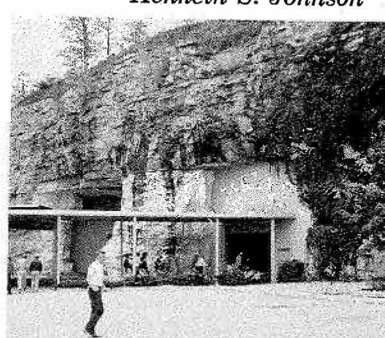
Twelve-foot-thick upper ledge of Burlington Limestone is worked for "marble" at Carthage, Missouri.

(Mississippian) are quarried from two 12-foot ledges, and then they are cut and polished for use as architectural and ornamental stone. Carthage "marble" is a pearl-gray stylolitic limestone which averages 98.57 percent $CaCO_3$. Recently the company converted 100,000 square feet of an abandoned portion of its mining operation to underground office and warehouse facilities.

The last stop was at the strip pit of Bill's Coal Company, Welch, Craig County, Oklahoma. Fourteen inches of coal in the Senora Formation (Pennsylvanian) is mined after removal of 6 to 30 feet of overburden. After washing the coal, the company trucks it to Springfield, Missouri, for power generation.

Credit for successful organization and leadership of the trip goes to the field-trip committee: Arnold Buzzalini, Doug Brockie, Ed Johnson, Lou Reeder, Peggy Rice, and Joe Mueller.

—*Kenneth S. Johnson*



Entry way to underground storage facilities in abandoned portion of limestone mine at Neosho, Missouri. Please note famous geologist (Tom Rowland) in foreground, anxiously advancing to the outcrop!

OU Granted Funds for Study of Water-Data Network

H. Garland Hershey, director of the U.S. Office of Water Resources Research (OWRR), announced in March that a grant of $99,858 had been made to The University of Oklahoma to study the operation of a national computer network of retrieval centers for water-resources information and to initiate and service the first three of these centers. The three selected for the study are state water-resources research institutes located at The University of Wisconsin, Cornell University, and North Carolina State University. These, along with the Water Resources Scientific Information Center (WRSIC) in OWRR, will be connected by remote terminals and telephone lines to the Merrick Computing Center facilities at The University of Oklahoma.

By using the innovative and proven Generalized Information Processing System (GIPSY), developed at The University of Oklahoma by James W. Sweeney, WRSIC will expand its quick-response and comprehensive retrieval services to the water-resources community.

Eventually, if the network is demonstrated to be feasible, additional water-resources research institutes, Federal water-resources agencies, and other interested groups may be added. Anyone desiring computer searches of the OWRR-WRSIC data base, comprising approximately 40,000 full-text abstracts in all fields of water resources, can now request them, for a fee, from one of the three retrieval centers mentioned. Researchers may conduct a dialog with the computer to refine their questions and answers, or they may request exhaustive bibliographies in current high-interest or problem areas of water resources.

In addition to WRSIC, other Federal agencies utilizing GIPSY include the U.S. Geological Survey and the National Oceanographic Data Center.

Construction Begun on EROS Data Center

Construction was begun in April on a major facility for the use of remote-sensor data to be obtained from aircraft and spacecraft for purposes of resources and environmental surveys. The $5 million facility, designated the EROS (Earth Resources Observation Systems) Data Center, is being built on a 315-acre site near Sioux Falls, South Dakota, and will be under the management of the U.S. Geological Survey.

When completed in the spring of 1973, the center will be a key installation as a national central repository for processing, interpretation, and dissemination of thousands of images per year of a wide variety of land and water features of the United States obtained from aerial photography and space-borne television and other remote-sensing equipment. The principal source of data to be processed at the center will be NASA's ERTS (Earth Resources Technology Satellite) satellites. Launching of the first experimental ERTS satellite is planned for June.

Mineral Development Opportunities in Oklahoma
A Symposium

Norman, Oklahoma, March 10, 1972

The following are abstracts from papers presented at the symposium, Mineral Development Opportunities in Oklahoma, held March 10, 1972, at the Oklahoma Center for Continuing Education, Norman. Permission of the authors to print them here is gratefully acknowledged. (Two papers from this symposium are printed in their entirety in this issue: the keynote address, which begins on page 71, and a paper on carbonate resources, which begins on page 73.)

Metallic Mineral Occurrences in Oklahoma

C. R. SEWELL, Geological Consultant, Tucson, Arizona

Our civilization is consuming 17.5 billion tons of mineral commodities annually. Future demands will be greater. Costs of exploration and development for mineral deposits have increased to the point that traditional captive sources of financing have given way to outside capital. The resultant change in ownership will strengthen domestic exploration and production.

Two-way communication between industry and various state and federal mineral-oriented agencies should be increased.

Traditionally, metallic mineral production in Oklahoma has been from lead-zinc deposits of the Tri-State District. These ores yield some minor metal by-products. Recently, argentiferous bedded copper deposits were brought into production in southwestern Oklahoma by a combined effort of the Oklahoma Geological Survey and industry.

If these metallic mineral deposits can be placed within the framework of a genetic model, it would facilitate the search for new ore bodies.

Gypsum and Salt Resources in Oklahoma

KENNETH S. JOHNSON, Geologist, Oklahoma Geological Survey, Norman, Oklahoma

Large reserves of high-purity Permian gypsum crop out and are at shallow depth in three regions of western Oklahoma. The northwest

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OKLAHOMA ABSTRACTS is intended to present abstracts of recent unpublished papers relating to the geology of Oklahoma and adjacent areas of interest. The editors are therefore interested in obtaining abstracts of formally presented or approved documents, such as dissertations, theses, and papers presented at professional meetings, that have not yet been published.

and southwest regions contain gypsum beds in the Blaine Formation which are 10 to 30 feet thick and are generally 95 to 98 percent pure. The west-central region contains the Cloud Chief Gypsum, which is 20 to 90 feet thick and has a purity of 92 to 97 percent. Estimated reserves of 48 billion short tons are almost equally divided among the three regions. Eight companies in the State currently mine almost 1 million tons of gypsum each year for wallboard, for plaster, as a retarder in portland cement, and as a soil conditioner. Future uses, under more favorable market conditions, may be in the chemical industries, largely because of gypsum's potential as a source of sulfur.

Three thick sequences of Permian rock salt underlie most of western Oklahoma at depths of 30 to 3,000 feet. Individual salt beds 5 to 25 feet thick are interbedded with thinner layers of shale and anhydrite. Five large salt plains are fed by natural brine springs. Reserves, estimated at 20 trillion tons, are virtually untapped, and, ironically, we import annually about 90 percent of the salt used in Oklahoma. Chemical data on the rock salt are lacking, but evaporated salt produced from brines is generally 97.5 to 99.5 percent pure. Current production from three solar-evaporation plants is used mainly for stockfeed, recharging water softeners, and de-icing roads. Potential uses are in the chemical industries, where salt or brine is a necessary raw material.

Coal Exploration and Development in Oklahoma

S. A. FRIEDMAN, Geologist, Oklahoma Geological Survey, Norman, Oklahoma

Although only 2.37 million tons of coal was mined in 1971, Oklahoma has sufficient coal resources to supply increasing demands for electric-power generation, coke manufacture, and gasification. At present, Oklahoma coal is shipped by rail to St. Louis, Kansas City, and Springfield, Missouri, and to coke plants in Texas; and it is barged on the Arkansas River Navigation System to St. Louis, Missouri, Memphis, Tennessee, and partway to Tampa, Florida, for use in electric-power generation. About 90 percent of current production is surface-mined, although only about 15 percent of the State's total resources is surface-minable.

Oklahoma contains at least 3.2 billion tons of remaining coal resources suitable for electric-power generation or coke manufacture, part of which is low-sulfur coal (1 percent or less sulfur). Three developing mines will increase the supply of low- and medium-volatile bituminous coal for coke manufacture by 1.5 million tons annually. The growing natural-gas shortage has resulted in a gasification feasibility study which proposes a plant with projected annual requirements of 10 million tons of high-volatile, high-sulfur bituminous coal. Oklahoma has sufficient coal resources of this rank and quality. Major obstacles to developing large-tonnage mines involve proving adequate recoverable reserves of a specified quality, financing, and applying proper technology in mine construction.

Details on coal thickness, depth, quality, and potential mining conditions are being determined from recent well data, provided by coal operators, and a drilling project by the Oklahoma Geological Survey.

Adjacent to abandoned mines the Survey has located a total of at least 200 million tons of recoverable high-volatile bituminous coal suitable for gasification. Furthermore, in parts of the coal field not presently mined, at least 200 million tons of additional remaining coal resources has been determined. Gulf General Atomic Corporation has indicated that if a gasification plant is deemed feasible for Oklahoma, such a plant must produce 150 billion cubic feet per year of synthetic, high-Btu pipeline gas, which is about one-tenth of the State's annual natural-gas production.

Thus, if operators develop additional coal mines with sustained production to supply the growing demand, 15 million tons of coal could be produced annually in Oklahoma.

Clay and Shale Products in Oklahoma

WILLIAM H. BELLIS, Geologist, Oklahoma Geological Survey, Norman, Oklahoma

In the United States, 90 percent of the volume of clays and shales mined is used in some type of fired-clay product. The remaining 10 percent provides 75 percent of the total dollar value placed on these clays and shales. Thus, there is a broad category of miscellaneous or general clays and a category of specialty clays. The former category includes clays used in such products as brick, cement, clay pipe, expanded lightweight aggregate, and art pottery. The latter category encompasses relatively pure deposits of kaolinite, bentonite, attapulgite, and montmorillonite.

Oklahoma has large resources of the general clays and only a limited reserve of the specialty clays. The 57 brick plants that operated in the State prior to 1932 attest to the vast reserves of miscellaneous clays. Today clay and shale mined in Oklahoma are used almost exclusively for manufacture of fired-clay products. Six companies operate 10 brick plants, 1 company operates 2 rotary kilns for expanded lightweight aggregate, 3 companies operate 3 cement plants, 1 company operates 1 clay-pipe plant, and 1 company operates 1 major art-pottery plant. The only specialty clay utilized in Oklahoma is bentonite, which is shipped out of state for use as an absorbent.

The value of clays and shales mined in Oklahoma has averaged 1.4 percent of the total dollar value of nonpetroleum mineral production during the past 12 years. An examination of clay and shale utilization for the years 1960-70 shows: cement, 47 percent; brick, 34 percent; expanded lightweight aggregate, 18 percent; and bentonite, less than 1 percent. The clay-pipe industry is not included in this total because Oklahoma's first clay-pipe plant began production in 1969 with a capacity of 40,000 tons of pipe per year.

The trends in the production of general clays and shales in Oklahoma depend upon trends in the construction industry. When construction activity is up, clay and shale production is up. Future growth for clay and shale use on a national level is expected to be between 2.8 and 4.1 percent, projected to the year 2000. Products such as expanded lightweight aggregate are expected to have high growth rates, and those such as brick low growth rates.

If Oklahoma expects to increase clay and shale production above the level of the normally expected growth rate, innovations are called for by the structural-clay-products industry to increase demand; in addition, exploration for and exploitation of specialty clays must be expanded.

AAPG-SEPM Annual Meetings, Denver, Colorado April 17-19, 1972

The following abstracts are reprinted from the March 1972 issue, v. 56, of the *Bulletin* of The American Association of Petroleum Geologists. Page numbers are given in brackets below each abstract. Permission of the authors and of A. A. Meyerhoff, managing editor of the *Bulletin,* is gratefully acknowledged.

Patterns of Flysch Deposition of Lower Stanley Group (Mississippian), Ouachita Mountains, Oklahoma and Arkansas

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A southern proximal and a northern distal flysch facies are recognized in lower Stanley strata over an area of 5,000 sq mi in the southern and central Ouachita Mountains. Four distinctive tuffs (25-120 ft thick) interbedded with marine graywackes and shales serve as key units for detailed correlation of 8 sections 500-1,500 ft thick. Sandstone geometry, lithology, sedimentary structures, and ratio of sandstone to shale in the proximal and distal facies are similar to modern deep sea fans and associated basin sediments off the southern California coast. Individual sandstones appear to be discontinuous finger- to fan-shaped bodies on isopach and paleocurrent maps.

A gradational contact (10-100 ft) between the Arkansas Novaculite and the overlying lower Stanley strata over most of the Ouachitas records a gradual change from predominantly biological/chemical precipitation to clastic sedimentation. A local high, or highs, in the Ouachita trough is indicated by (1) novaculite conglomerate lenses, (2) an angular unconformity, and (3) thinning of the tuffs and strata between the tuffs.

The lower 500 ft of the Stanley Group is predominantly a distal flysch facies of shales and thin (6-in.) siltstones over much of the Ouachitas. The distal facies was superseded by a prograding wedge of proximal flysch facies in the southern Ouachitas. The proximal facies changes laterally to a distal flysch facies in the central Ouachitas. The source area may have been a northeastern extension of the buried Luling overthrust front of Texas.

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Late Mississippian Epeirogeny and the Wichita Orogeny in the Mid-Continent

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Widespread epeirogeny in Late Mississippian time uplifted elements of the Transcontinental arch and bordering regions. Late Mississippian deposition in the Mid-Continent was confined to the Anadarko, Ardmore, and Arkoma basins where maximum thicknesses of 5,000, 3,000, and 2,000 ft of sediments (respectively) accumulated. Erosional processes accompanied regional uplift and continued after the cessation of Late Mississippian deposition. Consequently, over the Mid-Continent an erosional surface was etched on a terrane of predominately carbonate Paleozoic sediments and igneous Precambrian rocks.

A maximum thickness of 4,000 ft of Morrowan (Early Pennsylvanian) sediments was deposited in the Anadarko basin. From there, northward to southwestern Nebraska, Morrowan beds onlap the Late Mississippian erosional surface and truncate rocks ranging in age from Late Mississippian to Precambrian. This depositional onlap accounts for the limits and much of the thinning of the Morrowan Series from the Anadarko basin toward the north and northeast. Morrowan rocks on the order of 3,000 ft and 5,000 ft in thickness were deposited in the Ardmore and Arkoma basins, respectively. In these basins Morrowan sediments lie on Late Mississippian rocks with minor unconformity.

The post-Morrowan, pre-Atokan Wichita orogeny brought the aligned Criner Hills-Amarillo-Wichita uplift-Cimarron arch into existence through strong vertical uplift accompanied by high-angle faulting with an estimated 10,000-15,000 ft of maximum vertical displacement. Concurrently a foredeep began to form in the Arkoma basin which would subside rapidly and receive phenomenal thicknesses of Atokan rocks—12,000 ft in the western Arkoma basin and 19,500 ft in the eastern part of the basin.

Meanwhile, an area on the western margin of this developing Atokan foredeep became mildly positive, possibly in response to the strong downwarping of the foredeep. From the Criner Hills this area trends northward across the Ardmore basin and the Arbuckle uplift, and turns northeastward toward the Ozark uplift, a distance of approximately 175 mi. This belt was about 125 mi wide and it encompassed the southeastern flank of the Anadarko basin and the northwestern flank of the Arkoma basin. Morrowan rocks were eroded from this positive area with the exception of those in the Ardmore basin, those on the southeastern flank of the Anadarko basin, and those on the northwestern margin of the Arkoma basin. These rocks exhibit an angular, unconformable relation with overlying Atokan or Desmoinesian beds. Elsewhere in the Arkoma basin, and in the Anadarko basin and on its shelf area, the contact of Morrowan and Atokan rocks is nonangular and probably disconformable.

In western Oklahoma, western Kansas, and southwestern Nebraska, the depositional limit of Morrowan sediments is overstepped eastward by Atokan beds, and the depositional limit of Atokan beds