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SHALE AND CARBONATE-ROCK RESOURCES OF OSAGE COUNTY, OKLAHOMA

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Title Page Illustration

Ink drawing by Roy D. Davis from a photograph (see fig. 8b, p. 35) of the Deer Creek–Lecompton limestone unit of Pennsylvanian (Virgilian) age, showing typical bedding.

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SHALE AND CARBONATE-ROCK RESOURCES OF OSAGE COUNTY, OKLAHOMA

William H. Bellis[1] and T. L. Rowland[2]

Abstract—The shale and carbonate-rock resources of Osage County, Oklahoma, were investigated to determine their mineralogical, physical, and petrographic properties so their potential could be assessed for use in the manufacturing and construction industries.

The rock sequence studied ranges in age from Missourian through Gearyan and has been assigned in its entirety to the Upper Pennsylvanian in this report, following current practice of the Oklahoma Geological Survey. Previous usage called for placement of the Gearyan in the Lower Permian.

Some of the Osage County shale units were found to be potentially suitable for the manufacture of sewer pipe, all grades of common and facing brick, structural tile, art pottery, cement, and possibly expanded lightweight aggregate. Shales of the eastern two-thirds of the County probably are more suitable for the manufacture of ceramic products than those of the younger units of the western one-third.

Four carbonate units are considered to have economic potential (in descending order): Red Eagle–Foraker limestones, Deer Creek–Lecompton limestones, Wildhorse Dolomite, and Avant Limestone. These units meet the specifications for road stone, agricultural lime, roofing aggregate, asphalt mix, concrete aggregate, and similar uses. Only the Deer Creek–Lecompton unit is considered to have potential for chemical-grade limestone, and this is marginal at best. The Wildhorse Dolomite is considered a chemical-grade dolomite.

PART I. INTRODUCTION

William H. Bellis and T. L. Rowland

Geographic and Geologic Setting

Osage County is the largest in land area of the 77 counties in Oklahoma. It encompasses 2,272 square miles and has a population of 29,750 (U.S. Bureau of Census, 1972, p. 38-16). Osage County is in the northeastern part of the State and is adjacent to the cities of Tulsa (population 331,638), Bartlesville (population 29,683), and Ponca City (population 25,940) (fig. 1). Three railroads serve the County, the Atchison, Topeka, and Santa Fe; the Missouri, Kansas, and Texas; and the Texas and Pacific. In addition, there is an adequate network of paved highways (fig. 1).

The County boundary encloses a total of 1,470,559.09 acres, of which all the mineral rights—surface and subsurface—of 1,469,077.63 acres are owned and controlled by the Osage Tribal Council. Information on mining permits, royalties, and leases can be obtained from the Superintendent, Osage Agency, Pawhuska, Oklahoma.

The rock sequence that crops out in Osage County ranges in age from Missourian (Coffeyville Formation) through Gearyan (Herington Limestone) (see stratigraphic chart on panel 1). It should be noted that the term Gearyan is used instead of the familiar Wolfcampian in order to be consistent with the accepted usage of the State Geological Survey of Kansas (O'Connor, 1963; Zeller, 1968). Although previous workers have placed the Gearyan in the Permian—and our inclination was to do so—the current practice of the Oklahoma Geological Survey calls for a Pennsylvanian age assignment for the Gearyan, based on palynological determinations and physical characteristics (see Branson, 1962, p. 431; Wilson and Rashid, 1971; Clendening, 1971;

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Wilson, 1973). Even though, to our knowledge, this systemic change has not been formalized, the entire Osage County outcrop is considered Upper Pennsylvanian in this report. (The Pennsylvanian-Permian contact generally has been placed at the top of the Brownville Limestone; the Oklahoma Geological Survey now places it higher in the section, at the top of the Herington Limestone and at the base of the Wellington Formation.)

The surface rocks of the eastern two-thirds of the County are characterized by sandstones, shales, and thin marine limestones of the Missourian and Virgilian Series (panel 1). The strike is generally northeast-southwest, with a gentle 1° dip to the west. The strike, dip, and resistance of the sandstones to erosion result in a topography that is expressed as a series of cuestal ridges throughout the eastern two-thirds of the County. These sandstone ridges support a dense growth of trees except where the land has been cleared for agricultural purposes. The exposed rocks of the western third of the County are shales, siltstones, and marine limestones of the Gearyan Series (panel 1). The strike and dip of these rocks are about the same as those rocks in the eastern part of the County, but the limestones are thinner and less resistant to erosion than the thick sandstones of the eastern part, which results in a topography of gently rolling hills. These rolling hills are grass covered because of the high calcium content of the soils derived from the carbonate rocks.

Previous Work

The early geological investigations of Osage

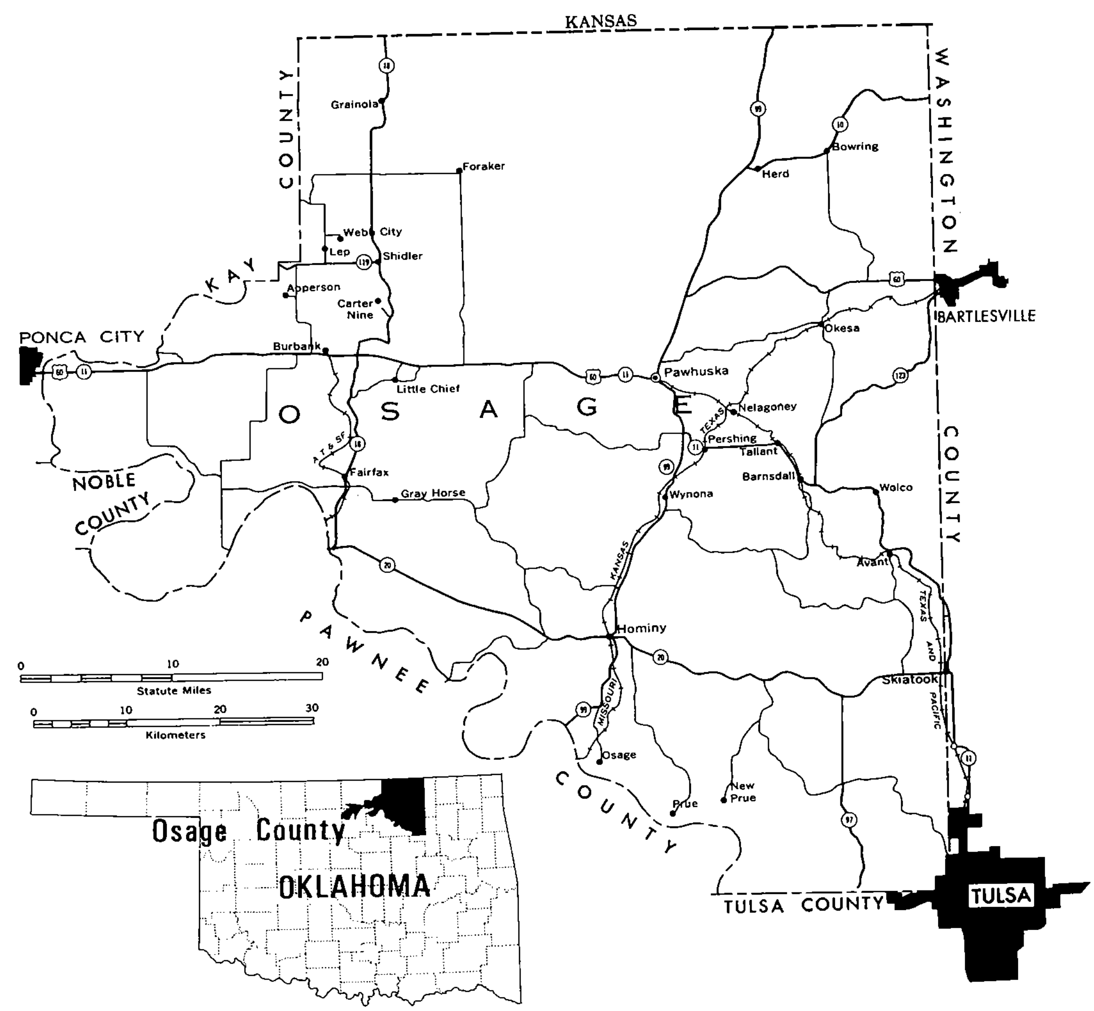


Figure 1. Map of Osage County, showing cities, major roads, and railroads. (Base from U.S. Geological Survey map of Oklahoma, 1975, scale 1:500,000.)

County were stimulated and influenced by interest in oil and gas exploration. The works of White and others (1922) and Beckwith (1928) are examples of this early interest. Snider (1911, p. 166-168, 170-172, 188-191, 224) and Sheerar and Redfield (1932, p. 192-195) provided clay and shale test data for several of the rock units in Osage County. Oakes mapped parts of Osage County in conjunction with his work on Washington County (1940) and Tulsa County (1952). Detailed surface geologic maps for Osage County are included in the works of Taylor (1953), Carter (1954), Shannon (1954), Tanner (1956), Bryant (1957), Carl (1957), and Gardner (1957). These maps provide nearly total coverage for Osage County (fig. 2). More recently, Mogharabi (1966) and Al-Khersan (1969) made petrologic studies of the Foraker and Red Eagle Limestones.

Current Investigation

This investigation involved the examination of the major shale and carbonate units of Osage County in order to determine their mineralogical, physical, and petrographic properties. These properties can be used to evaluate the potential that these rocks have in the manufacturing and construction industries. Sampling of the rocks was done at the most feasible and accessible localities throughout the outcrop length. For the shales, the sample localities were generally road cuts, and for the carbonate rocks they were active and abandoned quarries.

Although we collaborated in all phases of this report, the investigation of the shales was the responsibility of Bellis, and Rowland was responsible for the carbonate rocks.

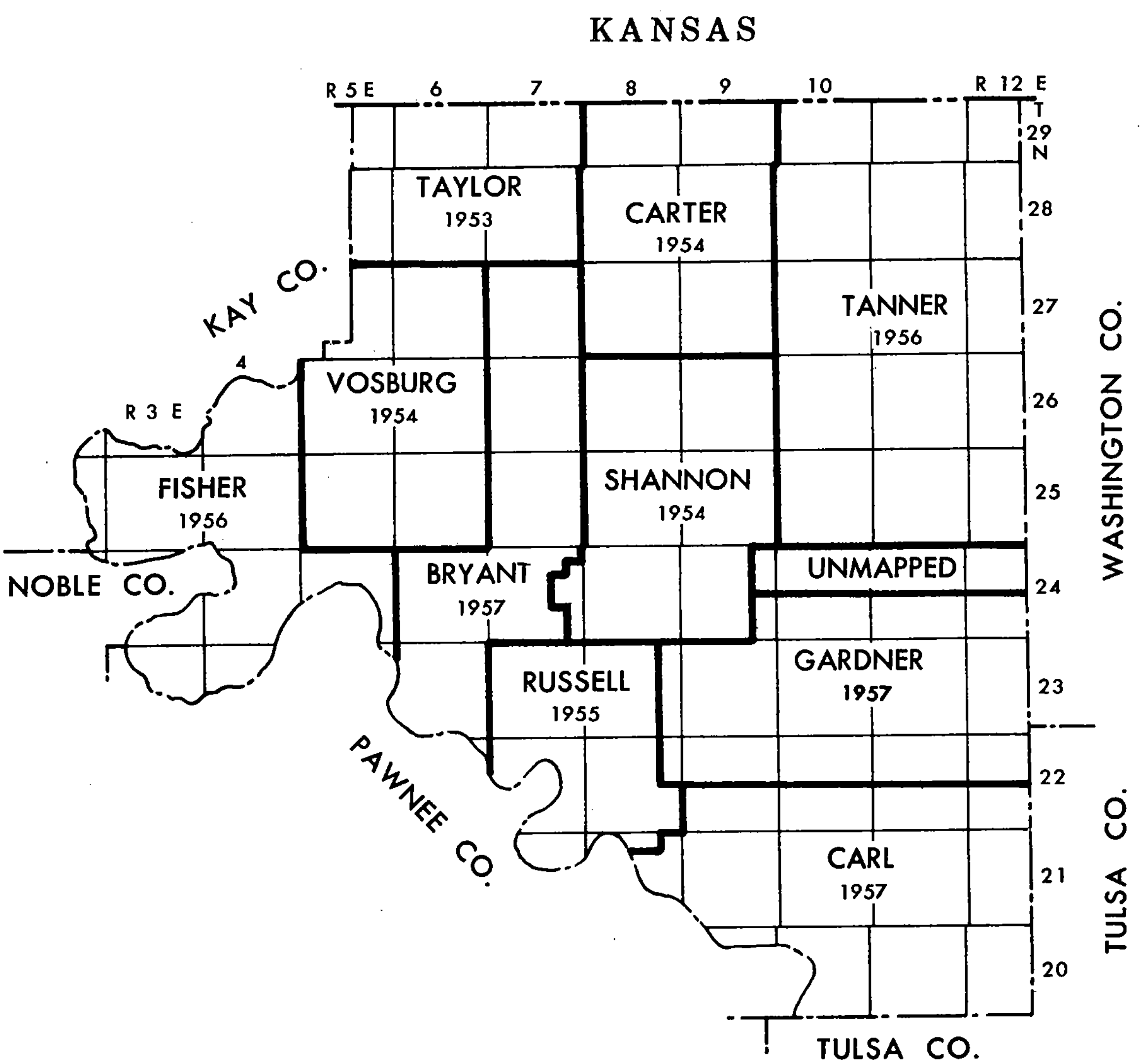


Figure 2. Index to geologic mapping in Osage County.

Acknowledgments

We are grateful to the Osage Tribal Council, who provided part of the financial support for this project (contract no. G00C14201395 between The University of Oklahoma Research Institute and the Osage Tribal Council), and to John Pappan and David Baldwin, successive superintendents of the Osage Agency, and their staffs, who were always willing to provide us with any information we needed.

Physical-test data on the carbonate rocks were furnished by Willard McCasland, Research and Development Division, Oklahoma Department of Highways; Wildhorse Dolomite analyses (crusher run and tailings) were provided by Henry McCabe, then president of Delta Mining Corp.; the U.S. Bureau of Mines furnished shale-test data on three samples; William Isom collected most of the shale samples used in the evaluation tests; and Carroll Kinney and Jerry Mooney performed the tests on the shales in the Oklahoma Geological Survey laboratory. We are appreciative to all these persons and organizations for their valuable assistance.

PART II. SHALE RESOURCES OF OSAGE COUNTY

William H. Bellis

General Uses and Requirements of Shales

Clays and shales have a great many uses in the manufacturing industry, many of which are not pertinent to this report (see Grim, 1962, ch. 8, and Klinefelter and Hamlin, 1957, p. 43-50). The major use of shale from Osage County would be for structural-clay products (including bricks and tile, roofing tile, terra cotta, clay pipe, and expanded lightweight aggregate), art pottery, and cement. The suitability of the raw material for the above-listed uses depends on the mixing properties of the shale or clay with water, the firing characteristics, and the chemical composition.

Common or building brick and facing brick can be made from a variety of clays and shales. However, facing brick is supposed to have higher quality, and, as a result, the standards are more restrictive. The American Society for Testing and Materials (ASTM) recognizes three grades of building brick (ASTM, 1962a) and two grades of facing brick (ASTM, 1962b). The grades of building brick are SW, MW, and NW; whereas the SW grade can be exposed to freezing temperatures and water permeation, the MW grade is frost resistant but not likely permeated by water and the NW grade is for interior masonry. The two grades of facing brick are SW and MW; the SW grade has a high and uniform resistance to frost action, and the MW grade has a moderate and somewhat nonuniform resistance to frost. In general, bricks require a raw material with a fair degree of plasticity, a drying and firing shrinkage of no more than 8 percent, and a firing temperature of about 2,000°F (Klinefelter and Hamlin, 1957, p. 36). For SW-grade bricks, common or facing, the water absorption should not exceed 17 percent, and for MW grade, no more than 22 percent (ASTM, 1962a, p. 2; 1962b, p. 9). Colors of the fired brick should be straight reds, buffs, or mingled shades. The technology of color control has reached the point where a red-firing brick can be changed to almost any desired shade by body coloring, englobes, glazes, surface stains, or colored aggregates (Bebbington and Bland, 1973). The desired chemical composition of common-brick raw material is not too restrictive. However, such components as sulfates, carbonates, large amounts of iron, alkalies, and alkaline earths are detrimental to the final brick product and should be avoided. Facing brick, considered a better grade than common brick, should use a raw material that definitely avoids the above-mentioned components (Grim, 1962, p. 129, 130).

Structural tile requires about the same raw material as a brick product; however, the shale or clay should be a better grade, that is, relatively free of sand but still characterized by low drying and firing shrinkage (Klinefelter and Hamlin, 1957, p. 37). For roofing tile, the clay or shale quality is about the same, with the absorption for an unglazed product not exceeding 10 percent.

Clays and shales that can make good-quality bricks are also generally good for vitrified clay-pipe products. In addition, the fired product should have a wide vitrification range and an absorption that does not exceed 8 percent (Klinefelter and Hamlin, 1957, p. 37).

Raw material from which terra-cotta products are made should have fair plasticity, high strength, low firing shrinkage, and must fire to a buff color, which almost demands a fire-clay type of material (Klinefelter and Hamlin, 1957, p. 37).

A shale suitable for the production of brick is often suitable for the production of expanded lightweight aggregate. For expanded aggregate, the shale must produce enough gas to cause a bloat, at a temperature at which the material is pyroclastic, in order to trap the gas. In addition, there needs to be vitrification and a viscosity such that the gas is trapped in small, evenly distributed pores. It is also desirable that the temperature range, from the initial bloat to the formation of a sticky mass, be from 100° to 200°F. The chemical and mineralogical composition of the clay or shale is thus a factor in the bloatability of the material. Bush (1973, p. 338, 339) reviewed the disagreement among researchers as to the source of the evolved gases and suggested that no single factor is important but that several simultaneous reactions result in gas evolution. Riley (1951) defined bloating-material limits based on SiO_2, Al_2O_3, and fluxes (CaO, MgO, FeO, Fe_2O_3, K_2O, Na_2O). White (1960) extended the range of bloating material toward higher Al_2O_3 and lower fluxes, and later Sweeney and Hamlin (1965) showed that the range extended to higher flux content. Lapham and Hoover (1971) suggested that the critical criteria for expanded aggregate are CO_2 content, total iron content, kaolinite content, and possibly mica content. However, as Bush (1973, p. 339) pointed out, the ultimate evaluation is what the material does in a commercial operation.

The two commercial methods for the production of expanded aggregate in this country are by rotary kiln and sintering. Generally, raw material that expands without addition of some bloating aid is processed in a rotary kiln, and if an additive is required, such as coal or fuel oil, or if there is too much fine material after crushing, then a sintering process is used. Ironman (1971) reported on a new sintering process developed in West Germany, which supposedly bloats almost any clay or shale without additives.

Art-pottery clays can include a wide range of clay material, but they should be clean, free from grit, and have a low-maturing temperature of approximately 1,950°F (Klinefelter and Hamlin, 1957, p. 38).

The shale or clay used in the manufacture of portland cement should be uniform in mineralogical components so that the kiln operation can be adjusted for a uniform product. Precise knowledge of the elemental composition of the raw-cement mix is necessary; therefore, the composition of the shale or clay is important. Most shales with a uniform composition can be used for cement manufacturing. However, those with a high chlorite content might not be usable, especially if such use causes the cement clinker to exceed a maximum of 5-percent MgO (Grim, 1962, p. 349). This could be especially critical if the carbonate rock used in the clinker contained magnesium carbonate. In general, the common clay minerals found in shale would not add any harmful constituents to the clinker mix.

Sampling and Testing Procedures

For this investigation, field sampling was done during the winter and summer of 1969, and laboratory tests were conducted on the samples collected during 1970 and the first half of 1971.

Channel samples were taken for all the shales tested. From 6 to 12 inches of the weathered shale surface was scraped away prior to sampling; even so, the shale was probably still somewhat weathered. Approximately 15 pounds of sample was collected for each 20 feet of stratigraphic section. If a locality comprised a shale more than 20 feet thick, then the samples were mixed and split in the laboratory.

Clay-testing procedures used in the Oklahoma Geological Survey laboratory were modified from those of Klinefelter and Hamlin (1957) and Hamlin and Templin (1962). The raw material was dried overnight at 230°F, then ground to pass through a 20-mesh screen; 10 grams of the ground material was mixed with distilled water in a 50-ml beaker, and the pH was determined with a pH meter. One hundred grams of the ground shale was used in the modified Atterberg plasticity test; the remainder was mixed with water and worked into a plastic state, then molded into 2½-by-2-by-3/8-inch briquettes. These briquettes were marked for linear shrinkage and dried overnight at 140°F. The dry linear shrinkage was recorded, and six test specimens were placed in a laboratory kiln for slow-fire tests. The temperature of the kiln was raised to 1,800°F in about a 4-hour period, and a briquette was taken from the kiln at 100°F intervals from 1,800°F through 2,300°F, after a 15-minute soak period for each specified temperature. The color and fired linear shrinkage on a dry basis were recorded. The absorption test on the fired briquettes determined the amount of water absorbed after boiling the specimen in water for 5 hours. Bulk-density measurements were made on the fired briquettes.

Summary of Shale Suitability

Shales from Osage County are suitable for the manufacture of sewer pipe, all grades of common and facing brick, structural tile, art pottery, cement, and probably expanded lightweight aggregate. The test evaluations are concentrated on uses for sewer pipe and brick with the assumption that structural tile and art pottery could in most cases be manufactured from material with similar characteristics.

A total of 110 shale samples were tested to determine their potential use in the manufacture of ceramic products. Of these, 25 samples, or about 23 percent, have criteria that suggest possible use in the manufacture of sewer pipe as well as brick products. Forty-two samples, about 38 percent, seem to be suitable for facing or common brick. Four samples could be used to manufacture a brick used entirely for interior decoration. Thirty-nine samples, or about 35 percent, seem to be unsuitable, at least based on these tests, for ceramic uses. The test bricks for these unsuitable samples showed either too much cracking or complete crumbling after the firing test.

X-ray diffractograms were run on 173 samples, showing that illite and kaolinite are the chief clay minerals for those argillaceous units from the Coffeyville Formation upward through the Brownville Limestone (see panel 1). Montmorillonite becomes one of the predominant clay minerals from the Brownville upward through the remainder of the stratigraphic section. Carbonate minerals also become a major constituent in the clay-size fraction of samples from the stratigraphic units above the Brownville. It appears from the test data and mineralogy that the shales of the eastern two-thirds of the County probably are more suitable for the manufacture of ceramic products than those of the younger units of the western one-third.

Survey and Evaluation of Shale Resources

In order to facilitate illustration of the general stratigraphic positions and outcrop patterns of major shale units within Osage County, it was considered appropriate to "lump together" many of the rock formations. This lumping is strictly informal, and these units are identified as map units **P**1 through **P**13 on panel 1 (map A and stratigraphic chart). The physical-test data (table 1) for these argillaceous units represent their characteristics at the sampled localities and thus may not be wholly representative of the units throughout their outcrop. In addition, these data are preliminary and should not be used for plant or process design without sufficient corroborating data.

Map Unit IP1 (Coffeyville and Hogshooter)

The Coffeyville Formation and overlying Hogshooter Limestone crop out in the southeastern corner of Osage County (panel 1, map A). Carl (1957, p. 9-14) described the Coffeyville as a gray and blue shale with lenticular sandstones, siltstones, and thin coals. The entire map unit is about 300 feet thick. The lower 100 feet is predominantly shale, as are the middle 100 feet and about 40 feet of the top. The clay mineralogy of the unit is predominantly illite and chlorite with minor kaolinite. Preliminary work suggests that the kaolinite content increases toward the southwest.

Potential uses.—There are no sample-test results from Osage County; however, Sheerar and Redfield (1932, p. 231-237) gave test results on seven samples from the Coffeyville in Tulsa County. These tests indicate that the Coffeyville shales have good working properties, including a plasticity of 21-32 percent, a drying shrinkage of 5-10 percent, a firing shrinkage of 6-9 percent at a firing temperature of 1,800°-2,000°F, and only slight to no scumming with one sample scumming badly. These data suggest that the Coffeyville can be used for all structural-clay products and art ware. In fact, it is currently used by Acme Brick Co. (plant no. 2) in Tulsa County (SW¼ sec. 36, T. 20 N., R. 12 E.), by Sapulpa Brick and Tile Corp. in Creek County (SW¼ sec. 34, T. 18 N., R. 11 E.), and by Frankoma Pottery, Inc., in Creek County.

Map Unit IP2 (Nellie Bly and Dewey)

The Nellie Bly Formation (Carl, 1957, p. 18-22) is composed of dark-colored shales with interbedded siltstones, deltaic sandstones, and thin limestones. This sequence has a thickness that ranges from 230 to 300 feet and is bounded by the Hogshooter and Dewey Limestones. X-ray-diffraction analysis shows illite to be the dominant clay mineral, with a mixed-layer clay, kaolinite, and possibly vermiculite in minor amounts. Here as with the Coffeyville, the kaolinite content seems to increase toward the southwest, and in sample 1442 (panel 1, map A) kaolinite is the dominant clay mineral.

Potential uses.—Firing tests were run on five samples, and of these, two samples crumbled. The three remaining test samples indicated (table 1) that the Nellie Bly could be used for common and possibly facing brick. The low absorption indicated by sample 1483 might allow this material to be used for sewer pipe.

Map Unit IP3 (Chanute–Wann)

This map unit includes the Chanute, Iola, and Wann Formations (panel 1, stratigraphic chart). These rocks are shale, sandstone, limestone, and coal with a total stratigraphic thickness of about 410 feet (Carl, 1957, p. 27-29, 35-37). The shales in the lower part of the Wann are 100-170 feet thick. Chief clay minerals are illite and kaolinite, minor and varying amounts of mixed-layer clays, vermiculitic clays, and chlorite.

Potential uses.—Nineteen samples from this unit were collected and tested, representing fairly good coverage of the outcrop area (panel 1, map A). Samples 1443 and 1492 showed a low-enough absorption to be usable for the manufacture of sewer pipe as well as for common and facing brick (table 1). Samples 1437, 1444, 1476, 1478, 1479, 1486, and 1487 appeared to have the potential for making common and facing brick. Samples 1446, 1481, and OGS-11 seemed to have marginal suitability because of efflorescence on the fired bricks, but they might suffice for the production of common brick. The rest of the samples—1440, 1474, 1480, 1490, 1501, and 1502—showed cracking of the fired test bricks, and sample 1489 completely crumbled.

Map Unit IP4 (Barnsdall)

Carl (1957, p. 38-43) and Gardner (1957, p. 30-37) indicated that the Barnsdall Formation is 110 to about 170 feet thick and consists of sandstone and shale with a dolomite lentil. The shale thickness averages about 80 feet, and illite and kaolinite are the dominant clay minerals with small to trace amounts of chlorite, vermiculite, and mixed-layer clays.

Potential uses.—Fourteen samples of the Barnsdall shale were tested, and of these, samples 1425, 1426, 1462, 1470, 1498, and 1500 showed potential for use in the manufacture of common and facing brick and possibly sewer pipe. Samples 1424, 1473, and 1477 indicated potential for common and facing brick; with sample 1477 there was a problem of white efflorescence on the fired product. Samples 1463, 1471, 1493, 1505, and 1506 all showed good brick-making potential except that they showed cracking in the fired bricks.

Map Unit IP5 (Tallant–Middle Vamoosa)

This map unit includes the Tallant Formation and the lower and middle members of the Vamoosa Formation including the Wynona Sandstone but excluding the Kanwaka Shale (panel 1, stratigraphic chart). This is a complex stratigraphic unit of thin to thick lenticular sandstones, red and green shales, and thin limestones of the delta or delta-fringe environment. The total thickness of the unit is about 750 feet. The clay minerals are dominantly illite and kaolinite with minor vermiculite, mixed-layer clays, and chlorite. Some of the samples also have calcite in the fine-size fraction.

Potential uses.—Firing tests on 32 samples of this unit indicate that samples 1422, 1451, 1453, 1456, 1457, 1467, 1468, 1496, 1503, 1508, and 1510 showed suitable characteristics for making sewer pipe, facing brick, and common brick (table 1). Samples 1419, 1421, 1432, 1435, 1445, 1455, 1494, 1497, 1507, and 1511 indicated potential for the manufacture of common and facing brick. Sample 1513 showed possibility for the production of common brick, and sample 1499 seemed suitable for common or decorative brick. The remaining samples (1418, 1428, 1431, 1466, 1469, 1514, 1515, 1519, and 1521) exhibited cracking and crumbling when fired.

Map Unit IP6 (Upper Vamoosa)

This unit includes the upper members of the Vamoosa Formation, the Kanwaka Shale and the Elgin Sandstone (panel 1, stratigraphic chart). The Kanwaka is a dark-gray to olive-drab shale about 80 feet thick (Shannon, 1954, p. 17). The shale becomes more silty toward the top, where it is overlain by the thick (about 50 feet) Elgin Sandstone. X-ray analysis of the shale shows illite and kaolinite as the chief clay minerals, with vermiculite and a mixed-layer clay in minor amounts and possibly some chlorite.

Potential uses.—Eight samples were tested, and two, 1347 and 1404, showed low-enough absorption and shrinkage and good-enough working characteristics to be used for sewer pipe (table 1). Samples OGS-2 and OGS-4 showed potential for common or facing brick. Sample 1359 had too high a fired shrinkage for common or facing brick, but the addition of a nonplastic grog would probably help reduce the shrinkage. Samples 1408 and 1516 showed cracking of the fired test bricks, and the bricks of sample 1351 completely crumbled. Quick-fire tests on sample OGS-4 indicated that it was a possible bloating material for use as expanded aggregate, but the rotary-kiln test (table 2) on the same material found that the shale completely disintegrated in the kiln at low temperatures. It may well be that this material could be used in a sintering process.

The Kanwaka Shale was used by the Pawhuska Vitrified Brick and Tile Company in the early 1900's. The plant and shale pit (sample OGS-4; see panel 1, map A) were located northwest of Pawhuska (NE¼ sec. 5, T. 25 N., R. 9 E.) (Snider, 1911, p. 224). The shale proved to be the source of a good brick product, but there was some efflorescence on the fired bricks.

Map Unit IP7 (Pawhuska)

The Pawhuska Formation is a series of thin limestones separated by shales and silty shales that grade into sandstone. This stratigraphic unit ranges in thickness from 200 feet in the northern part of the County to 100 feet in the southern part (Russell, 1955, p. 21). Carter (1954, p. 23-43) described 6 limestones with 5 intervening shales that are individually 10 to 30 feet thick. In the southern part of the County only 4 limestones are recognized, and there are 3 intervening shales 15 to 30 feet thick.

The chief clay minerals in these shales are illite, kaolinite, mixed-layer clays (probably illite-montmorillonite), and minor chlorite. Calcite is a common fine-fraction constituent of these shale units.

Potential uses.—The firing tests (table 1) on the Pawhuska shales indicated high drying (sample 1354) and high-firing shrinkage (sample 1362). The addition of quartz sand or some other nonplastic grog to the raw material would probably help the high-firing-shrinkage problem. Considerable calcite and expandable mixed-layer-clay minerals in these shales are not good attributes for a ceramic raw material.

Map Unit IP8 (Severy)

The lithology of the Severy Shale is gray to maroon shale with sandstones and siltstones. The thickness ranges from about 30 to about 90 feet (Shannon, 1954, p. 53). The clay minerals of the Severy are primarily kaolinite and illite, with mixed-layer illite-montmorillonite, minor vermiculite, and chlorite. Calcite is evident in some of the material.

Potential uses.—The three samples of the Severy that were tested indicated that this material does not have much potential for ceramic products (table 1). Sample 1364 showed a very high water-absorption percentage and a high dry shrinkage, indicating a lack of desirable qualities. The test bricks of sample 1409 had cracks and white inclusions, probably from calcite. Sample 1411 indicated possibility for use as an MW-grade brick, as the absorption was somewhat high for SW grade.

Map Unit IP9 (Bird Creek–Auburn)

This unit includes the sequence from the top of the Severy Shale upward through the Auburn Shale (panel 1, stratigraphic chart). These rocks are shales, silty shales, and thin limestones. The shales are buff to gray to black and total about 80 to 100 feet of the 125-foot section (Shannon, 1954, p. 56-61). The Auburn Shale is various shades of maroon to gray to brown and contains discontinuous sandstones; it is about 60 feet thick (Bryant, 1957, p. 22).

The clay minerals are primarily kaolinite and illite, with lesser quantities of mixed-layer clays and minor chlorite; some samples have traces of montmorillonite.

Potential uses.—Three samples from this unit were tested, and, of these, one (1381) completely crumbled, another (1402) showed cracking of the fired bricks, and sample 1401 had a high fired shrinkage that might be controlled by the addition of a nonplastic grog (table 1). With the fired shrinkage controlled, the last sample showed possible use for making common or facing brick.

Map Unit IP10 (Reading–Brownville)

This stratigraphic interval contains the rocks from the top of the Auburn Shale upward to the top of the Brownville Limestone (panel 1, stratigraphic chart). The sequence is a series of limestones and intervening shales with minor development of a sandstone and siltstone facies. The intervening shales are various shades of maroon to buff and have thicknesses that range from 10 to some 50 feet for individual shale units (Bryant, 1957, p. 27-38).

The clay minerals are chiefly kaolinite and illite, with lesser amounts of mixed-layer clays, minor chlorite, and montmorillonite. The fine-size fraction also shows traces of calcite, siderite, and ankerite in some of the samples.

Potential uses.—Ten samples were collected and tested, and two of the samples (1387 and 1395) resulted in crumbling of the test bricks after firing (table 1). Samples 1397 and 1399 showed an appropriate shrinkage and water absorption that suggest possible use for sewer pipe as well as for facing and common brick. Samples 1377 and 1400 indicated use for an MW-grade brick, and samples 1396 and 1398 indicated possibilities for use as common or maybe even facing brick if the fired shrinkage could be lowered by use of a nonplastic grog. Sample 1378 showed a very high water absorption but might suffice for an interior-decorative brick. Sample 1388 showed a high drying shrinkage, which would probably limit its usefulness as a ceramic product; however, the fired shrinkage and water absorption were low.

Map Unit IP11 (Five Point–Red Eagle)

This unit includes those rocks between the top of the Brownville Limestone and the top of the Red Eagle Limestone (panel 1, stratigraphic chart). Total shale thickness is about 60 to 75 feet, but the individual shale units between the limestones are 10 to 20 feet thick. The shales are poorly exposed on the slopes of the rolling hills, which are capped by limestone. X-ray analysis of the fine fraction shows montmorillonite as the principal clay mineral, with minor illite and mixed-layer clays. Calcite is the chief mineral of the clay-size fraction.

Potential uses.—Three samples were tested (table 1), and in all three tests the bricks crumbled. The high calcite and montmorillonite content of these shales should certainly render this material potentially poor for use in ceramic products.

Map Unit IP12 (Roca–Eskridge)

Included in this unit are the shales from the top of the Red Eagle Limestone to the base of the Beattie Limestone (panel 1, stratigraphic chart). The two main shales are the Roca and the Eskridge. These shales are of various colors but are predominantly maroon; their total thickness is about 100 feet (Fisher, 1956, p. 30-37). The dominant clay minerals are montmorillonite, kaolinite, and illite, with minor mixed-layer clays and chlorite. The carbonate minerals ankerite and calcite are the chief constituents in the clay-size fraction of these shales.

Potential uses. —Six samples were tested, which resulted in most of the test bricks breaking or crumbling (table 1). This result should have been expected because of the high montmorillonite and carbonate content. However, when the bricks did survive the firing temperature, they had pleasing pale-red and rose colors that would make an interesting interior-decorative brick. Sample 1529 had a high kaolinite content and a low-enough absorption percentage to indicate potential for MW-grade bricks.

Map Unit IP13 (Beattie–Herington)

All the shales from the Beattie Limestone to the Herington Limestone are included in this unit (panel 1, stratigraphic chart). This sequence is a series of shales and limestones several hundred feet thick, and both the shales and limestones are poorly exposed. The clay minerals show a great deal of variation from sample to sample. In samples 1523 and 1524, kaolinite was the chief clay mineral, with illite, chlorite, and mixed-layer clays in minor amounts. Sample 1522 had a high calcite content, and the clays were poorly crystalline illite and kaolinite; sample 1525 was predominantly montmorillonite with minor kaolinite.

Potential uses.—Four samples were tested (table 1). Sample 1523 showed a fired-shrinkage and water-absorption value low enough to have potential for the manufacture of sewer pipe as well as common and facing brick. Sample 1524 indicated suitability for facing and common brick. Sample 1525 showed a high dry shrinkage, and the fired test bricks contained white inclusions. All the test bricks for sample 1522 crumbled upon firing.

Table 1.—Physical Properties of Osage County Shales

Sample number, location, and map unit	Unfired characteristics: pH	Unfired: Color	Unfired: Water of plasticity %	Unfired: Drying shrinkage %	Firing temperature ^oF	Ceramic property tests: Color	Ceramic: Total fired shrinkage %	Ceramic: Absorption %	Ceramic: Bulk density gm/cm^3	Remarks
1442 NE 33-21N-11E IP 2 (Nellie Bly shale)	7.0	Gray	20-24	6.0	1,800	Light brown	0.0	18.0	1.83	
					1,900	Light brown	0.0	17.0	1.87	
					2,000	Light brown	0.0	17.0	1.87	
					2,100	Medium brown	0.0	15.0	1.91	
					2,200	Gray brown	0.0	16.0	1.90	
					2,300	Gray brown	0.0	14.0	1.95	
1482 SW 15-22N-12E IP 2 (Nellie Bly shale)	8.2	Tan	19-29	3.0	1,800	Light brown	0.0	20.0	1.78	Bricks showed some cracking.
					1,900	Light brown	3.0	17.0	1.88	
					2,000	Medium brown	3.0	12.0	2.03	
					2,100	Medium brown	7.0	10.0	2.10	
					2,200	Gray brown	7.0	4.0	2.30	
					2,300	Dusky brown	---	4.0	2.30	
1483 W½ 10-22N-12E IP 2 (Nellie Bly shale)	8.4	Tan	23-36	3.0	1,800	Light brown	0.0	20.0	1.74	
					1,900	Light brown	3.0	13.0	1.93	
					2,000	Light brown	3.0	11.0	2.01	
					2,100	Medium brown	7.0	7.0	2.13	
					2,200	Medium brown	10.0	2.0	2.35	
					2,300	Gray brown	0.0	9.0	1.84	
1484 NW 10-22N-12E IP 2 (Nellie Bly shale)	8.3	Gray	17-27	6.0	-----	------------	---	---	----	All bricks crumbled.
1485 S½ 33-23N-12E IP 2 (Nellie Bly shale)	7.4	Tan	21-29	3.0	-----	------------	---	---	----	All bricks crumbled.
[1]OGS-11 NW 25-20N-10E IP 3 (Chanute-Wann shales)	8.8	Gray	21.1	5.0	1,800	Orange tan	7.5	7.2	2.11	Highly effervescent with HCl.
					1,900	Light brown	7.5	4.3	2.22	
					2,000	Medium brown	10.0	0.7	2.34	
					2,100	------------	Expanded	---	----	
1437 W½ 34-21N-10E IP 3 (Chanute-Wann shales)	7.8	Brown	18-24	3.0	1,800	Light tan	0.0	17.0	1.88	
					1,900	Tan	0.0	15.0	1.97	
					2,000	Tan	3.0	13.0	2.04	
					2,100	Light brown	7.0	12.0	2.05	
					2,200	Brown	7.0	9.0	2.16	
					2,300	Dark brown	7.0	6.0	2.21	
1440 S½ 34-21N-10E IP 3 (Chanute-Wann shales)	7.2	Gray	20-27	6.0	1,800	Light tan	0.0	16.0	1.96	Showed some cracking.
					1,900	Light tan	0.0	15.0	1.92	
					2,000	Dark tan	0.0	10.0	2.08	
					2,100	Light brown	4.0	9.0	2.14	

1443 NW 17-22N-12E IP 3 (Chanute-Wann shales)	8.2	Gray	23-34	6.0	1,800	Tan	4.0	17.0	1.91	
					1,900	Tan	4.0	17.0	1.92	
					2,000	Dark tan	4.0	13.0	2.03	
					2,100	Brown	7.0	4.0	2.32	
					2,200	Dark brown	7.0	4.0	2.38	Showed good glaze at $2,200^{o}$. Melted.
					2,300	Red brown	---	8.0	2.52	
1444 S½ 8-22N-12E IP 3 (Chanute-Wann shales)	7.5	Gray	23-32	10.0	1,800	Light tan	0.0	15.0	1.88	Drying shrinkage high, but still may have brick potential.
					1,900	Tan	0.0	15.0	1.88	
					2,000	Tan	0.0	12.0	2.00	
					2,100	Light brown	3.0	8.0	2.15	
					2,200	Brown	7.0	3.0	2.27	
					2,300	Dark brown	7.0	3.0	2.38	
1446 E½ 24-22N-11E IP 3 (Chanute-Wann shales)	8.0	Gray	21-27	6.0	1,800	Light brown	4.0	17.0	1.85	Had white efflorescence.
					1,900	Light brown	4.0	14.0	2.01	
					2,000	Medium brown	4.0	----	----	
					2,100	Medium brown	4.0	12.0	2.04	
					2,200	Gray brown	---	----	----	Began to melt.
					2,300	------------	---	----	----	Melted.
1474 SE 30-21N-11E IP 3 (Chanute-Wann shales)	8.0	Gray	18-26	3.0	1,800	Light tan	0.0	17.0	1.88	Showed some cracking.
					1,900	Tan	0.0	15.0	2.07	
					2,000	Dark tan	0.0	14.0	2.07	
					2,100	Light brown	3.0	9.0	2.13	
					2,200	Dark brown	3.0	5.0	2.41	
					2,300	Dark brown	3.0	5.0	2.40	
1476 SE 30-21N-11E IP 3 (Chanute-Wann shales)	7.8	Gray-tan	17-27	3.0	1,800	Light tan	0.0	16.0	1.94	
					1,900	Light tan	4.0	16.0	1.95	
					2,000	Tan	4.0	16.0	1.99	
					2,100	Light brown	4.0	12.0	2.13	
					2,200	Brown	7.0	12.0	2.14	
					2,300	Dark brown	7.0	5.0	2.39	
1478 NE 27-22N-11E IP 3 (Chanute-Wann shales)	9.0	Tan	18-23	3.0	1,800	Light tan	0.0	16.0	1.92	
					1,900	Light tan	0.0	16.0	1.94	
					2,000	Tan	3.0	14.0	2.01	
					2,100	Dark tan	3.0	14.0	2.02	
					2,200	Brown	3.0	10.0	2.17	
					2,300	Dark brown	3.0	8.0	2.19	
1479 SW 33-23N-11E IP 3 (Chanute-Wann shales)	---	Gray-tan	19-30	3.0	1,800	Light tan	3.0	17.0	1.90	
					1,900	Tan	3.0	15.0	1.91	
					2,000	Tan	3.0	15.0	1.93	
					2,100	Light brown	8.0	10.0	2.13	
					2,200	Brown	10.0	4.0	2.33	
					2,300	Dark brown	7.0	6.0	2.35	Began to bloat.
1480 N½ 18-23N-12E IP 3 (Chanute-Wann shales)	7.6	Tan	20-26	3.0	1,800	Tan	3.0	17.0	1.83	Showed considerable cracking.
					1,900	Tan	3.0	17.0	1.85	
					2,000	Tan	3.0	15.0	1.91	
					2,100	Brown	3.0	10.0	2.11	
					2,200	Brown	3.0	7.0	2.16	
					2,300	Dark brown	3.0	6.0	2.15	

Table 1.—Physical Properties of Osage County Shales—*Continued*

Sample number, location, and map unit	Unfired characteristics: pH	Color	Water of plasticity %	Drying shrinkage %	Firing temperature °F	Ceramic property tests: Color	Total fired shrinkage %	Absorption %	Bulk density gm/cm³	Remarks
1481 E½ 36-24N-11E IP 3 (Chanute-Wann shales)	8.1	Gray	21-32	6.0	1,800	Light tan	0.0	19.0	1.82	
					1,900	Light tan	0.0	19.0	1.82	
					2,000	Light tan	0.0	18.0	1.84	Showed white washing.
					2,100	Light brown	0.0	17.0	1.85	Showed glaze at 2,200°.
					2,200	Dark brown	7.0	14.0	1.86	
					2,300	Dark brown	---	12.0	1.90	Began to melt.
1486 31-24N-12E IP 3 (Chanute-Wann shales)	7.6	Tan	18-28	6.0	1,800	Light tan	0.0	15.0	1.88	
					1,900	Light tan	0.0	15.0	1.88	
					2,000	Light tan	0.0	14.0	1.90	
					2,100	Dark tan	4.0	13.0	1.96	
					2,200	Dark brown	4.0	6.0	2.18	
					2,300	Dark brown	4.0	6.0	2.18	
1487 NW 30-24N-12E IP 3 (Chanute-Wann shales)	7.9	Tan	18-26	6.0	1,800	Tan	0.0	13.0	2.02	
					1,900	Tan	0.0	11.0	1.98	
					2,000	Dark tan	0.0	11.0	2.10	
					2,100	Dark tan	0.0	14.0	1.99	
					2,200	Brown	0.0	8.0	2.21	Began to burn at 2,200°.
					2,300	Dark brown	0.0	6.0	2.21	
1489 N½ 30-24N-12E IP 3 (Chanute-Wann shales)	7.3	Tan	20-31	6.0	-----	----------	---	----	----	All bricks crumbled.
1490 SW SE 21-24N-12E IP 3 (Chanute-Wann shales)	8.5	Tan	22-32	3.0	1,800	Light tan	0.0	16.0	1.89	Possible use as SW-grade brick; showed some cracking.
					1,900	Light tan	0.0	15.0	1.94	
					2,000	Tan	0.0	11.0	2.04	
					2,100	Brown	3.0	10.0	2.10	
					2,200	Dark brown	7.0	6.0	2.22	
					2,300	Dark brown	7.0	5.0	2.23	
1492 4-24N-12E IP 3 (Chanute-Wann shales)	7.3	Tan	21-29	3.0	1,800	Light tan	0.0	16.0	1.95	Possible use as SW-grade brick.
					1,900	Light tan	0.0	16.0	1.95	
					2,000	Tan	0.0	14.0	2.01	
					2,100	Light brown	0.0	8.0	2.26	
					2,200	Dark brown	7.0	5.0	2.33	
					2,300	Dark brown	7.0	4.0	2.40	Began to get sticky.
1501 NW 19-26N-12E IP 3 (Chanute-Wann shales)	7.5	Gray	18-25	0.0	1,800	Light tan	0.0	18.0	1.87	Possible use as SW-grade brick, but showed some cracking.
					1,900	Tan	0.0	15.0	1.92	
					2,000	Tan	0.0	15.0	1.92	
					2,100	Brown	3.0	8.0	2.18	
					2,200	Red-brown	0.0	8.0	2.17	
					2,300	Dark brown	3.0	5.0	2.21	
1502 NW 19-26N-12E IP 3 (Chanute-Wann shales)	8.0	Gray	18-24	0.0	1,800	Light brown	0.0	17.0	1.97	Possible use as MW-grade brick, but showed cracking.
					1,900	Light brown	0.0	16.0	2.02	
					2,000	Light brown	0.0	15.0	2.02	
					2,100	Medium brown	0.0	9.0	2.08	

					2,200	Red-brown	3.0	9.0	2.23	
					2,300	Dark brown	3.0	7.0	2.26	
1424 S½ 29-22N-10E IP 4 (Barnsdall shale)	7.5	Tan	18-26	2.0	1,800	Light tan	3.0	16.0	1.95	
					1,900	Tan	3.0	18.0	1.87	
					2,000	Tan	3.0	15.0	1.93	
					2,100	Light brown	7.0	14.0	1.98	
					2,200	Brown	7.0	12.0	2.03	
					2,300	Dark brown	10.0	11.0	2.07	
1425 SE 28-22N-10E IP 4 (Barnsdall shale)	8.0	Tan	29-38	3.0	1,800	Tan	3.0	19.0	1.82	
					1,900	Tan	3.0	11.0	2.09	Firing shrinkage a little high.
					2,000	Light brown	7.0	4.0	2.19	
					2,100	Brown	10.0	3.0	2.46	
					2,200	Dark brown	10.0	6.0	2.19	Began to show signs of melting.
					2,300	Dark brown	10.0	7.0	2.07	
1426 NE 21-22N-10E IP 4 (Barnsdall shale)	7.3	Gray	19-25	3.0	1,800	Light tan	0.0	16.0	1.91	
					1,900	Light tan	0.0	14.0	1.99	
					2,000	Tan	0.0	14.0	2.07	
					2,100	Light brown	3.0	9.0	2.18	White efflorescence.
					2,200	Brown	7.0	6.0	2.23	White efflorescence.
					2,300	Dark brown	7.0	5.0	2.29	
1462 N½ 7-23N-11E IP 4 (Barnsdall shale)	7.8	Tan	19-28	3.0	1,800	Light tan	2.0	16.0	1.93	
					1,900	Tan	3.0	16.0	1.95	
					2,000	Tan	3.0	13.0	2.01	
					2,100	Light brown	7.0	9.0	2.15	
					2,200	Brown	11.0	4.0	2.35	
					2,300	Red-brown	11.0	3.0	2.37	
1463 NE 14-23N-10E IP 4 (Barnsdall shale)	7.4	Light maroon	18-23	3.0	1,800	Tan	0.0	17.0	1.89	Showed some cracking.
					1,900	Tan	0.0	14.0	1.97	
					2,000	Light brown	3.0	12.0	2.06	
					2,100	Light brown	3.0	11.0	2.10	
					2,200	Red-brown	3.0	7.0	2.21	
					2,300	Red-brown	3.0	6.0	2.23	
1470 SE 33-23N-10E IP 4 (Barnsdall shale)	8.0	Gray-tan	19-28	6.0	1,800	Light tan	0.0	18.0	1.80	
					1,900	Tan	4.0	14.0	1.95	
					2,000	Light brown	4.0	----	----	
					2,100	Light brown	4.0	9.0	2.13	
					2,200	Brown	7.0	3.0	2.16	
					2,300	Brown	4.0	3.0	2.16	
1471 SE 34-23N-10E IP 4 (Barnsdall shale)	8.1	Tan	19-27	3.0	1,800	Light tan	3.0	17.0	1.92	Showed some cracking.
					1,900	Tan	3.0	15.0	2.00	
					2,000	Dark tan	3.0	12.0	2.11	
					2,100	Light brown	7.0	9.0	2.22	
					2,200	Brown	7.0	6.0	2.31	
					2,300	Dark brown	10.0	5.0	2.34	
1473 SW 30-23N-11E IP 4 (Barnsdall shale)	8.1	Gray-tan	18-24	3.0	1,800	Light tan	0.0	19.0	1.87	Showed signs of burning at 2,200°.
					1,900	Tan	0.0	16.0	1.89	
					2,000	Tan	3.0	12.0	1.94	
					2,100	Light brown	3.0	9.0	1.99	

Table 1.—Physical Properties of Osage County Shales—*Continued*

Sample number, location, and map unit	Unfired characteristics: pH	Unfired characteristics: Color	Unfired characteristics: Water of plasticity %	Unfired characteristics: Drying shrinkage %	Firing temperature °F	Ceramic property tests: Color	Ceramic property tests: Total fired shrinkage %	Ceramic property tests: Absorption %	Ceramic property tests: Bulk density gm/cm³	Remarks
					2,200	Brown	4.0	9.0	2.03	
					2,300	Red-brown	3.0	6.0	2.18	
1477 10-21N-10E IP 4 (Barnsdall shale)	7.4	Maroon	23-33	3.0	1,800	Tan	0.0	17.0	1.88	Showed some efflorescence.
					1,900	Tan	0.0	16.0	1.95	
					2,000	Tan	3.0	13.0	2.03	
					2,100	Light brown	7.0	12.0	2.07	
					2,200	Brown	7.0	5.0	2.31	
					2,300	Dark brown	7.0	3.0	2.38	
1493 21-25N-12E IP 4 (Barnsdall shale)	8.3	Tan	18-23	6.0	1,800	Light tan	0.0	16.0	1.81	Showed some cracking.
					1,900	Light tan	0.0	14.0	1.98	
					2,000	Tan	0.0	10.0	2.14	
					2,100	Light brown	0.0	8.0	2.21	
					2,200	Brown	4.0	4.0	2.28	
					2,300	Red-brown	4.0	4.0	2.37	
1498 SW 33-26N-11E IP 4 (Barnsdall shale)	7.3	Tan	20-28	3.0	1,800	Tan	7.0	16.0	1.85	
					1,900	Tan	7.0	16.0	1.86	
					2,000	Tan	7.0	12.0	2.00	
					2,100	Light brown	7.0	8.0	2.15	
					2,200	Brown	10.0	5.0	2.20	
					2,300	Dark brown	10.0	3.0	2.26	
1500 NW 30-26N-12E IP 4 (Barnsdall shale)	6.0	Tan	23-33	3.0	1,800	Light tan	0.0	16.0	1.84	
					1,900	Light tan	0.0	16.0	1.84	
					2,000	Light tan	0.0	14.0	1.88	
					2,100	Light brown	0.0	9.0	2.07	
					2,200	Brown	3.0	4.0	2.25	
					2,300	Dark brown	3.0	4.0	2.24	
1505 NW 1-26N-11E IP 4 (Barnsdall shale)	7.5	Gray	18-29	3.0	1,800	Light tan	0.0	16.0	1.89	Showed some cracking.
					1,900	Light tan	0.0	16.0	1.89	
					2,000	Tan	0.0	11.0	2.09	
					2,100	Light brown	3.0	7.0	2.22	
					2,200	Brown	7.0	5.0	2.26	
					2,300	Dark brown	3.0	4.0	2.23	
1506 SE 5-26N-12E IP 4 (Barnsdall shale)	---	Gray	19-29	3.0	1,800	Light tan	0.0	18.0	1.86	Showed some cracking.
					1,900	Tan	0.0	16.0	1.94	
					2,000	Dark tan	0.0	13.0	2.02	
					2,100	Brown	3.0	11.0	2.10	
					2,200	Dark brown	3.0	6.0	2.21	
					2,300	Dark brown	0.0	5.0	2.22	
1418 CW½ 6-22N-9E IP 5 (Tallant-middle Vamoosa shales)	8.9	Tan	26-32	---	1,800	----------	---	----	----	All bricks crumbled.

1419	8.4	Maroon	20-30	6.0	1,800	Tan	0.0	16.0	1.96	
C 6-22N-9E					1,900	Tan	0.0	16.0	1.94	
IP 5 (Tallant-					2,000	Light brown	4.0	13.0	2.06	
middle Vamoosa					2,100	Brown	4.0	11.0	2.11	
shales)					2,200	Dark brown	4.0	9.0	2.19	
					2,300	Dark brown	4.0	8.0	2.22	
1421	8.9	Beige	25-32	6.0	1,800	Tan	0.0	16.0	1.89	
SW 20-22N-9E					1,900	Tan	0.0	15.0	1.94	
IP 5 (Tallant-					2,000	Tan	0.0	15.0	2.01	
middle Vamoosa					2,100	Brown	0.0	10.0	2.00	
shales)					2,200	Dark brown	4.0	7.0	2.26	
					2,300	Dark brown	4.0	7.0	2.38	
1422	7.7	-----	23-35	6.0	1,800	Light tan	0.0	17.0	1.86	
W½ 30-22N-10E					1,900	Tan	4.0	10.0	2.14	
IP 5 (Tallant-					2,000	Tan	4.0	8.0	2.21	
middle Vamoosa					2,100	Brown	7.0	5.0	2.28	
shales)					2,200	Dark brown	7.0	5.0	2.37	
					2,300	Dark brown	7.0	3.0	2.43	
1428	7.5	Tan	19-26	2.0	1,800	Tan	0.0	16.0	1.91	Showed cracking and
SW 13-22N-9E					1,900	Tan	0.0	15.0	1.96	efflorescence.
IP 5 (Tallant-					2,000	Tan	2.0	14.0	2.00	
middle Vamoosa					2,100	Light brown	2.0	10.0	2.11	
shales)					2,200	Brown	5.0	7.0	2.22	
					2,300	Dark brown	5.0	5.0	2.25	
1431	7.7	Gray-	18-22	3.0	1,800	Light tan	0.0	18.0	1.93	Showed considerable
SE 14-22N-9E		tan			1,900	Tan	0.0	17.0	1.94	cracking.
IP 5 (Tallant-					2,000	Light brown	3.0	13.0	2.07	
middle Vamoosa					2,100	Brown	3.0	9.0	2.21	
shales)					2,200	Dark brown	3.0	7.0	2.24	
					2,300	Dark brown	3.0	7.0	2.19	
1432	7.8	Maroon	19-29	6.0	1,800	Tan	0.0	17.0	1.70	
SE 9-22N-9E					1,900	Dark tan	4.0	15.0	1.84	
IP 5 (Tallant-					2,000	Light brown	4.0	12.0	2.09	
middle Vamoosa					2,100	Brown	4.0	10.0	2.17	
shales)					2,200	Dark brown	4.0	7.0	2.22	
					2,300	Dark brown	4.0	6.0	2.20	Began to melt.
1435	8.0	Maroon	18-24	2.0	1,800	Light tan	7.0	19.0	1.82	
NW 26-21N-9E					1,900	Tan	7.0	18.0	1.84	
IP 5 (Tallant-					2,000	Tan	7.0	17.0	1.88	
middle Vamoosa					2,100	Brown	7.0	13.0	1.97	
shales)					2,200	Brown	7.0	13.0	2.00	
					2,300	Dark brown	7.0	9.0	2.13	
1449	7.5	Maroon	25-39	6.0	1,800	Tan	0.0	15.0	1.96	
NE 26-24N-9E					1,900	Tan	4.0	14.0	1.95	
IP 5 (Tallant-					2,000	Tan	4.0	13.0	1.99	
middle Vamoosa					2,100	Brown	7.0	3.0	2.31	
shales)					2,200	Brown	11.0	2.0	2.36	
					2,300	Dark brown	7.0	2.0	2.51	

Table 1.—Physical Properties of Osage County Shales—*Continued*

Sample number, location, and map unit	Unfired characteristics: pH	Unfired characteristics: Color	Unfired characteristics: Water of plasticity %	Unfired characteristics: Drying shrinkage %	Firing temperature °F	Ceramic property tests: Color	Ceramic property tests: Total fired shrinkage %	Ceramic property tests: Absorption %	Ceramic property tests: Bulk density gm/cm³	Remarks
1451 N½ 20-24N-10E IP 5 (Tallant-middle Vamoosa shales)	7.7	Gray-tan	21-34	6.0	1,800	Tan	4.0	18.0	1.86	
					1,900	Tan	4.0	14.0	1.99	
					2,000	Tan	4.0	13.0	1.99	
					2,100	Brown	7.0	6.0	2.30	
					2,200	Brown	7.0	4.0	2.36	
					2,300	Dark brown	4.0	3.0	2.35	Began to melt.
1453 NW 16-24N-10E IP 5 (Tallant-middle Vamoosa shales)	7.2	Gray	25-31	6.0	1,800	Light tan	7.0	10.0	2.00	
					1,900	Tan	7.0	8.0	2.09	
					2,000	Dark tan	7.0	5.0	2.17	
					2,100	Brown	11.0	1.0	2.36	
					2,200	Dark brown	11.0	----	----	Bricks began to get soft at 2,200°.
					2,300	Dark brown	11.0	----	----	
1455 SW 10-24N-10E IP 5 (Tallant-middle Vamoosa shales)	7.9	Tan	23-33	6.0	1,800	Light brown	0.0	15.0	1.94	Showed some gas bubbles at two highest temperatures.
					1,900	Light brown	0.0	14.0	1.94	
					2,000	Red brown	4.0	11.0	2.18	
					2,100	Medium brown	7.0	10.0	2.38	
					2,200	Medium brown	7.0	7.0	2.23	
					2,300	Gray-brown	7.0	6.0	2.02	
1456 SW 12-24N-10E IP 5 (Tallant-middle Vamoosa shales)	7.2	Tan	24-33	6.0	1,800	Light brown	0.0	17.0	----	Showed some white efflorescence through 2,100°.
					1,900	Light brown	0.0	17.0	1.87	
					2,000	Medium brown	4.0	12.0	2.11	
					2,100	Medium brown	4.0	8.0	2.18	
					2,200	Gray-brown	7.0	4.0	2.31	
					2,300	Gray-brown	7.0	3.0	2.21	
1457 NW 18-24N-11E IP 5 (Tallant-middle Vamoosa shales)	7.0	Tan	22-28	6.0	1,800	Light brown	0.0	16.0	1.88	
					1,900	Light brown	0.0	13.0	1.99	
					2,000	Light brown	0.0	10.0	2.09	
					2,100	Medium brown	7.0	6.0	2.25	
					2,200	Gray-brown	7.0	3.0	2.31	
					2,300	Gray-brown	7.0	3.0	2.31	
1466 11-23N-10E IP 5 (Tallant-middle Vamoosa shales)	8.1	Maroon	17-21	3.0	1,800	Light brown	0.0	16.0	1.90	Showed considerable cracking.
					1,900	Light brown	0.0	15.0	1.94	
					2,000	Light brown	3.0	13.0	2.06	
					2,100	Medium brown	3.0	10.0	2.15	
					2,200	Medium brown	7.0	8.0	2.25	
					2,300	Medium brown	7.0	6.0	2.33	
1467 N½ 25-23N-9E IP 5 (Tallant-middle Vamoosa shales)	8.0	Maroon	21-35	6.0	1,800	Medium brown	0.0	17.0	1.88	
					1,900	Medium brown	0.0	16.0	1.93	
					2,000	Medium brown	0.0	13.0	2.04	
					2,100	Medium brown	4.0	9.0	2.18	
					2,200	Gray-brown	7.0	4.0	2.42	
					2,300	Gray-brown	7.0	2.0	2.47	

1468	8.2	Maroon	22-35	6.0	1,800	Light brown	4.0	14.0	1.96	
SW 32-23N-9E					1,900	Light brown	4.0	12.0	2.01	
IP 5 (Tallant-					2,000	Light brown	7.0	10.0	2.05	
middle Vamoosa					2,100	Medium brown	7.0	5.0	2.30	
shales)					2,200	Medium brown	7.0	3.0	2.35	
					2,300	Gray-brown	11.0	1.0	2.44	
1469	8.2	Gray-tan	23-37	13.0	1,800	Light brown	----	----	----	Brick crumbled.
E½ 36-23N-9E					1,900	Light brown	----	----	----	Brick crumbled.
IP 5 (Tallant-					2,000	Light brown	3.0	13.0	1.98	
middle Vamoosa					2,100	Medium brown	----	----	----	Broken brick.
shales)					2,200	Medium brown	3.0	5.0	2.27	
					2,300	Dusky red	0.0	5.0	2.09	Brick became soft.
1494	8.0	Gray	19-27	3.0	1,800	Light brown	0.0	16.0	1.87	
SE 29-25N-11E					1,900	Light brown	0.0	16.0	1.88	
IP 5 (Tallant-					2,000	Light brown	0.0	14.0	1.95	
middle Vamoosa					2,100	Medium brown	0.0	14.0	1.92	
shales)					2,200	Red-brown	0.0	12.0	2.08	
					2,300	Dusky red	3.0	6.0	2.33	
1496	7.6	Gray	21-34	0.0	1,800	Light brown	0.0	16.0	1.88	
SW 32-25N-10E					1,900	Light brown	0.0	16.0	1.88	
IP 5 (Tallant-					2,000	Light brown	0.0	14.0	1.96	
middle Vamoosa					2,100	Medium brown	3.0	3.0	2.32	
shales)					2,200	Medium brown	3.0	3.0	2.32	
					2,300	Dusky brown	3.0	3.0	2.36	
1497	7.6	Tan	19-28	3.0	1,800	Light brown	0.0	15.0	1.97	
NW 25-26N-10E					1,900	Light brown	0.0	13.0	2.01	
IP 5 (Tallant-					2,000	Light brown	0.0	13.0	2.02	
middle Vamoosa					2,100	Medium brown	0.0	11.0	2.08	
shales)					2,200	Gray-brown	3.0	7.0	2.23	
					2,300	Red-brown	3.0	6.0	2.26	
1499	7.9	Beige	27-39	3.0	1,800	Light brown	0.0	21.0	1.66	Pleasant colors.
9-25N-11E					1,900	Light brown	0.0	20.0	1.73	
IP 5 (Tallant-					2,000	Light brown	3.0	18.0	1.76	
middle Vamoosa					2,100	Light brown	3.0	18.0	1.76	
shales)					2,200	Medium brown	3.0	14.0	1.85	
					2,300	Medium brown	3.0	14.0	1.91	
1503	8.2	Tan	20-30	6.0	1,800	Light brown	0.0	16.0	1.79	
30-27N-12E					1,900	Light brown	0.0	13.0	1.86	
IP 5 (Tallant-					2,000	Light brown	4.0	10.0	2.17	
middle Vamoosa					2,100	Medium brown	4.0	5.0	2.33	
shales)					2,200	Gray-brown	4.0	3.0	2.39	
					2,300	Gray-brown	10.0	3.0	2.48	
1507	7.3	Tan	21-27	3.0	1,800	Light brown	3.0	14.0	1.96	
E½ 14-27N-10E					1,900	Light brown	3.0	14.0	1.93	
IP 5 (Tallant-					2,000	Light brown	3.0	11.0	2.01	
middle Vamoosa					2,100	Light brown	3.0	13.0	1.96	
shales)					2,200	Gray-brown	7.0	8.0	2.13	
					2,300	Gray-brown	3.0	7.0	2.13	

Table 1.—Physical Properties of Osage County Shales—*Continued*

Sample number, location, and map unit	Unfired characteristics: pH	Color	Water of plasticity %	Drying shrinkage %	Firing temperature °F	Ceramic property tests: Color	Total fired shrinkage %	Absorption %	Bulk density gm/cm^3	Remarks
1508 SW 25-28N-10E IP 5 (Tallant-middle Vamoosa shales)	7.4	Tan	21-28	3.0	1,800	Light brown	3.0	17.0	1.87	
					1,900	Light brown	3.0	14.0	1.97	
					2,000	Light brown	3.0	14.0	1.97	
					2,100	Medium brown	7.0	8.0	2.16	
					2,200	Gray-brown	7.0	6.0	2.21	
					2,300	Dusky brown	7.0	4.0	2.29	
1510 S½ 14-28N-11E IP 5 (Tallant-middle Vamoosa shales)	7.0	Tan	26-36	6.0	1,800	Light brown	0.0	18.0	1.83	
					1,900	Light brown	0.0	18.0	1.84	
					2,000	Light brown	0.0	15.0	1.92	
					2,100	Medium brown	7.0	6.0	2.19	
					2,200	Gray-brown	7.0	4.0	2.27	Developed glaze at 2,300°.
					2,300	Red-brown	7.0	3.0	2.29	
1511 NW 19-28N-12E IP 5 (Tallant-middle Vamoosa shales)	7.1	Light gray	20-31	3.0	1,800	Light brown	0.0	16.0	1.92	
					1,900	Light brown	0.0	16.0	1.92	
					2,000	Light brown	0.0	16.0	1.92	
					2,100	Light brown	3.0	10.0	2.18	
					2,200	Gray-brown	10.0	4.0	2.37	
					2,300	Dusky brown	----	----	----	Broken brick.
1513 S½ 20-28N-12E IP 5 (Tallant-middle Vamoosa shales)	8.7	Gray-tan	18-23	0.0	1,800	Light brown	0.0	20.0	1.65	Showed burning and melting at 2,200°-2,300°.
					1,900	Light brown	0.0	20.0	1.83	
					2,000	Light brown	0.0	20.0	1.80	
					2,100	Light brown	0.0	20.0	1.85	
					2,200	Medium brown	0.0	8.0	2.00	
					2,300	Dusky brown	0.0	11.0	2.08	
1514 7-28N-11E IP 5 (Tallant-middle Vamoosa shales)	8.1	Gray-tan	20-29	6.0	1,800	Light brown	0.0	18.0	1.80	Showed considerable cracking.
					1,900	Light brown	0.0	18.0	1.81	
					2,000	Medium brown	0.0	15.0	1.89	
					2,100	Medium brown	0.0	10.0	1.90	
					2,200	Gray-brown	4.0	6.0	2.02	
					2,300	Red-brown	4.0	6.0	2.07	
1515 N½ 33-29N-10E IP 5 (Tallant-middle Vamoosa shales)	8.6	Gray	20-24	3.0	1,800	Red-orange	3.0	13.0	2.00	Showed considerable cracking.
					1,900	Red-orange	3.0	12.0	2.01	
					2,000	Red-brown	3.0	11.0	2.01	
					2,100	Red-brown	3.0	11.0	2.02	
					2,200	Dark red-brown	3.0	6.0	2.02	
					2,300	Medium brown	3.0	6.0	2.03	
1519 N½ 7-28N-10E IP 5 (Tallant-middle Vamoosa shales)	7.8	Maroon	20-29	6.0	1,800	Light brown	0.0	15.0	1.91	Showed some cracking.
					1,900	Light brown	0.0	13.0	1.97	
					2,000	Light brown	0.0	10.0	2.12	
					2,100	Medium brown	3.0	6.0	2.25	
					2,200	Gray-brown	3.0	4.0	2.30	
					2,300	Gray-brown	3.0	4.0	2.32	

1521 NW 28-28N-10E IP 5 (Tallant-middle Vamoosa shales)	8.4	Tan	20-??	6.0	1,800	Orange-brown	4.0	12.0	2.00	Showed some cracking.
					1,900	Orange-brown	4.0	12.0	2.06	
					2,000	Red-brown	4.0	10.0	2.14	
					2,100	Medium brown	4.0	9.0	2.14	
					2,200	Gray-brown	7.0	5.0	2.32	
					2,300	Gray-brown	7.0	5.0	2.34	
[2]OGS-2 34-22N-8E IP 6 (Kanwaka Shale)	8.4	---	19.0	4.0	1,900	Orange-tan	5.0	7.8	2.15	$CaCO_3$ slightly positive. Slight warping at 2,000°.
					2,000	Light brown	8.0	3.2	2.35	
					2,100	Brown	9.0	0.7	2.45	
					2,200	Brown	8.0	0.0	2.37	
[2]OGS-4 NE 5-25N-9E IP 6 (Kanwaka Shale)	7.9	---	21.0	5.7	1,900	Orange-tan	2.1	11.0	1.95	Scumming 1,900° through 2,100°. $CaCO_3$ slightly positive.
					2,000	Light brown	5.3	4.2	2.20	
					2,100	Medium brown	7.6	0.7	2.39	
					2,200	Red-brown	7.5	0.0	2.42	
1347 2-22N-8E IP 6 (Kanwaka Shale)	7.8	Tan	18-26	6.0	1,800	Light brown	0.0	17.0	1.84	Began showing glaze at 2,200°.
					1,900	Light brown	0.0	12.0	2.04	
					2,000	Light brown	4.0	11.0	2.07	
					2,100	Brown	7.0	7.0	2.20	
					2,200	Dark brown	7.0	6.0	2.25	
					2,300	Dark brown	11.0	3.0	2.29	
1351 3-22N-8E IP 6 (Kanwaka Shale)	9.0	Maroon	27-33	6.0	1,800	----------	----	----	----	All bricks crumbled.
					1,900	----------	----	----	----	
					2,000	----------	----	----	----	
					2,100	----------	----	----	----	
					2,200	----------	----	----	----	
					2,300	----------	----	----	----	
1359 1-21N-7E IP 6 (Kanwaka Shale)	7.6	Tan	21-27	6.0	1,800	Light brown	11.0	17.0	1.86	Fired shrinkage too high for most structural clay products. Color good; addition of nonplastic grog might help shrinkage.
					1,900	Light brown	11.0	13.0	1.99	
					2,000	Light brown	11.0	11.0	2.04	
					2,100	Medium brown	14.0	7.0	2.18	
					2,200	Dark brown	14.0	4.0	2.28	
					2,300	Dark brown	14.0	4.0	2.35	
1404 E½ 5-25N-9E IP 6 (Kanwaka Shale)	7.2	Gray	21-27	3.0	1,800	Light brown	0.0	17.0	1.87	Began to glaze at 2,200°.
					1,900	Light brown	0.0	16.0	1.88	
					2,000	Light brown	0.0	7.0	2.14	
					2,100	Medium brown	3.0	7.0	2.24	
					2,200	Dark brown	7.0	5.0	2.25	
					2,300	Dark brown	3.0	5.0	2.25	
1408 NE 30-26N-9E IP 6 (Kanwaka Shale)	8.0	Tan	20-30	2.0	1,800	Light brown	0.0	17.0	1.85	Showed some cracking at higher temperatures.
					1,900	Light brown	2.0	15.0	1.88	
					2,000	Light brown	2.0	13.0	1.89	
					2,100	Medium brown	2.0	8.0	2.23	
					2,200	Dark brown	2.0	7.0	2.25	
					2,300	Dark brown	3.0	6.0	2.26	
1516 SW 19-29N-10E IP 6 (Kanwaka Shale)	8.3	Tan	19-25	3.0	1,800	Light brown	0.0	17.0	1.85	Began to show burning and cracking at 2,200°.
					1,900	Light brown	0.0	17.0	1.85	
					2,000	Light brown	0.0	17.0	1.87	
					2,100	Medium brown	0.0	15.0	1.95	
					2,200	Medium brown	3.0	8.0	2.19	
					2,300	Dark brown	3.0	8.0	2.18	

Table 1.—Physical Properties of Osage County Shales—*Continued*

Sample number, location, and map unit	Unfired characteristics: pH	Color	Water of plasticity %	Drying shrinkage %	Firing temperature °F	Ceramic property tests: Color	Total fired shrinkage %	Absorption %	Bulk density gm/cm^3	Remarks
1354 3-22N-8E IP 7 (Pawhuska shales)	8.0	Tan	25-29	13.0	1,800	Light brown	0.0	14.0	1.91	High drying shrinkage.
					1,900	Light brown	0.0	14.0	1.99	
					2,000	Medium brown	0.0	9.0	1.99	
					2,100	Medium brown	3.0	8.0	1.99	
					2,200	Gray-brown	7.0	7.0	2.10	
					2,300	Dusky brown	11.0	7.0	1.96	
1355 SE 24-22N-7E IP 7 (Pawhuska shales)	9.2	Maroon	22-28	6.0	1,800	-----------	---	----	----	All the bricks cracked and crumbled.
					1,900	-----------	---	----	----	
					2,000	-----------	---	----	----	
					2,100	-----------	---	----	----	
					2,200	-----------	---	----	----	
					2,300	-----------	---	----	----	
1362 26-23N-7E IP 7 (Pawhuska shales)	7.3	Tan	22-27	6.0	1,800	Light brown	7.0	18.0	1.90	High firing shrinkage; nonplastic grog might help this.
					1,900	Light brown	7.0	12.0	1.92	
					2,000	Medium brown	11.0	7.0	1.98	
					2,100	Medium brown	11.0	3.0	2.27	
					2,200	Gray-brown	11.0	3.0	2.30	
					2,300	Dusky brown	11.0	7.0	2.41	
1364 27-23N-7E IP 8 (Severy Shale)	8.9	Tan	23-27	13.0	1,800	Red-orange	0.0	54.0	1.30	High dry shrinkage and very high absorption.
					1,900	Light brown	0.0	50.0	1.40	
					2,000	Medium brown	0.0	58.0	1.27	
					2,100	Gray-brown	4.0	38.0	1.67	
					2,200	Gray-brown	4.0	38.0	1.44	
					2,300	Dusky brown	---	----	----	Melted.
1409 SE 10-26N-8E IP 8 (Severy Shale)	7.8	Tan	25-36	3.0	1,800	Light brown	3.0	16.0	1.94	Showed some cracking and white inclusions.
					1,900	Light brown	3.0	11.0	2.11	
					2,000	Medium brown	3.0	6.0	2.22	
					2,100	Medium brown	7.0	4.0	2.22	
					2,200	Medium brown	7.0	4.0	2.39	
					2,300	Medium brown	7.0	4.0	2.51	
1411 N½ 17-26N-8E IP 8 (Severy Shale)	7.6	Tan	21-30	0.0	1,800	Light brown	3.0	19.0	1.52	
					1,900	Light brown	3.0	19.0	1.50	
					2,000	Light brown	3.0	17.0	1.57	
					2,100	Medium brown	3.0	13.0	2.01	
					2,200	Dusky brown	3.0	5.0	2.16	
					2,300	Dusky brown	6.0	4.0	2.11	
1381 NE 4-24N-7E IP 9 (Bird Creek-Auburn shales)	8.6	Gray-tan	25-31	3.0	1,800	-----------	---	----	----	All the fired bricks crumbled.
					1,900	-----------	---	----	----	
					2,000	-----------	---	----	----	
					2,100	-----------	---	----	----	
					2,200	-----------	---	----	----	
					2,300	-----------	---	----	----	

1401	9.4	Tan	29-39	3.0	1,800	Red-orange	3.0	15.0	1.75	
11-24N-7E					1,900	Red-orange	7.0	15.0	1.94	
IP 9 (Bird Creek-					2,000	Red-brown	10.0	6.0	2.28	
Auburn shales)					2,100	Medium brown	10.0	4.0	2.33	
					2,200	Gray-red	10.0	6.0	2.46	
					2,300	Gray-brown	----	----	----	Began to get soft.
1402	7.0	Tan	24-35	3.0	1,800	Light brown	3.0	17.0	1.83	Showed some cracking.
NE 12-25N-7E					1,900	Light brown	----	----	----	
IP 9 (Bird Creek-					2,000	Red-brown	3.0	11.0	2.05	
Auburn shales)					2,100	Medium brown	7.0	6.0	2.24	
					2,200	Gray-brown	7.0	4.0	2.27	
					2,300	Gray-brown	7.0	4.0	2.22	
1377	8.2	Tan	20-28	3.0	1,800	Light brown	0.0	18.0	1.81	
SW 13-24N-6E					1,900	Light brown	3.0	16.0	1.88	
IP 10 (Reading-					2,000	Medium brown	7.0	12.0	1.98	
Brownville					2,100	Medium brown	7.0	11.0	2.02	
shales)					2,200	Medium brown	7.0	7.0	2.09	
					2,300	Gray-brown	10.0	6.0	2.11	
1378	5.6	Gray-tan	18-21	3.0	1,800	Orange-pink	3.0	30.0	1.74	
N½ 16-24N-7E					1,900	Orange-pink	7.0	25.0	1.92	
IP 10 (Reading-					2,000	Orange-pink	7.0	23.0	2.08	
Brownville					2,100	Light brown	7.0	20.0	2.28	
shales)					2,200	Medium brown	7.0	13.0	2.35	
					2,300	Medium brown	11.0	13.0	2.48	
1387	8.5	Red-brown	25-34	13.0	1,800	------------	----	----	----	All the bricks crumbled and broke.
SE 24-28N-7E					1,900	------------	----	----	----	
IP 10 (Reading-					2,000	------------	----	----	----	
Brownville					2,100	------------	----	----	----	
shales)					2,200	------------	----	----	----	
					2,300	------------	----	----	----	
1388	8.7	Maroon	25-34	10.0	1,800	Red-brown	0.0	12.0	1.68	
NE 36-28N-7E					1,900	Medium brown	0.0	8.0	1.70	
IP 10 (Reading-					2,000	Medium brown	3.0	4.0	1.70	
Brownville					2,100	Medium brown	3.0	2.0	1.72	
shales)					2,200	------------	7.0	1.5	1.87	
					2,300	Gray-brown	11.0	5.0	2.39	
1395	8.1	Tan	21-29	13.0	1,800	------------	----	----	----	Most of the bricks crumbled on firing; the two that did not contain white inclusions.
NW 8-23N-6E					1,900	------------	----	----	----	
IP 10 (Reading-					2,000	------------	----	----	----	
Brownville					2,100	------------	----	----	----	
shales)					2,200	Medium brown	0.0	8.0	2.08	
					2,300	Medium brown	0.0	3.0	2.30	
1396	7.8	Gray-tan	27-33	6.0	1,800	Light brown	7.0	19.0	1.82	
NW 8-23N-6E					1,900	Light brown	7.0	12.0	2.01	
IP 10 (Reading-					2,000	Medium brown	11.0	7.0	2.30	
Brownville					2,100	Medium brown	11.0	7.0	2.32	
shales)					2,200	Gray-brown	11.0	3.0	2.32	
					2,300	Dusky brown	14.0	1.0	2.67	

Table 1.—Physical Properties of Osage County Shales—*Continued*

Sample number, location, and map unit	Unfired characteristics: pH	Color	Water of plasticity %	Drying shrinkage %	Firing temperature °F	Ceramic property tests: Color	Total fired shrinkage %	Absorption %	Bulk density gm/cm³	Remarks
1397	9.1	Tan	26-32	6.0	1,800	Light brown	7.0	20.0	1.82	
NW 8-23N-6E					1,900	Light brown	7.0	13.0	2.00	
IP 10 (Reading-					2,000	Medium brown	7.0	8.0	2.24	
Brownville					2,100	Medium brown	7.0	8.0	2.24	
shales)					2,200	Medium brown	7.0	7.0	2.26	
					2,300	Gray-brown	11.0	7.0	2.29	
1398	9.2	Maroon	24-30	3.0	1,800	Light brown	3.0	19.0	1.83	
NW 8-23N-6E					1,900	Medium brown	3.0	16.0	1.94	
IP 10 (Reading-					2,000	Medium brown	7.0	9.0	2.17	
Brownville					2,100	Medium brown	11.0	10.0	2.10	
shales)					2,200	Medium brown	11.0	6.0	2.24	
					2,300	Gray-brown	11.0	6.0	2.27	
1399	9.1	Maroon	22-29	6.0	1,800	Medium brown	0.0	11.0	2.11	
E½ 14-23N-6E					1,900	Medium brown	4.0	9.0	2.48	
IP 10 (Reading-					2,000	Medium brown	4.0	8.0	2.25	
Brownville					2,100	Medium brown	7.0	6.0	2.21	
shales)					2,200	Gray-brown	7.0	4.0	2.23	
					2,300	Dusky brown	---	4.0	2.06	Began to melt.
1400	9.1	Maroon	24-30	6.0	1,800	Red-brown	0.0	21.0	1.83	
E½ 17-24N-6E					1,900	Red-brown	0.0	20.0	1.83	
IP 10 (Reading-					2,000	Red-brown	0.0	18.0	1.83	
Brownville					2,100	Red-brown	0.0	17.0	1.86	
shales)					2,200	Medium brown	0.0	15.0	1.88	
					2,300	Gray-brown	---	9.0	1.90	Melted.
1385	9.0	Tan	28-32	13.0	1,800	-----------	----	----	----	All the fired bricks
NW 28-27N-7E					1,900	-----------	----	----	----	crumbled.
IP 11 (Five					2,000	-----------	----	----	----	
Point-Red					2,100	-----------	----	----	----	
Eagle shales)					2,200	-----------	----	----	----	
					2,300	-----------	----	----	----	
1389	9.1	Maroon	29-38	10.0	1,800	-----------	----	----	----	All the fired bricks
S½ 11-26N-6E					1,900	-----------	----	----	----	crumbled.
IP 11 (Five					2,000	-----------	----	----	----	
Point-Red					2,100	-----------	----	----	----	
Eagle shales)					2,200	-----------	----	----	----	
					2,300	-----------	----	----	----	
1390	8.8	Maroon	-----	----	1,800	-----------	----	----	----	Crumbled.
S½ 11-26N-6E					1,900	-----------	----	----	----	Crumbled.
IP 11 (Five					2,000	Red-pink	----	28.0	1.62	
Point-Red					2,100	-----------	----	----	----	Crumbled.
Eagle shales)					2,200	Red-pink	----	23.0	1.72	Began to burn.
					2,300	-----------	----	----	----	Crumbled.

1372 E½ 31-26N-6E IP 12 (Roca-Eskridge shales)	9.2	Gray	20-25	6.0	1,800	-----------	---	----	----	Most of the bricks crumbled, but color is good.
					1,900	Pale orange	4.0	21.0	2.15	
					2,000	-----------	---	----	----	
					2,100	-----------	---	----	----	
					2,200	-----------	---	----	----	Melted.
					2,300	-----------	---	----	----	Melted.
1374 SW 32-26N-6E IP 12 (Roca-Eskridge shales)	9.1	Gray	26-30	3.0	1,800	Gray-pink	0.0	32.0	1.56	Good color, but bricks cracked and crumbled.
					1,900	Pale orange	3.0	32.0	1.55	
					2,000	Pale orange	3.0	33.0	1.52	
					2,100	------------	---	----	----	
					2,200	------------	---	----	----	Melted.
					2,300	------------	---	----	----	Melted.
1526 SW SE 30-27N-6E IP 12 (Roca-Eskridge shales)	9.4	White	39-44	10.0	1,800	Gray-pink	4.0	----	----	Contains white inclusions, but has a very pleasing color.
					1,900	Gray-pink	4.0	----	----	
					2,000	Gray-pink	4.0	----	----	
					2,100	Pale orange	7.0	26.0	1.64	
					2,200	Pale orange	7.0	26.0	1.62	
					2,300	Pale orange	---	----	----	Melted and burned.
1527 SW SE 30-27N-6E IP 12 (Roca-Eskridge shales)	9.5	Pink	32-45	10.0	1,800	Pale red	0.0	31.0	1.55	Pleasing colors.
					1,900	Pale red	4.0	32.0	1.55	
					2,000	Pale red	4.0	30.0	1.62	
					2,100	Gray-pink	4.0	31.0	1.56	
					2,200	Gray-pink	4.0	29.0	1.62	
					2,300	Yellow-gray	19.0	10.0	2.17	Melted and burned.
1528 SW 1-27N-5E IP 12 (Roca-Eskridge shales)	9.5	Pink	27-38	6.0	1,800	Red-brown	4.0	24.0	1.68	Attractive colors.
					1,900	Pale red	4.0	24.0	1.66	
					2,000	Pale red	4.0	25.0	1.66	
					2,100	Pale red	7.0	25.0	1.65	
					2,200	Yellow-brown	7.0	25.0	1.66	
					2,300	Dusky yellow	7.0	----	----	Melted and burned.
1529 SW 1-27N-5E IP 12 (Roca-Eskridge shales)	9.4	Pink	25-31	10.0	1,800	Red-orange	0.0	19.0	1.76	Attractive colors.
					1,900	Pale red	0.0	19.0	1.73	
					2,000	Pale red	0.0	19.0	1.77	
					2,100	Pale red	0.0	19.0	1.77	
					2,200	Dusky yellow	4.0	6.0	2.06	Began to melt.
					2,300	Dusky yellow	4.0	8.0	2.11	Melted and burned.
1522 34-26N-4E IP 13 (Beattie-Herington shales)	9.0	Red	22-31	6.0	1,800	------------	---	----	----	All fired bricks crumbled.
					1,900	------------	---	----	----	
					2,000	------------	---	----	----	
					2,100	------------	---	----	----	
					2,200	------------	---	----	----	
					2,300	------------	---	----	----	
1523 NE 23-26N-4E IP 13 (Beattie-Herington shales)	9.2	Tan	20-32	6.0	1,800	Light brown	0.0	16.0	1.94	
					1,900	Light brown	0.0	11.0	2.08	
					2,000	Medium brown	4.0	8.0	2.19	
					2,100	Medium brown	4.0	7.0	2.26	
					2,200	Gray-brown	7.0	2.0	2.36	
					2,300	Dusky yellow-brown	7.0	2.0	2.39	

Table 1.—Physical Properties of Osage County Shales—*Continued*

Sample number, location, and map unit	Unfired characteristics: pH	Color	Water of plasticity %	Drying shrinkage %	Firing temperature °F	Ceramic property tests: Color	Total fired shrinkage %	Absorption %	Bulk density gm/cm³	Remarks
1524	9.1	Tan	21-29	6.0	1,800	Light brown	0.0	17.0	1.81	
NW NE					1,900	Light brown	0.0	16.0	1.87	
7-26N-5E					2,000	Light brown	4.0	15.0	1.88	
IP 13 (Beattie-					2,100	Medium brown	4.0	14.0	1.90	
Herington					2,200	Medium brown	4.0	14.0	1.92	
shales)					2,300	Gray-brown	7.0	3.0	2.07	
1525	9.2	Brown-orange	19-29	10.0	1,800	Red-orange	---	17.0	1.83	Contains white inclusions.
NE 6-26N-5E					1,900	Red-orange	---	17.0	1.85	
IP 13 (Beattie-					2,000	Red-orange	---	16.0	1.85	
Herington					2,100	Medium brown	---	14.0	1.89	
shales)					2,200	Gray-brown	---	9.0	2.00	
					2,300	Gray-brown	---	9.0	1.95	

[1]Tested by U.S. Bureau of Mines, Tuscaloosa, Alabama.

[2]Tested by Morris Laboratories, Sacramento, California.

Table 2.—Physical Properties of Kanwaka Shale

(Rotary-kiln test)

Sample number	Screen analysis: Size	Wt., %	Cumulative %	Comments	Firing data: Size range	Pour wt. of feed	Bloat T, °F	Logging T	Comments
[1]OGS-4	3/4" - 1/2"	32.17	32.17	Tabular fragments.	-3/4" +8mesh	87.24PCF	2,100-2,300	Nodules stick together.	Quick-fire test reveals good bloating 2,10^°-2,300°F; consi~erable decrepitation also shown at 1,800°F. 50 lb. sample completely disintegrated in kiln at low T (feed end 500°F). Hot zone at 2,260°F maximum.
	1/2" - 3/8"	16.74	48.91	+3/4" material 13.59% of					
	3/8" - 4mesh	23.33	72.24	total crushed shale.					
	4mesh-8mesh	11.84	84.08						
	8mesh	15.92	100.00						

[1]Tested by Illinois Institute of Technology Research Institute, Chicago. Sample locality shown on panel 1, map A.

PART III. CARBONATE-ROCK RESOURCES OF OSAGE COUNTY

T. L. Rowland

Introduction

This report presents results of the investigation of the carbonate rocks of Osage County. Initial field work was undertaken in May and June 1970, and final field investigations were completed in June 1971.

Physical-test data (table 3) for the study were provided by Willard McCasland of the Research and Development Division of the Oklahoma Department of Highways. Crusher-run and tailings-aggregate analyses of the Wildhorse Dolomite were provided by Henry McCabe of Delta Mining Corp., Mill Creek, Oklahoma. Chemical analyses (table 4) were performed by the Shilstone Testing Laboratory of Houston, Texas. The $CaCO_3$ values given in table 4 were calculated from the CaO values, and the $MgCO_3$ values, similarly from the MgO values.

Four carbonate units in the County have economic potential (in descending order): the Red Eagle–Foraker limestones, the Deer Creek–Lecompton limestones, the Wildhorse Dolomite, and the Avant Limestone (panel 1, stratigraphic chart). These units are evaluated in this section with respect to their physical and chemical characteristics and their potential uses. The outcrop patterns of these units, generalized from previous mapping, are shown on panel 1, map B. Locations of sampled and measured sections (OS-1 through OS-6) are also shown on map B; descriptions of these sections are given in the Appendix.

Usage of Terms

Many of the terms used throughout Part III, and especially in the Appendix, may be unfamiliar to some readers. Following is a list of these terms with definitions and descriptions. It is hoped that this will enable the reader to make better use of the information provided in the report.

Carbonate–refers to rocks composed principally of calcium carbonate (limestone–$CaCO_3$), or calcium magnesium carbonate (dolomite–$CaMg(CO_3)_2$), or a mixture of the two (referred to as dolomitic limestone where dolomite is present in the limestone and calcitic dolomite where the dolomite contains limestone). In analyzing the chemical character of these types of rocks, the principal components are reported in terms of the amounts of $CaCO_3$ and $MgCO_3$ present.

Skeletal–pertaining to material derived from organisms and consisting of the hard parts secreted by the organisms or of the hard material around or within organic tissue. Many limestones are composed of skeletal debris.

Algal–refers to photosynthetic, almost exclusively aquatic plants of a large and diverse division (algae) of the thallophytes, including seaweeds and their fresh-water allies. Algal limestone is a rock composed mainly of the remains of calcium-secreting algae or one in which such algae serve to bind together the fragments of other calcium-secreting forms.

Fossil–any remains, trace, or imprint of a plant or animal that has been preserved, by natural processes, in the Earth's crust since some past geologic time.

Brachiopod, pelecypod, pelmatozoan–types of organisms that secreted hard parts of either whole shells or partial shells that are contained in limestone as skeletal or fossil debris.

Micrite–calcium carbonate particles up to 4 microns in diameter.

Mudstone–a carbonate rock with a matrix of micrite. Also called fine-grained limestone by most quarry operators. The stone has a dense appearance.

Wackestone–a carbonate rock containing a matrix of micrite with more than 10-percent grains (particles with diameters greater than 20 microns).

Calcarenite–a limestone consisting predominantly (more than 50 percent) of detrital particles of sand size (0.0625 to 2.00 mm).

Uses and Specifications for Limestone and Dolomite

Uses for limestone and dolomite are much too numerous to list in their entirety, but some of the major ones include manufacture of portland cement, manufacture of lime and hydrated lime, as flux stone, in concrete aggregate, in glass manufacture, in agriculture, in whiting, in roofing aggregate, as road stone or road metal, as railroad ballast, and as dimension stone. To determine the suitability of a limestone or a dolomite for one or more of these purposes, the chemical and physical characteristics of the stone must be examined.

For chemical use, limestones and dolomites must be sufficiently pure to make quicklime and hydrated lime. Limestones containing 99-percent calcium carbonate normally make the best lime and are naturally the most eagerly sought after; such purity is rare, however, so that stone of lesser purity is extensively used. No exact specifications are available, but most of the ASTM standards agree generally with the lime industry that limestones must contain at least 95-percent calcium carbonate for this purpose. Most stones with less than 97-percent total carbonate would be considered marginal at best. This means that the total content of silica (SiO_2), alumina (Al_2O_3), iron oxide (Fe_2O_3), and other impurities must not exceed 3 percent. In firing limestone to make lime, silica and alumina are particularly objectionable, because at the high temperatures of the kiln they combine with the quicklime to make chemically inert compounds that detract from the value of the lime.

In portland-cement manufacture, the magnesium carbonate ($MgCO_3$) content must be less than 3 percent, since there is a maximum of 5-percent MgO in all specifications on finished portland cement (Boynton, 1966, p. 98); the silica content should not be in the form of chert and should be uniformly distributed in the limestone strata. In glass manufacture, the iron oxide content must not exceed 0.06 percent.

Summary Evaluation of Carbonates

Four carbonate units in Osage County are thick enough (i.e., more than 6 feet) to be considered for their economic potential: Avant Limestone, Deer Creek–Lecompton limestones, Red Eagle–Foraker limestones, and Wildhorse Dolomite (see panel 1, stratigraphic chart).

All units examined meet the specifications for road stone, agricultural lime, roofing aggregate, asphalt mix, concrete aggregate, railroad ballast, and any of the other major uses that do not demand a high carbonate content.

From analysis of chemical data, only one limestone is considered to have potential for chemical-grade stone, the Deer Creek–Lecompton at locality OS-5, and it is deemed marginal at best. Possibly its most suitable use in this category would be for the manufacture of portland cement. The Wildhorse Dolomite is considered a chemical-grade dolomite.

Reserves in these four units are considered ample in the vicinity of all localities sampled to supply demand for crushed stone for many years to come. At present, current production in the County and production in Tulsa County to the southeast provide sufficient stone for existing markets.

Sampling and Testing Methods

Physical Testing

The physical properties of the limestones and dolomites were determined from examination of the outcrops, varnished and etched hand specimens, and thin sections. The physical-test data provided additional information on the physical properties.

For physical testing, 30-40 pounds of rock was collected from each measured-section locality. Tests were performed by the Materials Testing Division of the Oklahoma Department of Highways. Data resulting from the tests are included in table 3. These tests consisted of the Los Angeles Abrasion Test, ASTM test no. C 131-55; the Absorption Test; the Bulk-Specific-Gravity Test, including ASTM test nos. C 128-68 for fine aggregate and C 127-68 for coarse aggregate; and the $NaSO_4$ Soundness Test, ASTM test no. C 88-63.

The Los Angeles Abrasion Test is a severe, accelerated test for measuring the abrasive resistance of limestones and dolomites. It involves testing different specified weights and gradations of stone in the Los Angeles machine, which consists of an enclosed hollow steel cylinder into which an abrasive charge of a prescribed number of steel spheres are tumbled together by a rotating mechanism. After the specified number of revolutions the sample is screened to determine the weight loss by abrasion of the stone; from this is calculated the percentage of wear of the stone. The Osage County rocks were tested by the B gradation, which is 2,500 grams passing the ¾-inch screen and retained on the ½-inch screen, and 2,500 grams passing the ½-inch screen and retained on the 3/8-inch screen. The limitations for acceptable-grade stone are 10-percent maximum wear per 100 revolutions and 40-percent maximum wear per 500 revolutions.

The tests for absorption, bulk specific gravity, and soundness are all closely related. In effect, these tests measure the weatherability of a limestone or dolomite. The Absorption Test indicates the amount of moisture a stone may absorb, the Bulk-Specific-Gravity Test gives the density and porosity of the stone, and the Soundness Test indicates the effects of freezing and thawing. A low figure for bulk specific gravity indicates high porosity; it also is a function of the rock type. A high figure for absorption indicates that more water may be absorbed, the maximum limit being about 5 percent. A limit of 10 percent for the Soundness Test is normally the maximum. Thus all these tests give an indication of how the stone will react to the weather. If the stone is porous, and especially if the pores are microscopic in size and absorb abundant water, some solution may occur in the warmer seasons; expansion and contraction from freezing and thawing in the winter generally cause deterioration of aggregate particles.

Sampling for Chemical Analysis

To determine the chemical character of the limestones and dolomites, and thus to evaluate their possibilities for chemical uses, each measured-section locality was sampled for chemical analysis. Six samples of limestone and four of dolomite were analyzed. A composite of chip samples was obtained, whereby approximately 1 cubic-inch sample of rock was chipped from the fresh quarry or outcrop face for each 6 inches of vertical thickness. This method garnered about 5 pounds of rock for each 25-foot interval. As the quarry faces were generally excellent, the samples collected are considered fully representative of the limestones and dolomites sampled. Exceptions to this sampling procedure were the crusher-run and tailings samples of the Wildhorse Dolomite and the shot-face samples of the Avant Limestone, which were random samples of stock-piled crushed stone.

Each composite sample was crushed and carefully mixed in the laboratory, then ground and quartered for chemical analysis. Analyses were

Table 3.—Physical-Test Data for Osage County Limestones and Dolomites

Sample number, location, and unit	Los Angeles Abrasion B gradation: 100 revolutions percent wear 10% max.	Los Angeles Abrasion B gradation: 500 revolutions percent wear 40% max.	Absorption	Bulk specific gravity	Soundness $NaSO_4$
OS-1 SW NE NW 24-22N-11E Avant Limestone	5.12	24.10	2.63	1.48	n.d.
OS-2 NE 19-22N-10E Wildhorse Dolomite	8.00	32.34	2.79	1.06	n.d.
OS-3 SW W½ 17-23N-12E Avant Limestone	8.98	37.66	2.52	2.64	n.d.
OS-4 NW SE 3-22N-8E Deer Creek-Lecompton limestones	5.48	25.92	2.67	1.02	n.d.
OS-5 NE NE 11 NW 12-25N-8E Deer Creek-Lecompton limestones	n.d.	25.80	1.50	2.67	4.6
OS-6 SE 25-26N-5E Red Eagle-Foraker limestones	n.d.	28.67	1.35	2.62	7.4

n.d. = not determined.

made at the Shilstone Testing Laboratory, Houston, Texas. The crusher-run and tailings analyses of the Wildhorse were made in the laboratory of the Sharp Schurtz Co. of Lancaster, Ohio, and supplied to us by Henry McCabe of Delta Mining Corp., Mill Creek, Oklahoma.

Description of Carbonate Resources

Each of the limestone and dolomite units summarized in a previous section is given detailed consideration in this section in terms of its geographic and stratigraphic occurrence, its physical and chemical properties, its production, and its potential uses. The physical-test data are shown in table 3, and the chemical-analysis data are in table 4 and figures 3, 4, 6, 7, 14, and 16.

Avant Limestone

Occurrence.—The Avant Limestone, the topmost member of the Iola Formation, crops out in the southeastern part of Osage County (panel 1, stratigraphic chart and map B). This unit was sampled at two localities, OS-1 and OS-3, both of which are abandoned quarries. The stratigraphic sections, plan views of the quarries, and an outcrop photograph are shown in figures 3-5.

The Avant has a maximum thickness of 42 feet in the abandoned quarry where section OS-3 (fig. 4) was measured and described. Throughout the remaining portion of the area mapped by Gardner (1957) the unit is 25-30 feet thick; this area includes the outcrops in T. 23 N., R. 12 E., and the northern part of T. 22 N., Rs. 11 and 12 E. (panel 1, map B). At locality OS-1 (fig. 3) the Avant is 18½ feet thick; it has an average thickness of about 15 feet south of OS-1 in the southern part of T. 22 N., R. 11 E. (Carl, 1957; panel 1, map B, this report). Farther south the Avant has an average thickness of about 10 feet, and toward the southern edge of the County it contains abundant quartz sand and some thin beds of sandstone and shale. This area includes T. 20 N., Rs. 10 and 11 E.

Physical properties.—The Avant is essentially a fine- to coarse-grained, skeletal, algal limestone. It is mostly massive bedded at locality OS-3, whereas it is thinner bedded at OS-1. The workable thickness at OS-1 is 18½ feet, and at OS-3 about 30 feet underground and 40 feet in open pit.

At locality OS-3 the Avant contains abundant veins of coarse sparry calcite and has a pseudobrecciated appearance as a result of dense mudstone patches surrounded by coarse-grained, skeletal limestone. Beds of shale and coarse-grained, skeletal limestone occur in the top of the unit at this locality.

Silica is present in the form of partially silicified grains and scattered silt-size quartz grains. Pockets and thin stringers of shale and clay are present, and iron oxide and glauconite occur in small quantities.

The Avant Limestone falls within the maximum limitations for the Los Angeles Abrasion Test, as shown in table 3, although it is close for locality OS-3, with 8.98 and 37.66 for 100 and 500 revolutions, respectively. These results indicate that the Avant would be suitable for most of the major stone uses.

The Avant also fares well in the Absorption and Specific-Gravity Tests, as shown in table 3. No Soundness Test was run; however, the weathered aggregate in the quarry stockpiles shows no appreciable deterioration. The bulk specific gravity of the stone is a bit low at locality OS-1 but is still acceptable. These figures correlate well with the Los Angeles test results and also indicate the Avant to be suitable for most stone uses.

Chemical properties.—The Avant was sampled for chemical analysis at localities OS-1 and OS-3. At locality OS-3 a channel sample of an inside face was taken along with a random sample from the stockpiles in front of the six shot faces. Locality OS-1 was sampled from the quarry face. These three analyses are given in table 4 and figures 3 and 4.

The chemical analyses in table 4 show some basic differences in the chemical character of the stone from one locality to the other. Although chemically the rock is essentially all calcium carbonate, with some magnesium carbonate, the overall chemical character is better at locality OS-3 than at OS-1. The insoluble-residue and SiO_2 content is substantially higher at OS-1, whereas the MgO content is somewhat higher at OS-3. The higher Al_2O_3 and SiO_2 content is probably due to the thin shale stringers and scattered quartz sand grains seen at OS-1. A considerable difference between the chemical data from the channel sample and the stockpile sample at OS-3 is due mainly to the greater amount of $MgCO_3$ in the stockpile sample.

The analyses of this stone indicate that it is not of sufficient purity for chemical-grade limestone. The total CaO content is too low, and the impurities, such as MgO, SiO_2, and Al_2O_3, too high.

Production.—No quarries are operating in the Avant Limestone at the present time. However, the Avant was worked at locality OS-3 for railroad

Table 4.—Chemical Analyses of Osage County Limestones and Dolomites

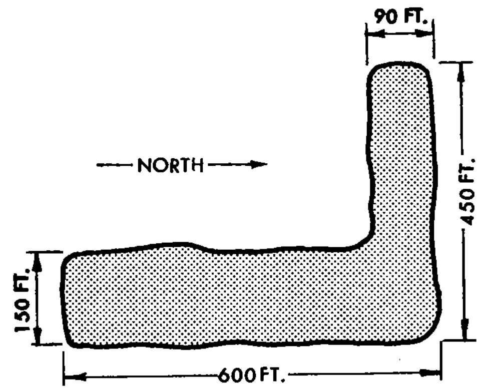
(Values given as percentages)

Sample number, location, and unit	Thickness (feet)	Description	$CaCO_3$ [1]	$MgCO_3$ [2]	CO_2	CaO	MgO	SiO_2	Al_2O_3	Fe_2O_3	FeO	P_2O_5	Na_2O	K_2O	S	H_2O	Insoluble residue
OS-1 SW NE NW 24-22N-11E Avant Limestone	18½	Limestone; quarry face	90.04	2.51	40.78	50.45	1.20	4.49	1.67	0.80	0.72	0.03	0.11	0.18	0.09	0.07	5.87
OS-2 NE 19-22N-10E Wildhorse Dolomite	26	Dolomite; quarry face	53.26	39.05	45.13	29.84	18.67	1.70	1.76	2.73	2.46	0.02	0.11	0.07	0.14	0.09	2.20
		Crusher run	53.29	40.11	n.d.	29.86	19.18	1.25	0.64	3.06	n.d.	n.d.	0.01	0.03	n.d.	n.d.	n.d.
		Tailings	50.83	35.45	n.d.	28.48	16.95	5.49	2.52	3.71	n.d.	n.d.	0.01	0.37	n.d.	n.d.	n.d.
OS-3 SW W½ 17-23N-12E Avant Limestone	40	Limestone; 2A, channel sample, quarry face	93.18	3.68	42.89	52.21	1.76	1.06	0.57	0.63	0.56	0.01	0.09	0.06	0.106	0.036	1.93
		Stock piles of shot faces	86.05	8.85	43.27	48.22	4.23	0.79	1.11	2.79	2.51	0.03	0.09	0.06	0.078	0.057	1.93
OS-4 NW SW 3-22N-8E Dear Creek-Lecompton limestones	18	Limestone; quarry face	90.36	4.33	41.86	50.63	2.07	2.31	1.94	0.80	0.72	0.01	0.09	0.10	0.09	0.13	3.34
OS-5-1 NE NE 11 & 12-25N-8E Deer Creek-Lecompton limestones	4	Dolomite; quarry face	56.01	34.93	44.05	31.38	16.70	2.48	1.25	3.77	3.39	0.02	0.10	0.07	0.37	0.03	3.34
OS-5-2 & 3 NE NE 11 & 12-25N-8E Deer Creek-Lecompton limestones	23	Limestone; quarry face	95.02	2.28	43.00	53.24	1.09	1.66	0.33	0.39	0.35	0.04	0.07	0.05	0.36	0.03	1.90
OS-6 SE 25-26N-5E Red Eagle-Foraker limestones	27	Limestone; quarry face	82.07	5.94	39.04	45.98	2.84	7.30	2.80	0.60	0.54	0.02	0.32	0.22	0.11	0.09	10.24

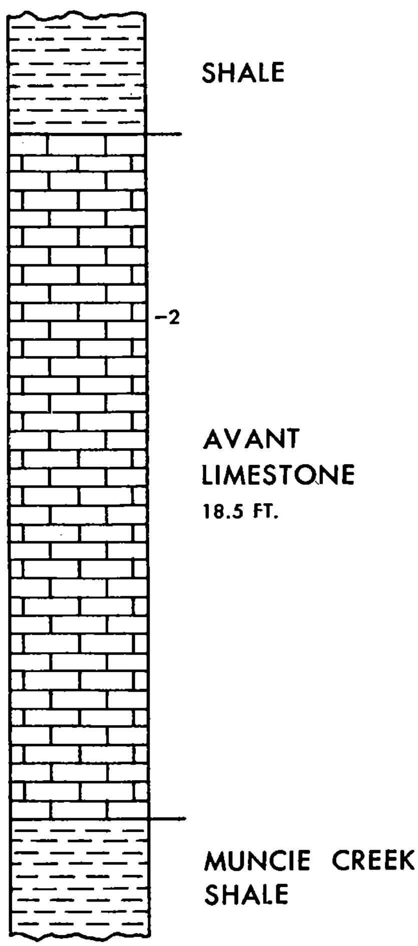
[1] $CaCO_3$ values calculated from CaO.

[2] $MgCO_3$ values calculated from MgO.

n.d. = not determined.



PLAN VIEW OF QUARRY

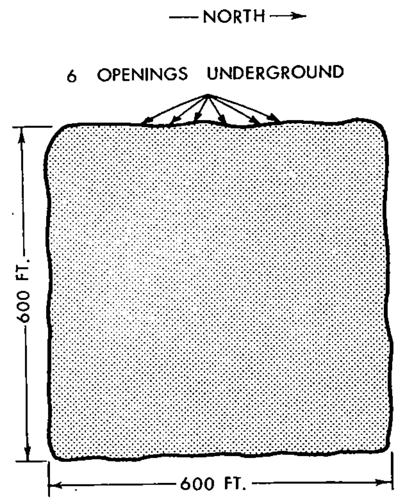


CHEMICAL ANALYSIS OS-1-2

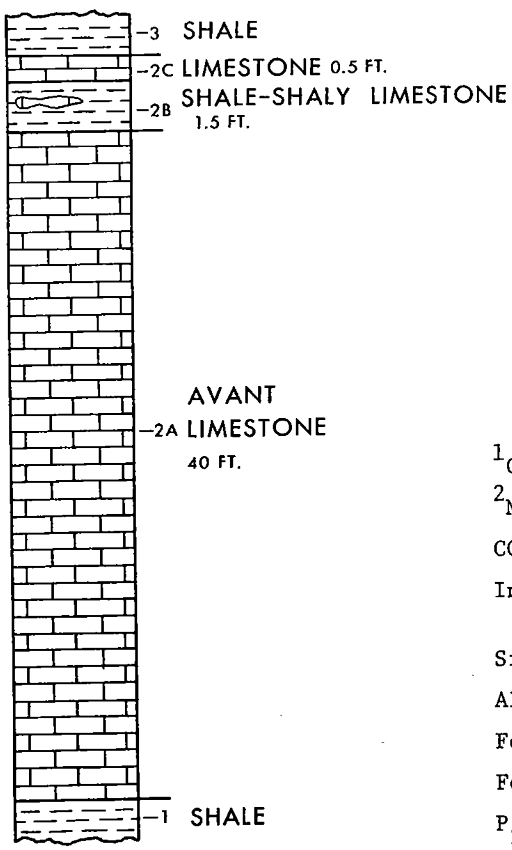
	Composite sample
$^{1}CaCO_3$	90.04%
$^{2}MgCO_3$	2.51%
CO_2	40.78%
Insoluble residue	5.87%
SiO_2	4.49%
Al_2O_3	1.67%
Fe_2O_3	.80%
FeO	.72%
P_2O_5	.03%
Na_2O	.11%
K_2O	.18%
S	.09%
H_2O	.07%

$^{1}CaCO_3$ calculated from CaO.
$^{2}MgCO_3$ calculated from MgO.

Figure 3. Avant Limestone in abandoned quarry, locality OS-1, sec. 24, T. 22 N., R. 11 E.



PLAN VIEW OF OPEN QUARRY



CHEMICAL ANALYSIS OS-3-2a

	Composite sample	Random sample from shot faces
[1] $CaCO_3$	93.18%	86.05%
[2] $MgCO_3$	3.68%	8.85%
CO_2	42.89%	43.27%
Insoluble residue	1.93%	2.96%
SiO_2	1.06%	.79%
Al_2O_3	.57%	1.11%
Fe_2O_3	.63%	2.79%
FeO	.56%	2.51%
P_2O_5	.01%	.03%
Na_2O	.09%	.09%
K_2O	.06%	.06%
S	.106%	.078%
H_2O	.036%	.057%

[1] $CaCO_3$ calculated from CaO.
[2] $MgCO_3$ calculated from MgO.

Figure 4. Avant Limestone in abandoned quarry, locality OS-3, sec. 17, T. 23 N., R. 12 E.

ballast in the 1920's by the Midland Valley Railroad, a total of 1,315,000 tons having been removed at the surface and from underground drifts. Considerably less stone was removed from three smaller abandoned quarries northeast of OS-3; this stone was used for road-base material. At locality OS-1 a total of 175,000 tons of stone was quarried, most of which was used for road stone.

Potential uses.—The Avant Limestone should be suitable for most major stone uses, such as concrete aggregate, road-base material, roofing gravel, and similar industrial applications. Although chemical analyses of samples from two localities indicate that the Avant is not of chemical grade, the possibility remains that chemical-grade stone may occur at some points along the outcrop.

Deer Creek–Lecompton Limestone Unit

Occurrence.—The Deer Creek–Lecompton limestone interval crops out through approximately the central part of Osage County from T. 29 N., R. 9 E., southward and slightly westward to the Arkansas River alluvium in T. 21 N., R. 7 E., as shown on panel 1, map B. The outcrop of this unit covers that area of the County mapped by Carter (1954), Shannon (1954), and Russell (1955), as shown in figure 2.

Previous mapping showed the Deer Creek and Lecompton to be two separate limestones with an intervening sequence of shale and some thin sandstone beds, all members of the Pawhuska Formation. Thin, discontinuous limestones also occur within the total interval, and one is named the Plummer (panel 1, stratigraphic chart). Across the northern outcrop area in that portion of the County mapped by Carter (1954) the total interval is 50-65 feet, with the limestones averaging 20-34 feet. The Deer Creek unit is the thickest of the limestones, at 14-18 feet. In some places the entire sequence consists of limestone, and for this reason the Deer Creek–Lecompton interval has been considered one unit in this report.

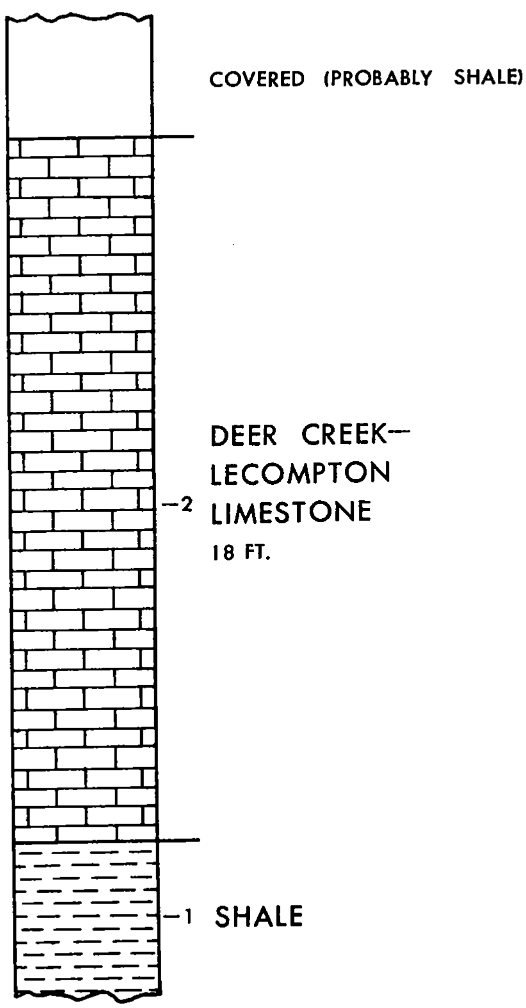
In the area mapped by Shannon (1954), in the central part of the County, the total interval is 20-45 feet, with the limestones 22-42 feet. Again, the Deer Creek is the thicker of the two main limestones, averaging 14 feet.

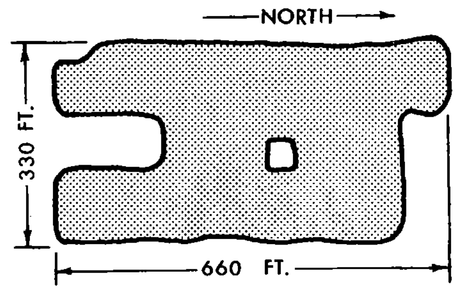
In the southern outcrops, mapped by Russell (1955), the total interval averages 20-30 feet in thickness, with the limestones about 15-20 feet. In this area Russell mapped the Lecompton as the thicker limestone unit. (I feel that Russell's mapping is in error in this area and that he probably mapped the Deer Creek as the Lecompton.)

The Deer Creek–Lecompton interval was sampled at two localities, OS-4 and OS-5 (panel 1, map B). Section OS-4 is in an abandoned quarry west of Hominy, where the thickness of workable

Figure 5. View of abandoned quarry in Avant Limestone, locality OS-1.

limestone is 18 feet (fig. 6). The Sedan Limestone Co. (Blake Stone Co.) quarry is the site of section OS-5 (fig. 7). Here, the stone thickness is 27 feet, the upper 23 feet consisting of limestone and the lower 4 feet dolomite. As this quarry is presently being worked, the quarry dimensions were not measured. The stratigraphic sections and plan views of the quarries are shown in figures 6 and 7. Outcrop photographs of these localities are shown in figures 8-13.





PLAN VIEW OF QUARRY

CHEMICAL ANALYSIS OS-4-2

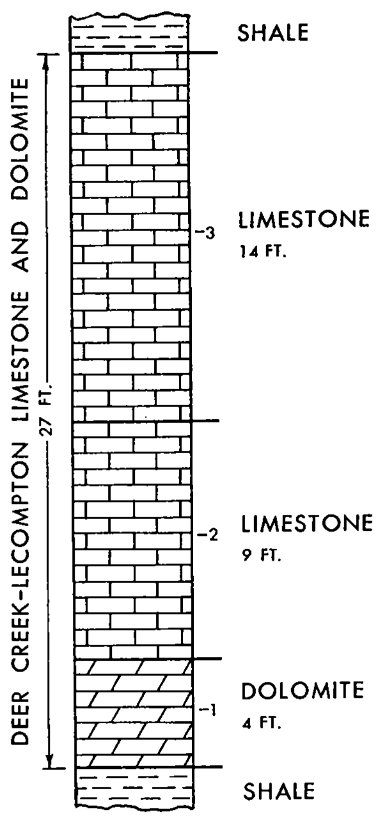
	Composite sample
[1]$CaCO_3$	90.36%
[2]$MgCO_3$	4.33%
CO_2	41.86%
Insoluble residue	3.34%
SiO_2	2.31%
Al_2O_3	1.94%
Fe_2O_3	.80%
FeO	.72%
P_2O_5	.01%
Na_2O	.09%
K_2O	.10%
S	.09%
H_2O	.13%

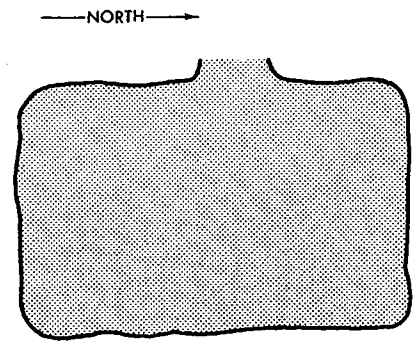
[1]$CaCO_3$ calculated from CaO.
[2]$MgCO_3$ calculated from MgO.

Figure 6. Deer Creek–Lecompton limestone unit in abandoned quarry, locality OS-4, sec. 3, T. 22 N., R. 8 E.

Physical properties.—The Deer Creek–Lecompton is essentially a fine-grained limestone, and the specific limestone type is an algal mudstone. The limestone is medium to thick bedded and at locality OS-4 contains some beds of coarse-grained limestone (fig. 8b). At locality OS-5, unit 1 of the measured section consists of 4 feet of dolomite that is fine to medium grained and massive bedded. The quarried thickness is 18 feet at OS-4 and 27 feet at OS-5 (fig. 11).

A few stringers of clay are present in the basal dolomite beds, and iron oxide is abundant. The



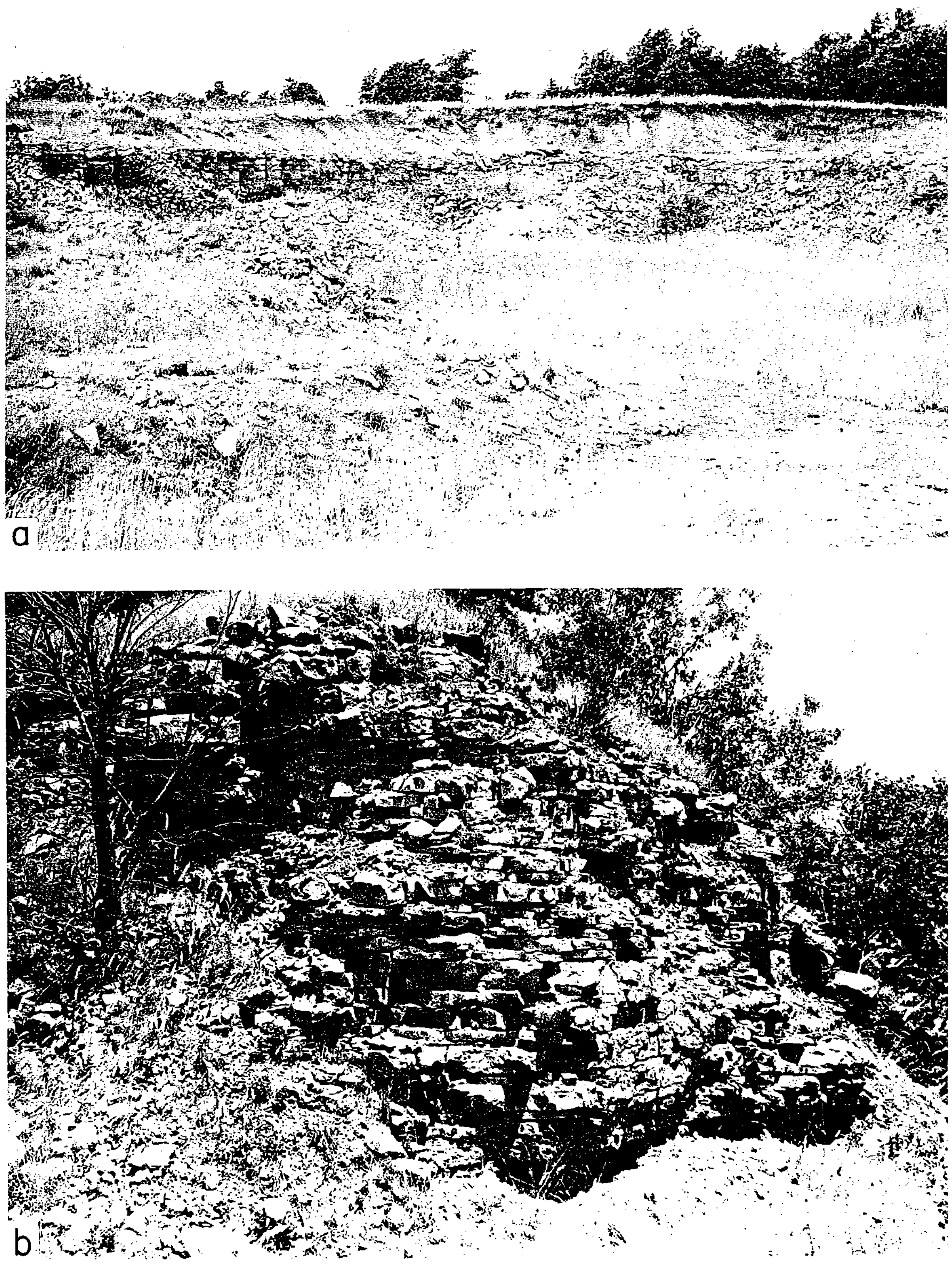


CHEMICAL ANALYSIS OS-5

	OS-5-1	OS-5-2 and 3
[1] $CaCO_3$	56.01%	95.02%
[2] $MgCO_3$	34.13%	2.28%
CO_2	44.05%	43.00%
Insoluble residue	3.34%	1.90%
SiO_2	2.48%	1.66%
Al_2O_3	1.25%	.33%
Fe_2O_3	3.77%	.39%
FeO	3.39%	.35%
P_2O_5	.02%	.04%
Na_2O	.10%	.07%
K_2O	.07%	.05%
S	.37%	.36%
H_2O	.03%	.03%

[1] $CaCO_3$ calculated from CaO.
[2] $MgCO_3$ calculated from MgO.

Figure 7. Deer Creek–Lecompton limestone unit in Sedan Limestone Co. (Blake Stone Co.) quarry, locality OS-5, secs. 11, 12, T. 25 N., R. 8 E.



a

b

Figure 8. a. View of abandoned quarry in Deer Creek–Lecompton limestone unit, locality OS-4.
b. Close-up of Deer Creek–Lecompton limestone unit, showing typical bedding in quarry face at locality OS-4.

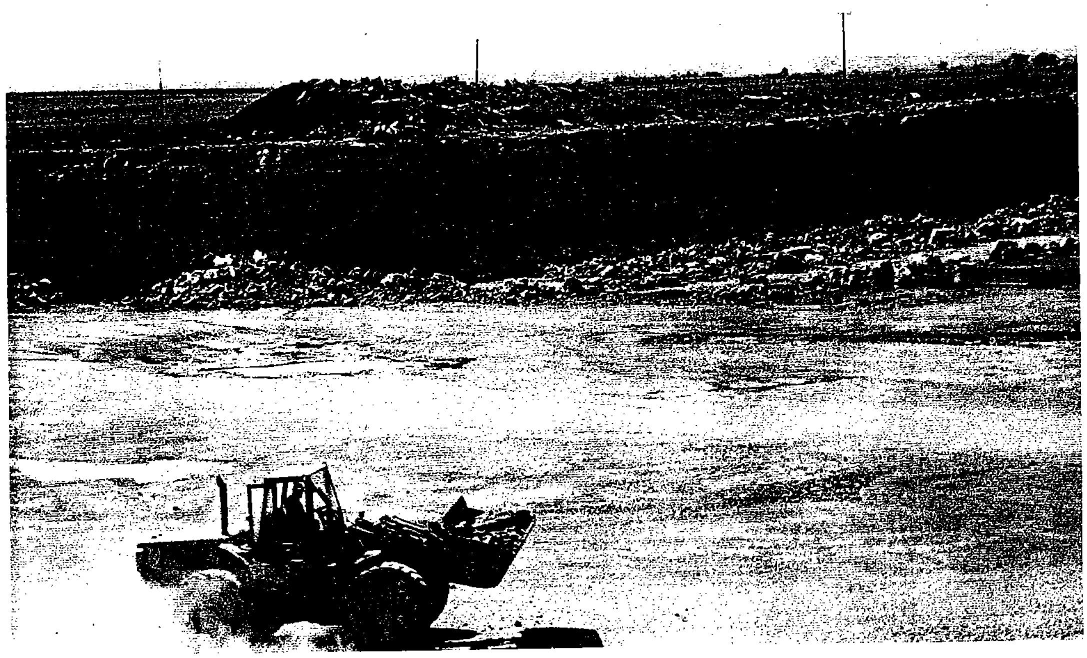


Figure 9. Sedan Limestone Co. (Blake Stone Co.) operating quarry in Deer Creek–Lecompton limestone unit, locality OS-5. View shows working face in June 1972.

Figure 10. Close-up of working face in Sedan Limestone Co. (Blake Stone Co.) quarry in Deer Creek–Lecompton limestone unit, locality OS-5. Front-end loader is shown scooping shot stone for loading purposes.

limestone beds of the Deer Creek–Lecompton contain minor amounts of silica in the form of silt-size quartz grains; there is also partial silicification of grains and some clay and iron oxide.

Results of the physical-test data indicate the Deer Creek–Lecompton to be suitable for the major stone uses, as shown in table 3. All the test results fall well within the maximum specified limits.

Chemical properties.–The Deer Creek–Lecompton was sampled for chemical analysis at two localities, OS-4 and OS-5. A total of three analyses were made, which are given in table 4 and figures 6 and 7.

Although the chemical composition of the rock is calcium carbonate except for unit 1 at section OS-5, where it is primarily calcium magnesium carbonate, the chemical data reveal a substantial difference in chemical composition from one locality to the other. At OS-4 the stone is high in SiO_2, Al_2O_3, and insoluble residues owing to its clay content and scattered quartz grains. It is somewhat low in CaO and somewhat high in MgO. It is not suitable at this locality for chemical-grade limestone.

Units 2 and 3 at locality OS-5 (fig. 7) are marginal for chemical-grade stone. The $CaCO_3$ content is just over 95 percent, about the marginal figure. Thus further investigation of this sequence in the vicinity of OS-5 for chemical-grade stone would be merited. Unit 1 at OS-5 is a dolomite only 4 feet thick, too thin to warrant economic development.

Production.–The Sedan Limestone Co. (Blake Stone Co.) quarry at locality OS-5 is one of the two active quarries in Osage County. In 1974 this quarry produced 186,776 tons from the Deer Creek–Lecompton, which, with the 362,900 tons produced by Standard Industries, Inc., from the Red Eagle Limestone at locality OS-6, amounted to a total value of $1,171,523.

The abandoned Deer Creek–Lecompton quarry at locality OS-4 produced about 150,000 tons, which was used for road stone in the construction of State Highway 20. This quarry was reopened in 1973 by Leco Materials, Inc. A smaller quarry in this unit south of locality OS-5 was not examined in detail; this quarry, shown on panel 1, map B, in T. 25 N., R. 8 E., southwest of section OS-5, was reopened by Tri-State Stone Co. to supply crushed stone for the Kaw Dam. The company was working 22 feet of the Deer Creek–Lecompton at this locality before shutting down in the summer of 1973. Examination of the stone in the quarry face indicated it is the same as at OS-5.

Potential uses.–The Deer Creek–Lecompton is considered suitable for concrete aggregate, road-base material, roofing gravel, and other main uses. In addition, this unit warrants further investigation for chemical-grade limestone, even though chemical analyses indicate it to be marginal. If higher grade deposits are found, their most suitable use

Figure 11. View of abandoned portion of Sedan Limestone Co. (Blake Stone Co.) quarry in Deer Creek–Lecompton limestone unit, locality OS-5.

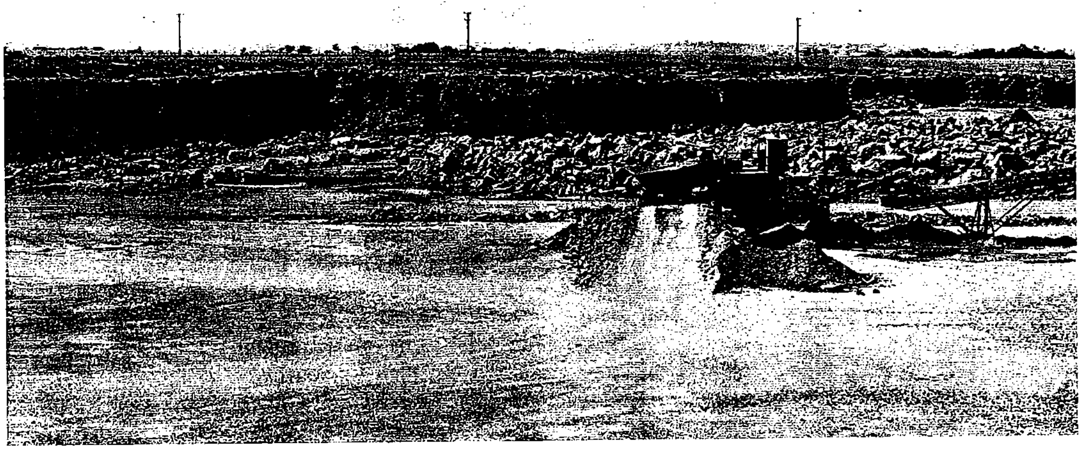


Figure 12. Primary crusher in Sedan Limestone Co. (Blake Stone Co.) quarry, locality OS-5. Working face (Deer Creek–Lecompton) shown in background.

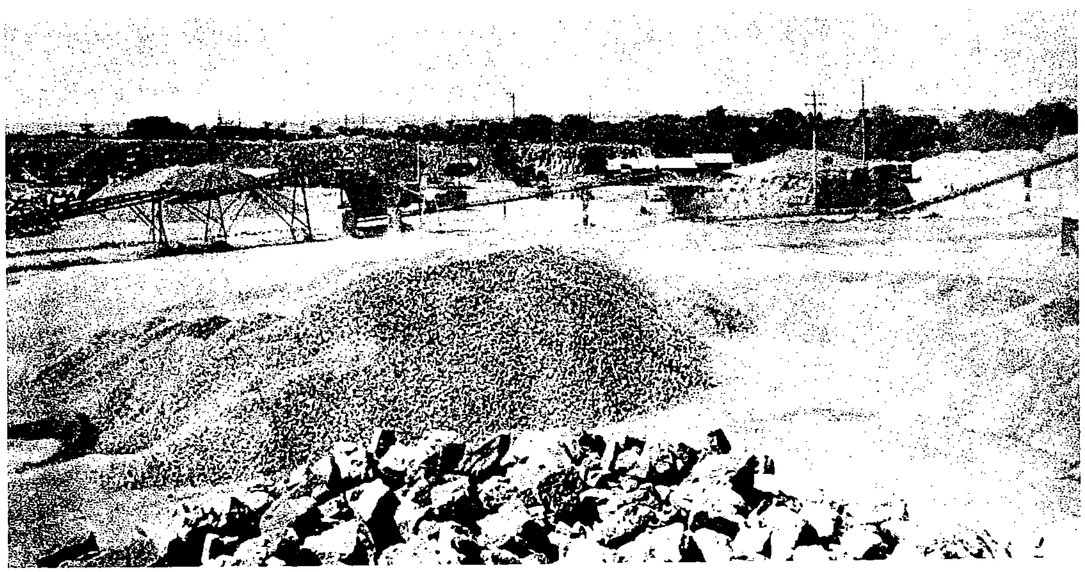


Figure 13. General view of Sedan Limestone Co. (Blake Stone Co.) operation, locality OS-5. Secondary crusher is near center of photograph.

would probably be for the manufacture of portland cement.

Red Eagle–Foraker Limestone Unit

Occurrence.–Rocks of this unit crop out in the western part of Osage County. From T. 29 N., R. 7 E., the outcrop trends southward and southwestward to the Arkansas River alluvium in T. 24 N., R. 4 E. (panel 1, map B). It covers that area of the County mapped by Taylor (1953), Vosburg (1954), Bryant (1957), and Fisher (1956), as shown in figure 2. The Foraker portion of this interval was the subject of a study by Mogharabi

(1966), and the Red Eagle portion the subject of a study by Al-Khersan (1969).

This interval consists of two principal limestones, the Foraker at the base and the Red Eagle at the top, separated by the Johnson Shale (panel 1, stratigraphic chart). In a few places the shale is not present, the whole sequence being limestone; for this reason the entire interval has been treated as a single unit in this report. Over most of the area the interval is 75-100 feet thick, with the Foraker 40-55 feet and the Red Eagle 10-28 feet. In the southern outcrops the interval is much thinner, 40-60 feet; here, the Foraker consists essentially of sandstone up to 40 feet thick, with little limestone, and the Red Eagle contains abundant shale and is only 10 to 15 feet thick.

The Foraker is divided into the Americus Limestone, the Hughes Creek Limestone, and the Long Creek Limestone, in ascending order (panel 1, stratigraphic chart). In most outcrops, even though the Foraker is a thick unit, continuous limestone more than 10-15 feet thick is rarely found; 10 feet or less is the usual thickness. Abundant shale is present in the Foraker together with a few thin sandstone beds, which are interbedded within the unit. Many of the Foraker limestones also are high in chert content.

The Red Eagle, on the other hand, is generally continuous limestone except for a few thin shale beds, and does not contain chert. Therefore, it is the portion of the interval most favorable for workable limestone.

The Red Eagle was sampled at one locality, OS-6, the working quarry of Standard Industries, Inc., northeast of Burbank, which is its thickest known occurrence. The stratigraphic section and plan view of the quarry are shown in figure 14. The thickness of the workable stone is 27 feet. As this quarry is presently being worked, its dimensions were not measured. Figure 15 illustrates the present working quarry at this locality.

Physical properties.—The Red Eagle—Foraker is essentially fine-grained, algal limestone. (The specific limestone type is an algal mudstone similar to the Deer Creek—Lecompton.) The unit is thin to medium bedded, and at locality OS-6 (Standard Industries quarry) it contains abundant thin shale partings; the workable thickness is 27 feet. Some iron oxide is present. Total and partial silicification of fossil grains is plainly evident.

The results of the physical-test data indicate that the Red Eagle—Foraker unit is suitable for many of the major stone uses, as shown in table 3, but the abundance of shale would limit its extensive use for concrete aggregate and some other applications.

Chemical properties.—The Red Eagle portion of this unit was sampled at one locality, OS-6, an active quarry of Standard Industries, Inc. The chemical analysis (table 4, fig. 14) shows a low content of $CaCO_3$ and a high content of SiO_2, Al_2O_3, and insoluble residue. The high SiO_2 content is due to silicification of grains, and the Al_2O_3 content to shale partings. The $MgCO_3$ content is also fairly high. All these factors indicate that the stone is not chemical grade, although further investigations should be made before the Red Eagle is ruled out for this purpose. However, Al-Khersan (1969) showed a high insoluble-residue content for the Red Eagle throughout its outcrop.

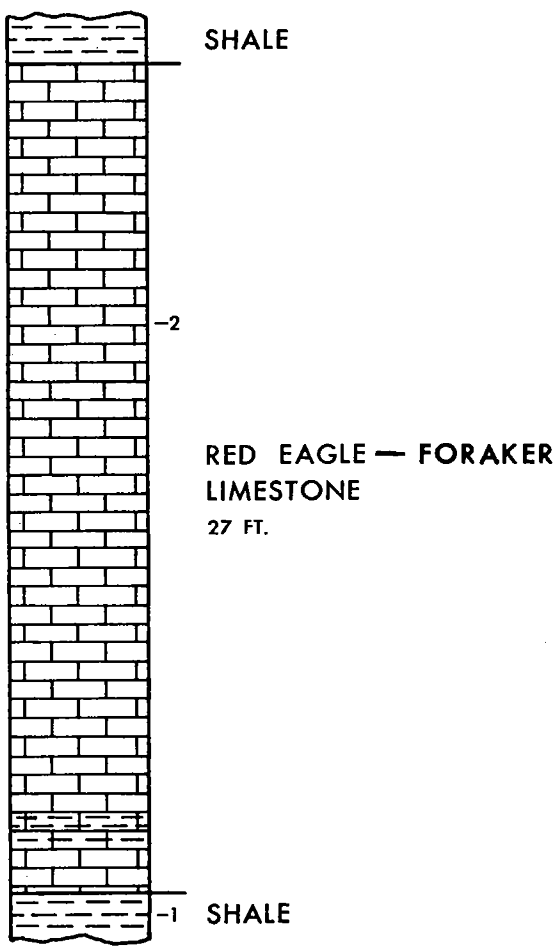
The Foraker portion of this unit contains substantial shale beds and chert, and, according to Mogharabi (1966), its insoluble-residue content is far too high for chemical-grade stone anywhere along its outcrop.

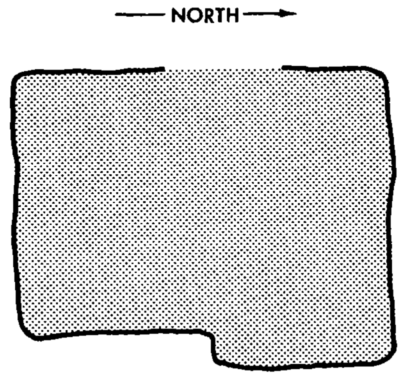
Production.—The quarry of Standard Industries, Inc., is presently working the Red Eagle portion of this unit, having produced 362,900 tons of stone in 1974. This company, together with the Sedan Limestone Co. (Blake Stone Co.), which is working the Deer Creek—Lecompton at locality OS-5, accounted for most of the stone produced in Osage County in 1974: they produced 549,676 tons, valued at $1,171,523. Tri-State Stone Co., in producing aggregate for the Kaw Dam from the Deer Creek—Lecompton, accounted for an unknown amount of tonnage. This operation was completed in the summer of 1973.

Potential uses.—The Red Eagle—Foraker is thought to be suitable for some of the main stone uses, such as road-base and roofing material, but the abundant shale in the unit would probably preclude its use for concrete aggregate and other purposes unless it could be extracted in advance. Even though chemical analysis shows the unit to be unsuitable for chemical-grade stone, the Red Eagle portion, on the basis of one sample, cannot be definitely eliminated from consideration for this purpose throughout its outcrop until further chemical evaluations are made.

Wildhorse Dolomite

Occurrence.—The Wildhorse Dolomite crops out in the southern part of Osage County, in the area between the Deer Creek—Lecompton and the Avant (panel 1, map B). The Wildhorse outcrop is limited to the southern part of T. 23 N., R. 10 E., the western part of T. 22 N., R. 10 E., and the northwestern part of T. 21 N., R. 10 E., the area





PLAN VIEW OF QUARRY

DIMENSIONS NOT KNOWN

STANDARD INDUSTRIES

CHEMICAL ANALYSIS OS-6

	Composite sample
[1]$CaCO_3$	82.07%
[2]$MgCO_3$	5.94%
CO_2	39.04%
Insoluble residue	10.24%
SiO_2	7.30%
Al_2O_3	2.80%
Fe_2O_3	.60%
FeO	.54%
P_2O_5	.02%
Na_2O	.32%
K_2O	.22%
S	.11%
H_2O	.09%

[1]$CaCO_3$ calculated from CaO.
[2]$MgCO_3$ calculated from MgO.

Figure 14. Red Eagle—Foraker limestone unit in Standard Industries, Inc., quarry, locality OS-6, sec. 25, T. 26 N., R. 5 E.

of the County mapped by Gardner (1957) and Carl (1957), as shown in figure 2. This unit is unique in being the only thick dolomite in this area of the State.

The Wildhorse is 0.1 foot thick at the south line of the SW¼ sec. 22, T. 23 N., R. 10 E., and thickens southward to approximately 20 feet in the SW¼ sec. 6, T. 22 N., R. 10 E. It retains a thickness of about 20 feet over most of T. 22 N., R. 10 E., but begins to thin in the southern part of T. 22 N. It is only 1 foot thick in the NW¼ sec. 18, T. 21 N., R. 10 E., and finally grades into calcareous shale of the Barnsdall Formation (see panel 1, stratigraphic chart). It also grades into calcareous shale of the Barnsdall in its northernmost outcrops.

The Wildhorse was sampled at one locality, OS-2, an abandoned quarry (panel 1, map B). This is the thickest occurrence of the dolomite, which averages 26 feet of workable stone in the west quarry face. The stratigraphic section and plan view of the quarry are shown in figure 16, and views of the quarry are given in figures 17 and 18.

Physical properties.—The Wildhorse is a fine- to medium-grained dolomite with abundant veins and vugs filled with calcite and dolomite. It is mostly thin to medium bedded with some thick beds. Abundant thin reddish stringers of iron oxide are present along with a few grains of pyrite, an iron sulfide mineral. Also, clay is present in minor amounts, and some partial silicification of grains has occurred. The quarried thickness of the unit is 26 feet. A few inches of limestone constitutes the very base of the Wildhorse unit.

The physical-test data, as shown in table 3, indicate that the Wildhorse is suitable for most of the major stone uses. Because of its porosity it could possibly be an attractive stone for landscape architects and gardeners.

Chemical properties.—This unit was sampled at one locality, OS-2, an abandoned quarry. Three chemical analyses are given in table 4 and figure 16. One is from a composite chip sample of the quarry face, and the others were supplied by Delta Mining Co. from crusher-run and tailings stockpiles.

All three chemical analyses are about the same and show the Wildhorse to be composed essentially of the mineral dolomite (calcium magnesium carbonate). The SiO_2 and Al_2O_3 content from the tailings is much higher, but this is to be expected as this material is the rejected fine-particle-size gradation. The iron oxide content is the highest of the rocks tested. The chemical data indicate that the Wildhorse is chemical-grade dolomite.

Production.—The abandoned quarry in the Wildhorse at locality OS-2 is the biggest in Osage County, having produced about 7 million tons of road stone for the construction of State Highway 20.

Potential uses.—The physical-test data and chemical analyses indicate that the Wildhorse can be used for most of the major stone uses.

Figure 15. View of Standard Industries, Inc., operating quarry in Red Eagle—Foraker limestone unit, locality OS-6.

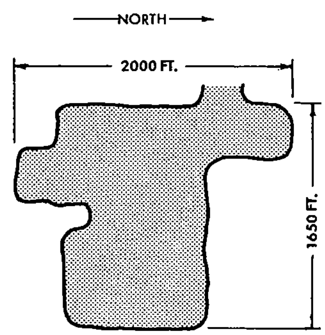
Summary

Three limestone units and one dolomite unit are considered to have economic potential in Osage County: the Avant Limestone, the Deer Creek–Lecompton limestone unit, the Red Eagle Limestone, and the Wildhorse Dolomite.

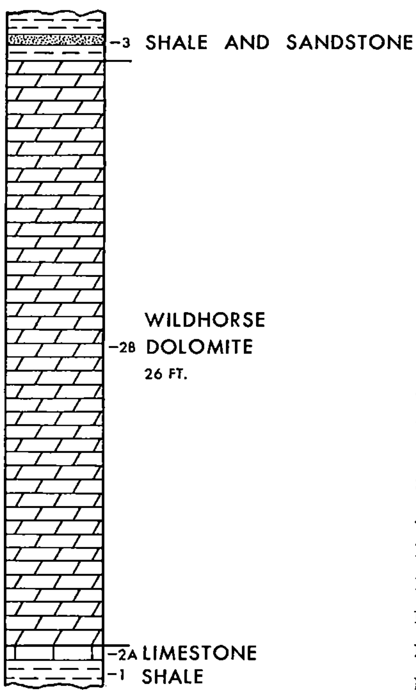
Only one limestone was determined to be of chemical grade, the Deer Creek–Lecompton at locality OS-5, and it is deemed marginal. The Wildhorse Dolomite is considered chemical-grade dolomite.

The units examined generally meet the specifications for road stone, agricultural lime, roofing aggregate, asphalt mix, concrete aggregate, and similar uses.

At present (May 1976), two operating quarries supply existing markets. Ample reserves of stone are available in the County to supply a considerable market expansion. If demand should increase, the chances for reopening and operating additional abandoned quarries on an economically profitable basis would be good.



PLAN VIEW OF QUARRY



CHEMICAL ANALYSIS OS-2-2b

	Composite sample	Crusher run	Tailings
[1]$CaCO_3$	53.26%	53.29%	50.83%
[2]$MgCO_3$	39.05%	40.11%	35.45%
CO_2	45.13%	--	--
Insoluble residue	2.20%	--	--
SiO_2	1.70%	1.23%	5.49%
Al_2O_3	1.76%	.64%	2.52%
Fe_2O_3	2.73%	3.06%	3.71%
FeO	2.46%	--	--
P_2O_5	.02%	--	--
Na_2O	.11%	< .01%	< .01%
K_2O	.07%	.03%	.37%
S	.14%	--	--
H_2O	.09%	--	--

[1]$CaCO_3$ calculated from CaO.
[2]$MgCO_3$ calculated from MgO.

Figure 16. Wildhorse Dolomite in abandoned quarry, locality OS-2, sec. 19, T. 22 N., R. 10 E.

Figure 17. View of abandoned quarry in Wildhorse Dolomite, locality OS-2.

Figure 18. Close-up of Wildhorse Dolomite, showing typical bedding in quarry face at locality OS-2.

Appendix to Part III

Measured Stratigraphic Sections

Section OS-1
Avant Limestone Quarry West of Quapaw Creek

Location.—Abandoned quarry in the Avant Limestone, SW¼NE¼NW¼ sec. 24, T. 22 N., R. 11 E., Osage County, Oklahoma. To reach the section, proceed west on State Highway 20 from the west edge of Skiatook, Tulsa County, Oklahoma, for 3½ miles. About 5/8 mile west of Quapaw Creek turn north through a white gate, then turn left up an old road that leads to the quarry floor.

Remarks.—Section measured, described, and sampled by W. H. Bellis and T. L. Rowland June 10, 1970. The quarry, now abandoned, was originally worked for crushed stone for use in road ballast and road metal during the construction of State Highway 20. The quarry is L-shaped, with dimensions of 200 by 50 yards and 150 by 30 yards. Approximately 175,000 tons of stone has been removed.

The quarry floor is underlain by shale, which in many places forms the floor. The overlying beds are covered where measured and sampled, but the northwest part of the quarry contains beds of shale with thin to medium units of sandstone well exposed above the main limestone unit. The average thickness for the quarried limestone is 18½ feet.

A composite chip sample consisting of approximately 1 cubic inch per 6 inches of vertical section was collected from the west quarry face in the southwest part of the quarry. Hand specimens were collected as follows: OS-1-1, northwest part of quarry, highest beds; OS-1-2, upper beds in measured area; OS-1-3, lower beds; OS-1-4, middle beds.

Unit and no.	Description	Thickness (feet)
Iola Formation		
Avant Limestone		
2	Limestone: fine skeletal, algal mudstone. Light gray to gray fresh; weathers gray, buff, and brown. Thin bedded with some medium beds. Abundant iron oxide stain. Some beds almost a fine, micritic calcarenite. A few paper-thin shale stringers. Abundant skeletal debris of bryozoans and algae; some bedding planes contain large brachiopods, pelecypods, and other fossils.	18.5
Muncie Creek Shale		
1	Shale: dark-gray shale below limestone of quarry. In places forms quarry floor. Thickness not measured.	

Section OS-2
Wildhorse Dolomite Quarry East of Hominy

Location.—Abandoned quarry in the Wildhorse Dolomite, NE¼ sec. 19, T. 22 N., R. 10 E., Osage County, Oklahoma. To reach the quarry, proceed approximately 16½ miles west on State Highway 20 from the west edge of Skiatook, Tulsa County, Oklahoma. The quarry is behind a hill just south of the highway. To enter, turn south on the first gravel road on the west side of the quarry; this road leads to the quarry floor.

Remarks.—Section measured, described, and sampled by W. H. Bellis and T. L. Rowland June 10, 1970. The quarry, now abandoned, was originally worked for crushed stone for road stone during the construction of State Highway 20 and also for the construction of Keystone Dam. The dimensions of the quarry are approximately 2,000 feet by 1,650 feet. About 7 million tons of stone has been removed.

The quarry floor is composed of the basal limestone (unit 2a) at some places; however, in much of the quarried area the floor is composed of the underlying shale (unit 1). The beds overlying the Wildhorse Dolomite have been stripped in the quarrying operation, but in the southwest part where quarrying had ceased they are well exposed. Here they consist of shale with interbeds and lenses of sandstone with a total thickness of at least 25 feet. The average thickness for the quarried stone is 26 feet.

A composite chip sample consisting of approximately 1 cubic inch per 6 vertical inches was collected from the northwest part of the quarry. Hand samples were collected as follows: OS-2-1, upper bed; OS-2-2, middle bed; and OS-2-3, lower bed.

Unit and no.	Description	Thickness (feet)
Barnsdall Formation		
3	Shale and sandstone: gray shale with thick to thin sandstone beds. Sandstone is fine grained, calcareous. Unit well exposed in south-central part where quarry operations had ceased.	25+
Wildhorse Dolomite		
2b	Dolomite: medium to coarse skeletal calcareous dolomite. Tan to gray, fresh; weathers buff to brown. Thin to medium bedded with some thick beds. Rock appears the same in character and thickness throughout entire quarry. Measured in 3 places along west wall; average thickness is 26 feet.	26
2a	Limestone: coarse skeletal (bryozoan, pelmatozoan) calcarenite. Only a few inches thick; underlies massive Wildhorse Dolomite.	0.3
1	Shale: dark-gray; underlies quarry floor and in many places forms floor. Base covered.	

Section OS-3
Avant Limestone Quarry Southeast of Avant

Location.—Abandoned quarry in the Avant Limestone, SW¼W½ sec. 17, T. 23 N., R. 12 E., Osage County, Oklahoma. To reach the quarry, proceed west from Skiatook, Tulsa County, Oklahoma, for 2 miles on State Highway 20. Turn north on the blacktop road that leads to Avant, Osage County. Approximately 7 miles north from the turnoff, follow a dirt road to the east. This road is directly south of a large oval oil-storage tank; a white frame house is situated just inside the cattle guard south of the road. Travel this road east and north for approximately 1 mile to the quarry.

Remarks.—Section measured, described, and sampled by T. L. Rowland and R. P. Lockwood June 22, 1971. The quarry, now abandoned, was originally worked by the Midland Valley Railroad in the 1920's during construction of the railroad.

The stone was worked in two steps. The first, an open pit with dimensions of 200 yards by 200 yards, yielded 1,150,000 tons of stone. As the shale overburden was substantially thick at this stage, the stone was worked horizontally into the cliff face through six openings by means of the standard underground room-and-pillar method. The underground portion is about 540 feet by 150 feet in rooms about 30 by 30 by 30 feet. A total of

165,000 tons of stone was removed in this operation. Thus a total of 1,315,000 tons of stone has been removed from the quarry. The workable stone face in the open pit is 40 feet, whereas that underground is 30 feet.

A composite chip sample of approximately 1 cubic inch per 6 vertical inches was collected from an inside face, giving 30 feet of sampled stone. An additional sample was randomly collected from each of the six faces where stone had been shot down. Hand specimens were collected as follows: OS-3-2a, 2 samples; OS-3-2a, top.

Unit and no.	Description	Thickness (feet)
Iola Formation		
3	Shale: dark-gray calcareous shale that crops out above the quarry face. Thickness not measured.	
Avant Limestone		
2c	Limestone: coarse-grained skeletal calcarenite. Gray to dark gray. Consists of one bed 6 inches thick.	0.5
2b	Shale and shaly limestone: gray to dark-gray calcareous shale with thin lenses of limestone. Forms beds directly above thick quarry face. Averages 1.5 to 2 feet in thickness.	1.5-2
2a	Limestone: gray to light-gray mottled, fine- to coarse-grained skeletal wackestone to packstone with buff to reddish streaks. Abundant veins of calcite. Rock appears to be a pseudobreccia. Grades upward into a gray skeletal, algal wackestone. Mostly massive bedded in lower part and thinner bedded in upper part.	40
1	Shale: gray to dark-gray calcareous shale; grades upward into unit 2a. Exposed on north side of quarry cliff just south of railroad track. Top beds also exposed at base of cliff face of quarry. Base covered.	

Section OS-4
Deer Creek–Lecompton Limestone Quarry West of Hominy

Location.–Abandoned quarry in the Deer Creek–Lecompton limestone unit, NW¼SE¼ sec. 3, T. 22 N., R. 8 E., Osage County, Oklahoma. To reach the section, travel west on State Highway 20 from the west edge of Hominy, Osage County, for about 1½ miles. The quarry is just north of the highway and just northwest of Hominy Municipal Lake.

Remarks.–Section measured, described, and sampled by W. H. Bellis and T. L. Rowland June 10, 1970. The quarry, now abandoned, was originally used for road ballast and road metal in the construction of State Highway 20 and also in the construction of the dam for Hominy Municipal Lake. The quarry is roughly rectangular in shape with dimensions averaging 220 yards by 110 yards. Approximately 150,000 tons of stone has been removed.

The quarry floor consists of shale. The beds overlying the limestone along the abandoned faces consist of shale and soil. The average thickness of the quarried stone is 18 feet, although in the southeast part of the quarry the stone is 2 to 3 feet thicker.

A composite chip sample consisting of approximately 1 cubic inch per 6 vertical inches was collected from the northwest corner of the quarry. The following hand samples were collected: OS-4-1, highest bed in southeast part; OS-4-2, middle bed in southeast part; OS-4-3, bottom beds where collected.

Unit and no.	Description	Thickness (feet)
Pawhuska Formation		
3	Overburden: shale and soil.	10-12
Deer Creek–Lecompton limestone unit		
2	Limestone: fine algal (skeletal) mudstone with interbedded zones of micritic, coarse-grained, skeletal calcarenite. Medium to thick bedded. Gray to light gray fresh; weathers buff to brown. Abundant skeletal debris throughout with numerous zones of large brachiopods. Zone near top of a bed about 2 feet thick consisting of fine-grained quartz-silty, skeletal, dolomitic, recrystallized calcarenite; dark gray fresh, buff to reddish weathered. Entire unit may be dolomitic.	18
1	Shale: gray shale underlying quarry floor exposed as the lowest beds in northwest corner where channel sample was collected. Not measured.	

Section OS-5
Deer Creek–Lecompton Limestone Quarry South of Pawhuska Airport

Location.–Sedan Limestone Co. (Blake Stone Co.) quarry in the Deer Creek–Lecompton limestone unit, NE¼NE¼ sec. 11, NW¼, sec. 12, T. 25 N., R. 8 E., Osage County, Oklahoma. To reach the quarry, proceed west about 4 miles on U.S. Highway 60 from Pawhuska, Osage County. The quarry operation is south of the highway, directly across from the airport, and is easily visible.

Remarks.–Section measured, described, and sampled by W. H. Bellis and T. L. Rowland June 10, 1970. The limestone being actively worked by the Sedan Limestone Co. (Blake Stone Co.) is the Deer Creek portion of the unit and averages 27 feet in thickness. Dark-gray shale underlies the quarry floor and is well exposed in the southeast and south quarry faces. A few feet (5) of soil overburden overlies the working face in some areas of the quarry.

Two composite chip samples of approximately 1 cubic inch per 6 vertical inches were collected from the southeast part of the quarry. Unit 1 was sampled separately from units 2 and 3. The following hand samples were collected: OS-5-1a, middle; OS-5-2, base; OS-5-2a, middle; OS-5-3, top.

Unit and no.	Description	Thickness (feet)
Pawhuska Formation		
Deer Creek–Lecompton limestone unit		
3	Limestone: fine dense mudstone with scattered skeletal debris. Medium bedded; gray fresh; weathers brown to buff.	14.0
2	Limestone: fine- to medium-grained skeletal (algal), micritic calcarenite (algal wackestone to packstone). Medium to thick bedded. Weathers buff, light gray fresh. Two feet from bottom is 6 inches of dark-gray shale containing limestone nodules.	9.0
1	Dolomite: fine- to medium-grained, calcareous. Massive bedded. Dark gray fresh; weathers buff to brown.	4.0

Section OS-6
Red Eagle–Foraker Limestone Quarry East of Burbank

Location.–Standard Industries, Inc., quarry in Red Eagle–Foraker limestone unit, SE¼ sec. 25, T. 26 N., R. 5 E., Osage County, Oklahoma. To reach the section, proceed on old U.S. Highway 60 eastward for 2 miles from Burbank, Osage County. The quarry is easily visible south of the highway.

Remarks.–Section measured, described, and sampled by W. H. Bellis and T. L. Rowland June 11, 1970. The Red Eagle–Foraker limestone is being actively worked by Standard Industries, Inc., of Tulsa.

A composite chip sample of 1 cubic inch per 6 vertical inches was collected on a face opposite the easternmost wall of the quarry. The following hand samples were collected: OS-6-1, bottom; OS-6-2, middle; OS-6-3, top.

Unit and no.	Description	Thickness (feet)
Roca Shale		
3	Overburden: shale with sandstone lenses.	5+
Red Eagle–Foraker limestone unit		
2	Limestone: fine- to medium-grained skeletal (algal), micritic calcarenite. Grades upward into more of a calcarenite mudstone to mudstone; some beds dolomitic. Buff to gray fresh, weathers buff to brown. Abundant thin shale partings throughout. Southeast part of quarry face contains abundant shale beds.	27.0
1	Shale: gray to dark-gray; underlies quarry floor and in many places forms floor. Not measured.	

REFERENCES CITED

Al-Khersan, Hashim, 1969, Carbonate petrography of the Red Eagle Limestone (Lower Permian), southern Kansas and north-central Oklahoma: University of Oklahoma unpublished Ph.D. dissertation, 187 p.

American Society for Testing and Materials, 1962a, Standard specifications for building brick (solid masonry units made from clay or shale), *in* 1962 supplement to book of ASTM standards, including tentatives: pt. 5, C 62-62, p. 1-7.

_____ 1962b, Standard specifications for facing brick (solid masonry units made from clay or shale), *in* 1962 supplement to book of ASTM standards, including tentatives: pt. 5, C 216-62, p. 8-13.

Bebbington, G., and **Bland, M. G.**, 1973, the colouring of bricks: Claycraft and Structural Ceramics, v. 46, no. 5, p. 12-14.

Beckwith, H. T., 1928, Oil and gas in Oklahoma; geology of Osage County: Oklahoma Geological Survey Bulletin 40-T, 63 p.

Boynton, R. S., 1966, Chemistry and technology of lime and limestone: New York, Interscience Publishers, 520 p.

Branson, C. C., 1962, Pennsylvanian System of the Mid-Continent, *in* Branson, C. C. (editor), Pennsylvanian System in the United States–a symposium: American Association of Petroleum Geologists, p. 431-460.

Bryant, D. G., 1957, Geology of the Gray Horse area, Osage County, Oklahoma: University of Oklahoma unpublished M.S. thesis, 119 p.

Bush, A. L., 1973, Lightweight aggregates, *in* Brobst, D. A., and Pratt, W. P. (editors), United States mineral resources: U.S. Geological Survey Professional Paper 820, p. 333-355.

Carl, J. B., 1957, Geology of the Black Dog area, Osage County, Oklahoma: University of Oklahoma unpublished M.S. thesis, 105 p.

Carter, J. A., Jr., 1954, Geology of the Pearsonia area, Osage County, Oklahoma: University of Oklahoma unpublished M.S. thesis, 114 p.

Clendening, J. A., 1971, Palynological evidence for assignment of the Gearyan Stage of Kansas to the Pennsylvanian [abstract]: Geological Society of America Abstracts with Programs, v. 3, p. 234-235.

Fisher, H. C., Jr., 1956, Surface geology of the Belford area, Osage County, Oklahoma: University of Oklahoma unpublished M.S. thesis, 96 p.

Gardner, W. E., 1957, Geology of the Barnsdall area, Osage County, Oklahoma: University of Oklahoma unpublished M.S. thesis, 102 p.

Grim, R. E., 1962, Applied clay mineralogy: New York, McGraw-Hill Book Co., 422 p.

Hamlin, H. P., and **Templin, George**, 1962, Evaluating raw materials for rotary-kiln production of lightweight aggregate: U.S. Bureau of Mines Information Circular 8122, 23 p.

Ironman, Ralph, 1971, Thermoshock treatment produces expanded aggregates in 45 seconds: Rock Products, v. 74, no. 6, p. 60-62.

Klinefelter, T. A., and **Hamlin, H. P.**, 1957, Syllabus of clay testing: U.S. Bureau of Mines Bulletin 565, 67 p.

Lapham, D. M., and **Hoover, K. V.**, 1971, Preliminary evaluation of the factors affecting the use potential of clays and shales in Pennsylvania, *in* American Institute of Mining, Metallurgical, and Petroleum Engineers transactions: Society of Mining Engineers, v. 250, p. 292-295.

Mogharabi, Ataolah, 1966, Carbonate petrology of the Foraker Formation (Lower Permian), north-central Oklahoma: University of Oklahoma unpublished Ph.D. dissertation, 189 p.

Oakes, M. C., 1940, Geology and mineral resources of Washington County, Oklahoma: Oklahoma Geological Survey Bulletin 62, 208 p.

_____ 1952, Geology and mineral resources of Tulsa County, Oklahoma (includes parts of adjacent counties): Oklahoma Geological Survey Bulletin 69, 234 p.

O'Connor, H. G., 1963, Changes in Kansas stratigraphic nomenclature: American Association of Petroleum Geologists Bulletin, v. 47, p. 1873-1877.

Riley, C. M., 1951, Relation of chemical properties to the bloating of clays: American Ceramic Society Journal, v. 34, p. 121-128.

Russell, O. R., 1955, Geology of the Hominy area, Osage County, Oklahoma: University of Oklahoma unpublished M.S. thesis, 84 p.

Shannon, P. J., 1954, The geology of the Pawhuska area, Osage County, Oklahoma: University of Oklahoma unpublished M.S. thesis, 98 p.

Sheerar, L. F., and **Redfield, J. S.**, 1932, The clays and shales of Oklahoma: Oklahoma Agricultural and Mechanical College Division of Engineering Publication 17, v. 3, no. 5, 251 p.

Snider, L. C., 1911, Preliminary report on the clays and clay industries of Oklahoma: Oklahoma Geological Survey Bulletin 7, 270 p.

Sweeney, J. W., and **Hamlin, H. P.**, 1965, Lightweight aggregates–expansion properties of selected Illinois shales and clays: U.S. Bureau of Mines Report of Investigations 6614, 34 p.

Tanner, W. F., 1956, Geology of northeastern Osage County, Oklahoma: Oklahoma Geological Survey Circular 40, 76 p.

Taylor, R. C., 1953, The geology of the Foraker area, Osage County, Oklahoma: University of Oklahoma unpublished M.S. thesis, 108 p.

U.S. Bureau of Census, 1972, Census of population, 1970: U.S. Department of Commerce, Characteristics of the Population, v. 1, pt. A, Number of Inhabitants, sec. 2, Missouri-Wyoming, etc.

Vosburg, D. L., 1954, Geology of the Burbank-Shidler area, Osage County, Oklahoma: University of Oklahoma unpublished M.S. thesis, 110 p.

White, David, and others, 1922, Structure and oil and gas resources of the Osage Reservation, Oklahoma: U.S. Geological Survey Bulletin 686, 427 p.

White, W. A., 1960, Lightweight aggregate from Illinois shales: Illinois Geological Survey Circular 290, 29 p.

Wilson, L. R., 1973, Palynological evidence for a Pennsylvanian age assignment [of the Eskridge Shale] [abstract]: Geological Society of America Abstracts with Programs, v. 5, p. 288.

Wilson, L. R., and **Rashid, M. A.**, 1971, Palynological evidence for a Pennsylvanian age assignment of the Gearyan Series in Kansas and Oklahoma [abstract]: Geological Society of America Abstracts with Programs, v. 3, p. 248.

Zeller, D. E. (editor), 1968, The stratigraphic succession in Kansas: Kansas Geological Survey Bulletin 189, 81 p.

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