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# SILICIFIED ROCK IN THE OGALLALA FORMATION

By

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## ABSTRACT

Silicified zones and lentils in the Ogallala formation of Pliocene age provide the most abundant rocks of hard and durable character in the central Great Plains, and are known to occur over a region extending from South Dakota to west-central Texas. The two major rock types are so-called quartzite (sandstone and conglomerate with opaline cement) and chert, which consists of opal, chalcedony, various quantities of calcium carbonate, and scattered sand grains. Silicified rock occurs at many stratigraphic positions within the formation, but the type here referred to as quartzite is restricted to the lower part, below the horizon of prominent volcanic ash deposits. The cementing material of the quartzite is believed to have been derived from the hydration and leaching of volcanic ash during Ogallala time; the source of the silica in the chert is thought to have been largely Pleistocene volcanic ash. Deposition of the opaline silica seems to have occurred by the replacement of calcium carbonate.

Field examination, petrographic studies, chemical analyses, and physical tests indicate that the silicified Ogallala rock has a wide range of possible commercial uses. Several million tons of quartzite are available in northwestern Kansas, the greatest abundance being found in southern Phillips County. Sizable quantities of Ogallala chert are known to occur at many localities in Kansas.


## INTRODUCTION

*Purpose of the study.*—The central Great Plains (Fenneman, 1931) is a region generally lacking in hard durable rock for construction and other uses. The pre-Tertiary bedrock of western Kansas consists predominantly of shales, chalky limestones, friable sandstones, and relatively soft siltstones of Cretaceous, Permian, and locally Triassic age, blanketed by gravel, sand, and silt of Pliocene and Pleistocene age. In some areas the chalky limestones —and to a less extent some of the sandstone beds—have been used for building purposes, but they are inadequate to meet the requirements of heavy construction and such other uses as railroad ballast, concrete aggregate, and riprap. Plans for extensive construction projects being formulated by the United States Engineer office, Kansas City, Missouri, and the United States Bureau of Reclamation, in addition to the large number of inquiries concerning hard rock that have come to the Geological Survey from railroad companies, quarry operators, and contractors, have emphasized the need for an inventory of durable rock in western Kansas. Although at several localities tightly cemented sandstone beds included within the strata of the Dakota formation are known to constitute a desirable material for many purposes, by far the largest quantity of hard and durable rock—more than nine million tons—is represented by silicified zones in the Ogallala formation of Pliocene age. It is with this rock that the present report is concerned. All formerly known localities have been visited in the field and many new deposits have been located. Petrographic studies of samples from many exposures were made. The first part of this report treats the general distribution, stratigraphy, physiographic expression, and petrology of silicified rocks in the Ogallala formation. This is followed by descriptions of individual silicified rock localities in each of 12 counties in western Kansas.

*Distribution of silicified rock.*—Silicified rock is known to occur in the Ogallala formation over a region extending from South Dakota to west-central Texas. The largest quantities of quartzite, or silicified sand and gravel, are believed to occur in the north-central and northwestern parts of Kansas. The distribution of the Kansas localities studied by us is shown in Figure 1. Quartzite has been reported from the Ogallala formation in Franklin County, Nebraska, just north of the Kansas line, and from the Missouri Valley area in northeastern Nebraska and southeastern South Dakota. Samples were also obtained from two localities in Texas, one 13 miles northeast of Midland and one 3 miles south-southwest of Canyon. Chert occurs at many stratigraphic positions within the Ogallala formation and is more widespread geographically in Kansas than quartzite, but it has smaller potential value as a construction material.

*Possible commercial uses.*—Field examination, petrographic studies, chemical analyses, and physical tests indicate that the silicified Ogallala rock has a wide range of possible commercial uses. Ogallala quartzite has been quarried for construction of buildings in several northern Kansas towns and for foundations of numerous farm buildings; it has also been used as road material, railroad ballast, concrete aggregate, and for other purposes. At some localities the striking colors and the mottled appearance of the conglomeratic zones suggest their value as an ornamental stone and in terrazzo. The extensive construction program of flood control and irrigation dams being planned for northern Kansas and adjacent Nebraska probably will create a large demand for durable rock to be used in this area as concrete aggregate and riprap.

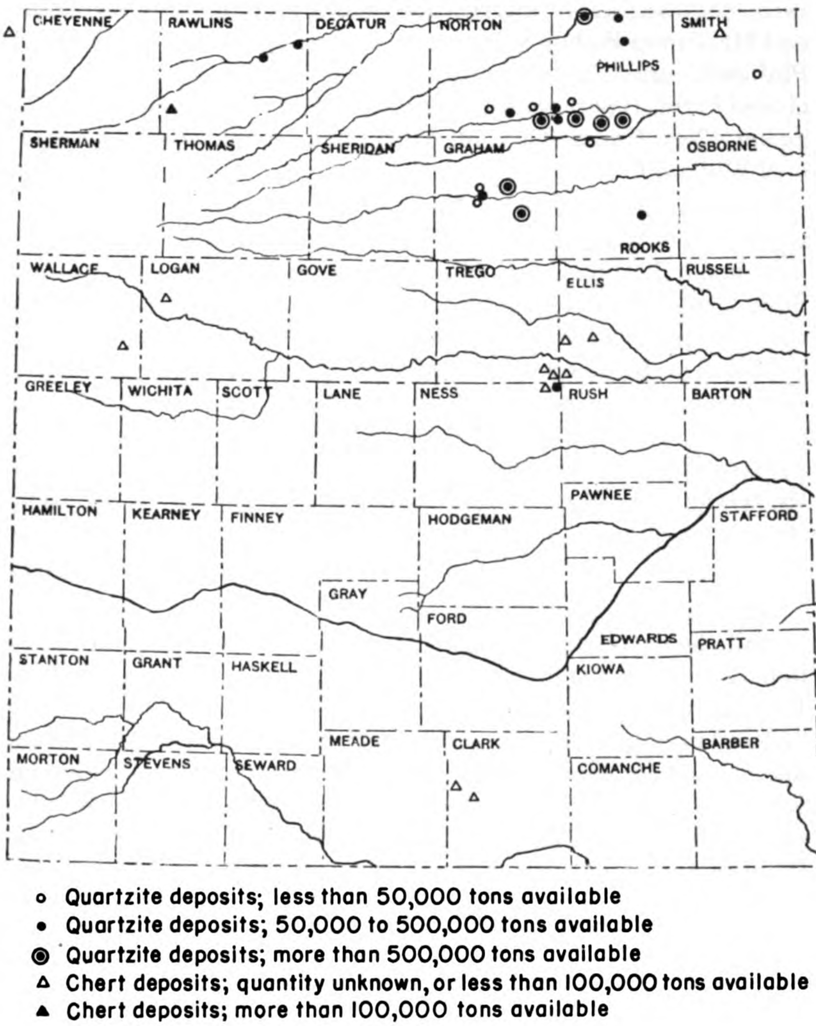


FIG. 1. Map of western Kansas showing localities from which samples of Ogallala quartzite and chert were collected for study.

*Acknowledgments.*—We are especially indebted to the staff of the United States Engineer office, Kansas City, Missouri. Mr. Clifford Philo spent three days in the field with Frye locating and sampling quartzite deposits, and furnished data concerning other deposits that he had previously examined; Dr. Stafford C. Happ

furnished geological information concerning several localities; and Mr. James Bishop supplied us with samples from a locality in Phillips County. The chemical analyses and physical test data included in this report were furnished to us by the United States Engineer office, Kansas City, Missouri, through the courtesy of Colonel William E. Potter.

Mr. Alvin R. Leonard, of the Federal and State Geological Surveys Ground Water Division office at Lawrence, contributed to the field data in Phillips and Rooks Counties. Mr. E. C. Reed, Associate State Geologist of Nebraska, furnished samples of Ogallala quartzite from northern Nebraska and southern South Dakota. Dr. M. K. Elias of the Nebraska Geological Survey, supplied several samples from the Ogallala of western Texas, and identified fossil seeds collected from strata associated with the quartzite deposits of western Kansas. The manuscript has been read and criticized by Dr. Raymond C. Moore, Dr. Robert M. Dreyer, and Dr. Stafford C. Happ.

## STRATIGRAPHY

Silicified rock was found to occur at many stratigraphic positions within the Ogallala formation. As noted by Elias (1931, p. 136) chert occurs in Wallace County, Kansas, a few feet below the "Algal limestone," which is presumed to mark the top of the formation, and rock that is believed to be equivalent to this limestone was found to be partly silicified near Lamesa, Texas. At many localities in Kansas (Graham, Ness, Norton, Phillips, and Rawlins Counties) quartzite is in direct contact with Cretaceous strata or only a few feet above the base of the Ogallala. Even though silicified zones occur high within the Ogallala, the available evidence indicates that the lithology here referred to as quartzite is restricted to the lower part of the formation.

Detailed stratigraphic subdivision of the Ogallala has been made only in Nebraska, where it has been considered by Lugn (1939, pp. 1258-1264) as a group composed of the following formations in ascending order: Valentine, Ash Hollow, Sidney, and Kimball. Elsewhere within the Great Plains the Ogallala has been classed as a formation and has not been subdivided into named stratigraphic units. Elias (1942) has described fossil seeds from these beds in Kansas and Nebraska and established floral zones. He designated the lowest such zone within the formation as the

*Stipidium commune* zone and considered it to include most of the Valentine of Nebraska classification. His *Krynitzkia coroniformis* zone occurs next higher and is believed to include the upper Valentine and lower Ash Hollow beds. Elias' *Biorbia fossilia* zone includes all but the lowermost part of the Ash Hollow. The Kimball formation is generally barren of fossil seeds.

Although detailed regional stratigraphic studies on the Kansas Ogallala have yet to be made, the available data seem to indicate that the lowest beds included in the formation near the Nebraska line (*Stipidium* zone and possibly the *Krynitzkia* zone) are early Pliocene in age (Hibbard, 1942; Elias, 1942; Hibbard and Phillis, 1945), and that equivalents are absent in southwestern Kansas and Oklahoma or may be in part represented by the Laverne formation (Frye and Hibbard, 1941). Thus the stratigraphic position of the extensive quartzite deposits of north-central Kansas is lower than any part of the Ogallala formation in southwestern Kansas. Southward in Kansas younger Ogallala overlaps older Ogallala deposits.

In contrast to this north to south overlap of the Kansas Ogallala, the lower part of the formation seems to be relatively continuous in any one latitude eastward from the Colorado line, whereas the upper part has been largely removed by erosion in the eastern part of the outcrop area. Study of the stratigraphy of the Ogallala formation in Wallace County, Kansas, by Elias (1931) indicates that the formation there attains a maximum thickness of 210 feet (p. 134) and contains *Biorbia* in the upper 80 to 90 feet. On the basis of test hole samples, Frye (1945, p. 66) states that the Ogallala attains a maximum thickness of 266 feet in Thomas County, Kansas. Still farther east, near Lenora in southwestern Norton County, Kansas, exposures have yielded fossil seeds identified by M. K. Elias as *Biorbia fossilia* (Berry) from beds 115 to 135 feet below the top of the local Ogallala section and an unknown distance above the Cretaceous contact. In northeastern Norton County this same species occurs only 40 feet below the top of the local section (Swineford and Frye, 1946, p. 10) and more than 100 feet above the Cretaceous contact. At this same locality *Krynitzkia coronoformis* was collected 45 feet below the beds that yielded *Biorbia*. Meager fossil data, obtained at one locality only, suggest that the quartzite occurs in the zone of *Stipidium commune* or the lower part of the zone of *Krynitzkia coroniformis*. Available information indicates that the Ogallala does not thin markedly eastward across the region of prominent quartzite exposures, and points to removal of the upper part of the formation by erosion during post-Ogallala time and to a restricted occurrence of the quartzite in the lower part of the formation.

Inasmuch as the presence of lenticular deposits of volcanic ash is believed to be related to the origin of the quartzite, it is important to establish the relative stratigraphic positions of ash beds and quartzite. Swineford and Frye (1946, pp. 9-11) have discussed the stratigraphy of the Ogallala volcanic ash deposits in Norton County, and in a measured section south of Almena report the occurrence of this ash 66 to 79 feet above the base of the formation. They place the ash at the top of Elias' *Krynitzkia coroniformis* zone and below his *Biorbia fossilia* zone, but present evidence indicating that some ash may belong in the lower part of the *Biorbia fossilia* zone. Thus, the horizon of the Ogallala volcanic ash occurs stratigraphically above the zone of the prominent quartzite lentils.

Although it has not been possible everywhere to define the stratigraphic position of the quartzite lentils within the Ogallala section precisely and conclusively, at many places the exposures are adequate to permit determination of their approximate horizon by means of fossil seeds or stratigraphic methods. The Ogallala strata adjacent to the quartzite are best exposed in the area lying south of North Solomon River and west of Glade. In this area zones of quartzite occur at several horizons throughout the lower 80 feet of the formation. The following section measured south of Speed shows the repetition of quartzite lentils in this part of the formation. Exposures in near-by gullies clearly indicate that the contact of the Ogallala with the Niobrara chalk is not more than 30 feet below the base of the section.

*Measured section south of Speed, SW¼ sec. 13, T. 5 S., R. 19 W. Phillips County, Kansas* (Measured by John C. Frye, Ada Swineford, and A. R. Leonard)

| | *Thickness, feet* |
|---|---|
| PLEISTOCENE | |
| 12. Silt and sand, tan | 8.0 |
| TERTIARY | |
| Ogallala formation | |
| 11. Quartzite, fine-grained, dense, green | 1.5 |
| 10. Sand, massive, green and red; contains fragmentary Mastodon tooth | 5.0 |
| 9. Quartzite, fine-grained, fairly well cemented, green | 1.0 |

| | |
|---|---|
| 8. Sand and silt, massive, green; spotted and streaked with white calcium carbonate | 3.0 |
| 7. Silt and sand, massive, partly silicified, hard, light gray | 1.5 |
| 6. Sand, silty, massive, tightly cemented with calcium carbonate; weathers to a deeply etched surface of vertical columns and horizontal sheets | 1.0 |
| 5. Sand, fine, and silt, green; speckled with calcium carbonate | 2.5 |
| 4. Quartzite, fine-grained, lenticular, light green; lenses out along road ditch | 1.5 |
| 3. Silt and fine sand, partly covered, light greenish gray, weathers to ash gray; contains a few nodules of calcium carbonate | 2.5 |
| 2. Sand, fine, and silt, indistinct bedding, very light greenish gray, weathers to platy and nodular surface; loosely cemented throughout with calcium carbonate; forms indistinct bench along near-by canyon side | 4.5 |
| 1. Silt, sandy, calcareous; contains calcium carbonate in irregular nodules and stringers; upper part more clayey, darker gray, contains less carbonate | 6.0 |
| Total | 38.0 |

West of this measured section, fossil seeds of *Stipidium commune* Elias were collected from 12 feet below a thin bed of quartzite in sec. 17, T. 5 S., R .20 W., Phillips County. Although the beds below the *Stipidium*-bearing strata are mostly covered, partly silicified sand and gravel is exposed approximately 75 feet below the upper quartzite.

Exposures of the lower part of the Ogallala formation were studied in the area immediately west of Sugar Loaf Mound in Rooks County. Well-silicified quartzite was not found in the immediate area of the measured section given below, but a lower zone is partly silicified and the horizon of the upper quartzite was approximately established within the section by hand level from its occurrence in the prominent mound less than one-half mile to the east. In the immediate vicinity of Sugar Loaf Mound, three lenticular zones of quartzite, the upper two of which are visible in Plate 2B, occur in the interval included in the measured section.

All other quartzite deposits of the North Solomon and Bow Creek Valleys area, except for one exposure in the NE¼ sec. 18, T. 5 S., R. 19 W., occur in the lower 25 to 30 feet of the Ogallala (Pl. 3B). This is also true of the quartzite deposits in Rawlins, Graham, and Ness Counties. The exposure in Ness County is of particular interest because three zones of silicification—Niobrara chalk immediately below the base of the Ogallala, conglomeratic green quartzite, and white to gray chert—occur in a vertical interval of 40 feet.

*Measured section west of Sugar Loaf Mound, SE¼ sec. 8, T. 6 S., R. 19 W., Rooks County, Kansas.*

| | Thickness, feet |
|---|---|
| **Tertiary** | |
| Ogallala formation | |
| 7. Sand, loose, partly covered; contains carbonate nodules. This interval is approximately at the same horizon as the lenticular quartzite forming the caprock of Sugar Loaf Mound | 5.0 |
| 6. Sand, loose, green; contains calcium carbonate nodules in lower part; cemented in upper part to a bench-forming ledge; contains root molds | 4.5 |
| 5. Sand, silty, green; poorly cemented with calcium carbonate in lower part; upper 2 feet well cemented to a bench-forming ledge; contains *Celtis willistoni* (Cockerell) Berry | 11.0 |
| 4. Covered | 21.0 |
| 3. Sandstone, cemented with calcium carbonate, silty in upper part, grains of lower part stained green; lower 2 feet green and partly silicified in SE¼ NE¼ sec. 8, T. 6 S., R. 19 W. | 10.0 |
| 2. Covered | 21.0 |
| **Cretaceous** | |
| Niobrara formation | |
| 1. Chalky shale, blue gray | |
| Total | 72.5 |

An appreciable vertical range in the stratigraphic position of the quartzite lentils of the Ogallala in other regions is indicated by the presence of two such beds separated by an interval of 40 feet in South Dakota (Todd, 1889). Data are not adequate for accurate correlation of the quartzite in west-central Texas with the Kansas Ogallala section. The position of these lentils in the local Texas section and their distance below the "Algal limestone" horizon suggest that they are not younger than mid-Ogallala.

Chert deposits have been observed at many stratigraphic positions within the Ogallala from the "Algal limestone" at the top to near the base; however, chert has not been observed in the basal few feet of the formation or below the lower zone of quartzite.

## PHYSIOGRAPHIC EXPRESSION

The lenticular masses of silicified rock in the Ogallala formation of north-central Kansas are more resistant to erosion than any other type of rock occurring in that area. Some of the most striking topographic features of the region have been produced by differential weathering and erosion which have left quartzite beds as the cap rock of buttes and rock benches along the valley sides. Sugar Loaf Mound and Twin Mounds in Rooks County, the series of high buttes south of Glade in Phillips County, and McAllister

Buttes in Logan County are capped by Ogallala quartzite or chert. The easternmost outcrop of this rock known in Kansas is the cap rock of Stony Mound, an isolated low mound standing above the adjacent topography 1 mile south of Bellaire in Smith County. At many places where this rock was examined, it forms a cap rock on hills or ridges and makes a pronounced rock bench on slopes (Pls. 1, 2, and 3). This typical physiographic expression was found to be of considerable aid in locating and mapping outcrops of quartzite and chert. Along the eastern fringe of Ogallala outcrops, where the present streams have cut their valleys deep into the Cretaceous bedrock, the silicified deposits occur on the crests of major divides and thus have maximum topographic expression. Farther west, a thick section of Ogallala and Pleistocene deposits overlies the bedrock and the silicified zones generally occur low along the valley sides where they produce only minor interruptions in the slopes.

In several areas, the geographic position of the quartzite deposits has probably at least partly controlled the shape and location of present valleys. This is illustrated by the constriction of South Solomon Valley at Penokee, where quartzite caps the bluffs both north and south of the river, and particularly by the anomalous bend in Prairie Dog Creek west of Woodruff in Phillips County. Two to 3 miles west of Woodruff and just south of the Nebraska state line, an elongate hill is capped by lentils of quartzite in loose sand, gravel, and silt. Southwest from this hill Prairie Dog Creek flows in a relatively straight valley but immediately south of the quartzite locality it turns abruptly to the west for 1.5 miles, then sharply north for about 1 mile and back toward the east, rejoining its former trend just north of the state line. Prairie Dog Creek flows on three sides of this low quartzite hill and seemingly during the period of downcutting was forced westward into its present position by the greater resistance of the quartzite lentils.

Bow Creek flows eastward from northern Graham County along the Phillips-Rooks County line, joining North Solomon River in southeastern Phillips County. The elevation of its channel bottom is distinctly higher than those of the major valleys both north and south to which it is roughly parallel. Quartzite crops out along both sides of the valley in western Rooks and Phillips Counties and forms a rock bench in some places. Even though the channel is now cut into Cretaceous bedrock, a distinct steepening occurs in the stream gradient in the vicinity of Sugar Loaf Mound a short distance west of the eastern margin of the quartzite outcrops. These data seem to indicate that the position of the stream across an extensive area of quartzite has retarded its downcutting with a resultant loss of tributaries.

## PETROLOGY

Samples of silicified Ogallala rock for petrographic study were selected from 27 localities in Kansas; from three localities in Texas —near Midland, Canyon, and Lamesa; and one sample each from a locality near Beecher Island, Colorado, from Gregory County, South Dakota, and from Holt County, Nebraska. Extensive use of thin sections was made; these were supplemented by chemical analyses and study of crushed fragments. The cementing material was found to consist, for the most part, of silica in the form of opal associated with a small amount of chalcedony.

The silicified rocks of the Ogallala formation are grouped, on the basis of their texture, color, degree of cementation, and predominant lithology of the original deposit, into two major categories—here termed quartzite and chert—and several special types of minor extent and importance.

### Quartzite

The quartzite occurs in lentils ranging in size from a few feet to more than a half mile in lateral extent and from less than 1 foot to more than 15 feet in thickness. Where exposures are adequate, these lentils may be observed to occur in loose sand and gravel, locally interbedded with silt and clay; the adjacent clastic material generally contains no appreciable amount of calcium carbonate cement. Bedding planes are commonly obscure, except in a few exposures where cross bedding is observed. Joints are rare and the few that were noted in the field display thin incrustations of silica on the joint surfaces. In many places Ogallala quartzite immediately overlies chalky shale of the Niobrara formation (Cretaceous), which, in such association, is generally at least partly silicified. In Rawlins County, Kansas, the quartzite occurs a few feet above the Pierre shale (Cretaceous).

The texture of the quartzite ranges from fine-grained sand to coarse poorly sorted conglomerate containing boulders that have a maximum diameter of more than 50 centimeters. Where large

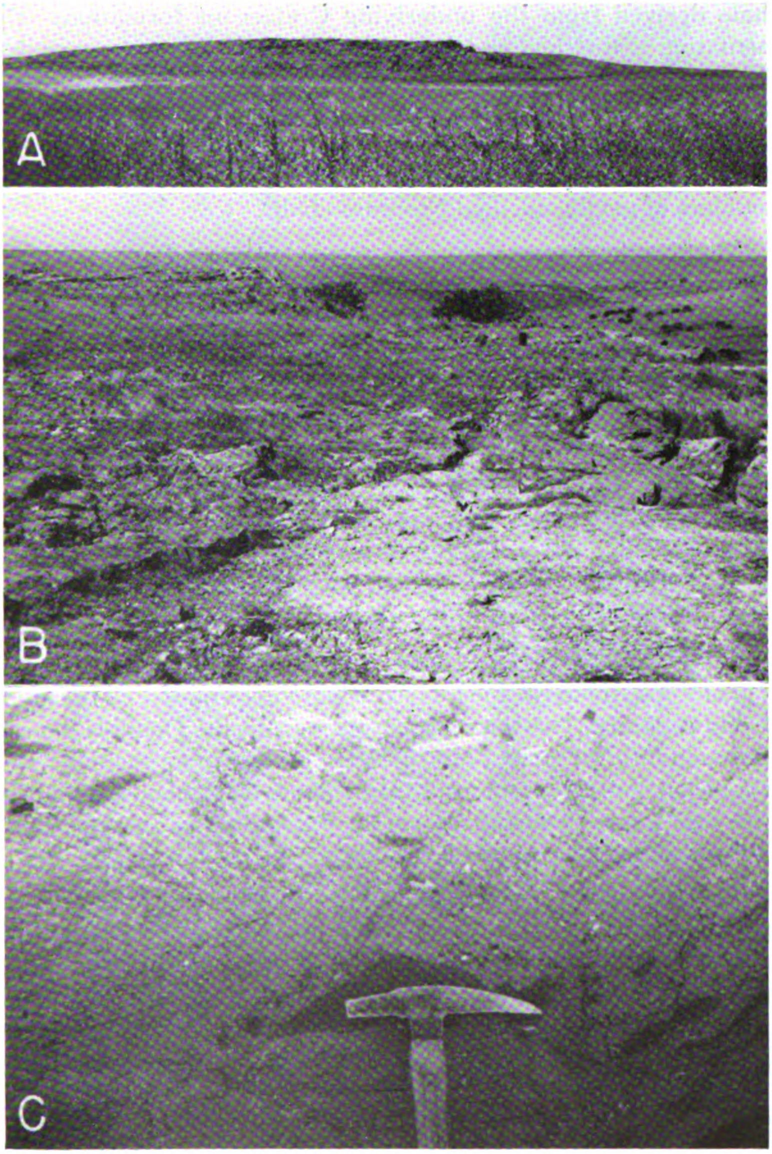


**Plate 1.** Ogallala quartzite in Phillips and Norton Counties, Kansas. *A*, Hill capped by quartzite in NE¼ sec. 28, T. 5 S., R. 19 W., Phillips County; *B*, quartzite outcrops in the NE¼ sec. 15, T. 5 S., R. 21 W., Norton County; *C*, surface of exposure shown in *B*.

boulders are present, they are invariably composed of chalk or shale derived from the underlying Cretaceous formations. Cementation of the sand and gravel ranges from the nearly complete filling of all original pore spaces with silica to only partial filling of the pore spaces, producing a minutely cavernous appearance. A cavernous appearance on some exposed surfaces is also caused by the lower resistance to weathering of the included pebbles and boulders of partly silicified Niobrara chalk.

The Ogallala quartzite in the region north of Texas ranges in color from greenish gray to greenish brown to bright green. The weathered color is light gray or white and reddish-brown. In some places the presence of special features, such as abundant white feldspar in some of the quartzite of Rawlins County, Kansas, gives the rock a distinctive appearance. The several quartzite exposures examined in western Texas display a pink to gray-pink color.

The rock has a hardness very little below that of quartz, and breaks through, rather than around, the constituent grains, often displaying a subconchoidal fracture. The apparent specific gravity given in Table 1 ranges from 2.37 to 2.41 except for one sample from near Woodruff in Phillips County, Kansas, which has a specific gravity of 2.63.

The constituents of the quartzite were determined by the study of thin sections. The grains, as in the rest of the Ogallala, consist predominantly of quartz but include variable amounts and types of feldspar and also scattered fragments from igneous, metamorphic, and a few sedimentary rocks. In some thin sections much material of local derivation is present.

The sand grains are subangular to rounded and fine to coarse in texture. Where opalization is most complete the very fine fractions are absent and the material is generally well sorted as in the sample from Norton County shown in Plate 4, figure 1. The feldspars include microcline, plagioclase, and orthoclase (Pl. 4, fig. 2), and range in quantity from less than 10 percent to more than 40 percent of the grains. Some of the quartzite from Rawlins County (Pl. 5, fig. 4) is characterized by a large proportion of somewhat altered white feldspar and an almost complete absence of the pink feldspars which are found elsewhere. This rock is a true arkose. In quartzite from other localities, the feldspars are comparatively fresh or show only incipient alteration.

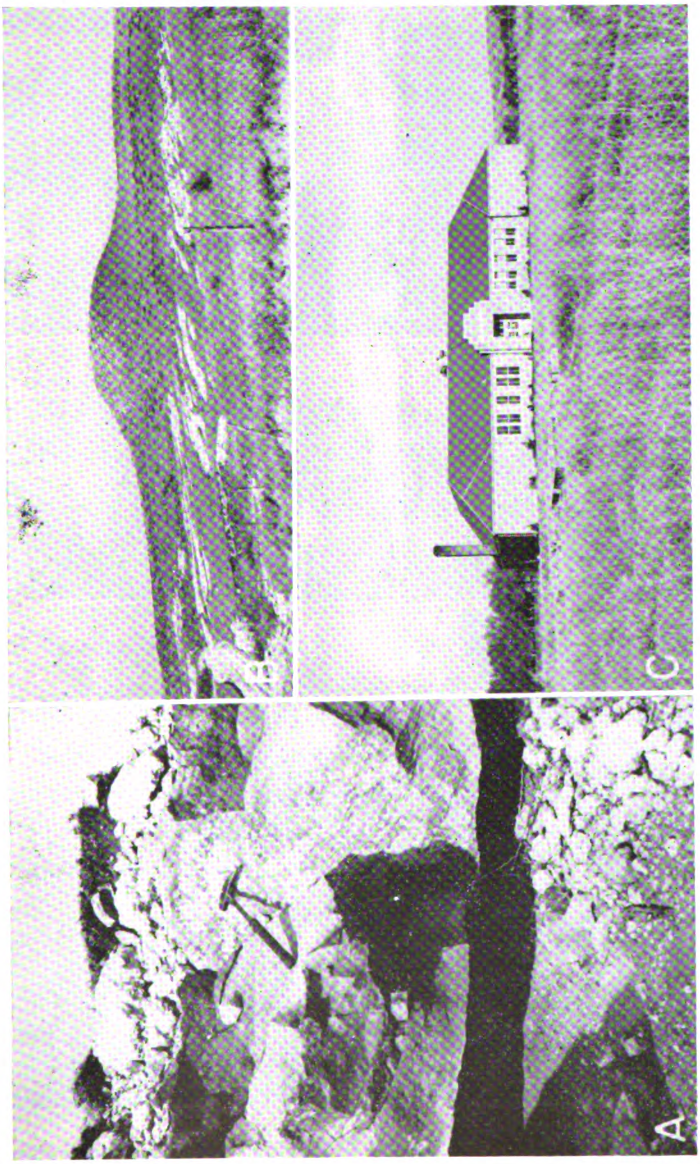


PLATE 2. *A*, Quartzite in quarry face, on top of Sugar Loaf Mound, sec. 10, T. 6 S., R. 19 W., Rooks County; *B*, Sugar Loaf Mound, looking north; *C*, school building constructed of Ogallala quartzite, Ludell, Rawlins County, Kansas.

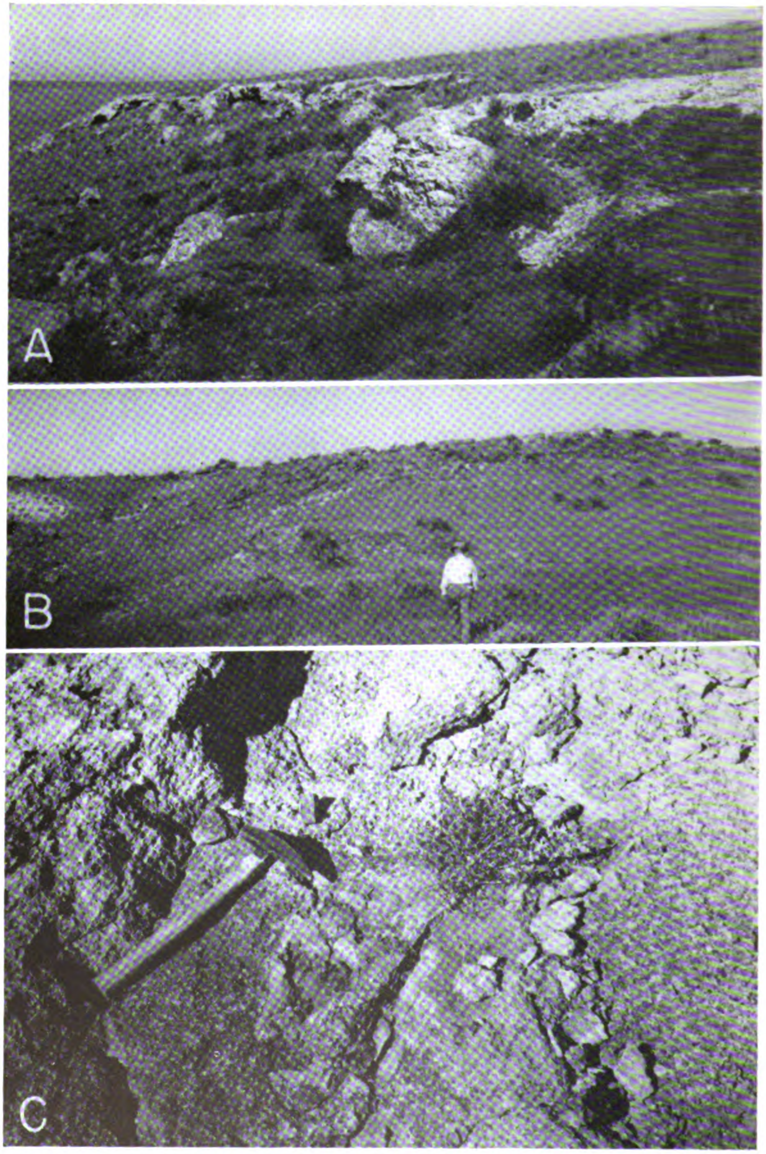

PLATE 3. Ogallala chert and quartzite in Rawlins and Graham Counties, Kansas. *A,* Chert outcrops in the NE¼ sec. 16, T. 4 S., R. 36 W., Rawlins County; *B,* hill of Niobrara chalky shale capped by quartzite, NW¼ sec. 13, T. 8 S., R. 24 W., Graham County; *C,* weathered surface of outcrop shown in *B.*

The material of local origin consists of fragments of shale or chalky shale, pieces of pelecypod shell, and a small amount of bone and foraminiferal tests. Plate 5, figure 1, is a thin section of basal Ogallala quartzite from northeastern Ness County showing a large shell fragment believed to be from the prismatic layer in the shell of a mollusk of the genus *Inoceramus* (Boggild, 1930, p. 262). This figure also shows several foraminifers and small pieces of chalky shale from the Niobrara which appear black in the photomicrograph. The foraminifers and the large shell fragment are composed of calcite. The pieces of chalky shale have been partly silicified but nevertheless contain a large amount of calcium carbonate. Many thin sections and hand specimens show penetration of sand grains into the chalky shale. Most of the foraminiferal tests in the quartzite are filled with optically continuous calcite. Tests in the underlying partly silicified Niobrara chalk (Pl. 5, fig. 2) have fillings of chalcedony or chalcedony and calcite, but the tests themselves, as in the quartzite, are calcareous. A large Niobrara boulder in basal Ogallala quartzite capping a hill 2 miles northwest of Logan has a silicified rind ranging in thickness from one-fourth to one-half inch. Plate 5, figure 3, shows the sharp contact between silicified (light-colored) and unsilicified parts of the boulder. Opalization of the basal sand and gravel in this area is incomplete and spotty.

Quartzites containing large fragments of Cretaceous rock are not limited to the basal part of the Ogallala; they have been found higher than 70 feet above the base on Sugar Loaf Mound and on a butte in sec. 17, T. 5 S., R. 20 W., 4 miles southwest of Logan in Phillips County.

Several degrees of opalization are observed. In many specimens opal completely fills the interstices between the grains, and the rock is dense and tough, showing an absorption (Table 1) as low as 1 percent. Other specimens contain small vugs in the opal, some of which are lined with colorless chalcedony or calcite. Plate 4, figure 3, shows vugs lined with small calcite crystals.

Quartzite from the lower part of the Ogallala formation of northern Nebraska (SW cor. NW¼ sec. 30, T. 32 N., R. 11 W., Holt County) and from the base of the Ogallala in southern South Dakota (southeastern edge of Dallas in western Gregory County) is similar in appearance to the green quartzite of Kansas (Pl. 6, fig. 5). Thin sections of the pink quartzite from Midland and Canyon, Texas (Pl. 6, figs. 1, 2, and 3), have only small areas and streaks of opaline cement, and much of the cementing material is partly calcareous. In the Texas samples the sand is fine-grained and contains some silt. Plate 6, figures 1 and 2, shows an area of chalcedony surrounded by finely banded opal. This feature is more closely related to the lithology of the Ogallala chert than to that of the green quartzite of Kansas, Nebraska, and South Dakota. The Texas quartzite should perhaps be regarded as intermediate in several characteristics between the chert and the green quartzite.

The use of the term quartzite, as applied to this particular rock, is admittedly not consistent with some of the definitions that have been proposed for this term (Holmes, 1920, p. 194; Pirsson and Knopf, 1926, p. 381; Dana, 1932, p. 386; Grout, 1932, p. 366; Allen, 1936, p. 38; Hatch, Rastall, and Black, 1938, p. 104); however, its use in this sense is allowed by other definitions (Chamberlin and MacClintock, 1934, p. 24; Sellards and Baker, 1934, p. 239; Milner, 1940, p. 370). It seems to us advisable to use quartzite as designation of this particular lithology rather than some lesser known or more cumbersome name, because of its use in earlier literature (Hicks, 1888; Barbour, 1903, p. 163; Condra, 1908, pp. 18-23; 1908a, p. 49; Landes and Keroher, 1942, pp. 284, 306), by the residents of the area, and by many of the engineers and contractors who have used the rock for construction purposes.

## Chert

The rock within the Ogallala formation here referred to as chert occurs as irregular areas of uneven or spotty silicification of "caliche" or "marl" that contain various amounts of silt or sand. Smith (1940, p. 46) has described an exposure of this chert in western Clark County as follows:

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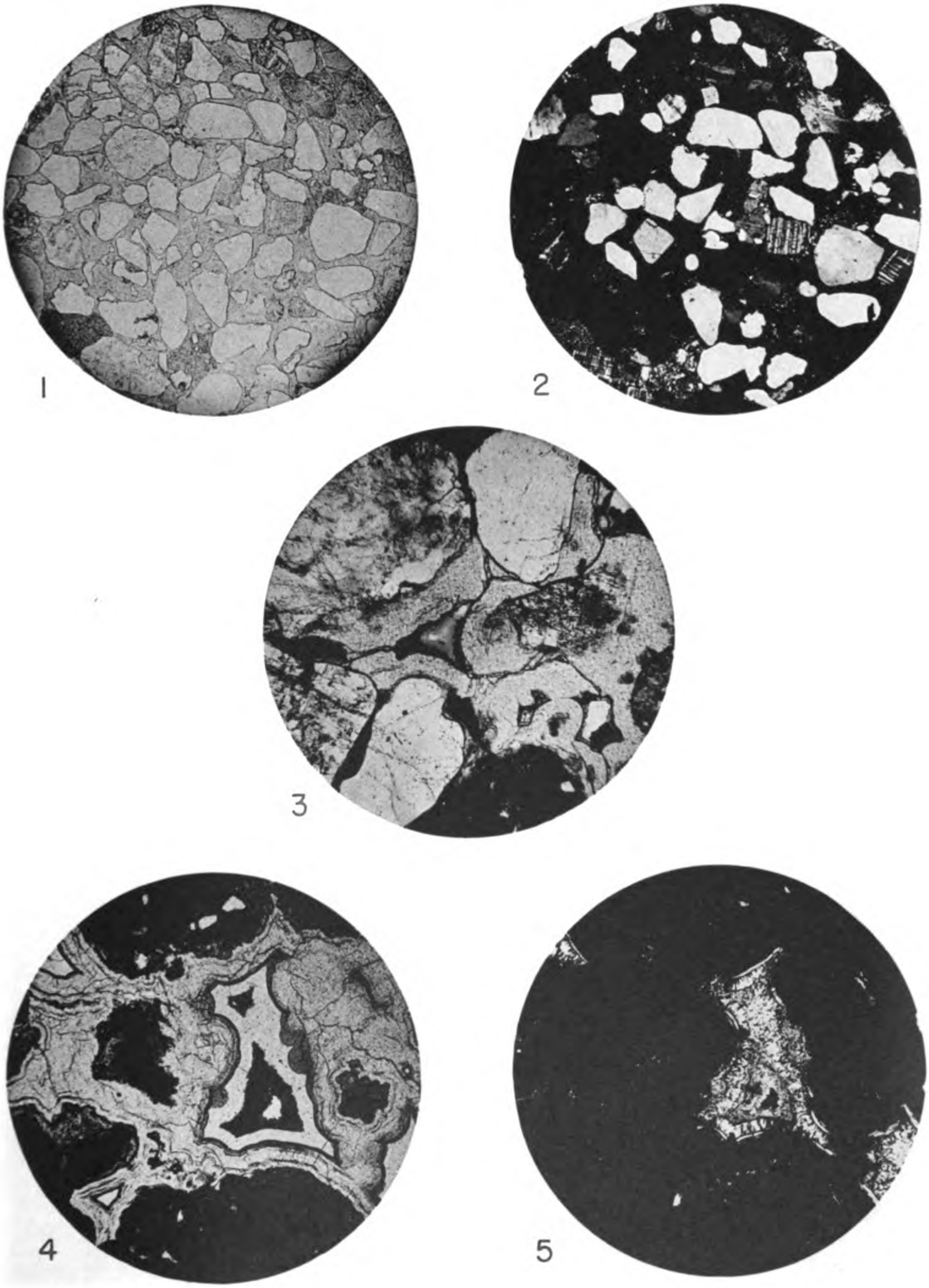
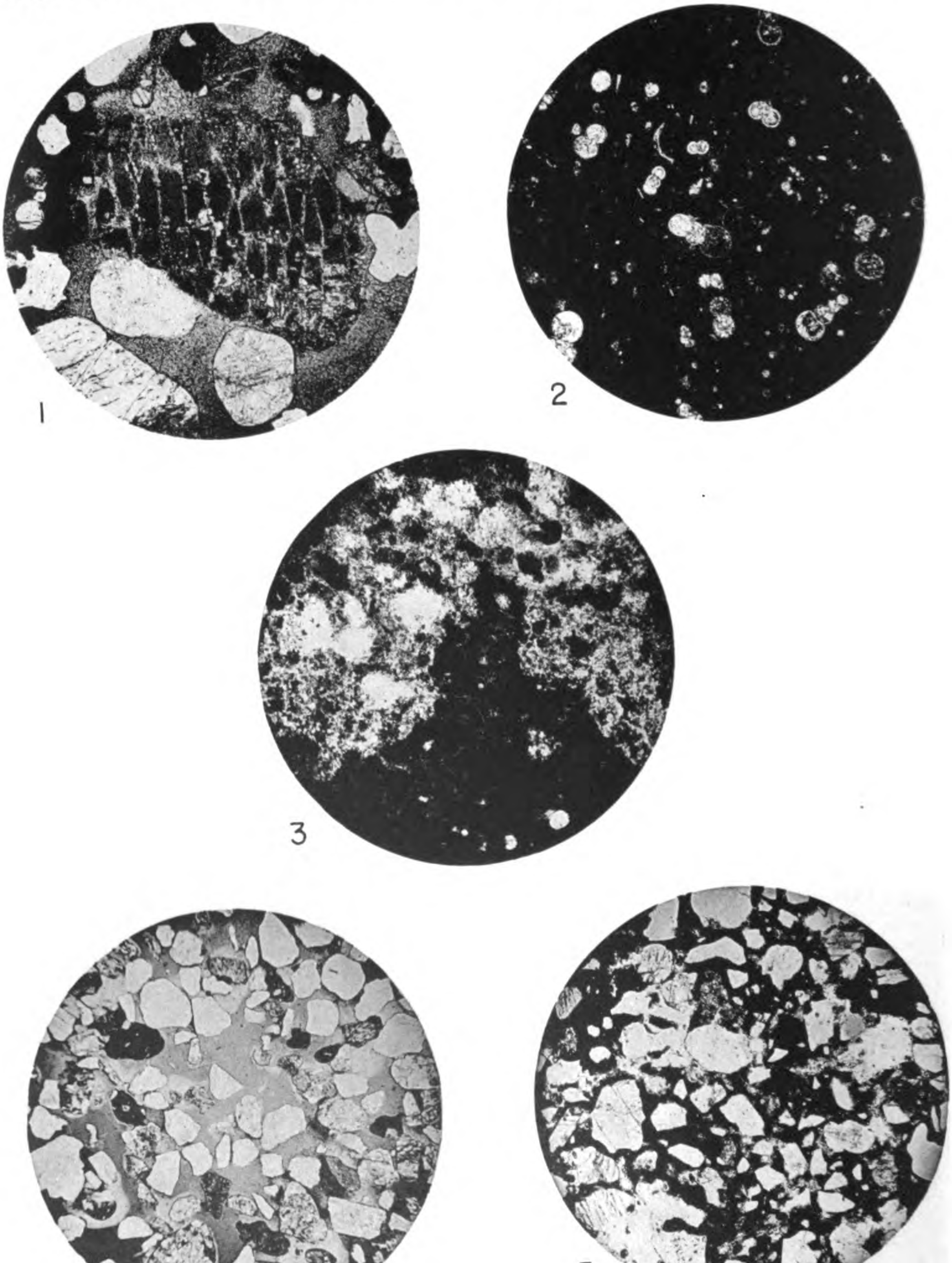
Plate 4. Photomicrographs of Ogallala quartzite and chert from Norton, Graham, and Rawlins Counties, Kansas. Fig. 1—Fine-grained quartzite showing opaline cement from SE cor. sec. 5, T. 5 S., R. 22 W., Norton County, Kansas; plane polarized light, X 25. Fig. 2—Same as 1; crossed nicols, X 25. Fig. 3. —Coarse-grained quartzite from Cen. S. line, sec. 31, T. 7 S., R. 22 W., Graham County, Kansas, showing vugs lined with calcite in opaline cement; plane polarized light, X 35. Fig. 4.—Chert, showing fine-grained calcium carbonate, opal, chalcedony, and calcite from NE¼ sec. 16, T. 4 S., R. 36 W., Rawlins County, Kansas; plane polarized light, X 35. Fig. 5.—Same as 4; crossed nicols, X 35.




Frye and Swineford, Silicified Ogallala




Frye and Swineford

It forms a prominent white ledge, visible for a considerable distance. The chert is very brittle and easily shattered by the hammer, forming irregular, hackly fragments; seemingly it is thoroughly traversed by incipient fractures. The color ranges from white on the weathered surface to light gray on a fresh surface, and shows some dark mottlings. The rock is megascopically opaque, but contains scattered and irregular clots and veinlets of translucent, opaline silica. The veinlets are locally so prominent as to give the rock a brecciated appearance.

This description is equally applicable to the extensive chert deposits that occur in southwestern Rawlins County and elsewhere. However, the percentage of silica varies within wide limits and at some localities the silica consists merely of irregular spots scattered through an otherwise calcareous deposit. Such minor amounts of silicification occur widely throughout the area of Ogallala outcrop and are typical of the deposits immediately below the "Algal limestone" (Elias, 1931, p. 136).

A specific gravity of 2.21, which is about 0.20 below the average for the Ogallala quartzite, was determined for the one chert sample tested.

The major constituents of the chert, as determined by the study of thin sections, are opal, chalcedony, and very fine-grained crystalline calcium carbonate, with minor amounts of quartz and feldspar grains and secondary calcite. Some samples contain more than 50 percent very fine-grained calcium carbonate mingled with an undetermined amount of disseminated silica (Pl. 6, fig. 4), whereas other samples consist predominantly of silica in the form of opal and chalcedony. A layer of opal is invariably found marginal to the very fine-grained calcium carbonate. Vugs in the opal are commonly found to be lined with chalcedony, which in a few thin sections is in turn lined with crystalline calcite. Plate 4,

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PLATE 5. Photomicrographs of silicified rock and Ogallala "mortar bed" from Ness, Phillips, and Rawlins Counties, Kansas. Fig. 1.—Quartzite, showing shell fragment, foraminifers, and chalky shale from the underlying Niobrara formation; Cen. W. side, sec. 1, T. 16 S., R. 21 W., Ness County, Kansas; plane polarized light, X 35. Fig. 2.—Partly silicified Niobrara chalky shale from below the quartzite shown in 1; plane polarized light, X 35. Fig. 3.—Contact between silicified rind and unsilicified interior of boulder of Niobrara chalky shale included within the basal Ogallala quartzite; in sec. 29, T. 4 S., R. 20 W., Phillips County, Kansas; plane polarized light, X 25. Fig. 4.—Quartzite, showing opaline cement and weathered feldspar grains; from NW¼ sec. 29, T. 2 S., R. 32 W., Rawlins County, Kansas; plane polarized light, X 10. Fig. 5.—Ogallala silty sand cemented with calcium carbonate; from sec. 19, T. 3 S., R. 19 W., Phillips County, Kansas; plane polarized light, X 25.

figures 4 and 5, shows this relationship in a sample from Rawlins County. A similar relationship is observed in a sample of partly silicified "Algal limestone" from near Lamesa, Texas, but the secondary crystalline calcite is optically continuous and completely fills the central part of the vug. All stages of this sequence, including the association of opal alone with the fine-textured calcium carbonate, may be observed. Grains of quartz sand occur in all parts of the rock except in the zones of chalcedony and secondary crystalline calcite.

Although use of the term chert as applied to the above-described variety of rocks may be questioned, it is believed to accord with definitions and usage prevalent in the literature (Twenhofel, 1939, pp. 367-368).

## Miscellaneous Types

Hydrous silica is present not only in the two important lithologic types that have been described but also in several other well-indurated rocks more or less related to them. It has been observed by us to occur in minor amounts in many samples of Ogallala rock not associated with quartzite or chert. Irregular masses (up to 8 inches in long diameter) of dense, cream-colored, waxy or resinous opal were found on the east side of sec. 5, T. 2 S., R. 17 W., northeastern Phillips County, Kansas, in a lenticular bed composed largely of calcium carbonate several feet above a green quartzite. This material contains vugs lined or filled with the more common translucent opal and some chalcedony, and on the outside consists of dull white porous silica. A thin section shows a uniform texture, a high degree of opacity, and very few clastic grains. The rock is brittle and breaks easily with pronounced conchoidal fracture into small splinters.

In the same section, and below the bed containing the "resin" opal, is a bed of sandy silt containing large elongated pale-buff or cream-colored mammillary or colloform concretions, 10 to 14 inches long, of sandy to argillaceous silt cemented with opaline silica (Pl. 7, fig. 3). These are very similar to the green quartzite except for their silty character and the general absence of green coloration, although a few of the concretions have pale green centers.

Another type of silicified rock occurs immediately below the uppermost quartzite near the measured section in sec. 24, T. 5 S.,

R. 19 W., 4.5 miles south of Speed in Phillips County. This consists of a bed 20 inches to 3 feet thick, composed of fine sandy silt cemented with opaline silica and some calcium carbonate into a dense rock of uneven hardness. Much of the opal is concentrated in small irregularly shaped green spots which are surrounded with alternating rings of greenish-gray and green material. Plate 7, figures 1 and 2, are photomicrographs of a thin section cut through one of the green spots. Differential weathering causes the green centers to protrude from the surface, whereas one or more of the outer circles may be sharply indented. Some of the green centers are encircled by three or more green rings representing a total diameter of more than 1.5 inches. Calcium carbonate concentrated in some of the outer greenish-gray circles is apparently a factor in differential weathering. This rock seems to be similar to the contraction spheroids in very calcareous porcelanites described by Taliaferro (1934, p. 205).

Associated stratigraphically with the green quartzite is still another variety of rock that in some respects is very similar lithologically to the pink Ogallala quartzite from Texas. It is dense, green, fine-grained material characterized by small areas (less than 1 inch in diameter) of white or colorless silica, which may also occur as the lining of small vugs. The green rock itself shows some areas consisting predominantly of opaline silica cement and others of mixed silica and fine-grained calcium carbonate. This rock occurs abundantly in at least three localities in Kansas—in sec. 7, T. 2 S., R. 17 W., northeastern Phillips County, where it grades laterally into green quartzite; capping a long butte 75 feet above brownish-green basal Ogallala quartzite in the NE¼ sec. 18, T. 5 S., R. 19 W., southern Phillips County (Pl. 7, figs. 4 and 5); and capping Twin Mounds in the SE¼ sec. 4, T. 9 S., R. 17 W. in eastern Rooks County, where it is also fairly high within the lower Ogallala. Plate 7, figures 4 and 5, shows part of one of the areas of colorless silica. It is chert or very fine cryptocrystalline chalcedony surrounded by opal (which is white by reflected light) and set in green opaline and calcareous siltstone.

Reference has been made to silicified Niobrara chalk associated with silicified areas within the Ogallala. Landes and Keroher (1942, p. 306) have described this rock in some detail. A sample of silicified Niobrara chalk from northeastern Ness County (Pl. 5, fig. 2) was digested in dilute hydrochloric acid and was found to be 78 percent soluble by weight. The residue did not disintegrate, but was a white porous coherent mass consisting almost entirely of silica that had been evenly disseminated throughout the chalk.

## Origin

Discussion of the origin of silicified Tertiary deposits in the Great Plains region, as follows, deals mainly with the green quartzite of Kansas because our knowledge of the geographic extent and stratigraphic position of this rock is much more adequate than that concerning the Ogallala chert or the pink quartzite of Texas.

Sandstone with opaline cement has been considered by most petrographers to be a very uncommon type of rock. A possible reason for this conclusion may well be the failure on the part of many geologists to recognize its character in the field or to consider the nature of siliceous cement, when observed, important enough to mention in reports. No previous writer, from 1888 to the present (Hicks, 1888; Todd, 1889; Haworth, 1897; Barbour, 1903; Condra, 1908, 1908a; Moss, 1932; Elias, 1937, p. 23; Landes and Keroher, 1942) describing the green Ogallala quartzite from Kansas, Nebraska, or South Dakota, has mentioned the opaline character of the cement. The literature on Tertiary deposits of Texas, on the other hand, is replete with discussions of the petrology and genesis of opaline sandstone (Goldman, 1915; Udden, Baker, and Böse, 1916; Dumble, 1918; Bailey, 1926; Plummer, 1932; Bowling and Wendler, 1933; Sellards and Baker, 1934), although a discussion of the quartzite in the Ogallala formation of Texas has not been found. Elsewhere, references to the occurrence of opaline cement seem to be rare; Pöhlmann (1886, p. 246) mentions an occurrence in Paraguay and Wanless (1923, p. 258) notes the presence of opaline cement in sandstone dikes in the White River beds of South Dakota.

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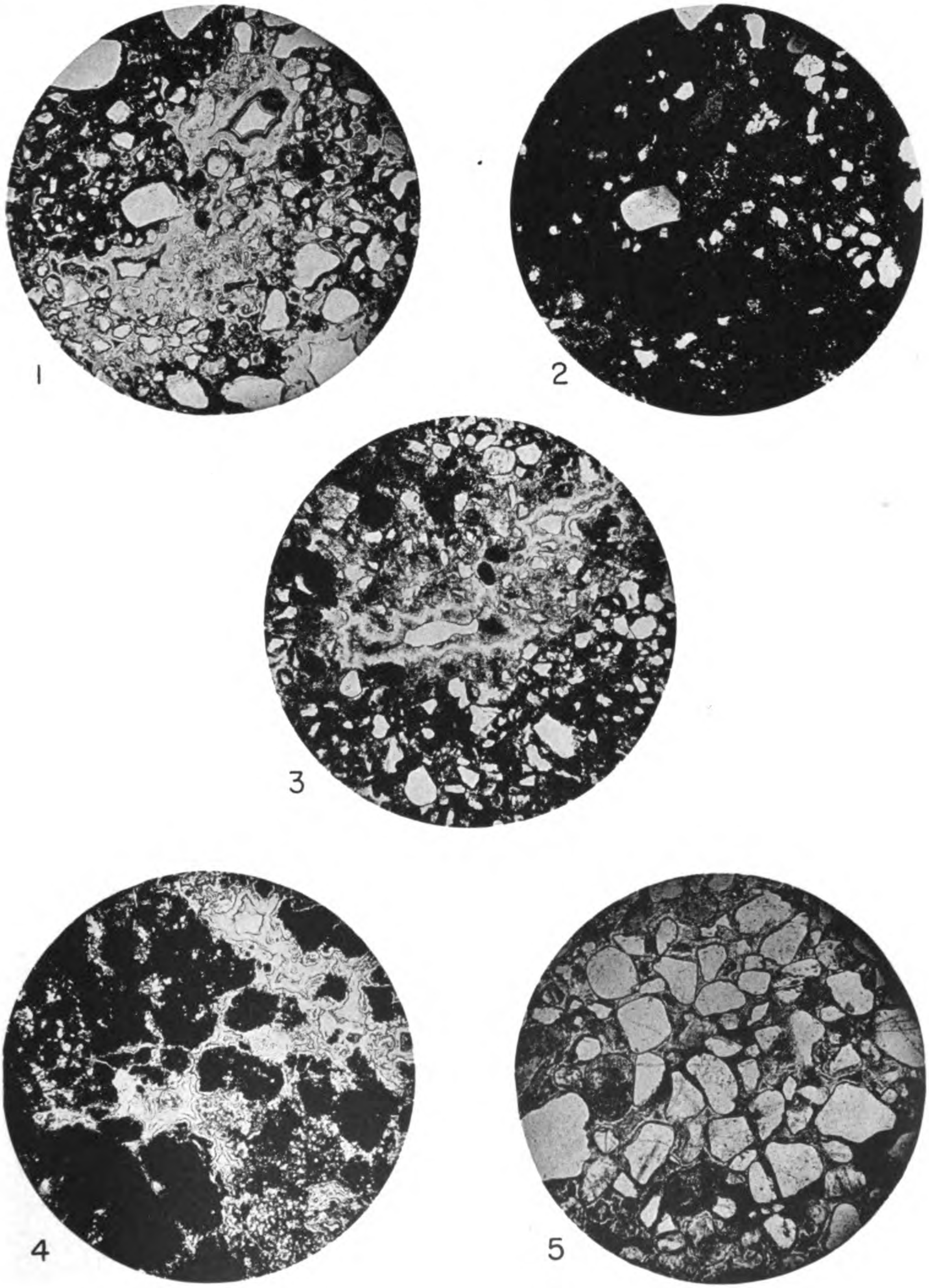
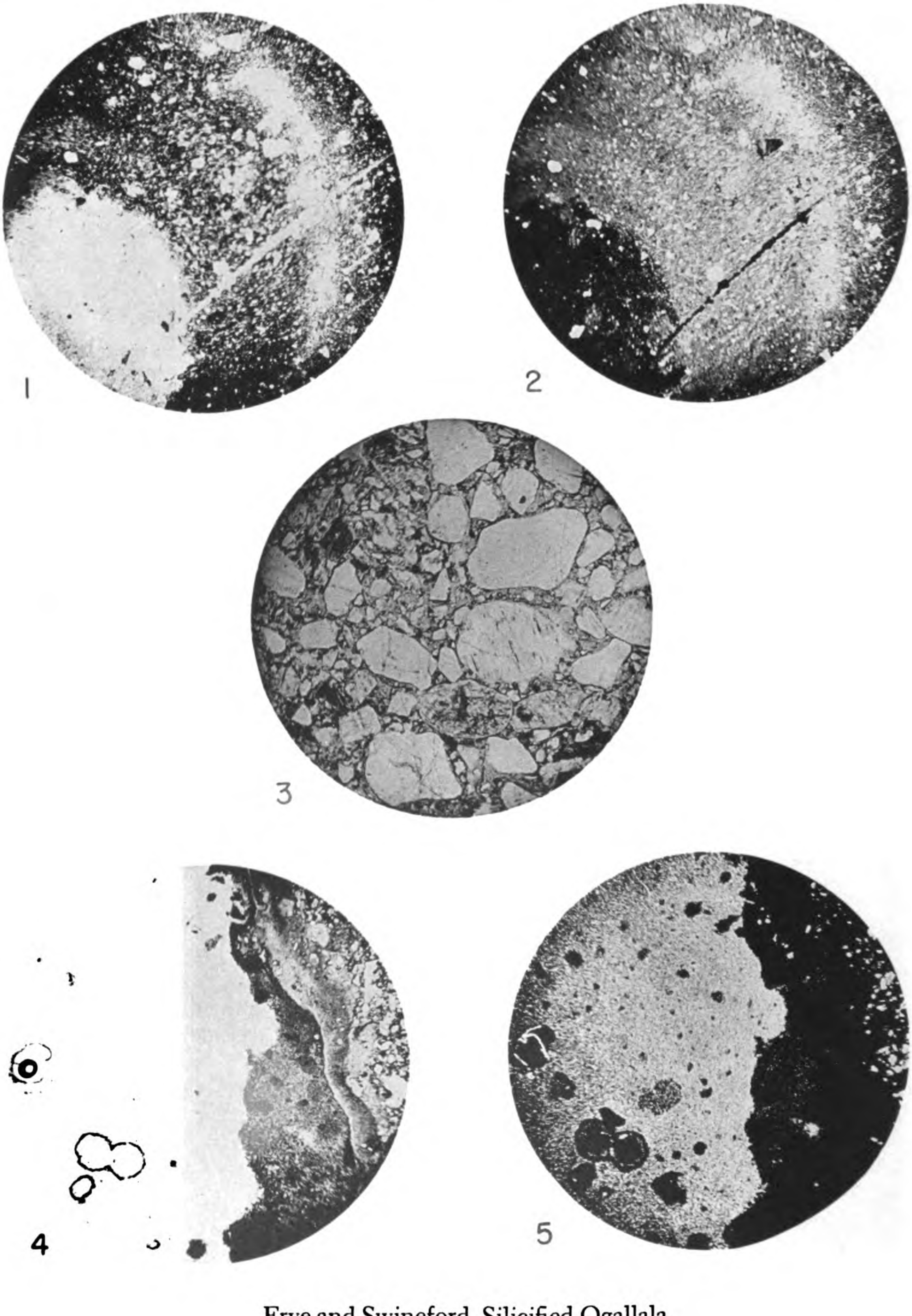
Plate 6. Photomicrographs of silicified Ogallala from Texas, Colorado, and South Dakota. Fig. 1.—Fine-grained quartzite showing opaline and chalcedonic cement from near Midland, Texas; plane polarized light, X 25. Fig. 2.—Same as 1; crossed nicols, X 25. Fig. 3.—Fine-grained Ogallala quartzite from southwest of Canyon, Texas; plane polarized light, X 25. Fig. 4.—Chert from near Beecher Island, Colorado; plane polarized light, X 25. Fig. 5.—Quartzite from the southeast edge of Dallas, Gregory County, South Dakota; plane polarized light, X 25.




Frye and Swineford, Silicified Ogallala




Frye and Swineford, Silicified Ogallala

Study of the origin of the Ogallala quartzite requires attention to several major problems: the source of the silica; the causes of its deposition in the form of opal and its localization in lentils; the relationship of the silicification to the sequence of geologic events during Pliocene and Pleistocene time; and the cause of the prevalent green color of the rock.

*Source of silica.*—Mudge, who in 1874 (pp. 115-116) first noted the presence of silicified Ogallala in western Kansas, believed that the silica might have been supplied by thermal springs or related phenomena. Penrose (1889, p. 88) believed that silicic acid contained in surface waters was the source of siliceous cement in the Fayette sandstone of Texas. Silica is a common constituent of many natural waters. It is noteworthy, however, as pointed out by Roy (1945), that the silica found in most ground waters has a low concentration and occurs in the form of a true solution rather than colloidal suspension. Inasmuch as the cement of the Ogallala quartzite is preponderantly opaline in character, the silica is probably in the colloidal form (Dana, 1932, p. 355; Hatch, Rastall, and Black, 1938, p. 199) and the waters from which the cementing material was deposited must have been heavily charged with colloidal silica in contrast to the low concentration of silica in true solution found in normal ground water. Thus an abundant and relatively near-by source of silica must have existed during the period of cementation so as to provide chemical character of the waters differing markedly from surface and ground waters associated with Ogallala deposits at the present time. The only adequate source of such silica seems to be the extensive deposits of volcanic ash that occur at a higher stratigraphic position within the Ogallala formation. Volcanic ash is known to occur widely in the younger Pleistocene strata also and may have constituted a source for the stratigraphically higher Ogallala chert. Ash deposits are considered by several workers (Rubey, 1928; Reed and Longnecker, 1932, p. 72;

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PLATE 7. Photomicrographs of silicified Ogallala from Phillips County, Kansas. Fig. 1.—Silicified sandy silt, showing zonation of silicification; from the NW¼ sec. 24, T. 5 S., R. 19 W., Phillips County, Kansas; plane polarized light, X 10. Fig. 2.—Same as 1; crossed nicols, X 10. Fig. 3.—Concretions in silty sand, showing opaline cement; from sec. 5, T. 2 S., R. 17 W., Phillips County, Kansas; plane polarized light, X 25. Fig. 4.—Part of an irregular mass of chert included within fine-grained quartzite, from the NE¼ sec. 18, T. 5 S., R. 19 W., Phillips County, Kansas; plane polarized light, X 10. Fig. 5.—Same as 4; crossed nicols, X 10.

Price, 1933, pp. 506, 519; Smith, 1934; Murata, 1940; Frye, 1942, p. 101) to be the probable source of silica in some sediments, and volcanic ash is judged to have been the source of the opaline cementing material in the sandstones of the Catahoula, Fayette, and Oakville formations in Texas (Dumble, 1918, p. 147; Bailey, 1926, pp. 12-13; Plummer, 1932, p. 725). Relationships are particularly clear in the case of the Catahoula where opaline-cemented sand is interbedded with ash deposits and grades laterally into them. The most extensive deposits of volcanic ash in the Ogallala of Kansas occur stratigraphically higher than the quartzite. Since deposits overlying the quartzite beds have been removed by erosion at most places where the latter are found, the interpretation of origin of the opaline silica here given cannot be confirmed by finding ash beds or bentonitic clays derived from ash in the vicinity of quartzite deposits. The only unquestioned occurrence of bentonite in association with quartzite was found in the large quarry west of Woodruff in Phillips County.

*Factors controlling deposition.*—The extreme localization of the quartzite as lentils in the Ogallala formation, commonly bounded by a sharp contact with uncemented sand, gravel, or silt, and the restriction of silicification in the Niobrara to the zone immediately below its contact with the Ogallala, seem to have an important bearing on the origin of the silica. It has been repeatedly demonstrated that colloidal silica is precipitated by such ions as calcium, magnesium, and bicarbonate in aqueous solution (Cox, Dean, and Gottschalk, 1916, pp. 7-12; Tarr, 1917, p. 436; Lovering, 1923, p. 536). If solutions heavily charged with silica are somewhat acid in nature, as implied by Roy (1945, p. 398), the required environment for precipitation of colloidal silica is produced where these solutions encounter an area of existing calcium carbonate cement (Lovering, 1923, p. 536). Such an origin of silica deposits has been suggested for the Gueydan formation (Catahoula tuff) by Bailey (1926, p. 57), the Oakville, Catahoula, and Lower Reynosa formations by Price (1933, pp. 505-506), and the Ogallala formation by Landes and Keroher (1942, p. 284). Accordingly, it seems probable that the opaline cement of the Ogallala quartzite was deposited as replacement of an earlier generation of calcium carbonate cement, and that the opal of the silicified Niobrara was formed as a partial replacement of the chalk.

Conclusion that the siliceous cement of the quartzite originated by replacement of calcareous cement is supported by the physical resemblance of hard lentils seen in outcrops of the Ogallala, some showing sand and gravel cemented by calcium carbonate and others having an opaline siliceous cement. Pebbles of silicified Niobrara chalk may be observed in loose noncalcareous sand and gravel only a few feet below some of the quartzite lentils. The fact that such chalk pebbles were silicified after deposition is demonstrated by incorporation of sand grains in peripheral portions of the pebbles. Study of thin sections shows that small grains of calcium carbonate are included locally within the opal cement. The silicification of the Niobrara chalk, and particularly the development of chert deposits at several stratigraphic positions within the Ogallala, is observed to have been incomplete and gradational within the dominantly calcium carbonate rock.

The chalcedony linings of vugs may be the result of a change in chemical character of the depositing waters. Evidently such linings of chalcedony were deposited after the large mass of opaline cement was introduced into the rock, and the absence of sand grains in the linings indicates that the chalcedony microcrystals grew outward into cavities. Plate 5, figure 5, is a photomicrograph of a thin section of "mortar bed" showing no replacement by silica. The general similarity between the textures and types of vugs of this rock to those of the Ogallala quartzite is apparent. As silica in dilute solutions is believed by some to be crystalloid (Roy, 1945), the relationships of the chalcedony vug linings suggest that following deposition of opaline silica concentration of silica in Ogallala waters decreased possibly because an advanced stage in the leaching of ash deposits had been reached, because the water table had declined, or because ash beds serving as source of the silica had been removed by erosion. These conclusions are strengthened by the presence in some vugs of crystalline calcite as a band deposited on the chalcedony, which seems to indicate a return to normal ground-water conditions.

*Age of silicification.*—Although it is impossible to establish conclusively from available evidence the time at which the silica was introduced into the Ogallala quartzite, some data indicate the following sequence of events. During deposition of the Ogallala sediments the regional water table must have stood relatively near the surface (Frye, 1945a). As has been pointed out, the quartzite invariably occurs stratigraphically low in the Ogallala, and although the volcanic ash is also low, it is believed to occur higher in the section than the quartzite. Shortly after accumulation of the ash, these deposits would be below the water table and subject to hydration and leaching, so that heavily charged siliceous waters would move downward and outward. That leaching and subsequent precipitation of the opal occurred while the ash was below water level rather than later is suggested by the green color of the cement, which is caused by the presence of ferrous iron. Ferrous iron (Reiche, 1945, p. 24) is believed to be readily adsorbed by silica gel, which may account for the intensification of green coloration in the opal cement of the quartzite when compared with the pale green color of some other lower Ogallala deposits. This iron would probably have been altered to the ferric state if the ash had been exposed to weathering above the water table (Reiche, 1945, p. 32). The inferred sequence of conditions is also indicated by the presence of bentonitic rather than kaolinitic altered volcanic ash in the Woodruff quarry (Ross and Hendricks, 1945, pp. 60, 66). It is possible that an erosional disconformity occurs within the Ogallala of northwestern Kansas, and if this is true, the silicification of the quartzite probably preceded the erosion interval. The presence of a small area of unsilicified limestone surmounting the quartzite cap of Sugar Loaf Mound (Pl. 2A) suggests that erosion had reduced the land surface to such level after the silicification that produced the quartzite and before the final stage of Ogallala deposition.

Some of the scattered chert deposits in the Ogallala occur at a high stratigraphic position within the formation, and since the only obvious source of this silica is early Pleistocene volcanic ash beds, the date of the silicification must have been later than early Pleistocene. It is to be noted that these younger chert deposits lack the distinctive green color that characterizes the quartzite.

## USES

The usefulness of the silicified Ogallala rock is shown by physical test data, chemical analyses, and petrographic descriptions.

Eight samples of Ogallala quartzite and one sample of chert were subjected to standard physical tests and chemical analyses by the United States Engineer Corps. The results of these tests, presented in Table 1, have been furnished to us and supplement the petrographic descriptions given above.

*Test data.*—The apparent specific gravity of the nine samples ranges from 2.21 to 2.63; the lowest observed gravity is that of chert from Rawlins County, and the highest represents quartzite from northwestern Phillips County.

The percentage of absorption ranges from 1.05 to 3.27, the highest absorption being shown by the chert sample. More than half the samples had an absorption of more than 2 percent, which is sometimes the maximum allowable for high grade concrete aggregate. In determining absorption the test procedure was in accord with the A.S.T.M. standard test C-127-90, as modified by the Central Concrete Laboratory of the Corps of Engineers, U.S. Army (War Department, 1942, pp. 49-50). Specimens are prepared by quartering the field sample to a size of approximately 5 kg., rejecting all material passing the 3/8 inch sieve. In the case of homogeneous aggregates all material is retained on the one-inch sieve. After drying to constant weight the sample is immersed in water at 15 to 25 degrees Centigrade, thoroughly agitated to remove dust or other coatings from the particles, and allowed to absorb water for 24 hours. The material is then removed from the water, surface dried, and weighed. The percent absorption is calculated from the weight before and after immersion.

The freezing and thawing tests were made according to the A. S.T.M. standard test procedure C-137-38T, as modified by the Central Concrete Laboratory (War Department, 1942, pp. 69-73). The samples were subjected to 5 cycles of alternate freezing and thawing, and the percentage of loss was computed by subtracting from the original weight of the sample the final weight of all particles which had not broken into three or more pieces during testing. The nine samples showed losses ranging from zero to 0.77 percent, all of which are comparatively low.

Abrasion tests were made in a Deval machine, in which the crushed aggregate is placed in iron cylinders that are rotated on a shaft for 10,000 revolutions at a rate of 30 to 33 r.p.m. This test is designed to simulate resistance to wear under traffic conditions. At completion of the test the material is removed from the cylinders and sieved on a No. 12 (1680-micron) sieve, the part passing the sieve being considered as a measure of the wear. Wear is expressed either as percent of loss of original sample, or as the French coefficient of wear calculated by dividing the weight in grams of the detritus under 0.168 cm. in size, per kilogram of rock used, into 400. The test procedure was according to A.S.T.M. standard method D-289-42T (A.S.T.M., 1944, pp. 1369-1371). Of the nine samples tested, only that from one quartzite locality in Graham County has a French coefficient of more than 14, and the chert sample and two of the quartzite samples have coefficients below 8. Five of the samples tested fall within a range of 8 to 13. According to Nash (1918, p. 148), "The best wearing rocks have a percent of wear of 2 or coefficient of 20. If this coefficient of wear is below 8, it is considered as low; from 8 to 13 medium; from 14 to 20 high; and above 20, very high."

Solubility of the quartzite samples in hydrochloric acid is less than 6 percent in all cases, whereas the chert sample shows a solubility of nearly 50 percent. Chemical analyses show the silica content of the quartzite samples to range from 86.98 to 98.00 percent, as contrasted with a silica content of 55.08 percent for the chert sample.

As pointed out by Mielenz (1946), petrographic data may have considerable bearing on the usefulness of a rock for concrete aggregate and other construction purposes. Small amounts of opaline silica in aggregate may cause excessive expansion in high-alkali cement (Blanks, 1943); Hanna (1943) has suggested that opal may be deleterious even in low-alkali cement. Mielenz (1946, p. 315) writes that opal does not generally react if the cement contains less than 0.60 percent total alkalies ($Na_2O$ plus $K_2O$, expressed as soda equivalents). Since all the rock described in this report contains sizable quantities of opal, its use as a concrete aggregate in conjunction with high-alkali cement may prove unsatisfactory.

*Conclusions.*—The data presented in this report, supplemented by meager information from local users, indicate that the Ogallala quartzite is far superior to any other deposit in the northwestern part of Kansas and in most cases will probably be suitable for railroad ballast and riprap, and possibly also for a local source of road metal. The unusual coloration and mottled appearance of some deposits should make them desirable for monuments and ornamental stone, and if economical methods of quarrying and finishing are developed, the quartzite may be useful as a durable building stone. The rock is harder than many others used for such purposes, and is closely comparable in resistance and weathering properties to a

TABLE 1.—*Data from standard physical tests and chemical analyses of silicified Ogallala rock from Kansas*

(Data furnished by the United States Engineer Office, Kansas City, Missouri)

| COUNTY | LOCATION (sec., T., R.) | Specific Gravity | Absorption, percent | Loss freeze and thaw, 5 cycles percent | ABRASION Percent loss | ABRASION French coefficient | Sol. in HCl, percent | CHEMICAL ANALYSIS (percent) Loss on ignition | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | CaO | MgO | $SO_3$ | Moisture | $Na_2O$ + $K_2O$ | Total | Rock Type |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Graham | 31-7-22W | 2.38 | 2.0 | 0.35 | 6.81 | 5.9 | 4.90 | 2.21 | 88.09 | 3.50 | 1.35 | 0.69 | 1.08 | 0.00 | | 1.01<br>1.47 | 99.40 | Quartzite |
| Graham | 34-8-22W | 2.41 | 1.05 | 0.27 | 2.81 | 14.2 | 3.62 | 1.52 | 97.10 | 1.26 | 0.06 | 0.00 | 0.10 | 0.00 | | | 100.04 | Quartzite |
| Graham | 13-8-23W | 2.37 | 2.50 | 0.44 | 4.54 | 8.8 | 5.62 | 2.08 | 86.98 | 3.71 | 1.89 | 1.08 | 1.13 | 0.00 | | 1.20<br>1.49 | 99.56 | Quartzite |
| Norton | 15-5-21W | 2.39 | 1.54 | 0.11 | 3.45 | 11.6 | 2.78 | 1.18 | 98.00 | 0.52 | 0.06 | 0.04 | 0.06 | 0.00 | | | 99.86 | Quartzite |
| Phillips | 4-1-19W | 2.63 | 1.75 | 0.00 | 4.54 | 8.8 | | 2.00 | 87.00 | 4.01 | 1.59 | 1.10 | 0.00 | | 1.00 | 3.30 | 100.00 | Quartzite |
| Phillips | 7-5-17W | 2.39 | 2.42 | 0.40 | 4.81 | 8.3 | 5.2 | 2.3 | 95.40 | 1.33 | 0.29 | 0.06 | 0.11 | 0.00 | | | 99.49 | Quartzite |
| Phillips | 23-5-19W | 2.39 | 1.42 | 0.17 | 4.0 | 10.0 | 3.60 | 1.60 | 96.30 | 1.28 | 0.24 | 0.08 | 0.10 | 0.00 | | | 99.60 | Quartzite |
| Rawlins | 10-4-36W | 2.21 | 3.27 | 0.49 | 8.54 | 4.7 | 46.30 | 20.32 | 55.08 | 1.07 | 0.11 | 22.50 | 0.80 | 0.00 | | | 99.88 | Chert |
| Rooks | 10-6-19W | 2.39 | 2.89 | 0.77 | 8.00 | 5.0 | 5.10 | 1.32 | 96.50 | 0.78 | 0.32 | 0.44 | 0.06 | 0.00 | | | 99.42 | Quartzite |

good grade of granite. Although it has been reported that Ogallala quartzite has been used locally with success as concrete aggragate, it contains a large amount of opal (Mielenz, 1946) and caution should be exercised when it is used in concrete or terrazzo, particularly if it is used in conjunction with high alkali cement, until its suitability for such purposes has been more thoroughly investigated.

Physical test data on Ogallala chert are available for only one sample, and accordingly conclusions concerning its possible uses are not well founded. Furthermore, it is more variable from one locality to another than the quartzite. It seems to be poorly suited to use as a building or ornamental stone, and less satisfactory than the quartzite for riprap, railroad ballast, and road material.

## OCCURRENCE IN KANSAS BY COUNTIES

The following paragraphs present a description, by counties, of all localities examined in the field. Estimates of the available tonnage have been obtained solely from surface observations, no core hole data being available. Rock believed to be overlain by a thickness of overburden sufficient to preclude commercial development has not been included in the tonnage estimates. Although the quantities reported are conservative in most cases, the lenticular nature of the deposits may have led to excessively high or low estimates for a few localities. The field inventory of the quartzite was extensive, but it is to be expected that additional localities will be found in the future, particularly if the value of the material for construction purposes comes to be widely recognized.

### Clark County

All the deposits of silicified rock known to occur within the Ogallala formation of Clark County are of the chert variety, and contain only a few included grains of sand size. As early as 1897 Haworth (pp. 267-268) reported the presence of siliceous cement in the Tertiary deposits near "St. Jacobs well." Two localities were examined by us. These are located at "St. Jacobs well," in sec. 24, T. 32 S., R. 25 W., and near the Meade County line along U.S. Highway 160 in secs. 6 and 7, T. 32 S., R. 25 W. The deposits in the vicinity of "St. Jacobs well" consist of outcrops along the north side of the sink hole and slump blocks along the sides of the "well."

Silicification in this area was quite irregular, giving the rock a mottled appearance. Owing to the solution-subsidence topography and the presence of large slump blocks, it is difficult to estimate the total tonnage present. The deposits near the county line are the same type of rock; they crop out along a small valley side, and probably do not attain a maximum thickness of more than 10 feet. The total quantity of rock present is estimated at about 100,000 tons.

### Ellis County

In the southwestern quarter of the county (secs. 4 and 10, T. 14 S., R. 20 W.; sec. 33, T. 13 S., R. 19 W.; and sec. 30, T. 15 S., R. 20 W.) small outcrops of cherty and calcareous fine-textured Ogallala deposits were observed in fields and along hilltops. The total quantity present is not known.

### Graham County

Approximately 2,500,000 tons of quartzite is known to occur in Graham County. This rock ranges in particle size from fine sand to coarse conglomerate tightly cemented by silica. Six localities were examined in the vicinity of Penokee, northeast of Hill City and southwest of Bogue.

In the Penokee area quartzite caps the bluffs along the north and south sides of South Solomon Valley. On the north side of the valley the bed attains a maximum thickness of 14 feet; the average thickness for an east-west distance of more than 300 yards is 10 feet. The quantity available is estimated at 150,000 tons. This quartzite is green in color and its texture ranges from medium fine-grained to conglomeratic. Chemical analysis shows this material to contain 86.98 percent silica; its loss after five cycles of freeze and thaw is only 0.44 percent; and the French coefficient of abrasion was determined as 8.8. South of Penokee the bed of quartzite has an average thickness of little more than 1 foot and extends about 500 feet along the valley bluff. It is green in color, fine- to medium-grained and partly conglomeratic. A quarry has been in operation at this locality. A small quarry in the SW¼ sec. 2, T. 8 S., R. 24 W., 2 miles north of Penokee, yielded a dense, uniformly fine-textured bright-green rock used for facing purposes, and in the quarry face the quartzite has a maximum thickness of 5 feet. Another quarry, located in the SE¼ of the same section, yielded from a 2-foot bed a medium-grained light-green rock used for building stone.

Three miles northeast of Hill City (sec. 31, T. 7 S., R. 22 W.) a bed of even-textured medium- to coarse-grained, gray to greenish-gray quartzite, displaying a dull rusty-red color on weathered surfaces, forms a bench along the west side of a minor stream valley. Outcrops believed to represent the same bed were observed along gullies a quarter of a mile to the west. The maximum thickness in this section is about 15 feet, but the average probably does not exceed 8 feet, and the available quantity is estimated as more than 500,000 tons. Chemical analysis shows this material to contain 88.09 percent silica; its loss after five cycles of freeze and thaw is only 0.35 percent; and the French coefficient of abrasion was determined as 5.9.

Five miles southwest of Bogue (sec. 24, T. 8 S., R. 22 W.), 4 to 12 feet of quartzite caps a large hill and crops out along its flanks and in small gullies. The rock is here largely medium-grained, gray green in color, and somewhat cavernous. Samples from this locality display the highest French coefficient of abrasion, 14.2, of any samples tested. Furthermore, the quantity available is exceptionally large, being estimated at about 2,000,000 tons. Chemical analysis shows this material to contain 97.10 percent silica, and its loss after five cycles of freeze and thaw is only 0.27 percent.

### Logan County

A layer of chert more than 4 feet thick forms the cap rock of McAllister Buttes in sec. 13, T. 12 S., R. 37 W. The area of outcrop is quite small and the chert serves to protect the easily erodible Pierre shale flanks of the buttes. Our field work in Logan County was not extensive and it is likely that further search may reveal other deposits.

### Ness County

Moss (1932, p. 14) has reported the presence of Ogallala quartzite in the northeastern corner of Ness County. The only exposures of this rock found by us occur in sec. 1, T. 16 S., R. 21 W. in gullies and along the north slope of a prominent ridge. In this area the quartzite is only a few feet above a zone of silicified chalk at the top of the Niobrara formation, and about 35 feet below a 5-foot thick zone of Ogallala chert that caps the hill. The quartzite bed has a maximum thickness of 8 feet, is conglomeratic throughout, being typified by large silicified blocks of Niobrara chalk, and is green in color. Cross-bedding is prominent and weathered surfaces appear somewhat cavernous. The available quantity of quartzite was estimated at 400,000 tons.

Chert crops out not only above the quartzite bed but also forms benches interrupting the general north slope of the topography for a distance of 2.5 miles west from this locality. As is generally true of Ogallala chert, the silicification is uneven and the rock is believed to be of small commercial value. It is probably this bed of chert that extends into adjacent parts of Ellis and Trego counties.

## Norton County

Quartzite crops out at several places in southeastern Norton County both north and south of North Solomon River, and represents a westward extension of the more extensive deposits in southern Phillips County (Pl. 8). The largest quantity of rock is believed to occur in secs. 14 and 15, T. 5 S., R. 21 W., where it is estimated 500,000 tons are available. The quartzite is exposed along the south valley wall of a tributary to North Solomon River and immediately overlies chalky shales of the Niobrara formation. It is green to gray green, medium- to coarse-textured, cross-bedded (Pl. 1B and 1C), and has a maximum thickness of 12 feet. Chemical analysis shows this material to contain 98.00 percent silica, the highest percentage of any sample analyzed. Its loss after five cycles of freeze and thaw is 0.11 percent, which is next to the lowest loss of any sample tested, and it has the second highest, 11.6, French coefficient of abrasion.

The second largest deposit in the county, estimated at 100,000 tons, occurs in the SE¼ sec. 5, T. 5 S., R. 22 W., and crops out along the west valley wall of a tributary to North Solomon River. The rock at this locality is very fine-grained (Pl. 4, fig. 1), dense, and brown in color. The average thickness of the exposed bed is 6 feet.

In the SW¼ sec. 28, T. 4 S., R. 21 W., quartzite is exposed along the bottom and sides of a small valley, and the hard ledge forms a sharp break in the slope of the valley bottom. The bed of quartzite is 2 feet thick and immediately overlies about 4 feet of loose sand and gravel which rests on chalky shales of the Niobrara formation. It is estimated that a minimum of 40,000 tons of rock is available.

Quartzite has also been quarried in the SE cor. sec. 30, T. 4 S., R. 21 W., where it accurs as lentils in loose sand, and at the Cen. E. line sec. 33, and Cen. W. line sec. 34, T. 4 S., R. 23 W.

A small deposit of this rock in a bed 2 feet thick occurs in the SE¼ sec. 9, T. 5 S., R. 21 W., where it immediately overlies chalky shales of the Niobrara formation.

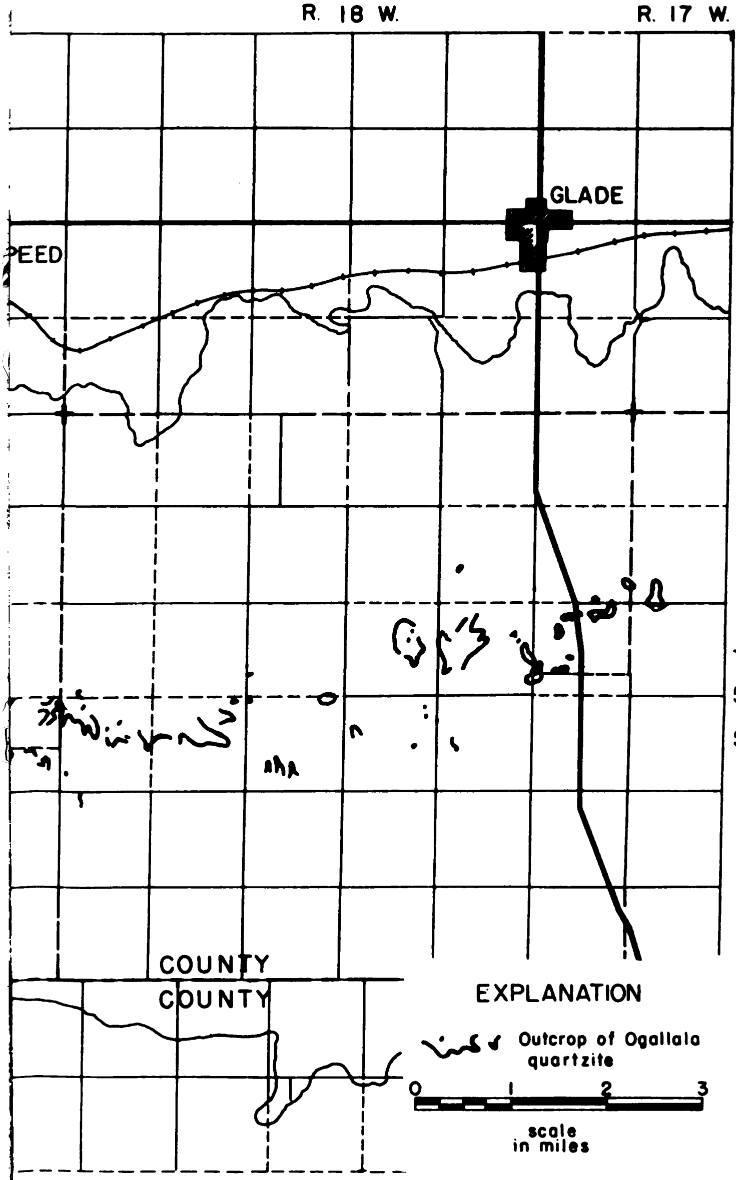
## Phillips County

Extensive deposits of Ogallala quartzite occur in Phillips County, the total available quantity being estimated at more than 3,800,000 tons. The exposures of this rock occur widely scattered over the county and will be discussed by grouping them in four general regions: (1) an area extending from south of Glade to the Norton County line and lying south of North Solomon River, (2) the area north of North Solomon River near Logan, (3) the northeastern Phillips County area, and (4) a small area west of Woodruff.

*Southern area.*—Outcrops of Ogallala quartzite extend in a discontinuous irregular line along the south side of North Solomon Valley and tributary valleys from sec. 7, T. 5 S., R. 17 W., to sec. 18, T. 5 S., R. 20 W., on the Norton County line. Silicified Ogallala has previously been noted in this area by Haworth (1897, pp. 267-268) and by Landes and Keroher (1942, p. 308). At the eastern extremity of this line of outcrops the quartzite represents the easternmost extent of Ogallala deposits on the North Solomon-Bow Creek divide; they immediately overlie chalky shales and limestones of the Niobrara formation, and form the cap rock of isolated buttes that contain the highest points in the local topography. Farther west, quartzite occurs at several stratigraphic positions within the Ogallala formation, the highest being about 80 feet above the base. The locations of outcrops in this area are shown on the map (Pl. 8). The total quantity of available quartzite in the southern area is estimated as more than 2,000,000 tons.

In the eastern part of this area the rock is medium-grained, green to brown in color, and ranges from 2 to 10 feet in thickness. A sizeable quantity is believed to occur in the S½ sec. 14, T. 5 S., R. 18 W., and it has been quarried in the Cen. E. side of adjacent sec. 15. South of Speed the quartzite bed near the base of the formation is coarse-grained to conglomeratic, brownish green in color, ɔks Counties, Kansas.





and weathers red brown. In the same area a higher quartzite zone is fine-grained, green, and ranges from 1 to 5 feet in thickness. Southeast of Logan the silicified lentils occur in the lower 20 to 30 feet of the formation and are similar lithologically to the lower bed farther east. A higher silicified zone in the NE¼ sec. 18, T. 5 S., R. 19 W., however, is very fine-grained, gray green in color, and breaks into small angular fragments. Several lentils of quartzite that occur in a vertical interval of about 40 feet have been quarried in sec. 8, T. 5 S., R. 20 W., 2.5 miles southwest of Logan. The lowermost bed, which occurs immediately above Niobrara chalky shale, is green in color and coarse-grained to conglomeratic, whereas the higher zones are very fine-grained, even-textured, and well silicified throughout.

Analytical and test data are available for two localities in the southern Phillips County region. A sample collected in sec. 9, T. 5 S., R. 18 W., contains 95.40 percent silica, shows a loss after five cycles of freeze and thaw of 0.40 percent, and has a French coefficient of abrasion of 8.3. A sample from sec. 23, T. 5 S., R. 19 W., containing 96.30 percent silica, shows a loss after five cycles of freeze and thaw of 0.17 percent, and has a French coefficient of abrasion of 10.0.

*Logan area.*—Quartzite was examined at four localities along the north side of North Solomon Valley in the vicinity of Logan: a quarry in the SW¼ sec. 29, T. 4 S., R. 20 W.; small outcrops in the SE¼ sec. 13, T. 4 S., R. 20 W.; Cen. N. line, sec. 23, T. 4 S., R. 20 W.; and in the NW¼ sec. 19, T. 4 S., R. 19 W. The available rock in sec. 29, T. 4 S., R. 20 W. is estimated at 200,000 tons. The small outcrops northeast of Logan contain very conglomeratic material that is yellow green and greenish brown in color, and range in thickness from 1 to 10 feet. The quartzite exposed in the vicinity of the quarry situated at the top of a prominent hill about 2 miles northwest of Logan occurs immediately above chalky shales of the Niobrara formation, is 1 to 8 feet thick, and is conglomeratic at the base with light-green uniformly fine-grained rock at the top.

*Northeastern area.*—Quartzite occurs in two small areas in northeastern Phillips County, which are approximately 2 and 7 miles south of the state line and about 11 miles west of the Smith County line. The location and extent of the outcrops are shown in detail on the maps in Plate 8. In the northernmost of these two small areas it is estimated that 75,000 tons of rock is available. It has a maximum thickness of 12 feet and ranges from fine- to coarse-grained in texture, is dense, and green in color.

Landes and Keroher (1942, p. 308) have noted the presence of quartzite in the southern of the two localities. It is now estimated that a total of a least 50,000 tons of rock occurs in this area. The distribution of outcrops is shown in Plate 8. The deposit ranges in thickness from 1 to 5 feet, is mostly bright green in color, and includes all varieties of texture from slightly conglomeratic to fine-grained.

*Woodruff area.*—For many years the presence of quartzite in the strata lying above the Niobrara formation in several hilltops 3 to 4 miles west of Woodruff has been known. This quartzite, which occurs less than one-half mile south of the Nebraska state line, was noted by Haworth (1897, pp. 267-268), Barbour (1903, p. 163), Condra (1908, pp. 18-23 ) and Landes and Keroher (1942, p. 308). Rock has been quarried extensively in secs. 4 and 5, T. 1 S., R. 19 W. At one time a railroad spur was operated from the Oberlin branch of the Chicago, Burlington, and Quincy Railroad and quartzite from these quarries was used for railroad ballast and other purposes over a wide area, chiefly in Nebraska.

The quartzite occurs in lenticular masses in loose sand and gravel, and at a few places in the quarry face beds of fine material were observed. The zone in which the quartzite occurs is more than 12 feet in thickness but none of the individual lenses of hard rock exceeds 5 or 6 feet in thickness. It is medium-grained to conglomeratic, green to gray green in color, and according to estimate about 500,000 tons of rock is available. Samples from these quarries show the best results of any samples tested in freeze and thaw, having no loss after five cycles. Chemical analysis shows the material to have 87.00 percent silica, and the French coefficient of abrasion was determined to be 8.8.

## Rawlins County

Quartzite crops out at several localities in northeastern Rawlins County along the south side of Beaver Creek, where it immediately overlies Pierre shale (Elias, 1937, p. 23), and in the southwestern part of the county a thick bed of chert occurs at a higher stratigraphic position within the Ogallala. It is estimated that more than 300,000 tons of quartzite, and as much as 500,000 tons of chert are available in the county.

Several years ago quartzite was quarried in the NW¼ sec. 10, T. 2 S., R. 31 W., south of Herndon. In this area the rock is lenticular and interbedded with loose sand and gravel. The zone of silicification has a maximum thickness of 24 feet; the rock is green in color, and ranges from fine-textured at the top to conglomeratic near the base. Another, larger quarry is located in the NW¼ sec. 29, T. 2 S., R. 32 W., east of Ludell. The quartzite bed here is about 10 feet thick, gray green to green in color, and ranges from fine-grained to conglomeratic. It is characterized by a relative abundance of white feldspar grains in some zones. In the same area an older now abandoned quarry (Elias, 1937, p. 23), located in the SE¼ sec. 30, T. 2 S., R. 32 W., provided rock for the Ludell school (Pl. 2C).

South of McDonald in sec. 10, T. 4 S., R. 36 W., Ogallala chert is exposed for a distance of nearly a half mile along the south side of Little Beaver Creek Valley (Pl. 3A). This bed has a maximum thickness of 12 feet, is gray to white to cream colored, and has a mottled appearance on the outcrop. This area contains a larger available tonnage of Ogallala chert than any other locality examined by us. Chemical analysis shows this material to contain only 55.08 percent silica and a much larger percentage of calcium carbonate than any quartzite sample analyzed. Its loss after five cycles of freeze and thaw is 0.49 percent and the French coefficient of abrasion was determined to be 4.7, which is lower than that of any of the quartzite samples tested.

## Rooks County

Quartzite occurs in the Ogallala of Rooks County along the south side of Bow Creek Valley in the northwestern corner of the county as shown in Plate 8, and as the cap rock of two buttes referred to as Twin Mounds, 6 miles northeast of Plainville. It is estimated that about 500,000 tons of silicified rock is available in the county.

South of Bow Creek Valley the outcrops extend from the vicinity of Sugar Loaf Mound in sec. 10, T. 6 S., R. 19 W., to sec. 4, T. 6 S., R. 20 W. The quartzite is lenticular and occurs at several stratigraphic positions within the Ogallala, the highest being as much as 75 feet above the contact with the Cretaceous Niobrara formation. The rock is green to brownish green in color and ranges from fine-grained to conglomeratic in texture. Chemical analysis of a sample from sec. 10, T. 6 S., R. 19 W. shows the rock to contain 96.50 percent silica. The loss after five cycles of freeze and thaw, 0.77 percent, is the highest of any quartzite sample tested, and the French coefficient of abrasion was determined to be 5.0, which is the lowest of any quartzite sample tested.

At Twin Mounds in the SE¼ sec. 4, T. 9 S., R. 17 W., a very fine-textured variety of gray-green quartzite occurs relatively high within the lower Ogallala and forms the cap rock of these two buttes. On the southern of the two buttes the lower part of the bed has been quarried. In this area the rock has a total thickness of about 12 feet.

### Smith County

Green quartzite has been quarried in the NE¼ sec. 21, T. 3 S., R. 12 W., and an outcrop of Ogallala chert has been noted in sec. 29, T. 1 S., R. 13 W. The quartzite, which has an average thickness of about 3 feet, caps a low mound and represents the easternmost known extent of this rock in Kansas. It is green in color and the texture ranges from fine-grained to conglomeratic. It is estimated that about 30,000 tons is available in this area.

### Trego County

In the southeastern corner of the county (secs. 25, 34, and 36, T. 15 S., R. 21 W.) small outcrops of cherty and calcareous fine-textured Ogallala deposits were observed in fields and along hilltops. The total quantity present is not known.

### Wallace County

One outcrop of Ogallala chert was examined in the W½ sec. 7, T. 14 S., R. 38 W., Wallace County. At this locality the chert occurs high in the Ogallala and is not far below the "Algal limestone" which marks the top of the formation. The occurrence of such rock in the Tertiary of Wallace and Logan Counties was noted as early as 1874 by Mudge. As Wallace County was not explored in the search for silicified Ogallala, other and more extensive deposits of this type may be found.

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State Geological Survey of Kansas

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# Map of Ogallala Quartzite in Adjacent Parts of Norton, Phillips, and Rooks Counties, Kansas.